DEENDAYAL PORT AUTHORITY
(Erstwhile Deendayal Port Trust)

दीनदयाल पत्तन प्राधिकरण
DEENDAYAL PORT AUTHORITY

Administrative Office Building
Post Box NO. 50
GANDHIDHAM (Kutch).
Gujarat: 370 201.
Fax: (02836) 220050
Ph.: (02836) 220038.

www.deendayalport.gov.in

EG/WK/4751/Part (Stage II)/109

Date: 09/08/2024

The Director
Govt. of Gujarat,
Forest & Environment Department,
Block No.14, 8th floor,
Sachivalaya,
Gandhinagar – 382 010.

Sub:- Development of Integrated facilities (Stage-II) within the existing Deendayal Port Trust (Erstwhile Kandla Port Trust) at District Kutch, Gujarat. (1. Setting up of Oil Jetty No.7. 2. Setting up of Barge jetty at Jafarwadi 3. Setting up of Barge port at Veera; 4. Administrative office building at Tuna Tekra; 5. Road connecting from Veera barge jetty to Tuna gate by M/s Deendayal Port Authority (Erstwhile Deendayal Port Trust) **Compliances of the stipulated conditions in CRZ Recommendations req.**

Ref.:1) GCZMA CRZ recommendation vide Letter No- ENV-10-2015-251 -E (T Cell) dated 29.06.2016
2) DPT letter EG/WK/4751/Part (Remaining 3 facilities)/53 dated 29/07/2021
3) DPT letter EG/WK/4751/Part (Remaining 3 facilities)/144 dated 08/02/2022
4) DPT letter EG/WK/4751/Part (Stage II)/141 dated 01/07/2022
5) DPA letter EG/WK/4751/Part (Stage II)/292 dated 03/05/2023
6) DPA letter EG/WK/4751/Part (Stage II)/371 dated 03/10/2023

Sir,

It is requested to kindly refer the above cited references for the said subject.

In this connection, it is to state that, the Gujarat Coastal Zone Management Authority vide above referred letter dated 29/6/2016 had recommended the aforesaid project of Deendayal Port Authority. Subsequently, the MoEF&CC,GoI had accorded the Environmental & CRZ Clearance vide letter dated 19/2/2020.

Subsequently, DPA vide letter dated 22(24)/12/2020 has submitted compliance report of the stipulated conditions mentioned in the CRZ Recommendation letter 29/6/2016.

.............Cont.........

Now, as directed under Specific Condition No. 28 mentioned in the CRZ Clearance letter dated 29/6/2016 i.e. ***A six-monthly report on compliance of the conditions mentioned in this letter shall have to be furnished by the DPA on a regular basis to this Department /MoEF&CC, GoI***, please find enclosed herewith compliance report (Up to May 2024) of stipulated conditions along with necessary annexure, for kind information & record please **(Annexure I).**

Further, as per the MoEF&CC, Notification S.O.5845 (E) dated 26.11.2018, which stated that "***In the said notification, in paragraph 10, in sub paragraph (ii), for the words "hard and soft copies" the words "soft copy" shall be substituted***". Accordingly, we are submitting herewith soft copy of the same in CD as well as through e-mail ID gczma.crz@gmail.com & direnv@gujarat.gov.in.

This has the approval of Chief Engineer, Deendayal Port Authority.

Yours faithfully,

29/8/24

Dy. Chief Engineer and EMC (I/C)

Deendayal Port Authority

Copy to:

Shri Amardeep Raju,
Scientist E, Ministry of Environment, Forest and Climate Change,
& Member Secretary (EAC-Infra.1),
Indira Paryavaran Bhawan,
3rd Floor, Vayu Wing, Jor Bagh Road, Aliganj,
New Delhi- 110 003;
E-mail: ad.raju@nic.in

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Annexure I

Point wise compliance of CRZ recommendation

Subject: **Development of Integrated facilities (Stage-II) within the existing Deendayal Port Trust (Erstwhile Kandla Port Trust) at District Kutch, Gujarat. (1. Setting up of Oil Jetty No.7. 2. Setting up of Barge jetty at Jafarwadi 3. Setting up of Barge port at Veera; 4. Administrative office building at Tuna Tekra; 5. Road connecting from Veera barge jetty to Tuna gate by M/s Deendayal Port Trust (Erstwhile Kandla Port Trust)**

CURRENT STATUS OF WORK – Upto May 2024

Sr.No.	Name of Project	Status
1.	**Setting up of Oil Jetty No.7**	Under operation w.e.f January 2023.
2.	**Setting up of Barge jetty at Jafarwadi**	No construction activity started yet.
3.	**Setting up of Barge port at Veera**	No construction activity started yet.
4.	**Administrative office building at Tuna Tekra;**	No construction activity started yet.
5.	**Road connecting from Veera barge jetty to Tuna gate**	No construction activity started yet.

Subject: Point-wise Compliance Status Report for CRZ Clearance for Developing Integrated facilities (Phase-II)- within the existing Kandla Port at Kandla Dist: Kutch by M/s. Kandla Port Trust – Regarding (For the period up to May 2024)

1. **Setting up of Oil Jetty No.7**
2. **Setting up of Barge jetty at Jafarwadi**
3. **Setting up of Barge port at Veera**
4. **Administrative office building at Tuna Tekra**
5. **Road connecting from Veera barge jetty to Tuna gate**

Ref No: - GCZMA CRZ recommendation vide Letter No- <u>ENV-10-2015-251-E (T Cell)</u> dated 29.06.2016

S No	CRZ Conditions	Compliance Status
	SPECIFIC CONDITIONS	
1.	The provision of the CRZ notification 2011 shall be strictly adhered to by the KPT. No activity in contradiction to the provision of the CRZ notification shall be carried out by the KPT.	The work of project at Sr. No. 1 of EC i.e. ***"Setting up of Oil jetty no. 7"*** is Completed and it is under operation w.e.f January 2023. The Consent to Operate (CCA) from the Gujarat Pollution Control Board has already been obtained dated 20/1/2023 **<u>Copy submitted along with the compliance report submitted on 03/10/2023.</u>** However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet), it is assured that, the provisions of the CRZ Notification, 2011 will be strictly adhered to by DPA
2.	All necessary permissions under various laws/Rules/Notifications issued thereunder from different Government Department/agencies shall be obtained by M/s. KPT before commencing any enabling activities for proposed project.	The Consent to Establish (CTE) from the GPCB had already been obtained vide CTE No. 74134 granted by the GPCB vide letter no. PC/CCA-KUTCH 1319/GPCB ID 48573 dated 27/11/2015. In addition to this as the construction work for the project at Sr 1 is completed and it is under operation w.e.f January 2023 therefore CCA has obtained from the Gujarat Pollution Control Board vide GPCB/CCA-Kutch-1319/ID-48573/701442 dated 20/01/2023. **<u>Copy submitted along with the compliance report submitted on 03/10/2023.</u>**
3.	The KPT shall have to ensure that there shall not be any damage to the existing mangrove area.	The construction work for the project at Sr 1 is completed and it is under operation w.e.f January 2023. However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet), it is assured that, there shall not be any damage to the existing mangrove area
4.	The KPT shall effectively implement the mangrove Development, Protection & Management plan for control of indirect impacts on mangrove habitat	DPA had already undertaken Mangrove Plantation in an area of 1600 Ha. till date since the year 2005. A statement showing details of the mangrove plantation and the cost incurred is again placed in **Annexure A** In addition to the above, DPA appointed M/s GUIDE, Bhuj, for "Regular Monitoring of Mangrove Plantation carried out by DPA" (period 15/9/2017 to 14/9/2018 vide work order dated 1/9/2017 and 24/5/2021 to 23/5/2022 vide work order dated 3/5/2021). The final report submitted by M/s GUIDE, Bhuj for the year 2021 to 2022. Submitted along with the compliance report submitted on 03/05/2023.
5.	The KPT shall have to make a provision that mangrove areas get proper flushing water and free flow of water shall not be	The construction work for the project at Sr 1 is completed and it is under operation w.e.f January 2023.

S No	CRZ Conditions	Compliance Status
	obstructed	However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet), it is assured that, provision will be made for mangrove areas will get proper flushing of water and free flow of water is not obstructed.
6.	The KPT shall have to dispose of the dredged material only after scientific study to be carried out by the Institute of National repute and at a location suggested by them.	The work of project at Sr. No. 1 of EC i.e. "Setting up of Oil jetty no. 7" is Completed and it is under operation w.e.f January 2023. Capital Dredging at O.J. completed on 14/04/2023. It is submitted that, in compliance of specific condition no. xi of the EC dated 19/02/2020 DPA appointed IIT-Mumbai as an Independent agency for monitoring the dredging activities undertaken, vide work order no. HD/WK/1078/2022/OJ7/dredging/ENV610 dated 21/12/2022. However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet), it is assured that condition mentioned will be complied with.
7.	The KPT shall have to maintain the record for generation and disposal of capital dredging and maintenance dredging.	Point noted for the compliance.
8.	No dredging, reclamation or any other project related activities shall be carried out in the CRZ area categorized as CRZ I (i) and it shall have to be ensured that the mangrove habitats and other ecologically important and significant areas, if any, in the region are not affected due to any of the project activities	It is hereby assured that DPA will undertake only activities recommended by the GCZMA vide letter dated 29/06/2016 and EC & CRZ clearance accorded by the MoEF&CC, GOI vide letter dated 18/02/2020. DPA has already prepared a mangrove preservation plan for the entire Kandla area In addition to the above, DPA appointed M/s GUIDE, Bhuj, for "Regular Monitoring of Mangrove Plantation carried out by DPA" (period 15/9/2017 to 14/9/2018 vide work order dated 1/9/2017 and 24/5/2021 to 23/5/2022 vide work order dated 3/5/2021). The final report submitted by M/s GUIDE, Bhuj, for the years 2017 to 2018 has been submitted in the earlier compliance report, and the final report for the year 2021 to 2022 is Submitted along with the compliance report submitted on 03/05/2023. In continuation of same, DPA appointed M/s GUIDE, Bhuj, for "Monitoring of Mangrove Plantation 1600 ha carried out by DPA" (period 10/06/2024 to 09/06/2025 vide work order dated 10/6/2024.A copy is attached as **Annexure B** Further, DPA had assigned the work to M/s GUIDE, Bhuj for "Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme covering all seasons on various aspects of the Coastal Environs covering Physico-chemical parameters of marine water and marine sediment samples coupled with biological indices, as per the requirements of EC & CRZ Clearances reg. (for three years (2021-2024)). The final report for the year 2021-22 has already been communicated with the last compliance report submitted vide letter 11/07/2022. The final report for the year 2023-2024 submitted is attached herewith as **Annexure C.**

S No	CRZ Conditions	Compliance Status
		In continuation of the same, DPA had assigned the work to M/s GUIDE, Bhuj for "Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme covering all seasons on various aspects of the Coastal Environs covering Physico-chemical parameters of marine water and marine sediment samples coupled with biological indices as per the requirements of EC & CRZ Clearances reg. (for three years (2024-2027)) vide its work order dated 10/06/2024. Copy of same is attached herewith as **Annexure D** It is relevant to mention here that, DPA has already undertaken Mangrove Plantation in an area of 1600 Ha. till date since the year 2005. A statement showing details of the mangrove plantation and the cost incurred is again placed in **Annexure A.**
9.	The KPT shall participate financially for installing and operating the vessel traffic management system in the Gulf of Kutch and shall also take lead in preparing and operational sing the Regional Oil Spill Contingency plan in the Gulf of Kutch	DPA had already contributed an amount of Rs. 98.955 crore i.e 25% of the total project cost of 395.82 crore for installing and operating VTMS in Gulf of Kachchh
10.	The KPT shall strictly ensure that no creeks or rivers are blocked due to any activity at Kandla	The work of project at Sr. No. 1 of EC i.e. "Setting up of Oil jetty no. 7" is Completed and it is under operation w.e.f January 2023. However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet), it is assured that condition mentioned will be complied with.
11.	Mangrove plantation in an area of 50 ha shall be carried out by the KPT within 2 years in a time bound manner on Gujarat coastline either within or outside the Kandla port Trust area and six-monthly compliance report along with the satellite images shall be submitted to the ministry of Environment and Forest as well as to this Department without fail.	DPA has signed MoU with Gujarat Ecology Commission, Gandhinagar to carry out mangrove plantation through PPP mode for the year 2020-2021. DPA (Erstwhile KPT) had already undertaken Mangrove Plantation in an area of 1600 Ha. till date since the year 2005. A statement showing details of the mangrove plantation and the cost incurred is again placed in **Annexure A**. In addition to the above, DPA appointed M/s GUIDE, Bhuj, for "Regular Monitoring of Mangrove Plantation carried out by DPA" (period 15/9/2017 to 14/9/2018 vide work order dated 1/9/2017 and 24/5/2021 to 23/5/2022 vide work order dated 3/5/2021). The final report submitted by M/s GUIDE, Bhuj, for the years 2017 to 2018 has been submitted in the earlier compliance report, and the final report for the year 2021 to 2022 is Submitted along with the compliance report submitted on 03/05/2023
12.	No activity other than those permitted by the competent authority under the CRZ Notification Shall be carried out in the CRZ area.	The construction work for the project at Sr 1 is completed and it is under operation. The work of project at Sr. No. 1 of EC i.e. ***"Setting up of Oil jetty no. 7***" is Completed and it is under operation w.e.f January 2023. The Consent to Operate (CCA) from the Gujarat Pollution Control Board has already been obtained dated 20/1/2023 .Copy of same is already submitted in the earlier compliance report submitted on 03/10/2023.

S No	CRZ Conditions	Compliance Status
		However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet), it is assured that, no activity other than those permitted by the competent authority under the CRZ Notification Shall be carried out in the CRZ area
13.	No ground water shall be tapped for any purpose during the proposed expansion/modernization activities.	The work of project at Sr. No. 1 of EC i.e. "Setting up of Oil jetty no. 7" is Completed and it is under operation w.e.f January 2023 required water supply is purchased from GWSSB. However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet), it is assured that condition mentioned will be complied with.
14.	All necessary permissions from different Government Departments/agencies shall be obtained by the KPT before commencing the expansion activities.	DPA had already obtained the necessary EC & CRZ clearance for the project on dated 19/02/2020. Further, Consent to establish from GPCB had already been obtained from GPCB for the same. Subsequently, DPA obtained EC to CTE (PCB ID 48573) vide GPCB Order dated 13/10/2020 after obtaining Environmental and CRZ Clearance from MoEF&CC, GoI vide F. No. 11-13/2015-IA-III dated 19/02/2020 In addition to this as the construction work for the project at Sr 1 is completed and it is under operation w.e.f January 2023 therefore CCA has obtained from the Gujarat Pollution Control Board vide GPCB/CCA-Kutch-1319/ID-48573/701442 dated 20/01/2023. Copy of same is already submitted in the earlier compliance report submitted on 03/10/2023.
15.	No effluent or sewage shall be discharged into the sea/creek or in the CRZ area and it shall be treated to confirm to the norms prescribed by the Gujarat Pollution Control Board and would be reused/recycled with in the plant premises.	In this regard, it is to state that, DPA is already having a sewage treatment plant capacity of 1.5MLD for the treatment of domestic sewage. The treated sewages from STP of DPA are utilized for plantation / Gardening. DPA has been conducting regular monitoring of Environmental parameters through NABL Accredited laboratory since the year 2016 in continuation of this DPA appointed M/s Gujarat Environment Management Institute (GEMI), Gandhinagar (NABL Accredited laboratory) for regular Monitoring of environmental parameters vide work order dated 15/02/2023. The work is in progress & DPA is submitting the monitoring data regularly to all the concerned authorities along with compliance reports submitted. The latest Environmental Monitoring Reports is enclosed herewith as **Annexure E.** Further, necessary provisions will be made for the projects at Sr. No. 2 – 5 to not discharge effluent or sewage into the sea/creek or in CRZ area
16.	All the recommendations and suggestions given by the Mantec Consultant Pvt. Ltd. New Delhi in their Comprehensive Environment Impact Assessment report for conservation/protection and betterment of environment shall be implemented strictly by the KPT.	DPA has installed Mist Canon at the Port area to minimize the dust Further, DPA has already installed continuous sprinkling system to prevent dust pollution. Further, to control dust pollution in other area, regular sprinkling through tankers on roads and other staking yards is being done. Regular sweeping of spilled cargo from roads is done by parties on regular basis.

S No	CRZ Conditions	Compliance Status
		DPA has been conducting regular monitoring of Environmental parameters through NABL Accredited laboratory since the year 2016 in continuation of this DPA appointed M/s Gujarat Environment Management Institute (GEMI), Gandhinagar (NABL Accredited laboratory) for regular Monitoring of environmental parameters vide work order dated 15/02/2023. The work is in progress & DPA is submitting the monitoring data regularly to all the concerned authorities along with compliance reports submitted. The latest Environmental Monitoring Reports is enclosed herewith as **Annexure E.** For ship waste management, DPA issued Grant of License/Permission to carry out the work of collection and disposal of "Hazardous Waste/Sludge/ Waste Oil" and "Dry Solid Waste (Non- Hazardous)" from Vessels calling at Deendayal Port" through DPA contractors Further, it is to state that, all ships are required to follow DG Shipping circulars regarding the reception facilities at Swachch Sagar portal DPA assigned work to M/s GUIDE, Bhuj, for regular monitoring of Marine Ecology since the year 2017 (From 2017 – 2021), and reports of the same are being submitted regularly to the Regional Office, MoEF&CC, GoI, Gandhinagar as well as to the MoEF&CC, GoI, New Delhi along with compliance reports submitted The final report for the Holistic Marine Ecological Monitoring for the period up to May 2021 was submitted on 22.05.2021. Copy of the report was communicated vide earlier compliance report submitted vide letter dated 29/6/2021 Further, it is to submit that DPA issued a work order to M/s GUIDE vide its letter no. EG/WK/ 4751 /Part (Marine Ecology Monitoring) /11 dated 03/05/2021 for Regular monitoring of Marine Ecology in and around Deendayal Port Authority (Erstwhile Deendayal Port Trust) and continuous Monitoring Program covering all seasons on various aspects of the Coastal Environs for the period 2021-24. The copy of the final report submitted by M/s GUIDE for the year 2021-22 has already been communicated with the last six-monthly compliance report submitted vide letter dated 11/07/2022. The final year report for the year 2023-2024 submitted is attached herewith as **Annexure C**. In continuation of the same, DPA had assigned the work to M/s GUIDE, Bhuj for "Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme covering all seasons on various aspects of the Coastal Environs covering Physico-chemical parameters of marine water and marine sediment samples coupled with biological indices as per the requirements of EC & CRZ Clearances reg. (for three years (2024-2027)) vide its work order dated 10/06/2024. Copy of same is

S No	CRZ Conditions	Compliance Status
		attached herewith as **Annexure D** As already informed, DPA entrusted work of green belt development in and around the Port area to the Forest Department, Gujarat at Rs. 352 lakhs (Area 32 hectares). The work is completed DPA has appointed Gujarat Institute of Desert Ecology (GUIDE) for "Green belt development in Deendayal Port Authority and its Surrounding Areas, Charcoal site' (Phase-l)" vide Work Order No.EG/WK/4757/Part [Greenbelt GUIDE, dated 31st May, 2022. The work completed. A copy of Final report is submitted along with the compliance report submitted on 03/10/2023. Further DPA has accorded the work of "Green belt development in DPA and its surrounding area (Phase II) to Gujarat Institute of Desert Ecology (GUIDE), Bhuj for the plantation of 10000 saplings of suitable species vide work order dated 23/06/2023. The same is in process For dredged material management, DPA assigned work to M/s GUIDE, Bhuj for analysis of dredged material since the year 2017 and the reports are being submitted from time to time along with compliance reports submitted The Final year Report submitted by M/s GUIDE, Bhuj for the period 2022-2023 is attached herewith as **Annexure F.** Further, Dredged Material will be disposed of at designated location as identified by the CWPRS, Pune For energy conservation measures, DPA is already generating 20 MW of Wind energy. In addition to it, DPA has commissioned a 45 kWP Solar Plant at Gandhidham. Further, it is relevant to mention that, two out of four Nos. of Harbour Mobile Crane (HMC) made electric operated. Balance 02 Nos. shall be made electric operated by 2023-2024. Four Nos. of Diesel operated RTGs converted to e-RTGs. Retrofitting of hydrogen fuel cell in Tug Kalinga and Pilot Boat Niharika to be done as a pilot project under the guidance of MoPSW. Also, 14 Nos. of EV cars to be hired in this year and 03 Nos. EV Bus to be procured by the year 2023-24. Further, for Oil Spill Management, DPA is already having Oil Spill Contingency Plan in place and Oil Response System as per the NOS-DCP guidelines.
17.	The construction and operational activities shall be carried out in such a way that there is no negative impact on mangrove and other coastal/marine habitats. The construction activities and dredging shall be carried out only under the constant supervision and guidelines of the Institute of National repute like NIOT	The construction work for the project at Sr 1 is completed and it is under operation w.e.f January 2023 and due care is being taken for so that, there is no negative impact on mangrove and other coastal/marine habitats. Further, for project at Sr. No. 2 to 5 (Construction not yet started); however, the specified condition will be complied with
18.	The KPT shall contribute financially for any	Point noted for the compliance.

S No	CRZ Conditions	Compliance Status
	common study or project that may be proposed by this Department for environmental management/conservation /improvement for the Gulf of Kutch	
19.	The construction debris and/or any other type of waste shall not be disposed of into the sea, creek or in the CRZ areas. The debris shall be removed from the construction site immediately after the construction is over.	The work of project at Sr. No. 1 of EC i.e. ***"Setting up of Oil jetty no. 7***" is Completed and it is under operation w.e.f January 2023. The Consent to Operate (CCA) from the Gujarat Pollution Control Board has already been obtained dated 20/1/2023. Copy of same submitted along with compliance report submitted on 03/10/2023. However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet) DPA had already issued general circular vide dated 3/9/2019 regarding Construction and Demolition Waste Management for strict implementation in DPA. Copy is already submitted during the compliance report submitted on 03/05/2023
20.	The construction camps shall be located outside the CRZ area and the construction labour shall be provided with the necessary amenities, including sanitation, water supply and fuel and it shall be ensured that the environmental conditions are not deteriorated by the construction labours.	The work of project at Sr. No. 1 of EC i.e. ***"Setting up of Oil jetty no. 7***" is Completed and it is under operation w.e.f January 2023. The Consent to Operate (CCA) from the Gujarat Pollution Control Board has already been obtained dated 20/1/2023 Copy of same is already submitted in the earlier compliance report submitted on 03/10/2023. However, for other projects mentioned at Sr. no. 2 to 5 (no construction activities started yet) the condition will be complied with
21.	The KPT shall regularly update their Local oil spill contingency and disaster management plan in consonance with the National oil Spill and Disaster Contingency plan and shall submit the same to this Department after having it vetted through the Indian Coast Guard.	DPA already has updated Disaster management plan and Local oil spill contingency plan. The copy of the same has already been submitted with the last compliance report communicated vide letter dated 11/07/2022. DPA has also executed MOU with Oil companies, i.e., IOCL, HPCL, BPCL etc, for setting up of Tier I facility for combating the Oil Spill at Kandla.
22.	The KPT shall bear the cost of the external agency that may be appointed by this Department for supervision/monitoring of proposed activities and the environmental impacts of the proposed activities.	Point noted for the compliance.
23.	The KPT shall take up massive green belt development activities in and around Kandla and also within the KPT limits.	DPA assigned work for green belt development in an area of about 32 hectares to the Forest Department, Govt. of Gujarat, in August 2019 at the cost of Rs. 352.32 lakhs. The work is completed. Further, DPA also undertook massive green belt development in and around the Port area and at the Gandhidham area. DPA has appointed Gujarat Institute of Desert Ecology (GUIDE) for "Green belt development in Deendayal Port Authority and its Surrounding Areas, Charcoal site' (Phase-I)" vide Work Order No.EG/WK/4757/Part [Greenbelt GUIDE, dated 31st May, 2022. The work completed. A copy of Final report is submitted along with the compliance report submitted on 03/10/2023. Further DPA has accorded the work of "Green belt

S No	CRZ Conditions	Compliance Status
		development in DPA and its surrounding area (Phase II) to Gujarat Institute of Desert Ecology (GUIDE), Bhuj for the plantation of 10000 saplings of suitable species vide work order dated 23/06/2023. The same is in process
24.	The KPT shall have to contribute financially for taking up the socio-economic upliftment activities in this region in consultation with the Forests and Environment Department and the District Collector/District development officer.	DPA has already been undertaking CSR activities. The details of CSR Activities implemented as well as proposed are enclosed herewith as **Annexure G.**
25.	A separate budget shall be earmarked for environmental management and socio-economic activities and details there of shall be furnished to this Department as well as the MoEF,GOI. The details with respect to the expenditure from this budget head shall also be furnished.	DPA has already kept Rs. 657 lakhs in B.E. 2024-25 under the scheme "Environmental Services & Clearance thereof". .
26.	A separate environmental management cell with qualified personnel shall be created for environmental monitoring and management during construction and operational phases of the project.	DPA already has an Environment Management Cell. Further, DPA has also appointed an expert agency to provide Environmental Experts from time to time. Recently, DPA appointed M/s Precitech Laboratories, Vapi, vide work order dated 5/2/2021 Further, DPA has appointed a Manager Environment on a contractual basis for a period of 3+2 years. (Copy already submitted along with the compliance report submitted on 03/05/2022.)
27.	An Environmental report indicating the changes if any, with respect to the baseline environmental quality in the coastal and marine environment shall be submitted every year by the KPT to this Department as well as to the MoEF&CC,GOI	DPA has been conducting regular monitoring of Environmental parameters through NABL Accredited laboratory since the year 2016 in continuation of this DPA appointed M/s Gujarat Environment Management Institute (GEMI), Gandhinagar (NABL Accredited laboratory) for regular Monitoring of environmental parameters vide work order dated 15/02/2023. The work is in progress & DPA is submitting the monitoring data regularly to all the concerned authorities along with compliance reports submitted. The latest Environmental Monitoring Reports is enclosed herewith as **Annexure E.** DPA has been submitting the environmental monitoring report along with the compliance report to IRO, MoEF&CC, GoI
28.	The KPT shall have to contribute financially to support the National Green Corps Scheme being implemented in Gujarat by the GEER foundation. Gandhinagar in consultation with Forests and Environment Department.	Point noted for the compliance.
29.	A six monthly report on compliance of the conditions mentioned in this letter shall have to be furnished by the KPT on regular basis to this Department/MoEF&CC,GOI	DPA has been regularly submitting a six-monthly report in compliance with the conditions mentioned to GCZMA and MoEF&CC, GOI. Last compliance submitted on 03/05/2023.
30.	Any other condition that may be stipulated by this Department and MoEF&CC,Gol from time to time for environmental protection / management purpose shall also have to be complied with by DPT.	Point noted.

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Annexure A

Statement of Mangrove Plantation

DEENDAYAL PORT AUTHORITY

DETAILS OF MANGROVE PLANTATION ALREDY CARRIED OUT & Proposed To be Carried Out :

Sr. No	Name of the Organization	Total Mangrove Plantation carried out in Hectares till date and place of plantation and agency	Cost incurred
(A) MANGROVE PLANTATION ALREDY CARRIED OUT			
1	DEENDAYAL PORT TRUST (CRZ Recommendation 13th to 16th CB issued by the GCZMA) (Total 1000 ha.)	20 Hectares – 2005-06 Satsida Bet,Kandla, by GUIDE,Bhuj 50 Hectares – 2008-09 Nakti Creek,Kandla by Patel Construction 100 Hectares – 2010-11 Nakti Creek ,Kandla by GEC. (Board 29/1/2010) 200 Hectares – 2011-12 by Forest Department, GoG at Satsaida Bet 300 Hectares – 2012-13 by Forest Department, GoG at Satsaida Bet 330 Hectares – 2013-14 by Forest Department, GoG at Satsaida Bet **TOTAL 1000 HA.**	Rs. 8.8 lakhs Rs. 27.4 lakhs Rs.24.5 lakhs Rs. 66.5 lakhs Rs. 157.5 lakhs (total 630 hectares)
2	Creation of Berthing & allied Facilities off- tekra near Tuna (Outside Kandla Creek) – EC & CRZ Clearance. (Total 500 ha. – 250Ha. by DPT & 250 ha by Adani (concessionaire) MOU signed with GEC during Vibrant Gujarat Summit 2015 for 300 Ha.	**300 Hectares** – 2015-17 by GEC at Kantiyajal, Bharuch District	Rs. 90.0 lakhs
3.	EC & CRZ Clearance dated 19/12/2016 for Developing 7 integrated facilities (Condition 100 Ha).	**100 Ha**. –2018- 20 by GEC (50 Ha- Satsaida Bet & 50 Ha – Kantiyajal, Bharuch)	Rs. 45 lakhs

4.	EC & CRZ Clearance dated 18/2/2020 (Dev. 3 remaining facility) and EC & CRZ Clearance dated 19/2/2020 (Dev. Of Integrated Facilities 5 projects (Stage II). Ref.: CRZ Recommendation GCZMA 100 Ha.(50 Ha. + 50 Ha.)	**100 Ha.** By GEC 2021-22 (kantiyajal, Bharuch)	Rs. 45 lakhs
5	CRZ Recommendation Outfitting Jetty & floating Dry Dock at Vadinar by DPA.	100 Ha. By GEC : 2022-23, Location (Sat Saida Bet)	Rs. 50 lakhs
Total Mangrove Plantation done by DPA since 2005-06 to till date : 1600 Ha at the cost of Rs. 514.7 Lakhs			

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Annexure B

Monitoring of mangrove Plantation (1600 ha)

DEENDAYAL PORT AUTHORITY

दीनदयाल पत्तन प्राधिकरण
DEENDAYAL PORT AUTHORITY

www.deendayalport.gov.in

Administrative Office Building
Post Box NO. 50
GANDHIDHAM (Kutch).
Gujarat: 370 201.
Fax: (02836) 220050
Ph.: (02836) 220038

NO.EG/WK/4751/Part (Marine Ecology Monitoring)/70 Dated : 10 /06/2024

To,
The Gujarat Institute of Desert Ecology,
P.O.Box No. 83,
Opp. Changleshwar Temple, Mundra Road,
Bhuj (Kachchh)- 370 001,Gujarat (India).
Tel.: 02832-329408, 235025.
Tele/Fax: 02832-235027
Email: desert_ecology@yahoo.com

Kind Attn.: Dr.V.Vijay Kumar, Director, GUIDE, Bhuj.

Sub: Monitoring of Mangrove Plantation 1600 Hectares carried out by DPA (Statutory Requirement) reg.

Ref.: 1) DPA request vide letter no. EG/WK/4751/Part (Marine Ecology Monitoring)/23 dated 12/2/2024.
2) Offer submitted by GUIDE, Bhuj vide letter no. GUIDE/DPA/Offer/ Mang. Plant/13 dated 4/4/2024.

Sir,

Your offer for the subject work submitted vide above referred letter dated 4/4/2024 **(Copy attached – Annexure A)** amounting to Rs. 33,60,000.00 + 18% GST (Rupees Thirty-Three Lakhs and Sixty Thousand only plus eighteen percent GST) with all terms & conditions mentioned in the offer letter, has been accepted by the competent authority in DPA.

2. Scope of work :

Monitoring of Mangrove Plantation (1600 Hectares) carried out by DPA (statutory requirement). The monitoring study will cover components such as density, diversity and abundance. Other variables such as canopy cover, GBH, height, along with the recruitment and regeneration classes will also be investigated. Additionally, carbon sequestration potential of the plantation will also be studied in view of Climate Change mitigation measures.

.........Cont......

3. The terms of payment:

i) 50 % of the project budget should be paid within 15 days from the date of Submission of Inception Report by GUIDE, Bhuj.
ii) 25% of the project budget should be paid within 15 days from the date of submission of Draft report by GUIDE, Bhuj.
iii) 25% of the project budget should be paid within I5 days from the date of submission of Final report by GUIDE, Bhuj.

4. Obligation of DPA :

- Assistance regarding the statutory clearance from concerned authorities to be rendered by DPA for field visits.
- Study area map along with GPS co-ordinates is to be provided by the DPA.

5. Time Period: One year (One time monitoring in a year) i.e. from 10 /6/2024 to 09/6/2025.

6. Kindly send the acknowledgement of this work order & start the work immediately.

Thanking you.

Yours faithfully,

10/6/24

Dy. Chief Engineer & EMC (I/c)
Deendayal Port Authority

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Annexure C

Final Report (2023-24) of Marine ecology monitoring

Annual Report

Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme

Submitted to

DEENDAYAL PORT AUTHORITY
Administrative Office Building
Post Box No. 60, Gandhidham (Kuchchh)
Gujalet-370201

Submitted by

Gujarat Institute of Desert Ecology
P.O Box No. #83, Opp. Changleshwar Temple,
Mundra Road Bhuj - 370001
Gujarat - India

May 2024

Annual Report

Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme

Submitted to

DEENDAYAL PORT AUTHORITY

DEENDAYAL PORT AUTHORITY
Administrative Office Building
Post Box No. 60, Gandhidham (Kuchchh)
Gujalet-370201

Submitted by

Gujarat Institute of Desert Ecology
P.O Box No. #83, Opp. Changleshwar Temple,
Mundra Road Bhuj - 370001
Gujarat - India

May 2024

Project Team

Project Coordinator

Dr. V. Vijay Kumar, Director

Principal Investigator		
Dr. Durga Prasad Behera	Scientist	Phytoplankton & Zooplankton, Physico-chemical parameters, Seaweed, Seagrass & Marine Fisheries,Intertidal.
Team Member		
Dr. Kapilkumar Ingle	Project Scientist	Mangrove Ecology
Dr. L. Prabha Devi	Advisor	Management Plan
Dr. Dhara Dixit	Project Scientist	Halophytes
Mr. Viral. D. Vadodariya	Project Fellow	Avifauna
Mr. Dayesh Parmar	Project officer	GIS & Remote sensing
Mr. Mukesh H. Koladiya	Project Fellow	Avifauna
Ms. Pallavi V. Joshi	Junior Research Fellow	Phytoplankton and Zooplankton
Mr. Deep Dodiya	Junior Research Fellow	Intertidal
Ms. Muskan Karam Chandani	Junior Research Fellow	Lab analysis

Snapshot May-2023 to May 2024

S. No	Components of the Study	Remarks
1	MoEF & CC Sanction Letter and Details	(i). EC & CRZ clearance granted by the MoEF &CC, GoI dated 19/12/16 Dev. of 7 integrated facilities – specific condition no. xviii. (ii).EC & CRZ clearance granted by the MoEF &CC, GoI dated 18/2/2020 Dev. Remaining 3 integrated facilities – specific condition no. xxiii. (iii).EC & CRZ clearance granted by the MoEF &CC, GoI dated 19/2/2020 Dev. integrated facilities (Stage II-5 -specific condition no. xv. (iv). EC & CRZ clearance granted by the MoEF &CC, GoI dated 20/11/20 – Creation of waterfront facilities (OJ 8 to 11- Para VIII Marine Ecology, specific condition iv.
2	Deendayal Port letter Sanctioning the Project	DPT work Order: WK/4751/Part/ (Marine Ecology Monitoring)/11 date 03.05.2021
3	Duration of the Project	Three years-from 24.05.2021 to 23.05.2024
4	Period Of Survey Carried out	May 2023-May 2024
5	Survey Area Within the Port limit	All major and minor creek systems from Tuna to Surajbari and Vira coastal area.
6	Number of sampling locations	Fifteen sampling locations in and around DPA port jurisdiction
7	**Components of the report**	
7a	Mangroves	During the monsoon, the mean plant density was highest at the Veera site, with 2703 trees per hectare. n the post-monsoon season 2023-24, the overall average tree density in DPA area recorded was 3,647 trees/ha. uring the pre-monsoon season of 2024, the overall average tree density of the entire sites was 4,098 trees per hectare. The site S-7 in the Kharo area had the highest average tree density, with an impressive 6,774 trees per hectare
7b	Mudflats	Among the station of DPA port area the maximum bulk density ranges from 1.67 g/cm3 to 2.50 g/cm3and the minimum bulk density ranges was 1.18 g/cm3 to 1.25 g/cm3. Station wise the highest bulk density was recorded at station S-13 in monsoon season (1.52 g/cm3),

		whereas lowest bulk density was recorded in station S-2 and S-1 during pre-monsoon and post-monsdoon(1.25 g/cm3) (0.6%.) at S-7 and S-15 during monsoon and pre-monsoon seasons. he maximum sediment carbon ranges from 1.3% to 3.2% to and the minimum sediment carbon ranges was 0.4% to 2.4%. Stationwise the highest sediment carbon was recorded at station S-12 duringpost-monsoon (3.2%), whereas lowest sediment carbon was recorded in station S-2 during monsoon and premonsoon (2.4%.).
	Zooplankton	The zooplankton identified from the 15 stations falls under 8-12 phylum and 8-16 group for the period May-2023 to May 2024. In monsoon season 12 phylum and 16 zooplankton group was recorded, similarly, in post-monsoon season same phylum and 9 groups have been recorded from the entire study station, likewise in pre-monsoon season 8 phylum and 8 zooplankton group were recorded. The maximum percentage of composition of zooplankton ranged from 28.9% to 35.3% and the minimum percentage composition of zooplankton ranged from 1.1% to 2.3%. The Copepoda contribute highest percentage of composition in all-season In monsoon(28.60%) followed by post-monsoon (35.3%)and pre-monsoon (31.7%).N
7c	Phytoplankton	Season wise the maximum phytoplankton genera varied from 20 to 27 number with average variation of genera was 17-23 number and the minimum genera varied from 8to 20 number of generaThe Maximum percentage of phytoplankton composition for the period May 2023 to May 2023 varied from 54 %to 63% and the minimum percentage of phytoplankton was 1%. Four major group such Pennales, Centrales, Dinophyceae and Cyanophyceae phytoplankton was reported for the period 2023 to 2024. The percentage of composition pennales for three seasons varied from 28% to 38%. The Pennales percentage of composition is contribute highest percentage of composition followed by Centrales and Dinophyceae.
7d	Intertidal Fauna	The survey of the intertidal Fauna of DPA Kandla area recorded the presence of 4 phyla (Annelida, Arthropoda, Chordata, Mollusca). The species diversity was the highest for phylum Mollusca (23), followed by Arthropoda (12), Annelida (6) and Chordata (3) respectively .Highest number of animals was documented belong to species *Austruca iranica* followed by *Austruca variegate* in all three seasons followed by *Scylla olivacea*, *Austruca sindensis*, *Pirenella cingulate* and *Periophthalmus Walton*.
7e	Sub-tidal Macrobenthos	The subtidal Fauna of the DPA Kandla survey recorded the presence of 4 phyla (Annelida Arthropoda, Mollusca, Annelida, Chordata,), including 2 to 28 species. The species diversity was the highest in phylum Mollusca

		(28 species), followed by Arthropoda (14 species), Chordates (2species) respectively. The occurrence of subtidal benthic animals was documented during the three seasons. The highest no of organisms was documented from the pre-monsoon (638), followed by post-monsoon (386) and monsoon (228), respectively. During monsoon the highest percentage composition was shared by *Glauconome angulata* (15.8%) and *Pirenella cingulata* (11.7%) followed by *Capitella* sp. (8.8%). In the the post-monsoon the highest percentage composition of subtidal macrofauna was shared by the Nereis sp. (34.2%), Likewise in Pre-monsoon the highest percentage composition of intertidal macrofauna was shared by the Penaeus sp. (39.3%) respectively.
7f	Seaweeds and Seagrasses	No species of sea weeds and sea grass was recorded from the the stations sampled.
7g	Halophytes	During the period of May 2023 to May 2024 four major halophytes were recorded along the selected study stations of Deendayal Port Authority sites during the 3 seasons, were Salicornia brachiata, *Aeluropus lagopoides, Salvadora persica* and *Sesuvium portulacastrum.* Maximum percentage coverage of halophytes belongs to species *Salicornia brachiate* shared highest percentage of coverage in all season (100%) followed *Sesuvium portulacastrum* (30-45%)
7h	Mammals	During monsoon it was not cited in study area but in post-monsoon it was cited in between S-6 and S-11. Similarly in pre-monsoon it also not reported any one of the study stations.
7i	Reptiles	During the monsoon period of 2023 field surveys it was dighted at S-4 located in the northern part of Sat Saida bet opposite to oil jetty.In post-monsoon it was reported at S-10. similarly in pre-monsoon no individual sighted
7j	Fisheries	The major fish catch activity is carried out in extensive creek systems of Khari creek, Tuna creek, Navalakhi creek and Jhangi creek. For the period of period 2023-2024, cast net was operated in different creek system of Kandla and major fish catch was include during monsoon Mugil cephalus, Planiliza klunzingeri, *Planiliza planiceps*, *Planiliza macrolepis* and *Mugil cephalus* catch was the maximum. In post-monsoon same species were observed, of which *Mugil cephalus* catch also the maximum i.e 3.35 kg was caught in 1 hour of interval. Similarly, during pre-monsoon Mugil *cephalus*, *Planiliza planiceps*, *Planiliza macrolepis*, *Ribbiofish*, *Parapenaeus indicus* also catch. 10kg of different variety fish was catcher within 10 minutes around 1 km of distance.In sasonal basis fisheries cash also estimated from different creek system Dennday Port Authority.

7k	Avifauna	Overall, a total of 100 species belonging to 11 orders, 36 families and 73 genera were recorded from the coastal area of Kandla Port during this one-year study (Annexure 1). Among these, 61 species were aquatic and 39 species were terrestrial, which included six species listed as Near Threatened in the IUCN 2023, Red List.

Comparison Study of Marine Biodiversity of Deendayal Port Authority (DPA) Since 2019-2023

Habitat/ Groups	Major Taxa/Genera/Species	Year 2019-2020		Year 2020-2021		Year May 2021- May 2022			Year May 2022- May 2023		
		Pre Monsoon	Post monsoon	Pre monsoon	Post monsoon	Monsoon	Post monsoon	Pre monsoon	Monsoon	Post monsoon	Pre monsoon
Mangroves	*Avicennia marina*, *Ceriops tagal*, *Rhizophora mucronata, Aegiceras corniculatum*	4	4	4	4	4	4	4	4	4	4
Intertidal Habitat	Gastropods, Bivalves, Crustaceans Polychaetes, fishes, amphipods and Isopods	19	10	10	12	21	16	16	14	14	13
Subtidal Habitat	Polychaetes, molluscs, crustaceans,echinoderms	26	28	30	48	22	22	11	14	21	32
Phytoplankton	*Bacillaria, Navicula, Nitzschia, Chaetoceros, Coscinodiscus, Triceratium, Bidulphia, Melosira, Thassiosira*	32	26	23	19	35	23	23	24-33	22-26	21-26
Zooplankton	Copepods, Harpacticoids, Cyclopoids. brachyurans, cirripedes, Bivalve veligers	33	36	29	27	42	35	42	41	45	40
Seaweeds	Nil (Drifted tufts only)	Nil	Nil	drifted	drifted	drifted	drifted	drifted	NIL	NIL	NIL

Habitat/ Groups	Major Taxa/Genera/Species	Year		Year		Year			Year		
		2019-2020		2020-2021		May 2021- May 2022			May 2022- May 2023		
		Pre-M	**Post-M**	**Pre-M**	**Post-M**	**Monsoon**	**Post-M**	**Pre-M**	**Monsoon**	**Post-M**	**Pre-M**
Sea grasses	Nil (Drifted tufts only)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Halophytes	*Sesuvium portulacastrum, Salvadora persica, Aeluropus*	3	4	4	4	4	4	4	4 Salicrnia dominance	4 Salicrnia dominance	5 Salicrnia dominance
Avifauna	Charadriiformes, Phoenicopteriformes, Pelecaniformes, Passeriformes	49	89	49	69	62	84	52	49	79	53
Fishes	*Mugil cephalus, Harpodon nehereus, Pampus argenteus, Hilsa, Engraulis, Coilia* sp. *Peneaus,Portunus,lobester*	10	8	5	4	7	5	7		160 kg	50 kg
Marine Mammals	Dolphin, *Sousa plumbea*	1	1	Nil	Nil	1	Nil	Nil	1	1	Nil
Reptiles in the	The saw-scaled viper, *Echis*	1	1	Nil	1	Nil	Nil	1	1	1	Nil

For the period May 2023 to May 2024

Habitat/ Groups	Major Taxa/Genera/Species	Year May 2023- May 2024		
		Monsoon	Post monsoon	Pre monsoon
Mangroves	*Avicennia marina*, *Ceriops tagal*, *Rhizophora mucronata, Aegiceras corniculatum*	4	4	4
Intertidal Habitat	Annelida, Arthropoda, Chordata Mollusca	15	15	14
Subtidal Habitat	Annelida,Arthropoda,Mollusca Chordata	26	21	15
Phytoplankton	*Coscinodiscus* dominance in all season	20-25	8-27	11-20
Zooplankton	The phylum Arthropoda was the predominant represented 16 groups in monsoon and post-monsoon (9) and pre-monsoon it contain 6 group which mainly include Copepoda, Harpacticoida, Cyclopoida, Decapoda, Crab larvae and Malacostrac	29-36	15-36	15-31
Seaweeds	No observation of seaweed during the study period	NIL	NIL	NIL

Continue to next page

Habitat/ Groups	Major Taxa/Genera/Species	Year		
		May 2023- May 2024		
		Monsoon	Post monsoon	Pre monsoon
Sea grasses		NIL	NIL	NIL
Halophytes	*Sesuvium portulacastrum*, , Aeluropus lagopoides, *Salicornia brachiata*, *Suaeda nudiflora*	Present	Present	Present
Avifauna	55 species, 71 species , 68 species	55 species 8 order,24 families 23 genera	71 species 9 orders 29 families 55 genera	68 species 8 orders 28 families 53 genera
Marine Mammals	*Sousa plumbea*	No observation	S-6 and S-11	No observation
Fishes	*Mugil cephalus, Planiliza klunzingeri, Planiliza planiceps, Planiliza macrolepis*	*Mugil cephalus* More catch	*Mugil cephalus* More catch	Mugil cephalus
Reptiles	*Echis carinatus sochureki*	No observation	S-10	No observation

LIST of PLATES

Introduction

Deendayal Port is located at Kandla in the Kachchh district of Gujarat state, operated by Deendayal Port Authority (DPA) (constituted under the major port Authority Act and the administrative control of ministry of ports shipping & water way GOI)is India's busiest major port in recent years and is gearing to add substantial cargo handling capacity with private participation. DPA being one of the 12 major ports in India is situated at latitude 22°59'4.93N and longitude 70°13'22.59 E on the Kandla creek at the inner end of Gulf of Kachchh (GoK). Since its formation in the 1950s, the Deendayal Port provides the maritime trade requirements of states such as Rajasthan, Madhya Pradesh, Uttar Pradesh, Haryana and Gujarat. Because of its proximity to the Gulf countries, large quantities of crude petroleum are imported through this port. About 35% of the country's total export takes place through the ports of Gujarat in which the Deendayal port has a considerable contribution. Assortments of liquid and dry cargo are being handled at DPA Port. The dry cargo includes fertilizers, iron and steel, food grains, metal products, ores, cement, coal, machinery, sugar, wooden logs, etc. The liquid cargo viz. chemicals, edible oil, crude oil and other petroleum products etc. DPA has handled 132.3 MMTPA during the year 2023-2024. Presently, the Port has total 1-16 dry cargo berths for handling dry cargo, 7 oil jetties, and one barge jetty at Bunder basin, dry bulk terminal at Tuna Tekra, barge jetty at Tuna and two SPMs (2 local & 1 Nayara energy Limited and two product berths-Nayara energy Limited) at Vadinar for handling crude oil & petroleum product. Regular expansion or developmental activities such as the addition of jetties, allied SIPC and ship bunkering facilities oil jetty No 8 and container terminal at Tuna Tekra are underway in order to cope with the increasing the demand for cargo handling during the recent times. A developmental initiative of this magnitude is going on since past 7 decades, which will have its own environmental repercussions. Being located at the inner end of Gulf of Kachchh, Deendayal Port Authority encompasses a number of fragile marine ecosystems that includes a vast expanse of mangroves, mudflats, creek systems and associated biota. Deendayal Port is a natural harbour located on the eastern bank of North-South trending Kandla creek at an aerial distance of 90 km from the mouth of Gulf of Kachchh. The Port's location is marked by a network of major and minor mangrove lined creek systems with a vast extent of mudflats. Coastal belt in and around the port has an irregular and dissected configuration. Due to its location at the inner end of the Gulf, the tidal amplitude is elevated, experiencing 6.66 m during mean high-water spring (MHWS) and 0.78 m during mean low water spring (MLWS) with MSL of 3.88 m. Commensurate with the increasing tidal amplitude, vast intertidal expanse is present in and around the port environment. Thus, the occurrence of mudflats on the intertidal zone enables mangrove formation to an extensive area. Contrary to the southern coast of Gulf of Kachchh, the coral formations, seaweed and seagrass beds are absent in the northern coast due to high turbulence induced suspended sediment load in the water column, a factor again induced due to the conical Gulf geomorphology and surging tides towards its inner end.

1.1. Rationale of the present study

The ongoing developmental activities at Deendayal Port Authority has been intended for the following.

(i) The development of 3 remaining integrated facilities (Stage 1) within the existing Port at Kandla which includes development of a container terminal at Tuna off Tekra on BOT base T shape jetty, construction of port craft jetty and shifting of SNA section of Deendayal port and railway line from NH-8A to Tuna port.

(ii) EC & CRZ clearance granted by the MoEF &CC, GoI dated 18/2/2020 Dev. Remaining 3 integrated facilities (Stage I) with in existing Kandla port – specific condition no. xxiii.

(iii) EC & CRZ clearance granted by the MoEF &CC, GoI dated 19/2/2020 Dev. integrated facilities (Stage II-5 (1)Setting of oil jetty No7 (2) Setting up barrage jetty at jafarawadi (3) Setting up barrage port at Veera (4) Admirative office building at Tuna Tekra (5) Road connecting from Veera barrage jetty to Tuna gate by M/s DPA -specific condition no. xv.

(iv) EC & CRZ clearance granted by the MoEF &CC, GoI dated 20/11/20 – expansion of port by creation of water front facilities (Oil jetty 8,9,10 and 11) and development of land area 554 acres for associated facilities for storage at old Kandla , Gandhidham, Kachchh by Ms.Dpa Para VIII Marine Ecology, specific condition iv.

(v) Development of 7 integrated facilities (Stage I) within the existing Kandala port CRZ clearance MoEFcc ,GOI dated 19/12/2016-Specific condition (ii),(iii) and (iv) the project proponent ensure that ,not damage the mangrove patch without disturbing creek water circulation ,there is no blocking of creek or rivers of project area and shoreline also not damaged and it periodically monitored .

As per the environmental clearance requirements to these developmental initiatives, by MoEF & CC, among other conditions, has specified to conduct the continuous monitoring of the coastal environment on various aspects covering all the seasons. The regular monitoring shall include physico-chemical parameters coupled with biological indices such as mangroves, seagrasses, macrophytes and plankton on a periodic basis during the construction and operation phase of the project. Besides, the monitoring study also includes an assessment of Mudflats, Fisheries, and Intertidal fauna including the macrobenthos as components of the management plan. The regular marine ecology monitoring includes Micro, Macro and Mega floral and faunal components of marine biodiversity of the major intertidal ecosystems, the water and sediment characteristics. In accord with MoEF&CC directive, DPA has consigned the project on 'Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme" to Gujarat Institute of Desert Ecology (GUIDE), Bhuj during May, 2021. Further, Deendayal Port authorities has entrusted Gujarat Institute of Desert Ecology (GUIDE) to continue the study for another three years, *i.e.,* 2021 – 2024. The study covers all the seasons as specified by specific condition of the Ministry of Environment, Forest and Climate Change (MoEF&CC). The present study is designed considering the scope of work given in the EC conditions

Scope of the Work

The scope of the present investigation includes physico-chemical and marine biological components as mentioned in the specific conditions of MoEF&CC, EC & CRZ clearance dated 19.12.2016,18.2.2020,19.2.2022 and 20.11.2020 with specific conditions xviii, xxiii, xv & iv respectively. A detailed holistic approach to different components of marine physico-chemical parameters of water and sediment and marine biodiversity within the

Deendayal Port area will be carried out. Based on the results obtained during the project period, a detailed management plan will be drawn at the end of the project period. The biological and physico-chemical variables will be investigated during the present study on a seasonal basis *i.e.,* monsoon, post monsoon and pre-monsoon as follows.

- Physico-chemical characteristics of water and sediment
- Detailed assessment of mangrove vegetation structure including density, diversity, height, canopy, and other vegetation characteristics.
- GIS and RS studies to assess different ecological sensitive land use and land cover categories within the Port area such as the extent of dense and sparse mangroves, mudflats, creek systems, and other land cover categories within the port limits.
- Quantitative and qualitative assessment of the intertidal fauna, composition, distribution, diversity, density, and other characteristics.
- Data collection on the species composition, distribution, diversity and density of sub-tidal benthic fauna.
- Estimation of primary productivity at the selected sampling sites located in around the DPA area.
- Investigation of the species composition, distribution, density, and diversity of phytoplankton and zooplankton.
- Recording the occurrence and diversity distribution of halophytes, seagrasses, seaweeds and other coastal flora.
- Investigations on the Avifaunal density, diversity, composition, habitat, threatened and endangered species and characters.
- Fishery Resources – Species composition, diversity, Catch Per Unit Effort (CPUE) and other socio-economic information.

1.3. Study area

The entire study area covering latitude 22°59'4.93N and longitude 70°13'22.59 E on the Kandla creek .The different sampling station and its collection GPS coordinated presented in table 1 and figure1. The coastal belt in and around Deendayal Port Authority jurisdiction is characterized by a network of creek systems and mudflats which are covered by sparse halophytic vegetation like scrubby to dense mangroves, creeks and salt-encrusted landmass which form the major land components. The surrounding environment in 10 km radius from the port includes built-up areas, salt pans, human habitations and port related structures on the west and north creek system, mangrove formations and mudflats in the east and south. The nearest major habitation is Gandhidham town located about 12 km away on the western part with a population of 2,48,705 (as per 2011 census**).**

Table1.Latitude and longitude of Study Area

Station	latitude	longitude
S-1	22.94100000000	70.13580000000
S-2	22.96160000000	70.12440000000
S-3	22.98760000000	70.23450000000
S-4	23.02850000000	70.23310000000
S-5	23.08040000000	70.22450000000
S-6	23.16220000000	70.39510000000
S-7	22.97710000000	70.21250000000
S-8	23.03780000000	70.40700000000
S-9	22.99600000000	70.39320000000
S-10	23.10070000000	70.29610000000
S-11	23.16080000000	70.49480000000
S-12	22.94460000000	70.10620000000
S-13	22.90670000000	70.00020000000
S-14	22.89590000000	70.07450000000
S-15	23.06540000000	70.21720000000

Figure 1. Map showing the proposed sampling locations 2021-2024

2.1. Land use and Land Cover Changes

In order to understand the spatial and temporal changes in the vicinity of the Deendayal port jurisdiction area, Remote Sensing and GIS technique has been employed. Land cover classification was carried out using digital satellite imageries. Images for the Deendayal Port area were acquired for the period of April 2017, December 2019 and March 2020, November 2020, April 2021, March 2022 and March 2023 were used for the study. These were brought to UTM projection with spheroid and datum named WGS 84 in UTM zone 42 north.

Table 2. Satellite imagery used for Land use and Land Cover Map

Image use	Satellite name	Sensor	Spatial Resolution	Date acquired
2017	IRS-R2A	LISS IV	5.8m	26 April- 2017
2019	IRS-R2A	LISS IV	5.8m	24-DEC-2019
2020	IRS-R2A	LISS IV	5.8m	29-March-2020
2020	IRS-R2	LISS IV	5.8m	17-Nov-2020
2021	IRS-R2	LISS IV	5.8m	10-APR-2021
2022	IRS-R2	LISS IV	5.8m	12-March-2022
2023	IRS-R2	LISS IV	5.8m	31-March-2023

2.2. Methodology

Training samples were collected from these imageries. Selecting training samples from these cloud-free mosaics was straightforward due to the very distinctive signature of mangrove area. High contrast with open water, saltpan and mudflat helped in selecting the training data successfully. Same training samples with slight modifications in each imageries mosaic (addition and removal of few training samples) were used for the classification of all different date images. Six major classes *viz*., mangrove, water, mudflat, other vegetation, salt pan and port were delineated. For the tonal variation and pixel values in the imageries, NDVI (Normalised Differential Vegetative Index) and a supervised Maximum Likelihood Classification (MLC) methods were used for the classification. ERDAS Imagine 9.3 was used for satellite image processing, classification and data transformation whereas ARC GIS 10.3 was used for the map formation. For graphs and databases processing, MS WORD and MS EXCEL were used.Ground truth study comprises data collection of ground features along with the respective geographical positions in terms of latitudes and longitudes with Garmin e-Trex Vista GPS. Thus, the data were interpreted using all the collected information

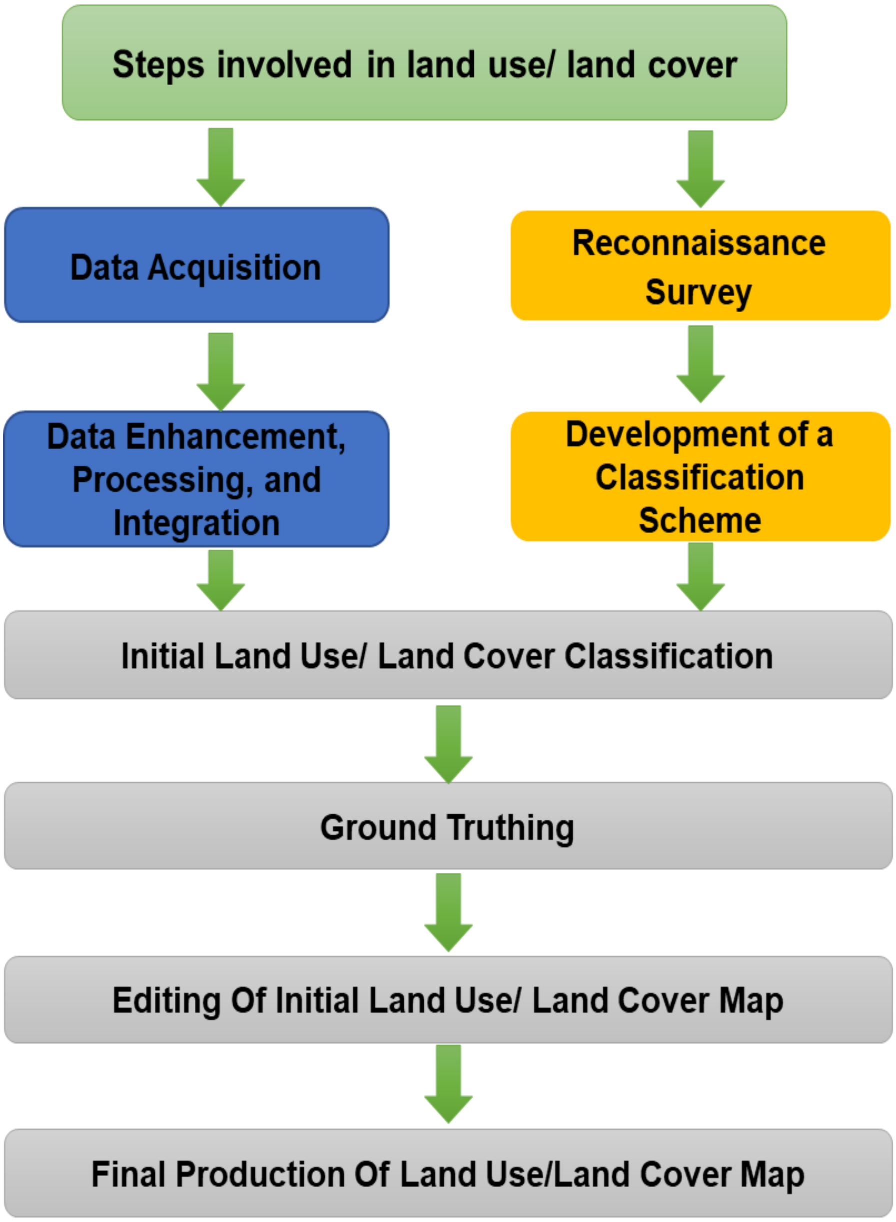

Figure 2. Methodology for land use Land cover

2.3. Land use /land cover

Classified imageries are presented in Fig 3 to Fig 4 and detailed presented in table 2 and 3.

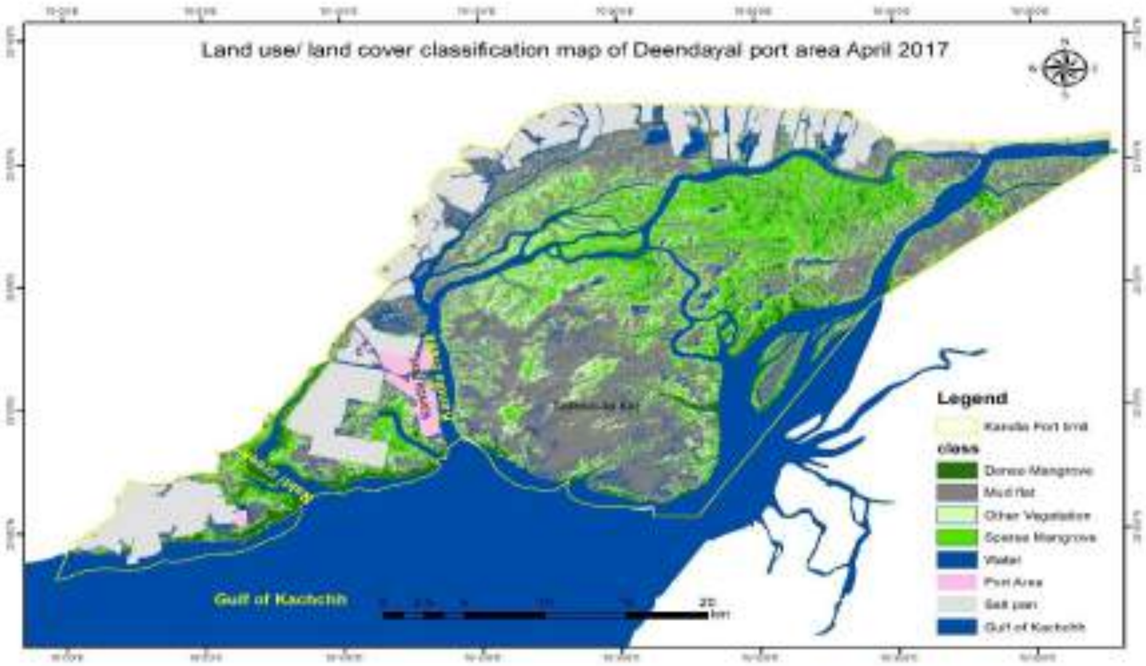

Figure 3. Land use/ Land cover classification in DPA area- April-2017

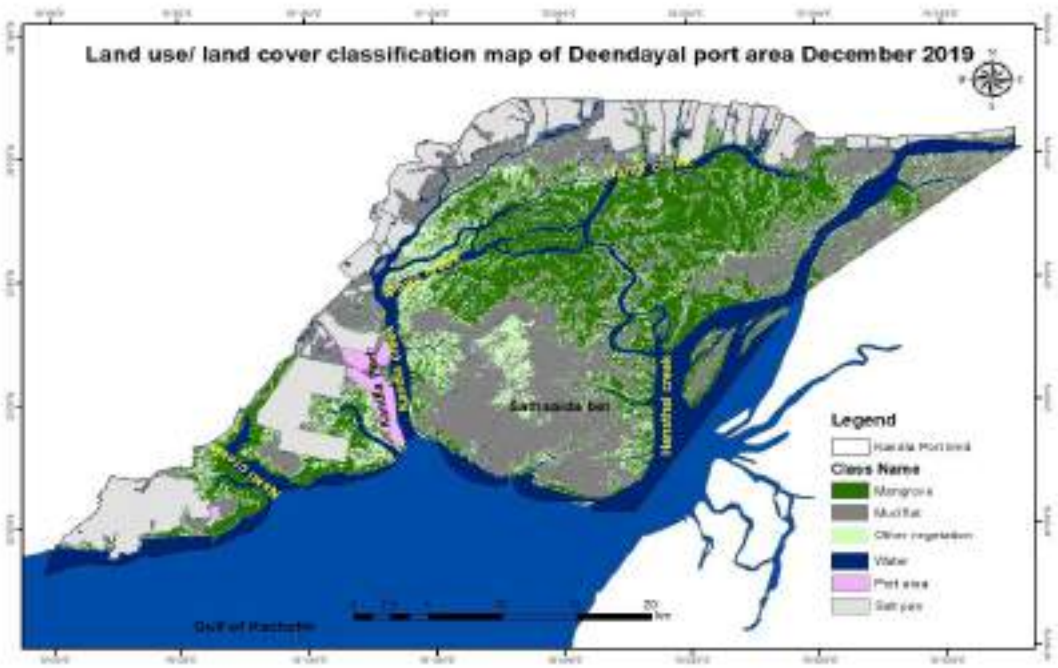

Figure 4. Land use/ land cover classification in DPA area December-2019

Table 3. Land use /Land cover statistics in the DPA area - April-2017

Class Name	Area (ha)	Percentage
Mangrove (Dense + Sparse)	19319.71	19.32
Mudflat	31293.43	31.3
Other veg	12438.8	12.44
Port Area	1243.67	1.24
Salt pan	15016.1	15.02
Water	20674.3	20.68
Total	**99986.01**	**100**

Table 4. Land use /Land cover statistics in the DPA area - December-2019

Class Name	Area (ha)	Percentage
Mangrove	23060.04	23.06
Mudflat	31179.87	31.18
Other vegetation	12333.21	12.33
Water	16953.68	16.96
Port area	1346.21	1.35
Salt pan	15113	15.12
Total	**99986.01**	**100**

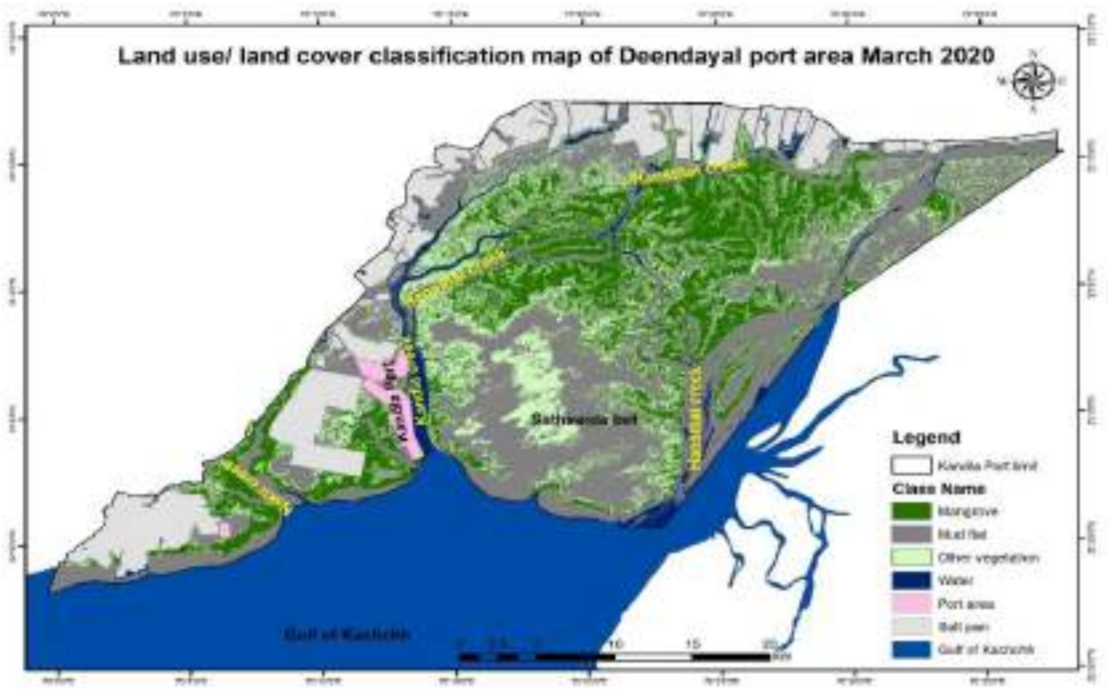

Figure 5. Land use/ land cover classification in DPA area March-2020

Table 5. Land use /land cover statistics in the DPA area- March-2020

Class name	Area (ha)	Percentage
Mangrove	23168.4	23.17
Mudflat	40714.6	40.72
Other vegetation	15991.69	15.99
Port area	1346.21	1.35
Salt pan	15054.5	15.06
Water	3710.61	3.71
Total	**99986.01**	**100**

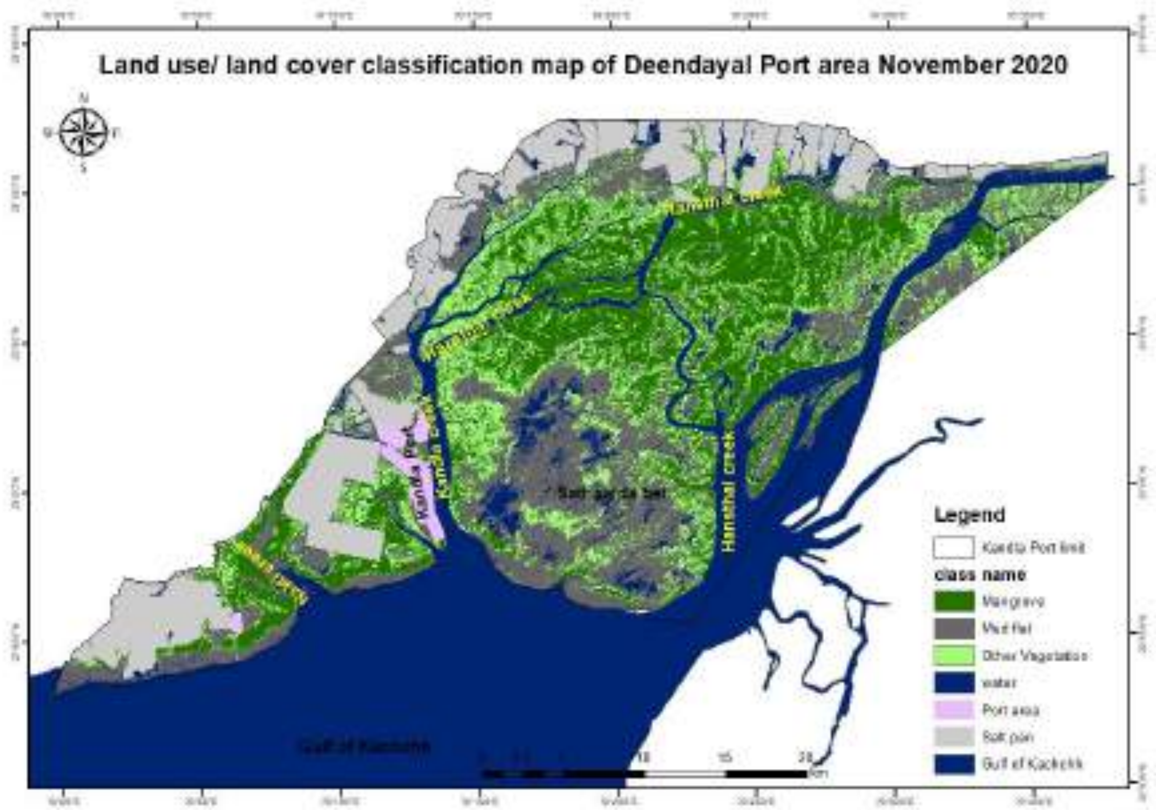

Figure 6. Land use/ land cover classification in Deendayal port area November 2020

Table 6. Land use /land cover statistics in the DPA area- November2020

Class	Area (ha)	Percentage
Mangrove	23856.8	23.86
Mudflat	28764.6	28.77
Other Vegetation	16346.1	16.35
Port area	1346.21	1.35
Salt pan	15193.5	15.2
water	14478.8	14.48
Total	99986.01	100

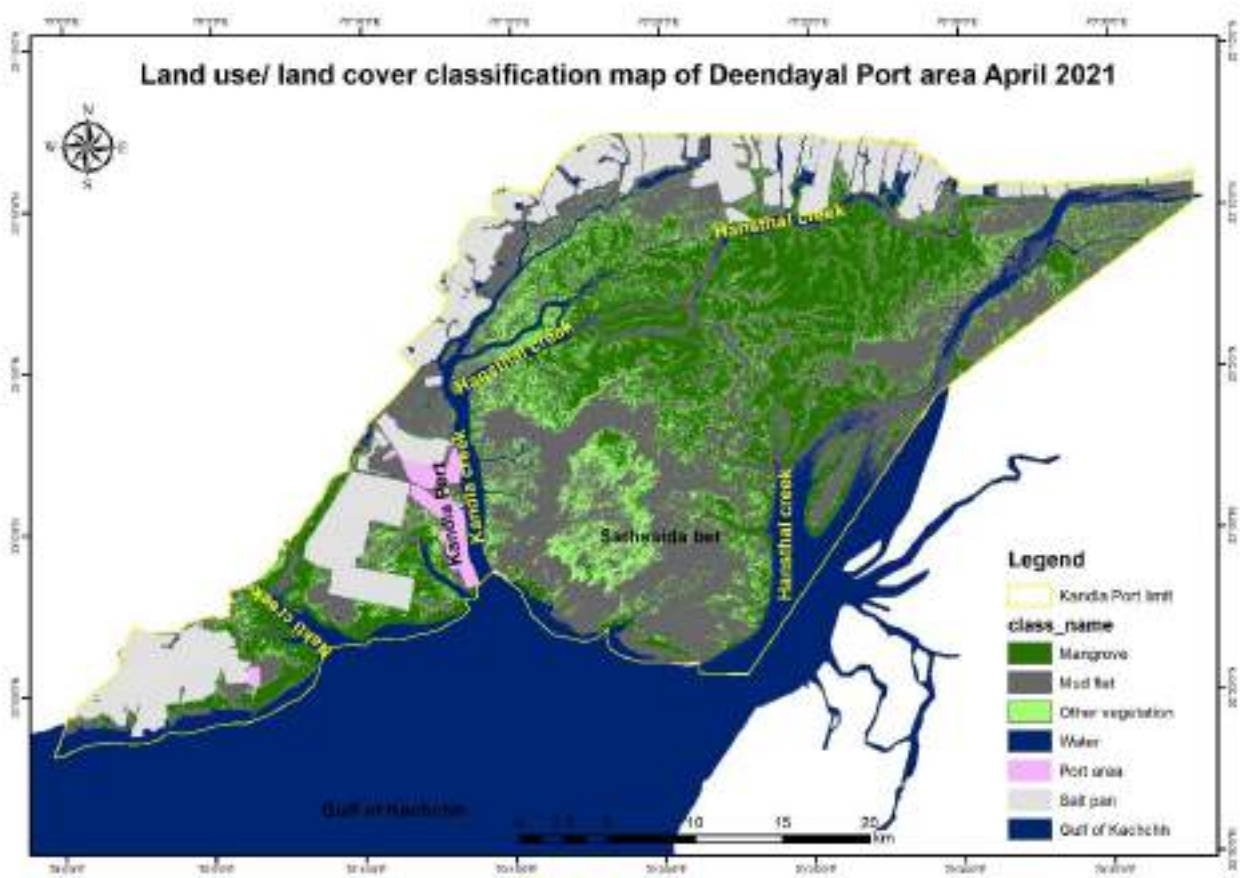

Figure 7. Land use/ land cover classification in Deendayal port area April-2021

Table 7. Land use /land cover statistics in the DPA area April-2021

class name	Area (ha)	Percentage
Mangrove	23967.4	23.97
Mudflat	36909.3	36.91
Other vegetation	11230.4	11.23
Port area	1346.21	1.35
Salt pan	15236.6	15.24
Water	11296.1	11.3
total	**99986.01**	**100**

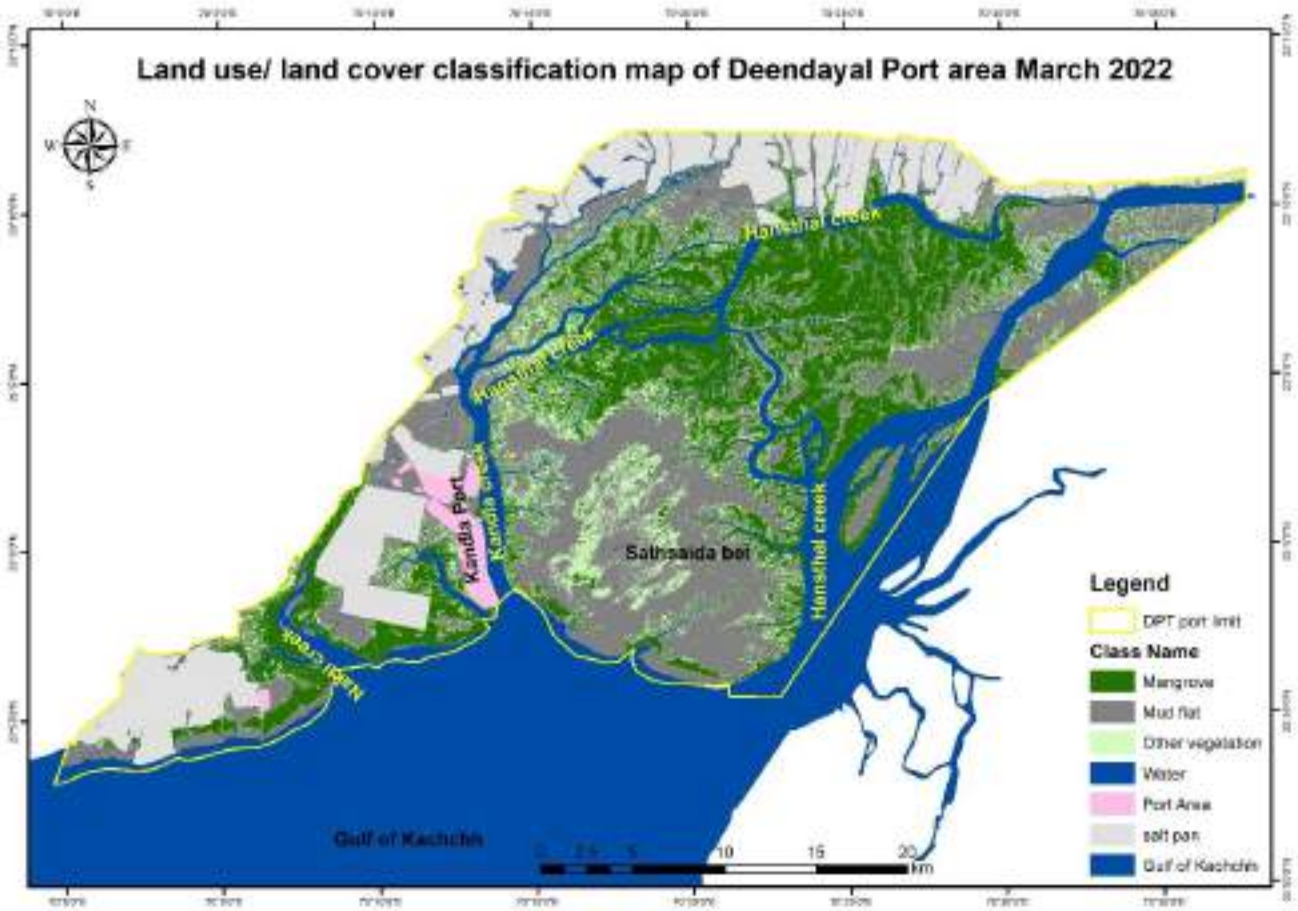

Figure 8.Land use/ land cover classification in Deendayal port area March-2022

Table 8. Land use /land cover statistics in the DPA area March-2022

class name	Area (ha)	Percentage
Mangrove	24328.7	24.33
Mudflat	31089.06	31.09
Other vegetation	11561.2	11.56
Port Area	1436.75	1.44
salt pan	15545.7	15.55
Water	16024.6	16.03
Total	**99986.01**	**100**

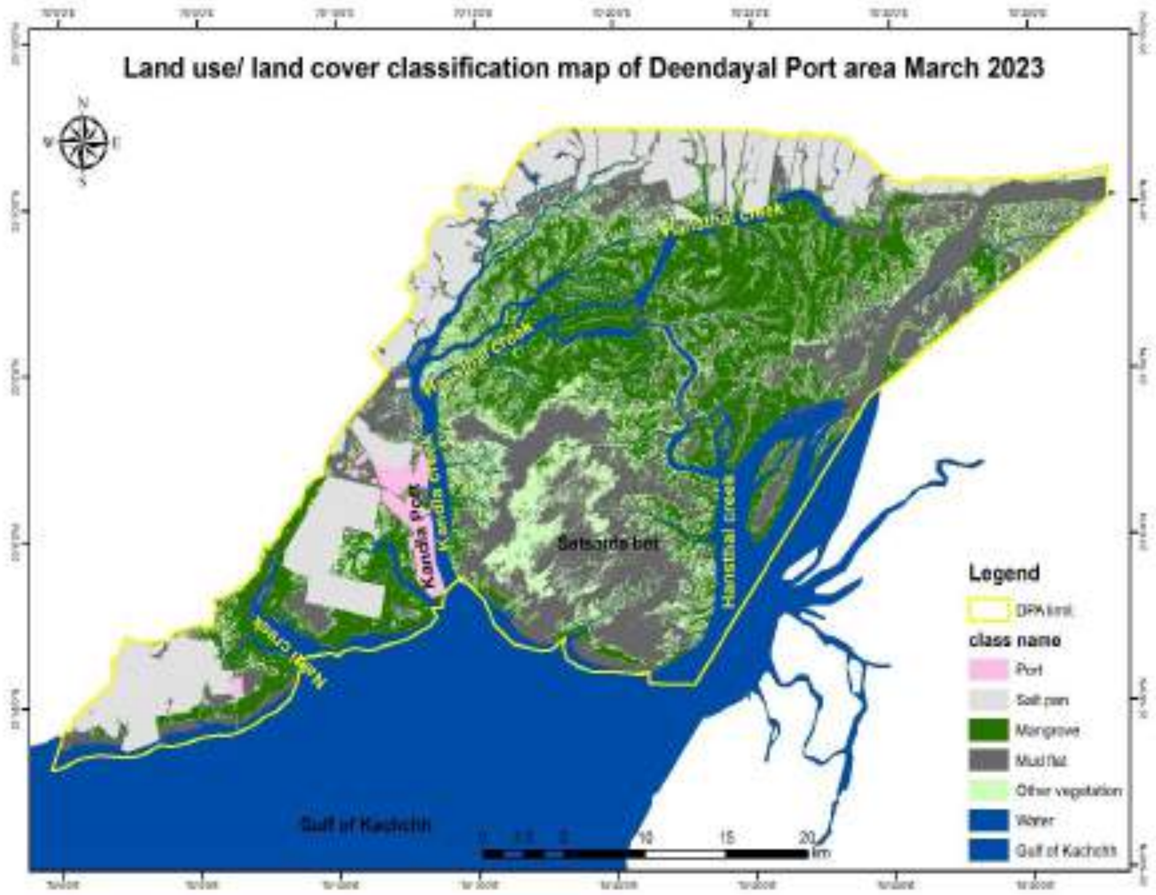

Figure 9. Land use/ land cover classification in Deendayal port area March-2023

Table 9. Land use /land cover statistics in the DPT area for March-2023

class name	Area (ha)	Percentage
Mangrove	26520.56	26.52
Mud flat	27547.90	27.55
Other vegetation	15969.90	15.97
Port	1436.75	1.44
Salt pan	16094.80	16.10
Water	12416.10	12.42
Total	**99986.01**	**100.00**

2.2.2. Comparative analysis of Land use and Land cover study

From April 2017 to March 2023 the overall mangrove area increased from 19319 ha to 26520.5 ha, i.e. 7 % of the total area of DPA. Mangrove area is replacing on the mostly on mudflat, hence there is a decreasing trend of the mudflat is clearly seen. Since this area comes under the influence of the tidal time mudflat area comes high value in that case water area decrease. But overall trends show mudflat is replaced by mangroves. (Fig 3.9). Good monsoon and favorable environment have positively impacted the mangroves to flourish. The below graph shows clearly, year on year mangrove area in DPA vicinity is increasing, currently, around 26.5% of the total area of DPT is covered by mangroves.

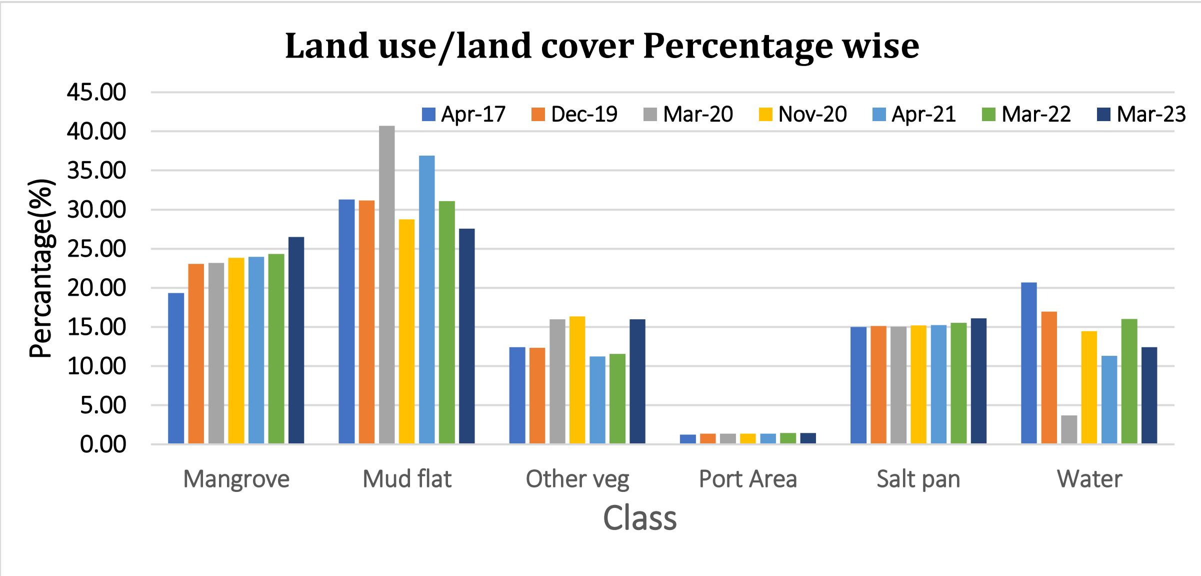

Figure 10. LU/LC Percentage area for the period 2017 to 2023 in Deendayal Port Authority

Table 10. Land use /land cover Percentage wise in the vicinity of DPA area for the study period 2017-2023

Month-Year	**Apr-17**	**Dec-19**	**Mar-20**	**Nov-20**	**Apr-21**	**Mar-22**	**Mar-23**
Class Name	Area (ha)						
Mangrove	19.32	23.06	23.17	23.86	23.97	24.33	26.52
Mudflat	31.30	31.18	40.72	28.77	36.91	31.09	27.55
Other veg	12.44	12.33	15.99	16.35	11.23	11.56	15.97
Port Area	1.24	1.35	1.35	1.35	1.35	1.44	1.44
Salt pan	15.02	15.12	15.06	15.20	15.24	15.55	16.10
Water	20.68	16.96	3.71	14.48	11.30	16.03	12.42
Total	100	100	100	100	100	100	100

3. Methodology

3.1. Physico-chemical characteristics of water and sediment

A port is a location on a coast or shore containing one or more harbors where ships can dock and transfer people or cargo to or from land. Port locations are selected to optimize access to land and navigable water, for commercial demand, and for shelter from wind and waves. Harbors can be natural or artificial. An artificial harbor has deliberately constructed breakwaters, sea walls, or jetties, or otherwise, they could have been constructed by dredging, and these require maintenance by further periodic dredging.Ports are economic instruments for trade and a vital component in the nation's economy. Nevertheless, port activities such as land reclamation, dredging and large-scale construction and its continuous expansion negatively affect the marine ecosystems in its vicinity.

In a port environment, activities like dredging, continuous movement of vessels and humans create major impacts at the marine/coastal environment and the living resources. This will have several impacts on the coastal environmental health which can be reflected by the nature of the physico-chemical characteristics of water which in turn indicates in its productivity. The change in productivity pattern of the marine environment is highly influenced by the flow of nutrients which generally originates from natural and anthropogenic sources. This change in quality of marine water, impacts the composition and availability of aquatic organisms directly and also affects the natural process in the marine ecosystem biological component, coral reefs and seagrass habitats etc. Similar to water, marine sediments also receive pollutants / such as heavy metals, petroleum hydrocarbons, polyaromatic hydrocarbons, polychlorinated biphenyls etc as contaminants from various activities, both off shore and on shore near ports and harbours. Hence assessing the water and sediment characteristics is imperative to understand the environmental changes and to suggest scientific interventions to restore the ecosystem integrity

3.1.1. Sampling Parameters & Water sample collection

Sampling was carried out for the coastal water (surface) and sediment for the determination of physical and chemical characteristics from the prefixed sampling sites. The biological parameters (benthic and pelagic fauna, flora and productivity) were also estimated (Table 10).

Table-11. Physico-chemical and biological parameters analysed

Parameters		
Water	**Mangrove & Other Flora**	**Intertidal fauna**
▪ pH ▪ Temperature ▪ Salinity (ppt) ▪ Petroleum Hydrocarbon-PHC ▪ Dissolved oxygen ▪ Total Suspended Solids (TSS) ▪ Total Dissolved solids (TDS) ▪ Petroleum Hydrocarbons (PHs) **Nutrients** ➢ Nitrate (NO_3) ➢ Nitrite (NO_2) ➢ Total Nitrogen ➢ Phosphate ➢ Silicate **Sediment** ✓ Texture ✓ Total organic carbon (TOC) **Biological Parameters** ✓ Phytoplankton- Genera, abundance, diversity and biomass ✓ Productivity-Chlorophyll a ✓ Zooplankton – Species, abundance, diversity ✓ Macrobenthos - genera, abundance, diversity ✓ Fishery Resources - Common fishes available, composition, diversity, Catch Per Unit Effort (CPUE)	**Mangrove** Vegetation structure density, diversity, height, canopy cover Other vegetation characteristics. **Halophytes:** Occurrence, Distribution, and diversity **Seagrass and Seaweed** Occurrence Distribution and diversity.	**Intertidal fauna:** composition, distribution, diversity, density and other characteristics. **Avifauna:** Density, diversity, composition, habitat, threatened and endangered species and characters

The water samples were collected from each pre-designated sites in pre-cleaned polyethylene bottles. Prior to sampling, the bottles were rinsed with sample water to be collected and stored in an ice box for transportation to laboratory and refrigerated at 4°C till further analysis. The analysis of the water quality parameters was carried out by following standard methods (APHA, 2017). All extracting reagents were prepared using metal-free, AnalaR grade chemicals (Qualigens Fine Chemicals Division of Glaxo SmithKline Pharmaceuticals Limited, Mumbai) and double distilled water prepared from quartz double distillation assembly. There is one water sample will be collect from each designated sampling locations and period of survey will be carried out June to September as Monsoon, October to January will be designated as Post-monsoon and February to May will be designated as Pre-monsoon.

3.1.2. pH and Temperature

A Thermo fisher pH / EC / Temperature meter was used for pH and temperature measurements. The instrument was calibrated with standard buffers just before use.

3.1.3. Salinity

A suitable volume of the sample was titrated against Silver nitrate (20 g/l) with Potassium chromate as an indicator. The chlorinity was estimated, and from that, salinity values were derived using a formula (Strickland and Parsons,1972).

3.1.4. Total Suspended Solids (TSS)

About 100 ml of the water sample was filtered through pre-weighed filter paper and placed in the Hot air oven at a specified temperature as per the protocol for 1 hour. The filter paper was allowed to cool in a desiccator to obtain a constant weight by repeating the drying and desiccation steps.

3.1.5. Total Dissolved Solids (TDS)

The water samples were subjected for gravimetric procedure for confirmation of the readings obtained from the hand -held meter. About 100 ml of the water sample was taken in a beaker and filtered which was then dried totally in a Hot Air Oven (105°C). The TDS values were calculated using the difference in the initial and final weight of the container**.**

3.1.6. Turbidity

The sample tube (Nephelometric cuvette) was filled with distilled water and placed in the sample holder. The lid of the sample compartment was closed. By adjusting the 'SET

ZERO' knob, the meter reading was adjusted to read zero. The sample tube with distilled water was removed, the 40 NTU standard solutions were filled in the tube, and the meter reading was set to read 100. Other standards were also run. The turbidity of the marine water sample was then found by filling the sample tube with the sample, and the reading was noted.

3.1.7. Dissolved Oxygen (DO))

DO was determined by Winkler's method (Strickland and Parsons,1972).

3.1.8. Petroleum Hydrocarbon (PHs)

The water sample (1liter) was extracted with hexane and the organic layer was separated, dried over anhydrous sulphate and reduced to 10 ml at 30°C under low pressure. Fluorescence of the extract was measured at 360 nm (excitation at 310 nm) with Saudi Arabian crude residue as a standard. The residue was obtained by evaporating lighter fractions of the crude oil at 120°C.

3.1.9. Phosphate

Acidified Molybdate reagent was added to the sample to yield a phosphomolybdate complex that is reduced with Ascorbic acid to a highly coloured blue compound, which is measured at the wavelength of 690 nm in a Spectrophotometer (Shimadzu UV 5040). Phosphorus compounds in the sample were oxidized to phosphate with alkaline Potassium per sulphate at high temperature and pressure. The resulting phosphate was analyzed and described as total phosphorous.

3.1.10. Nitrite

Nitrite in water sample was allowed to react with Sulphanilamide in acid solution. The resulting diazo compound was reacted with N-1-Naphthyl ethylenediamine dihydrochloride to form a highly coloured azo-dye. The light absorbance was measured at the wavelength of 543 nm in Spectrophotometer (Shimadzu UV 5040).

3.1.11 . Nitrate

Nitrate was determined as nitrite (as mentioned above) after its reduction by passing the sample through a column packed with amalgamated Cadmium.

3.1.12 . Silicate

The determination of dissolved silicon compounds in natural waters is based on the formation of a yellow silicomolybdic acid when an acid sample is treated with a molybdate solution. It is Spectrophotometrically measured by absorbance (810 nm for maximum absorbance and 660 for about 40% by adopting method of s Grasshoff et.al 1999**.**

3.2. Sediment characteristic

Sediment samples were collected from the prefixed stations by using a Van Veen grab having a mouth area of 0.04m^2 or by a non-metallic plastic spatula. Sediment analysis was carried out using standard methodologies. In each location (grid), sediment samples were collected from three different locations and pooled together to make a composite sample, representative of a particular site. The collected samples were air dried and used for further analysis.

3.2.1. Sediment Texture

For texture analysis, specified unit of sediment sample was sieved through sieves of different mesh size as per Unified Soil Classification System (USCS). Cumulative weight retained in each sieve will be calculated starting from the largest sieve size and adding subsequent sediment weights from the smaller size sieves (USDA,1951). The percentage of the various fractions was calculated from the weight retained and the total weight of the sample. The cumulative percentage was calculated by sequentially subtracting percent retained from 100%.

3.2.2. Total Organic carbon

Percentage of organic carbon in the dry sediment was determined by oxidizing the organic matter in the sample by Chromic acid and estimating the excess Chromic acid by titrating against Ferrous ammonium sulphate with Ferroin as an indicator (Walkley and Black, 1934).

3.3. Biological Characteristics of water and Sediment

3.1.1. Primary productivity

Phytoplankton possess the plant pigment chlorophyll 'a' which is responsible for synthesizing the energy for metabolic activities of phytoplankton through the process of photosynthesis in which CO_2 is used and O_2 is released. It is an essential component to understand the consequences of pollutants on the photosynthetic efficiency of phytoplankton in the system. To estimate this,a known volume of water (500 ml) was filtered through a 0.45 µm Millipore Glass filter pa,per and the pigments retained on the filter paper were extracted in 90% Acetone. For the estimation of chlorophyll 'a' and pheophytin pigm,ents the fluorescence of the Acetone extract was measured using Fluorometer before and after treatment with dilute acid (0.1N HCL) (Strickland and Parsons,1972).

3.3.2. Phytoplankton

Phytoplankton samples were collected from prefixed 15 sampling sites from the coastal water in and around DPA location using standard plankton net with a mesh size of 25µm and a mouth area of 0.1256 m^2 (20 cm radius). The net fitted with a flow meter (Hydrobios) was towed from a motorized boat moving at a speed of 2 nautical miles/hr. Plankton adhering to the net was concentrated in the net bucket by splashing seawater transferred to a pre-cleaned and rinsed container and preserved with 5% neutralized formaldehyde and appropriately labelled indicating the details of the collection, and stored for further analysis. The Quantitative analysis of phytoplankton (cell count) was carried out using a Sedgewick-Rafter counting chamber. The density (No/l) was calculated using the formula: $N=n \times v/V$ (Where, N is the total No/liter, n is the average number of cells in 1 ml, v is the volume of concentrate; V is the total volume of water filtered. The identification was done by following the standard literature of Desikachary, (1987), Santhanam *et.al*. (2019) and Kamboj *et.al*. (2018).

3.3.3. Zooplankton

Zooplankton samples were collected using a standard zooplankton net made of bolting silk having 50µm with mouth area of 0.25 m^2 fitted with a flow meter. The net was towed from a boat for 5 minutes with a constant boat speed of 2 nautical miles/hr. The initial and final reading in the flow meter was noted down and the plankton concentrate collected in the bucket was transferred to appropriately labeled container and preserved with 5% neutralized formaldehyde. One ml of the zooplankton concentrate was added to a Sedgwick counting chamber and observed under a compound microscope and identified by following standard literature. The group/taxa were identified using standard identification keys and their number was recorded. Random cells in the counting chamber were taken for consideration and the number of zooplankton was noted down along with their binomial name. This process was repeated for five times with 1 ml sample and the average value was considered for the final calculation. For greater accuracy, the final density values were counter-checked and compared with the data collected by the settlement method. Univariate measures such as Shannon-Wiener diversity index (H'), Margalef's species richness (d), and Simpson's dominance (D) was determined using PAST software.

3.3.4. Intertidal Fauna

Intertidal faunal assemblages were studied for their density, abundance and frequency of occurrence during monsoon 2021 at the pre-fixed 15 sampling locations within the DPA jurisdiction. Sample collection and assessment of intertidal communities were done in the intertidal zone during the low tide period. At each site, 1 x1 m^2 quadrates were placed randomly and all visible macrofaunal organisms encountered inside the quadrate were identified, counted and recorded. At each site, along the transects which run perpendicular to the waterfront, three to six replicate quadrate samples were assessed for the variability in macro-faunal population structure and the density was averaged for the entire intertidal belt. Organisms, which could not be identified in the field, were preserved in 5% formaldehyde, brought to the laboratory and identified using standard identification keys (Abott, 1954; Apte, 2012;2014). Average data at each site were used to calculate the mean density (No/m^2).

3.3.5. Subtidal Macro Benthic Fauna

The sampling methods and procedures were designed in such a way to obtain specimens in the best possible condition, as to maximize the usefulness of the data obtained. For studying the benthic organisms, triplicate samples were collected at each station using Van Veen grab which covered an area of 0.04m2. The wet sediment was passed through a sieve of mesh size 0.5 mm for segregating the organisms. The organisms retained in the sieve were fixed in 5-7% formalin and stained further with Rose Bengal dye for the ease of spotting at the time of sorting. The number of organisms in each grab sample was expressed as No. /m2. All the species were sorted, enumerated and identified by following available literature. The works of Fauvel (1953) and Day (1967) were referred for polychaetes; Barnes (1980) and Lyla et al. (1999) for crustaceans; Subba Rao et al. (1991) and Ramakrishna (2003) for molluscs. Further, the data were processed for univariate statistical methods in PRIMER (Ver. 6.) statistical software (Clark and Warwick, 2001).

Plate 1: Estimation of intertidal fauna by the quadrate method

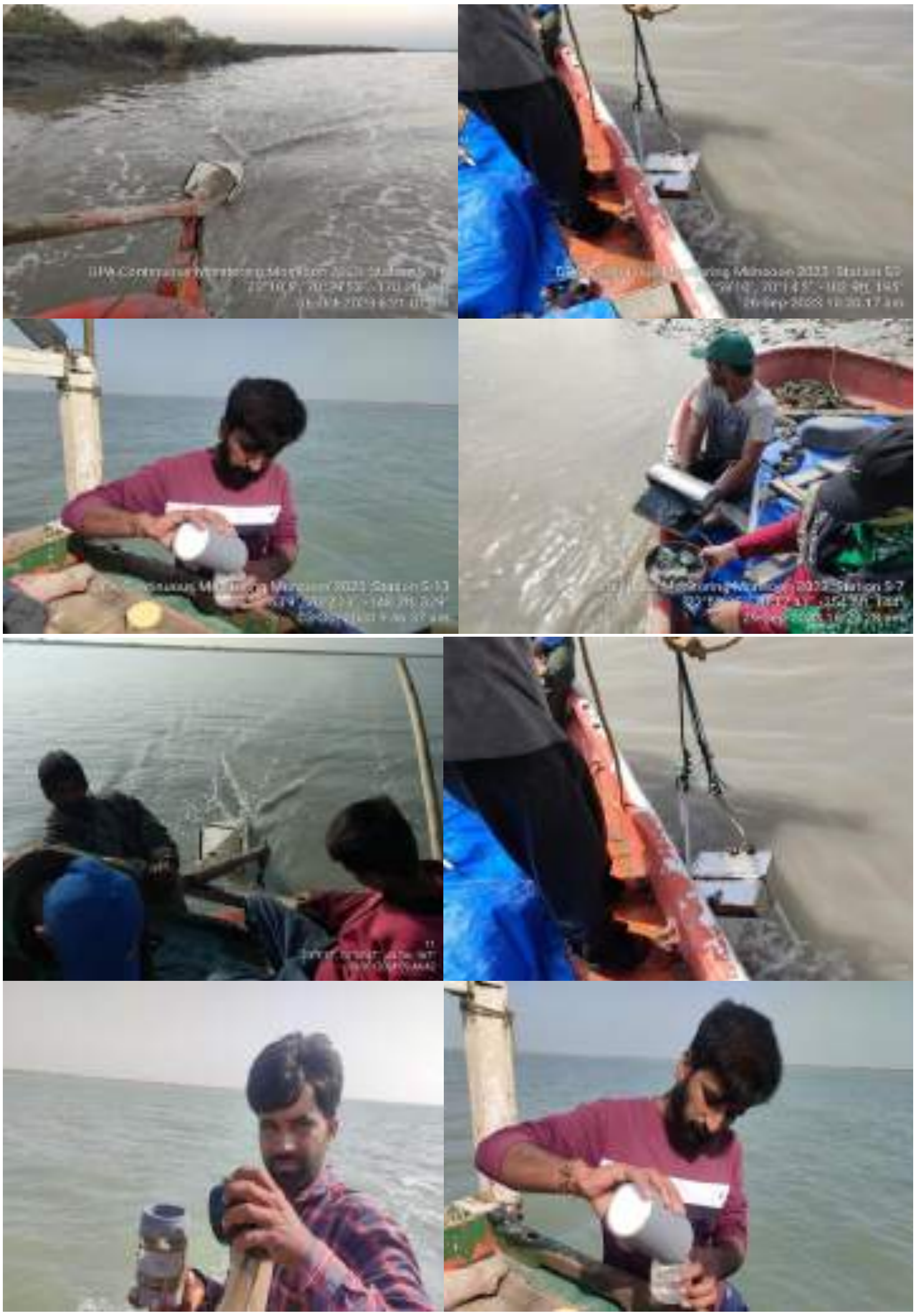

Plate 2: Collection of Plankton and macrobenthos in subtidal habitat

3.4. Mudflats

Mudflats are ecologically and socio-economically vital ecosystems that bring benefits to human populations around the globe. These soft-sediment intertidal habitats, with >10% silt and clay (Dyer 1979), sustain global fisheries through the establishment of food and habitat (including important nursery habitats), support resident and migratory populations of birds, provide coastal defenses, and have aesthetic value. Mudflats are intimately linked by physical processes and dependent on coastal habitats, and they commonly appear in the natural sequence of habitats between subtidal channels and vegetated salt marshes. In some coastal areas, they may be several kilometers wide and commonly form the largest part of the intertidal area. Mudflats are characterized by high biological productivity and abundance of organisms, but low in species diversity with few rare species.

The mudflat biota reflects prevailing physical conditions of the region. Intertidal mudflats can be separated into three distinct zones such as the lower tidal mudflats, middle mudflats and upper mudflats. The lower mudflats lie between mean low water neap and mean low water spring tide levels, and are often subjected to strong tidal currents. The middle mudflats are located between mean low water neaps and mean high water springs. The upper mudflats lie between the mean high-water neap and mean high water springs. The upper mudflats are the least inundated part and are only submerged at high water by spring tides (Klein, 1985). Salt marsh vegetation may colonize as far seaward as mean high water neaps. Mudflats will often continue below the level of low water spring tides and form sub-tidal mudflats (McCann, 1980). The upper parts of mudflats are generally characterized by coarse clays, the middle parts by silts, and the lower region by sandy mud (Dyer et al., 2000). The intertidal mudflats are prominent sub-environments that occurred on the margin of the estuaries and low relief sheltered coastal environments. The fine-grained sediments of intertidal mudflats (70%-90%) are derived from terrestrial and marine regions (Lesuere *et.al* .,2003). Estuarine mudflats are potential sites for deposition of organic matter derived from terriginous, marine, atmospheric and anthropogenic sources and are mainly associated with fine grained particles (Wang *et.al*., 2006)

3.4.1. Sampling locations

The Sediment samples were collected from 15 sampling locations by using sediment corer. From each site triplicate samples were collected from up to 100 cm depth with four intervals (0-25cm, 25-50cm, 50-75cm & 75-100cm) area and made into composite sample for analysis. The samples were packed in zip lock bags, stored in icebox and shifted to the laboratory for subsequent analysis.

Plate 3: Sediment sample collection at mangrove and mudflat areas

3.4.2. Total Organic Carbon

The organic carbon content of the mudflats was estimated to assess the biological productivity of the sediment. Soil Organic Carbon (SOC) was estimated following the method of Walkley and Black (1934). In this method, organic matter (humus) in the soil gets oxidized by Chromic acid (Potassium dichromate plus concentrated H_2SO_4) by utilizing the heat evolved with the addition of H_2SO_4. The unreacted dichromate is determined by back titration with Ferrous ammonium sulphate (redox titration). Organic carbon was determined by following the below given formula:

$$\text{Oxidizable organic carbon (\%)} = \frac{10\ (B - T)}{B} \times 0.003 \times \frac{100}{\text{wt. of soil}}$$

Where B = volume (mL) of Ferrous ammonium sulfate is required for blank titration. T = volume of Ferrous ammonium sulfate needed for soil sample. Wt. =weight of soil (g).

3.4.3. Estimation of Bulk Density (BD)

The soil under field condition exists as a three-phase system *viz.* solid (soil particles), liquid (water) and gas (mostly air). The soil organic matter contained in a unit volume of the soil sample is called its bulk density. The amount of bulk density depends on the texture, structure and organic matter status of soils. High organic matter content lowers the bulk density, whereas compaction increases the bulk density. To determine the bulk density of the sediment samples collected during the present study, the oven-dry weight of a known sediment volume was considered, and mass per unit volume was calculated (Maiti, 2012).

3.5. Mangrove assessment

Mangroves are widely distributed on the Deendayal Port Authority jurisdiction along the Kandla coast. The 15 mangrove sites selected at the different creeks belong to Deendayal Port Authority jurisdiction and all these stations are supposed to be sufficient to represent the mangroves status in Kandla. The mangrove stations in this study were named Tuna, Jangi, Kandla, Phan and Navlakhi which are based on the nearest location to their respective creek system. The Point Centered Quadrate Method (PCQM) was used for the collection of data of mangrove vegetation structure (fig.11). The data included measurements of density of plants, height variations, canopy and basal area of mangrove trees as per method (Cintron and Novelli, 1984). For this method, a transect of a maximum of 200 m was applied mostly perpendicular or occasionally parallel to the creek.

The sampling points considered at an interval of every 10 m and the vegetation structure of the that area were recorded. As orientation of the transect line was already fixed, it was easy for movement within the station area for data recording. The distance between trees from the centre of the sampling point for nearest 4 trees of four different directions, height of trees from the ground level , canopy length and conopy width were measured to determine the canopy cover were measured in this study. The equipments utilized in these field were handy and easy to use such as ranging rods, pipes and for measurement of girth at root collar above the ground (GRC) measurement tape was used. The plants with a height <50 cm were considered as regeneration class and >50 cm but <100 cm were considered as recruitment class. Along the transects, sub-plots of 1×1 m^2 for regeneration and 2×2 m^2 were laid randomly for recruitment class.

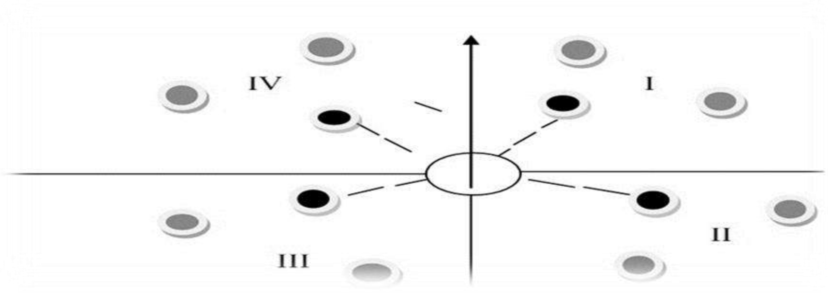

Figure 11. Point Centered Quadrate Method (PCQM)

Plate 4: Assessment of mangrove density, height, canopy cover & girth

3.6. Halophytes

To quantify and document the halophytes at Deendayal Port Authority region, quadrate method was followed. At each sampling location quadrates of various sizes have been laid during every seasonal sampling. For recording plant density at each transect, quadrate 1 x 1m have been laid within each tree quadrates were used randomly (Misra,1968; Bonham 1989). Four quadrates each for shrubs and herbs were laid in side each tree quadrate to assess the halophytes and its percentage cover in the study area. To enrich the species inventory, areas falling outside the quadrates were also explored and the observed species were recorded and photographed and species were identified using standard keys. Specimens of the species were collected to know more information on habitat and for the preparation of herbarium.

Plate 5: Assessment of halophytes cover

3.7. Marine Fishery

Fishery resources and diversity were assessed from the selected sampling sites. Finfish and shellfish samples were collected using a gill net with 10 mm mesh size. The net was operated onto the water from a canoe or by a person standing in waist deep water during the high tide using a cast net. For effective sampling, points were fixed at regular distance within the 15 offshore sites for deploying fishing nets to calculate the Catch per Unit effort estimated per hour. The collected specimens were segregated into groups, weighed and preserved in 10% neutralized formalin solution. Finfishes were identified following Fischer and Bianchi (1984), Masuda *et al*. (1984), de Bruin *et al*. (1995) and Mohsin and Ambiak (1996). Relevant secondary information pertaining to fishery resources of Deendayal Port creek systems were gathered through technical reports, District Fisheries department, Government gazette and other research publications.

Plate 6: Collection of fisheries information from DPA environment

3.8. Avifauna

The Avifauna along DPA mangrove strands was demarcated into fifteen major stations. In each station creeks were of varying length from 2 to 5 km. These creeks were surveyed by using boat and adopting "line transect" method (fig.12). A total of fifteen boats transect (one in each site) survey was conducted in the Monsoon (June-September 2021), Post-monsoon (October-January2021-2022) and pre-monsoon season (February-may 2022). Survey was done in both terrestrial habitats like Mangrove plantation adjoining the mudflats waste land, and aquatic habitats like creek area, rivers and wetland.

Boat Surveys

Mangrove bird diversity was calculated by using Boat Survey method. Birds were observed from an observation post aboard the boat which was given the greatest angle of clear view. Birds within a 100 meter transect on one side of the boat were counted in 10-minute blocks of time (Briggs et al. 1985; van Franeker 1994). Detection of birds was done with a binocular (10 x 40) and counts were made: (1) continuously of all stationary birds (swimming, sitting on mangrove, or actively feeding) within the transect limits and (2) in a snap-shot fashion for all flying birds within the transect limits. The speed of the boat determines the forward limit of the snapshot area within a range of 100 meters. Longer or shorter forward distances were avoided by adapting the frequency of the snapshot counts. Birds following and circling the boat were omitted from both snapshot and continuous counts. If birds arrive and then follow the boat, they were included in the count only if their first sighting falls within a normal snapshot or continuous count of the transect area. For each bird observation species, number of individuals and activity at the time of sighting, were recorded. Species richness and diversity index were calculated for different mangrove patches (i.e. fifteen station) of the study station in Deendayal port Authority.

Figure .12 Line transect method for Avifauna survey

3.9. Data analysis

Data collected in situ and through laboratory analysis of samples were subjected to descriptive statistical analysis (PAST and Primer 7.0) for the mean, range and distribution of different variables from the selected 15 study stations.

Plate 7 Statistical Data analysis methods

4. Results

4.1. Physico-Chemical Characteristics of water and Sediment

4.1.1. Water quality assessment

The data on the mean water quality parameters measured at the time of sampling of the biological components from the 15 study sites are presented in Table11.

Table-12 Physico-chemical characteristics of the DPA Jurisdiction From May 2023- May 2024

Parameter		Monsoon 2022	Post Monsoon 2022-23	Pre Monsoon 2024
Temperature	max	30	20	31
	min	23	10	25
pH	max	8.1	8.0	7.9
	min	7.7	7.7	7.7
Salinity	max	44	43	47
	min	36	38	39
Dissolved oxygen (mg/L)	max	3.2	7.7	8.6
	min	1.0	2.0	7.0
Total Suspended Solids (TSS) (mg/L	max	538	669	1104
	min	130	189	210
Total Dissolved solids (TDS) (mg/L)	max	44,060	39,774	56,400
	min	26,954	34,911	44,032
Turbidity (NTU)	max	67	183	489
	min	20	16	34
Nitrate (NO3) (mg/L)	max	0.05	0.09	0.08
	min	0.01	0.04	0.01
Nitrite (NO2) (mg/L)	max	0.048	0.005	0.005
	min	0.005	0.001	0.001
Total Phosphorus (mg/L)	max	9.76	2.88	0.42
	min	1.10	1.50	0.04
Total silicate	max	0.76	0.05	4.19
	min	0.18	0.02	0.54
PHs (µg/L)	max	9.1	85.8	9.1
	min	0.3	2.5	0.4
Chlorophyll a (mg/L)	max	0.67	0.38	2.98
	min	0.03	0.11	0.11

Temperature (°C)

The values for the Temperature obtained from 15 different sampling station for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure-13. During monsoon, the value ranged from 23°C to 30°c to while in post monsoon observation, the value ranged from 16°c to 20°c . However, in pre monsoon the values were noted in the range of 25°c to 31°c. During monsoon, the highest temperature was noted at station S-7 while the lowest temperature was noted at S-6. In post-monsoon maximum temperature was recorded 20°c at S-14 and lowest at at S-2&S-3 while in pre-monsoon highest temperature exhibited at S-8 &S-9 and lowest temperature observed at S-1,2,5 and S-6.

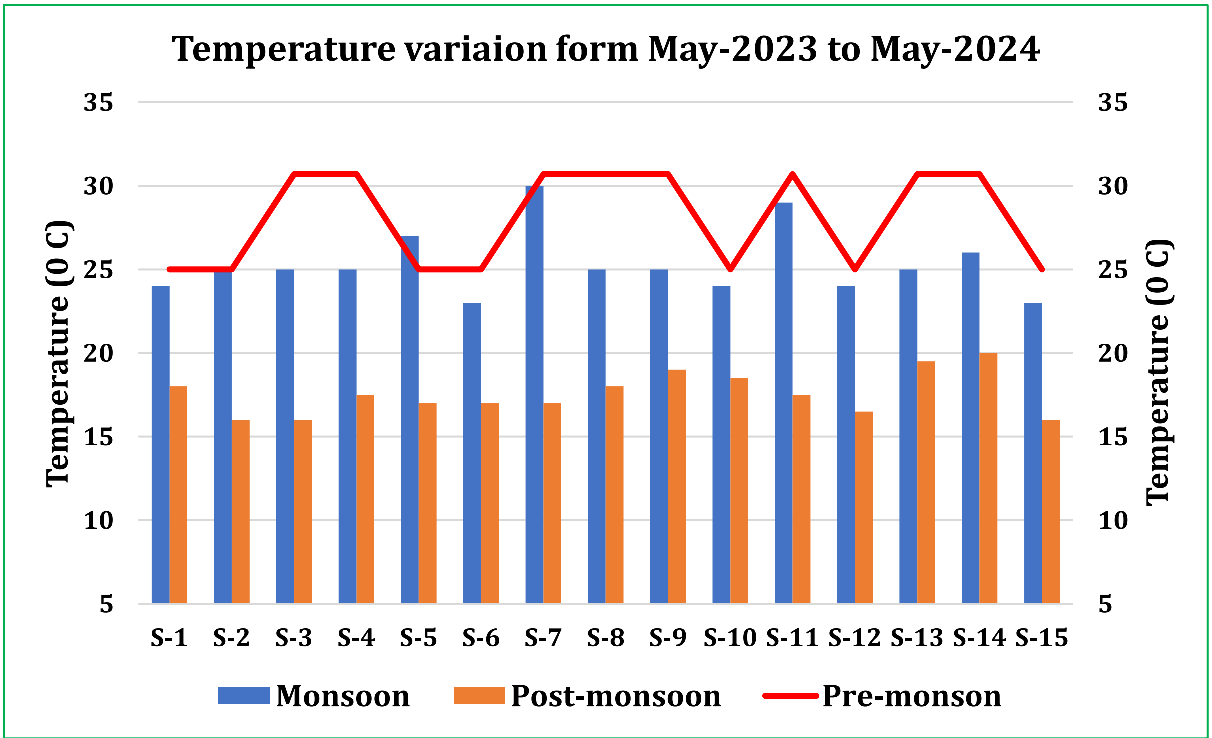

Figure 13. Temperature variation in DPA study sites during 2023-2024

The average temperature throughout the year in Deendayal port authority Jurdiction varied from 18° c to 28°c in 3 season (table 11)

pH

The pH obtained from 15 different sampling station for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure-14. During monsoon, the value ranged from 7.7 to 8.1 to while in post monsoon observation, the value ranged from 7.7 to 8.0. However, in pre monsoon the values were noted in the range of 7.7 to 7.9. During monsoon, the highest pH was noted at station S-12 while the lowest pH was noted at S-8 . The throughout the year maximum pH was recorded in monsoon at S-12 and lowest was recorded both in monsoon and post-monsoon and Pre-monsoon at station S-11 & S-15 & S-10 in three season.

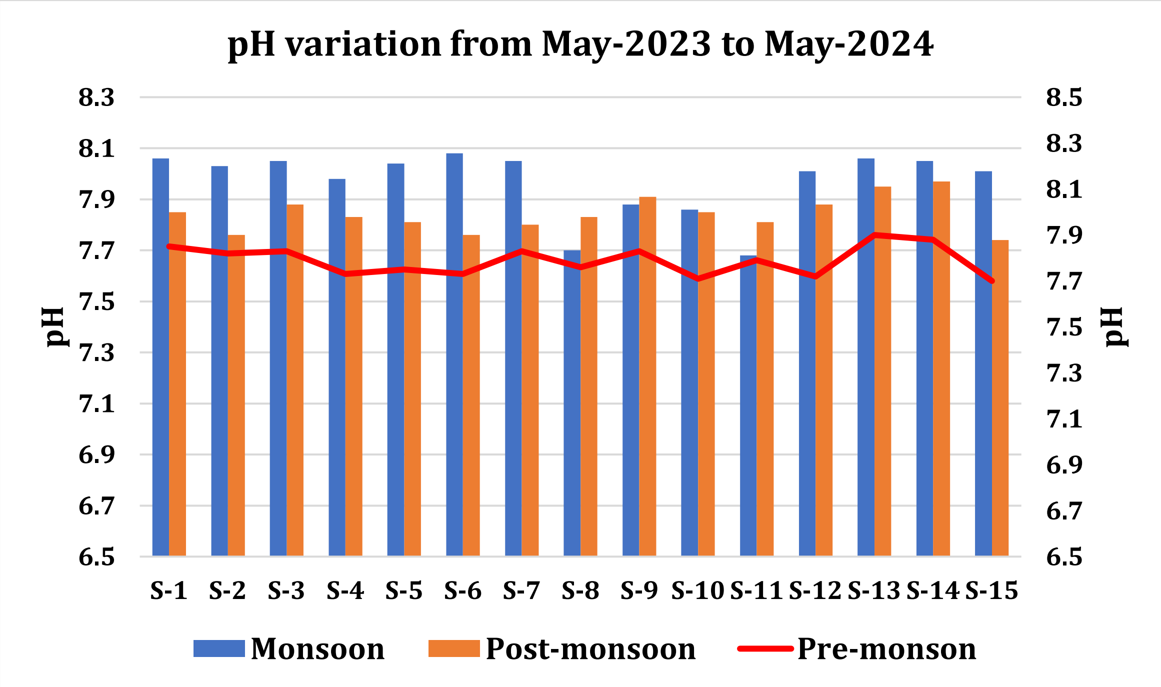

Figure 14. pH variation May 2022 to May 2023 in Deendayal Port Authority

The average pH throughout the year in Deendayal port authority Jurdiction varied from 7.8 to 8.0 in 3 season (table 11)

Salinity

The salinity obtained from 15 different sampling station for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure-15. During monsoon, the salinity ranged from 36 ppt to 44 to while in post monsoon observation, the value ranged from 38 ppt to 43 ppt. However, in pre monsoon the values were noted in the range of 39 ppt 47ppt. During pre-monsoon, the highest salinity was noted at station S-12 while the lowest salinity was recorded at S-9. The throughout the year maximum salinity was recorded in pre-monsoon and lowest was recorded monsoon followed by post-monsoon. The average salinity throughout the year in Deendayal port authority Judication varied from 37ppt to 45 ppt in 3 season (table 11)

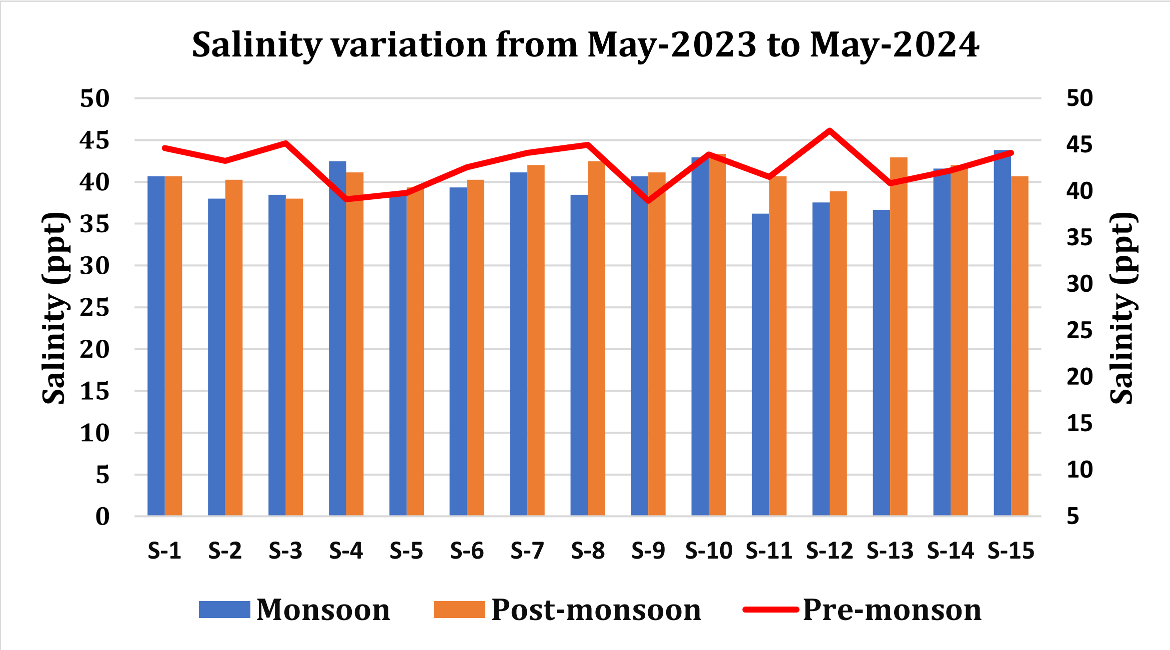

Figure 15. Seasonal variation of salinity during 2023-2024 at DPA

Dissolved oxygen (DO)

The maximum dissolved oxygen concentration of the sampling station for three seasons varied from 3.2 mg/L to 8.6 mg/L with average of 1.6 mg/L to 8.0 mg/L from May 2023 to May 2024 (Fig.16). The minimum DO values varied from 1.0 mg/L to 7.0 mg/L. The seasonal variation of water DO among stations is presented in figure-14. During Monsoon highest dissolved oxygen concentration was observed at station S-12 (3.2 mg/L), and the Lowest dissolved oxygen concentration was observed at S-1,S-7 (1.2 mg/L). In Post-monsoon, the highest dissolved oxygen was observed at S-10 (7.7 mg/L) and the lowest value at S-15 (2.0 mg/L). During Pre-monsoon, the highest and lowest DO values were observed at stations S-9 (8.6 mg/L) and S-3 (7.0mg/L), respectively

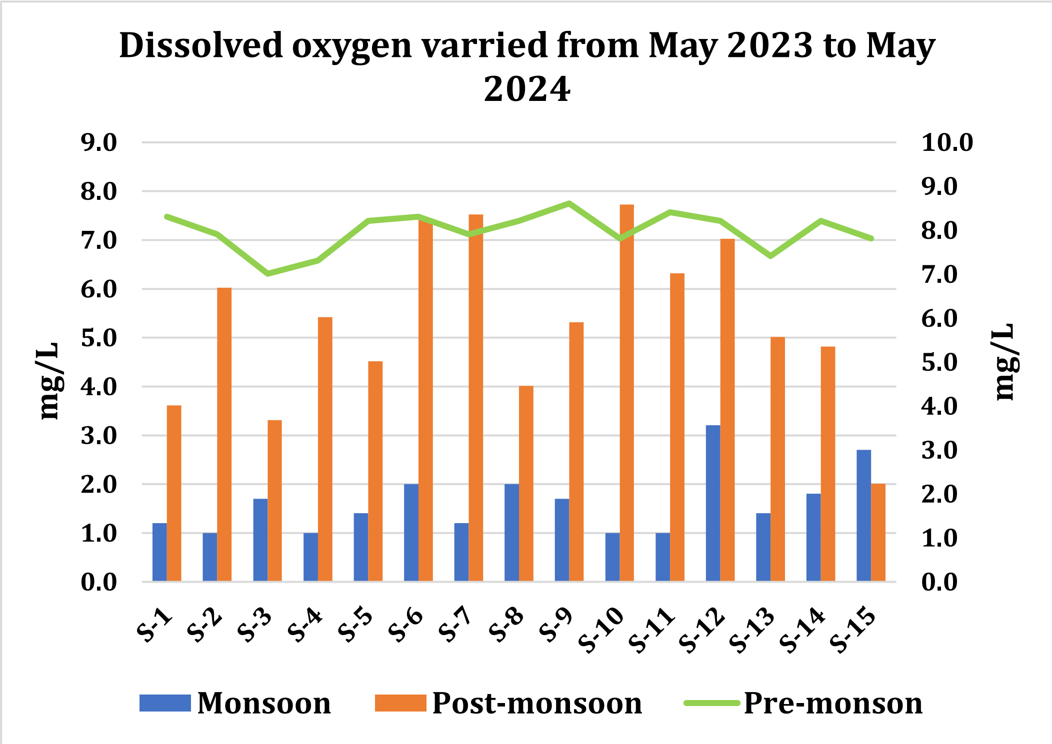

Figure 16. Seasonal variation Dissolved Oxygen (2023 to 2024)

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Total Suspended Solids (TSS)

The values for the Total Suspended Solids (TSS) obtained from 15 different sampling sites for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure-15. During monsoon, the value ranged from 130 mg/L to 538 mg/L, while in post monsoon observation, the value ranged from 189 mg/L to 669 mg/L. However, in pre monsoon the values were noted in the range of 210 mg/L to 1104 mg/L. During monsoon, the highest TSS was noted at site S-12 while the lowest TSS value was noted at S-15. The maximum TSS was obtained at S-6 and lowest at S-14 during post monsoon while site S-1 exhibited the highest value and lowest value was noted at S-7 during the pre-monsoon season. figure-16

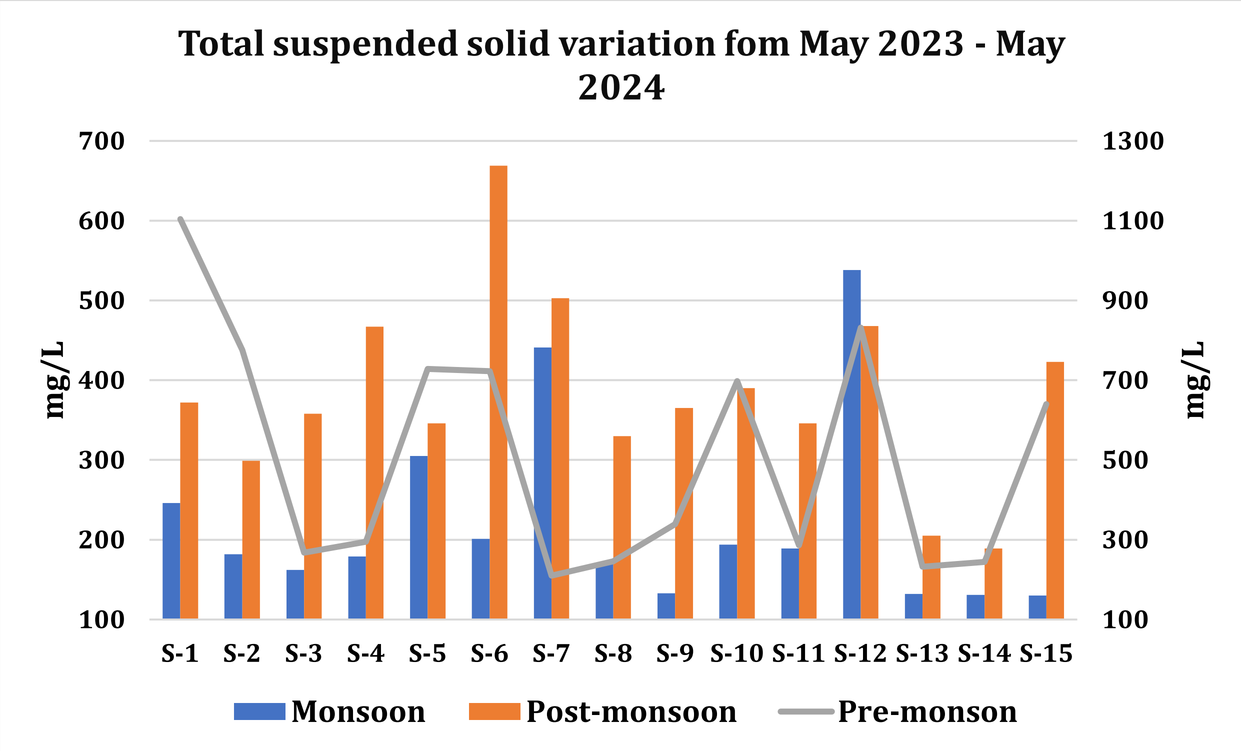


Figure 16. Seasonal variation of TSS during May 2023-May 2024

Total Dissolved Solids (TDS)

The values for the Total Dissolved Solids (TDS) obtained from 15 different sampling sites for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure-18. During monsoon, the value ranged from 26,954 mg/L to 44,060 mg/L, while in post monsoon observation, the value ranged from 34,911 mg/L to 39,774 mg/L. However, in pre monsoon the values were noted in the range of 44,032 mg/L to 56,400 mg/L. During monsoon, the highest TDS was noted at site S-6 while the lowest TDS value was noted at S-10. The maximum TDS was obtained at S-11 while site S-7 exhibited the lowest value post monsoon season but in pre exhibited highest TDS at S-11 and Lowest at S-1

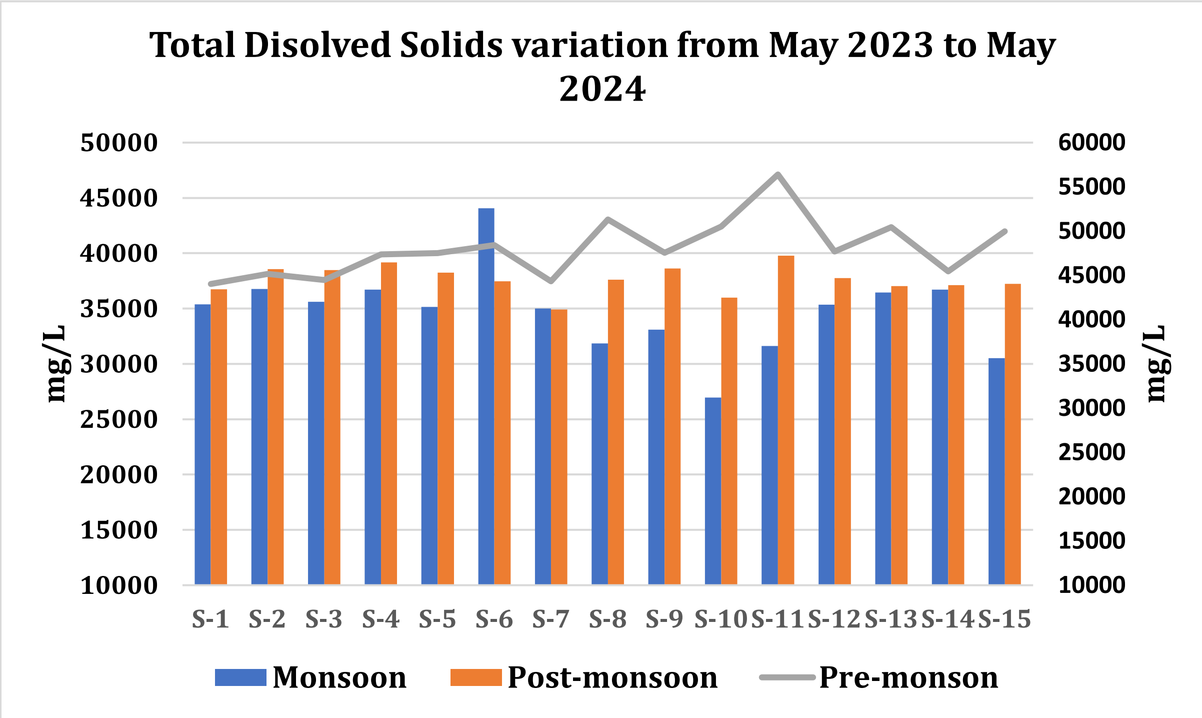


Figure 18. Total Dissolved Solids (TSS) May 2023 to May 2024

Turbidity (NTU)

The Turbidity of the sampling stations varied season wise from 20 NTU to 489 NTU for the period May 2023 to May 2024 (Fig.19). The seasonal variation of water turbidity among the stations is presented in Figure-17. During Monsoon, the highest Turbidity was observed at S-11 (67 NTU) and the lowest was at S-1 (20 NTU). In post-monsoon, the highest Turbidity was observed at station S-6 (342 NTU) and the lowest was at station S-8 (16 NTU). Similarly in Pre-monsoon, the highest and lowest turbidity was observed at S-2 (489 NTU), and it was lowest at S-7 (34 NTU).

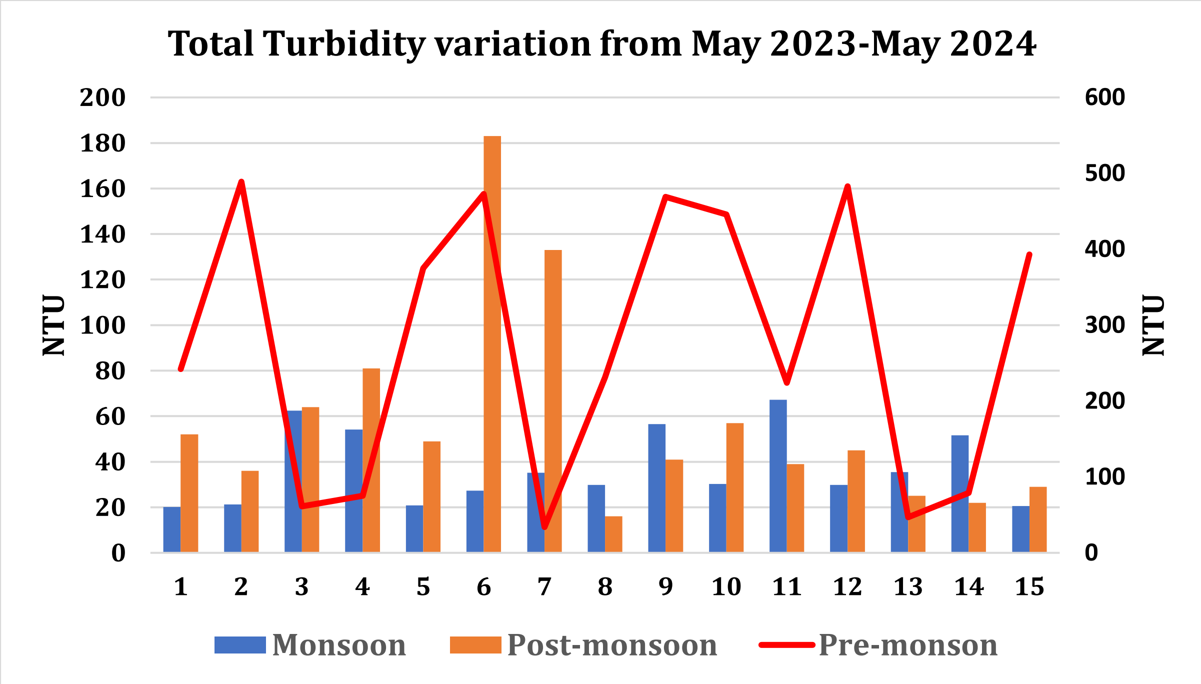


Figure 19. Seasonal variation during Turbidity May 2023 to May 2024

Nitrate

The amount of Nitrate in the water sample is relatively low throughout the study period. The maximum Nitrate value for the three seasons was 0.01 mg/L -0.09 mg/L from May 2023 to May 2024 (Fig.20). The minimum Nitrate value noted during the study was 0.01 mg/L at most of station during post monsoon and at S-6 during pre-monsoon. The seasonal variation of water Nitrate among all the stations is presented in figure-18. During Monsoon, the highest Nitrate value observed (0.05 mg/L) at station S-3 & S-4 the lowest Nitrate value was 0.01 mg/L (most of the station). During post-monsoon study, the values increased and highest Nitrate was observed at S-15 (0.09 mg/L) and lowest at S-9 (0.04 mg/L). Similarly in Pre-monsoon the highest (0.08 mg/L) and the lowest (0.01mg/L) were reported S-6 respectively.

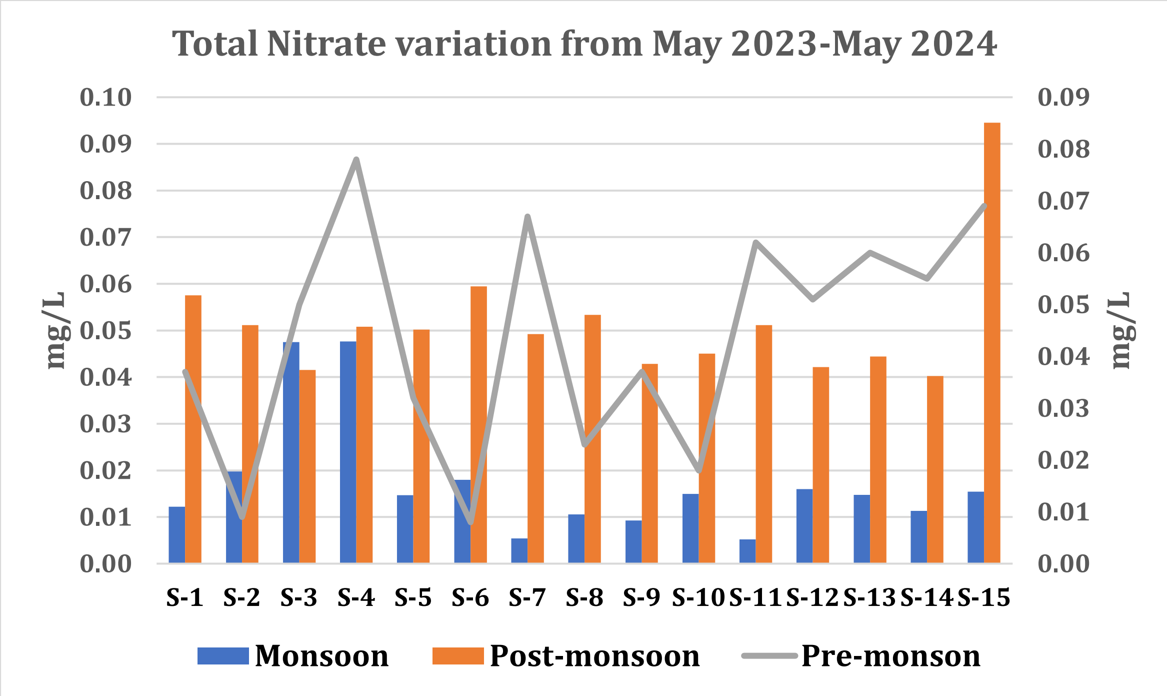


Figure 20. Seasonal variation of Nitrate concentration during May 2023 to May 2024

Nitrite

The amount of Nitrite in the water sample is relatively lower compared to the nitrate content throughout the study period. The maximum Nitrite value for the three seasons was 0.001 mg/L to 0.048 mg/L from May 2023 to May 2024 (Fig.21). The seasonal variation of Nitrite concentration presented at Figure-19. During Monsoon, the highest nitrite concentration was noted at S-3&S-4 (0.048 mg/L) and the lowest was recorded at S-11 (0.005 mg/L). In post-monsoon, the maximum value was found at S-8 (0.005 mg/L) and lowest nitrite was observed at S-4, and S-14 (0.001mg/L). Similarly in Pre-monsoon, the highest nitrite content was (0.005 mg/L) at S-1 and the lowest content (0.001 mg/L) was observed at S-2 to S-7 respectively. Throughout the season the minimum concentration varied from 0.001 to 0.005 mg/L in study station.

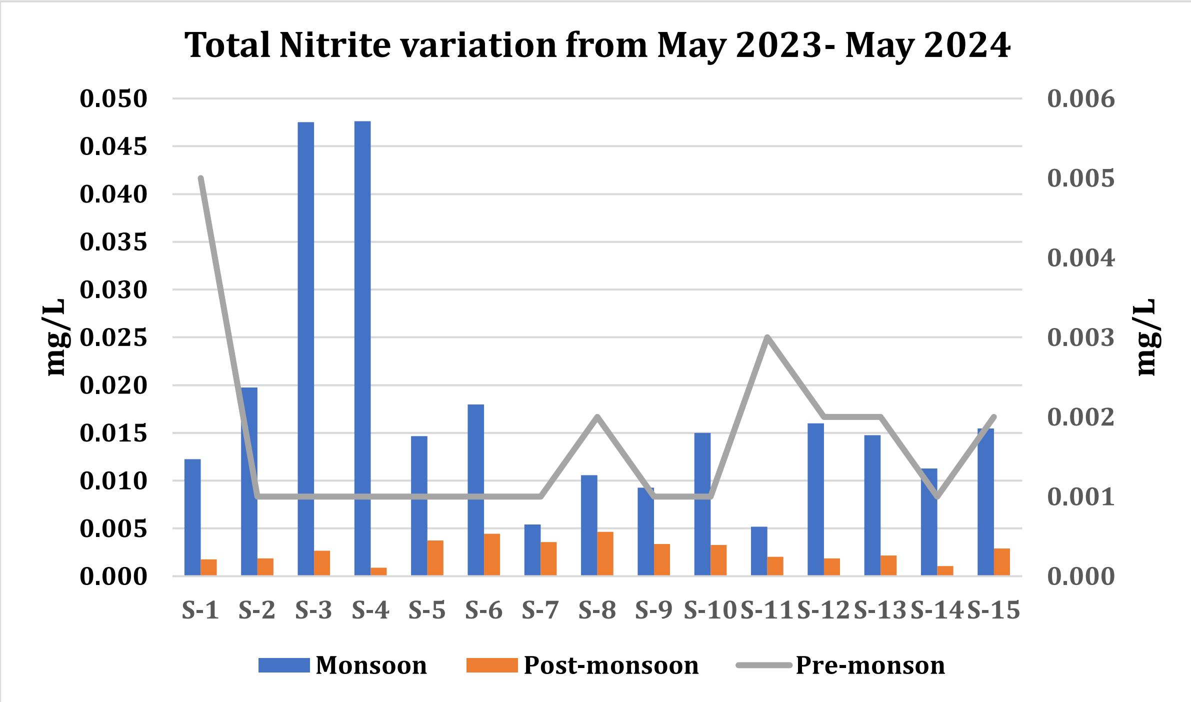


Figure 21. Nitrite concentration during May 2023 to May 2024

Total Phosphorous

The total phosphate content at S-1 was highest during the monsoon season during the study period. Seasonal observation revealed that the phosphate values were in the range of 0.04 mg/L to 9.76 mg/L (Fig.22). The seasonal variation for the total phosphorous among stations is presented in Figure 20. During Monsoon, the maximum value noted was 9.76 mg/L at (S-11) and the lowest was 1.10 mg/L at (S-14). In post-monsoon, the highest value was 2.88 mg/L at S-1 and lowest was 1.50 mg/L at S-14. In Pre-monsoon, the highest and the lowest values observed were 0.42 mg/L and 0.04 mg/L at S-2 and S-13 ans S-14 respectively.

Silicate

The total Silicate content at S-10 was highest during the Pre-monsoon season. Seasonal observation revealed that the silicate values were in the range of 0.02 mg/L to 4.19 mg/L. The seasonal variation for the total phosphorous among stations is presented in Figure 21. During Monsoon, the maximum value noted was 0.76 mg/L at (S-11) and the lowest was 1.18 mg/L at (S-12). In post-monsoon, the highest value was 0.05 mg/L at S-3,S12and S13 and lowest was 0.02 mg/L at S-3, S-10,S-12 and S-13. In Pre-monsoon, the highest and the lowest values observed were 4.19m mg/L and 0.54 mg/L at S-10 and S-7 respectively (Fig,23).

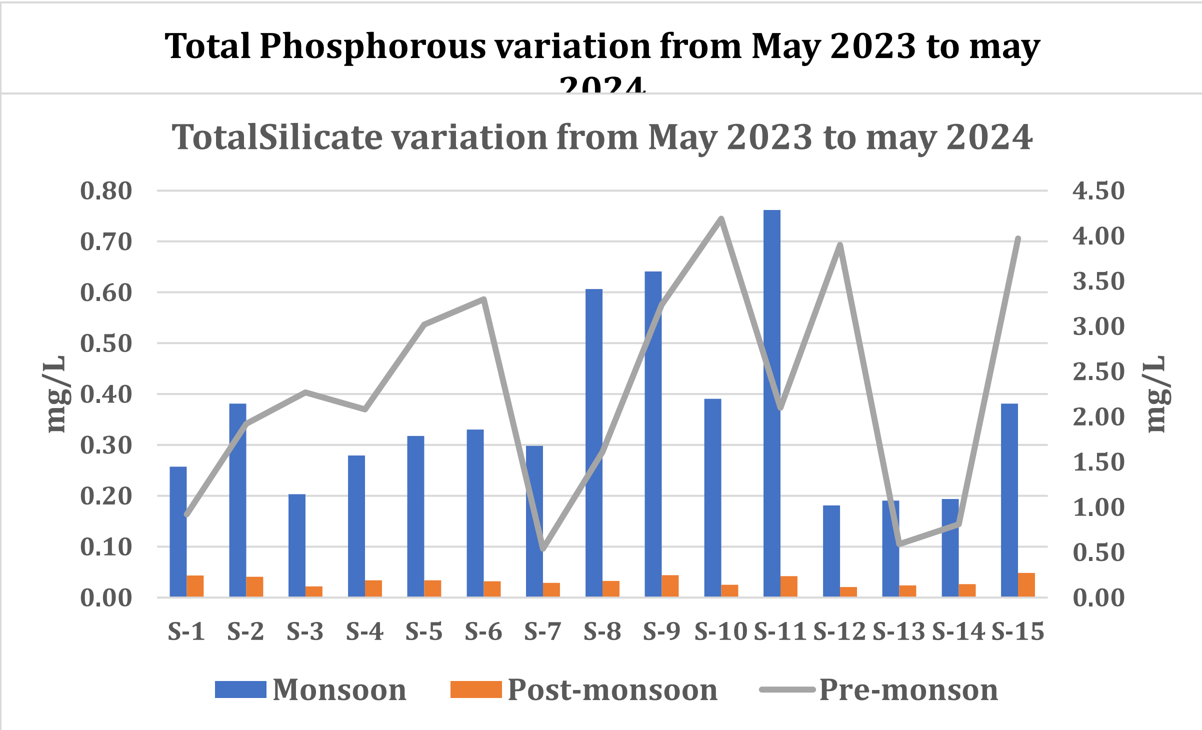


Figure 22. Seasonal variation Total Phosphorous   May 2023 to May 2024

Figure 23. Seasonal variation of Silicate   May 2023 to May 2024

4.1.2. Petroleum Hydrocarbon (PHs)

The PHs values were comparatively high at S-7 and S-8 during post-monsoon than the other seasons. The values for Petroleum Hydrocarbons (PHs) for the three-season varied from 0.3 µg/L to 85.8 µg/L (Fig.24). The PHs concentration in general, is at low level during monsoon. During Monsoon, the highest PH was observed at S-4 (9.1 µg/L) and lowest PHs was observed along S-10 (0.3 µg/L). In post-monsoon, the highest PH value was observed at S-7 (85.8 µg/L) and the lowest PH was observed S-6 (2.5 µg/L). Similarly in Pre-monsoon, the maximum PHs content was recorded (9.1 µg/L) at S-4 and the minimum was (0.4 µg/L) at S-14.

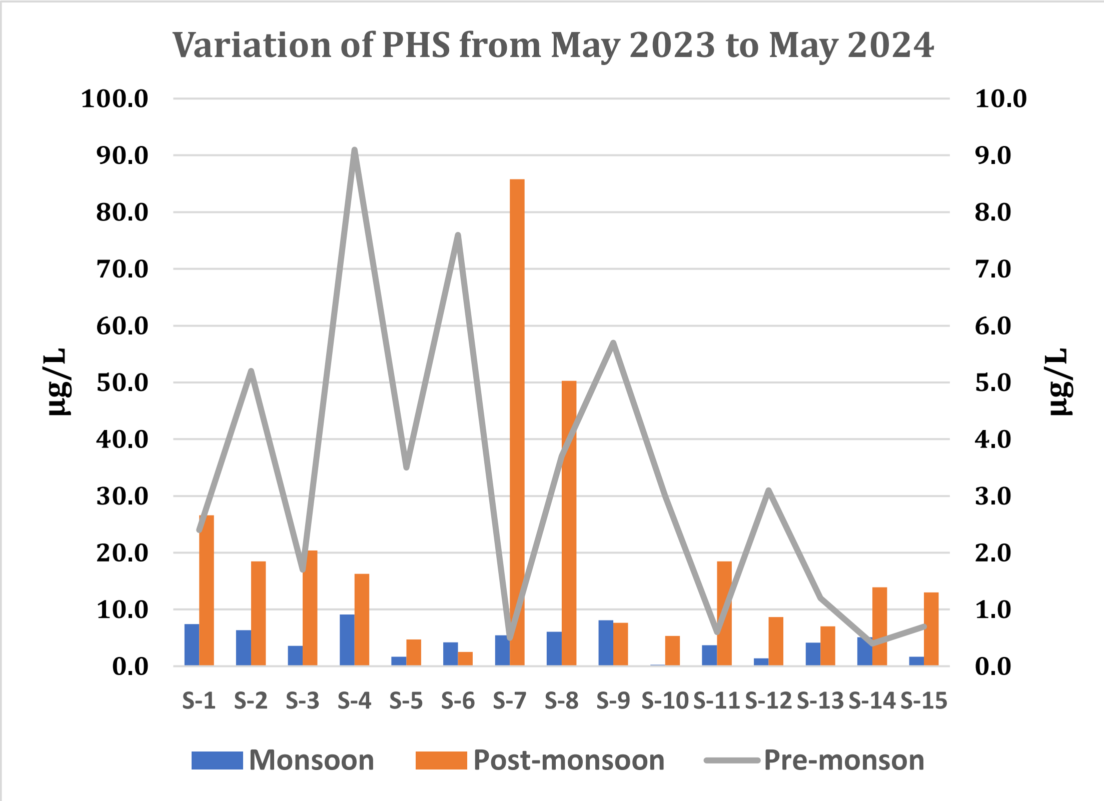


Figure 24. Seasonal Petroleum Hydrocarbon from May 2023 to May 2024

4.1.3. Sediment

Texture

The nature of soil texture was characterized by the proportion of clay, sand and silt fractions. Soil texture revealed dominance of silty-clay type in all the stations during post and pre-monsoon expect in monsoon, which is depleted in figure 25.

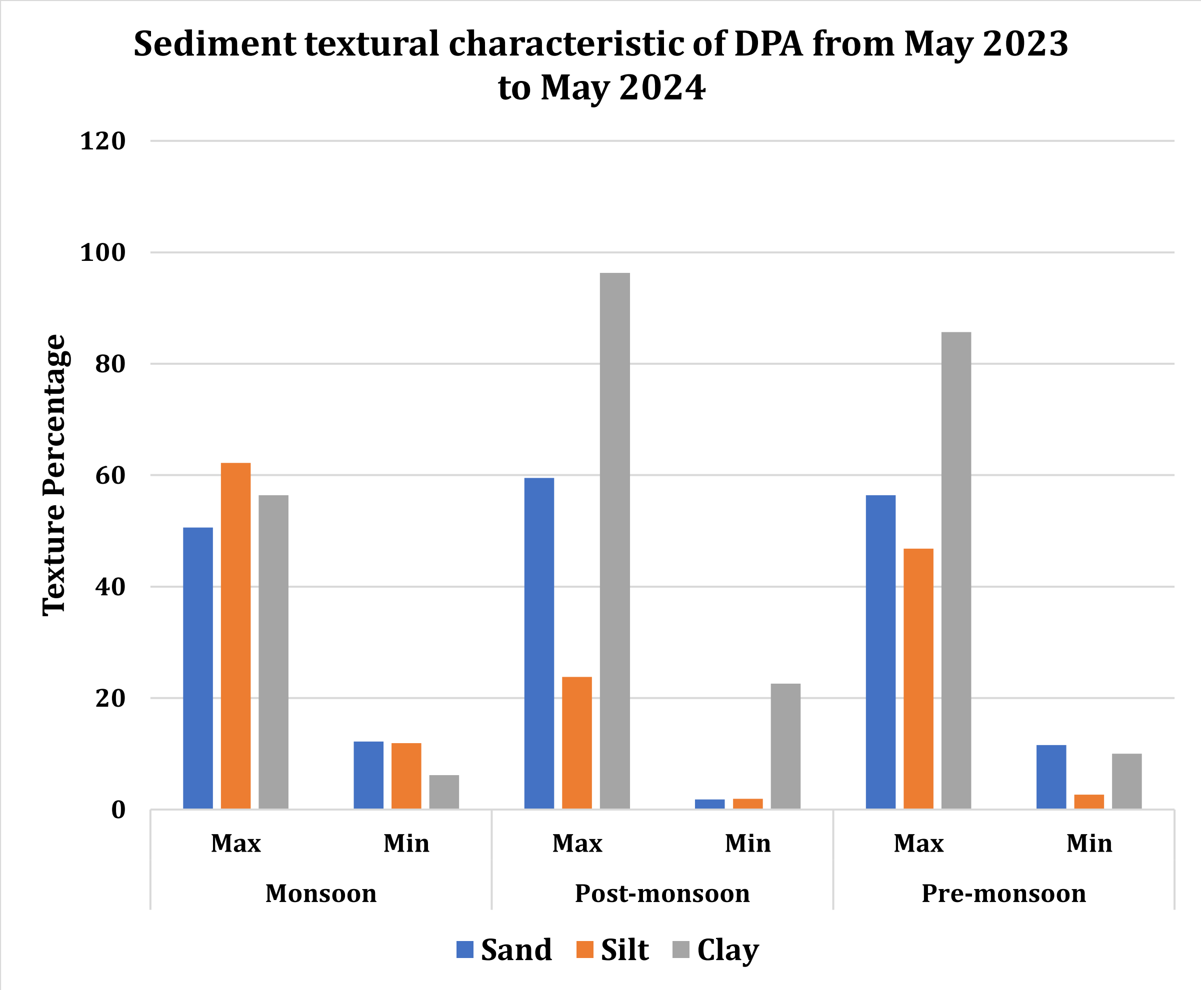


Figure 25. Soil textural chaacteristic from May 2023 to May 2024

In monsoon the percentage of Sand, Silt and Clay varied from 12-51%,12-62% and 6-56%. In post-monsoon the percentage Sand, Silt and Clay varied from 2-60%,2-24%and 23-96%. Similarly, in per-monsoon the percentage variation of sand was 12-56% and silt were 3-47% and the percentage of clay was 10-86% respectively.

4.2. Biological Characteristics of water and Sediment

4.2.1. Primary productivity

Chlorophyll ‘a’ the photosynthetic pigment which can be used as a representation for phytoplankton productivity and thus is an essential water quality parameter. Generally, the primary production of the water column is assessed from Chlorophyll ‘a’ concentration. It is well known that half of global primary production being mediated by the activity of microscopic phytoplankton. For the period of May 2023 to May 2024. The maximum Chlorophyll 'a' recorded from 0.38 mg/L to 2.98 mg/L. The minimum Chlorophyll 'a' values ranged from 0.11 mg/L to 0.03 mg/L, The highest Chlorophyll 'a' concentration was observed at 2.98 mg/L at S-8 during pe-monsoon.The seasonal variation of Chlorophyll 'a' among stations is presented in figure-26.

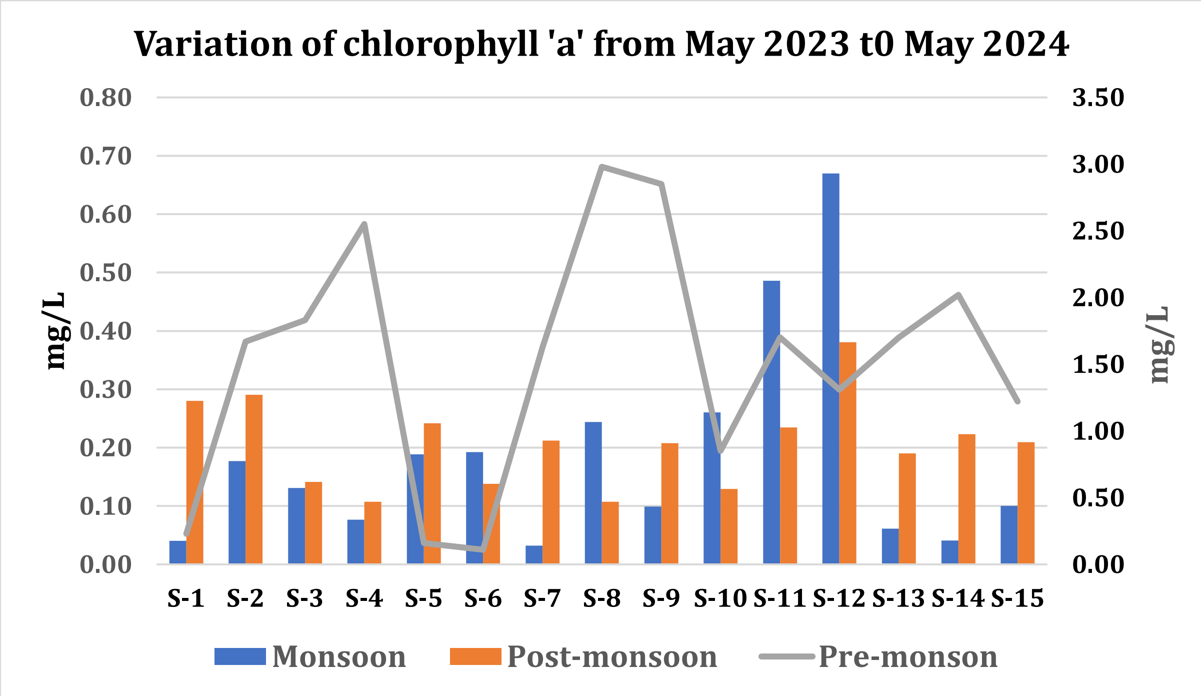


Figure 26. Concentration of Chlorophyl 'a' from May 2023 to May 2024

4.2.2. Phytoplankton

Phytoplankton are the main primary producers of marine and freshwater ecosystems. They play specific roles in biogeochemical cycling in marine ecosystems. Their roles in calcification, silicification, dimethyl sulphide (DMS) production and nitrogen fixing have been well established. These tiny organisms initiate the marine food chain by the process of photosynthesis and serve as primary food in marine pelagic zone. Phytoplankton, as the basis of the trophic chain, forms the biological community which regulates the food chain for which scientific attention is focused when a management plan is needed or an evaluation of the ecosystem health is required. The phytoplankton populations are mostly represented by members of Cyanobacteria, Chlorophyta, Dinophyta, Euglenophyta, Haptophyta, Chrysophyta, Cryptophyta, and Bacillariophyta. Planktonic representative taxa are absent in other algal divisions like Phaeophyta and Rhodophyta.

Generic Status

Season wise the maximum phytoplankton genera varied from 20 to 27 number with average variation of genera was 17-23 number and the minimum genera varied from 8 to 20 number of genera (Fig.27).

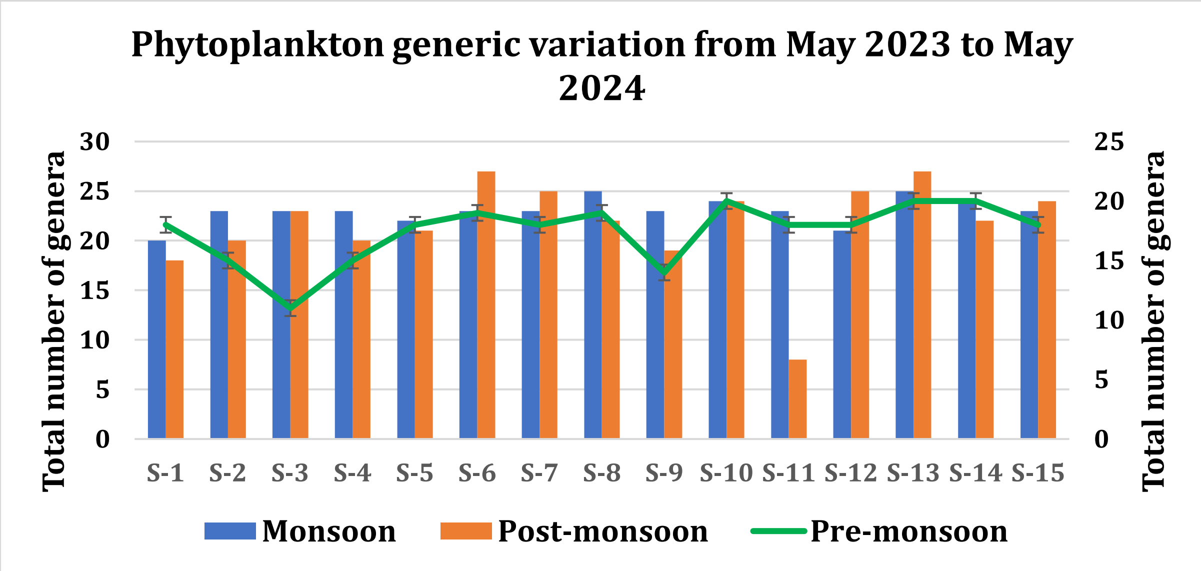


Figure 27. Seasonal variation of Phytoplankton genera from May-2023 to May2024

During monsoon the phytoplankton genera varied from 20 to 25 number and the highest genera was observed at station S-13 (25 no) and lowest genera was observed at station S-1 (20no).In post-monsoon genera varied from 8 to 27 number and the highest genera was observed at S-6&S-13 (27 no) and lowest genera was observed at station S-11 (8).Similarly during pre-monsoon genera 11 to 20 number of genera noticed and the highest numbering genera was observed at S-10,S-13 &S-14 (20) and lowest genera was observed at station S-3 (11).

Percentage composition

The Maximum percentage of phytoplankton composition for the period May 2023 to May 2023 varied from 54 %to 63% and the minimum percentage of phytoplankton was 1%.

Four major group such Pennales, Centrales, Dinophyceae and Cyanophyceae phytoplankton was reported for the period 2023 to 2024. The percentage of composition pennales for three seasons varied from 28% to 38%. The Pennales percentage of composition is contribute highest percentage of composition followed by Centrales and Dinophyceae (Fig.28).

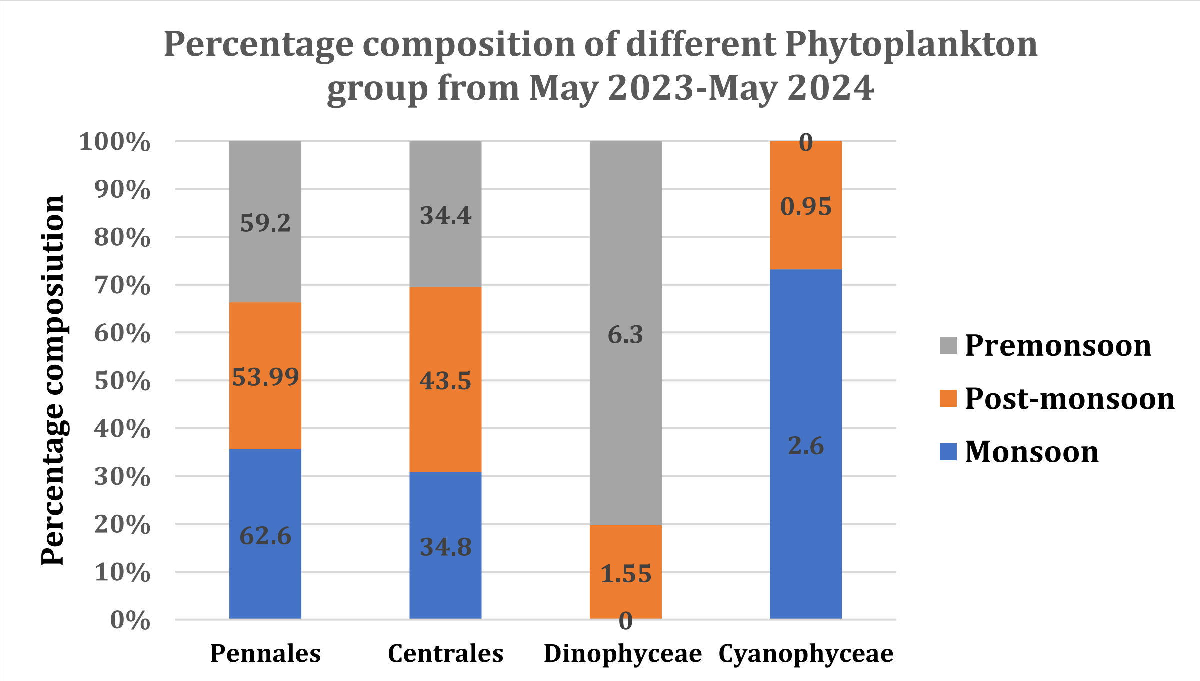


Figure 28. Percentage composition of different phytoplankton group from May 2023 to May 2024

Percentage of Occurrence

Season wise percentage occurrence of the different groups of phytoplankton varied from 13% to 100%. Highest percentage of occurrence was found during the monsoon & post-monsoon season which constitute 14 phytoplankton genera (100%) followed by monsoon season 7 phytoplankton genera. Overall, the occurrence of phytoplankton genera was more in monsoon and post-monsoon (Fig.29). The phytoplankton genera, *Coscinodiscus* were found (100%) at all the three seasons (Plate 8).

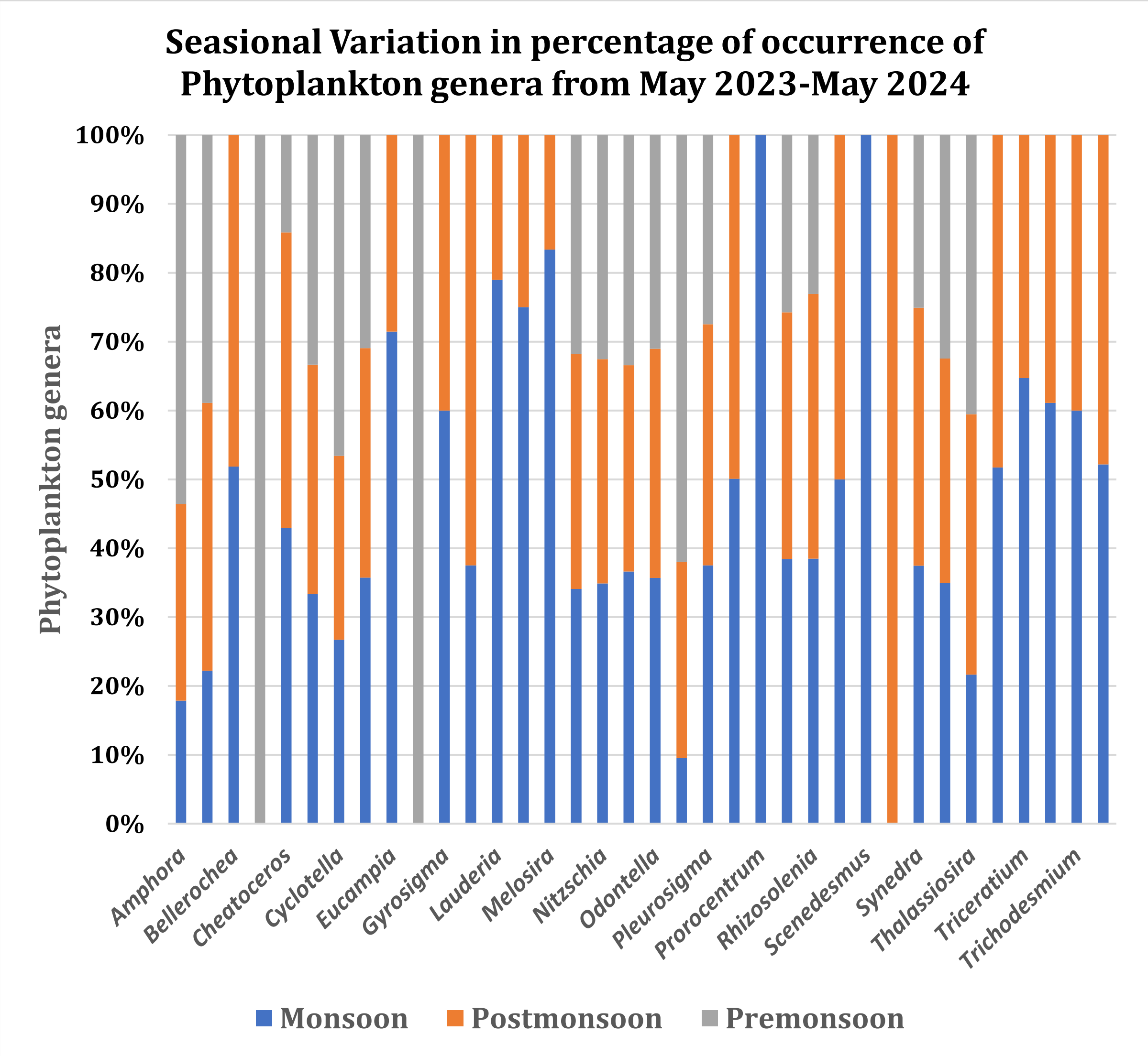


Figure 29. Percentage occurrence of phytoplankton genera from May 2023to May 2024

Phytoplankton density

The density signifies the abundance of plankton which is measured as cell/ individual/L. The maximum phytoplankton density variation for 3 seasons varied from 17,920 No/L to 28,960 No/L with average variation of 23,733 and the minimum phytoplankton density was varied from 3,040 No/L to 12,160 No/L with average variation of 7,413 (Fig.30).

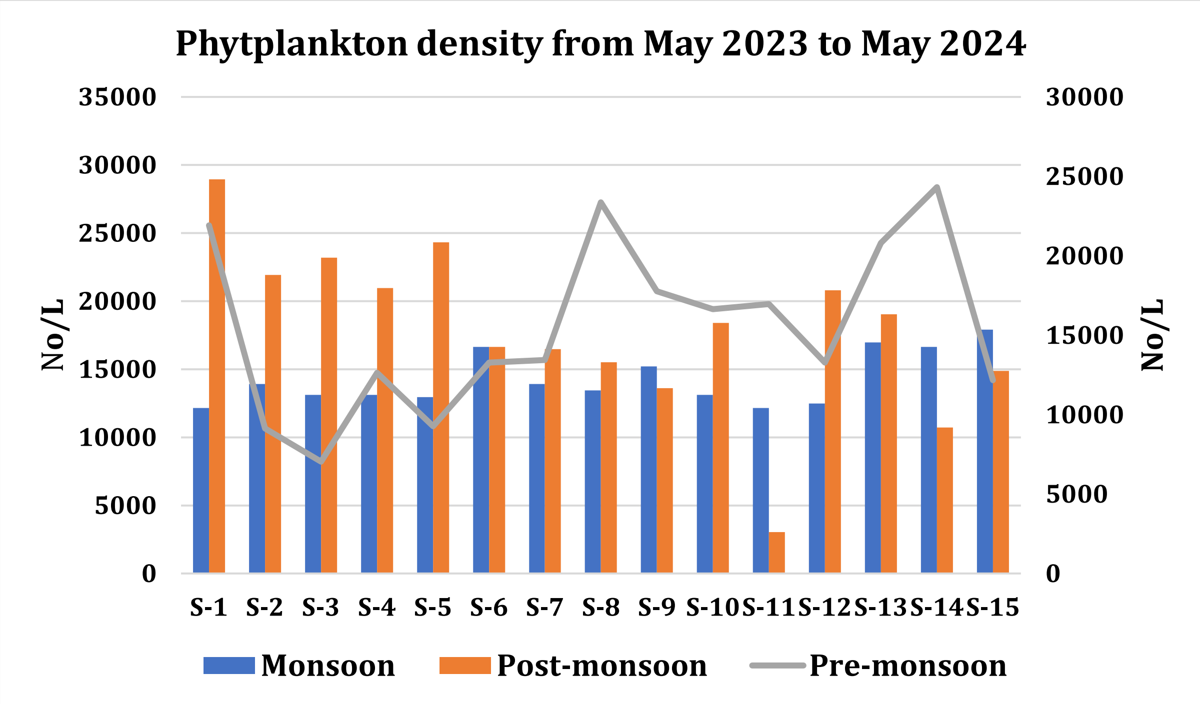
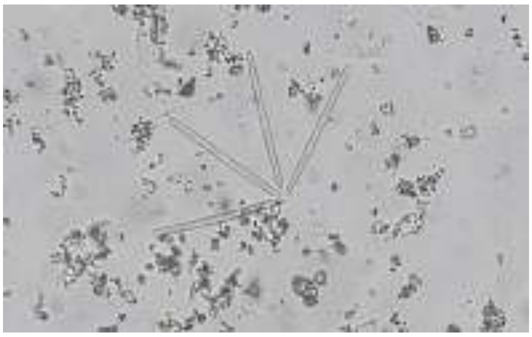


Figure 30. Seasonal variation Phytoplankton density during May 2023 to May 2024

During monsoon the phytoplankton density varied from 12,160 No/L to 17,920 No/L where highest density was observed at S-15.In post-monsoon cell density varied from 3,040 No/L (S-11) to 28,960 No/L (S-1).Similarly during pre-monsoon density varied from 7,040 no/L to 24,320 no/L and the highest density was observed at S-14 (24,320) and lowest density was observed at S-3 (7,040).

Hemidiscus ***Coscinodiscus***



Odontella ***Thalassionema***

Thalassiothrix ***Cheatoceros***

Plate 8: Phytoplankton of Deendayal Port Authority

4.2.3. Zooplankton

Zooplankton is a key player in pelagic marine ecosystems particularly as prey for shellfish, fish, marine mammals and seabirds. In addition, zooplankton waste products are also of importance for the vertical flux of organic matter. The sediment matter fuels the benthic community thus, zooplankton occupies a key position in shaping the pelagic system and coupling of pelagic and benthic food webs.The zooplankton fauna of Indian waters is very diverse, which could be due to a series of environmental factors, most significantly ocean currents (Jagadeesan et al., 2013), upwelling (Madhupratap et al., 1990), high primary productivity (Smith & Madhupratap, 2005) and salinity. These studies also recorded species compositions of the plankton community with marked spatial, seasonal, and diurnal fluctuations in both the Bay of Bengal and the Arabian Sea. Zooplanktons are strongly responsive to environmental variables, including light, temperature, salinity, pH, dissolved oxygen, turbulence, and food availability. In recognition of this multifaceted ecological and economic significance of zooplankton in marine environments, there has been a long emphasis on studying their systematics, ecology, and other biological aspects at different spatiotemporal scales.

Zooplankton plays a major role in the functioning and productivity of aquatic ecosystems through its impact on the nutrient dynamics and its unique position in the food web. Many species of zooplankton can be used as biological indicators for water pollution, water quality, and eutrophication. Zooplankton communities are highly influenced by Spatio-temporal variations in hydrochemical parameters and physical forces. The Spatio-temporal variations in zooplankton species composition and distribution in the Arabian Sea and Bay of Bengal have been extensively studied during the past 100 years and with more emphasis since the 1950s. Copepods are the most dominant zooplankton group and the most diverse in species composition in the pelagic realm of the marine environment. The preponderance of copepods among the various taxonomic groups has been reported as a common feature in coastal and oceanic environments. As the study area of DPA is under the influence of various port and cargo handling activities, regular monitoring is highly essential to know the environmental pressures at the Kandla coast and its nearby creek environment with respect to plankton which supports the fishery resources and several ecological services.

Phylum group and generic status

The zooplankton identified from the 15 stations falls under 8-12 phylum and 8-16 group for the period May-2023 to May 2024. In monsoon season 12 phylum and 16 zooplankton group was recorded, similarly, in post-monsoon season same phylum and 9 groups have been recorded from the entire study station, likewise in pre-monsoon season 8 phylum and 8 zooplankton group were recorded (Fig.31).

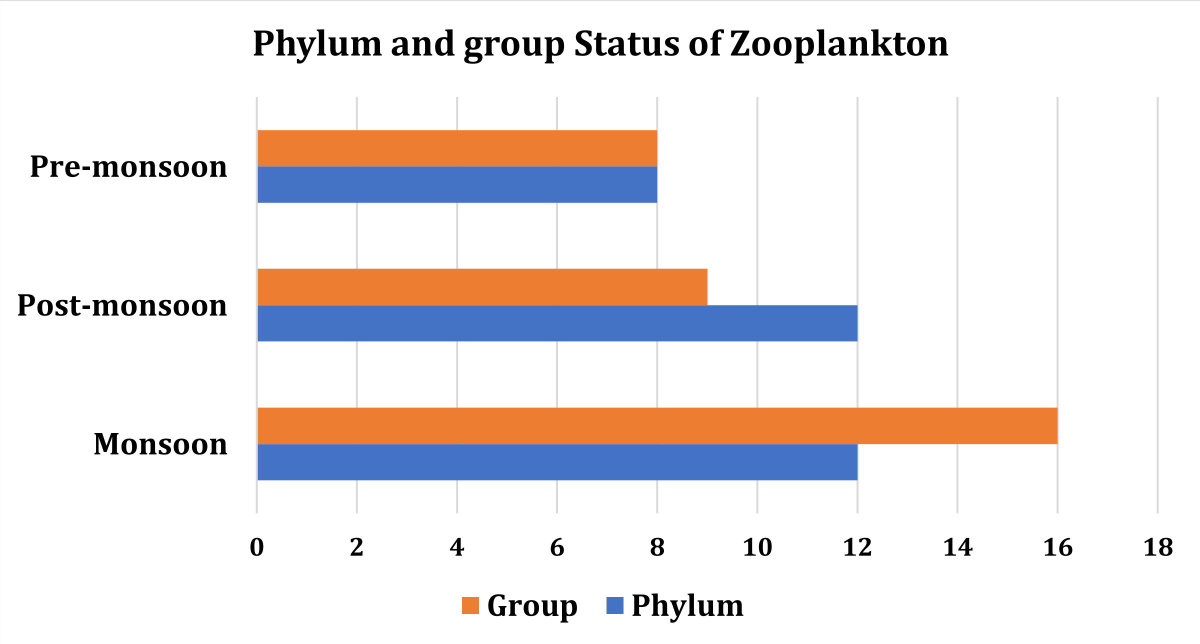


Figure 31. Zooplankton status from May 2023 to May 2024

The phylum Arthropoda was the predominant represented 16 groups in monsoon and post-monsoon (9) and pre-monsoon it contain 6 group which mainly include Copepoda, Harpacticoida, Cyclopoida, Decapoda, Crab larvae and Malacostraca. Maximum number zooplankton genera among the stations DPA area varied from 31 to 36 with an average variation of 34, and the minimum zooplankton genera varied from 15-29 with an average variation of 20. During monsoon season highest and lowest genera were observed at the S-1 (36 no) & S-9 (29). In post-monsoon, the highest genera were observed S-13 (36) and the minimum genera were observed at S-11 (15). Likewise, in pre-monsoon, the highest and lowest genera were observed at stations S-1 (31no) and S-15 (15), which is presented in figure 32.

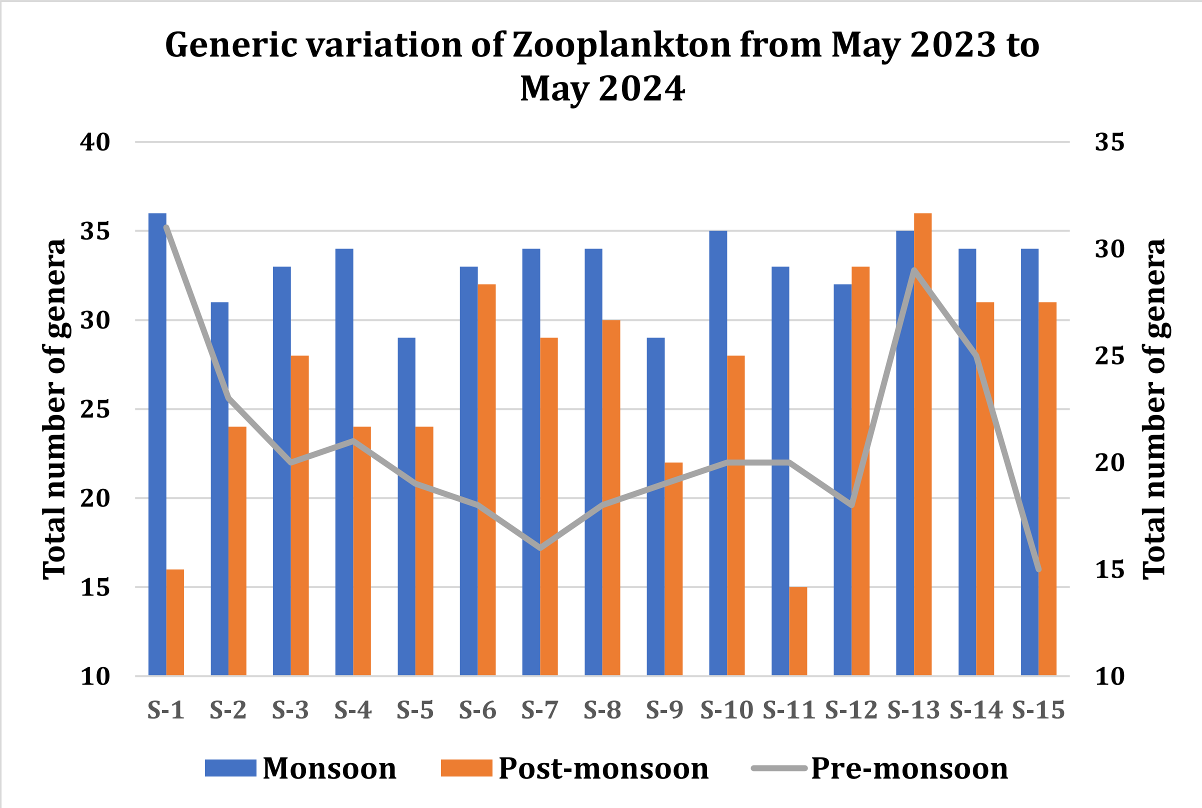


Figure 32. Generic status of Zooplankton during May 2023 to May 2024

Percentage of composition

The maximum percentage of composition of zooplankton ranged from 28.9% to 35.3% and the minimum percentage composition of zooplankton ranged from 1.1% to 2.3%. The Copepoda contribute highest percentage of composition in all-season In monsoon (28.60%) followed by post-monsoon (35.3%)and pre-monsoon (31.7%).Next to this the group contribute Decapoda contribute second highest contribution in terms of composition i.e monsoon (8.10%), post-monsoon (8.7%) followed by pre-monsoon (28.90%). The brachyuran larve contribute another significant contribution to species composition i.e in monsoon (16.06%), post-monsoon (15.2%) followed by pre-monsoon (10.40%). The least number of group as others composition was highest in pre-monsoon (9.50%) which presented in figure 33.

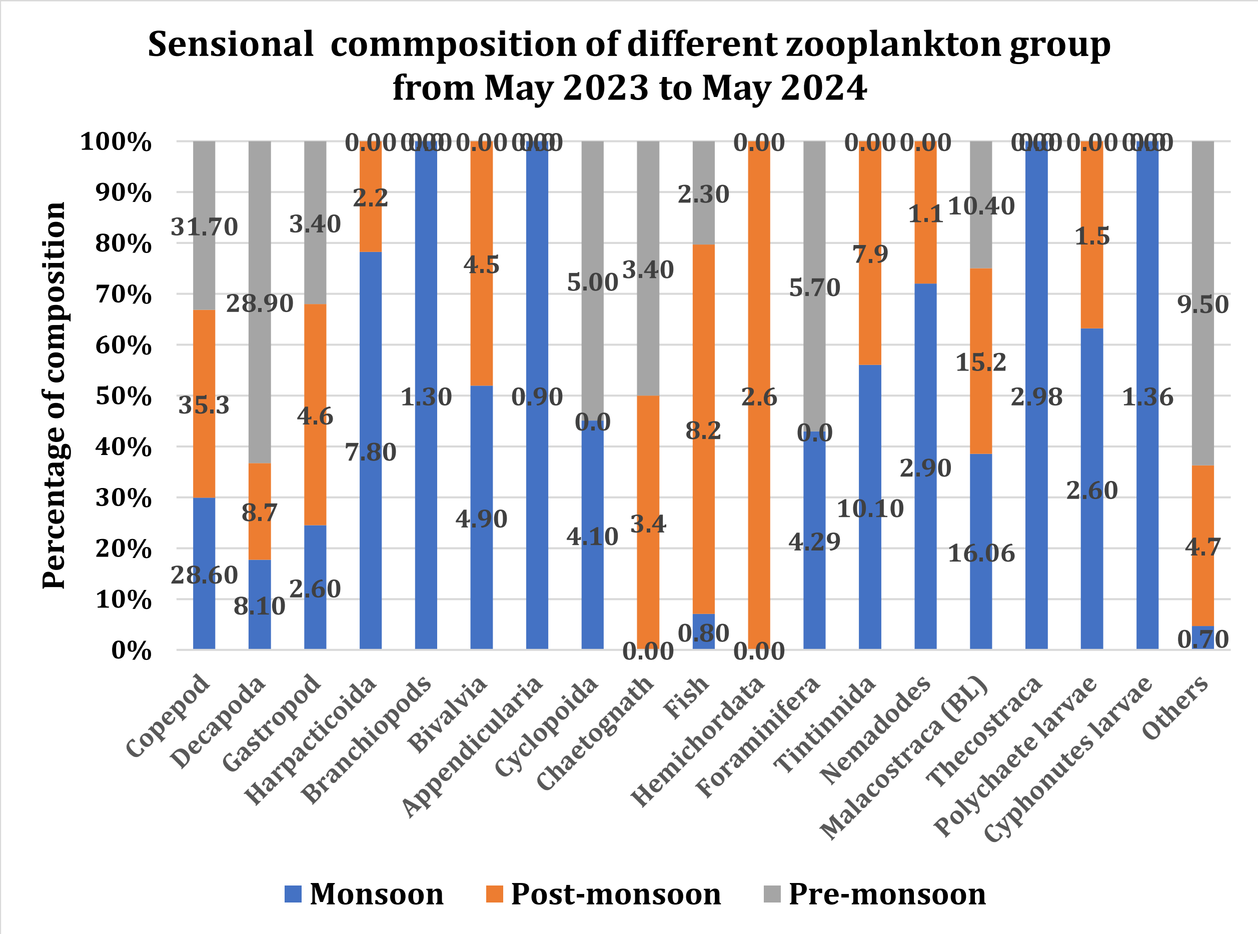


Figure 33. Percentage composition of Zooplankton during May-2023 to May2024

Percentage of occurrence

Percentage occurrence of zooplankton genera varied from 13-100%. In the monsoon season, the maximum percentage of occurrence was contributed by 21 genera as (100%) In post-monsoon maximum percentage of occurrence contributed by five genera (100%). Similarly in pre-monsoon maximum percentage of occurrence contributed by *Zoea Larvae, Lucifer* (100%) and it is presented in figure 34. The highest percentage occurrence was contributed by Globigerina,*Codonellopsis*, *Tintinnopsis*, *Nemadodes*, *Polychaete larvae*, *Acartia*, *Acrocalanus*, *Aetideus* ect. Least percentage of occurrence contributed by Oikopleura , Globigerina in pre-monsoon (13%) where as in post-monsoon least percentage of occurrence contributed by Bipinaria larvae (20%) (Plate 9).

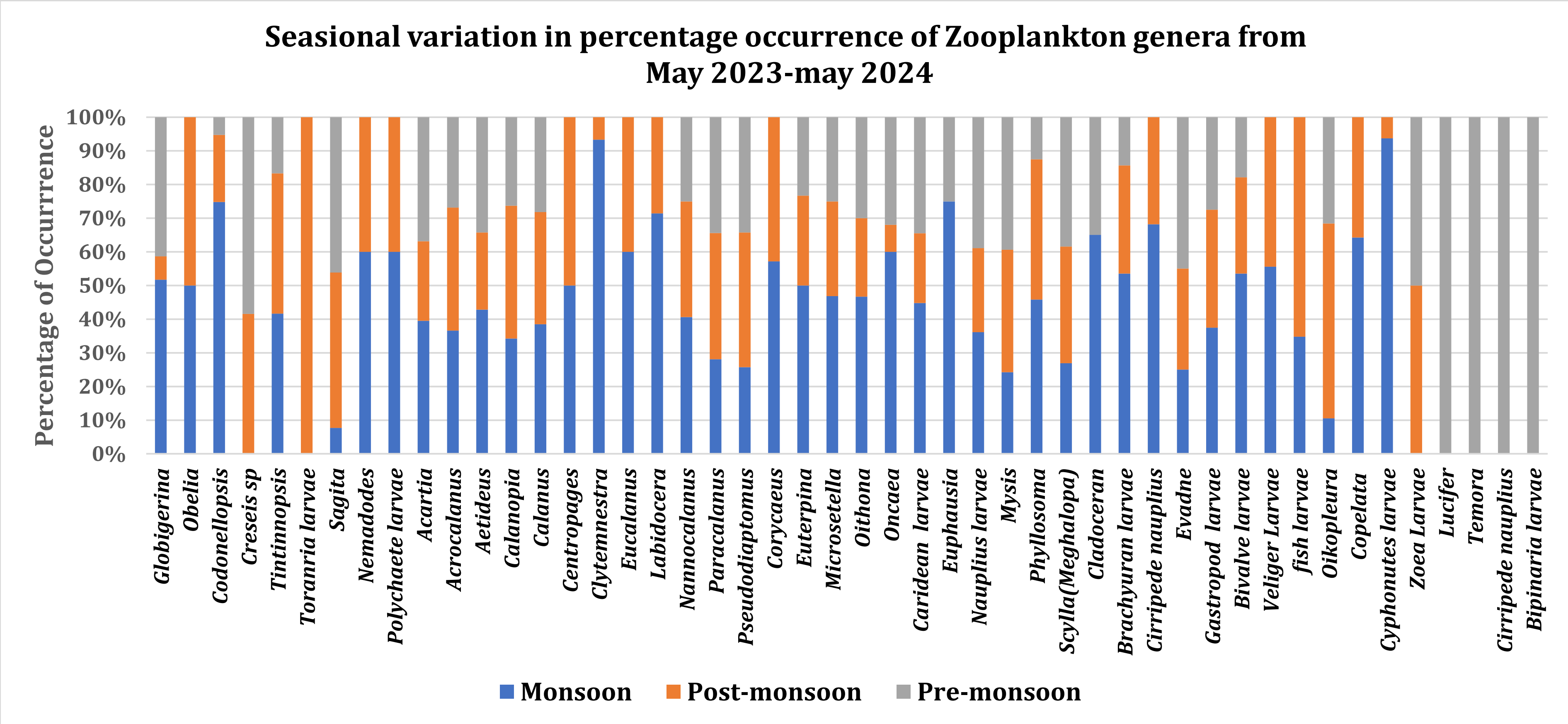


Figure 34. Percentage occurrence of Zooplankton in Deendayal Port Authority May-2023 to May-2024

Zooplankton density

During monsoon the phytoplankton density varied from 10,780 no/L to 15,260 no/L where highest density was observed at station S-1 and lowest density was observed at station S-3. In post-monsoon and per-monsoon the density varied from 6,400no/L to 16,320 no/L where the highest density was observed at station S-12 and lowest density was observed at station S-1 which is depleted in figure 35. About the zooplankton density observation peculiarity is highest density was observed in monsoon followed by pre-monsoon and post-monsoon.

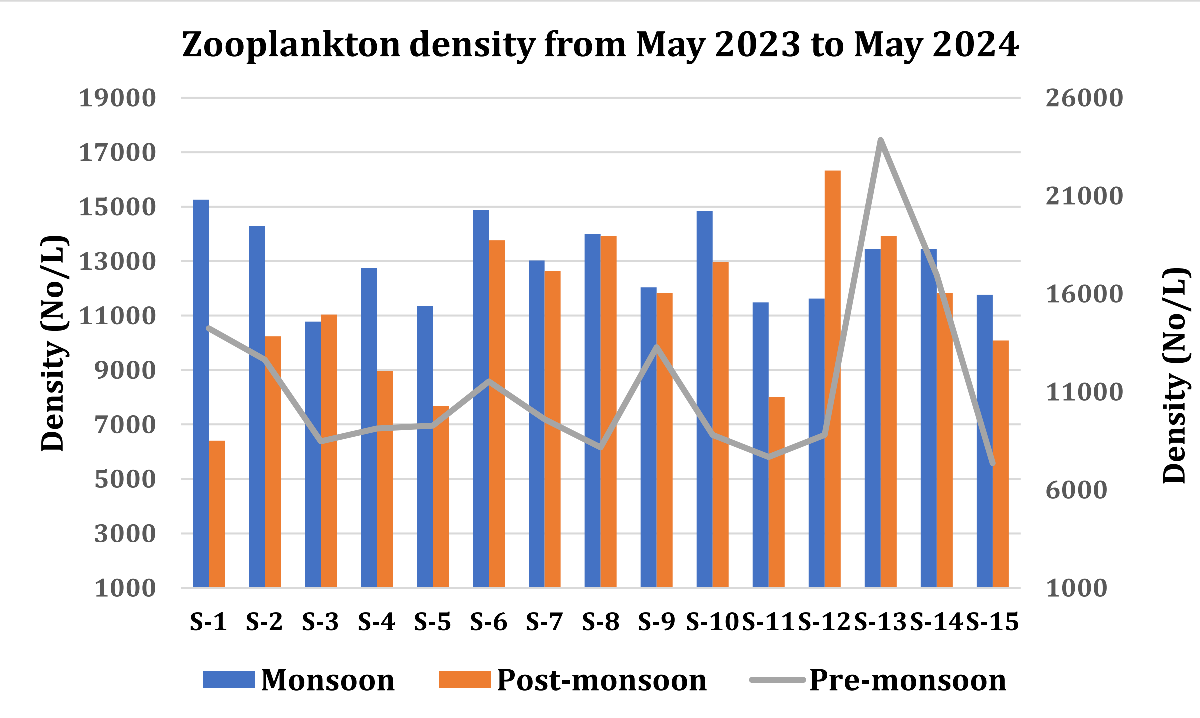
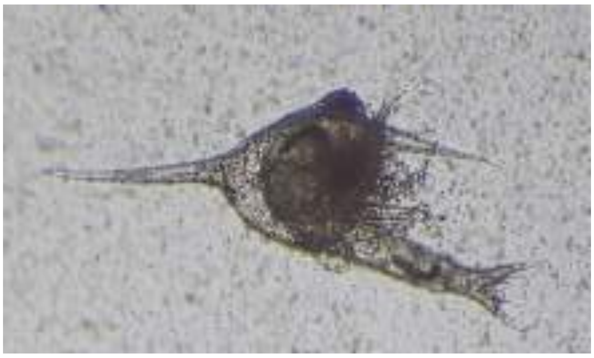
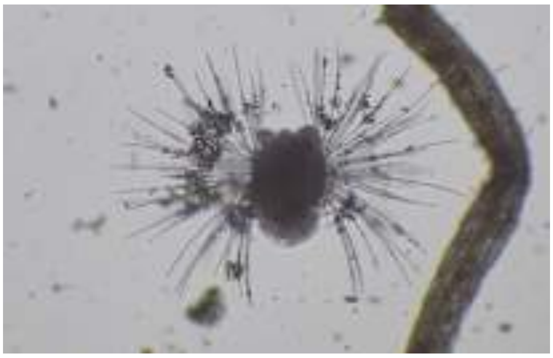


Figure 35. Density Zooplankton in DPA from May-2023 to May-2024



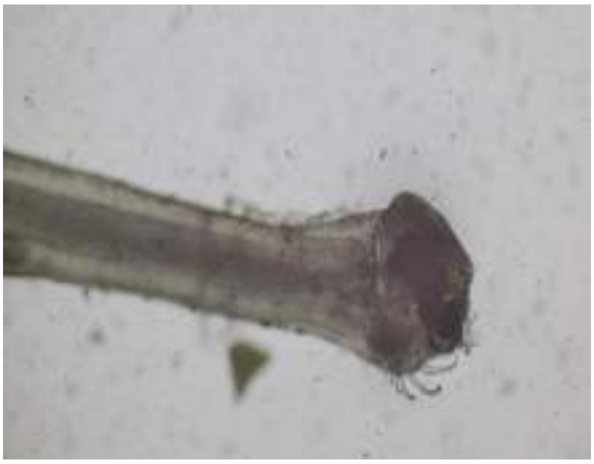
Zoea larvae



Globigerina

Copepod

Tintinnopsis



Sagita

Lucifer

Plate 9: Zooplankton of Deendayal Port Authority due

4.2.4. Intertidal fauna

The intertidal habitats are found along the margins of the oceans and include estuaries, mudflats, salt marshes and rocky shores (Chakraborty 2017). This intertidal zone is rich in diversity because high concentrations of nutrients drift from the land. Although these habitats differ in many respects, they share the common feature that organisms living in them experience enormous changes in their abiotic environment caused by the tidal cycle. The tide rises roughly every 12.5 h, and during this time, intertidal organisms can be exposed to marine-like temperature and salinity conditions. The Gulf of Kachchh (GoK), occupying an area of 7300 km2, is biologically one of the most productive environments with diversified habitats along the west coast of India. The southern shore has numerous Islands and inlets which harbour vast areas of mangroves and coral reefs. The northern shore with numerous shoals and creeks also sustains large stretches of mangroves. A variety of marine wealth existing in the Gulf includes algae, mangroves, corals, sponges, molluscs, prawns, fishes, reptiles, birds and mammals.

The marine environment is a complex system influenced by various physical, chemical and biological processes and harbours broad assemblages of diversified Fauna. Intertidal Fauna represents species of invertebrates and chordates. They have an essential role in the pelagic and benthic food chain at different trophic levels in the coastal environment. Hence, periodic environmental monitoring to assess the abundance and diversity of macrofauna in this habitat is inevitable. The intertidal Fauna was comparatively less mortality based on the condition of their habitat, and many environmental impacts can be identified by following the changes in the assemblages of intertidal Fauna. Activities of organisms influence sedimentation and erosion and sediment physical and chemical nature. Tidal flats occur mainly in areas where saline and freshwater mix. Benthic organisms occur here usually in high densities because estuaries are among the most productive regions in the sea. Nutrient input by freshwater discharges sustains a relatively high primary production by phytoplankton and micro-and macro flora. Living on the tidal flats provides food for this abundant animal life. Moreover, there is a high input of organic matter (food) from rivers. However, as the organisms must tolerate rapid tidal and seasonal changes in salinity, the number of benthic species is usually lower than in the open sea and freshwater. Therefore, the macrofauna of the intertidal area worldwide has received considerable attention in recent years. Rapid coastal industrialisation in recent years has underlined the importance of complete understanding and continuous monitoring of marine environments, especially coastal stretches where human activity is intense, to evaluate their stability and functioning. In ports, activities like dredging, frequent vessel movement, and human interference in large numbers have a significant impact on the living organisms in the intertidal zone. Assessment of these effects has usually targeted bottom substrata and the associated benthic Fauna. Hence benthic communities are logical targets whose density, diversity, community structure and seasonal shift will be a powerful tool for understanding any marine environment.

Phylum wise diversity

The survey of the intertidal Fauna of DPA Kandla area recorded the presence of 4 phyla (Annelida, Arthropoda, Chordata, Mollusca). The species diversity was the highest for phylum Mollusca (23), followed by Arthropoda (12), Annelida (6) and Chordata (3) respectively (Fig.36).

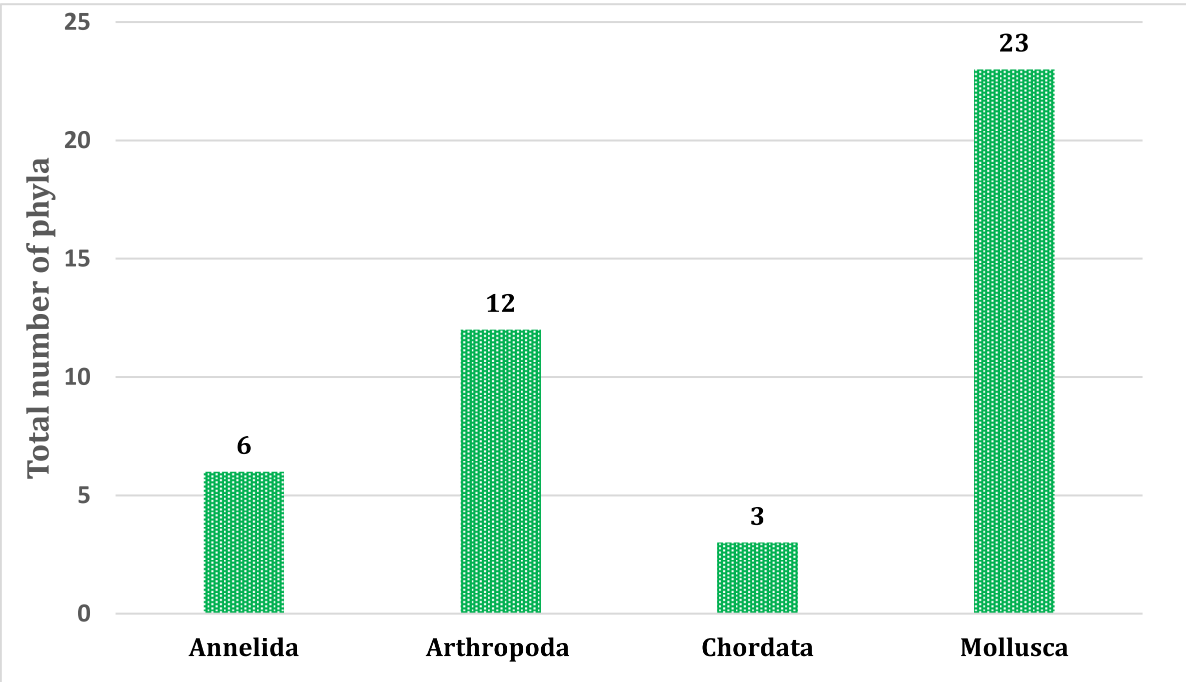


Figure 36. Phylum wise intertidal faunal diversity during May-2023 to May-2024

Density variation of intertidal fauna

The total density of intertidal organism varrieed from 704 No/m2 to 848 No/m^2. The highest number of organisms was documented from the post-monsoon (848), followed by monsoon (842) and pre-monsoon (704), respectively. The intertidal fauna of DPA Kandla survey recorded the presence of 3-36 species classified under 4 phyla (Annelida, Arthropoda, Chordata, Mollusca).The mollusc diversity was very high in all the seasons; during the monsoon (9 species), Post-monsoon (9) and pre-monsoon (8 species), respectively. The second most dominant phyla, Arthropoda sharing (5 Species in all seson. The total number in 3 season presented in figure 37.

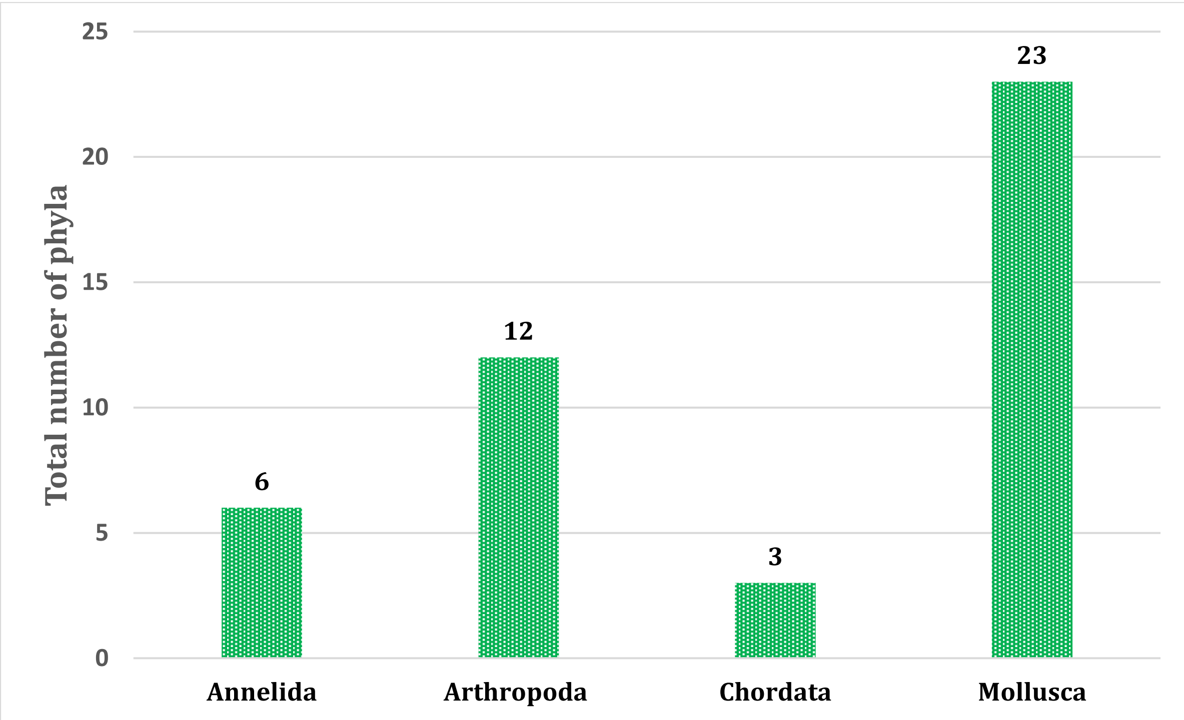


Figure 37. Season wise total intertidal population No/m^2 from May-2023 to May-2024

Phylum wise and season wise intertidal diversity

Highest number of animals was documented belong to species *Austruca iranica* followed by *Austruca variegata*in in all three seasons (Fig.38) followed by *Scylla olivacea*, *Austruca sindensis*, *Pirenella cingulate* and *Periophthalmus waltoni*

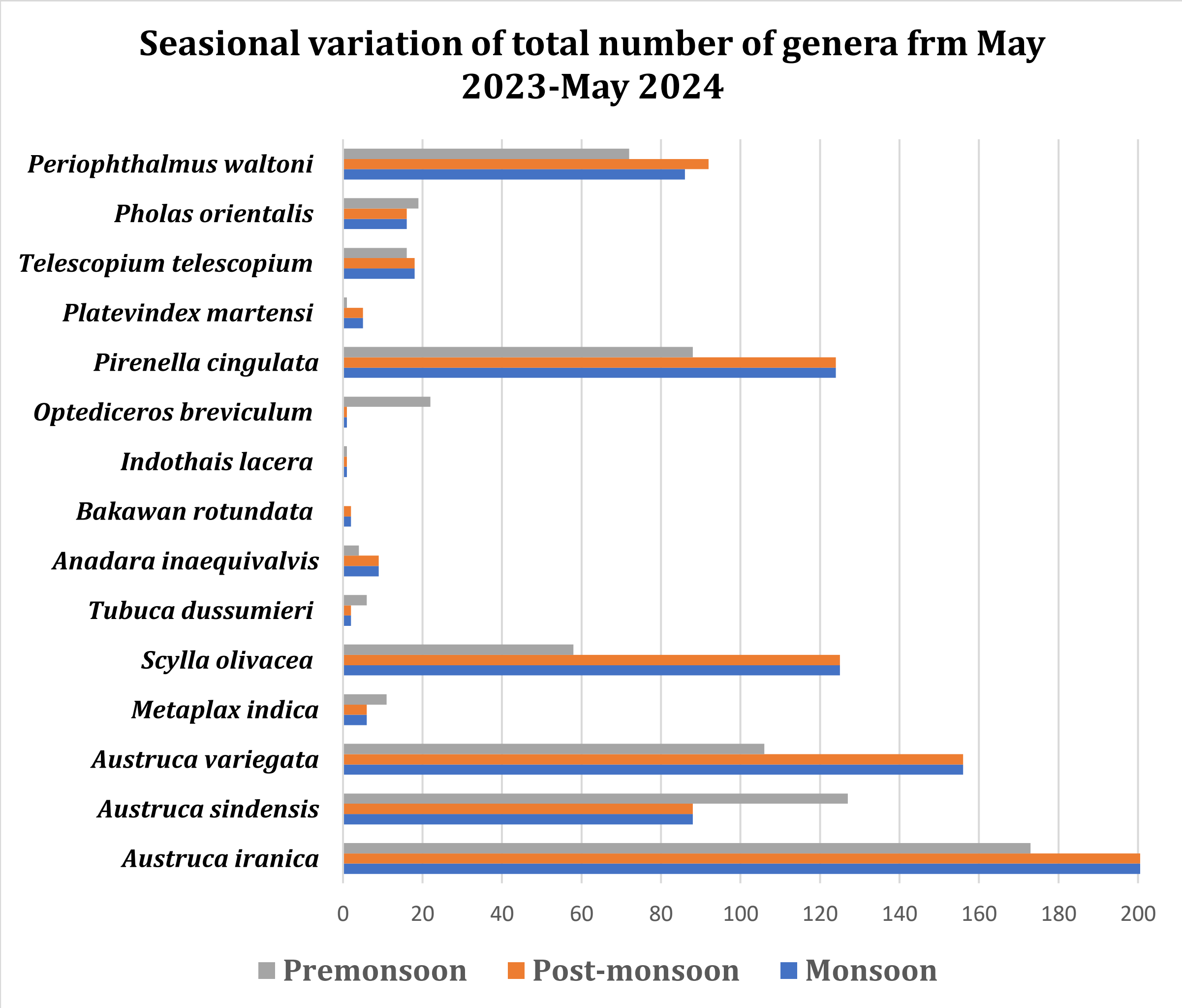


Figure 38. Season wise intertidal faunal diversity during May-2023 to May-2024

Station wise Intertidal Fauna density (No/m^2)

The intertidal faunal density among different station was documented, where the highest no of organisms was documented from the post-monsoon season (133 No/m^2) at , followed by same station in monsoon (127 No/m2) and pre-monsoon (78 No/m2), respectively. Minimum density variation was observed at S-11 in both monsoon and post-monsoon followed by pre-monsoon S-10 Fig.39).

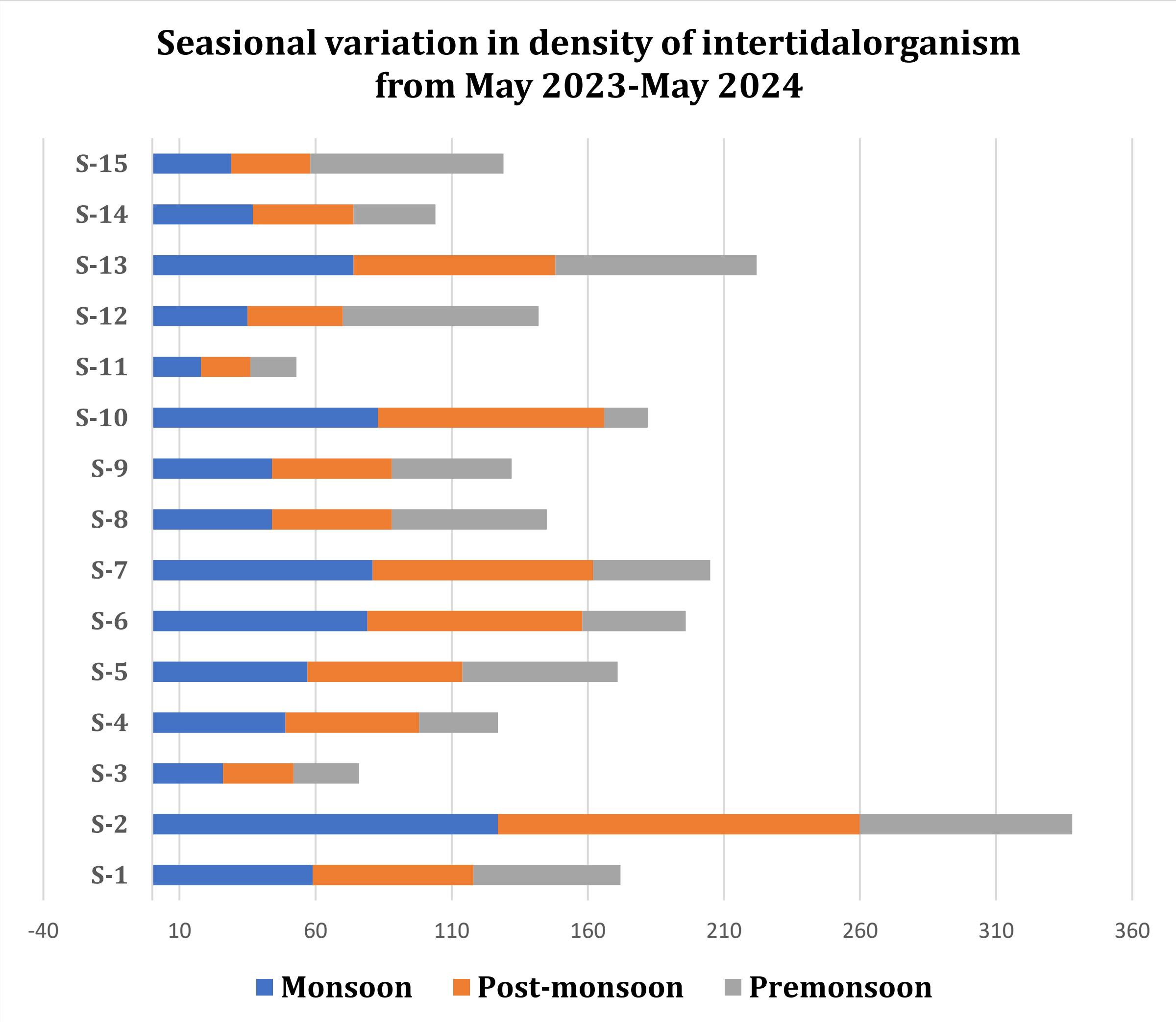


Figure 39. Season wise intertidal faunal diversity during May-2023 to May-2024

Percentage of composition

In all 3 season highest percentage of composition was contributed by *Austruca iranica Austruca sindensis*, *Austruca variegate* and *Pirenella cingulata*. The most negligible percentage of diversity was documented from the *Indothais lacera* (0.1%) and *Bakawan rotundata* (0.2%). (fig.40).

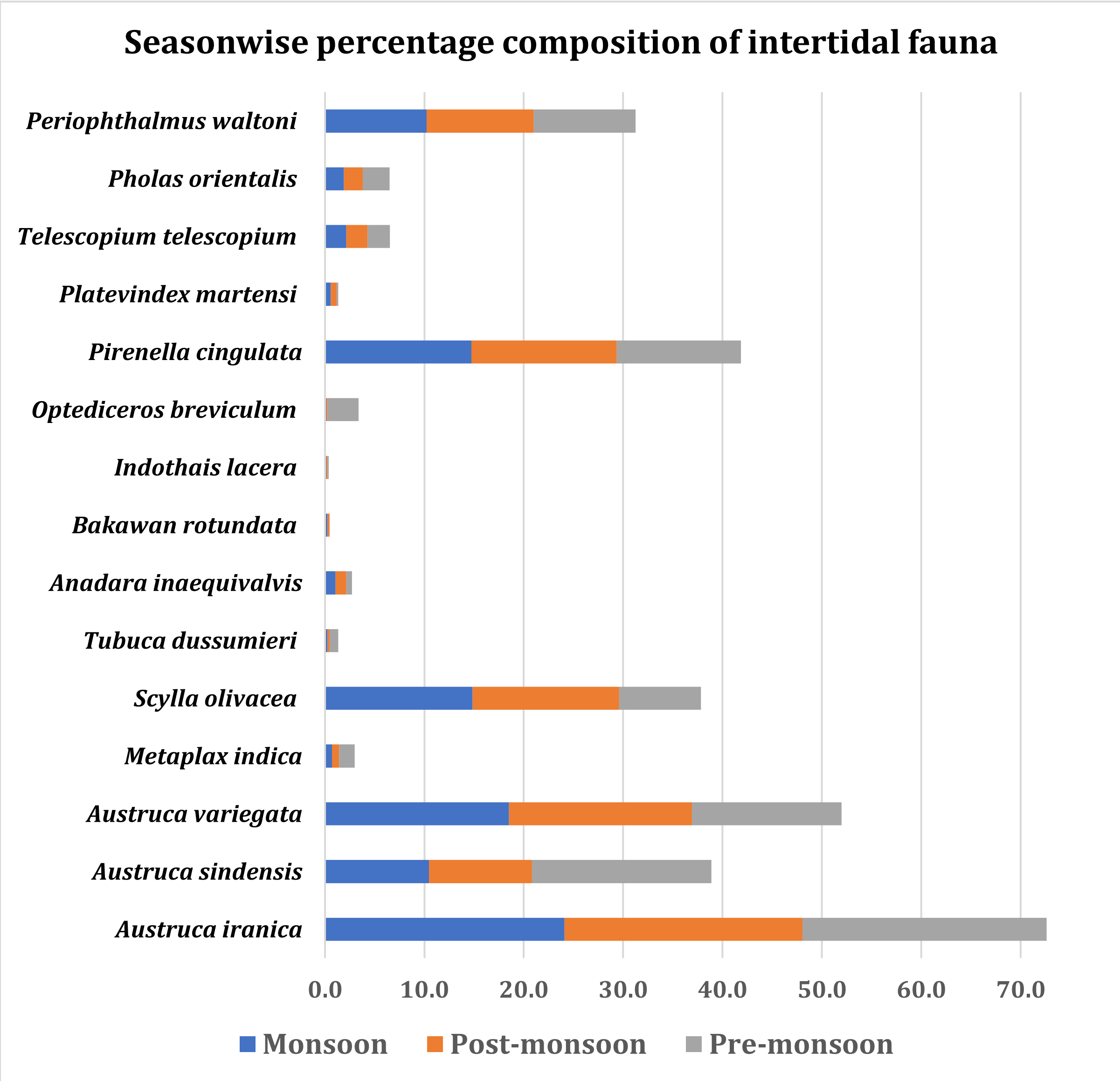


Figure 40. Season wise Percentage composition intertidal faunal diversity May-2023 to May-2024

4.2.5. Subtidal Fauna

Intertidal and subtidal environments may be composed of parts of both estuarine systems and marine systems (Aquatic Ecosystems Task Group, 2012; Cowardin et al., 1979). Subtidal benthic habitats are essential for estuarine and marine life since marine species depend directly or indirectly on the seafloor for food, hide, rest or reproduction and nutrient recycling. The Seasonal difference in rainfall, salinity, nutrients and light intensity might be a remarkable succession in the subtidal diversity. Subtidal ecosystems are permanently submerged owing to tidal influence. However, intertidal ecosystems are found among the high tide and low tide, facing the regular fluctuations and influences from the land and sea (Karleskint, 1998; Levinton, 1995; Pitcher et al., 2007; Rees, 2009). The intertidal and subtidal mangrove forests are important nurseries for the breeding ground of many species of fishes and crustaceans. They provide food and shelter for the larval and juvenile stages. Most soft bottom subtidal animals are dominated by infaunal or burrowing invertebrates such as polychaetes, crustaceans, and molluscs. These organisms associated with soft bottom subtidal environments provide various environmental services, such as nutrient recyclers, deposit feeders and microorganisms living within the sediments (Chaves and Bouchereau, 1999; Vendel et al., 2002).

Phylum wise and season wise density of subtidal fauna

The subtidal Fauna of the DPA Kandla survey recorded the presence of 4 phyla (Annelida Arthropoda, Mollusca, Annelida, Chordata,), including 2 to 28 species. The species diversity was the highest in phylum Mollusca (28 species), followed by Arthropoda (14 species), Chordates (2species) respectively. The occurrence of subtidal benthic animals was documented during the three seasons. The highest no of organisms was documented from the pre-monsoon (638), followed by post-monsoon (386) and monsoon (228), respectively (Fig.41 &42).

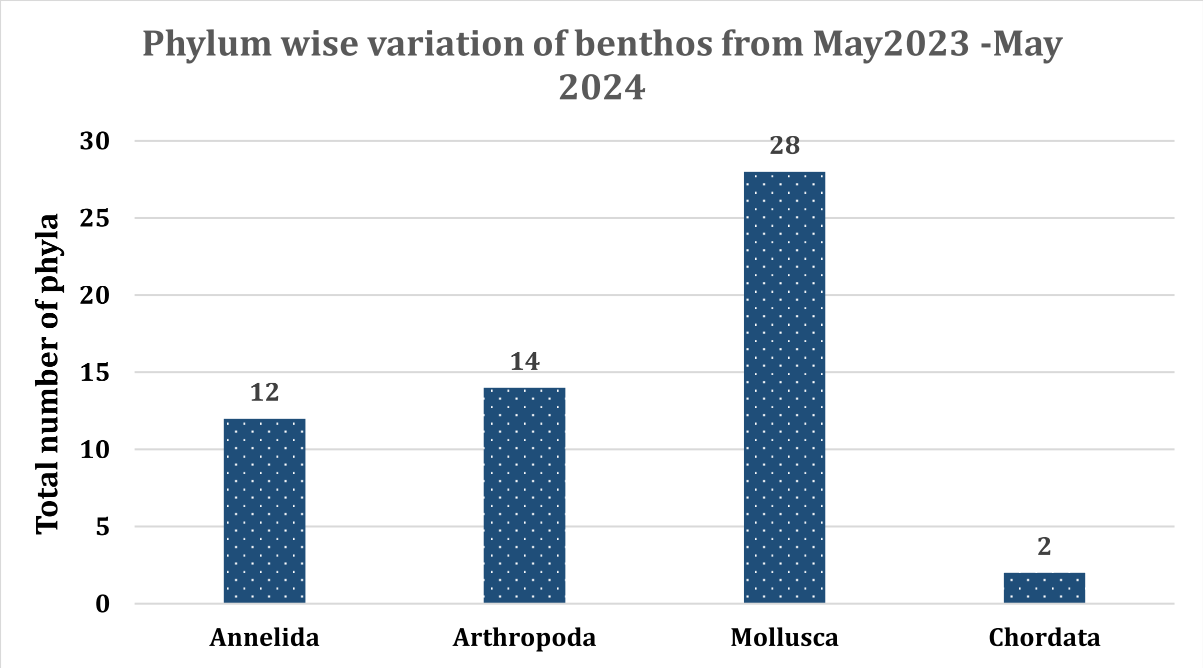


Figure 41. Phylum wise subtidal faunal diversity during May-2023 to May-2024

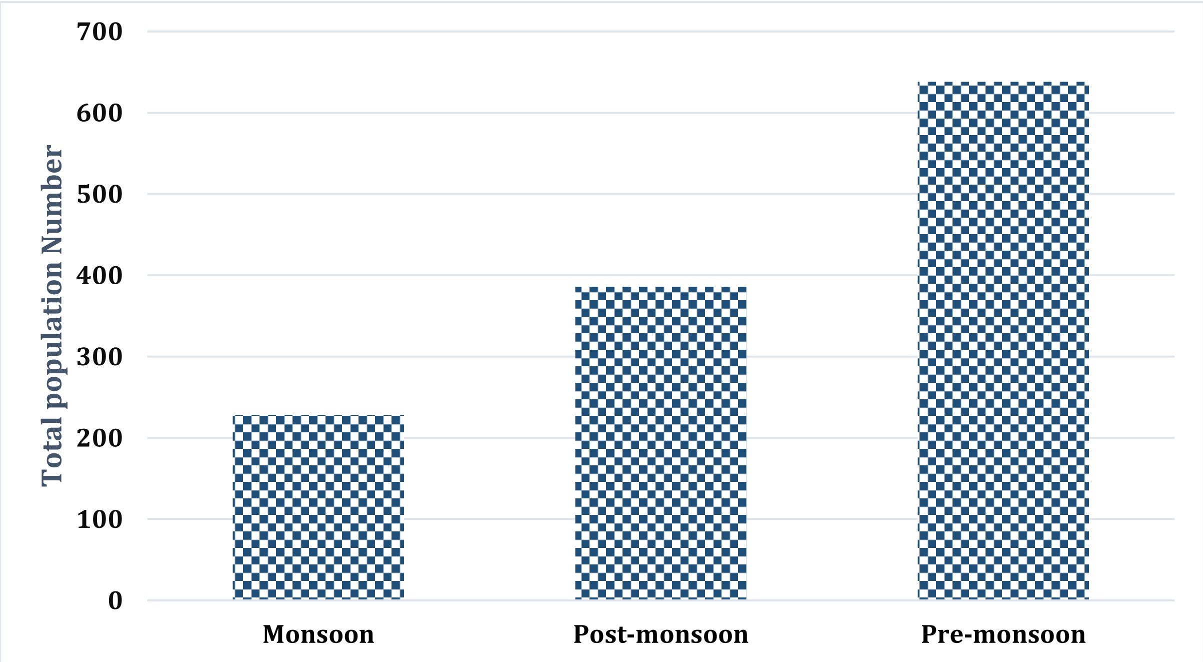


Figure 42. Season wise subtidal species density (No/m^2) during May-2023 to May-2024

Density of subtidal benthos

Total density of subtidal benthic organism varied from 5,700 No/m^2 to 15,950 No/m^2 with average density of 10,592No/m^2. Highest density was recorded in pre-monsoon followed by post-monsoon (Fig.41). Among the season highest density of organism was recorded during pre-monsoon at S-12 followed by S-2 during post-monsoon and S-14 during monsoon(Fig.43 &44).

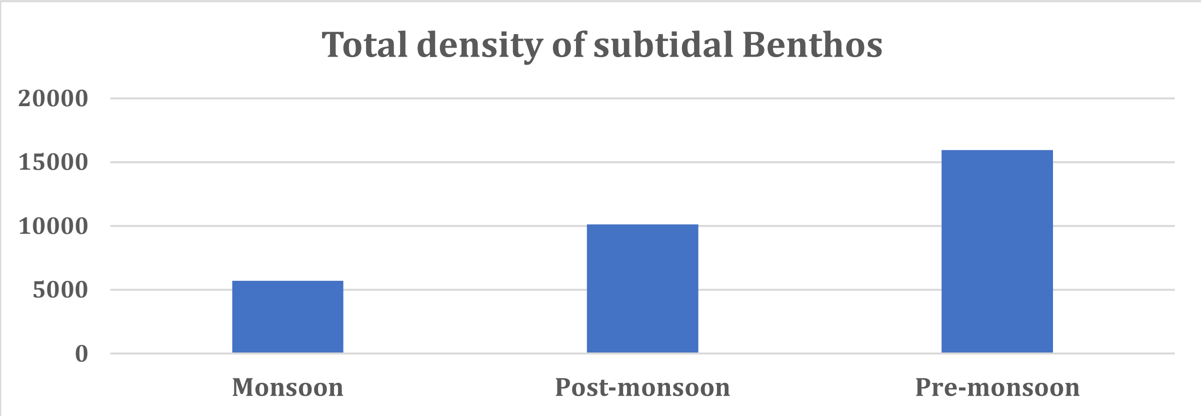


Figure 43. Subtidal benthic organism density (No/m^2) in DPA from May2023- May2024

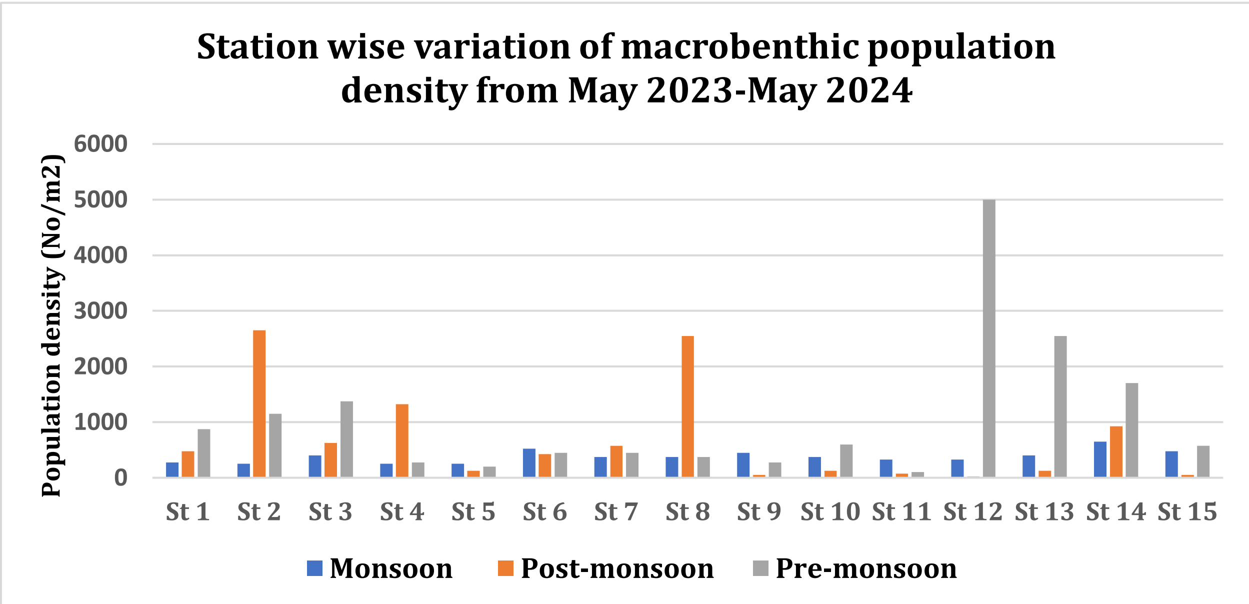


Figure 44. Station wise density of subtidal benthos (No/m^2) in DPA from May2023- May2024

Percentage of composition

During monsoon the highest percentage composition was shared by *Glauconome angulata* (15.8%) and *Pirenella cingulata* (11.7%) followed by Capitella sp. (8.8%). In the the post-monsoon the highest percentage composition of subtidal macrofauna was shared by the *Nereis sp. (*34.2%), Likewise in Pre-monsoon the highest percentage composition of intertidal macrofauna was shared by the Penaeus sp. (39.3%) respectively. (Fig.45).

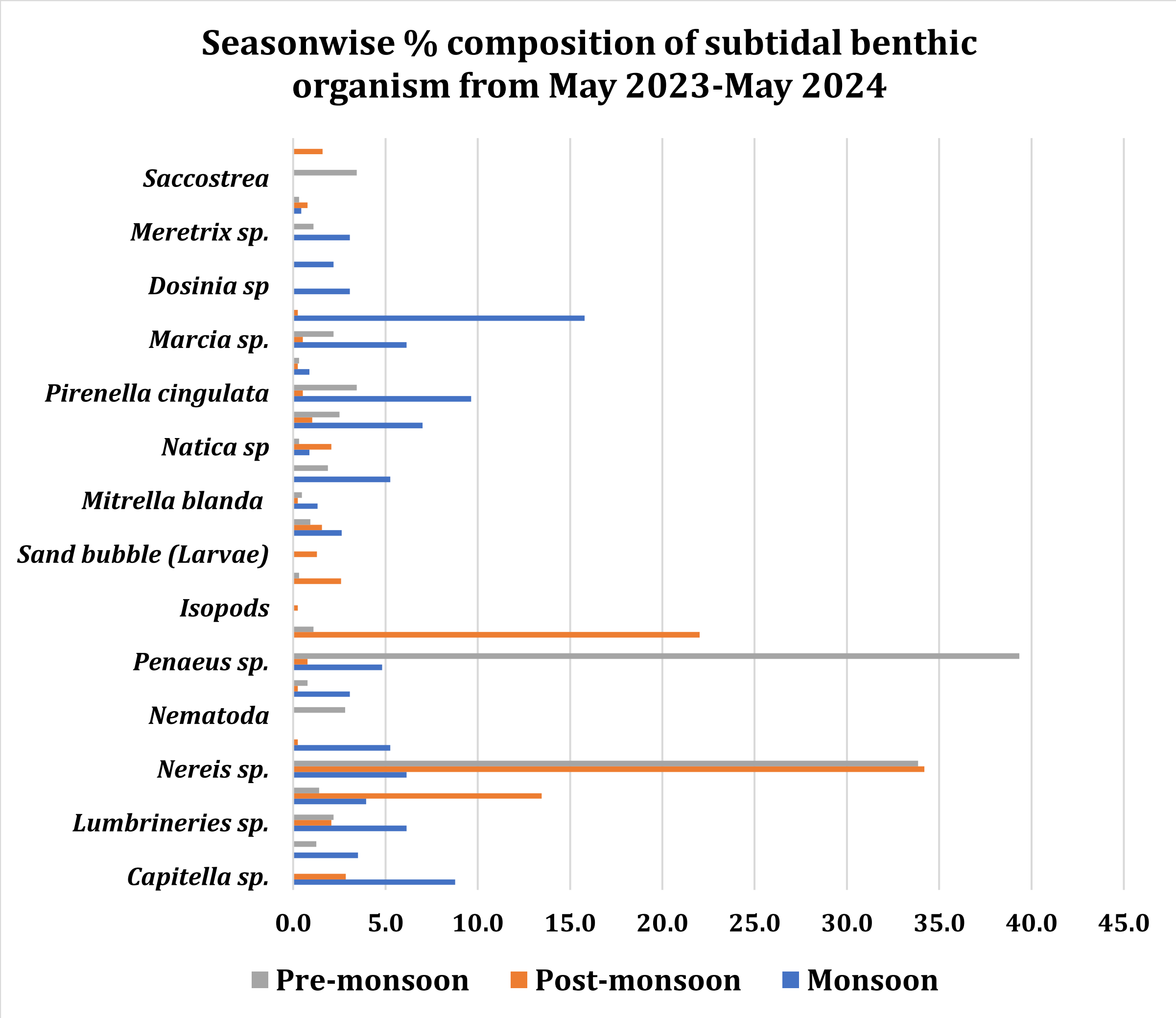


Figure 45 Percentage composition of subtidal organisms from May 2023 to May 2024

4.3. Mudflats

Mudflats and mangroves establish a major ecosystem of the DPA coastal region and the significance of ecosystem services rendered by mudflat is endorsed in Coastal Regulation Zone (CRZ, 2011) as it accords special status to highly productive zone. Mudflat has an assemblage of plant-animal-geomorphological entities. DPA has been surrounded by two major ecosystems such as mangroves and mudflats which support a number of ecosystem services like nursery grounds for fish and shellfishes and breeding/feeding grounds for the birds (Spencer and Harvey, 2012). The TOC concentration is a direct indicator of mudflat productivity and blue carbon sequestration.

4.3.1. Bulk density of the sediment

The data on the bulk density of the sediment samples are presented (Fig.46). Among the station of DPA port area the maximum bulk density ranges from 1.67 g/cm^3 to 2.50 g/cm^3 and the minimum bulk density ranges was 1.18 g/cm^3 to 1.25 g/cm^3. Station wise the highest bulk density was recorded at station S-13 in monsoon season (1.52 g/cm^3), whereas lowest bulk density was recorded in station S-2 and S-1 during pre-monsoon and post-monsdoon(1.25 g/cm^3).

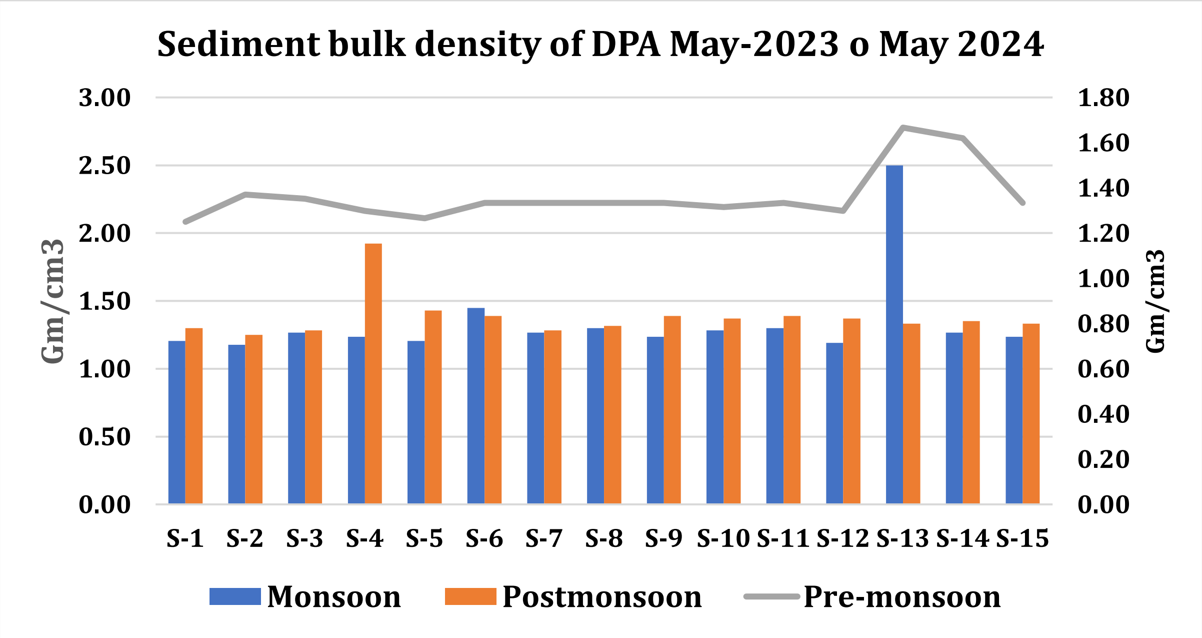


Figure 46 Bulk density of sediment from May 2023 to May 2024

4.3.2. Total Organic Carbon (TOC)

The data on the total organic carbon of the sediment samples are presented (Fig.47). Among the station of DPA port area the maximum sediment carbon ranges from 1.3% to 3.2% to and the minimum sediment carbon ranges was 0.4% to 2.4%. Stationwise the highest sediment carbon was recorded at station S-12 during post-monsoon (3.2%), whereas lowest sediment carbon was recorded in station S-2 during monsoon and pre-monsoon (2.4%.).

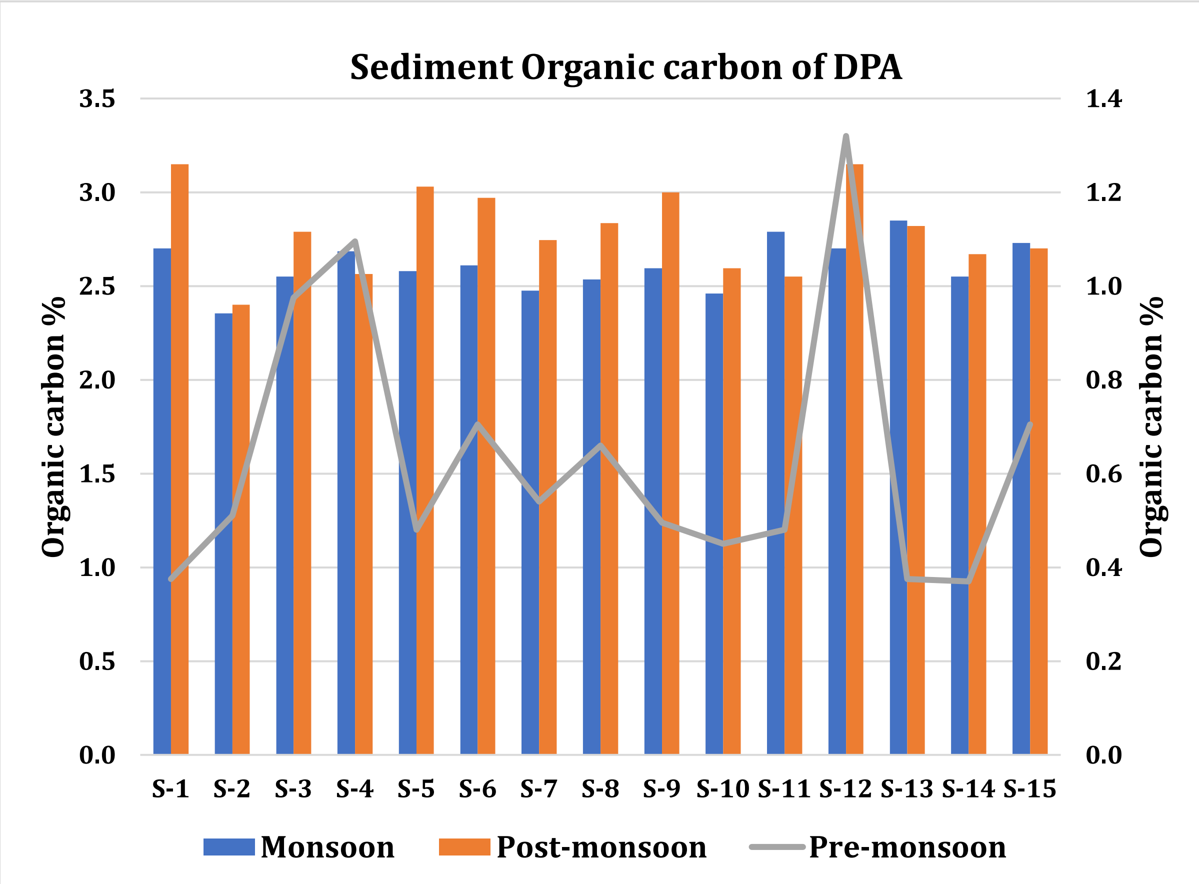


Figure 47. Percentage of organic carbon in sediment from May 2023 to May 2024

4.4. Mangroves

Mangroves are coastal plants that primarily serve coastal communities around the world. They fulfil various needs, including fodder, firewood, medicines, timber and in some cases as vegetables. Beyond their direct utility, mangroves play a crucial role in protecting coastal biodiversity by providing ecological services. The mangrove ecosystem is one of the most productive ecosystems, covering 47% of the world's mangrove area. These remarkable plants thrive in diverse habitats across 30 countries bordering the Indian Ocean. Their essential role in enhancing coastal biodiversity is evident, with almost 85% of the world's mangrove species contributing to this vital function.

India, despite its extensive coastline spanning approximately 7516.6 km, has a relatively modest mangrove cover of only 4992 km^2. Among Indian states, West Bengal boasts the maximum mangrove cover, spanning 2114 km^2, followed by Gujarat with 1175 km^2. Interestingly, Gujarat is home to 15 mangrove species, including Acanthus illicifolius, Aegiceras corniculatum, Avicennia alba, Avicennia marina, Avicennia officinalis, Bruguiera cylindrica, Bruguiera gymnorrhiza, Ceriops decandra, Ceriops tagal, Excoecaria agallocha, Kandeliacandel, Lumnitzera racemosa, Rhizophora apiculata, Rhizophora mucronata, and Sonneratia apetala. However, it's worth noting that Gujarat's mangrove cover is largely dominated by a single species, that is *A. marina* (Plate10).

4.4.1. Tree Density

A total of 13 mangrove sites were assessed during the three seasons for the period 2023-24 respectively monsoon and post-monsoon of 2023 and pre-monsoon of 2024 in order to record the mangrove density and the other growth parameters, height, girth and canopy cover. During the monsoon, the mean plant density was highest at the Veera site, with 2703 trees per hectare. The Janghi station followed closely with a mean density of 2588 trees per hectare. Regarding individual sample locations, S-6 station at Janghi Creek had the highest tree density (3086/ha). The S-8 station at Navlakhi Creek showed 2894 trees per hectare. The lowest average tree density (1042 trees /ha) was observed at location S-9 in Navlakhi Creek (fig. 48).

In the post-monsoon season 2023-24, the overall average tree density in DPA area recorded was 3,647 trees/ha. The site S-14 in the Veera area had the highest average tree density, (5,780 trees/ha) and S-7, located in the Kharo creek, (5,340 trees/ha). The S-5 and S-15, situated in Phang creek and Kandla creek showed the lowest average tree density, (1,194 trees/ha and 1,689 trees/ha) respectively. Among the creeks, the Veera area showed the highest average tree density.

During the pre-monsoon season of 2024, the overall average tree density of the entire sites was 4,098 trees per hectare. The site S-7 in the Kharo area had the highest average tree density, with an impressive 6,774 trees per hectare. Following closely was site S-4, located in the Kandla creek, it was 6,637 trees/ha and Site S-5 recorded the lowest average tree density, (1,338 trees/ha) The site S-11, situated in the Jangi creek, also had an average density of 1,469 trees per hectare.

The inconsistent tree density across different locations reflects variations in local geomorphology and the prevailing environmental factors influenced by the rainfall rate, tidal currents and land drainage and so on. Seasonal changes likely play a role in shaping the mangrove tree density patterns. Overall, these findings highlight the importance of considering both biological and environmental factors when assessing mangrove ecosystems.

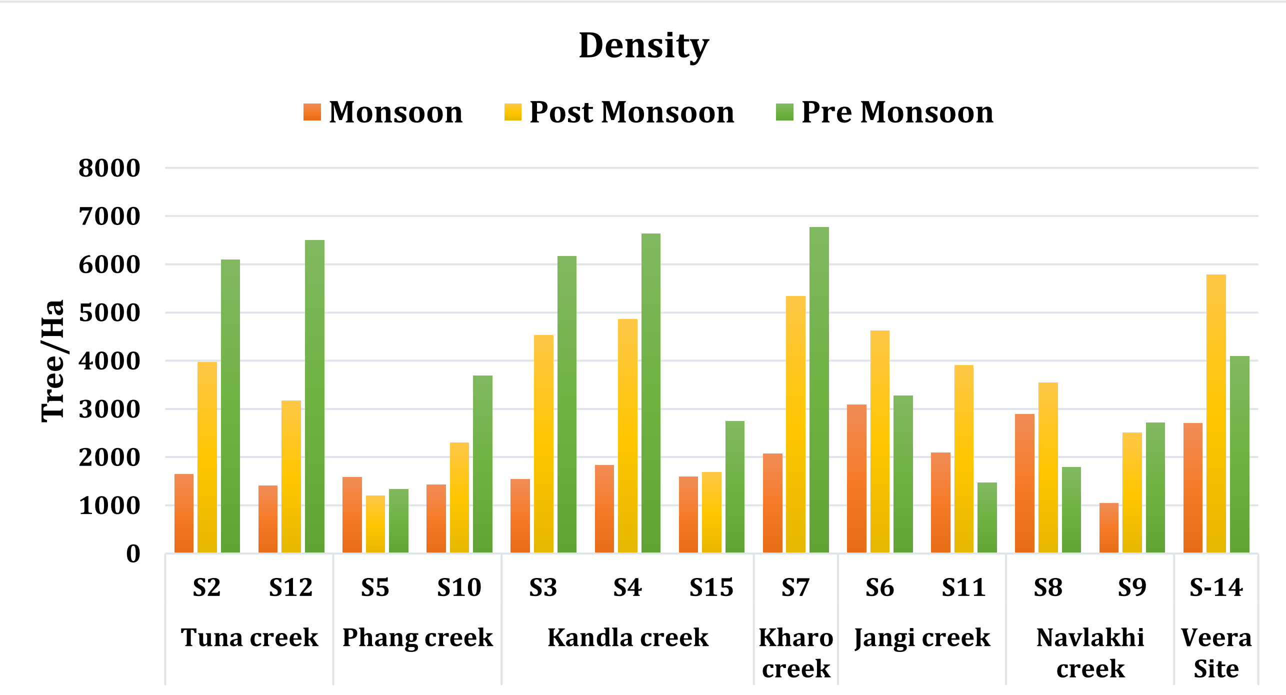


Figure 48. Density of mangrove from in Deendayal Port Authority area from May 2023- May 2024

4.4.2. Tree Height

The overall mean height of the mangroves from the study sites along the DPA, Kandla environment for the three seasons ranged from 1.7 to 2 m (Fig.49). During all three seasons survey, the highest average tree height was recorded at Tuna creek area, followed by Phang creek. During the monsoon, in terms of individual sites, the average highest tree height was recorded at the site S-10 (2.4 m) located at Phang creek, followed by S-2 (2.2 m) located at Tuna creek. During post-monsoon, the highest tree height (2.7 m) was observed at S-2, located at Tuna creek, followed closely by S-10 (2.4m) situated at Phang creek. However, while examining individual sampling sites, during the pre-monsoon of 2024, tree height was maximum 2.3 m observed a S-12 in Tuna Creek, and 2.2m at S-8 (Navlakhi Creek). Tree height is a crucial factor since it indicates whether trees are developing normally or exhibiting stunted growth.

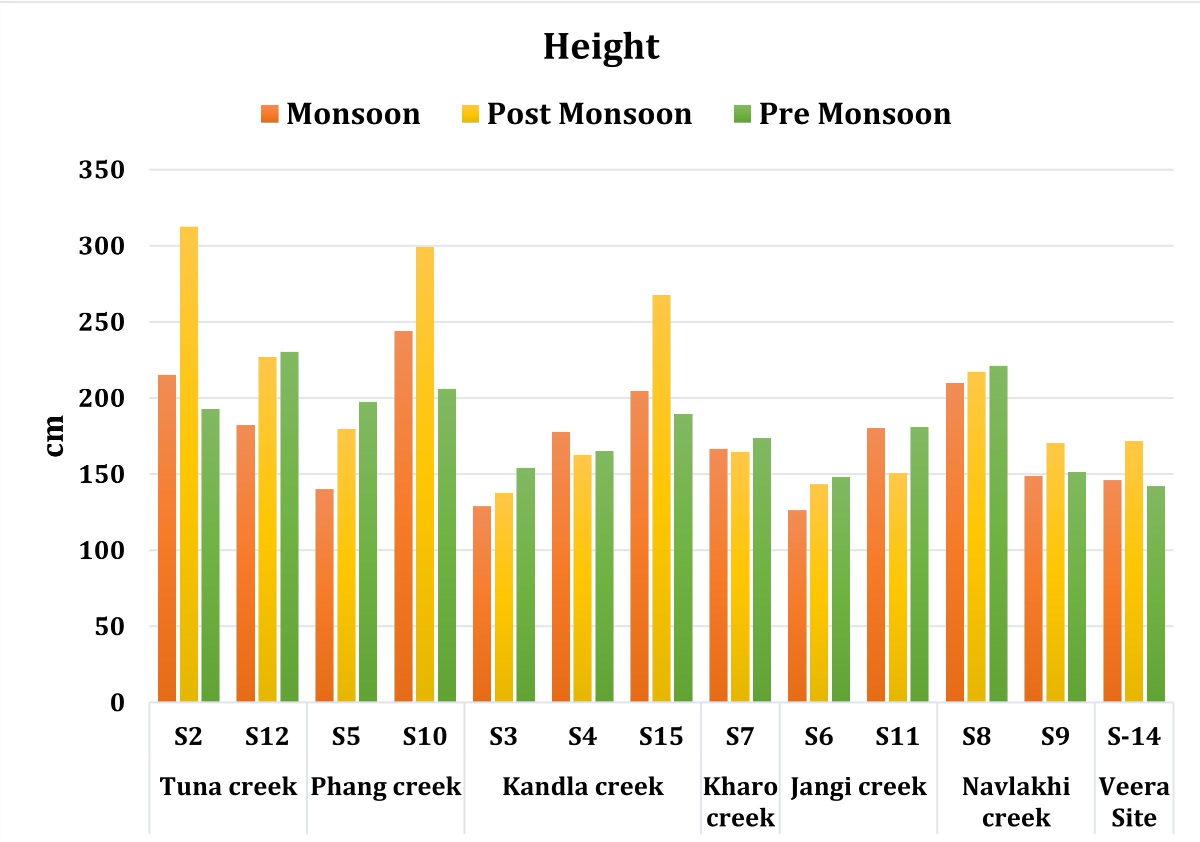


Figure 49. Mangrove plant height from in Deendayal Port Authority from May 2023- May 2024

4.4.3. Canopy Crown Cover

In the DPA Kandla sampling area, the canopy cover of mangroves exhibits wide variations. The overall seasonal average canopy cover of the trees ranged from 4.1 m2 to 5.5 m^2. During monsoon, in comparison to other locations, S-2 at Tuna Creek, and S-10 at Phang creek had higher average canopy cover while, S-3 at Kandla Creek, and S-6 at Janghi Creek had lowest canopy cover (Fig.50) The Tuna creek showed the highest average canopy cover (8.6 m2), followed by Phang creek (7.2 m2) during the monsoon. In case of post-monsoon, the highest average canopy was also reported at S-2 (9.6 m^2) in the Tuna creek, followed by S-15 (7.1 m^2). The lowest average canopy was reported at S-3 (2 m^2), followed by S-4 (2.3 m^2) located at Kandla creek. During pre-monsoon 2024, notably, the highest average canopy cover was reported at site S-8 (7.9 m^2) at Navlakhi Creek, and S-5 (5.3 m^2) at Phang Creek. The lowest average canopy cover (2.7 m^2) was recorded at S-3 and S-7 located in Kandla Creek and Kharo Creek, respectively.

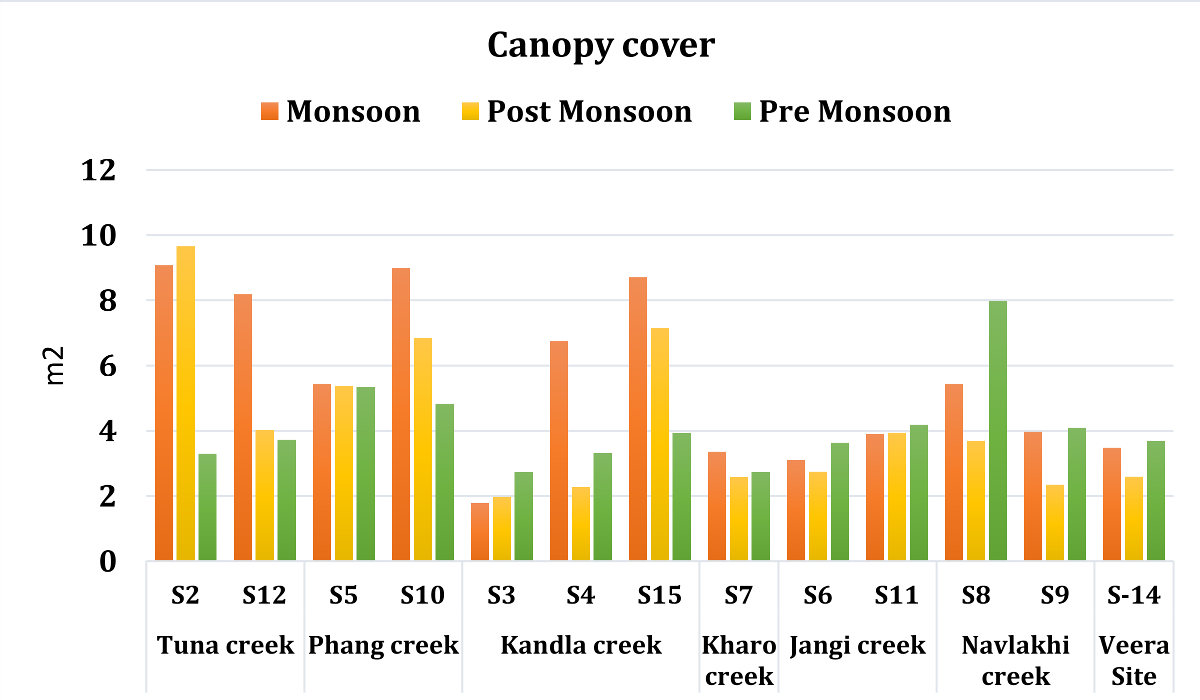


Figure 50. Station wise average tree canopy cover of mangroves from May 2022 to May 2023

4.4.4. Basal Area (Girth)

The overall average basal girth of the mangroves of the DPA sampling sites estimated varied between 12 cm to 14 cm tfor the three seasons. During monsoon, the highest average basal area (25 cm) was noticed at S-2 followed by S-15 (22 cm), located in the Tuna creek and Kandla creek respectively (fig 51). The lowest average basal girth was recorded from S-6 (7 cm) located at Janghi creek. During post-monsoon, the highest average value (25 cm) was noticed at S-2 located in the Tuna creek, followed by S-10 (21 cm) located in the Phang creek. The lowest average basal girth was reported at S-14 of Veera area (8.5 cm), followed by S-11 (8.9 cm) of Jangi creek. During pre-monsoon of 2024, the highest average girth was observed at S-15 (23 cm) and S-5 (16 cm) at Kandla creek and Phang creek respectively. The lowest average basal girth was recorded at S-9 in Navlakhi creek. Similar to the other parts of Gujarat coast, DPA Kandla mangrove stand also predominantly covered by Avicennia marina and variation in basal girth is a common characteristic of this species.

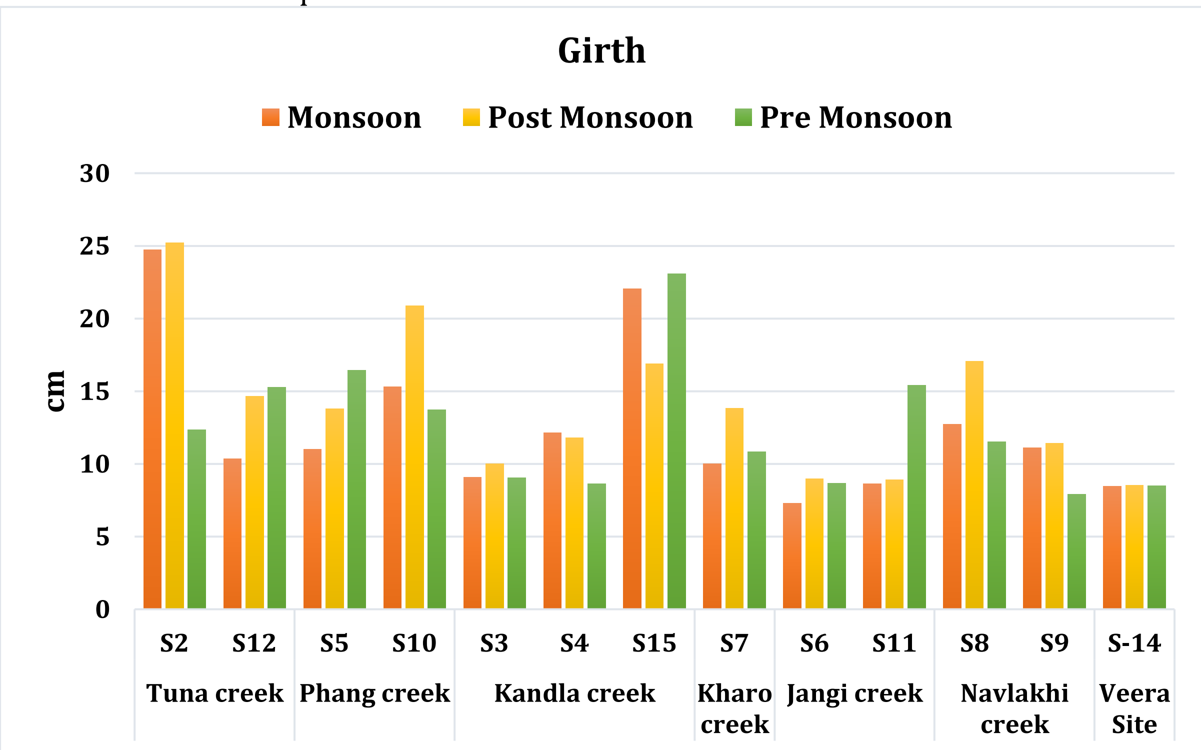


Figure 51. Station wise average tree girth of mangroves in during May 2023 to May 2024

4.4.5. Regeneration and Recruitment Class

During the monsoon, the overall average regeneration class density recorded was 53,769 plants/ha in DPA study area. In the site-wise observations, the highest average regeneration class (135,000 plants/ha) was recorded at S-8 located in Navlakhi creek, during this survey. In post-monsoon season, the overall density of this category was 40,887 plants/ha. In site wise observation, the density of regeneration class was maximum (80,000 plants/ha) at S-15 in Kandla creek, followed by S-5 (74,118 plants/ha) located in the Phang creek. During the pre-monsoon of 2024, the overall average density of regeneration class was 42,054 plants/ha. Notably, in site wise observation, the highest density of 114,000 plants/ha was observed at S-8 in Navlakhi Creek, closely followed by S-6 in Jangi Creek (113,000 plants/ha).In case of recruitment class, during the monsoon, the overall average density was 9,154 plants/ha and the maximum value (24,250 plants/ha) was found at S-7 in the Kharo creek during this survey. During post-monsoon, the overall average density was 10,543 plants/ha and the highest density was 25,147 plants/ha at S-5 from the Phang creek followed by site S-6 with 22,375 plants/ha located in the Jangi creek. During pre-monsoon 2024, the average density of recruitment-class plants was less, 8,463 plants/ha and at S-4 (16,250 plants/ha) and S-7 (16,000 plants/ha) in Kandla Creek and Kharo Creek exhibited the highest density. The study concludes that the presence of regeneration and recruitment-class plants in the sampling sites ensures a backup for mature trees in case of any harm.

a. *Avicenna marina* **b.** *Aegiceras corniculatum* **c.** *Ceriops tagal* **d.** *Rhizophora mucronata*

Plate 10. Mangrove Species of DPA Port Authority

4.5. Halophytes

The holophytes are the plants that are adopted in coastal estuaries and salt marshes. It is common in arid and desert milieu which often have substantial salt accumulation in salt. Technically this plant which has tolerance to moderate to high salt concentration in its growth substrate. Halophytes are plants that survive to reproduce in environments where the salt concentrations around 200 mM NaCl or more, constitute about 1% of the world's flora. (Timothy *et.al* 2008). Halophytes are classified based on their growth conditions as obligate halophytes, facultative halophytes, and habitat-indifferent halophytes. During the period of May 2023 to May 2024 four major halophytes were recorded along the selected study stations of Deendayal Port Authority sites during the 3 seasons, were *Salicornia brachiata*, *Aeluropus lagopoides*, *Salvadora persica* and *Sesuvium portulacastrum* (Plate.11). Maximum percentage coverage of halophytes belongs to species *Salicornia brachiate* shared highest percentage of coverage in all season (100%) followed by *Sesuvium portulacastrum* (30-45%) The percentage cover of different halophytes cover was depleted in figure 52.

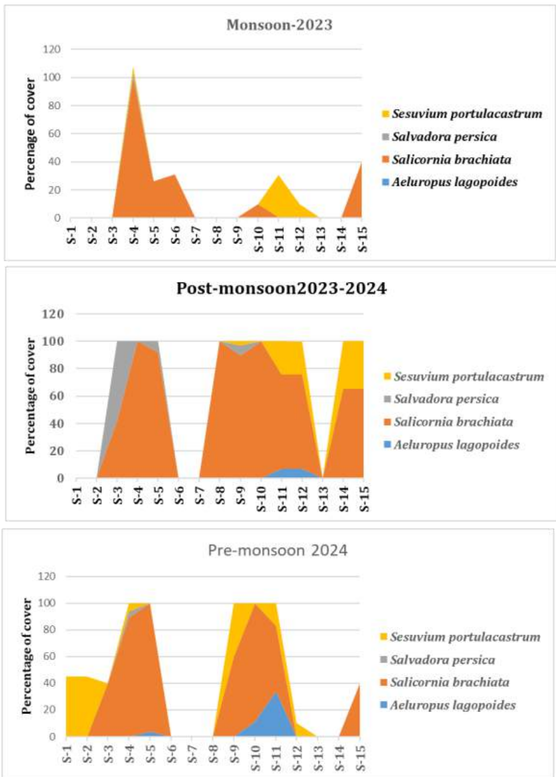


Figure 52. Percentage cover of halophytes reported during May 2023 to May 2024

a. *Salicornia brachiata* b. *Aeluropus lagopoides* c. *Salvadora persica* *d. Sesuvium portulacastrum*

Plate 11: Halophyte species recorded along Deendayal Port Authority

4.6. Seaweed and Seagrass

Seaweeds are an integral part of coastal ecosystems and offer invaluable ecosystem services supporting the life of many marine forms. The economic value of seaweeds significantly contributes to the sustainable development of rural coastal regions. Seaweeds are consumed as food in some Asian countries, but their utilization for the production of phycocolloids is widespread across the globe, with an estimated value of more than one billion US$. In India, seaweeds have been utilized exclusively for the production of phycocolloids but recently they are used for the production of plant growth stimulants for agricultural applications. The recent inventory from the Indian region documented the presence of approximately 865 seaweed taxa so far (Mantri et al., 2020). Various studies have been conducted since last few decades with respect to the distribution and diversity of seaweed from various parts of the Indian coast and few dotted pieces of literature available. Along the Gujarat coast which is represented by 1600 km coastline, harbours 198 species of which 109 species from 62 genera belonging to Rhodophyta, 54 species from 23 genera to Chlorophyta, and 35 species from 16 genera to Ochrophyta (Jha *et.al.*,2009). According to Mantri *et.al*. (2020) 13 potential sites have been identified for the occurrence of seaweed density and diversity.

The survey CSIR-CSMCRI (Jha *et.al.*, 2009) confirmed the presence of industrially important taxa, namely, *Gelidiella acerosa*, *Gelidium micropterum*, *G. pusillum*, *Ahnfeltia plicata*, *Gracilaria dura*, *G. debilis*, Gracilariopsis longissima (formerly *G. verrucosa), Hypnea musciformis*, Meristotheca papulosa, Porphyra sp, Asparagopsis taxiformis (Rhodophyta), *Sargassum tenerrimum*, *S. plagiophyllum*, *S. swartzii*, *Turbinaria ornate* (Ochrophyta), *Ulva prolifera* (formerly *Enteromorpha prolifera*), *Ulva compressa* (formerly *Enteromorpha compressa*), and *Ulva flexuosa* (formerly *Enteromorpha tubulosa*) (Chlorophyta) from the coastal waters of Gujarat. In the present study, an attempt was made to describe the occurrence, diversity and other ecological features of seaweeds within Deendayal Port jurisdiction but there is no observation of seaweed during the period from May 2023 to May 2024.Similar to seaweeds, sea grasses were also absent in the creek systems of Deendayal Port and in the adjacent coastal stretches of Kachchh due to inherent habitat conditions.

4.7. Marine fisheries

The Ichthyofauna diversity of the Gulf of Kachchh includes a total of 20 orders, 47 families and 96 species (Katira & Kardani 2017). Along the Sikka coast of Jamnagar where 112 ichthyofauna species belonging to 50 families, 12 orders, and 84 genera has been reported. Similarly, the localitynear the Marine National Park, in Jamnagar, Gulf of Kachchh reported 109 ichthyofauna species belonging to 58 families, 19 orders, and 93 genera (Brahmane *et al*. 2014). Apart from this, a recent study conducted by Sidat *et al.*, (2021) reported 96 species which include 20 order and 47 families.

Major fisheries in Kandla and its periphery environment

The Ichthyofauna diversity in specific to Kandla and its periphery environment mostly connected to Sikka coast of Jamnagar where 112 ichthyofauna species belonging to 50 families, 12 orders, and 84 genera has been reported (Katira & Kardani 2017). Similarly the locality of Jamnagar Marine National Park, Gulf of Kachchh reported 109 ichthyofauna species belonging to 58 families, 19 orders, and 93 genera (Brahmane et al. 2014).Apart from this, a recent study conducted by Sidat et,al (2021) and reported 96 species which include 20 order and 47 families.

The major fish catch activity is carried out in extensive creek systems of Khari creek, Tuna creek, Navalakhi creek and Jhangi creek. For the period of period 2023-2024, cast net was operated in different creek system of Kandla and major fish catch was include during monsoon *Mugil cephalus*, *Planiliza klunzingeri*, *Planiliza planiceps*, *Planiliza macrolepis* and *Mugil cephalus* catch was the maximum. In post-monsoon same species were observed, of which *Mugil cephalus* catch also the maximum i.e 3.35 kg was caught in 1 hour of interval. Similarly, during pre-monsoon Mugil cephalus, Planiliza planiceps, Planiliza macrolepis, Ribbiofish, Parapenaeus indicus also catch. 10kg of different variety fish was catcher within 10 minutes around 1 km of distance.In sasonal basis fisheries cash also estimated from different creek system Dennday Port Authority and it peripheriphery environment presented in plate12 .

Plate 12: Fisheries of DPA Jurisdiction

4.8. Marine mammals

Marine mammals play critical ecological roles as predators (mainy hunts fish) and prey, both for sharks and other, larger marine mammals (Roman & Estes2018).Dolphins are highly intelligent marine mammals and are part of the toothed whales, including orcas and pilot whales. They are distributed worldwide, mostly living on shallow seas of the continental shelves, and are carnivores, mostly eating fish and squid(Thomas 2009).The *Sousa plumbea* (plate.13),commonly known as the Indian Ocean humpback dolphin, is listed as “Endangered” by the International Union for the Conservation of Nature (IUCN 2022) and was documented from the Kandla waters during Premonsoon station between the S-9 (Navalaki creek) and S-5 & S-6 in the Phang creek at S-14 near to AKBTL jetty 1 adult and 2 juvenile dolphins (total 3 numbers) . These dolphins have a more uniform dark-grey (plumbeous or lead coloured) colour with white mottling interspersed with slight pink pigmentation in specific individuals. The belly or the ventral surface of the body is lighter. These dolphins are found close to the shore and around larger creeks and the open sea.Indian Ocean humpback dolphins mainly feed on fish like mullet, mackerel, sardines and pomfrets found along with the estuarine areas (Thomas et al., 2012). During monsoon it was not cited in study area but in post-monsoon it was cited in between S-6 and S-11. Similarly in pre-monsoon it also not reported any one of the study stations.

Plate 13: Marine Mammals of DPA Jurisdiction

4.9. Reptiles

India has the highest incidence of deaths due to snakebites in the world. *Echis carinatus* (EC) (Plate.14) is known as a saw-scaled viper, and its bite causes one of themost mortality and morbidity in the Indian subcontinent (Daniels2002, Rudresha et al., 2021). During the monsoon period of 2023 field surveys it was dighted at S-4 located in the northern part of Sat Saida bet opposite to oil jetty.In post-monsoon it was reported at S-10. similarly in pre-monsoon no individual sighted. This species was spotted on the branches of mangrove trees, on top of the *Salvadora persica* and bottom of the mangrove trees and halophytes. The colour pattern consists of a pale buff, greyish, reddish, olive or pale brown ground colour. This snake, during the daytime, does not active, and hides in the bottom of the trees, branches of mangrove trees, associated with halophytes and mangrove litter.

Plate 14: Marine reptiles of DPA Jurisdiction

4.10. Avifauna

Mangrove forest habitats serve as vital ecosystems for numerous bird species globally. Despite their importance, in-depth studies on bird ecology within mangrove habitats remain limited. Among the families commonly found in mangrove forests are Ardeidae (herons and egrets), Charadriidae (plovers), Laridae (gulls), Ciconidae (storks), Accipitridae (hawks and eagles), and Alcedinidae (kingfishers). Migratory birds visiting mangroves often undertake extensive journeys to access food sources and nesting sites within these unique ecosystems. (Parrish and Sherry, 1994).

Mangrove forests are extremely essential for the survival of many species of birds (Subramanian and Sethuraman, 1998; Sethuraman, 2000; Kathiresan, 2000), but information on birds associated with mangroves in India is scanty (Mukherjee, 1969; Samant, 1985; Rashid and Scott, 1988; Sampath, 1989; Sethuraman and Subramanian, 1997). A checklist of some birds associated with the mangroves of Ratnagiri has been prepared by Samant (1985) and in the same area Apate *et al.* (2005) reviewed the potential and prospects of estuarine ecotourism with special emphasis on mangrove birds. Deshmukh (1990) has recorded 147 bird species from the mangrove swamps of Vikhroli, near Mumbai. Kurup study on the birds of Purathur and Kadalundy estuaries and recorded several species of birds occurring in the mangrove patches all along the Kerala cost (Kurup, 1991b). Nature Education Society, Thrissur (NEST, 1993) published a list of birds seen in Kumarakam. Similarly, 57 species of birds occurring in the Asramam mangroves at Kollam recorded by Mohandas *et al.* (1994) and Jayson (1997) described the avifauna of different coastal protected areas in Kerala. Shreekumar (2001) study the species of birds of Vembanad Lake, Kerala. Vembanad, one of the declared Ramsar site, is a coastal lagoon which has significant bird diversity in mangrove forest habitats (Nameer 1993). Between 3,000 to 4,000 Black-crowned Night Herons *Nycticorax nycticorax* used to breed, along with Darter, Little Cormorant, Median Cormorant, Purple Heron, Large Egret and Pond Heron (Sreekumar 2002).

A large amount of research on bird diversity emphasizes the general negative effects of land conversion to human dominated habitats (Brooks *et al*. 1997; Castelletta *et al*. 2000). But human dominated and coastal habitats vary a lot and therefore the effect on birds can be very different. Birds depend on the habitats where they occurred, so the response of the species in particular habitat may always differ according to the habitat changes (Tworek, 2002, Winter & Faaborg 1999; Cornelius *et al*. 2000; Zanette 2000; Zanette *et al*. 2000; Johnson & Igl 2001; Beier *et al*. 2002; Kurosawa & Askins 2003).

Overall, a total of 100 species belonging to 11 orders, 36 families and 73 genera were recorded from the coastal area of Kandla Port during this one-year study (Fig.53), Annexure 1). Among these, 61 species were aquatic and 39 species were terrestrial, which included six species listed as Near Threatened in the IUCN 2023, Red List.

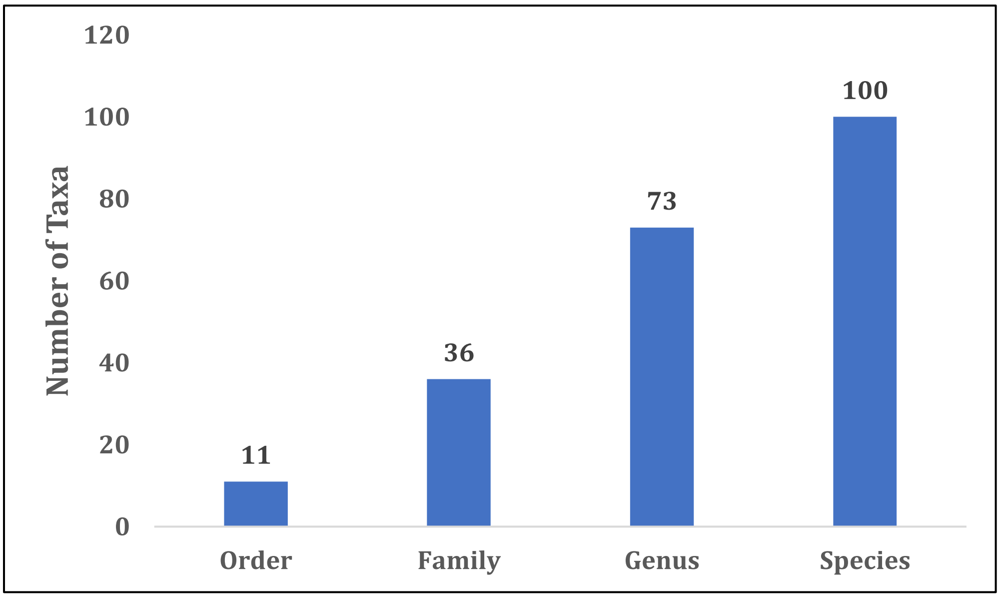


Figure 53: Taxonomic Diversity of Avifauna of the Study Area

Among the recorded species, nearly one-third belong to the order Charadriiformes (37 species), followed by Passeriformes (23 species), Pelecaniformes (17 species), Coraciiformes and Accipitriformes (6 species), Columbiformes and Gruiformes (3 species) while one order represented by two species each and three order represented by one species in the study area (Fig.54). The families with a greater number of species were Scolopacidae (fifteen spp.), Laridae (eleven spp.), Ardeidae (eight spp.), Charadriidae (six Spp.), Accipitridae (five Spp.), Hirundinidae (four spp.), Threskiornithidae, Phalacrocoracidae, Motacillidae, Columbidae and Alcedinidae (three spp. each). From the recorded species, 35 species were migrants, 13 species were local migrants or resident migrants, 52 species were breeding resident (Fig.55).

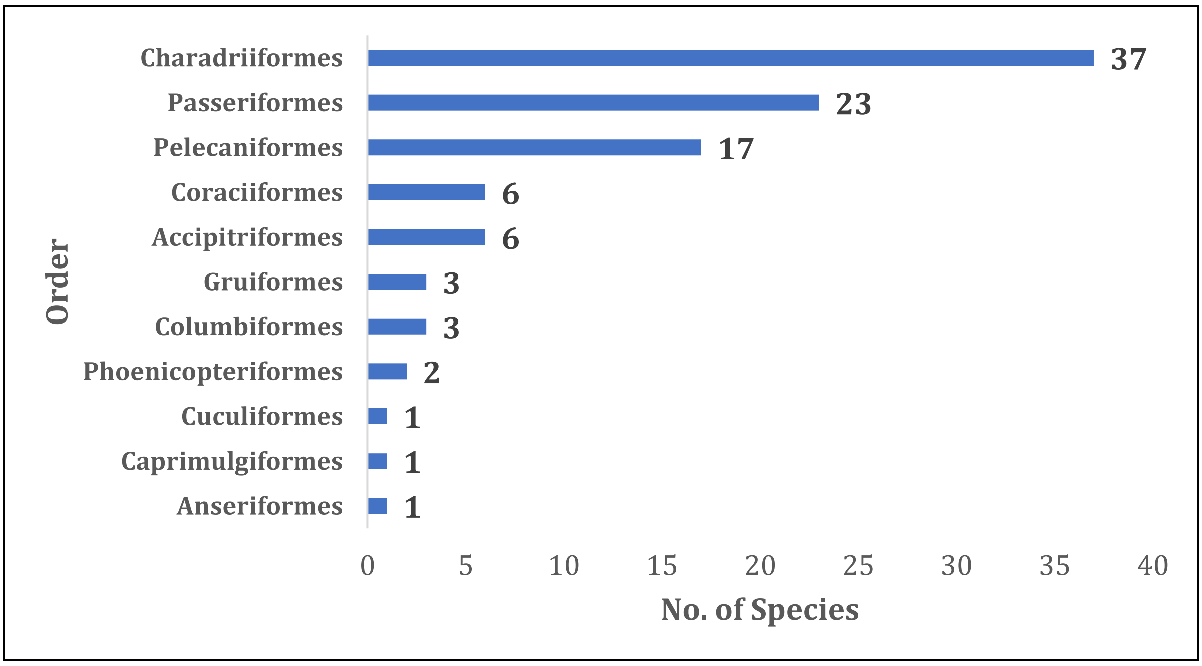


Figure 54 Species Recorded from Various Orders of Birds from the Study Area

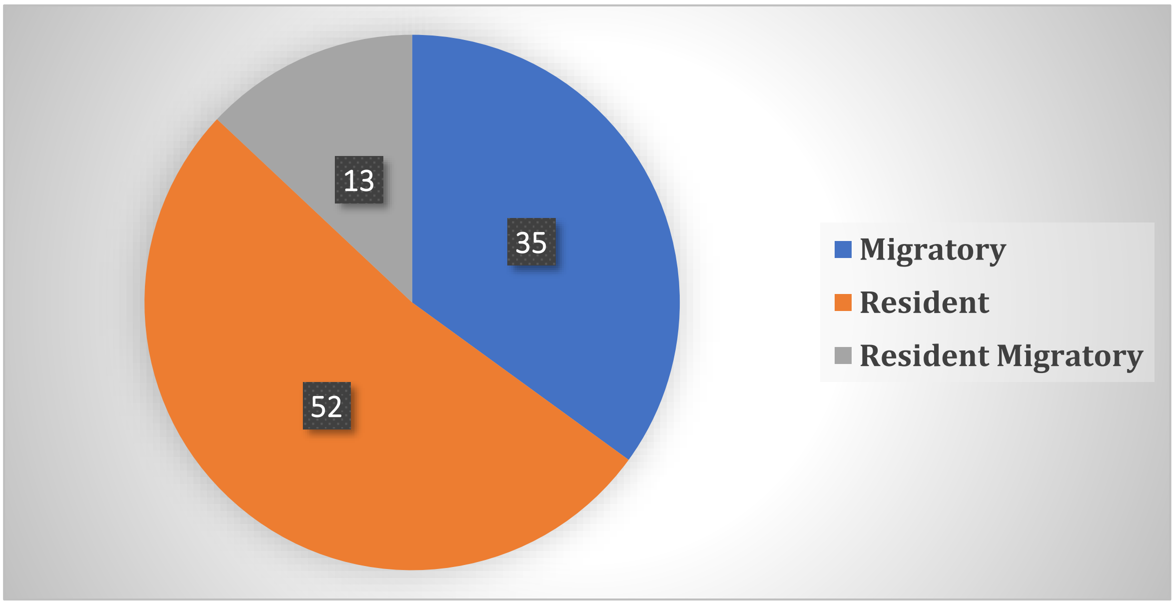


Figure 55: Migratory Status of Avifauna Recorded from the Study Area

Thirteen (13) kinds of feeding guilds, viz., aquatic invertebrate-feeder, piscivore, insectivore, granivore, frugivore, reptile-feeder, amphibian feeder, nectarivore, weedivore, plankton-feeder, herbivore, carrion-feeder and predatory were identified; among the bird species observed (Ali & Ripley 1987). Here, the aquatic invertebrate guild is the most frequent one with forty three percent incidence and 43 species occurring under this shared category. Whereas, omnivore, frugivore, granivore, and plankton-feeder guilds are the least frequent with only one species observed in each. Data collected from point counts allows us to calculate species diversity, richness and species composition. The overall three season results shows that the maximum diversity across the seasons found from the Site 7 (H' 3.15) followed by Site 3 (H' 3.02) and the minimum diversity recorded from site 9 (H' 1.89). The results of species richness shows that maximum species richness recorded from Site 7 (6.34 spp.) and minimum species richness recorded from Site 5 (3.306 spp.). Other diversity indices details were given in the table 1. Overall mean bird species is 100 calculated from the study area. The overall Shannon diversity (H') is 2.63 with overall species richness index for study area is 4.47. The overall species evenness index value for study area is 0.83 with overall Equitability is 0.91 (Table.13).

Table13. Overall Avifaunal Species Diversity in Different sites in the Study Area

Sites	No. of Species	Individuals	Shannon_H	Evenness_e^H/S	Richness	Equitability_J
Site 1	71	218	2.6973	0.953	4.862	0.978
Site 2	70	313	2.4300	0.772	3.675	0.862
Site 3	47	367	3.0230	0.791	5.628	0.922
Site 4	42	345	2.7760	0.741	4.761	0.889
Site 5	40	179	2.3680	0.810	3.306	0.908
Site 6	50	217	2.6810	0.880	4.115	0.947
Site 7	56	413	3.1510	0.774	6.338	0.922
Site 8	60	214	2.9910	0.952	5.471	0.978
Site 9	62	1186	1.8853	0.656	4.040	0.688
Site 10	58	233	2.4003	0.816	3.729	0.923
Site 11	56	248	2.7580	0.930	4.367	0.975
Site 12	45	151	2.4973	0.954	3.597	0.976
Site 13	65	1654	2.6257	0.510	5.497	0.746
Site 14	43	236	2.8720	0.973	4.254	0.988
Site 15	62	146	2.4047	0.894	3.345	0.949
Total	**100**	**6120**	**2.6374**	**0.827**	**4.466**	**0.910**

Comparative status of avifaunal species diversity over three seasons

Total fifteen sites were surveyed for three seasons, of which the maximum number of species (84 spp.) was found in Monsoon season and among the sites, Site 1 was recorded highest number of species (71 spp.) followed by Site 2 (70 spp.), Site 13 (65 spp.) and Site 9 & 15 (62 spp.). Site 5 recorded the least richness (40 spp.) (Table 2). Whereas, the minimum number of species (68 spp.) was recorded in post-monsoon season and among the sites, Site 7 was recorded highest number of species (43 spp.) followed by Site 8 (40 spp.), Site 9 (37 spp.) and Site 3 &13 (32 spp.). Site 10 recorded the least richness (8 spp.) (Table 13).

Table 14 . Season wise Number of species recorded from the study area.

	No. of Species			
Sites	**Pre-Monsoon**	**Monsoon**	**Post-Monsoon**	**Overall**
Site 1	34	61	24	71
Site 2	27	57	14	70
Site 3	37	37	32	47
Site 4	27	36	31	42
Site 5	19	34	12	40
Site 6	26	41	17	50
Site 7	32	48	43	56
Site 8	23	44	40	60
Site 9	20	49	37	62
Site 10	31	47	8	58
Site 11	24	43	29	56
Site 12	21	33	10	45
Site 13	39	40	32	65
Site 14	21	37	26	43
Site 15	19	46	12	62
Total	**71**	**84**	**68**	**100**

Seasonal Site wise migratory status showed that maximum migratory species (27 spp.) was found in Monsoon season and among the sites, Site 7 was recorded highest number of migratory bird species (30 spp.) followed by Site 1 & 2 (19 spp.) and Site 9 & 15 (18 spp.), Site 5 recorded the least number of migratory bird species (10 spp.) (Table 3). Whereas, the minimum number of migratory bird species was recorded in post-monsoon season (20 spp.) and among the sites, Site 13 was recorded highest number of Migratory bird species (14 spp.) followed by Sites 7 (13 spp.) and remaining Site 4 recorded the least species (12 spp.) (Table 14). The overall three season results shows that the maximum diversity across the seasons found from the Site 8 (H' 3.74) followed by Site 7 (H' 3.59) and the minimum diversity recorded from site 9 (H' 0.36). The results of species richness shows that maximum species richness recorded from Site 1 (11.43 spp.) and minimum species richness recorded from Site 8 (8.35 spp.). Other diversity indices details were given in the table 4a & 4b. Overall mean bird species is 100 calculated from the study area. The overall Shannon diversity (H') is 2.64 with overall species richness index for study area is 4.47. The overall species evenness index value for study area is 0.83 with overall Equitability is 0.91 (Table 15& 16).

Table 15.: Season wise Migratory status of Bird species recorded from the study area.

	Migratory			**Resident**			**Resident Migratory**		
Sites	Pre Monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon
Site 1	5	2	19	23	25	28	6	6	10
Site 2	8	3	19	20	25	29	3	5	7
Site 3	3	1	12	13	15	16	3	3	6
Site 4	3	2	15	12	14	15	3	4	5
Site 5	4	2	9	15	11	16	2	3	6
Site 6	6	1	13	14	16	19	5	6	6
Site 7	5	1	12	22	19	24	6	5	9
Site 8	1	2	16	12	13	19	4	7	8
Site 9	4	3	17	9	17	20	4	7	9
Site 10	3	1	14	15	18	24	4	7	7
Site 11	2	2	14	10	19	17	3	4	8
Site 12	3	1	13	14	13	12	4	4	7
Site 13	7	3	12	21	13	20	5	4	5
Site 14	5	3	14	13	17	14	5	5	5
Site 15	3	3	18	11	18	18	3	5	9
Total	**11**	**4**	**26**	**34**	**35**	**40**	**8**	**10**	**13**

Table 16. Comparative status of avifaunal species diversity over three Seasons in the study area during May 2023to May 2024

Diversity Indices	No. of Species			Individuals			Shannon_H		
	Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon
Site 1	34	20	24	147	29	42	3.152	1.581	3.359
Site 2	27	11	14	177	107	29	3.066	1.463	2.761
Site 3	37	15	32	183	44	140	3.43	2.34	3.299
Site 4	27	13	31	102	66	177	3.259	2.053	3.016
Site 5	19	11	12	115	38	26	2.606	1.922	2.576
Site 6	26	11	17	149	32	36	2.935	2.14	2.968
Site 7	32	21	43	174	58	181	2.99	2.866	3.597
Site 8	23	10	40	90	17	107	3.055	2.181	3.737
Site 9	20	6	37	1055	16	115	0.3629	1.7	3.593
Site 10	31	11	8	182	37	14	2.965	2.04	2.196
Site 11	24	7	29	116	12	120	3.087	1.907	3.28
Site 12	21	11	10	111	27	13	2.724	2.177	2.591
Site 13	39	30	32	376	1093	185	2.886	1.629	3.362
Site 14	21	11	26	91	25	120	3.042	2.311	3.263
Site 15	19	9	12	100	26	20	2.576	1.991	2.647
Total	**71**	**84**	**68**	**3168**	**1627**	**1325**	**2.80906**	**3.636**	**3.0830**

Table 17. Comparative status of avifaunal species diversity over three Seasons during May 2023 to May 2024

Diversity Indices	Evenness_e^H/S			Species Richness			Equitability_J		
	Pre-Monsoon	**Monsoon**	**Post-Monsoon**	**Pre-Monsoon**	**Monsoon**	**Post-Monsoon**	**Pre-Monsoon**	**Monsoon**	**Post-Monsoon**
Site 1	0.6875	0.9721	1.199	6.613	1.82	6.154	0.8938	0.9824	1.057
Site 2	0.7943	0.3925	1.129	5.023	2.14	3.861	0.9301	0.6099	1.046
Site 3	0.8346	0.6924	0.8466	6.91	3.7	6.273	0.9499	0.8642	0.9519
Site 4	0.9642	0.5994	0.6581	5.622	2.864	5.796	0.9889	0.8004	0.8781
Site 5	0.713	0.621	1.096	3.794	2.749	3.376	0.8851	0.8013	1.037
Site 6	0.7238	0.7724	1.144	4.996	2.885	4.465	0.9008	0.8923	1.048
Site 7	0.6212	0.8536	0.8484	6.009	4.926	8.079	0.8626	0.948	0.9563
Site 8	0.9224	0.8854	1.049	4.889	3.177	8.346	0.9742	0.9471	1.013
Site 9	0.07188	0.9125	0.9826	2.729	1.803	7.587	0.1212	0.9489	0.9951
Site 10	0.6259	0.6988	1.124	5.765	2.769	2.652	0.8635	0.8506	1.056
Site 11	0.9126	0.9621	0.9165	4.838	2.415	5.849	0.9712	0.9802	0.9741
Site 12	0.7255	0.8018	1.335	4.247	3.034	3.509	0.8946	0.9079	1.125
Site 13	0.4593	0.1699	0.9013	6.409	4.145	5.938	0.7876	0.4789	0.97
Site 14	0.9977	0.9165	1.005	4.434	3.107	5.222	0.9992	0.9636	1.002
Site 15	0.692	0.8137	1.176	3.909	2.455	3.672	0.875	0.9062	1.065
Total	**0.716392**	**0.7746**	**1.0274**	**5.079133**	**1.251**	**5.3853**	**0.859847**	**0.9344**	**1.0116**

These changes in individual species abundance, whether they occur independently of one another (Wiens, 1989) or are influenced by interactions with other bird species are governed by the degree of anthropogenic pressure including disturbance to habitat of species (Block & Brennan 1993). The distribution and abundance of many bird species are mainly determined by the configuration and composition of the vegetation that comprises a major element of their habitat (Cody, 1985; Block & Brennan 1993). As vegetation changes along complex geographical and environmental gradients, particular bird species may appear, increase in abundance, decrease, and disappear, when habitat becomes more or less suitable for its persistence. Total 16% species were found rarely distributed in the study area while 36% species were very common. Aquatic and Insectivores form the major groups while each of the frugivores, omnivores and nectarivores constitute about 2% of all species. Although more than 67% of the birds in the study area were Aquatic and insectivores, food competition was reduced by the utilization of different habitat types and distinct feeding behaviour. Largely insectivorous birds like babblers (Sylviidae) and drongos (Corvidae) feed on fruits and seeds of plants particularly during winter season due to the shortage of insect food. Aquatic birds were dominated largely by the aquatics followed by insectivore and grainivore species (Annexure 1).

The present three season study shows 100 different types of birds belonging to 11 orders and 36 families from the coastal area of Deendayal Port. The richness of avifauna is little low, indicator of ecological health of the coastal area of Deendayal Port. Proper and in-depth study, awareness, regarding the importance of birds and their role in ecosystem, to the local peoples through different massive programs will ultimately help the protection of birds of this region (Plate.15).

Crab-Plover

Great Thick-knee

Common Redshank

Great White Pelican

Plate 15. Avifauna status of Deendayal Port Area

5. Discussion

5.1. Physico-chemical status of Deendayal Port Authority Environment

Water quality of coastal water reveals the state of the overall environment. The quality of water determines the biological and other resources in the marine environment. However, water quality parameters in marine environment vary to a great extent, influenced by the climate,water currents and movements, input of pollutants in the form of effluent and sewage out fall and so on. The geophysical and geo-chemical factors such as shape and size of the coastal areas, prevailing currents, temperature, salinity, tidal impacts, directions of prevailing winds and influx of fresh water also influence the quality of water in the nearshore marine environment. The creeks and the intertidal zones are well known for the biodiversity and their role in the ecological services are well documented. mangroves are now recognized as one of the most effective nature based solutions for climate change adaption and to reduce disaster risk (Sunkur, 2023). To assess the health of mangrove forest is inevitable in the monitoring programme in which extensive field survey is carried out to select the representative sites for data collection. The plant growth characteristics indicates the status of the mangrove cover for which the height,canopy dimension, Girth, as well as the number of different age groups of plants are considered. The DPA port and the influencing environment are surrounded by the mangroves and tidal flat with marshes are potential carbon stocks which are conserved and restored. Yet,the various human interventions due to the port related activities tend to impair the water and sediment quality which in turn affect the biological productivity. In this regard some of the most influencing physical and chemical water and sediment are considered for the seasonal study from the 15 selected sites. The plankton and benthic fauna diversity, Chlorophyll 'a' are also recognized as indicators of the health status of the environment (Adams,2002). The rate of variations in the different stress indicators in the water are followed in the monitoring process to evaluate the impacts that are likely to occur both in the near future as well as in the long term at the present rate of occurrence.

Temperature and pH

Water temperature in DPA port area generally varies in the range 16°C to 31.°C. However, the present study shows a increased range of water temperature in Kandla DPA port in previous year of 2022. Water temperature Port region varies during monsoon, ranged from 23°C to 30°c to while in post monsoon observation, the value ranged from 9°c to 28°c to . However, in pre monsoon the values were noted in the range of 16°c to 20°C.The monsoon water temperature has been recorded as high (30°C). There is no vertical variation in temperature of marine water in Kandla Port area due to lack of thermal stratification in Creek (NIO,1998). This is because of the strong currents, high tidal impact and low depth of the harbour areas. The currents influence vertical mixing and restrict the stratification of water layer in the harbour area. High temperature during pre-monsoon attributed to high rate of evaporation and less rain fall.

pH

The pH of seawater of DPA Port area varied in the range of 7.9 to 8.1. Generally, the pH of seawater is controlled by Carbonate and biocarbonate system and falls in the narrow range of (0.2-0.3). pH was alkaline during summer and showed downward pattern up to monsoon and remained alkaline during postmonsoon, (Vajravelu *et.al* 2018). Changes in pH will depend on the factor like the removal of CO2 by photosynthesis through bicarbonate degradation, fresh water influx, reduction in salinity and temperature and decomposition of organic matter (Rajasegar et al., 2002).

Salinity

As temperature influences the salinity of marine water in the tropics, water in DPA region has higher salinity in the range of 36ppt 47ppt. Highest salinity observed during pre-monsoon (47ppt) at station S-12. The higher salinity towards inner regions around S-12 indicates localized effects of seepage of high saline (brine) water from salt marshes and saltpans of salt industries (Zingde& Anand ,1996). Hundreds of salt industries in and around Kandla Port use seawater with salinity in the range of 35 to 50 ppt. They release 'bittern' remains of salt after manufacturing, which has salinity as high as 250 ppt in Kandla Creek, thereby increasing the salinity in isolated regions of port areas (Chhaya, & Chhaya, 1997). Lack of fresh water from catchments coupled with higher evaporation is the cause of higher salinity in Kandla Port area. In the Little Gulf of Kuchchh water salinity has been recorded as high as 50 ppt (NIO,1998).

Dissolved oxygen

DO is consumed in marine ecosystem by the respiration and decaying organic matter in the water column. Loads of high organic matters may deplete the DO to its minimum level, which can be detrimental for the aquatic life. A severe depletion of DO may lead to 'Eutrophication' in an aquatic system. However, no such event has been reported in Kandla port region so far. DO in marine water of DPA region has been found in the range of 1,0 mg/l to 8.6 mg/l for in 3 seasons. The current range of dissolved oxygen in the marine water of Kandla Port region conforms to the designated best use for Salt pans, Shell fishing, Mariculture and Ecologically Sensitive Zone. For ecologically sensitive zone not less than 3.5mg/l at any time in a year (or 5.0 mg/l at 60 percent saturation level) of DO is essential for the protection of aquatic life. But in presentation observation less content of do in monsoon at S-2 might be due certain nutrient load from mangrove environment.

Total Suspended Solids

Suspended solids in Deendayal port area varied in the range 130 mg/l to 1104 mg/l. Generally, the suspended solids in the Deendayal region are high and vary to a great extent from the inner port region to the out harbour region and further towards outer Gulf..The higher value of suspended solids and their variations across the stations in the inner Gulf including Kandla Port regions results from the dispersion of sediment loads due to strong currents and tidal influence Zingde& Anand (1996)

Turbidity

The Kandla Port areas fall under inner Gulf of Kuchch, there is a high turbulence in the· Creek, due to strong an ocean currents and tidal influence. Therefore, the turbidity of tropical seas is higher than other tropical and subtropical seas. The marine water turbidity is expressed in Nephelo Turbidity Unit (NTU). Water turbidity in DPA Port region has been recorded in the range of 16 NTU to 489 NTU. Generally, water turbidity is high due to high organic load of mud and silt. (Omprakash, 1997) Higher turbidity of marine water at the DPA Port regions may also be associated with the washed sediment from mangrove environment and partially dredging activities, which is done on a regular basis along the Kandla Creek.

Nutrients

Nutrients in marine water such as Nitrate and Nitrite ,Phosphate and silicate are very crucial for the marine life. Their increase in concentration enhances the primary productivity in marine water. Nonetheless, excessive concentration sometimes can be detrimental to the aquatic life especially in creeks, estuaries and bays where there is a restricted water exchange. These increased nutrients lead to an excessive growth of algae resulting in eutrophication in some extreme cases (NIO,1998). During the period of May 2023 to May 2024 covering 3 season with respect to nutrient concentation it was observed that the concentration were with in permissible limit to marine life.

Petroleum Hydrocarbon (PHs)

Petroleum hydrocarbons in the water column of Deendayal port area have been found in the range of 0.3 µg/l to 85.8µg/l. The high range of petroleum hydrocarbon results from the spills and leakage during the handling of crude petroleum products at the Port especially at oil terminals (NIO2002).

5.2. Biological status of Deendayal Port Authority Environment

Biological resources of a marine area reflect the overall environment of the region in question. The coastal areas especially bays, creeks and estuaries are rich in biota and are habitat of many marine species. Usually, ports are also built in these areas for their geographical advantages. The port and harbour activities in these locations disturb the habitat of many marine biota. However, in the process many habitats are also created for marine biota. The Gulf of Kachchh is an example of such habitat and has been considered to be rich in biodiversity. Kandla port has been built right in the gulf and has been serving this region nearly seventy years.

Chlorophyll ‘a’ Phytoplankton and Zooplankton

In general the basic parameters of marine biota like Chlorophyll ‘a’ and Phytoplankton are observed to be moderate in their values but similar to those prevailing along the coastal waters of India (NIO,2002). During the period May 2023 to May 2024 the Chlorophyll ‘a’ concentrayion is within limits of 0.11 mg/l to 2.98mg/l which is quite satisfactory for port environment. The index value of both phytoplankton and Zooplankton of 3 season shows moderate environmental status (Fig.56). As per Shannon Wiener’s rules the aquatic environment i.e both soil and water classified as very good when H' value is greater than four (>4), whereas the good quality represents the H' value with a range of 4-3, similarly moderate-quality (H' value 3-2), poor quality (H' value 2-1) and very poor-quality H' value significantly less than one (<1). Presently DPA port and its periphery environment has been influenced by contaminants deposited from industries and the cargo movements. Accordingly, species diversity decreases at sites with poor water quality. As deduced from the Shannon diversity index values between 3-4 overall 3 season representing the moderate quality of environmental status dominated by the few genera such as Coscinodiscus sp. and Synedra sp,and copepod sp. A community dominated by relatively few species indicates environmental stress (Plafkin et al., 1989). According to Staub et. al (1970) species diversity index value between 3.0 to 4.5 represents slightly polluted and the lightly polluted environment, the index value characterizes 2.0-3.0, similarly, moderately polluted environment shows index value of 1.0-2.0 and finally, the heavily polluted environment index value is 0.0-1.0. While considering the overall index values it is inferred that the study sites can be included under the category of lightly polluted environment.

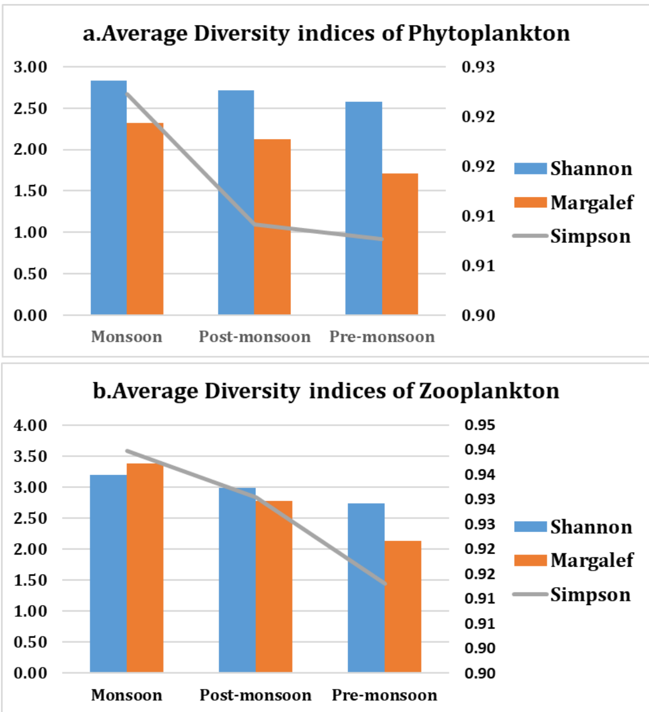


Figure 56 Diversity indices of Phytoplankton and Zooplankton

Natural geographical processes such as strong currents and higher tidal influence have been responsible for the high turbidity and suspended solids which in turn reduce the light penetration thereby reducing the growth of Plankton and primary productivity. As a result the seasonal distribution of phytoplankton in DPA was 3,040 No./l to 28,960 No./l and Zooplankton density ranges from 6,40No./l to 23,840 No./l .

Intertidal Fauna

Macrofaunal communities did not show much spatial and temporal variation in their components at 15 sampling locations. The distribution of intertidal Fauna seems to be entirely governed by the environmental parameters like Physico-chemical and biological characteristics of the ambient milieu. Generally, intertidal Fauna on the Kachchh coast scope a harsher environment with relatively high salinity, wide temperature fluctuations, seasonal fluctuation of different hydrological parameters and a high sedimentation rate. The water suspended solids (SS) were generally found due to the dispersion of fine sediment from the bed and the intertidal mudflats due to tidal movements at the mouth of the Kachchh coast (Kandla).

An earlier study by Saravanakumar et al. (2007) revealed the presence of five intertidal Fauna in the mangrove environments along the Kachchh coast, with a diversity index ranging from 1.84 to 2.45. The species composition and diversity indices reported during 2018-2019, 2019-2020, 2020-21, and 2021-2022 did not vary significantly in the DPA port environment. It was understood that the intertidal fauna community in the Kachchh mangrove had not varied much in terms of its species diversity. An earlier study by Saravanakumar et al. (2007) revealed the presence of five intertidal Fauna in the mangrove environments along the Kachchh, with a diversity index ranging from 1.84 to 2.45. During the 2023 to 2024 average Shannon diversity indices varied from 1.51 to 1.6 similarly the Margalef and Simpson idices ranged from 1.43 to 1.5 and 0.7 to 0.73 (Fig. 57)

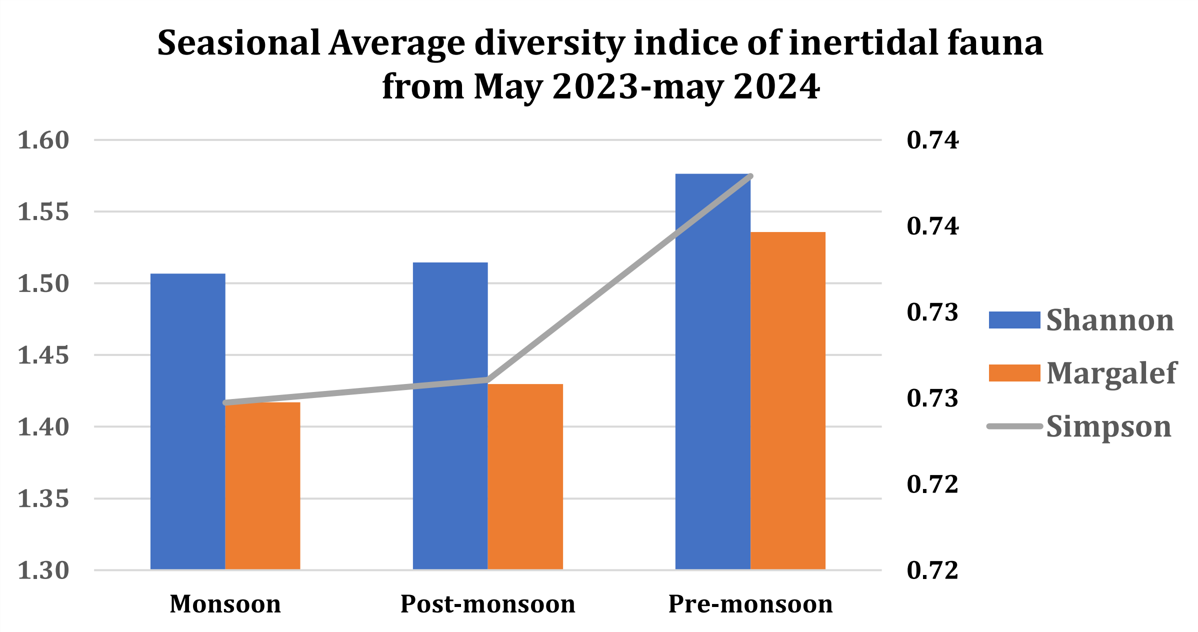


Figure 57 Average diversity indices of intertidal fauna of DPA from May 2023-May 2024

According to Magurran (1991), the Shannon diversity index of >3.0 indicates a healthy coastal environment. However, diversity indices around the DPA coastal environment were <2.0, indicating that the lower moderate faunal diversity.In the present observation, the species composition of the benthic macrofauna showed dominance in the Phyla Molluscs, Arthropoda, Annelida, Nematoda, Nemertea and Chordata. Previously, Ansari et al. (1986), Mohammed (1995) and Kumar (2001) recorded the presence of the Molluscs, Arthropoda, Annelida, and Chordata in various parts of Indian coastal waters.

Subtidal Fauna

The subtidal faunal diversity was varied from 5700 No/m^2 to 15,950 No/ with average density of 10,592 No/m^2. Mahapatro et al. (2011) documented the macrofaunal diversity in Bhitarkanika (Odisha coast) mangroves, and the diversity ranged from 1870 No/m^2. Ramakrishna et al. (2011) recorded the population structure and density of macrofaunal from the Andaman and Nicobar Islands and documented diversity from 1015 No/m^2 in the. In the Gulf of Katchh, Saravanakumar et al. (2007) documented that from 1999 to 2000.

The Shannon diversity indices ranged from 0.65 to 1.77, similarly Margalef and Simpson indices ranged from 0.75 to 2.18, 0.35 to 0.80. The results obtained from this study represent similar moderate to lower environmental status for the period 2023-2024 (Fig.58). There is a need for an in-depth study of Fauna and their interactions in mangrove ecosystems. Also, practices directed at managing mangrove resources should go hand in hand with conservation strategies.

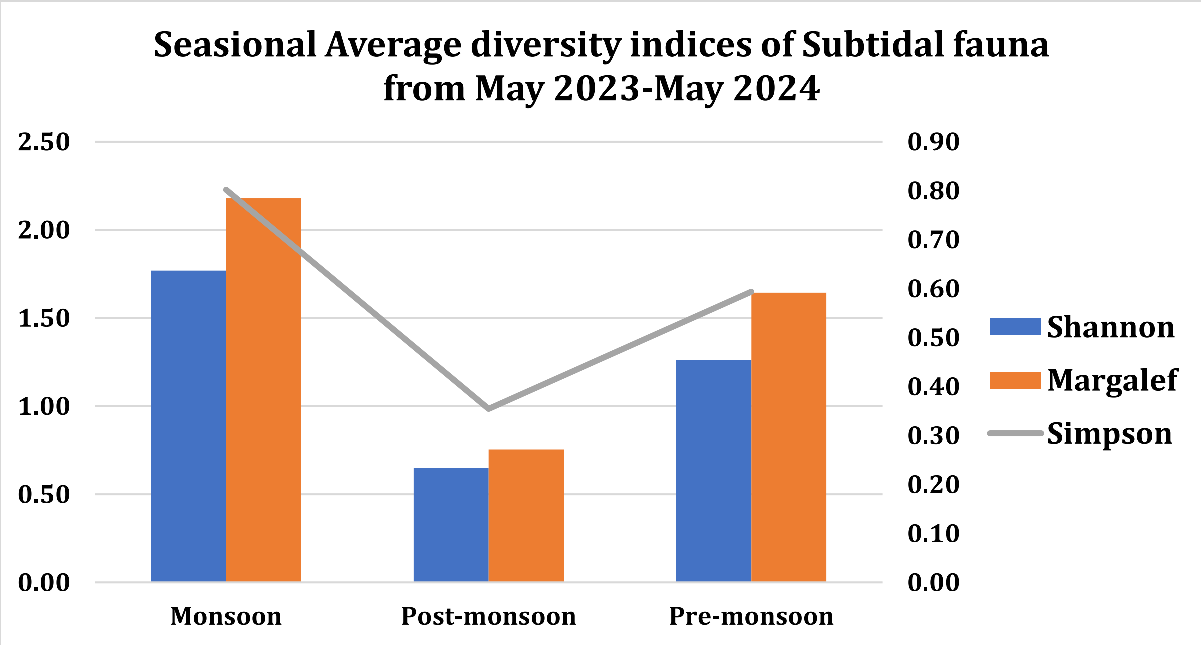


Figure 58 Average diversity indices of intertidal fauna of DPA from May 2023 -May 2024

6. Impact identification and Evaluation

Many major ports of the world have now initiated efforts to preserve their port environment. The operation of ports has implications on the air quality at the regional and local level and leads toward the choice of ‘‘greener’’ seaport options. Even factors such as people, business, culture and history of a place are often included in addition to natural resources in evaluating the greenness of a port. Green port construction is a long, comprehensive, systematic and complex task and is a matter concerning the overall situation and long-term strategic perspective (Bailey and Solomon, 2004). A green or an ecological port is a sustainably developed port in which there is a balance between economic and social goals existing with minimum deterioration of the natural system even though there is the utilization of resources for the various activities. The Deendayal Port, Kandla, in Kachchh district is surrounded by a large number of port associated industries and salt pans and salt processing industries. There are a number of minor and creeks that are connected to the Gulf of Kachchh. The DPA has been the prominent industrial and transport facility primarily associated with the inter connected creek environment which influences the open oceanic zone. The general consequences of the port associated activities, particularly on the free-floating microscopic animals and plants, the macrofauna inhabiting the sub-tidal and Intertidal habitats and the birds have been well known, The coast of Gulf of Kuchchh is well known for the multitude of the biological resources, productive mangroves,muddy shores with marshes,and extensive flats with enormous life forms belonging to microscopic protista to macroscopic invertebrates and vertebrates, coral reefs, sea grass meadows. In this respect it is imperative to analyze the major impacts and put forth effective mitigation measures,even though there were no major environmental and biodiversity issues were reported from the earlier studies undertaken by GUIDE.

Routine dredging Impact

Dredging is a worldwide excavation activity that involves removing sediment (Tillin et al., 2011; WODA, 2013) by four main types of dredger, cutter suction dredgers (CSDs), trailing suction hopper dredgers (TSHDs), grab dredgers, and backhoe dredgers, are used commonly for dredging operations.Since dredging impacts the marine environment, sustainable management of the activity is required, based on an in-depth understanding of how dredging affects marine habitats and associated fauna and flora. To date, the positive and negative effects of dredging on marine flora, benthic infauna, and the seabed are relatively well documented (Tillin et al., 2011).

- Dredging and dredge spoil disposal activities for port development and maintenance can induce short- and long-term impacts on aquatic systems, namely degradation of marine resources such as fisheries and other aquatic biota.
- Dredging activities often disturb sediments reducing visibility and transparency of water.
- Dredging activities potentially affect not only the site itself, but also surrounding areas, through a large number of impact factors such as turbidity, sedimentation, re-suspension and release of contaminants which can be a hindrance to the survival of the eggs and larvae and the plankton communities immediate to the site. Dreging impacts the shoreline as a result depending of the channels in addition to the tidal effects. Further,depending on the shore substratum and the the physio-graphic nature, there happens sedimentation at some sites and accretion in other parts. This changes in the inter tidal and sub-tidal zone tend to alters or influence the distribution of the benthic fauna and flora and their survival.
- Assessing impacts of the effects of suspended sediments and the nature of sedimentation are species-specific, but invertebrates, eggs, and larvae are most vulnerable. Positive effects, including an increase in food, result from greater nutrient loads are noticed, but are often short term. A comprehensive dredging and dredged materials management plan should be considered for the port and harbour facilities to ensure that project can be carried out with minimum environmental effects. Both capital and maintenance dredging affect water quality; particularly turbidity and this in turn can marginally affect marine ecology and fisheries. Capital dredging has high potential to disperse the fine-grained sediment in the water column, thereby increasing the particular load.

- The guideline by Govt of India for Environment friendly dredging shall be a permanent element in dredging projects. It is recommended that for dredging projects, wherein the most appropriate disposal option for dredge material to be undertaken in a time bound manner with duration up to 10 years(2020-2030).

Impact on Air quality of Port pemises

The nnature of the activities, and services carried out in the port area, multiple environmental risk situations arise which may affect the air and water quality. The logistics operation imparts release of Green house gases, dust and noise in the hinterland transport. The intensity and range of impacts such as air pollution, noise pollution, CO2 emissions, and congestion (Chiu *et al*., 2014) depends on the materials being handled and the location and the size of the population. Emissions from burning waste materials and escaping dust (due to handling of fine-particulate materials such as fertilizers and minerals causing air pollution in port and the adjacent human settlement areas,crops and the wildlife. Evaluating air pollution impacts of ports requires consideration of numerous sources, including marine vessels, trucks, locomotives, and off-road equipment used for moving cargo. The air quality impacts of ports are significant, with particularly large emissions of diesel exhaust, particulate matter, and nitrogen oxides which brings health hazards to the local residents (Baile and Solomon.,2004).

Impact on Avifauna

Impact-I Location of the Deendayal port Site in the close vicinity of ecologically sensitive terrestrial ecosystem (migratory route, breeding and nesting sites of avifauna) may impact the overall biodiversity values due to project associated activities.

A. Habitat degradation due to pollution

B. Loss of habitat and shift in the feeding grounds

C. Overall impact on biodiversity of the protected area

Evaluation: The Deendayal SEZ project site located in the mid of the Deendayal Port area surrounded by port associated industrial sectors and predominately salt industries. There is absence of ecologically sensitive ecosystem (Protected Areas) located within 10 km radius of the project site. Due to the prevailing land use no impact on protected areas was foreseen. Further, from the selected study sites any migratory route of major animal groups, nesting and breeding sites of avifauna are noticed.

Impact on threatened flora and Fauna – Inter-tidal coastal habitat.

Impact 2

The sedimentation accretion process in the vicinity of ports leads to the loss or disappearance of several intertial fauna and it takes long time to establish their population .These organisms are the prey for many shore birds, crabs and fishes. The loss of inter-tidal habitat like salt marshes and mangrove threatens aquatic avifauna, including the migratory species .

Evaluation: As per land use land cover study, the project area is dominated by creeks covered with extensive stands of *Avicennia marina* mangroves on the intertidal zones and the periphery of the salt pans. This vegetation cover serves as an ideal habitat for a nuber of marine and terrestrial animals. The study list includes only six threatened species (Painted Stork – 24, Lesser flamingo 68, Black-tailed Godwit- 11, Black-headed Ibis, 38, Darter 6 and Eurasian Curlew -17) belong to Near threatened category and counted few individuals within study area.

Since the area beyond 5 km of the port has large number of salt marshes and salt pans with a large number of aquatic birds, the overall impact on the avifauna reported is minimal (Annexure 1). In spite of that, implementing, proper mangrove plantation activity and restoration of the available vegetation cover surrounding the salt pans ill facilitates the birds to utilize the space and the food resources and there were no endangered species reported from this study area

Impact on marine Mammals

The direct effects of dredging on marine mammals are more complex, and considerably less well understood. Dredging has the potential to impact marine mammals, but effects are species and location-specific, varying also with dredging equipment type. In general, evidence suggests that if management procedures are implemented, effects are most likely to be masking and short-term behavioural alterations and changes to prey availability (Todd et al.,2015). A review of the literature suggests that dredging causes reductions in biomass, abundance, and species diversity of mammals for varying lengths of time, depending on surrounding conditions. Marine mammals often inhabit turbid environments and many utilize sophisticated sonar systems to sense the environment around them (Au *et a*l., 2000). Evidence that turbidity affects cetaceans or Sirenians directly is not evident in the literature. Hence it could be inferred the absence of these animals are not permanent, and needs investigation.

Impact on plankton communities

Plankton Given that effects are greatest during the egg and larval stages, impacts can be reduced by implementing temporal restrictions on dredging activity, known as environmental windows, which ensure activity is restricted in spawning and nursery grounds at critical time.

7. Mitigation

Port and harbour development usually generates local environmental problems; however, development associated with sensitive estuaries or inland or freshwater rivers may yield regional scale problems. The impacts on environment will differ from place to place depending upon the variations of geography, hydrology geology ,types and size of the shipping, materials transported and the infrastructure facilities and so on.

Adopting mitigation techniques for reducing the effects of the combined environmental changes and the associated biodiversity issues and the pollution in the air,land and water are crucial in the overall management of larger ports. Expansion and conservation of the green belt in and around the ports and the influencing areas is given priority as it helps in the reduction of carbon emission along with the coastal vegetation and the plankton in the coastal waters. The green vegetation cover reduces the heat energy in the atmosphere and the impacts of noise arising from the port activities. Depending on the physical and chemical characteristics of the dredged material, disposal may be carried out in the open water, along the shoreline or on land. Ultimately, EMP acts as a comprehensive manual for environmental protection, reduction in carbon (GHG) emission and finally it helps in converting major ports into "Green Ports". The ultimate goal of a Green Port Plan program is to achieve long-term environmental, societal and economic benefits through resource conservation, waste reduction and pollution prevention. The Green Port Program unifies the Port's environmental sustainability goals (in many key areas) by way of setting measurable goals and evaluating progress in each area on an annual basis.

Pollution control

The major health impacts of pollution from ports are related to the gaseous and particulate emissions arising from the combustion of petroleum products and coal leading to various respiratory tract diseases, cardiovascular disease, lung cancer and also climate change related issues. Petroleum contamination is a very common problem these days arising from leaking tanks, oil spill, and gas into the surrounding water and soil and takes long time for reclamation by bioagents or physical and chemical treatments. A process called thermal soil remediation helps in the remediation of contaminated soil which can be reclaimed and reused by this method. Emission benefits can be substantial when diesel fueled engines are replaced with alternative fuel systems. Switching to alternative fuels completely eliminates emissions of diesel particulate matter (PM) and significantly reduces NOx emissions (USEPA,2002b)

The possible soil contamination due to spillage of oil residues, petroleum products, cement, paint, plastics, non -degradable solids etc. are to be handled effectively by scrupulous preventive management guidelines. The laborer and officials should be aware of the extend of damage they can bring on the ecosystem and in turn to human as well through the process of biomagnification through the marine food chain. In this regard any potentially contaminated soils from construction activities must be handled, transported and disposed of in accordance with the Environmental Management Act (EMA) and its Regulations of Government of India.

Afforestation

The port authority should take up plantation of various kinds according to the space, soil types and water availability. Also, it is utmost necessary to carry out promotion compensatory mangrove and associated vegetation plantation along the shoreline at the suitable tidal level with the common species. The development such green belts surrounding the whole project area will enhance the integrity of the ecosystem and provide ecological and economic services at large on a long and regular basis. The plantation needs to be carried out with higher density of seedlings to realize high survival rates and growth performance considering the past experiences in the coast and the type of natural stands existing creek system as well.

Mangrove plantation

The Green Port Program is an umbrella program designed to achieve the Port's environmental sustainability goals by adopting appropriate afforestation programmes to develop large green belt areas at all prospective locations. The afforestation would not only contribute to the aesthetics but also would serve as a 'sink' for the pollutants released from the station and would thereby protect the quality of ecology and environment in and around the projects. Green belt will help in supporting the biological diversity, controls soil moisture, erosion control and coastal protection, increase the rate of ground water recharge and act as carbon sink to reduce climate change. Green cover interventions capture the fugitive, attenuate the noise, subside the particulate matter in the air and reduce the temperature in the surroundings. The mangrove plantation is expected to support the avifauna diversity of the local environment. It is recommended that construction activities to be restricted during the non-migratory season of the bids (November – February) to avoid disturbance to the migratory species as the Kachchh wetlands serve as major wintering grounds, located in the major central Asia fly way. Since the intertidal zone of the creeks comprising the mangroves and salt pan habitats support many benthic fauna including finfishes and shell fishes, aquatic and terrestrial migratory birds, the protection of these productive environments is very much essential for the restoration of the biodiversity and the livelihood of the fishermen. The above suggested mangrove plantation needs to be monitored for the next five years till it attains maturity and later on evaluation of the ecosystem and economic services rejoiced by the community in view of the evolving climate change related issues. The monitoring of the mangrove and coastal zone should include the study of species composition, population characteristics, growth rate of plants, abundance of the flora and fauna in order to estimate the diversity and health status at every season of the entire environment.

Soil erosion control

Shore line substratum erosion is a major threat to the intertidal habitats in DPA port jurisdiction. Often the rate of erosion is severe in the port environment due to the continuous vessel movement and the churning effect induced hydrological regime and other natural causes. During the present study it was noticed that few creeks stretch in Kandla are susceptible to erosion due to high water currents and tides. The dual purpose of controlling erosion and promoting intertidal biodiversity could be best achieved by installation of artificial reef structures, limestone rocks, laterite, cement and granite as well as bio reefs. Artificial coastal structures are cheap and installation is easy and adaptable and for better results it can be supplemented with the addition of a substrate that will support marine organisms as that of the natural intertidal and sub tidal environment. The structural diversity of the artificial reef will determine the diversity of marine organisms utilizing the created habitat. Artificial reefs once built will last for decades and would enrich marine biodiversity in a short period of time by providing ideal habitat for sessile and free-living benthic organisms and their larvae. Natural materials such as dead shells can be used for building artificial reefs and are environment-friendly. Reef balls are another form of artificial reef increasingly used in western countries to create sustainable marine reef habitat which may be easily attempted at Deendayal port Areas. Both reef balls and artificial reefs being inexpensive and locally available, can be built in different creek systems of the port jurisdiction. Application of coir mats are also suitable to control the shoreline erosion in the mangrove patches and open shore in conjunction with the rocky and cement structures.

8. Conservation and management Plan

Conservation of biodiversity is considered as the key component for administration of natural assets. Biodiversity encompasses the concept that describes the magnitude of the biological resources and their environment addressing the wide range of life associated with different types ecosystems. Biodiversity conservation is the protection and management of the biotic ad abiotic resources for sustainable development and existence and preservation of the diverse species. Sustainable utilization of species in the ecosystem along with the maintenance of the life-supporting systems are essential for the functioning of the various ecological processes. It is an integral part of any commercial activity and infrastructure development in the marine environment. Emphasis is given towards the reinstatement of the physical, chemical and biological characteristics of the coastal ecosystem which are much complex and vulnerable on which the human is highly dependent. Management of the marine biodiversity is the prime concern in the development of Ports and harbours which occupy the fragile continental shelf which is highly productive and harbors numerous living resources. Hence Environmental Management Plan (EMP) is considered as an important component in any developmental activity with sustainable management goals which are to be fulfilled within a time frame. Thus, EMP aims to suggest concrete measures that would mitigate the impacts paving way for maintaining the integrity of the project environment.

Development of ports involves effective management plan towards environmental wellbeing that guarantees both sustainable port growth and a healthy ecosystem functioning in its vicinity. There is a need for innovative solutions for port development which are in harmony with the ecosystem and which are robust or adaptable under change. The recent trends like growth of global trade, increasing vessel movements and size, modernize port facilities, driving urgent investments in ports has been negatively impact water quality and marine flora and fauna. This simultaneously calls for sustainable and inclusive development which ensures productive nature of its marine environment.

The port authorities mandate to their activities environmentally sustainable and benign need to understand the marine ecological setting of their ports including water quality, biotic components and the factors that impact them. In spite of all the pressures, the ecosystem continues to deliver many services which are often intangible. In order to maintain these services intact, it is imperative that different biotic and abiotic components of the port environment are sustainably managed in the long run.

Accordingly Deendayal Port has initiated several environmental management measures as mandated by the MoEF &CC from time to time with the purpose of maintaining and preservation of its terrestrial and coastal environmental integrity. The following measures have been taken by the port authorities:

Ongoing Environment Management Measures by DPA

i) A holistic and comprehensive study on the marine ecology of the port including different marine fauna and floral components and preparation of management plan has been initiated as per the specific condition No. xviii of the EC & CRZ Clearance accorded by the MoEF & CC, GoI dated 19/12/2016. The results of the seasonal observations on the environmental characteristics and biodiversity of the intertidal zones have been compiled along with the conservation plan recommendation for three consecutive years (2023-2024)

ii) Mangrove plantation has been carried out to the tune of 900 ha in Sat Saida Island, 150 ha in Nakti creek, 450 ha in Kantiyajal by Deendayal Port. The black mangrove *Avicennia marina* was used in these plantation activities as this species is more suitable to the existing environmental condition in this coast.

Based on the information gathered through the seasonal studies on the different biotopes and the biodiversity along with the mangrove, macrofauna, plankton density and diversity, productivity of mudflat and avifauna for the period 2023-2024 in the limits of the Deendayal port, it is evident that the impact is insignificant since management action plans are showing positive responses to a large extent in spite of the climate change induced impacts on the marine ecosystem. This project aims to draw a holistic management framework for conserving the Marine Biodiversity and Ecology of the DPA port marine environment which include many biotopes such as mangroves, intertidal and subtidal realms, mudflats and salt marshes, each serving as an abode for a variety of fauna and flora. Given the economic importance of DPA port and the increasing national and global demand for sustainability, it is decided to continue the ecological monitoring in future inline with the recommendations and directions described by the competent research organizations. .The proceeding section outlines management initiatives to be undertaken by the port authorities for holistic management of marine biodiversity within the port limits envisaging several facilities will be built within port premises in the future.

Intertidal and Subtidal Biodiversity Management

The intertidal zone constitutes the coastal environment where land and sea meet, i.e., the area between extreme high-water springs (EHWSs) and extreme low water springs (ELWSs). The subtidal zone lies below the lowest water level beyond the intertidal zone. Both these zones provide habitats for various marine fauna and flora and needs to be managed effectively for the overall wellbeing of the ecosystem. In addition, intertidal zone biodiversity index did not vary very much in the recent years but the population density has not increased and remained stable. The intertidal zone may be susceptible to natural and anthropogenic pressures such as soil erosion, industrial pollution, continuous dredging and sedimentation. Hence, interventions are required to mitigate or support the natural recovery of the fauna in the bottom sediment. The sedentary benthic species produce a large number of their larva as an adaptation for their survival which get attached to the mangrove surfaces and metamorphose into adults and also serve as food for several fishes and shellfishes. Hence, soil erosion control interventions could help to improve the restoration of many benthos and plankton productivity. In the DPA vicinity, intertidal and subtidal zones are mostly dominated by clayey substratum admixed with silt and there are no rocky or sandy shores. The intertidal belts of the study area support many biological elements indicating the overall health of the ecosystem.

Study conducted from MAY 2023 to MAY-2024

The results on the quantitative and qualitative data of the intertidal organisms showed that the crustaceans (crabs) and mudskippers (Fish) are the predominant groups at all the sampling sites throughout the year. These two groups of fauna are having excellent physiological adaptations to survive in the muddy intertidal shores and mangroves than other invertebrates. The other invertebrates such as molluscs and polychaetes which are generally inhabitants of the intertidal zone are very much restricted or even absent. Hence, it is imperative to take measures to conserve and promote the intertidal biodiversity of DPA coastal / creek environments. Mangroves and the associated salt marshes provide ideal habitats natural habitats for many intertidal microflora and fauna which serve as food for the avifauna, several commercially important fishes and crustaceans and also aid in the sediment reworking and nutrient cycling. Hence, promoting mangrove plantation and conserving the minor water canals to hold water and sediment to conserve the intertidal biodiversity. Mangroves, mudflats and intertidal creeks are the major ecological entities within the port boundary and they function in close synchrony with each other, thus their conservation and management call for a holistic approach.

Plankton and Productivity

Planktonic community and productivity were studied in the creek waters of Deendayal port jurisdiction from the period 2023 to 2024. Diversity and density of phytoplankton community in DPA port creek environment was moderate as only 24 to 30 genera were reported during monsoon, post-monsoon and winter seasons. Similarly, a maximum of 35 genera of zooplankton have been reported during post-monsoon and winter. The productivity of the water column was low as indicated by the Chlorophyll 'a' pigment concentration, due to the prevalence of high rate of suspended solids which prevents the photosynthesis. However, the observed species diversity was moderate and support the biodiversity of the creek system.

Mangrove Management

DPA has around 23.967km^2 of mangroves cover in their jurisdiction which consists of many major and minor creek systems within its limit, port infrastructure occupies only ~1% of the total area. Establishment of facilities is a continuous process and the expansion of infrastructure over the coming years will bring remarkable changes in the landscape and seascape in and around the port area. Mangrove environment will continue to be stable and balanced if there are no external stressors such as change in hydrology, elevation and slope, soil and water salinity and pH, soil texture and wave energy are maintained in a natural condition without wide fluctuations. In addition, human centered stress factors such as resource collection, camel grazing, tree felling and other habitat modification activities are controlled. Generally, micro-topography controls the distribution and well-being of mangroves, and physical processes play a dominant role in the formation and functioning of the mangrove ecosystem through reproduction, seed germination and establishment of young plants. The mangrove forests undergo self-repair over a period of time, provided that the normal tidal hydrology is not disrupted and the availability of water borne seeds are not blocked. Regular monitoring of mangrove hydrology through simple scientific methods will go a long way in maintaining ecosystem balance. The natural regeneration capacity of the stand is to be assessed by quantifying the degree and extent of the entrance of younger classes such as saplings into the mature tree category. The ratio between these different size classes will indicate the dynamic state of the mangrove forest. Only if the natural seedling recruitment is not occurring does the system requires an assisted recovery by plantation and physical amendments. The present study displays that natural regeneration of the mangrove as indicated by the increment in the density of younger classes. In addition to *Avicennia marina*, three species namely, *Rhizophora mucronata, Ceriops tagal* and *Aegiceras corniculatum*, have been recorded sporadically within DPA limits. It is strongly recommended that in all the future plantation efforts, these additional species also could be selected at appropriate locations and tidal levels.The overall mangrove plant density has increased during the three season survey indicating the prevalence of suitable environmental conditions as the rate of rainfall was higher during the monsoon season.

Conservation of Island

Islands support a rich marine fauna, flora and avifauna diversity and deserve special conservation efforts. Land cover classification of Sat Saida Island using GIS tool revealed sparse and dense mangroves, mudflats and halophytic vegetation other than mangroves are other prominent land cover categories. Though equipped with all the features to support a dense mangrove formation, the mangroves of Sat Saida Island are rather sparse and scrubby and confined mostly to creek banks. Different elevation features of the Island render the tidal flooding and hydroperiod in the interior region poor resulting in sparse and open mangrove formations. This Island could be an ideal site for mangrove plantations while implementing ministry’s mandated plantation activities, other mangrove restoration and rehabilitation activities with biophysical amendments such as desilting existing creeks, joining existing minor creeks could be taken up which will increase the mangrove cover in this Island. These physical activities in the mangrove lined minor creeks will increase tidal flooding and hydro-period and convert sparse mangroves into dense mangroves in due course of time. Deendayal port has already carried out 1400 ha of mangrove plantation since 2006 with good success rate in various locations and additional 200 ha is in progress.

Management plan to improve the water quality in the port area

- The drains and outfall should be cleaned regularly to avoid anaerobic decomposition and also for proper flow of water/wastewater. This will also enable the characterization of wastewater and calculation of waste load.
- Domestic and canteen wastewater should be discharged only after proper treatment.
- The solid waste generated from the canteen and other diffused sources should be collected and disposed properly for which modern purification system should be established.
- The discharge of oil waste into the sea from the following main sources should be controlled
    1. Discharge of oil waste from liquid chemical corridor area. This liquid waste is generated during tanker cleaning, and oil spills during filling operations,
    2. Oil spills at berth during unloading operations.
    3. Tanker ballast discharge from ships.
- Bulk material should not be disposed into the sea. All drains and roads should be cleaned before the rainy season to avoid runoff from land to sea carrying a myriad of pollutants, including chemicals that may be imposed for oily discharges in and around the port.

Management plan for marine fisheries

Regular dredging activities in the Port area can impact marine fauna and the flora particularly the phytoplankton and seaweeds. The fishes and other fishery resources such as shrimps and crabs through noise and vibration levels, water quality and loss of habitat and food sources. But since fishes in the water column are free swimming in nature, they tend to avoid the turbid areas and move to safer zones. Once the turbidity increase becomes reversed due to sedimentation and dispersion by current and wave influences, the fishes are expected to occupy the area. Hence, there will be virtually no impact on fish due to dredging in the long term. As the area does not have any breeding ground for fisheries, no significant impact on marine ecology and particularly the fishes are anticipated during the dredging phase. The most important potential impact would be the rise in suspended solid load, which hinders the photosynthesis of the producer communities, especially the phytoplankton and affects the food chain. The high turbidity due to heavy suspended solids load during dredging and reclamation can result in the clogging of the gills of the filter feeding organisms, thereby causing asphyxiation.

Mannagement plan for Avifauna

1. Direct and indirect impact on ecologically sensitive ecosystems

The Deendayal SEZ project site located in the mid of the Deendayal Port area surrounded by port associated industrial sectors and salt industries. Since no Protected Areas are located within 10 km radius of the SEZ site, impacts on sensitive ecosystem was not visualized.

2. Loss of Inter-tidal habitats - Coastal

- The plantation needs to be carried out with fourfold density of seedlings compare to the natural mangrove density of the Kandla creek area and to maintain the density at the requirement stage
- This mangrove plantation expected to support mangrove associated bird species and thereby enhance the avifauna diversity of the local environment. Since the intertidal (mangrove and creeks) and salt pan habitats supports few thousands of aquatic birds' species and migratory species, the project proponent should plan the establishment /construction activities (if any) outside the migratory season (November – February) to avoid the disturbance to the migratory species. The above suggested mangrove plantation needs to be monitored at least for the next five years till it attains maturity with the expert team to understand the growth rate and enhancement and assemblage of associated faunal species.

Since the area located in the Intertidal habitat and adjacent areas supports thousands of aquatic avifauna, the project proponent (Deendayal Port authority) should take up long-term (five years) Ecological Monitoring Program of the adjacent creek, mangrove and salt pan habitats to assess the change in avifaunal diversity due the any developmental activities take place in the future project

Co-Management with the Community

Management program for mangroves is feasible in the case of Deendayal Port Authority since all the mangrove formations are under its legal control and hence any management program could be implemented without any sectoral conflicts with forest or any other government departments. It was proven in many instances that involving the stakeholder communities in the surrounding villages will yield better results in mangrove management. Though the population in the port surroundings has different livelihood activities, fishermen community could be targeted to involve in community-based mangrove management.

The fishermen in the villages such as Vera, Khari Rohar, and Tuna close to the port could be involved by forming "Samithies" for the conservation of mangroves with possible funding resources. The communities are expected to involve in the plantation and management activities for which awareness campaign and interactive sessions are to be conducted time to time and the feedback and experiences are to be recorded and duly acknowledged. The community's resource dependency, perception about the conservation of mangroves and associated flora and fauna and their level of involvement in such resource management activities are to be assessed before forming such a community-based organization. They could be assigned the specific task of conserving the mangroves by involving them in plantation/restoration activities, physical protection and other conservation measures. This could be taken up as part of the port's CSR activity.

It was observed that at many sites the salt producers are extending their boundry by removing the plants for the construction of roads and placing pipes for collection of water.Besides the release of the brine/ high saline water after the production period through the mangrove leads to drying of plants. These activities should be taken care and to be controlled through discussions and proper interventions.The excessive saline water is unsuitable for the growth and survival of the younger class mangroves.

9. Summary and Conclusion

Intertidal Fauna

The survey of the intertidal Fauna of DPA Kandla area recorded the presence of 6 phyla (Nematoda, Nemertea, Annelida, Arthropoda, Mollusca and Chordata), including 26 species. The species diversity was the highest for phylum Mollusca (22), followed by Arthropoda (19), Annelida (4) and Nematoda, Nemertea, Chordata (1) respectively. diversity indices around the DPA coastal environment were <3.0, indicating that the moderate faunal diversity.In the present observation, the species composition of the benthic macrofauna showed dominance in the Phyla Molluscs, Arthropoda, Annelida, Nematoda, Nemertea and Chordata

Subtidal Fauna

The subtidal Fauna of the DPA Kandla survey recorded the presence of 4 phyla (Cnidaria, Annelida, Arthropoda and Mollusca,), including 26 species. Among the station highest number of animals was documented from during the post-monsoon containing species *Glauconome angulata* (51 no) followed by Pirenella cingulate (48 no) in post-monsoon. In pre-monsoon highest number of animals contributed by the species Pirenella cingulate (43 no) followed by *Glauconome angulate* (38 no). Similarly in monsoon highest number of species contributed by *Optediceros breviculum* (35 no) followed by *Pirenella cingulate* (27 no) overall Pirenella cingulate was dominated in all the season

Mangrove Environment

The overall average tree density of the mangrove for the three seasons for the entire study sites was 1915/h (monsoon)3647/h(post monsoon) and 4098/h (premonsoon) during the period 2023 to 2024. The overall population density showed increment during the survey period.

Halophytes

Halophytes are predominantly present in the premises of Deendayal Port since habitat conditions are suitable for halophytes at the inner part of Gulf of Kachchh. Halophytes are mostly found beyond highest high tidal levels where spring tides reach occasionally and pore-water salinity often reaches >90 ppt. Their presence is widely noticed intermingled with mangrove formations in all the mudflats. During period of May 2023 to May 2024, 4 halophyte species, respectively were recorded within the quadrates from 14 sampling locations.

Conclusion

It is imperative to create strong baseline data on the marine environment in the port vicinity in tune with the spatial extent of developmental activities. Continuous marine ecological monitoring study since May 2017 focused on the biological and productivity of mudflats. Based on the detailed investigations of marine ecological components and the possible impacts of the DPA port environment, it could be concluded that the effects on the various biotic components are minimal and confined to high activity areas only with limited impacts on the surroundings. The results of the studies conducted by GUIDE, 2017 to 2024, it was inferred that there was no significant variation with respect 2023 to 2024 taxa/genera/species composition as well as fauna and plankton community. The mangrove tree category density has shown higher values in all the sampling locations in the Deendayal port Authority and its creek environments.

In addition to biological parameters, the study cover essential Physico-chemical parameters like water and sediment of the mangrove sites, including and petroleum hydrocarbons in the port environment to assess the ecological status of the Deendayal Port Authority.

Knowledge of marine species diversity is incomplete, however, studies have highlighted an increase in the rate of decline in the population density of many vulnerable species with space and time due to several reasons including habitat destruction and alterations and the related stress es . The biodiversity of the coastal zone has been explored more extensively than the deep offshore areas due to the accessibility for sampling. These areas are considered to be highly productive due their shallow and dynamic nature suitable for the growth of the flora , phytoplankton, seaweeds and sea grasses. The, bio-geochemically more active zone provides all the major,minor and trace elements for the floating micro flora as well as the macroscopic algae and sea grasses that flourishes in the nearshore environments. The abiotic physical and chemical parameters of the water in all the study sites are found to be within the optimum level during the seasonal assessment. The prevailing higher turbidity of the water due to the high tidal currents inhibits the primary productivity of the phytoplankton and the benthic algae and seagrass. However, there exists several diatoms which have higher adaptive features to survive under such circumstances as evidenced from the present study. There are indicator species to assess the biodiversity status of ecosystems, the keystone species, such as the coral reefs, sea grasses and macro algae which are specific for the benthic habitat. These groups of plants and the fauna require clear water, optimum temperature aided through the high rate of light penetration through the water column. The absence of the seaweeds and seagrass beds could be well correlated with the relatively high level of suspended particles in the water in the selected study sites. The sediment entire creek environment bottom substratum is dominated by fine clay which holds organic and inorganic elements and acts as a sink for essential nutrient elements for the multitude of micro algae which are the primary source for the pelagic and benthic food chain, including the fin fishes and shell fishes in the creek as well as the nearby oceanic zone. The concentration of petroleum hydrocarbon at some locations is higher than the admissible level in the coastal waters. This chemical compound is highly hydrophobic in nature and tends to attach to the surface film of the water. Though the degradation is a slow process it has been distributed to longer distances and tends to settle down as tarballs. Also the residues if such particles persist for longer duration, affects the pelagic communities and ultimately the fishes and higher vertebrates. In the Kandla adjacent creek complex such incidents have not been reported and fishing is a regular activity in the mangrove environment by the fishermen who have a valid registration from the port Authority.

10. References

Abott, R.T. (1954). *American Sea shells*. Dvan Nostrand Company Inc, Newyork, pp 541.

Amr, Z.S. (2021) The state of biodiversity in Kuwait. Gland, Switzerland: IUCN; The State of Kuwait, Kuwait: Environmental Public Authority.

Ansari, Z. A., Ingole, B.S., Banerjee, G. & Parulekar, A.H. 1986. Spatial and temporal changes in benthic macrofauna from Mandovi and Zuari estuaries of Goa, West coast of India. *Indian Journal of Marine Sciences*, 15: 223–229.

APHA (2017). *Standard Methods for the Examination of Water and Wastewater*, 23nd edition. American Public Health Association,1546.

Apte, D.A. (2012) *Field Guide to the Marine Life of India - 1st Edition*. Stusa Mudra Private Limited Mumbai, 502pp.

Apte, D.A. (2014) *Sea Shells of India. An Illustrated Guide to Common Gastropods*. Bombay Natural History Society & Oxford University Press, Mumbai, 197pp.

Aquatic Ecosystems Task Group (2012), Aquatic Ecosystems Toolkit, Module 2: Interim Australian National Aquatic Ecosystem (ANAE) Classification Framework, Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Barnes, R.D. (1980). *Invertebrate Zoology,* Saunders College, Philadelphia 108pp.

Brahmane, V.T., Temkar, G.S., Metar, S.Y., Sikotaria, K.M. & Desai, A.Y. (2014). Ichthyofaunal diversity in the vicinity of marine protected areas, Jamnagar, Gulf of Kachchh, India. *Asian Journal of Advanced Basic Science,* 3: 78–88.

Chakraborty, S.K. (2017). Ecological Services of Intertidal Benthic Fauna and the Sustenance of Coastal Wetlands Along the Midnapore (East) Coast, West Bengal, India. In: Finkl, C., Makowski, C. (eds) Coastal Wetlands: Alteration and Remediation. Coastal Research Library, vol 21. Springer, Cham.

Chapgar, B.F. (1957). *Marine crabs of Bombay state,* Taraporevala Marine Biological Station, Bombay pp 88.

Chhaya, N.D (1997) Minding Out Marine Wealth: An Appraisal of Gujarat's Coastal Resources." Environment and Development Series, Centre for Environment Education, Ahmedabad, 44pp.

Cintron,G. & Novelli, Y.S. (1984). Methods for studying mangrove structure, In: Snedaker, S.C. & Snedaker, J.G. (eds.) *The mangrove ecosystem: research methods*. United Nations Educational, Scientific and Cultural Organization, Paris, 91-113.

Cowardin, L.M., Carter, F.C. & LaRoe, E.T. (1979), Classification of wetlands and deepwater habitats of the United States. Fish and wildlife Service, vol. FWS/OBS-79131, Fish and Wildlife Services, Washington, DC.

Crane, J. 1975. Fiddler crabs of the world. Ocypodidae: Genus Uca. Princeton University Press, Princeton, New Jersey.

Daniels, J.C. (2002). *The Book of Indian Reptiles and Amphibians*. Mumbai: Bombay Natural History Society & Oxford University Press. 252 pp.

Davidson, I.C., Crook, A.C., & Barnes, D.K.A. (2004). Quantifying Spatial Patterns of Intertidal Biodiversity: Is Movement Important?. *Marine Ecology*, 25 (1), 15–34.

Day, J.H. (1967). *A monograph on the Polychaeta of Southern Africa*. British Museum (Natural History). London. vol 1 & vol 2, 878pp.

Day, J.W., Hall. C.A.S., Kemp W.M. & Araneibia Y.A.C. (1989) *Estuarine Ecology*. John Wiley Sons, Inc.

De Bruin, G.H.P., Russell, B.C. & Bogush, A. (1995). *FAO species identification field guide for fishery purposes The Marine Fishery Resources of Sri Lanka,* Food and Agricultural Organization of the United Nations, Rome 110pp.

Desikachary, T.V. (1987). *Atlas of diatoms*, 3 and 25. Madras Science Foundation Madras: plates, 22-4000

Dyer, K.R., Christie, M.C. & Wright, E.W. (2000). The classification of intertidal mudflats. *Continental Shelf Research*, 20(10-11): 1039-1060.

Edward, J.K.P., Ravinesh, R. & Biju Kumar, A. 2022. *Molluscs of the Gulf of Mannar, India and Adjacent Waters: A Fully Illustrated Guide* (Dekker, H. & Oliver, P.G. Eds.). Suganthi Devadason Marine Research Institute, Tuticorin & Department of Aquatic Biology & Fisheries, University of Kerala, India, 524pp.

FAO, (2010). Global Forest Resources Assessment 2010: Main Report. FAO Forestry Paper 163.

Fauvel, P. (1953). *The Fauna of India including Pakistan, Ceylon, Burma and Malaya. Annelida: Polychaeta*, Allahabad. 507pp.

Fischer, W. & Bianchi, G. (1984). *FAO species identification sheets for fishery purposes Western Indian Ocean,* Fishing area 51 Prepared and prints with the support of the Danish International Development Agency DANIDA Rome, Food and Agricultural Organization of the United Nations, I-IV 20-55

FSI, (2017). The State Forest Report Forest Survey of India, Government of India- Ministry of Environment and Forest.

Gajbhiye, S. N. & Desai. B.N. (1981). Zooplankton variability in polluted and unpolluted waters off Bombay. *Mahasagar*., 14(3): 173-182.

Hai, N.T., Dell, B., Phuong, V.T. & Harper, R.J. (2020). Towards a more robust approach for the restoration of mangroves in Vietnam. Ann. For. Sci. 77, 18.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D. (2001). PAST: Paleontological statistics software package foreducation and data analysis. version 3.2.1.

Hartman, O. (1968). *Atlas of the errantiate polychaetous annelids from California*. Allan Hancock Foundation, University of Southern California. Los Angeles, 828.

Hartman, O. (1969). Atlas of the sedentariate polychaetous annelids from California. Allan Hancock Foundation, University of Southern California. Los Angeles, 812pp.

Hill, M.O. (1973). "Diversity and evenness: a unifying notation and its consequences". *Ecology.* 54 (2): 427–432.

Holthuis, L.B. (1993). *The Recent genera of the caridean and stenopodidean shrimps (Crustacea, Decapoda): With an appendix on the order Amphionidacea*. Nationaal Natuurhistorisch Museum Leiden. 328.

IUCN (2022). The IUCN Red List of Threatened Species. Version 2021-3. https://www.iucnredlist.org

Jha, B., Reddy, C.R.K., Thakur M.C. & Rao, M.U. (2009). *Seaweeds of India: the diversity and distribution of seaweeds of the Gujarat coast*. Springer, Dordrecht. 198

Joshi, A., Parmar, E.A.R., Temkar, G.S., Desai, A.Y. & Bhatt, A.J. (2018). Ichthyofaunal biodiversity of Kharakuva Fish Market, Veraval, Gujarat, India. *International Journal of Bioresource and Stress Management* 9: 596-605.

Kamboj, R.D., Salvi, H., Patel, R. & Bhagat, R. (2018) *Monograph on Phytolankton of Gulf of Kachchh*. Gujarat Ecological education and Research (GEER) Foundation. 182

Karleskint G. (1998). *Introduction to marine biology*. Harcourt Brace & Company. p.378

Klein, G.D. (1985). *Intertidal Flats and Intertidal Sand Bodies*, pp187-224. In: Davis, R.A. (eds) *Coastal Sedimentary Environments*. Springer, New York, NY.

Kumar, R.S. 1997. Vertical distribution and abundance of sediment dwelling macro invertebrates in an estuarine mangrove biotope, southwest coast of India. *Indian Journal of Marine Sciences*, 26: 26–30.

Kumari, P., Singh, J.K. & Pathak, B. (2020). Potential contribution of multifunctional mangrove resources and its conservation.

Levinton J.S. (1995). *Marine biology: function, biodiversity, ecology*. Oxford university press. p.420.

Lyla, P.S., Velvizhi, S. & Khan, A.S. (1999). A Monograph on the amphipods of Parangipettai coast, Annamalai University, India pp78.

Mahapatro, R.C., Panigrahy, S., Pati, K. & Samal, R.N. (2011). Macrobenthos of shelf zone off Dhamara estuary, Bay of Bengal. *Journal of Oceanography and Marine Sciences*, 2(2): 32-42.

Mantri, V.A., Kavale, M.G & Mudassar A.K (2020) Seaweed Biodiversity of India: Reviewing Current Knowledge to Identify Gaps, Challenges, and Opportunities. Diversity. 1-22.

Masuda, H., Amaoka, K., Araka, C., Vyeno, T. & Yoshino T (1984). *The Fishes of Japanese Archipelago*. Tokai University Press, Japan 437.

McCann, S.B. (1980). *Classification of tidal environments,* In, McCann, SB Ed, Sedimentary Processes and Animal Sediment Relationships in Tidal Environments, Short Course Notes, Geological Association Canada, St Johns, Newfoundland, 1: 1-24.

Medeiros, T.C.C. & Sampaio, E.V.S.B. (2008). Allometry of aboveground biomasses in mangrove species in Itamaracá, Pernambuco, Brazil. Wetl. Ecol. Manag. 16, 323–330.

Mohammed, S.Z. 1995. Observation on the benthic macrofauna of the soft sediment on western side of the Arabian Gulf (ROPME sea area) with respect to 1991 Gulf war oil spill. Indian Journal of Marine Sciences, 24: 147–152.

Mohsin, A.K.M. & Ambiak, M.A. (1996). *Marine Fishes and Fisheries of Malaysia and Neighboring Countries,* University Pertanian Malaysia Press, Serdang 743.

Morris, E. K., Caruso, T., Buscot, F., Fischer, M., Hancock, C., Maier, T. S., Meiners, T., Müller, C., Obermaier, E., Prati, D., Socher, S. A., Sonnemann, I., Wäschke, N., Wubet, T., Wurst, S., & Rillig, M. C. (2014). Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. *Ecology and evolution*, 4(18), 3514–3524.

Naderloo, R. (2017). Atlas of Crabs of the Persian Gulf. Springer International Publishing AG, Switzerland, 445pp.

Nagelkerken, I., Blaber, S.J.M., Bouillon, S., Green, P., Haywood, M., & Kirton, L.G. (2008). The habitat function of mangroves for terrestrial and marine fauna: a review. *Aquatic Botany*. 89, 155–185.

NIO (1998) "Environmental Studies for the Proposed BPCLJetty and Associated Facilities at Kandla." Rapid Marine EIA- Part I, 22pp.

NIO (2002) Monitoring of environmental Parameters in Kandla Port Area." Quarterly Report- I Sponsored by Kandla Port Trust, Gujarat.

NIO (2003) "Monitoring of environmental Parameters in Kandla Port Area." Quarterly Report - II (February, 2003-May, 2003) Sponsored by Kandla Port Trust, Gujarat, NIO, Bombay.

Oliver, P.G. (1992) Bivalved Seashells of the Red Sea. National Museum of Wales, Cardiff, 330 pp.

Oza, R.M., Krishnakumar, G.R., Mairh, O.P. & Zaidi, S.H. (2001) Cultivation of *Ulva fasciata* Delili on the coast of Diu, west coast of India. Seaweed Resarch utilisation, 23, 5–12

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*. 13: 131–144.

Pitcher, R.C.R., Doherty, P.P.J., Arnold, P.P., Hooper, J.J.N.A. & Gribble, N.N.A. (2007), Seabed biodiversity on the continental shelf of the Great Barrier Reef World Heritage Area, CSIRO Marine and Atmospheric Research.

Psomadakis, P.N., Osmany, H.B. & Moazzam, M. (2015). *Field identification guide to the living marine resources of Pakistan*. FAO Species Identification Guide for Fishery Purposes, Rome, FAO. 386.

Rajasegar, M., Sirnivasan, M. & Ajmal Khan, S. (2002). Distribution of sediment nutrients of Vellar estuary in relation to shrimp farming. *Indian Journal of Geo-Marine Science*, 31 (2), 153—156.

Ramakrishna and Dey (2007) *Hand book on Indian Freshwater Molluscs*. Published by the Director, Zoological survey of India, Kolkata, 399pp.

Ramakrishna, T.C.R., Sreeraj, C., Raghunathan, R., Raghuraman, P. & Yogesh Kumar, J.S. (2011). *An account of additions to the Icthyofauna of Andaman and Nicobar Islands,* Records of the Zoological Survey of India, Occasional Paper no 326, Published-Director, Zoological Survey of India, Kolkata, 140pp.

Rao N.V.S. (1989) *Handbook of freshwater molluscs of India*. Zoological Survey of India, Calcutta

Rao N.V.S., Rao, K.V.S. & Maitra, S. (1991). *Marine molluscs*. State Fauna Series 1, *Fauna of Orissa (Part 3).* Zoological Survey of India, Calcutta, 1-175.

Rao, N.V.S. (2003). Indian Sea Shells (Part I). Polyplacophora and Gastropoda. Zoological Survey of India, Kolkata, 416pp.

Rao, N.V.S. (2017) Indian Seashells, Part B Bivalvia. Zoological Survey of India, Kolkata, 676pp.

Ravinesh, R. & Biju Kumar A. (2013) Comparison of intertidal biodiversity associated with natural rocky shore and sea wall: A case study from the Kerala coast, India. *Indian Journal of Geo-Marine Sciences*, 42(2): 223-235.

Ravinesh, R. & Biju Kumar, A. (2022) *Collection, preservation, and documentation of estuarine and marine benthic invertebrates*.pp 33-82. In: Prince S.G., Salom, G.T.V. and Krishnakumar, S. (Eds) *Ecology and Biodiversity of Benthos*, Elsevier Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands.

Ravinesh, R., Biju Kumar, A. and Anjana, V.L (2021) Diversity and distribution of molluscan fauna of Asthamudi estuary, Kerala, India, Wetlands Ecology and Management. 29 (5), 745-765.

Rees, H. L. (ed). 2009. Guidelines for the study of the epibenthos of subtidal environments. ICES Techniques in Marine Environmental Sciences No. 42. 88 pp.

Robin S.W., Pat, H.A. & Glasby, C.J. (2003). *Polychaetes: An Interactive Identification Guide*. CSIRO Publishing, Melbourne.

Roman, J., & Estes, J. A. (2018). *Ecology*. Encyclopedia of Marine Mammals, 299–303.

Rountree, R. A., & Able, K.W. (1992). Fauna of Polyhaline Subtidal Marsh Creeks in Southern New Jersey: Composition, Abundance and Biomass. Estuaries, 15(2), 171. doi:10.2307/1352690

Rouse, G.W. & Pleijel, F. (2001). Polychaetes. Oxford University Press: Oxford, UK, 354 pp.

Rudresha, G.V., Urs, A.P., Manjuprasanna, V.N., Milan Gowda, M.D., Jayachandra, K., Rajaiah, R. &Vishwanath, B.S. (2021) *Echiscarinatus* snake venom metalloprotease-induced toxicities in mice: Therapeutic intervention by a repurposed drug, Tetraethyl thiuram disulfide (Disulfiram). *PLOS Neglected Tropical Diseases*,15(2): e0008596.

Santhanam, P., Pachiappan, P. & Begum, A. (2019). *Methods of Collection, Preservation and Taxonomic Identification of Marine Phytoplankton*. pp25-61. In: Santhanam, P., Begum, A., Pachiappan, P. (eds) *Basic and Applied Phytoplankton Biology*. Springer, Singapore.

Saravanakumar, A. (2002) Studies of Habitat Structure and Associated Faunal Diversity in Western Mangroves of Kuchchh - Gujarat." PhD. Thesis at the Centre for Advance Study in Marine Biology, Annamalai University, Tamil Nadu PhD thesis.

Saravanakumar, A., Sesh Serebiah, J., Thivakaran, G.A. and Rajkumar, M. (2007) Benthic macrofaunal assemblage in the arid zone mangroves of Gulf of Kachchh Gujarat. *Journal of Ocean University of China*, 6, 303–309.

Sidat Azaz., Mukherji P., Trivedi T. & Mankodi P.C. (2021) Ichthyofauna species diversity of Gulf of Kachchh, Gujarat, India Case study: Jakhau and Mandvi coast. *Iranian Journal of Ichthyology*. 8(2): 134-150

Terdalkar, S. & Pai. I.K. (2001) Statistical approaches for computing diversity of zooplankton in the Andaman Sea. *Tropical Ecology*, 42, 243-250.

Thomas A.J., Samuel K.H., Kelly M.R. & Frederick, I.A (2012). Life history of the Indo-Pacific humpback dolphin in the Pearl River Estuary, southern China. *Marine Mammal Science*. 28 (1): 84–104.

Thomas, I.W. (2009). *In Defense of Dolphins: The New Moral Frontier*. John Wiley & Sons, 229pp.

Tucker, C.M., Marc W.C., Silvia B.C., Jonathan, D.T., Simon, F., Susanne A.F., Rich, G., Matthew R.H., & Lanna S.J. (May 2017). A guide to phylogenetic metrics for conservation, community ecology and macroecology: A guide to phylogenetic metrics for ecology. *Biological Reviews*. 92 (2): 698–715.

Vaghela, B., Chirakkal, S., Putrevu, D. & Solanki, H. (2021). Modelling above-ground biomass of Indian mangrove forest using dual-pol SAR data. Remote Sens. *Remote Sensing Applications: Society and Environment,* 21, 100457.

Vajravelu, M., Yosuva, M., Saravanakumar, A. & Mayakrishnan, M. (2018) Seasonal influence of physico-chemical parameters on phytoplankton diversity, community structure and abundance at Parangipettai coastal waters, Bay of Bengal, South East Coast of India.*Oceanologia*, 60, 114-127.

Vine, P. (1986). *Red Sea Invertebrates*. Immel Publishing, London. 224 pp.

Walkley, A, & Black, I.A. (1934). An examination of the Degljareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37: 29-38.

Xavier, J. C., Cherel, Y., Boxshall, G., Brandt, A., Coffer, T., Forman, J., Havermans, C., Jażdżewska, A. M., Kouwenberg, K., Schiaparelli, S., Schnabel, K., Siegel, V., Tarling, G. A., Thatje, S., Ward, P. & Gutt, J. (2020) Crustacean guide for predator studies in the Southern Ocean. Scientific Committee on Antarctic Research, Cambridge, UK. 253 pp.

Zar, J.H. (1984) *Biostatistical Analysis*. 2nd Edition, Prentice-Hall, Inc., Englewood Cliffs, 718.

Zingde, M.D. & Anand, N.M. (1996) Implication of Coastal Refineries to the Ecology of the Gulf of Kuchchh," National Institute of Oceanography, Mumbai.

Annexure 1: Overall Checklist of Avifauna recorded from the Study area

SLNo	Order	Family	Species	MS	Habitat	FG	IUCN-2023
1	Accipitriformes	Accipitridae	Shikra *Accipiter badius*	R	T	C	LC
2	Accipitriformes	Accipitridae	Marsh Harrier *Circus aeruginosus*	M	T	C	LC
3	Accipitriformes	Accipitridae	Black-winged Kite *Elanus caeruleus*	R	T	C	LC
4	Accipitriformes	Accipitridae	Black Kite *Milvus migrans*	R	T	C	LC
5	Accipitriformes	Pandionidae	Osprey Pandion haliaetus	RM	T	P	LC
6	Accipitriformes	Accipitridae	Oriental Honey-buzzard *Pernis ptilorhynchus*	R	T	C	LC
7	Anseriformes	Anatidae	Common Teal *Anas crecca*	M	A	P	LC
8	Caprimulgiformes	Apodidae	Indian House Swift *Apus affinis*	M	T	I	LC
9	Charadriiformes	Scolopacidae	Common Sandpiper *Actitis hypoleucos*	R	A	AP/I	LC
10	Charadriiformes	Burhinidae	Eurasian Thick-knee *Burhinus oedicnemus*	R	A	IN	LC
11	Charadriiformes	Scolopacidae	Sanderling *Calidris alba*	RM	A	P	LC
12	Charadriiformes	Scolopacidae	Dunlin *Calidris alpina*	M	A	IN	LC
13	Charadriiformes	Scolopacidae	Curlew Sandpiper *Calidris ferruginea*	M	A	AP/I	LC
14	Charadriiformes	Scolopacidae	Little Stint *Calidris minuta*	M	A	IN	LC
15	Charadriiformes	Charadriidae	Little Ringed Plover *Charadrius dubius*	R	A	AP/I	LC
16	Charadriiformes	Charadriidae	Common Ringed Plover *Charadrius hiaticula*	RM	A	AP/I	LC
17	Charadriiformes	Charadriidae	Greater Sandplover *Charadrius leschenaultii*	M	A	O/Flesh	LC
18	Charadriiformes	Charadriidae	Lesser Sand Plover *Charadrius mongolus*	M	A	IN	LC
19	Charadriiformes	Laridae	Whiskered Tern *Chlidonias hybrida*	M	A	P	LC
20	Charadriiformes	Laridae	Brown-headed Gull *Chroicocephalus brumnicephalus*	M	A	P	LC
21	Charadriiformes	Laridae	Black-headed Gull *Chroicocephalus ridibundus*	M	A	O	LC

SLNo	Order	Family	Species	MS	Habitat	FG	IUCN-2023
22	Charadriiformes	Dromadidae	Crab-Plover *Dromas ardeola*	M	A	O	LC
23	Charadriiformes	Burhinidae	Great Thick-knee *Esacus recurvirostris*	R	A	AP/I	LC
24	Charadriiformes	Laridae	Gull-billed Tern *Gelochelidon nilotica*	M	A	P	LC
25	Charadriiformes	Recurvirostridae	Black-winged Stilt *Himantopus himantopus*	R	A	AP/I	LC
26	Charadriiformes	Laridae	Little Gull *Hydrocoloeus minutus*	M	A	IN	LC
27	Charadriiformes	Laridae	Caspian Tern *Hydroprogne caspia*	M	A	P	LC
28	Charadriiformes	Laridae	Pallas's Gull *Ichthyaetus ichthyaetus*	M	A	P	LC
29	Charadriiformes	Laridae	Lesser Black-backed Gull *Larus fuscus*	M	A	P	LC
30	Charadriiformes	Laridae	Hegulin's Gull *Larus heuglini*	M	A	P	LC
31	Charadriiformes	Scolopacidae	Bar-tailed Godwit *Limosa lapponica*	M	A	IN	NT
32	Charadriiformes	Scolopacidae	Black-tailed Godwit *Limosa limosa*	M	A	AP/I	NT
33	Charadriiformes	Scolopacidae	Eurasian Curlew *Numenius arquata*	M	A	AP/I	NT
34	Charadriiformes	Scolopacidae	Whimbrel *Numenius phaeopus*	M	A	AP/I	LC
35	Charadriiformes	Scolopacidae	Ruff *Philomachus pugnax*	M	A	AP/I	LC
36	Charadriiformes	Recurvirostridae	Pied Avocet *Recurvirostra avosetta*	M	A	P	LC
37	Charadriiformes	Laridae	River Tern *Sterna aurantia*	R	A	P	LC
38	Charadriiformes	Laridae	Little Tern *Sternula albifrons*	M	A	IN	LC
39	Charadriiformes	Scolopacidae	Spotted Redshank *Tringa erythropus*	M	A	IN	LC
40	Charadriiformes	Scolopacidae	Wood Sandpiper *Tringa glareola*	M	A	AP/I	LC
41	Charadriiformes	Scolopacidae	Common Greenshank *Tringa nebularia*	M	A	AP/I	LC
42	Charadriiformes	Scolopacidae	Marsh Sandpiper *Tringa stagnatilis*	M	A	AP/I	LC
43	Charadriiformes	Scolopacidae	Common Redshank *Tringa totanus*	M	A	AP/I	LC
44	Charadriiformes	Charadriidae	Red-wattled Lapwing *Vanellus indicus*	R	T	I	LC

SLNo	Order	Family	Species	MS	Habitat	FG	IUCN-2023
45	Charadriiformes	Charadriidae	Yellow-wattled Lapwing *Vanellus malabaricus*	R	T	I	LC
46	Columbiformes	Columbidae	Rock Pigeon *Columba livia*	R	T	G	LC
47	Columbiformes	Columbidae	Eurasian Collared Dove *Streptopelia decaocto*	R	T	G	LC
48	Columbiformes	Columbidae	Laughing Dove *Streptopelia senegalensis*	R	T	G	LC
49	Coraciiformes	Alcedinidae	Common Kingfisher *Alcedo atthis*	R	A	P	LC
50	Coraciiformes	Alcedinidae	Pied Kingfisher *Ceryle rudis*	R	A	P	LC
51	Coraciiformes	Coraciidae	Indian Roller *Coracias benghalensis*	M	T	I,RP	LC
52	Coraciiformes	Coraciidae	European Roller *Coracias garrulus*	M	T	I,RP	LC
53	Coraciiformes	Alcedinidae	White-throated Kingfisher *Halcyon smyrnensis*	R	A	P	LC
54	Coraciiformes	Meropidae	Green Bee-eater *Merops orientalis*	R	T	I	LC
55	Cuculiformes	Cuculidae	Asian Koel *Eudynamys scolopaceus*	R	T	F	LC
56	Gruiformes	Rallidae	Common Coot *Fulica atra*	R	A	IN,W,H	LC
57	Gruiformes	Rallidae	Watercock *Gallicrex cinerea*	R	A	IN	LC
58	Gruiformes	Rallidae	Common Moorhen *Gallinula chloropus*	R	A	H,I,IN	LC
59	Passeriformes	Sturnidae	Common Myna *Acridotheres tristis*	R	T	O	LC
60	Passeriformes	Hirundinidae	Red-rumped Swallow *Cecropis daurica*	R	T	I	LC
61	Passeriformes	Nectariniidae	Purple Sunbird *Cinnyris asiaticus*	R	T	N	LC
62	Passeriformes	Muscicapidae	Oriental Magpie-Robin *Copsychus saularis*	R	T	I	LC
63	Passeriformes	Corvidae	Large-billed Crow *Corvus macrorhynchos*	R	T	C	LC
64	Passeriformes	Corvidae	House Crow *Corvus splendens*	R	T	O	LC
65	Passeriformes	Dicruridae	Black Drongo *Dicrurus macrocercus*	R	T	I	LC
66	Passeriformes	Estrildidae	Indian Silverbill *Euodice malabarica*	R	T	G	LC
67	Passeriformes	Alaudidae	Crested Lark *Galerida cristata*	R	T	G	LC

SLNo	Order	Family	Species	MS	Habitat	FG	IUCN-2023
68	Passeriformes	Hirundinidae	Wire-tailed Swallow *Hirundo smithii*	R	T	I	LC
69	Passeriformes	Motacillidae	Citrine Wagtail *Motacilla citreola*	RM	A	I	LC
70	Passeriformes	Motacillidae	Yellow Wagtail *Motacilla flava*	R	T	I	LC
71	Passeriformes	Motacillidae	White-browed Wagtail *Motacilla maderaspatensis*	M	A	I	LC
72	Passeriformes	Passeridae	House Sparrow *Passer domesticus*	R	T	G	LC
73	Passeriformes	Sturnidae	Rosy Starling *Pastor roseus*	M	T	O	LC
74	Passeriformes	Hirundinidae	Streak-throated Swallow *Petrochelidon fluvicola*	M	T	I	LC
75	Passeriformes	Ploceidae	Baya Weaver *Ploceus philippinus*	R	T	G	LC
76	Passeriformes	Cisticolidae	Plain Prinia *Prinia inornata*	R	T	I	LC
77	Passeriformes	Cisticolidae	Ashy Prinia *Prinia socialis*	R	T	I	LC
78	Passeriformes	Hirundinidae	Dusky Crag Martin *Ptyonoprogne concolor*	R	T	I	LC
79	Passeriformes	Pycnonotidae	Red-vented Bulbul *Pycnonotus cafer*	R	T	I	LC
80	Passeriformes	Pycnonotidae	White-eared Bulbul *Pycnonotus leucotis*	R	T	F	LC
81	Passeriformes	Muscicapidae	Indian Robin *Saxicoloides fulicatus*	R	T	I	LC
82	Pelecaniformes	Anhingidae	Oriental Darter *Anhinga melanogaster*	R	A	P.A,OP	NT
83	Pelecaniformes	Ardeidae	Great Egret *Ardea alba*	RM	A	AP/I	LC
84	Pelecaniformes	Ardeidae	Grey Heron *Ardea cinerea*	RM	A	AP/I	LC
85	Pelecaniformes	Ardeidae	Intermediate Egret *Ardea intermedia*	R	A	AP/I	LC
86	Pelecaniformes	Ardeidae	Purple Heron *Ardea purpurea*	RM	A	AP/I	LC
87	Pelecaniformes	Ardeidae	Indian Pond Heron *Ardeola grayii*	R	A	AP/I	LC
88	Pelecaniformes	Ardeidae	Cattle Egret *Bubulcus ibis*	R	T	I	LC
89	Pelecaniformes	Ardeidae	Little Egret *Egretta garzetta*	R	A	AP/I	LC
90	Pelecaniformes	Ardeidae	Western Reef Egret *Egretta gularis*	R	A	AP/I	LC

SLNo	Order	Family	Species	MS	Habitat	FG	IUCN-2023
91	Pelecaniformes	Phalacrocoracidae	Little Cormorant *Microcarbo niger*	R	A	AP/I	LC
92	Pelecaniformes	Ciconiidae	Painted Stork *Mycteria leucocephala*	RM	A	AP/I	LC
93	Pelecaniformes	Pelecanidae	Great White Pelican *Pelecanus onocrotalus*	RM	A	P	LC
94	Pelecaniformes	Phalacrocoracidae	Great Cormorant *Phalacrocorax carbo*	R	A	P	LC
95	Pelecaniformes	Phalacrocoracidae	Indian Cormorant *Phalacrocorax fuscicollis*	R	A	P	LC
96	Pelecaniformes	Threskiornithidae	Eurasian Spoonbill *Platalea leucorodia*	RM	A	AP/I	LC
97	Pelecaniformes	Threskiornithidae	Indian Black Ibis *Pseudibis papillosa*	R	T	I,G,RP	LC
98	Pelecaniformes	Threskiornithidae	Black-headed Ibis *Threskiornis melanocephalus*	RM	A	AP/I	NT
99	Phoenicopteriformes	Phoenicopteridae	Lesser Flamingo *Phoeniconaias minor*	RM	A	PL	NT
100	Phoenicopteriformes	Phoenicopteridae	Greater Flamingo *Phoenicopterus roseus*	RM	A	PL,IN	LC
RM= Resident Migrant; R=Resident; M=Migratory; T=Terrestrial; A= Aquatic; FU=Frugivore; N=Nectarivore; P=Piscivore; G=Granivore; C=Carnivore; I=Insect and other terrestrial invertebrate feeder; PL=Plankton Feeder; IN=Aquatic Invertebrate feeder; A=Amphibian feeder; OP=Ophidiovore; RP=Reptile feeder; W= weedivore; H=Herbivore; PD=Predatory; NT= Near Threatened; LC= Least Concern							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Annexure D

Marine Ecology monitoring Work order dated 10/06/2024

DEENDAYAL PORT AUTHORITY

दीनदयाल पत्तन प्राधिकरण
DEENDAYAL PORT AUTHORITY

Website : www.deendayalport.gov.in

Administrative Office Building
Post Box NO. 50
GANDHIDHAM (Kutch)
Gujarat: 370 201.
Fax: (02836) 220050
Ph.: (02836) 220038
Email : kptemc@gmail.com

NO.EG/WK/4751/Part (Marine Ecology Monitoring)/72 Dated : 10/06/2024

To,
The Gujarat Institute of Desert Ecology,
P.O.Box No. 83, Opp.Changleshwar Temple, Mundra Road,
Bhuj (Kachchh)- 370 001,Gujarat (India).
Tel.: 02832-329408, 235025.
Tele/Fax: 02832-235027
Email: desert_ecology@yahoo.com.

Kind Attn.: Dr. V. Vijay Kumar, Director, GUIDE, Bhuj.

Sub: Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme covering all seasons on various aspects of the Coastal Environs covering Physico-chemical parameters of marine water and marine sediment samples coupled with biological indices (for three years 2024-2027) reg.

Ref.: 1) DPA request vide letter no. EG/WK/4751/Part (Marine Ecology Monitoring)/22 dated 12/2/2024.
2) Offer submitted by GUIDE, Bhuj vide letter no. GUIDE/DPT/Offer/Marine /05/2024-25 dated 2/4/2024.

Sir,

Your offer for the subject work submitted vide above referred letter dated 2/4/2024 **(Copy attached – Annexure A)** amounting to Rs. 1,55,72,700.00+ 18% GST (Rupees One Crore Fifty-Five Lakhs Seventy-Two Thousand and Seven Hundred only plus eighteen percent GST), for a period of three years i.e. 2024-2027 - per year cost Rs. 51,90,900.00 {Rs. 36,60,000 for regular monitoring of Marine Ecology + Rs. 15,30,900.00 for Continuous Monitoring Programme}, including all terms & conditions mentioned in the offer letter, has been accepted by the competent authority in DPA.

2. Scope of work :

(a) Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority in terms of Sea weeds, Sea grasses, Mudflats, Sand Dunes, Echinodenns, Shrimps, Turtles, Corals, Coastal vegetation, Mangrove and other marine biodiversity components as part of the Management Plan. Marine ecology will also be monitored in terms of all micro, macro and mega floral and faunal components of marine biodiversity.

- *The above scope of work is in order to comply with the stipulated condition mentioned in the following EC & CRZ Clearances accorded by the MoEF&CC,GoI to DPA, for various projects :*

........cont.......

(i) *EC & CRZ clearance granted by the MoEF&CC,GoI dated 19/12/16 - Dev. Of 7 Integrated facilities –* ***Specific condition no. xviii.***
(ii) *EC & CRZ Clearance granted by the MoEF&CC,GoI dated 18/2/2020 – Dev. Remaining 3 integrated facilities -* ***Specific condition xxiii.***
(iii) *EC & CRZ Clearance granted by the MoEF&CC,GoI dated 19/2/2020 – Dev. Integrated facilities (Stage II- 5 projects –* ***Specific condition xv.***
(iv) *EC & CRZ Clearance granted by the MoEF&CC,GoI dated 20/11/20 – Creation of water front facilities (OJ 8 to 11) ... -* ***Para VIII Marine Ecology, Specific condition iv.***

(b) A continuous Monitoring Programme covering all seasons on various aspects of the coastal environs covering Physico-chemical parameters of marine water and marine sediment samples coupled with biological indices such as Sand Dune Vegetation, Mangroves, Sea grasses, Macrophytes and Phytoplankton on periodic basis during construction and operational phase of the project. Additionally, Primary productivity will also be carried.

- *The above scope of work is in order to comply with the stipulated condition mentioned in the following EC & CRZ Clearances accorded by the MoEF&CC,GoI to DPA for various projects :.*

(i) *EC & CRZ Clearance granted by the MoEF&CC,GoI dated 18/2/2020 – Dev. Remaining 3 integrated facilities -* ***Specific Condition xix.***
(ii) *EC & CRZ Clearance granted by the MoEF&CC,GoI dated 19/2/2020 – Dev. Integrated facilities (Stage II- 5 projects) -* ***Specific Condition xiv.***
(iii) *EC & CRZ Clearance granted by the MoEF&CC,GoI dated 1/1/2024 – Augmentation of Liquid Cargo Handling Facility .... –* ***Specific condition no. XXV.***

3. The terms of payment:

For the period (2024-25) (Monitoring Period 10 /6/2024 to 09/6/2025):

1) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Inception report by GUIDE.
2) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of First Season report by GUIDE.
3) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Second Season report by GUIDE.
4) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Third Season report by GUIDE.
5) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Final report by GUIDE.

For the period (2025-26) (Monitoring Period 10 /6/2025 to 09/6/2026) :

1) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Inception report by GUIDE.
2) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of First Season report by GUIDE.
3) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Second Season report by GUIDE.
4) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Third Season report by GUIDE.
5) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Final report by GUIDE.

.........Cont.........

the period (2026-27) (Monitoring Period 10 /6/2026 to 09/6/2027) :

1) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Inception report by GUIDE.
2) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of First Season report by GUIDE.
3) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Second Season report by GUIDE.
4) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Third Season report by GUIDE.
5) 20% of the project budget (Rs.51,90,900/year) should be paid within 15 days from the date of submission of Final report by GUIDE.

4. Obligation of DPA :

- Assistance regarding the statutory clearance from authorities concerned to be rendered by DPA for field visits.
- Study area map along with GPS coordinates is to be provided by the DPA.

5. Time Period : Three years from date of issue of work order i.e. from 10 /6/2024 to 09/6/2027 (per year three monitoring all three seasons).

6. Kindly send the acknowledgement of this work order & start the work immediately.

Thanking you.

Yours faithfully,

10/6/24

Deputy Chief Engineer & EMC (i/c)
Deendayal Port Authority

Annexure -A

Dr. V. Vijay Kumar
Director

Gujarat Institute of Desert Ecology

GUIDE/DPA/Offer/Marine/ 05 **/ 2024-25**
02.04.2024

To
Sh. Rajendra Prasad Bethi
Dy. Chief Engineer & EMC (I/c)
Deendayal Port Authority
Administrative Office Building
Post Box No.50
Gandhidham, Kachchh-370201

Sir,

Sub. : Offer forRegular monitoring of Marine Ecology and Continuous Monitoring Programme Reg.,

Ref :Your Letter No. EG/WK/4751/Part (Marine Ecology Monitoring)/22 Dt. 12.02.2024.

This is w.r.t the above cited subject and reference, we are herewith submitting the Offer to carry out "Regular Monitoring of Marine Ecology in and around Deendayal Port Authority" along with "Continuous Monitoring Programme covering all seasons on various Coastal environs covering Physico-chemical and Biological components".

Kindly find enclosed herewith our offer to carry out the said study, with a budget of Rs. 51,90,900/- (Rupees Fifty-One Lakhs Nineteen Thousand Nine Hundred only) plus applicable GST per year. The quoted budget will remain same for a period of 3 years *i.e.*, (May 2024 – May 2027) which is Rs. 1,55,72,700 plus applicable GST.

Kindly consider our offer and revert back to us for any further clarifications.

Thanking you,

Sincerely yours,

K. Kathi

Director

F DIRECTOR
Gujarat Institute of Desert Ecology
Bhuj - Kachchh.

Gujarat Institute of Desert Ecology ✣ Bhuj

Manager (Env) / Shri Anurag ... EMC
6/4

Dr. V. Vijay Kumar
Director

Gujarat Institute of Desert Ecology

COMMERCIAL OFFER

Consignee address	Our Quotation Ref. No.	Date
Deendayal Port Authority Administrative office, Post Box No 50, Gandhidham –Kachchh, Gujarat.	GUIDE / Quotation /DPA / 05 / 2024-25	02.04.2024

Kind Attention.: Sh. Rajendra Prasad, Dy. Chief Engineer & EMC (I/c)

Sub. : Techno-Commercial offerfor Regular Monitoring of Marine Ecology and Continuous Monitoring Programme

Ref. : Your Letter No. EG/WK/4751/Part (Marine Ecology Monitoring)/22 Dt. 12.02.2024.

S. No.	EC & CRZ Accorded by MoEF&CC	Service Description	Frequency	Unit Rate Per Season (Rs.)	Total Value Per Year (Rs.)
1.	MoEF&CC EC & CRZ Clearance dated February 19th December 2016 (Specific condition No. xviii of the letter dated 19.12.2016) MoEF&CC EC & CRZ Clearance dated 18th February 2020 (Specific condition xxiii) MoEF&CC Clearance dated 19th February 2020 (Specific condition xv) MoEF&CC Clearance dated 20th November 2020 (VIII Marine Ecology, Specific condition viii)	Regular Monitoring of Marine Ecology in and around the Deendayal Port Trust in terms of Sea weeds, Sea grasses, Mudflats, Sand Dunes, Fisheries, Echinoderms, Shrimps, Turtles, Corals, Coastal vegetation, Mangrove and other marine biodiversity components as part of the Management Plan. Marine ecology will also be monitored in terms of all micro, macro and mega floral and faunal components of marine biodiversity.	Three season data covering Physico-chemical and biological components (Monsoon, Post-monsoon and Pre-monsoon)	12,20,000	36,60,000
2	MoEF&CC EC & CRZ Clearance dated 18th February 2020 (Specific condition xix)	A continuous Monitoring Programme covering all seasons on various aspects of the coastal environs covering Physico-chemical parameters of marine water and		5,10,300	15,30,900

Gujarat Institute of Desert Ecology Bhuj

PO. Box No. 83, Opp. Changleshwar Temple, Mundra Road, Bhuj (Kachchh) - 370 001, Gujarat (India)
Tel : 02832 - 235025-29
www.gujaratdesertecology.com, E-mail : desert_ecology@yahoo.com

Dr. V. Vijay Kumar
Director

	MoEF&CC Clearance dated 19th February 2020 (Specific condition xiv)	marine sediment samples coupled with biological indices such as Sand Dune Vegetation, Mangroves, Sea grasses, Macrophytes and Phytoplankton on periodic basis during construction and operational phase of the project. Additionally, Primary productivity will also be carried			
	MoEF&CC Clearance dated 1st January 2024 (Specific condition xxv)				
				Total budget per year	**51,90,900**
				Total budget for Three years	**1,55,72,700**
Rupees in words: One Crore Fifty Five Lakh Seventy Two Thousand and Seven Hundred only					
GST @ 18% extra as applicable					

GUIDE: Scope of work

- Complying with the conditions imposed by the DPA as per the EC & CRZ clearance mentioned above.

DPA: Scope of work

- Assistance regarding the statutory clearance from authorities concerned to be rendered by DPA for field survey.
- Study area map along with GPS co-ordinated is to be provided by the DPA.

Terms and conditions for Report submission and mode of Payment

- 20% of the budget to be paid to GUIDE within 15 days from the date of submission of Inception report by GUIDE.
- 20% of the project budget should be paid to GUIDE within 15 days from the date of submission of First Season report by GUIDE.
- 20% of the project budget should be paid to GUIDE within 15 days from the date of submission of Second Season report by GUIDE.
- 20% of the project budget should be paid to GUIDE within 15 days from the date of submission of Third Season report by GUIDE.
- 20% of the project budget should be paid to GUIDE within 15 days from the date of submission of Final report by GUIDE.

GUIDE's Recognitions / Accreditations:

- Recognized as DSIR-SIRO, Ministry of Science and Technology, New Delhi.
- Recognized as Schedule I- Environmental Auditors by GPCB, Gandhinagar.

Yours Sincerely

Director

I/c DIRECTOR
Gujarat Institute of Desert Ecology
Bhuj - Kachchh.

Gujarat Institute of Desert Ecology
Bhuj

/

/

Annexure E

Annual monitoring repot of GEMI

Environmental Monitoring Annual Report

prepared under

"Preparing and monitoring of environmental monitoring and management plan for Deendayal Port Authority at Kandla and Vadinar for a period of 3 years"

Monitoring Period: April 2023 - March 2024

Document Ref No.: GEMI/DPA/782(2)(3)/2024-25/103

Submitted to:

Deendayal Port Authority (DPA), Kandla

Gujarat Environment Management Institute (GEMI)

(An Autonomous Institute of Government of Gujarat)

GEMI Bhavan, 246-247, GIDC Electronic Estate, Sector-25, Gandhinagar-382025

"AN ISO 9001:2015, ISO 14001:2015 AND ISO 45001:2018 Certified Institute"

About this Document

Gujarat Environment Management Institute (GEMI) has been assigned with the work of "Preparing and monitoring of Environmental monitoring and Management plan for Deendayal Port Authority (DPA) at Kandla and Vadinar for a period of 3 years" by DPA, Kandla. Under the said project the report titled *"Environment Monitoring Annual Report (Monitoring Period: April 2023 - March 2024)"* is prepared.

- **Name of the Report:** *Environment Monitoring Report (Monitoring Period April 2023-March 2024)*
- **Date of Issue:** 26/06/2024
- **Version:** 1.0
- **Report Ref.:** GEMI/DPA/782(2)(3)/2024-25/103

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List of Abbreviations

A	Acceptable Limits as per IS: 10500:2012
AAQ	Ambient Air Quality
AWS	Automatic Weather monitoring stations
BIS	Bureau of Indian Standards
BOD	Biochemical Oxygen Demand
BQL	Below Quantification Limit
CCA	Consolidated Consent & Authorization
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
DO	Dissolved Oxygen
DPA	Deendayal Port Authority
EC	Electrical Conductivity
EMMP	Environmental monitoring and Management Plan
EMP	Environment Management Plan
FPS	Fine Particulate Sampler
FY	Financial Year
GEMI	Gujarat Environment Management Institute
IFFCO	Indian Farmers Fertiliser Cooperative Limited
IMD	India Meteorological Department
IOCL	Indian Oil Corporation Limited
LNG	Liquefied Natural Gas
MGO	Marine Gas Oil
MMTPA	Million Metric Tonnes Per Annum
MoEF	Ministry of Environment & Forests
MoEF&CC	Ministry of Environment, Forest and Climate Change
NAAQS	National Ambient Air Quality Standards
NO_x	Nitrogen oxides
NTU	Nephelometric Turbidity Unit
OOT	Off Shore Oil Terminal
OSR	Oil Spill Response
P	Permissible Limits as per IS: 10500:2012
PAH	Poly Aromatic Hydrocarbons
PM	Particulate Matter
PTFE	Polytetrafluoroethylene
RCC	Reinforced Concrete Cement
RDS	Respirable Dust Sampler
SAR	Sodium Adsorption Ratio
SBM	Single Bouy Mooring
SO_x	Sulfur oxides
STP	Sewage Treatment Plant
TC	Total Coliforms
TDS	Total Dissolved Solids
TOC	Total organic Carbon
TSS	Total Suspended Solids
VOC	Volatile Organic Compounds

CHAPTER 1: INTRODUCTION

1.1 Introduction

Kandla Port, also known as the Deendayal Port is a seaport in Kachchh District near the city of Gandhidham in Gujarat state in western India. Located on the Gulf of Kachchh, it is one of major ports on the western coast, and is located at 256 nautical miles southeast of the Port of Karachi in Pakistan and over 430 nautical miles north-northwest of the Port of Mumbai (Bombay). It is the largest port of India by volume of cargo handled. Deendayal Port's journey began in 1931 with the construction of RCC Jetty by Maharao Khengarji. Kandla was constructed in the 1950s as the chief seaport serving western India, after the independence of India. On 31st March 2016, Deendayal Port created history by handling 100 MMT cargo in a year and became the first Major Port to achieve this milestone. Deendayal Port Authority (DPA), India's busiest major port in recent years, is gearing up to add substantial cargo handling capacity with private sector participation. DPA has created new record by handling 137 MMTPA (at Kandla and Vadinar) during the financial year 2022-23. The DPA had commissioned the Off-shore Oil Terminal facilities at Vadinar in the year 1978, for which M/s. Indian Oil Corporation Limited (IOCL) provided Single Bouy Mooring (SBM) system, with a capacity of 54 MMTPA. Further, significant Quantum of infrastructural upgradation has been carried out & excellent maritime infrastructure has been created at Vadinar for the 32 MMTPA Essar Oil Refinery in Jamnagar District.

1.2 Green Ports Initiative

DPA is committed to sustainable development and adequate measures are being taken to maintain the Environmental well-being of the Port and its surrounding environs. Weighing in the environmental perspective for sustained growth, the Ministry of Shipping had started, Project Green Ports" which will help in making the Major Ports across India cleaner and greener. "Project Green Ports" will have two verticals - one is "Green Ports Initiatives" related to environmental issues and second is "Swachh Bharat Abhiyaan".

The Green Port Initiatives include twelve initiatives such as preparation and monitoring plan, acquiring equipment required for monitoring environmental pollution, acquiring dust suppression system, setting up of sewage/waste water treatment plants/ garbage disposal plant, setting up Green Cover area, projects for energy generation from renewable energy sources, completion of shortfalls of Oil Spill Response (OSR) facilities (Tier-I), prohibition of disposal of almost all kind of garbage at sea, improving the quality of harbour wastes etc.

DPA had also appointed GEMI as an Advisor for "Making Deendayal Port a Green Port-Intended Sustainable Development under the Green Port Initiatives. DPA has also signed MoU with Gujarat Forest Department in August 2019 for Green Belt Development in an area of 31.942 Ha of land owned by DPA. The plantation is being carried out by the Social Forestry division of Kachchh.

1.3 Importance of Environmental monitoring and management plan (EMMP)

Port activities can cause deterioration of air and marine water quality in the surrounding areas due to multifarious activities. The pollution problems usually caused by port and harbour activities can be categorized as follows:

1. Air pollutant emissions due to ship emissions, loading and unloading activities, construction emission and emissions due to vehicular movement.

2. Coastal habitats may be destroyed and navigational channels silted due to causeway construction and land reclamation.
3. Deterioration of surface water quality may occur during both the construction and operation phases.
4. Harbour operations may produce sewage, bilge wastes, solid waste and leakage of harmful materials both from shore and ships.
5. Human and fish health may be affected by contamination of coastal water due to urban effluent discharge.
6. Oil pollution is one of the major environmental hazards resulting from port/harbour and shipping operations. This includes bilge oil released from commercial ships handling non-oil cargo as well as the more common threat from oil tankers.
7. Unregulated mariculture activities in the port and harbour areas may threaten navigation safety.

Hence, for the determination of levels of pollution, identification of pollution sources, control and disposal of waste from various point and non-point sources and for prediction of pollution levels for future, regular monitoring and assessment are required during the entire construction and operation phase of a major port. As per the Ministry of Environment, Forest and Climate Change **(MoEF&CC)**, The Environmental Management Plan (EMP) is required to ensure sustainable development in the area surrounding the project. Hence, it needs to be an all encompasses plan consist of all mitigation measures for each item wise activity to be undertaken during the construction, operation and the entire life cycle to minimize adverse environmental impacts resulting from the activities of the project. for formulation, implementation and monitoring of environmental protection measures during and after commissioning of projects. The plan should indicate the details of various measures are taken and proposed to be taken for appropriate management of the environment of Deendayal Port Authority.

It identifies the principles, approach, procedures and methods that will be used to control and minimize the environmental and social impacts of operational activities associated with the port. An EMP is a required part of environmental impact assessment of a new port project but could also be evolved for existing ports. It is useful not only during the construction and operational phases of the new port but also for operation of existing ports to ensure the effectiveness of the mitigation measures implemented and to further provide guidance as to the most appropriate way of dealing with any unforeseen impacts.

It is extremely essential that port and harbour projects should have an Environmental Monitoring and Management Plan (EMMP), which incorporates monitoring of Ambient Air, Drinking Water, Noise, Soil, Marine (water, sediment, ecology) quality along with the collection of online meteorological data throughout the duration of the project.

To ensure the effective implementation of the EMP and weigh the efficiency of the mitigation measures, it is essential to undertake environmental monitoring both during construction and operation period. In view of the above, Gujarat Environment Management Institute (GEMI) has been awarded with the work "**Preparing and Monitoring of Environmental Monitoring and Management Plan for Deendayal Port Authority at Kandla and Vadinar for a period of 3 years**" vide letter No. EG/WK/EMC/1023/2011/III/239 dated: 15/02/2023 by DPA.

This document presents the Environmental Monitoring Report (EMR) for Kandla and Vadinar for the environmental monitoring done during the period from April 2023-March 2024.

1.4 Objectives and scope of the Study

In line with the work order, the key objective of the study is to carry out the Environmental Monitoring and preparation the Management Plan for Kandla and Vadinar for a period of 3 years". Under the project, Environmental monitoring refers to systematic monthly monitoring and assessment of ambient air, water (drinking and surface), soil, sediment, noise and ecology in order to monitor the performance and implementation of a project in compliance with Environmental quality standards and/or applicable Statutory norms.

The scope of work includes not limited to following:

1. To review the locations/stations of Ambient Air, Ambient Noise, drinking water, and Marine Water, Soil and Sediments monitoring within the impacted region in-and-around DPA establishment, in view of the developmental projects.
2. To assess the Ambient Air quality, quality at 6 stations at Kandla and 2 at Vadinar in terms of gases and particulate matter.
3. To assess the DG stack emissions (gases and particulate matter).
4. To assess Drinking water quality at twenty locations (18 at Kandla and 2 at Vadinar) in terms of Physical, Chemical and Biological parameters viz., Color, Odor, turbidity, conductivity, pH, Total Dissolved Solids, chlorides, Hardness, total iron, sulphate, NH_4, PO_4, and bacterial count on a monthly basis.
5. To assess the Marine water quality in terms of aquatic Flora and Fauna and Sediment quality in terms of benthic flora and fauna.
6. To assess Marine Water Quality and sediment in term of physical and chemical parameter.
7. To assess the trends of water quality in terms of Marine ecology by comparing the data collected over a specified time period.
8. Weekly sample collection and analysis of inlet & Outlet points of the Sewage Treatment Plant (STP) to check the water quality being discharged by DPA as per the CC&A.
9. Carrying out monthly Noise monitoring; twice a day at the representative stations for a period of 24 hours.
10. Meteorological parameters are very important from air pollution point of view, hence precise and continuous data collection is of utmost importance. Meteorological data on wind speed, wind direction, temperature, relative humidity, solar radiation and rainfall shall be collected from one permanent station at DPA, Kandla and one permanent station at Vadinar.
11. To suggest mitigation measures, based on the findings of this study and also check compliance with Environmental quality standards, Green Port Initiatives, MIV 2030, and any applicable Statutory Compliance.
12. To recommend Environment Management Plans based on Monitoring programme and findings of the study.

CHAPTER 2: METHODOLOGY

2.1 Study Area

Under the study, the locations specified by Deendayal Port Authority for the areas of Kandla and Vadinar would be monitored. The details of the study area as follows:

a. Kandla

Deendayal Port (Erstwhile Kandla Port) is one of the twelve major ports in India and is located on the West Coast of India, in the Gulf of Kutch at 23001'N and 70013'E in Gujarat. The Major Port Authorities Act 2021 is the governing statute for Administration of Major Ports, under which, Deendayal Port Trust (DPT) has become Deendayal Port Authority (DPA). At Kandla, DPA has sixteen (16) cargo berths for handling various types of Dry Bulk Cargo viz, fertilizer, food grains, Coal, sulphur, etc.

- **Climatic conditions of Kandla**

Kandla has a semi-desert climate. Temperature varies from 25°C to 44°C during summer and 10°C to 25°C during winter. The average annual temperature is 24.8 °C. The average rainfall is 410 mm, most of which occurs during the monsoon from the months of June-to-September.

b. Vadinar

Vadinar is a small coastal town located in Devbhumi Dwarka district of the Gujarat state in India located at coordinates 22° 27' 16.20" N - 069° 40' 30.01”. DPA had commissioned the Off Shore Oil Terminal (OOT) facilities at Vadinar in the year 1978, for which M/s. Indian Oil Corporation Limited (IOCL) provided Single Bouy Mooring (SBM) system, with a capacity of 54 MMTPA. The OOT of the DPA contributes in a large way to the total earnings of this port. Vadinar is now notable due to the presence of two refineries-one promoted by Reliance Industries and Essar Oil Ltd.

DPA also handled 43.30 MMT at Vadinar (which includes transhipment), the containerized cargo crossed 4.50 lakh TEU, grossing a total of 100 MMT overall. Major commodities handled by the Deendayal Port are Crude Oil, Petroleum product, Coal, Salt, Edible Oil, Fertilizer, etc.

- **Climatic conditions of Vadinar**

Vadinar has a hot semi-arid climate. The summer season lasts from March-to-May and is extremely hot, humid, but dry. The climatic conditions in Vadinar are quite similar to that recorded in its district head quarter i.e., Jamnagar. The annual mean temperature is 26.7 °C. Rainy season with extremely erratic monsoonal rainfall that averages around 630 millimetres. The winter season is from October-to-February remains hot during the day but has negligible rainfall, low humidity and cool nights.

The Kandla and Vadinar port have been depicted in the **Map 1 & 2** as follows:

SS

Map 1: Locations of Kandla and Vadinar Port

Map 2: Locations of Kandla Port

Map 3: Locations of Vadinar Port

2.2 Environmental Monitoring at Kandla and Vadinar

Regular monitoring of environmental parameters is of immense importance to assess the status of environment during project operation. With the knowledge of baseline conditions, the monitoring programme will serve as an indicator for identifying any deterioration in environmental conditions, thereby assist in recommending suitable mitigatory steps in time to safeguard the environment. Monitoring is as important as that of control of pollution since the efficiency of control measures can only be determined by a well-defined monitoring program. Environmental Monitoring is vital for monitoring the environmental status of the port for sustainable development. The list of main elements for which Environmental monitoring is to be carried out have been mentioned below:

- Meteorology
- Ambient Air
- DG Stack
- Noise
- Soil
- Drinking Water
- Sewage Treatment Plant
- Marine (Surface) water
- Marine Sediments
- Marine Ecology

GEMI has been entrusted by DPA to carry out the monitoring of the various aforementioned environmental aspects at the port, so as to verify effectiveness of prevailing Environment Management plan, if it confirms to the statutory and/or legal compliance; and identify any unexpected changes. Standard methods and procedures have been strictly adhered to in the course of this study. QA/QC procedures were strictly followed which covers all aspects of the study, and includes sample collection, handling, laboratory analyses, data coding, statistical analyses, interpretation and communication of results. The analysis was carried out in GEMI's NABL/MoEF accredited/recognized laboratory.

Methodology adopted for the study

Methodology is a strictly defined combination of practices, methods and processes to plan, develop and control a project along the continuous process of its implementation and successful completion. The aim of the project management methodology is to allow the control of whole process of management through effective decision-making and problem solving. The methodology adopted for the present study is shown in **Figure 1** as given below:

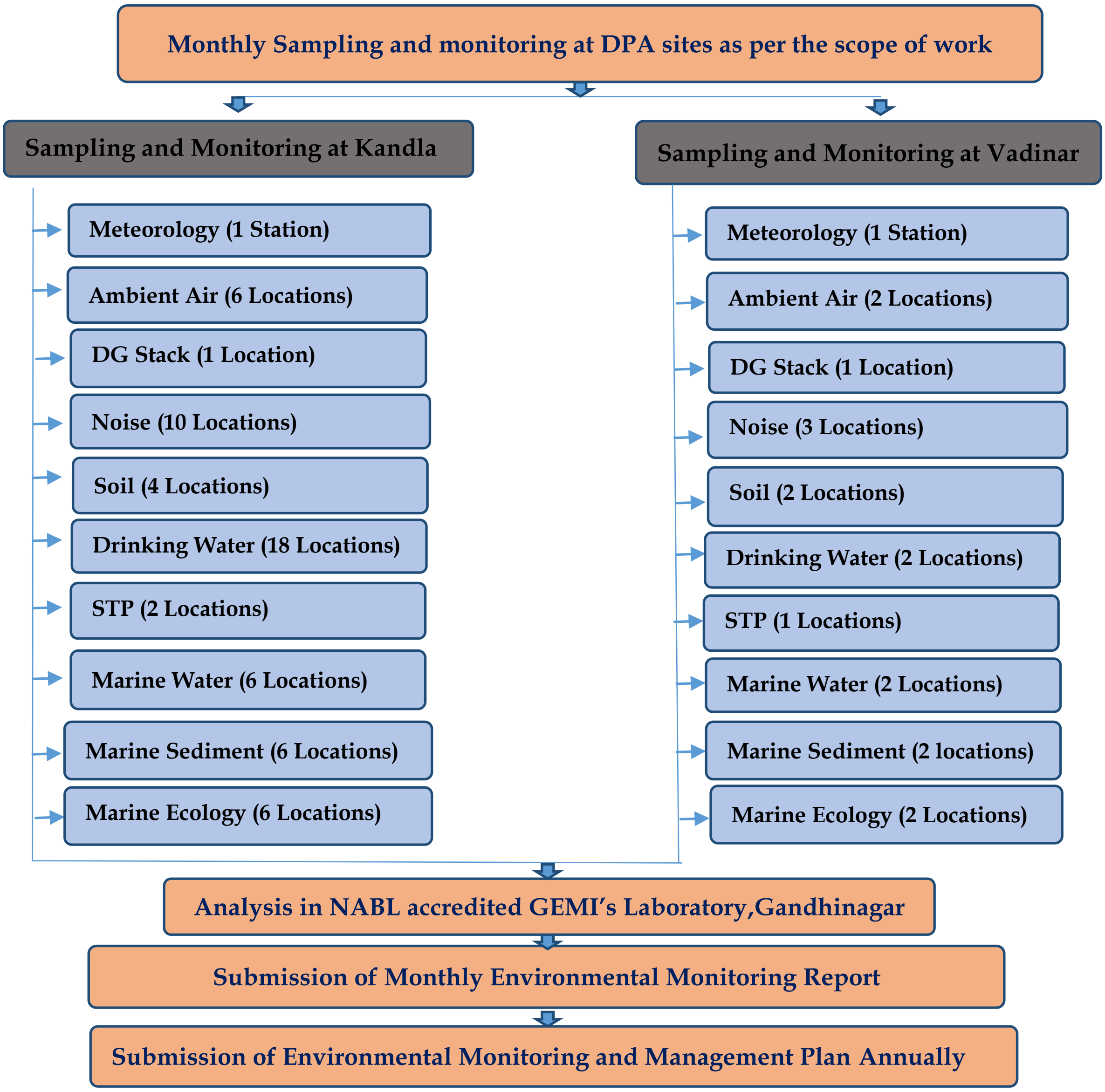


Figure 1: Methodology flow chart

The details of various sectors of Environment monitoring are described in subsequent chapters.

CHAPTER 3: METEOROLOGY MONITORING

3.1 Meteorology Monitoring

Meteorological conditions play a crucial role in dispersion of air pollutants as well as in environmental pollution studies particularly in pollutant transport irrespective of their entry into the environment. The wind speed and direction play a major role in dispersion of environment pollutants. In order to determine the prevailing micro-meteorological conditions at the project site an Automatic Weather Monitoring Stations (AWS) of Envirotech make (Model: WM280) were installed at both the sites of Kandla and Vadinar at 10 m above the ground. The details of the AWS installed have been mentioned in **Table 1** as follows:

Table 1: Details of Automatic Weather Station

Sr. No.	Site	Location Code	Location Name	Latitude Longitude
1.	Kandla	AWS-1	Environment Laboratory (DPA)	23.00996N 70.22175E
2.	Vadinar	AWS-2	Canteen Area	22.39994N 69.716608E

Methodology:

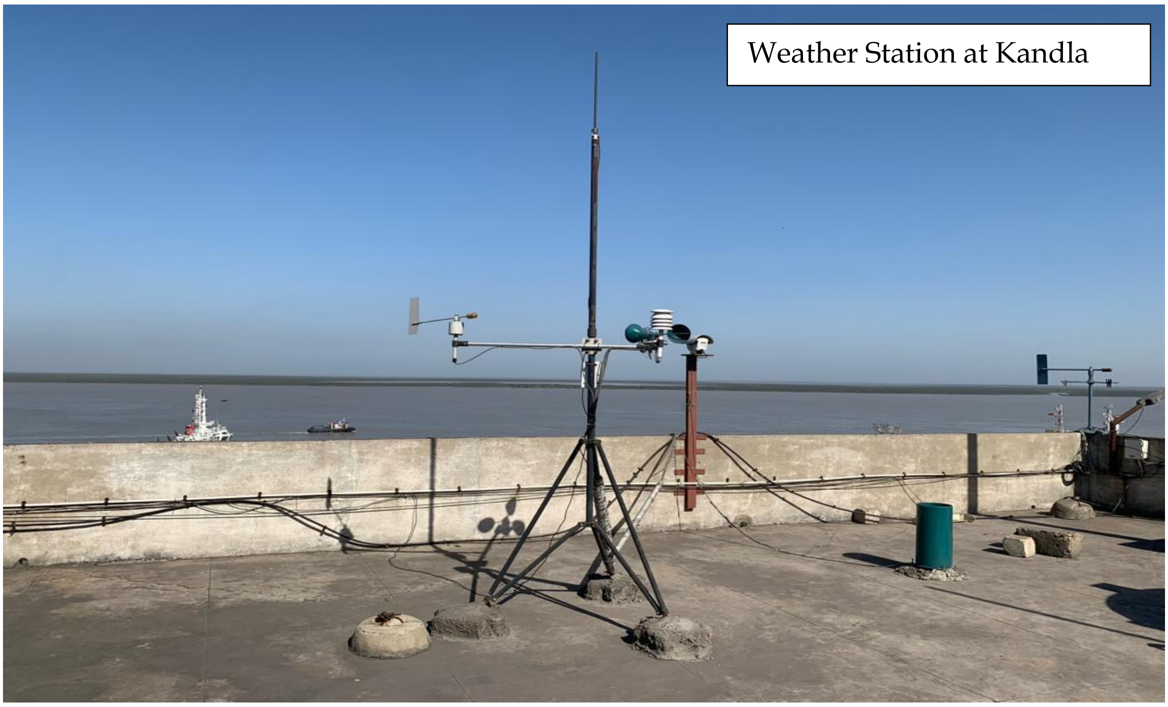
During the study, a continuous automatic weather monitoring station was installed at both the sites to record climatological parameters such as Wind speed, Wind Direction, Relative Humidity, Solar Radiation, Rainfall and Temperature to establish general meteorological regime of the study area. The methodology adopted for monitoring meteorological data shall be as per the standard norms laid down by Bureau of Indian Standards (BIS) and the India Meteorological Department (IMD). The details of Automatic Weather Monitoring Station have been mentioned in **Table 2**.

Table 2: Automatic Weather Monitoring Station details

Sr. No.	Details of Meteorological Data	Unit of Measurement	Instrument	Frequency
1.	Wind Direction	degree	Automatic Weather Monitoring Station (Envirotech WM280)	Hourly Average
2.	Wind Speed	Km/hr		
3.	Rainfall	mm/hr		
4.	Relative Humidity	% RH		
5.	Temperature	°C		
6.	Solar Radiation	W/m^2		

Monitoring Frequency:

The Meteorological parameters were recorded at an interval of 1 hour in a day for the period of April 2023 to March 2024 and the average value for all the Meteorological parameters were summarized for the sampling period of at both the observatory site.



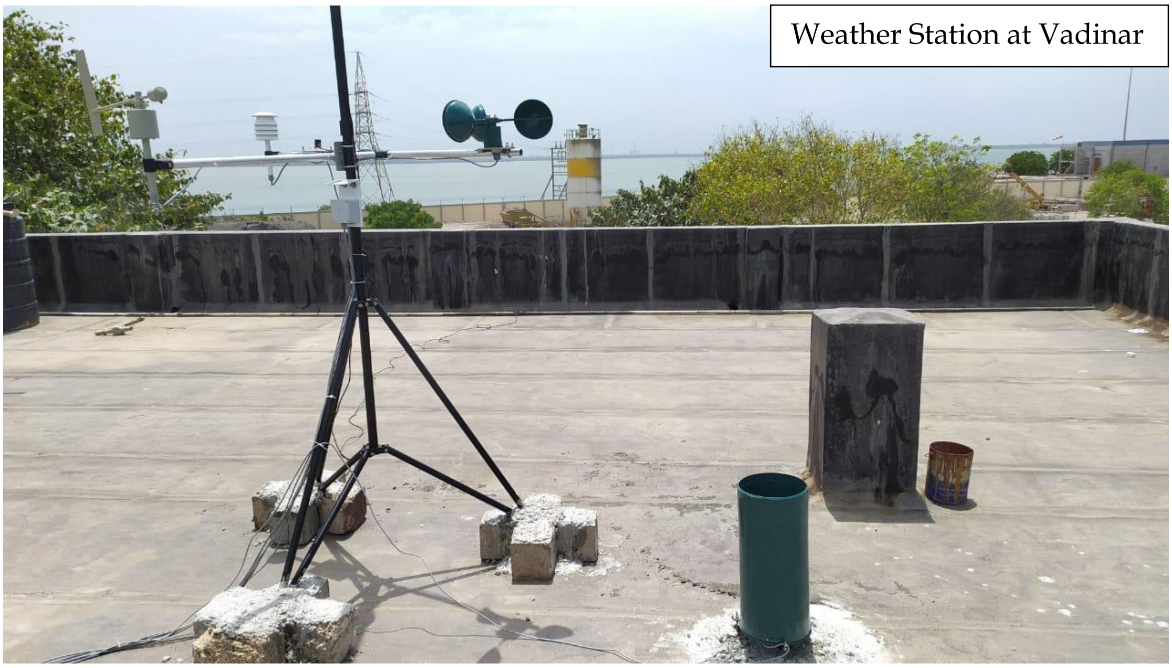


Figure 2: Photographs of Automatic Weather Monitoring Station at Kandla and Vadinar

3.2 Results and discussion

The summary of hourly climatological observations recorded at Kandla and Vadinar during the monitoring period of **April 2023 to March 2024,** with respect to significant parameters has been mentioned in **Table 3** as follows:

Table 3: Meteorological data for Kandla and Vadinar

Details of Micro-meteorological data at Kandla Observatory												
Monitoring Period	Wind Speed (Km/h)			Temperature (°C)			Relative humidity (%)			Solar Radiation (W/m²)	Wind Direction (°)	Rainfall (mm)
	Max.	Min	Avg.	Max.	Min	Avg.	Max.	Min	Avg.			
April-May 23	27.02	1.54	8.78	32.21	30.4	31.31	64.12	61.07	57.76	105.42	S.S.E	0.05
May-June 23	48.85	3.07	12.94	32.64	31.23	31.93	70.33	65.93	68.17	90.14	N & N.N.W	0.37
June- July 23	38.99	1.23	9.71	31.54	30.27	30.89	76.32	72.43	74.47	67.76	E.W.E & W.S.W	3.56
July-Aug 23	35.4	1.47	7.67	30.51	29.32	29.91	77.72	73.87	75.78	57.4	W.S.W	14.94
Aug-Sep 23	37.52	0.63	6.55	48.44	30.33	38.43	84.57	69.18	75.59	73.28	W.S.W	21.89
Sep- Oct 23	20.36	0.16	4.75	31.01	29.66	30.32	71.62	66.85	69.32	74.08	W.S.W	2.87
Oct- Nov 23	9.85	0.025	1.15	31.24	29.63	30.41	55.4	49.02	52.18	65.11	North	0.012
Nov- Dec 23	14.72	0	2.09	25.76	24.32	25.03	59.69	54.6	57.1	54.28	N.E	0.96
Dec- Jan 24	15.75	0	1.87	23.22	21.68	22.44	56.5	51.11	53.78	60.66	North	0
Jan- Feb 24	15.29	0.131	3.147	24.83	23.18	24	56	50.51	53.19	65.32	North	0
Feb- Mar 24	22.41	0.44	5.12	26.7	25.06	25.86	51.55	45.91	48.64	78.46	North	0.04
Mar- Apr 24	33.09	0.025	5.43	48.44	26.87	30.08	73.25	30.59	55.06	89.43	W.S.W	0

Details of Micro-meteorological data at Vadinar Observatory												
Monitoring Period	**Wind Speed (Km/h)**			**Temperature (°C)**			**Relative humidity (%)**			**Solar Radiation (W/m²)**	**Wind Direction (°)**	**Rainfall (mm)**
	Max.	**Min**	**Avg.**	**Max.**	**Min**	**Avg.**	**Mean**	**Max.**	**Min**			
April-May 23	26.33	7.78	13.24	28.74	28.04	28.17	73.47	70	71.08	110.76	W & South	0.02
May-June 23	34.08	7.63	16.76	29.96	29.22	29.34	71.77	69.03	69.83	102.95	S.S.E	0.19
June- July 23	12.31	1.62	5.19	29.51	28.86	28.94	77.68	75.42	75.95	78.26	South	0.27
July-Aug 23	31.69	5.39	13.12	28.62	27.99	28.06	79.51	77.31	77.77	60.86	South	0.22
Aug-Sep 23	28.07	5.2	12.96	27.75	27.18	27.22	75.13	72.87	73.42	88.14	South & S.W	0
Sep- Oct 23	21.82	4.64	9.59	28.12	27.5	27.56	77.12	74.66	75.32	87.51	South	0.06
Oct- Nov 23	13.8	1.77	4.17	27.89	27.1	27.28	63.61	59.58	61.15	81.61	N.E	0.18
Nov- Dec 23	19.37	3	4.84	24.79	24.11	24.24	64.12	60.47	61.79	70.68	S.S.E	0.03
Dec- Jan 24	16.76	1	4.18	22.94	22.14	22.34	63.13	59.25	60.71	73.37	South	0
Jan- Feb 24	10.62	1.99	3.94	23.24	22.92	22.7	65.66	64.19	64.9	87.29	South	0
Feb- Mar 24	16.92	5.36	8.55	24.16	23.6	23.82	62.34	60.91	61.51	101.99	N.N.W	0
Mar- Apr 24	29.61	0.31	11.63	29.8	24.96	26.5	82.36	57.41	71.08	114.77	N.N.W	0

3.3 Data Interpretation and Conclusion

1) Kandla:

a. The ambient temperature for the summer season varies in the range of **21.68** to **48.44** °C; in the monsoon season, the temperature varies between **29.32** and **33.38** °C; and in the winter season, the temperature varies between **21.68** and **31.24** °C. The yearly average temperature at Kandla is observed to be around **29.217** °C, with a standard deviation of 4.31.

b. The relative humidity for the summer season was recorded in the range of **30.59%** to **76.32%**; in the monsoon season, relative humidity was recorded in the range of **66.85%** to **84.57%**; and in the winter season, relative humidity was recorded in the range of **49.02** to **59.69%**; the yearly average humidity at Kandla was **61.75%** with a standard deviation of **10.635**.

c. The maximum rainfall at Kandla was observed at **21.89** mm for the monitoring period of August to September 2023; the yearly average rainfall was found to be **3.72** mm.

d. Wind speed and direction play a significant role in transporting pollutants and thus determining the air quality. In the summer season, wind blew from the North and North North West directions; in the monsoon season, wind blew from the West South West; and in the winter season, wind blew from the North direction.

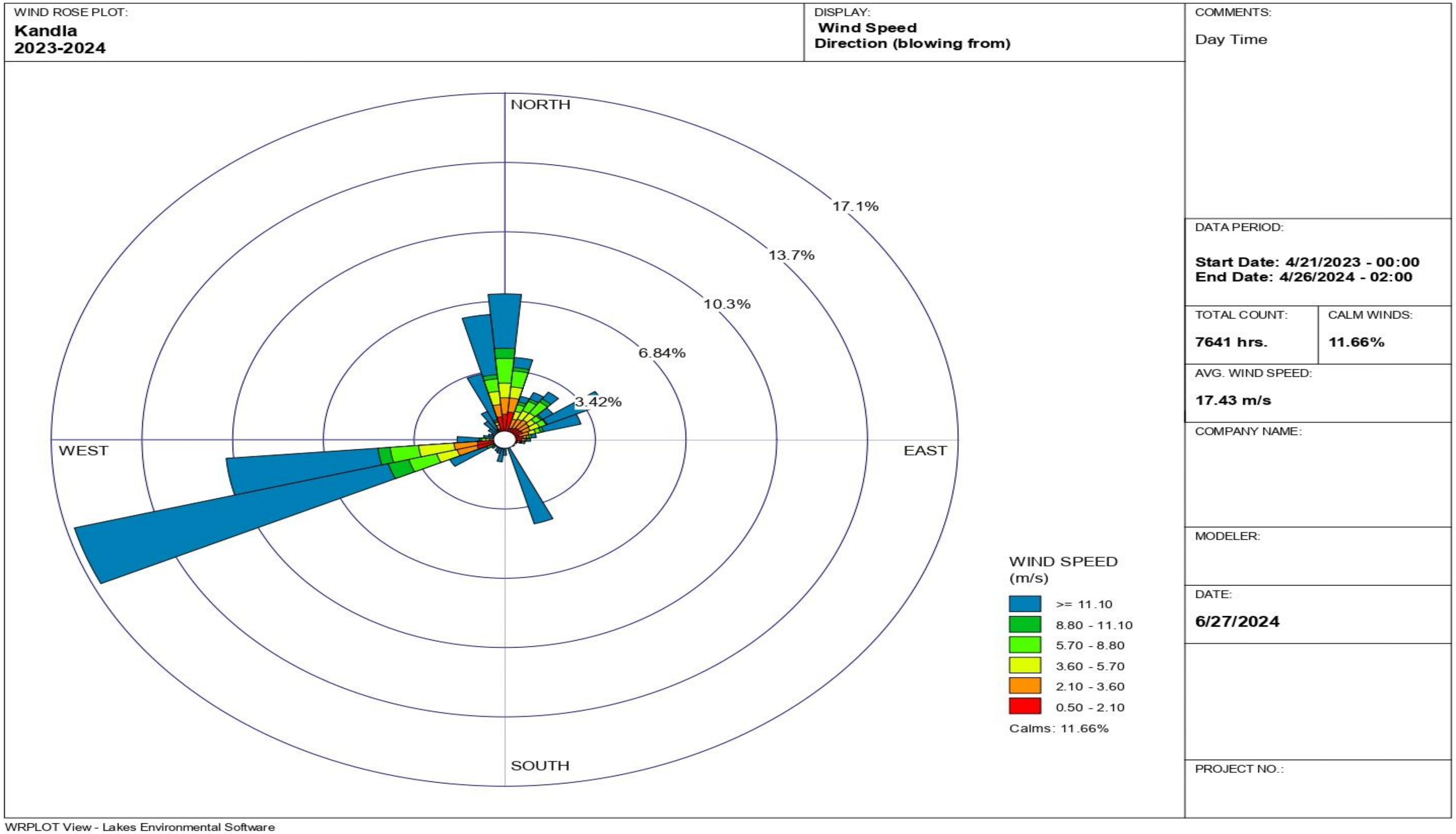
e. The wind speed recorded ranges from **0.025** to **48.85** km/h in the summer season; in the monsoon season, the wind speed recorded ranges from **0.16** to **37.52** km/h; and in the winter season, the wind speed recorded ranges from **0** to **15.75** km/h. The yearly average wind speed at Kandla is **5.77** km/h, with a standard deviation of 3.55.

f. The **maximum** solar radiation at Kandla was observed at **105.42** W/m^2 during the monitoring period **April to May 2023**; the **minimum** solar radiation at Kandla was observed at 54.**28** W/m^2 for the monitoring period **November to December 2023; and** the yearly **average** solar radiation was found to be **73.445** W/m2 with a standard deviation of 15.19.

Wind rose diagram:

The wind-rose diagram for the monitoring period has been drawn on the basis of hourly wind speed and direction data.

This Wind Rose Diagram reveals that at Kandla during the monitoring period, the prevailing winds predominantly blow from the West South West direction at Kandla, whereas, high speed winds were also observed to blow from North direction.


WIND ROSE PLOT:
Kandla
2023-2024
DISPLAY:
Wind Speed
Direction (blowing from)
COMMENTS:
Day Time
DATA PERIOD:
Start Date: 4/21/2023 - 00:00
End Date: 4/26/2024 - 02:00
TOTAL COUNT:
7641 hrs.
CALM WINDS:
11.66%
AVG. WIND SPEED:
17.43 m/s
COMPANY NAME:
MODELER:
DATE:
6/27/2024
PROJECT NO.:
NORTH
SOUTH
EAST
WEST
17.1%
13.7%
10.3%
6.84%
3.42%
WIND SPEED (m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 11.66%
WRPLOT View - Lakes Environmental Software

2) Vadinar:

a. The ambient temperature for the summer season varies between **23.6** and **29.96** °C; in the monsoon season, it varies between **27.18** and **28.62** °C; and in the winter season, it varies between **22.14** and **27.89** °C. The yearly average temperature at Vadinar is **2.347** °C with standard deviation of **2.4**.

b. The relative humidity for the summer season was recorded in the range of **57.41**% to **82.36**%; in the monsoon season, relative humidity was recorded in the range of **72.87**% to **79.51**%; and in the winter season, relative humidity was recorded in the range of **59.25**% to **65.66**%; the yearly average humidity at Vadinar was **68.7**% with a standard deviation of 6.38.

c. The **maximum** rainfall at Vadinar was observed at **0.27** mm for the monitoring period from **June to July 2023**; the yearly **average** rainfall was found to be **0.08** mm.

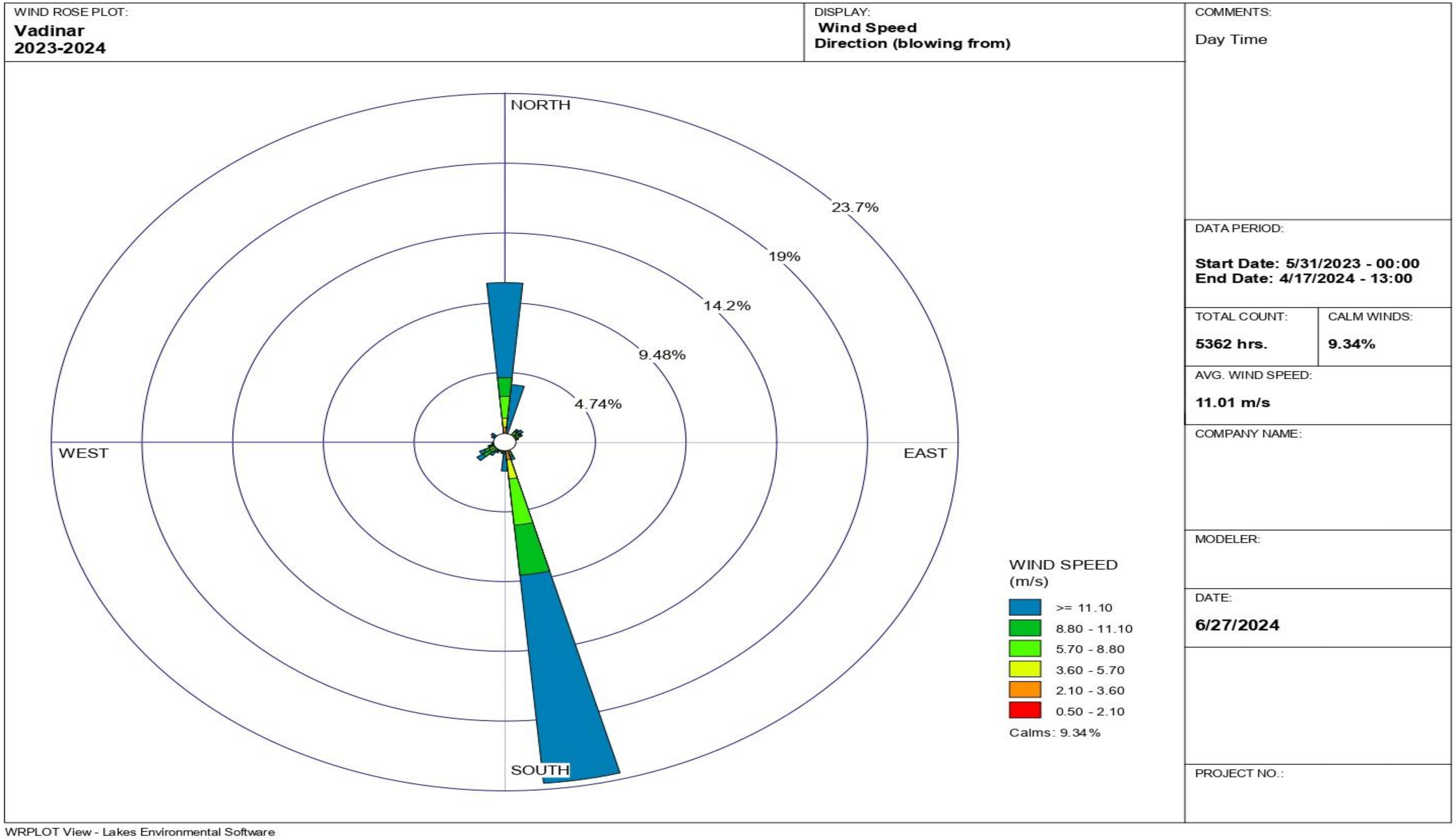
d. In Summer Season wind blew from South Direction, in Monsoon season wind blew from South and in Winter Season wind blew from South and South West direction. The recorded wind speed ranges from **0.31** to **34.08** km/hr in the summer season, **4.64** to **31.69** km/hr, and in the monsoon season, the recorded wind speed ranges from **1** to **19.37** km/hr. The yearly average wind speed at Vadinar is 9.014 km/h with a standard deviation of **4.49**.

e. The maximum solar radiation at Vadinar was observed at **114.77** W/m2 for the monitoring period April to May 2024; the minimum solar radiation at Vadinar was observed at **60.86** W/m2 for the monitoring period July to August 2023; and the yearly average solar radiation was found to be **88.182** W/m2.

Wind rose diagram:

The wind-rose diagram for the monitoring period has been drawn on the basis of hourly wind speed and direction data.

At Vadinar, the winds were observed to blow from Souths direction.


WIND ROSE PLOT:
Vadinar
2023-2024
DISPLAY:
Wind Speed
Direction (blowing from)
COMMENTS:
Day Time
NORTH
SOUTH
WEST
EAST
23.7%
19%
14.2%
9.48%
4.74%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 9.34%
DATA PERIOD:
Start Date: 5/31/2023 - 00:00
End Date: 4/17/2024 - 13:00
TOTAL COUNT:
5362 hrs.
CALM WINDS:
9.34%
AVG. WIND SPEED:
11.01 m/s
COMPANY NAME:
MODELER:
DATE:
6/27/2024
PROJECT NO.:
WRPLOT View - Lakes Environmental Software

CHAPTER 4: AMBIENT AIR QUALITY MONITORING

4.1 Ambient Air Quality

It is necessary to monitor the ambient air quality of the study area, in order to determine the impact of the shipping activities and port operations on the ambient air quality. The prime objective of ambient air quality monitoring is to assess the present air quality and its conformity to National Ambient Air Quality Standards i.e. NAAQS, 2009[1].

Methodology

The study area represents the area occupied by DPA and its associated Port area. The sources of air pollution in the region are mainly vehicular traffic, fuel burning, loading & unloading of dry cargo, fugitive emissions from storage area and dust arising from unpaved village roads. Considering the below factors, under the study, as per the scope specified by DPA eight locations wherein, 6 stations at Kandla and 2 at Vadinar have been finalized within the study area

- Meteorological conditions;
- Topography of the study area;
- Direction of wind;
- Representation of the region for establishing current air quality status
- Representation with respect to likely impact areas.

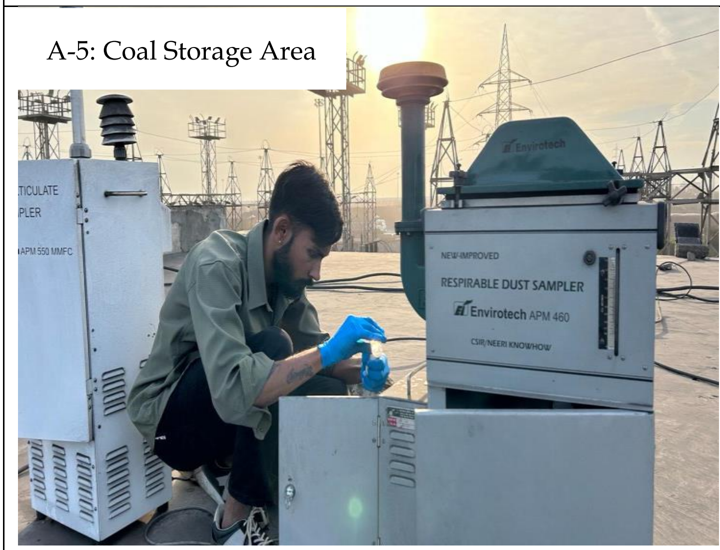
The description of various air quality stations monitored at Kandla and Vadinar have been specified in **Table 4**.

Table 4: Details of Ambient Air monitoring locations

Sr. No.	Location Code		Location Name	Latitude Longitude	Significance
1.	Kandla	A-1	Oil Jetty No. 1	23.029361N 70.22003E	Liquid containers and emission from ship
2.		A-2	Oil Jetty No. 7	23.043538N 70.218617E	
3.		A-3	Kandla Port Colony	23.019797N 70.213536E	Vehicular activity and dust emission
4.		A-4	Marine Bhavan	23.007653N 70.222197E	Construction and vehicular activity, road dust emission,
5.		A-5	Coal Storage Area	23.000190N 70.219757E	Coal Dust, Vehicular activity
6.		A-6	Gopalpuri Hospital	23.081506N 70.135258E	Residential area, dust emission, vehicular activity
7.	Vadinar	A-7	Admin Building	22.441806N 69.677056E	Vehicular activity
8.		A-8	Vadinar Colony	22.401939N 69.716306E	Residential Area, burning waste, vehicular activity

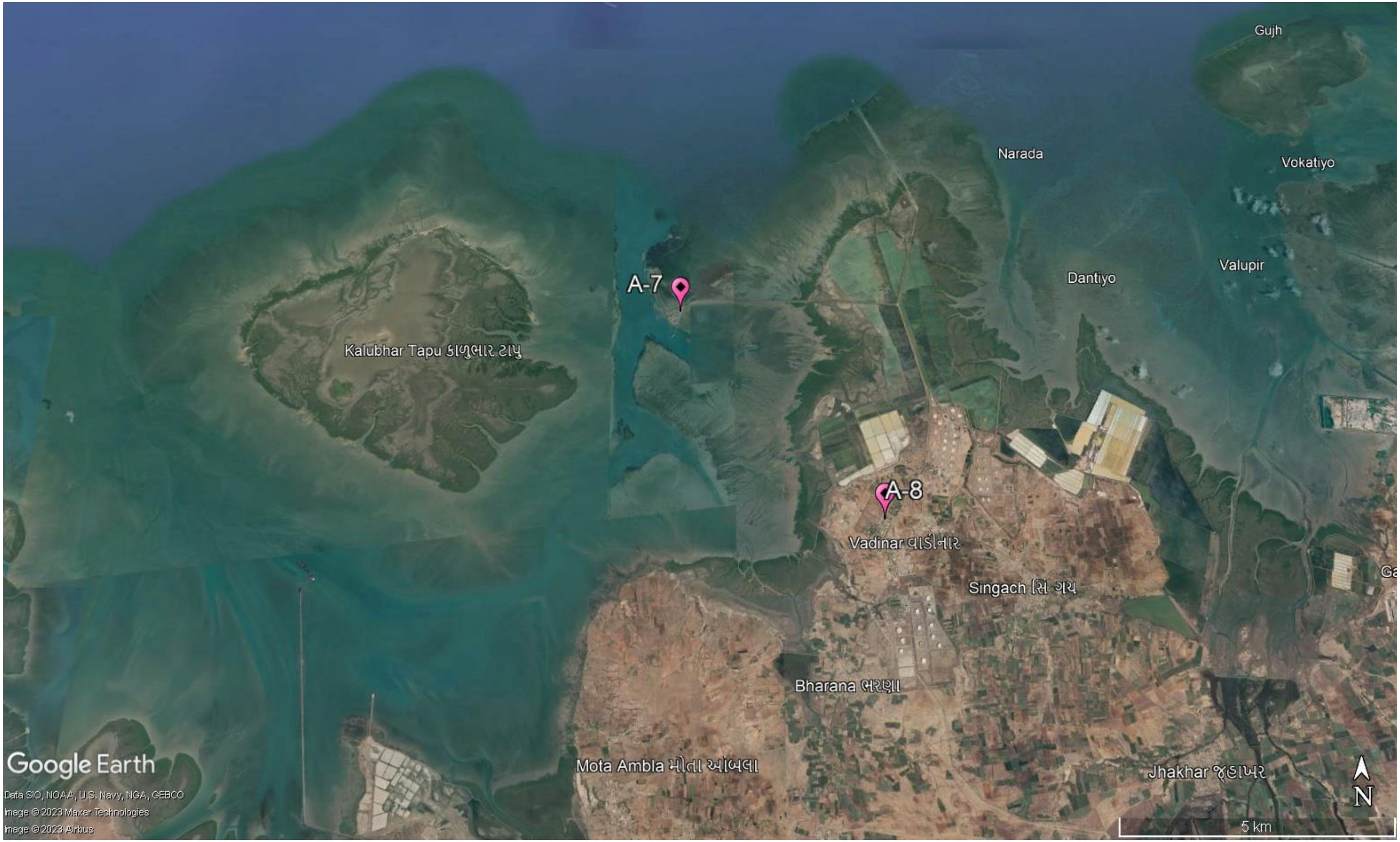
The monitoring locations at Kandla and Vadinar have been depicted in map in **Map 4 and 5** respectively.

Ambient Air monitoring photos

Kandla	
A-1: Oil Jetty No. 1 	A-2: Oil Jetty No. 7 
A-3: Kandla Port Colony 	A-4: Marine Bhavan 
A-5: Coal Storage Area 	A-6: Gopalpuri Hospital 

Vadinar	
A-7: Admin Building 	A-8: Vadinar Colony 

Map 4: Ambient Air Monitoring locations at Kandla



Map 5: Ambient Air Monitoring locations at Vadinar

Monitoring Frequency

The sampling for Particulate matter, i.e., PM_{10} and $PM_{2.5}$, and gaseous components like SO_x, NO_x, and CO, as well as the total VOCs, was monitored twice a week for a period of 24 hours a day. Whereas, the sampling for the components of PAH, benzene, and non-methane VOCs was conducted on a monthly basis. The monitoring period for this study is from April 15, 2023, to April 15, 2024. During this period, 95 air samples were taken from six locations in Kandla, and 97 samples were taken from two locations in Vadinar.

Sampling and Analysis

The Sampling of the Ambient Air Quality parameters and analysis is conducted as per the CPCB guidelines of National Ambient Air Quality Monitoring. The sampling was performed at a height of 3.5 m (approximately) from the ground level. For the sampling of PM_{10}, calibrated 'Respirable Dust Samplers' were used, where Whatman GF/A microfiber filter paper of size 8″x 10″ were utilized, where the Gaseous attachment of the make Envirotech instrument was attached with Respirable Dust Sampler for the measurement of SO_x and NO_x. The Fine Particulate Sampler for collection of $PM_{2.5}$ was utilized for the particulate matter of size <2.5 microns. A known volume of ambient air is passed through the cyclone to the initially pre-processed filter paper. The centrifugal force in cyclone acts on particulate matter to separate them into two parts and collected as following:

- Particles <10 μ size (Respirable): GF/A Filter Paper
- Particles <2.5 μ size (Respirable): Polytetrafluoroethylene (PTFE)

Sampling and analysis of ambient SO_2 was performed by adopting the 'Improved West and Gaeke Method'. The ambient air, drawn through the draft created by the RDS, is passed through an impinger, containing a known volume of absorbing solution of Sodium tetrachloromercurate, at a pre-determined measured flow rate of 1 liter/minute (L/min). Similarly, NO_x was performed by adopting the 'Jacob Hochheister Modified' (Na arsenite) method. The impinger contains known volume of absorbing solution of Sodium Arsenite and Sodium Hydroxide.

Data has been compiled for PM_{10}, $PM_{2.5}$, SO_x and NO_x samples of 24-hour carried out twice a week. In case of CO, one hourly sample were taken on selected monitoring days using the sensor-based CO Meter. For the parameters Benzene, Methane & Non-methane and Volatile Organic Carbons (VOCs), the Low Volume Sampler is used, where the charcoal tubes are used as sampling media. The sampling in the Low Volume Sampler (LVS) is carried out as per IS 5182 (Part 11): 2006 RA: 2017, where the ambient air flow rate is maintained at 200 cc/min, the volume of air that passes through the LVS during two hours monitoring is approx. 24 L.

The sampling of PAHs is carried out as per IS: 5182 (Part 12): 2004. Where, the EPM 2000 Filter papers are utilized in the Respirable Dust Sampler (RDS). For the parameters, Benzene, PAH & Non-methane VOC's, monthly monitoring is carried out. The details of the parameters with their frequency monitored are mentioned in **Table 5:**

Table 5: Parameters for Ambient Air Quality Monitoring

Sr. No.	Parameters	Units	Reference method	Instrument	Frequency
1.	PM_{10}	µg/m³	IS 5182 (Part 23): 2006	Respirable Dust Sampler (RDS) conforming to IS:5182 (Part-23): 2006	Twice in a week
2.	$PM_{2.5}$	µg/m³	IS:5182 (Part:24):2019	Fine Particulate Sampler (FPS) conforming to IS:5182 (Part-24): 2019	
3.	Sulphur Dioxide (SO_x)	µg/m³	IS 5182 (Part:2): 2001	Gaseous Attachment conforming to IS:5182 Part-2	
4.	Oxides of Nitrogen (NO_x)	µg/m³	IS:5182 (Part-6): 2006	Gaseous Attachment conforming to IS:5182 Part-6	
5.	Carbon Monoxide (CO)	mg/m³	GEMI/SOP/AAQM/11; Issue no 01, Date 17.01.2019: 2019	Sensor based Instrument	
6.	VOC	µg/m³	IS 5182 (Part 17): 2004	Low Flow Air Sampler	
8.	PAH	µg/m³	IS: 5182 (Part 12): 2004	Respirable Dust Sampler (RDS) conforming to IS:5182 (Part-12): 2004	Monthly
7.	Benzene	µg/m³	IS 5182 (Part 11): 2006 RA: 2017	Low Flow Air Sampler	
9.	Non-methane VOC	µg/m³	IS 5182 (Part 11): 2006	Low Volume Sampler	

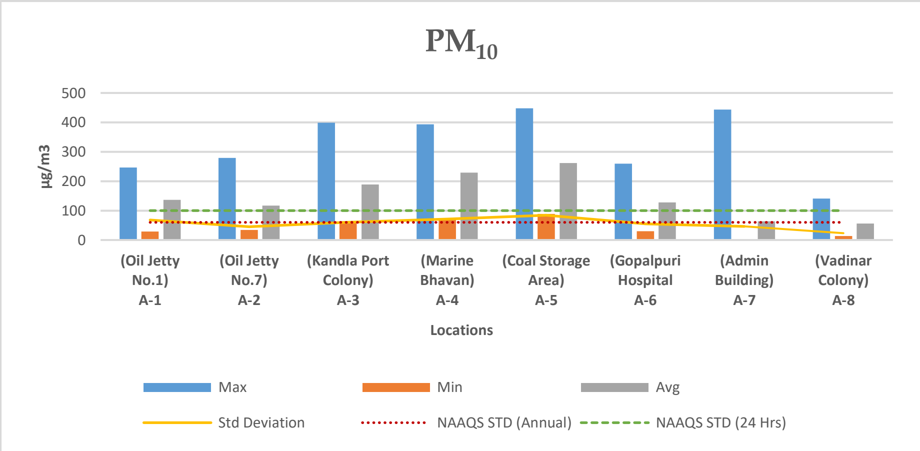
4.2 Result and Discussion

The summarized results of ambient air quality monitoring for the study period are presented in **Table-6 to 9** along with the graphical representation from **Graph 1 to Graph 6.** Various parameters monitored during the study have been presented by their maximum, minimum, average and Standard deviation**.**

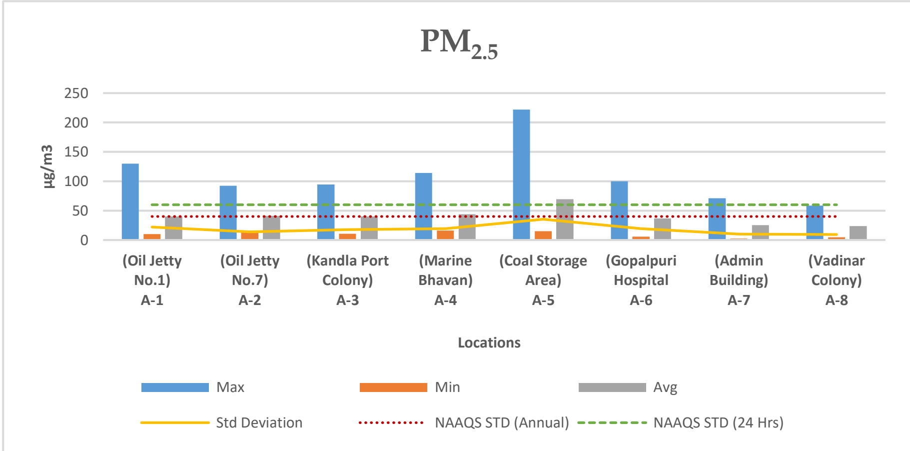
Table 6: Summarized results of PM_{10}, $PM_{2.5}$, SO_2, NO_x, VOC and CO for Ambient Air quality monitoring

Parameters	NAAQS by CPCB	Locations	(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
PM_{10} (µg/m3)	24 Hours -100 Annual -60	Max	247.03	279.33	399.25	393.74	448.12	259.88	443.2	140.7
		Min	28.68	34.39	63.28	71.77	89.21	30.3	1.45	13.89
		Avg	136.50	116.67	188.36	229.41	262.04	127.95	63.49	56.54
		Std Deviation	68.203	44.97	60.56	71.74	84.18	55.43	46.36	23.15
$PM_{2.5}$ (µg/m3)	24 Hours -60 Annual -40	Max	129.77	92.24	94.51	114.34	221.9	99.82	71.18	58.73
		Min	10.03	12.85	10.84	15.97	14.85	5.51	2.36	4.7
		Avg	40.27	41.2	40.26	43.70	69.70	36.95	25.11	23.73
		Std Deviation	22.049	13.87	17.52	19.15	35.36	19.04	10.06	9.33
SO_2 (µg/m3)	24 Hours -80 Annual -50	Max	51.87	151.58	79.24	55.04	283	49.89	59.69	69.81
		Min	0.65	1.18	1.1	1.19	1.1	1.12	0.52	1.4
		Avg	11.076	20.01	14.63	11.82	16.82	11.56	12.59	13.69
		Std Deviation	12.142	28.41	17.15	12.25	30.85	12.08	13.35	14.90
NO_X (µg/m3)	24 Hours -80 Annual -40	Max	54.33	52.54	80.67	55.39	80.94	79.88	52.76	33.79
		Min	2.29	1.11	2.36	1.29	1.97	1.01	2.89	0.9
		Avg	14.75	14.58	22.91	20.52	28.12	15.24	12.84	9.70
		Std Deviation	11.68	9.85	14.98	10.53	17.98	13.59	8.62	5.73
VOC (µg/m3)	-	Max	4.85	5.67	17.43	4.41	3.97	4.12	4.52	6.62
		Min	0.01	0.01	0.01	0.02	0.04	0.01	0.01	0.01
		Avg	1.20	1.226	1.52	0.98	0.94	0.96	0.96	0.95
		Std Deviation	1.155	1.298	2.275	0.99	0.94	0.99	0.93	1.12
CO (mg/m3)	8 Hours -2 1 Hour -4	Max	0.98	4.21	2.91	3.16	3.21	2.18	3.14	2.74
		Min	0.08	0.09	0.14	0.39	0.36	0.32	0.03	0.45
		Avg	0.73	0.848	0.89	0.95	1.13	0.74	0.78	0.94
		Std Deviation	0.194	0.557	0.41	0.39	0.53	0.32	0.46	0.36

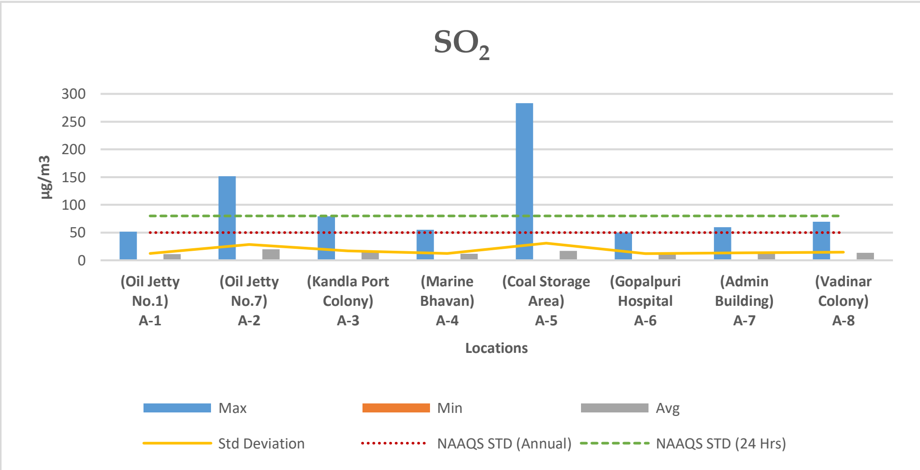
Graphs 1-6 shows spatial trend of ambient air parameter at all the eight-monitoring location (six at Kandla and 2 at Vadinar)



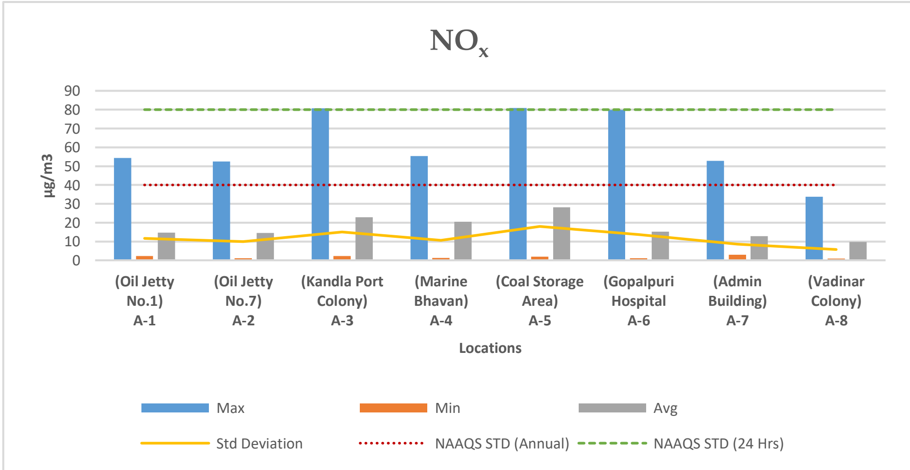
Graph 1 Spatial trend in Ambient PM_{10} Concentration



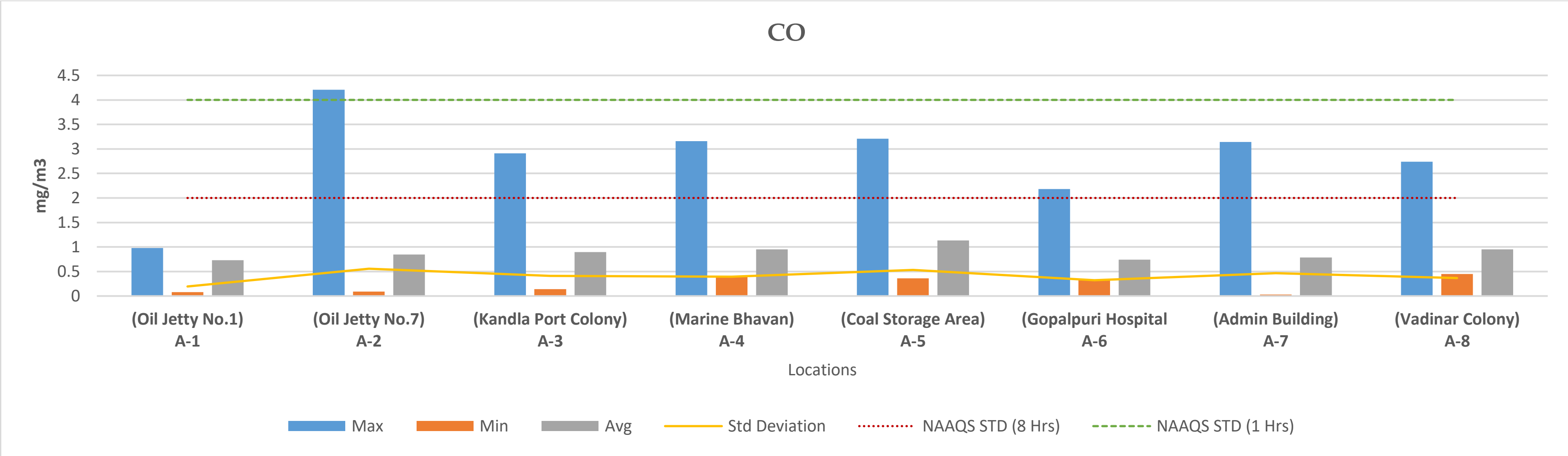
Graph 2 Spatial trend in Ambient $PM_{2.5}$ Concentration



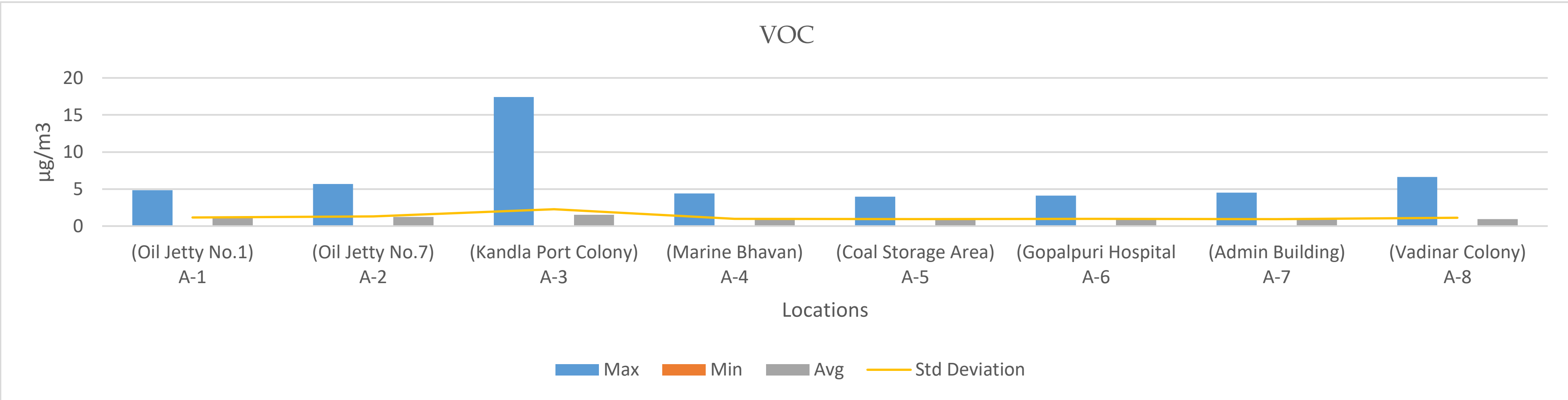
Graph 3 Spatial trend in Ambient SOx Concentration



Graph 4 Spatial trend in Ambient NOx Concentration



Graph 5 Spatial trend in Ambient CO Concentration



Graph 6 Spatial trend in Ambient Total VOCs

Table 7: Summarized results of Benzene for Ambient Air quality monitoring

Parameters \ Locations	NAAQS by CPCB		(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
Benzene (µg/m3)	Annual - 5	Max	3.8	1.84	1.43	1.95	1.11	1.97	1.03	0.95
		Min	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.01
		Avg	0.83	0.46	0.42	0.32	0.41	0.49	0.33	0.229

Table 8: Summarized results of Polycyclic Aromatic Hydrocarbons

Parameters \ Locations		(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
Napthalene (µg/m3)	Max	1.57	17.31	5.24	5.55	7.8	39.82	1.98	1.84
	Min	0.02	0.21	0.04	0.14	0.37	0.02	0.1	0.13
	Avg	0.40	3.29	0.58	1.05	2.01	4.96	0.45	0.42
Acenaphthylene (µg/m3)	Max	0.8	0.67	0.54	0.95	0.53	0.86	0.84	0.65
	Min	0.01	0.01	0.01	0.02	0.007	0.02	0.005	0.005
	Avg	0.15	0.20	0.17	0.31	0.15	0.18	0.19	0.17
Fluorene (µg/m3)	Max	0.39	0.39	22.99	178.72	10.88	27.22	7.57	11.64
	Min	0.01	0.05	0.04	0.11	0.01	0.06	0.01	0.01
	Avg	0.14	0.19	3.435	19.99	1.25	3.52	0.82	1.18
Anthracene (µg/m3)	Max	0.87	0.91	1.25	5.05	2.02	3.78	0.85	0.57
	Min	0.09	0.09	0.07	0.09	0.03	0.01	0.02	0.02
	Avg	0.3	0.42	0.40	0.94	0.94	0.69	0.23	0.19
Phenanthrene (µg/m3)	Max	0.9	0.82	0.84	0.91	1	0.99	0.82	0.74
	Min	0.01	0.009	0.01	0.01	0.01	0.01	0.07	0.06
	Avg	0.23	0.20	0.15	0.22	0.33	0.20	0.25	0.22
Fluoranthene (µg/m3)	Max	2.65	0.84	1.59	19.54	4.16	20.36	0.68	1.71
	Min	0.06	0.15	0.2	0.24	0.2	0.01	0.01	0.01
	Avg	0.43	0.36	0.74	3.61	1	2.12	0.24	0.30
Pyrene (µg/m3)	Max	3.52	1.13	2.4	42.23	40.25	51.22	0.87	0.74
	Min	0.01	0.14	0.23	0.15	0.02	0.01	0.01	0.01
	Avg	0.54	0.48	0.90	7.46	4.37	7.98	0.16	0.14
Chrycene (µg/m3)	Max	4.59	1.03	3.01	6.27	5.51	5.82	0.61	0.79

	Min	0.08	0.15	0.44	0.42	0.08	0.06	0.05	0.05
	Avg	0.78	0.51	1.01	1.50	1.47	1.22	0.19	0.22
Banz(a)anthracene (µg/m3)	Max	5.64	2.84	3.7	15.42	6.57	16.73	1.01	0.97
	Min	0.17	0.17	0.04	0.14	0.05	0.06	0.01	0.01
	Avg	0.89	0.65	0.88	2.66	1.44	2.93	0.25	0.31
Benzo[k]fluoranthene (µg/m3)	Max	7.67	1.99	5.98	4.81	4.06	6.89	0.84	0.69
	Min	0.15	0.38	0.14	0.48	0.05	0.06	0.03	0.03
	Avg	1.32	0.99	1.34	1.21	0.89	1.76	0.35	0.21
Benzo[b]fluoranthene (µg/m3)	Max	7.89	1.93	6.15	5.12	4.73	7.29	0.59	0.71
	Min	0.12	0.04	0.21	0.17	0.07	0.01	0.06	0.01
	Avg	1.09	0.62	1.053	1.43	1.06	1.65	0.17	0.20
Benzopyrene (µg/m3)	Max	10.9	2.79	8.42	7.25	8.91	9.19	0.96	0.69
	Min	0.24	0.08	0.39	0.39	0.01	0.04	0.01	0.01
	Avg	1.64	0.87	1.66	1.75	1.58	1.31	0.30	0.27
Indeno [1,2,3-cd] fluoranthene (µg/m3)	Max	2.39	6.67	0.95	2.46	1.68	4.61	0.52	0.98
	Min	0.13	0.07	0.42	0.26	0.11	0.09	0.07	0.06
	Avg	0.71	1.02	0.57	0.72	0.70	1.25	0.22	0.42
Dibenz(ah)anthracene (µg/m3)	Max	1.82	1.2	0.91	1.25	2.24	0.99	1.34	2.48
	Min	0.11	0.08	0.16	0.1	0.07	0.04	0.08	0.05
	Avg	0.47	0.32	0.35	0.46	0.54	0.24	0.31	0.4
Benzo[ghi]perylene (µg/m3)	Max	16.3	9.7	27.2	13.6	9.4	12.2	8	2.3
	Min	0.1	0.07	0.04	0.06	0.06	0.17	0.07	0.13
	Avg	2.049	2.63	2.95	2.55	1.61	2.13	0.83	0.47
Acenaphthene (µg/m3)	Max	0.69	0.45	15.1	119.08	2.54	11.8	0.67	2
	Min	0.01	0.05	0.04	0.11	0.01	0.06	0.01	0.01
	Avg	0.14	0.22	2.63	11.34	0.369	1.55	0.14	0.33

Table 9: Summarized results of Non-methane VOC

Parameters / Locations		(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
Non- Methane VOC (µg/m3)	Max	2.11	2.67	3.54	1.35	1.8	2.01	2.15	1.67
	Min	0.12	0.09	0.1	0.08	0.13	0.11	0.07	0.1
	Avg	0.73	0.79	0.87	0.79	1.09	0.93	0.91	0.74s

4.3 Data Interpretation and Conclusion

The results were compared with the National Ambient Air Quality Standards (NAAQS), 2009 of Central Pollution Control Board (CPCB).

1) Kandla:

Particulate matter:

- The concentration of PM_{10} varies very widely and is reported in the range of **28.68** to **448.12** µg/m3, with a yearly average value of **176.83** with standard deviation **64.185** µg/m^3. As shown in Graph 1, the highest concentration (value) of PM_{10} is reported at location A-5 (coal storage area) during the winter. It can be seen that PM_{10} exceeds the NAAQS annual limit, i.e., 60 µg/m^3, in all locations. It can be seen that location A-5 (coal storage area) had the maximum percentage exceedance, and location A-1 (oil jetty No. 1) had the minimum percentage exceedance while comparing with the NAAQS 24-hour limit, i.e., 100 µg/m^3.
- The concentration of PM2.5 varies in the range of 5.51 to 221.9 µg/m^3, with a yearly average value of 45.35 with standard deviation 21.16 µg/m^3. As shown in Graph 2, the highest concentration of $PM_{2.5}$ is at location A-5 (the coal storage area) in winter. It can be seen that $PM_{2.5}$ exceeds the NAAQS annual limit, i.e., 40 µg/m3, on five locations, and location A-6, i.e., Gopalpuri hospital, falls within the NAAQS annual limit. It can be seen that location A-5 (coal storage area) had the maximum percentage exceedance, and location A-6 (Gopalpuri hospital) had the minimum percentage exceedance while comparing with the NAAQS 24-hour limit, i.e., 60 µg/m^3.
- The highest concentration of Particulate matter at locations **A–5, (the coal storage area)**, could be attributed to the presence of heavy vehicular traffic in upwind areas, which have a higher impact, causing the dispersion of emitted particulate matter in the ambient air. Ther activities observed in the surrounding such as The unloading of coal directly into the truck using grabs, construction in the vicinity causes the dust to disperse in the air as well as coal dust to fall and settle on the ground. This settled coal dust again mixes with the air while trucks travel through it. Also, the coal-loaded trucks are generally not always covered with tarpaulin sheets, and this might result in increased suspension of coal from trucks or dumpers during their transit from vessel to yard or storage site. This might increase the PM in and around the coal storage area and Marine Bhavan.

Gaseous Pollutants:

- The concentration of SOx varies from **0.52** to **283** µg/m^3, with a yearly average concentration of **14.029** with standard deviation **18.85** µg/m^3. As shown in Graph 3, the highest concentration of SOx is at location **A-5 (the coal storage area)** in winter. It can be seen that at all locations, SOx are within the NAAQS annual limit, i.e., 50 µg/m^3. It can be seen that location A-2 **(Oil Jetty No. 7)** had the maximum percentage exceedance, i.e., **7.36**%, which is about 7 days out of 95 days of monitoring, and the other five locations comply with the standards (compliance more than 98% times) while comparing with the NAAQS 24-hour limit, i.e., 80 µg/m^3. The concentration of NOx varies from **1.01** to **80.94** µg/m3, with a yearly average concentration of **19.35** with standard deviation **13.10** µg/m3. As shown in Graph 4, the highest concentration of NOx is at location A-5 (the coal storage area) in winter. It can be seen that on all locations's NOx within the NAAQS annual limit, i.e., 40 µg/m^3, it can be seen that all locations comply with the standards (complied more than 98% times) while comparing with the NAAQS 24-hour limit, i.e., 80 µg/m^3.

- The concentration of CO varies from **0.08** to **4.21** mg/m^3, with a yearly average concentration of **0.884** with standard deviation **0.40** mg/m^3. As shown in Graph 5, the highest concentration of CO is at location A-2 (Oil Jetty No. 7) in winter. It can be seen that at all locations, they're complying (more than 98% of the time) with the NAAQS 1 hour limit, i.e., 4 mg/m^3. Location A-5 (the coal storage area) had the maximum percentage exceedance, i.e., **7.36**%, which is about 7 days out of 95 days of monitoring, and other locations such as Location A-2 (Oil Jetty No. 7), Location A-3 (Kandla Port Colony), Location A-4 (Marine Bhavan), and Location A-6 (Gopalpuri Hospital) had percentage exceedances of **5.26, 5.26, 2.85**, and **2.85**, respectively. And location A-1 (oil jetty no. 1) comply with the standards (compliance more than 98% times) while comparing with the NAAQS 8-hour limit, i.e., 2 mg/m3.

- The concentration of total VOC levels was recorded in the range of **0.01** to **17.43** µg/m3, with a yearly average value of **1.14** with standard deviation 1.21 µg/m3 at Kandla. As shown in graph 6, the highest concentration of VOCs is at location **A-3, (Kandla port colony)**; this is the only spike observed in the whole monitoring period for VOCs at this location. The main source of VOCs in the ambient air may be attributed to the burning of gasoline and natural gas in vehicle exhaust, burning fossil fuels, and garbage that releases VOCs into the atmosphere. During the monitoring period, the wind flows in the south direction at Kandla, and hence the wind direction and speed also contribute to increased dispersion of pollutants from the upward areas towards the downward areas.

  Polycyclic Aromatic Hydrocarbons (PAHs): are ubiquitous pollutants in urban atmospheres. Anthropogenic sources of total PAHs in ambient air emissions are greater than those that come from natural events. These locations are commercial areas where Vehicular activity and dust emission is common. PAHs are a class of chemicals that occur naturally in coal, crude oil, and gasoline. The higher concentration which results from burning coal, oil, gas, road dust, etc. Other outdoor sources of PAHs may be the industrial plants in-and-around the DPA premises.

- The concentration of Benzene levels was recorded in the range of **0.02** to **3.8** µg/m^3, with a yearly average value of **0.84** with standard deviation **0.64** µg/m^3. The highest concentration of Benzene is at location **A-1, (Oil Jetty No. 1)** in summer. It can be seen that at all locations, Benzene within the NAAQS annual limit, i.e., 5 µg/m3.

- The ambient air monitoring location of Kandla recorded the non-methane VOC (NM-VOC) concentration in the range of **0.08** to **3.54** µg/m3, with a yearly average value of **0.86** µg/m3 at Kandla. The highest concentration is at location **A-3, (Kandla Port Colony** in Winter.

2) Vadinar:

Particulate matter: The concentration of PM10 at Vadinar varies in the range of **1.45 to 443.2** µg/m³, with a yearly average value of **63.49** with a standard deviation of **34.76** µg/m3. As shown in Graph 1, the highest concentration of PM_{10} is at location A-7 (Admin Building Vadinar) in the winter. It can be seen that at location A-7 (Admin Building Vadinar), PM_{10} exceeds the NAAQS annual limit, i.e., 60 µg/m³, and at location A-8 (Vadinar Colony), it falls within the annual standards. It can be seen that locations A-7 (Admin Building Vadinar) and A-8 (Vadinar Colony) had a 5.15% percentage exceedance while comparing with the NAAQS 24-hour limit, i.e., 100 µg/m³.

- The concentration of $PM_{2.5}$ varies in the range of **2.36** to **71.18** µg/m³, with a yearly average value of **24.42** with a standard deviation **of 9.69** µg/m³. As shown in Graph 2, the highest concentration of $PM_{2.5}$ is at location **A-7 (Admin Building Vadinar)** in winter. It can be seen that in all two locations, $PM_{2.5}$ is within the NAAQS annual limit, i.e., 40 µg/m³. it can be seen that on both locations, **A-7 (building Vadinar)** and **A-8 (Vadinar Colony)** comply with the standards (complimented more than 98% times) while comparing with the NAAQS 24-hour limit, i.e., 60 µg/m³.

Gaseous Pollutants:

- The concentration of SOx varies from **0.52** to **69.91** µg/m3, with a yearly average concentration of 13.146 with a standard deviation of 14.14 µg/m3. As shown in Graph 3, the highest concentration of SOx is at location A-8 (Vadinar Colony) in the winter. It can be seen that in all locations, SOx are within the NAAQS annual limit, i.e., 50 µg/m³. It can be seen that both locations comply with the standards (compliance more than 98% times) while comparing with the NAAQS 24-hour limit, i.e., 80 µg/m³.
- The concentration of NOx varies from **0.9** to **52.76** µg/m³, with a yearly average concentration of **11.28** with a standard deviation of **7.17** µg/m³. As shown in Graph 4, the highest concentration of NOx is at location A-7 (Admin Building Vadinar) in the winter. It can be seen that in all locations, NOx is within the NAAQS annual limit, i.e., 40 µg/m³. It can be seen that all locations comply with the standards (compliance more than 98% of the time) while comparing with the NAAQS 24-hour limit, i.e., 80 µg/m³.
- The concentration of CO varies from **0.03** to **3.14** mg/m3, with a yearly average concentration of **0.87** with a standard deviation **0.41** mg/m³. As shown in Graph 5, the highest concentration of CO is at location **A-7, (Admin Building Vadinar)** in winter. it can be seen that at all locations they are complying (Complied more than 98% times) with the NAAQS 1 hour limit, i.e., 4 mg/m³. Both **locations A-7, (Admin building Vadinar)** and **A-8,(Vadinar Colony)** had **5.16%** exceedance, which is about 5 days out of 97 days of monitoring, while comparing with the NAAQS 8-hour limit, i.e., 2 mg/m3.
- The concentration of **Total VOCs** levels was recorded in a range of **0 to 6.62** µg/m³ with a yearly average value of **0.96** with a standard deviation of **1.051** µg/m³ at Vadinar. As shown in graph 6, the **highest** concentration of **VOCs** is at

location A-8, (Vadinar Colony), this is the only spike observed in the whole monitoring period for VOCs at this location.

Polycyclic Aromatic Hydrocarbons (PAHs):

- The concentration of **Benzene** levels was recorded in a range of **0.01 to 1.03** µg/m^{3,} with a yearly average value of **0.28** with a standard deviation of 0.36 µg/m^3. the **highest** concentration of Benzene is at **location A-7, (Admin building Vadinar)** in Winter. It can be seen that in all locations **Benzene** within the NAAQS annual limit, i.e., 5 µg/m^3.
- **Non-methane VOC** (NM-VOC) concentration at Vadinar was observed in the range of **0.07 to 2.15** µg/m^3 with a yearly average value of **0.82** with a standard deviation **0.085** µg/m^3. the **highest** concentration is at **A-7, (Admin building Vadinar)** in Winter.

With reference to the Ambient Air Quality monitoring conducted under the study, it may be concluded that the particulate matter PM_{10}, were reported in higher concentration and apparently exceeds the NAAQS particularly at locations of Kandla., whereas $PM_{2.5}$ complies with the NAAQS at majority of the locations. For both the ambient air monitoring parameters (PM_{10} and $PM_{2.5}$), the major exceedance was observed at location A-5 i.e. Coal Storage Area. The gaseous pollutants (NO_x, SO_x, CO, VOCs etc.) falls within the permissible limit. The probable reasons contributing to these emissions of pollutants into the atmosphere in-and-around the port area are summarized as follows: -

1. **Port Machinery:** Port activities involve the use of various machinery and equipment, including cranes, for lifts, tugboats, and cargo handling equipment. These machines often rely on diesel engines, which can emit pollutants such as NO_x, Particulate matter, and CO. Older or poorly maintained equipment tends to generate higher emissions.
2. **Port Vehicles:** Trucks and other vehicles operating within port and port area contributes to air pollution. Similar to port machinery, diesel-powered vehicles can emit NO_x, PM, CO, and other pollutants such as PAH, VOCs etc. Vehicle traffic and congestion in and around port areas can exacerbate the air quality issues.
3. **Coal Handling:** Resuspension of dust occurs due to the transportation of coal and the handling of coal.
4. **Construction Activities:** Another reason for the high particulate matter content in this area is due to high construction activities in the surrounding area.

4.4 Remedial Measures:

Efficient mitigation strategies need to be implementation for substantial environmental and health co-benefits. To improve air quality, DPA has implemented a number of precautionary measures, such as maintaining Green zone, initiated Inter-Terminal Transfer of tractor-trailers, Centralized Parking Plaza, providing shore power supply to tugs and port crafts, the use of LED lights at DPA area helps in lower energy consumption and decreases the carbon foot prints in the environment, time to time cleaning of paved and unpaved roads, use of tarpaulin sheets to cover dumpers at project sites etc. are helping to achieve the cleaner and green future at port. To address air pollution from port shipping activities, various measures that can be implemented are as follows:

- Practice should be initiated for using mask as preventative measure, to avoid Inhalation of dust particle-Mask advised in sensitive areas. Covering vehicles with tarpaulin during transportation will help to reduce the suspension of pollutants in air.
- Ensuring maintenance of engines and machinery to comply with emission standards.
- Frequent water sprinkling on roads to reduce dust suspension due to vehicular movement, this can be use during transporting coal to avoid suspension of coal dust.
- Use of proper transport methods, such as a conveyor belt, for excavated material and screens around the construction site.
- End to End pavement of roads in construction site could considerably reduce dust emission. Prohibition of use of heavy diesel oil as fuel could be possibly reduce pollutants. Encouraging use of low-sulfur fuels (viz. Marine Gas Oil (MGO)/Liquefied Natural Gas (LNG), can significantly reduce sulfur and PM emissions from ships.
- Retrofitting ships with exhaust gas cleaning systems can help reduce sulfur emissions. Engine upgrades, such as optimizing fuel combustion and improving engine efficiency, can reduce overall emissions.
- Investing in infrastructure for cold ironing allows ships to connect to the electrical grid while docked, reducing the need for auxiliary engines and associated emissions.
- Implementing efficient cargo-handling processes, optimizing logistics to reduce congestion and idling times, and encouraging use of cleaner port machinery and vehicles can all contribute to reducing air pollution in port areas.
- Shrouding shall be carried out in the work site enclosing the dock/proposed facility area. This will act as dust curtain as well achieving zero dust discharge from the site. These curtain or shroud will be immensely effective in restricting disturbance from wind in affecting the dry dock operations, preventing waste dispersion, improving working conditions through provision of shade for the workers.
- Dust collectors shall be deployed in all areas where blasting (surface cleaning) and painting operations are to be carried out, supplemented by stacks for effective dispersion.
- Periodic vacuum-sweeping mechanisms shall be adopted.

CHAPTER 5: DG STACK MONITORING

5.1 DG Stack Monitoring

A diesel generator is a mechanical-electrical machine that produces electrical energy (electricity) from diesel fuel. They are used by the residential, commercial, charitable and governmental sectors to provide power in the event of interruption to the main power, or as the main power source. Diesel generating (DG) sets are generally used in places without connection to a power grid, or as an emergency power supply if the grid fails. These DG sets utilize diesel as fuel and generate and emit the air pollutants such as Suspended Particulate Matter, SO_2, NO_x, CO, etc. from the stack during its functioning. The purpose of stack sampling is to determine emission levels from plant processes to ensure they are in compliance with any emission limits set by regulatory authorities to prevent macro environmental pollution. The stack is nothing but chimney which is used to disperse the hot air at a great height, emissions & particulate matters that are emitted. Hence, monitoring of these stacks attached to DG Sets is necessary in order to quantify the emissions generated from it.

As defined in scope by DPA, the monitoring of DG Stack shall be carried out at two locations, one at Kandla and one at Vadinar. The details of the DG Sets at Kandla and Vadinar have been mentioned in Table 10 as follows:

Table 10: Details of DG Stack monitoring locations

Sr. No.	Location Code	Location Name	Latitude/ Longitude
1.	DG-1	Kandla	22.98916N 70.22083E
2.	DG-2	Vadinar	22.44155N 69.67419E

The map depicting the locations of DG Stack Monitoring to be monitored in Kandla and Vadinar have been mentioned in **Map 6 and 7** as follows:

Map 6: DG Stack monitoring Locations at Kandla

Map 7: DG Stack monitoring Locations at Vadinar

Methodology:

Under the study, the list of parameters to be monitored under the projects for DG Stack Monitoring has been mentioned in **Table 11** as follows:

Table 11: DG stack parameters

Sr. No.	Parameter	Unit	Instrument
1.	Suspended Particulate Matter	**mg/Nm³**	**Stack Monitoring Kit**
2.	Sulphur Dioxide (SO_2)	PPM	**Sensor based Flue Gas Analyzer (Make: TESTO, Model 350)**
3.	Oxides of Nitrogen (NO_x)	PPM	
4.	Carbon Monoxide	%	
5.	Carbon Dioxide	%	

The methodology for monitoring of DG Stack has been mentioned as follows:

The monitoring of DG Stack is carried out as per the IS:11255 and USEPA Method. The Stack monitoring kit is used for collecting representative samples from the stack to determine the total amount of pollutants emitted into the atmosphere in a given time. Source sampling is carried out from ventilation stack to determine the emission rates/or characteristics of pollutants. Sample collected must be such that it truly represents the conditions prevailing inside the stack. Whereas the parameters Sulphur Dioxide, Oxides of Nitrogen (NO_x), Carbon Monoxide and Carbon Dioxide, the monitoring is carried out by using the sensor-based Flue Gas Analyzer.

Monitoring Frequency

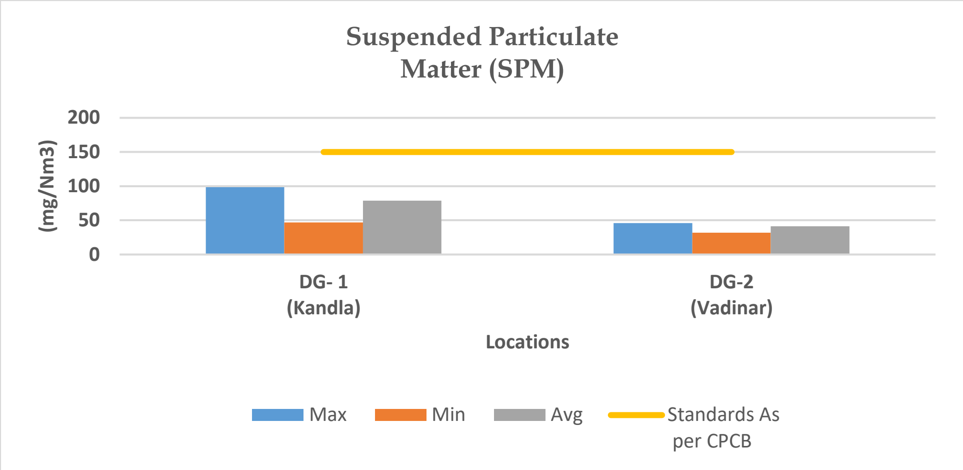
Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar for a period of April 2023 to March 2024.

5.2 Result and Discussion

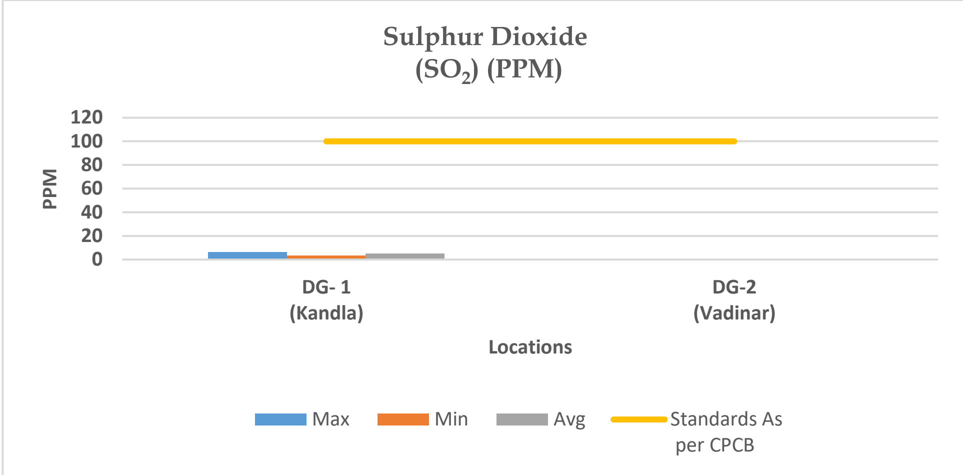
The sampling and monitoring of DG stack emission was carried out for monitoring period at Kandla and Vadinar and its comparison with CPCB or Indian standards for Industrial Stack Monitoring the flue gas emission from DG set has given in **Table 12.**

Table 12: DG monitoring data

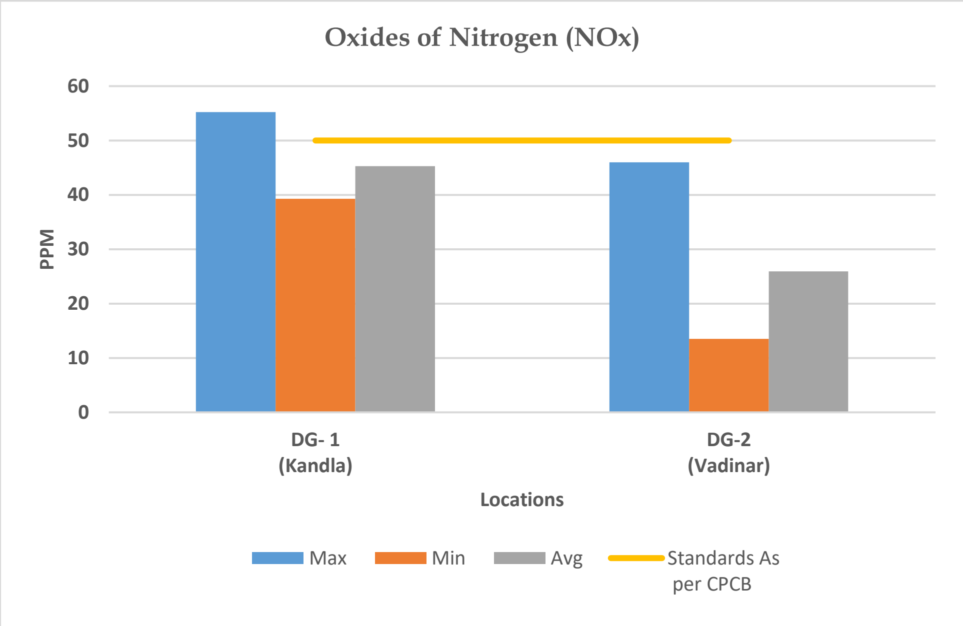
Sr. No.	Stack Monitoring Parameters for DG Sets		DG- 1 (Kandla)	DG-2 (Vadinar)	Stack Monitoring Limits /Standards As per CPCB
1.	**Suspended Particulate Matter (SPM) (mg/Nm³)**	**Max**	98.47	45.32	**150**
		Min	46.82	31.85	
		Avg.	78.96	41.33	
2.	**Sulphur Dioxide (SO2) (PPM)**	**Max**	6.45	N.D.	**100**
		Min	3.25	N.D.	
		Avg.	4.95	N.D.	
3.	**Oxides of Nitrogen (NO_x) (PPM)**	**Max**	55.2	46	**50**
		Min	39.27	13.52	
		Avg.	45.31	25.92	
4.	**Carbon Monoxide (CO) (%)**	**Max**	0.34	0.016	**1**
		Min	0.007	0.002	
		Avg.	0.16	0.01	
5.	**Carbon Dioxide (CO_2) (%)**	**Max**	3.09	1.42	**-**
		Min	1.21	1.03	
		Avg.	1.92	1.19	



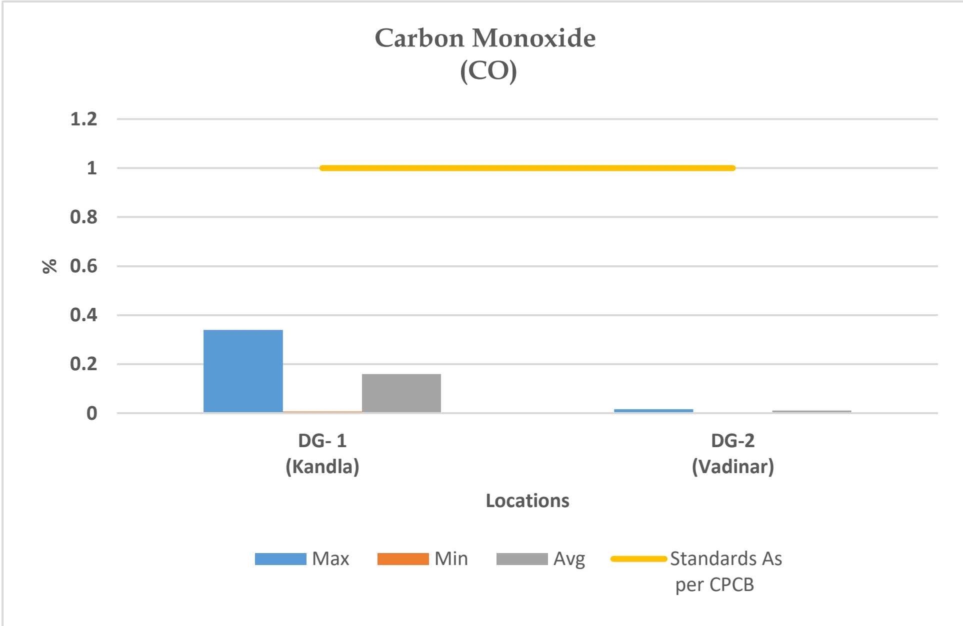
Graph 7 Spatial trend in SPM Concentration



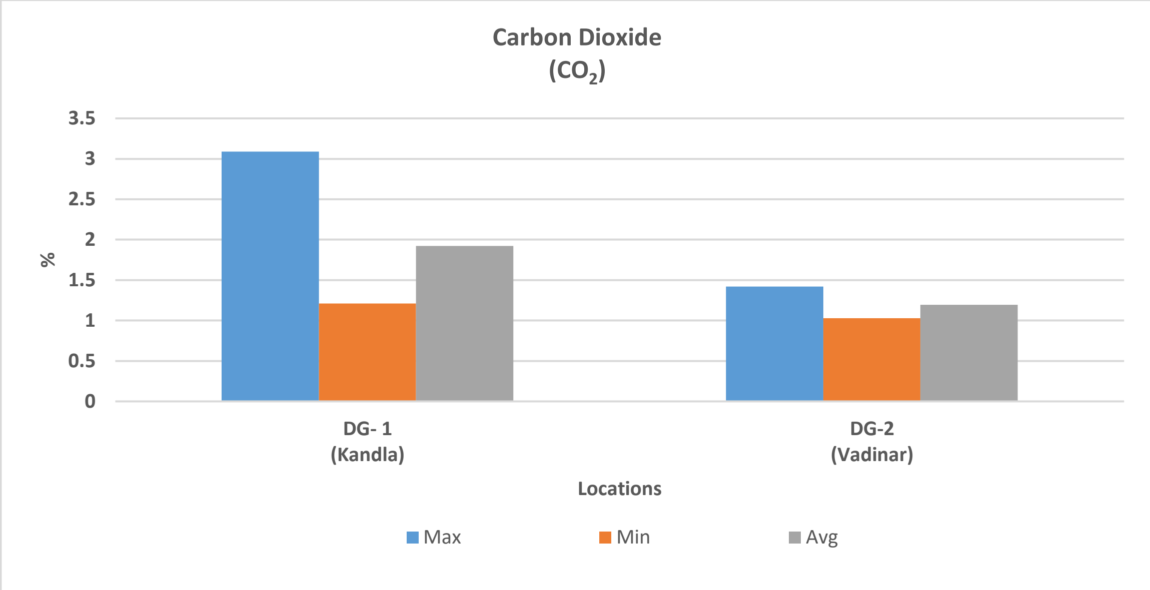
Graph 8 Spatial trend in SO_x Concentration



Graph 9 Spatial trend in NOx Concentration



Graph 10 Spatial trend in CO Concentration



Graph 11 Spatial trend in CO_2 Concentration

5.3 Data Interpretation and Conclusion

1) Kandla:

The Suspended Particulate Matter (SPM) varies in the range of **46.82** to **98.47** mg/m^3. The yearly average SPM of D.G stack-1 is **78.96** mg/m^3. The maximum concentration for SPM was observed in the monitoring period of October to November 2023. The Sulphur dioxide (SO_x) varies in the range of **3.25** to **6.45** PPM. The yearly average SO_x of D.G stack-1 is **4.95** PPM. The maximum concentration of SO_x observed in the monitoring period of October to November 2023.

The NO_x varies in the range of **39.27** to **55.2** PPM. The yearly average of NO_x of D.G stack-1 at Kandla is **45.31** PPM. The maximum concentration of NO_x observed in the monitoring period of July to August 2023.

The CO at Kandla varies in the range of **0.007** to **0.34** %. The yearly average of CO of D.G stack-1 at Kandla is **0.16** % The maximum concentration of CO observed in the monitoring period of March to April 2024.

The CO_2 at Kandla varies in the range of **1.21** to **3.09** %. The yearly average of CO_2 of D.G stack-1 at Kandla is **1.92** % The maximum concentration of CO_2 observed in the monitoring period of March to April 2024.

The results of all the above parameters of DG stack-1 at Kandla emission are compared with the permissible limits mentioned in the consent issued by GPCB, and have been found within the prescribed limit for all the monitored parameters.

2) Vadinar:

The Suspended Particulate Matter (SPM) in the range of **31.85** to **45.32** mg/m^3. The yearly average SPM of D.G stack-2 at Vadinar is **41.33** mg/m^3. The maximum concentration of SPM was observed in the monitoring period of March to April 2024. There is no Sulphur dioxide (SO_x) concentration detected at Vadinar.

The NO_x at Vadinar varies in the range of **13.52** to **46** PPM. The yearly average of NO_x of D.G stack-2 at Vadinar is **25.928** PPM. The maximum concentration of NO_x observed in the monitoring period of June to July 2023.

The CO at Vadinar varies in the range of **0.002** to **0.016** %. The yearly average of CO of D.G stack-2 at Vadinar is **0.0106** % The maximum concentration of CO observed in the monitoring period of October to November 2023.

The CO_2 at Vadinar varies in the range of **1.03 to 1.42** %. The yearly average in CO_2 of D.G stack-2 at Vadinar is **1.92** % The maximum concentration of CO_2 observed in the monitoring period of June to July 2024.

The results of all the above parameters of DG stack-2 at Vadinar emission are compared with the permissible limits mentioned in the consent issued by GPCB, and have been found within the prescribed limit for all the monitored parameters.

CHAPTER 6: NOISE MONITORING

6.1 Noise Monitoring

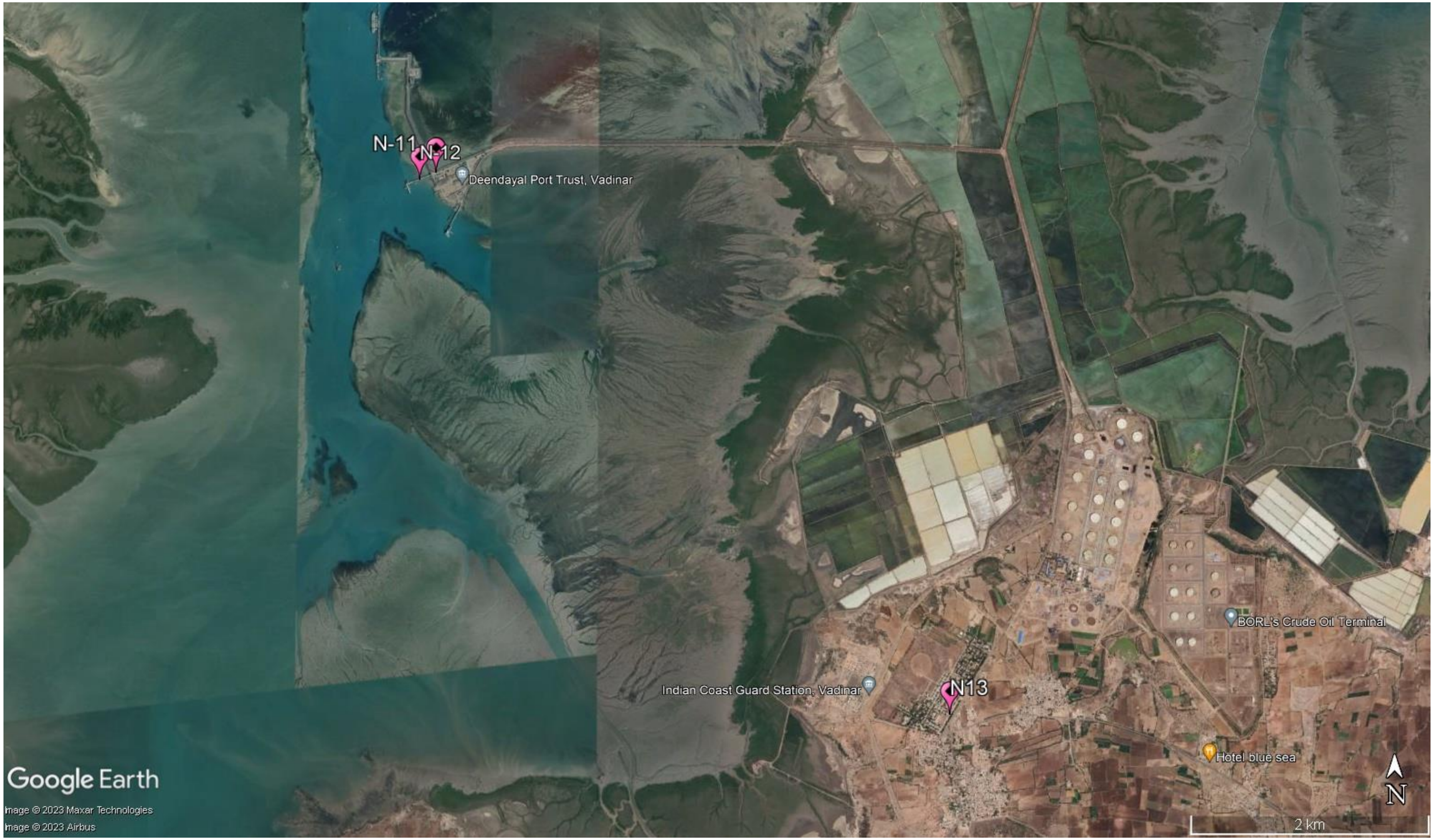
Noise can be defined as an unwanted sound, and it is therefore, necessary to measure both the quality as well as the quantity of environmental noise in and around the study area. Noise produced during operation stage and the subsequent activities may affect surrounding environment impacting the fauna and as well as the human population. Under the scope, the noise monitoring is required to be carried out at 10 locations in Kandla and 3 locations in Vadinar. The sampling locations for noise are not only confined to commercial areas of DPA but also the residential areas of DPA.

The details of the noise monitoring stations are mentioned in **Table 13** and locations have been depicted in the **Map 8 and 9** as follow:

Table 13: Details of noise monitoring locations

Sr. No.	Location Code		Location Name	Latitude/ Longitude
1.	Kandla	N-1	Oil Jetty 7	23.043527N 70.218456E
2.		N-2	West Gate No.1	23.006771N 70.217340E
3.		N-3	Canteen Area	23.003707N 70.221331E
4.		N-4	Main Gate	23.007980N 70.222525E
5.		N-5	Main Road	23.005194N 70.219944E
6.		N-6	Marin Bhavan	23.007618N 70.222087E
7.		N-7	Port & Custom Building	23.009033N 70.222047E
8.		N-8	Nirman Building	23.009642N 70.220623E
9.		N-9	ATM Building	23.009985N 70.221715E
10.		N-10	Wharf Area/ Jetty	22.997833N 70.223042E
11.	Vadinar	N-11	Near Main Gate	22.441544N 69.674495E
12.		N-12	Near Vadinar Jetty	22.441002N 69.673147E
13.		N-13	Port Colony Vadinar	22.399948N 69.716608E

Map 8: Locations for Noise Monitoring at Kandla



Map 9: Locations for Noise Monitoring at Vadinar

Methodology:

The intensity of sound energy in the environment is measured in a logarithmic scale and is expressed in a decibel (dB(A)) scale. The ordinary sound level meter measures the sound energy that reaches the microphone by converting it into electrical energy and then measures the magnitude in dB(A). Whereas, in a sophisticated type of sound level meter, an additional circuit (filters) is provided, which modifies the received signal in such a way that it replicates the sound signal as received by the human ear and the magnitude of sound level in this scale is denoted as dB(A). The sound levels are expressed in dB(A) scale for the purpose of comparison of noise levels, which is universally accepted. Noise levels were measured using an integrated sound level meter of the make Envirotech Sound Level Meter (Class-I) (model No. SLM-109). It has an indicating mode of Lp and Leq. Keeping the mode in Lp for few minutes and setting the corresponding range and the weighting network in "A" weighting set the sound level meter was run for one-hour time and Leq was measured at all locations.

Monitoring Frequency

Monitoring was carried out at each noise monitoring station for Leq. noise level (Day and Night), which was recorded for 24 hours continuously at a monthly frequency with the help of Sound/Noise Level Meter (Class-1). The details of the noise monitoring have been mentioned in **Table 14**.

Table 14: Details of the Noise Monitoring

Sr. No.	Parameters	Units	Reference Method	Instrument
1.	Leq (Day)	dB(A)	IS 9989: 2014	Noise Level Meter (Class-I) model No. SLM-109
2.	Leq (Night)	dB(A)		

Standard for Noise

Ministry of Environment & Forests (MoEF) has notified the noise standards vide the Gazette notification dated February 14, 2000 for different zones under the Environment Protection Act (1986). The day time noise levels have been monitored from 6.00 AM to 10.00 PM and night noise levels were measure from 10.00 PM to 6.00 AM at all the thirteen locations (10 at Kandla and 3 at Vadinar) monthly. The specified standards are as mentioned in **Table 15** as follows:

Table 15: Ambient Air Quality norms in respect of Noise[(2)]

Area Code	Category of Area	Noise dB(A) Leq	
		Daytime	Night time
A	Industrial Area	75	70
B	Commercial Area	65	55
C	Residential Area	55	45
D	Silence Zone	50	40

6.2 Result and Discussion

The details of the Noise monitoring conducted during the monitoring period April 2023 to March 2024 have been summarized in the **Table 16** as below:

Table 16: The Results of Ambient Noise Quality

Sr. No.	Station Code	Station Name	Category of Area	Standard	Day Time in dB(A)			Standard	Night Time in dB(A)		
					Max.	Min.	Avg.		Max.	Min.	Avg.
1	N-1	Oil Jetty 7	A	75	65.7	36.5	47.75	70	57.5	33	41.801
2	N-2	West Gate No.1	A	75	68.4	36.5	54.35	70	54.2	36.1	47.02
3	N-3	Canteen Area	B	65	66.2	38	52.61	55	52.1	33	43.46
4	N-4	Main Gate	A	75	61.4	35.3	50.69	70	50.8	36.1	43.33
5	N-5	Main Road	A	75	66.1	33.5	51.67	70	55.5	33.6	43.7
6	N-6	Marin Bhavan	B	65	62.3	38.9	52.52	55	52.3	31.9	43.23
7	N-7	Port & Custom Building	B	65	66.3	37.6	50.89	55	54.3	33.9	38.91
8	N-8	Nirman Building	B	65	60.8	40.9	51	55	58.9	35.2	43.02
9	N-9	ATM Building	B	65	65.1	35.1	49.7	55	53.4	34.1	39.25
10	N-10	Wharf Area/ Jetty	A	75	74.5	36.9	52.9	70	52.7	36	42.3
11	N-11	Near Main Gate	A	75	72.3	34	62.51	70	71.2	34.3	55.71
12	N-12	Near Vadinar Jetty	A	75	76.3	39.2	64.98	70	68.5	34.7	56.38
13	N-13	Port Colony Vadinar	C	55	77.5	37.7	50.05	45	65.9	36.2	49.5

6.3 Data Interpretation and Conclusion

1) **Kandla:** The noise level was compared with the standard limits specified in NAAQS by CPCB. During the Day Time, the average noise level at all 10 locations at Kandla ranged from **33.5** dB(A) to **74.5** dB(A) while, during Night Time the average Noise Level ranged from **31.9** dB(A) to **58.9** dB(A), of which six locations out of ten locations, noise level were within the permissible limits for the industrial, commercial area and residential zone for Day time and night time.

   Other Four locations such as i.e., **N-3 (Canteen Area)**, **N-7 (Port & Custom Building), N-8 (Nirman Building)** and **N-9 (ATM building)** which are Commercial areas, slightly exceed the standard limits prescribed by NAAQS by CPCB, in the monitoring period of **April to May 2023 and May to June 2023**.

2) **Vadinar:** The noise level was compared with the standard limits specified in NAAQS by CPCB. During the Day Time, the average noise level at all 3 locations at Vadinar ranged from **34** dB(A) to **77.5** dB(A) while, during Night Time the average Noise Level ranged from **34.3** dB(A) to **71.2** dB(A) at Vadinar, on location **N-11 (Near main gate)** noise level was within the permissible limits for the industrial zone for Day time and night time.

   On locations of Vadinar such as i.e., **N-12 (Near Vadinar jetty)**, which are considered as industrial area slightly exceed the standard limits prescribed by NAAQS by CPCB, in the monitoring period **of June to July 2023**. And on location **N-13 (Port Colony Vadinar)**, most frequently exceed the permissible limit during the day time as well as night time.

6.4 Remedial Measures

The noise levels detected at the locations of Kandla and Vadinar, are found within the prescribed norms. The noise can further be considerably reduced by adoption of low noise equipment or installation of sound insulation fences. Green belt of plants can be a good barrier. If noise exceeds the applicable norms, then the working hours may be altered as a possible means to mitigate the nuisances of construction activities.

CHAPTER 7: SOIL MONITORING

7.1 Soil Quality Monitoring:

The purpose of soil quality monitoring is to track changes in the features and characteristics of the soil, especially the chemical properties of soil occurring at specific time intervals under the influence of human activity. Soil quality assessment helps to determine the status of soil functions and environmental risks associated with various practices prevalent at the location.

As defined in scope by Deendayal Port Authority (DPA), Soil Quality Monitoring shall be carried out at Six locations, four at Kandla and two at Vadinar. The details of the soil monitoring locations within the Port area of DPA are mentioned in **Table 17:**

Table 17: Details of the Soil quality monitoring

Sr. No.	Location Code		Location Name	Latitude Longitude
1.	Kandla	S-1	Oil Jetty 7	23.043527N 70.218456E
2.		S-2	IFFCO Plant	23.040962N 70.216570E
3.		S-3	Khori Creek	22.970382N 70.223057E
4.		S-4	Nakti Creek	23.033476N 70.158461E
5.	Vadinar	S-5	Near SPM	22.400026N 69.714308E
6.		S-6	Near Vadinar Jetty	22.440759N 69.675210E

Methodology

As per the defined scope by Deendayal Port Authority (DPA), the sampling and analysis of Soil quality has been carried out on monthly basis.

The samples of soil collected from the locations of Kandla and Vadinar and analyzed for the various physico-chemical parameter. Collection and analysis of these samples was carried out as per established standard methods and procedures. The samples were analyzed for selected parameters to get the present soil quality status and environmental risks associated with various practices prevalent at the location. GEMI has framed its own guidelines for collection of soil samples titled as ***'Soil Sampling Manual'***. Soil samples were collected from 30 cm depth below the surface using scrapper, filled in polythene bags, labelled on-site with specific location code and name and sent to GEMI's laboratory, Gandhinagar for further detailed analysis. The samples collected from all locations are homogeneous representative of each location. The list of parameters to be monitored under the projects for the Soil Quality Monitoring been mentioned in **Table 18** as follows:

Monitoring Frequency

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar. The monitoring was done from April 2023, to March, 2024.

Table 18: Soil parameters

Sr. No.	Parameters	Units	Reference method	Instruments
1.	TOC	%	Methods Manual Soil Testing in India January, 2011, 09. Volumetric method (Walkley and Black, 1934)	Titration Apparatus
2.	Organic Carbon	%		
3.	Inorganic Phosphate	Kg/Hectare	Practical Manual Chemical Analysis of Soil and Plant Samples, ICAR-Indian Institute of Pulses Research 2017 Determination of Available Phosphorus in Soil	UV-Visible Spectrophotometer
4.	Texture	-	Methods Manual Soil Testing in India January 2011,01	Hydrometer
5.	pH	-	IS 2720 (Part 26): 1987	pH Meter
6.	Conductivity	µS/cm	IS 14767: 2000	Conductivity Meter
7.	Particle size distribution & Silt content	-	Methods Manual Soil Testing in India January 2011	Sieves Apparatus
8.	SAR	meq/L	Procedures for Soil Analysis, International Soil Reference and Information Centre, 6th Edition 2002 13-5.5.3 Sodium Absorption Ratio (SAR), Soluble cations	Flame Photometer
9.	Water Holding Capacity	%	NCERT, Chapter 9, 2022-23 and Water Resources Department Laboratory Testing Procedure for Soil & Water Sample Analysis	Muffle Furnace
10.	Aluminium	mg/Kg	EPA Method 3051A	ICP-OES
11.	Chromium	mg/Kg		
12.	Nickel	mg/Kg		
13.	Copper	mg/Kg	Methods Manual Soil Testing in India January, 2011, 17a	
14.	Zinc	mg/Kg	Methods Manual Soil Testing in India January, 2011, 17a	
15.	Cadmium	mg/Kg	EPA Method 3051A	
16.	Lead	mg/Kg		
17.	Arsenic	mg/Kg		
18.	Mercury	mg/Kg		

The map depicting the locations of Soil Quality Monitoring to be monitored in Kandla and Vadinar have been mentioned in **Map 10 and 11** as follows:

Map 10: Soil Quality Monitoring Locations at Kandla

Map 11: Soil Quality Monitoring Locations at Vadinar

7.2 Result and Discussion

The analysis results of physical analysis of the soil samples collected during environmental monitoring period during April 2023 to March 2024 mentioned in **Table 19** are shown below:

Table 19: Soil Quality for the Monitoring period

Sr. No	Parameters / Location		Kandla S-1 (Oil Jetty 7)	Kandla S-2 IFFCO Plant)	Kandla S-3 (Khori Creek)	Kandla S-4 (Nakti Creek)	Vadinar S-5 (Near SPM)	Vadinar S-6 (Near Vadinar Jetty)
1	pH	Max	9.53	8.8	8.88	9.48	8.69	9.36
		Min	7.3	6.48	6.52	7.86	7.19	8.16
		Avg.	8.24	8.20	7.96	8.52	8.14	8.55
2	Conductivity (µS/cm)	Max	71500	36500	75700	17850	501	625
		Min	587	526	586	204	63	127
		Avg	26881.17	11442	20646.33	5470	177.13	281.54
3	Inorganic Phosphate (Kg/ha)	Max	13.32	619.89	20.31	15.87	5.64	8.67
		Min	0.39	0.43	1.24	0.32	0.35	0.26
		Avg	4.21	57.15	5.64	4.71	2.39	2.25
4	Organic Carbon (%)	Max	2.83	2.54	3.83	3.35	0.85	2.48
		Min	0.03	0.08	0.14	0.27	0.06	0.14
		Avg	0.91	0.79	1.06	0.92	0.33	0.59
5	Organic Matter (%)	Max	4.88	4.38	6.6	5.78	1.47	4.28
		Min	0.06	0.14	0.24	0.32	0.09	0.241
		Avg	1.57	1.36	1.82	1.48	0.57	1.01
6	SAR (meq/L)	Max	41.45	22.91	31.51	10.01	0.25	0.45
		Min	0.81	0.36	0.5	0.36	0.05	0.09
		Avg	13.24	6.56	11.71	2.57	0.10	0.17
7	Aluminium (mg/Kg)	Max	8643.04	9065.97	10298.7	9286.91	15921.7	14806.19
		Min	812.75	830.95	840.71	916.4	735.77	754.58
		Avg	2223.8	2322.3	2517.4	2470.4	2848.2	2762.2
8	Chromium (mg/Kg)	Max	92.23	90.7	86.18	87.07	106	91.88
		Min	28.213	28.91	31.57	24.7	71.68	60.93
		Avg	52.28	58.79	59.005	53.30	82.46	70.91
9	Nickel (mg/Kg)	Max	33.32	36.66	38.1	45.41	41.425	42.68
		Min	13.17	11.82	11.91	10.43	27.14	25.52
		Avg	19.17	19.22	22.72	21.72	33.29	32.353
10	Copper (mg/Kg)	Max	92.51	88.31	150.7	192.72	123.18	104.64
		Min	12.42	14.71	14.74	12.8	81.14	60.57
		Avg	49.94	61.10	84.93	56.708	103.06	82.37
11	Zinc (mg/Kg)	Max	210.35	1755.44	188.29	142.71	88.14	97.36
		Min	16.46	42.93	29.9	23.57	37.03	15.33
		Avg	73.75	283.57	99.49	81.77	62.53	49.70
12	Cadmium (mg/Kg)	Max	0.397	23.47	0.59	0	3	0
		Min	0.397	0.5	0.59	0	3	0
		Avg	0.397	6.608	0.59	0	3	0
13	Lead (mg/Kg)	Max	50.28	277.82	47.87	26.48	1.58	21.07
		Min	3.79	2.58	1.29	2.26	0.59	0.89
		Avg	12.09	32.75	15.59	8.88	1.08	6.66

Sr. No	Parameters	Location	Kandla S-1 (Oil Jetty 7)	Kandla S-2 IFFCO Plant)	Kandla S-3 (Khori Creek)	Kandla S-4 (Nakti Creek)	Vadinar S-5 (Near SPM)	Vadinar S-6 (Near Vadinar Jetty)
14	Arsenic (mg/Kg)	Max	4.87	8.4	5.28	6.62	0.4	5.05
		Min	0.1	0.29	0.88	0.3	0.099	0.59
		Avg	2.38	3.04	2.97	2.26	0.22	2.82
15	Mercury (mg/Kg)	Max	0	0	0	0	0	0
		Min	0	0	0	0	0	0
		Avg	0	0	0	0	0	0
16	Water Holding Capacity (%)	Max	54	77.92	61.99	75.84	60	66
		Min	35.8	34	23.74	15.9	39.85	44
		Avg	42.66	46.48	43.95	48.34	47.70	60.01
17	Sand (%)	Max	77.61	77.7	85.46	82.36	62.4	78.46
		Min	44.4	46.57	48.27	13.39	42.26	42.25
		Avg	59.26	65.74	62.96	65.03	51.61	60.59
18	Silt (%)	Max	53.28	47.28	41.25	57.98	49.27	53.27
		Min	9.77	9.28	9.93	9.28	12.24	12
		Avg	30.41	26.40	28.84	24.13	34.72	29.17
19	Clay (%)	Max	19.53	14.32	22.35	28.63	35.92	21.02
		Min	2.32	0.63	0.64	0.48	1.75	1.74
		Avg	10.29	7.86	8.19	10.83	13.66	10.23
20	Texture		Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Loam	Sandy Loam

7.3 Data Interpretation and Conclusion

Soil samples were collected from 6 locations (4 at Kandla and 2 at Vadinar) and further analysed for its physical & chemical characteristics. Each of the parameters have been given an interpretation based on the observations as follows:

1) Kandla:

- The value of **pH** ranges from **6.48** to **9.53**, with the highest at location **S-1 (Oil Jetty 7)** and the lowest at **location S-2 (IFFCO plant),** while the average pH for Kandla was observed to be **8.23**. The pH in Kandla varies from **Slightly alkaline to strongly alkaline**

- At all monitoring locations, the value of **Electrical Conductivity** ranges from **204 to 75,700** µs/cm, with the highest at **location S-3 (Khori Creek**) and the lowest at **S-4 (Nakti Creek).** The average Electrical Conductivity is **16,109.87** µs/cm.

- The concentration of inorganic phosphate varied from **0.32** to **619.89** kg/ha, with an average of **17.93** kg/ha. The highest concentration of inorganic phosphate was found at **S-2 (IFFCO plant)** and the lowest concentration was found at **S-4 (Nakti Creek)**. The availability of phosphorus in the soil solution is influenced by several factors, such as organic matter, clay content, pH, temperature, and more.

- The concentration of **Total Organic Carbon** ranges from **0.03% to 3.86%,** with an average TOC of **0.92%** detected. The highest concentration was found at **location S-3 (Khori Creek),** and the minimum concentration was found **at S-1 (Oil Jetty 7).**
- The **Sodium Adsorption Ratio** ranges from **0.36** to **41.45** meq/L, with an average value of **8.25** meq/L at Kandla. The highest concentration of SAR is found at **S-1 (Oil Jetty 7)** and the lowest concentration at **S-4 (Nakti Creek)**.
- The **Water Holding Capacity (WHC)** in the soil samples of Kandla varies from **15.9% to 77.92%**, with an average of **45.36%**. The highest concentration of WHC was observed at **S-2 (IFFCO plant)** and the lowest concentration at **S-4 (Nakti Creek)**.
- The Soil Texture was observed as "**Sandy loam**" to "**loamy sand**" at all the monitoring locations in Kandla.

Heavy Metals

- During the sampling period, the concentration of **Aluminium** varied from **812.75** to **10,298.7** mg/kg. The average **Aluminium** concentration was observed to be **2,383.475** mg/kg at the Kandla monitoring station. The **highest concentration** was observed at **S-3 (Khori Creek)**, and the **lowest concentration** was observed at **S-1 (Oil Jetty 7)**.
- The concentration of **Chromium** varied from **24.7 to 92.23** mg/kg, with an average value of **55.848** mg/kg observed at the Kandla monitoring station. The highest concentration was observed at **S-1 (Oil Jetty 7)**, and the lowest concentration was observed at **S-4 (Nakti Creek)**.
- The concentration of **Nickel** varied from **10.43** to **45.41** mg/kg at Kandla, with an average value of **20.71** mg/kg at the Kandla monitoring station. The highest concentration was observed at **S-4 (Nakti Creek)**, while the lowest concentration was also observed at **S-4 (Nakti Creek)**.
- The concentration of **Zinc** varied from **16.46** to **1755.4** mg/kg at Kandla, with an average value of **134.64** mg/kg at the Kandla monitoring station. The highest concentration was observed at **S-2 (IFFCO plant)**, which was the only spike observed during the entire monitoring period at Kandla. The lowest concentration was observed at **S-1 (Oil Jetty 7)**.
- The concentration of **Copper** varied from **12.42** to **192.72** mg/kg, with an average value of **13.667** mg/kg observed at the Kandla monitoring station. The highest concentration was observed at **S-4 (Nakti Creek)** and the lowest concentration was observed at **S-1 (Oil Jetty 7)**.
- The concentration of Lead varied from **1.29 to 277.82** mg/kg, with an average value of **17.33** mg/kg. The highest concentration was observed at **S-2 (IFFCO plant)**; this was the only spike observed during the entire monitoring period, while the lowest concentration was observed at **S-3 (Khori creek)**.
- The concentration of A**rsenic** varied from **0.1 to 8.4** mg/kg, with an average value of **2.67** mg/kg. The highest concentration was observed at **S-1 (Oil Jetty 7)**, and the lowest concentration was observed at **S-3 (Khori Creek)**.
- The concentration of **Cadmium** varied from **0** to **23.47** mg/kg, with an average value of **1.89** mg/kg. The highest concentration was observed at **S-2 (IFFCO plant)**. During the monitoring period, it was observed that cadmium was mostly found **Below**

Quantification Limit (BQL) at all locations, with only one spike observed at **S-2 (IFFCO plant)** throughout the entire monitoring period.

- During the monitoring period, it was observed that the concentration of **Mercury** was mostly found **below the quantification limit (BQL)** at all locations.

2) Vadinar:

- The value of **pH** ranges from **7.675** to **9.36**, with the highest at location **S-6 (Near Vadinar jetty)** and the lowest at **location S-5 (Near SPM),** while the average pH for Vadinar was observed to be **8.34**. pH of Soil at Vadinar was found to be **moderately alkaline**.
- At all monitoring locations in Vadinar, the value of **Electrical Conductivity** ranges from **63 to 625** µs/cm, with the highest at **S-6 (Near Vadinar jetty)** and the lowest at **location S-5 (Near SPM).** The average Electrical Conductivity is **229.33** µs/cm.
- The concentration of **inorganic phosphate** varied from **0.26** to **8.67** kg/ha, with an average of **2.32** kg/ha. The highest concentration of inorganic phosphate was found at **S-6 (Near Vadinar jetty)** and the lowest concentration was found at **location S-5 (Near SPM)**.
- The concentration of **Total Organic Carbon** ranges from **0.06% to 2.48%,** with an average TOC of **0.46%** detected at Vadinar. The highest concentration was found at **S-6 (Near Vadinar jetty),** and the minimum concentration was found **at S-5 (Near SPM).**
- The **Sodium Adsorption Ratio** ranges from **0.05** to **0.45** meq/L, with an average value of **0.143** meq/L at Vadinar. The highest concentration of SAR is found at **6 (Near Vadinar jetty)** and the lowest concentration at **S-5 (Near SPM)**.
- The **Water Holding Capacity (WHC)** in the soil samples of Vadinar varies from **39.85% to 66%**, with an average of **53.85%**. The highest concentration of WHC was observed at **S-6 (Near Vadinar jetty)** and the lowest concentration at **S-5 (Near SPM)**.
- The soil texture of Vadinar varies from "loam" to "slit loam".

Heavy Metals

- During the sampling period, the concentration of **Aluminium** varied from **735.77** to **15921.72** mg/kg. The average **Aluminium** concentration was observed to be **2,805.2** mg/kg at the Vadinar monitoring station. The **highest concentration** was observed at **S-5 (Near SPM)**, and the **lowest concentration** was observed at **S-5 (Near SPM) but during different months**.
- The concentration of **Chromium** varied from **60.93 to 106** mg/kg, with an average value of **76.69** mg/kg observed at the Vadinar monitoring station. The highest concentration was observed at **S-5 (Near SPM)**, and the lowest concentration was observed at **S-6 (Near Vadinar jetty)**.
- The concentration of **Nickel** varied from **25.62** to **42.68** mg/kg, with an average value of **32.825** mg/kg at the Vadinar monitoring station. The highest concentration was observed at **S-6 (Near Vadinar jetty)**, and the lowest concentration was also observed at **S-6 (Near Vadinar jetty)** but during different months.

- The concentration of **Zinc** varied from **15.33** to **97.36** mg/kg, with an average value of **56.118** mg/kg at the Vadinar monitoring station. The highest concentration was observed at **S-6 (Near Vadinar jetty)**, and the lowest concentration was also observed at **S-6 (Near Vadinar jetty)** but during different months.
- The concentration of **Copper** varied from **60.57** to **123.18** mg/kg, with an average value of **92.71** mg/kg observed at the Vadinar monitoring station. The highest concentration was observed at **S-5 (Near SPM)** and the lowest concentration was observed at **S-6 (Near Vadinar jetty)**.
- The concentration of **Lead** varied from **0.59 to 21.07** mg/kg, with an average value of **3.875** mg/kg. The highest concentration was observed at **S-6 (Near Vadinar jetty)**; this was the only spike observed during the entire monitoring period at Kandla, while the lowest concentration was observed at **S-5 (Near SPM)**.
- The concentration of A**rsenic** varied from **0.099 to 0.59** mg/kg, with an average value of **5.05** mg/kg. The highest concentration was observed at **S-6 (Near Vadinar jetty)**, and the lowest concentration was observed at **S-5 (Near SPM)**.
- The concentration of **Cadmium** varied from **0** to **3** mg/kg, with an average value of **3** mg/kg. The highest concentration was observed at **S-5 (Near SPM)**. During the monitoring period, it was observed that cadmium was mostly found **Below Quantification Limit (BQL)** at all locations.
- During the monitoring period, it was observed that the concentration of **Mercury** was mostly found **below the quantification limit (BQL)** at all locations.

CHAPTER 8: DRINKING WATER MONITORING

8.1 Drinking Water Monitoring

It is necessary to check with the drinking water sources regularly so as to know whether water quality conforms to the prescribed standards for drinking. Monitoring the drinking water quality is essential to protect human health and the environment. With reference to the scope specified by DPA, a total of 20 locations (18 at Kandla and 2 at Vadinar) were monitored to assess the Drinking Water quality.

The details of the drinking water sampling stations have been mentioned in **Table 20** and the locations have been depicted through Google map in **Map 12 and 13.**

Table 20: Details of Drinking Water Sampling Locations

Sr. No.	Location Code		Location Name	Latitude/ Longitude
1.	Kandla	DW-1	Oil Jetty 7	23.043527N 70.218456E
2.		DW-2	Port & Custom Building	23.009033N 70.222047E
3.		DW-3	North Gate	23.007938N 70.222411E
4.		DW-4	Workshop	23.009372N 70.222236E
5.		DW-5	Canteen Area	23.003707N 70.221331E
6.		DW-6	West Gate 1	23.006771N 70.217340E
7.		DW-7	Sewa Sadan -3	23.009779N 70.221838E
8.		DW-8	Nirman Building	23.009642N 70.220623E
9.		DW-9	Custom Building	23.018930N 70.214478E
10.		DW-10	Port Colony Kandla	23.019392N 70.212619E
11.		DW-11	Wharf Area/ Jetty	22.997833N 70.223042E
12.		DW-12	Hospital Kandla	23.018061N 70.212328E
13.		DW-13	A.O. Building	23.061914N 70.144861E
14.		DW-14	School Gopalpuri	23.083619N 70.132061E
15.		DW-15	Guest House	23.078830N 70.131008E
16.		DW-16	E- Type Quarter	23.083306N 70.132422E
17.		DW-17	F- Type Quarter	23.077347N 70.135731E
18.		DW-18	Hospital Gopalpuri	23.081850N 70.135347E
19.	Vadinar	DW-19	Near Vadinar Jetty	22.440759N 69.675210E
20.		DW-20	Near Port Colony	22.401619N 69.716822E

Map 12: Drinking Water Monitoring Locations at Kandla

Map 13: Drinking Water Monitoring Locations at Vadinar

Methodology

The water samples were collected from the finalized sampling locations and analyzed for physico-chemical and microbiological parameter, for which the analysis was carried out as per APHA, 23rd Edition and Indian Standard method in GEMI's NABL Accredited Laboratory, Gandhinagar. GEMI has followed the CPCB guideline as well as framed its own guidelines for the collection of water/wastewater samples, under the provision of Water (Preservation and Control of Pollution) Act 1974, titled as '**Sampling Protocol for Water & Wastewater**'; approved by the Government of Gujarat vide letter no. ENV-102013-299-E dated 24-04-2014. The samples under the study were collected and preserved as per the said Protocol. The parameters finalized to assess the drinking water quality have been mentioned in **Table 21** as follows:

Table 21: List of parameters for Drinking Water Quality monitoring[3]

Sr. No.	Parameters	Units	Reference method	Instrument
1.	pH	-	APHA, 23rd Edition (Section-4500-H^+B):2017	pH Meter
2.	Colour	Hazen	APHA, 23rd Edition, 2120 B:2017	Color Comparator
3.	EC	µS/cm	APHA, 23rd Edition (Section-2510 B):2017	Conductivity Meter
4.	Turbidity	NTU	APHA, 23rd Edition (Section -2130 B):2017	Nephlo Turbidity Meter
5.	TDS	mg/L	APHA, 23rd Edition (Section-2540 C):2017	Vaccum Pump with filtration assembly and Oven
6.	TSS	mg/L	APHA, 23rd Edition, 2540 D: 2017	
7.	Chloride	mg/L	APHA, 23rd Edition (Section-4500-Cl-B):2017	Titration Apparatus
8.	Total Hardness	mg/L	APHA, 23rd Edition (Section-2340 C):2017	
9.	Ca Hardness	mg/L	APHA, 23rd Edition (Section-3500-Ca B):2017	
10.	Mg Hardness	mg/L	APHA, 23rd Edition (Section-3500-Mg B):2017	
11.	Free Residual Chlorine	mg/L	APHA 23rd Edition, 4500	
12.	Fluoride	mg/L	APHA, 23rd Edition (Section-4500-F-D):2017	UV- Visible Spectrophotometer
13.	Sulphate	mg/L	APHA, 23rd Edition (Section 4500-SO4-2-E):2017	
14.	Sodium	mg/L	APHA, 23rd Edition (Section-3500-Na-B):2017	Flame Photometer
15.	Potassium	mg/L	APHA,23rd Edition, 3500 K-B: 2017	
16.	Salinity	mg/L	APHA, 23rd Edition (section 2520 B, E.C. Method)	Salinity /TDS Meter
17.	Nitrate	mg/L	APHA, 23rd Edition, 4500 NO3- B: 2017	UV- Visible Spectrophotometer
18.	Nitrite	mg/L	APHA, 23rd Edition, 4500 NO2-B: 2017	
19.	Hexavalent Chromium	mg/L	APHA, 23rd Edition, 3500 Cr B: 2017	
20.	Manganese	mg/L	APHA,23rd Edition, ICP Method 3120 B: 2017	ICP-OES

Sr. No.	Parameters	Units	Reference method	Instrument
21.	Mercury	mg/L	EPA 200.7	
22.	Lead	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
23.	Cadmium	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
24.	Iron	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
25.	Total Chromium	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
26.	Copper	mg/L	APHA,23rd Edition, ICP Method 3120 B: 2017	ICP-OES
27.	Zinc	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
28.	Arsenic	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
29.	Total Coliforms	MPN/ 100ml	IS 15185: 2016	LAF/ Incubator

Monitoring Frequency

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar. Sample Collected from this location during the monitoring period April/2023 to March/2024.

8.2 Result and Discussion

The drinking water quality of the locations at Kandla and Vadinar and its comparison with the to the stipulated standard (Drinking Water Specifications i.e., IS: 10500:2012) (4) have been summarized in **Table 22A, 22B, 22C** as follows:

Table 22A: Drinking Water Quality for the Monitoring period

Parameters	Standard values as per IS-		DW-1 (Oil Jetty 7)			DW-2 (Port & Custom Building)			DW-3 (North Gate)			DW-4 (Workshop)			DW-5 (Canteen Area)			DW-6 (West Gate 1)			DW-7 (Sewa Sadan -3)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH	6.5-8.5		7.9	6.6	7.4	8.4	6.8	7.3	8.0	6.8	7.3	8.1	7.1	7.4	8.2	7.3	7.7	8.4	7.2	7.7	8.2	7.2	7.5
Colour (Hazen)	5	15	5.0	1.0	1.7	5.0	1.0	1.3	5.0	1.0	1.3	5.0	1.0	1.3	5.0	1.0	3.3	5.0	1.0	1.7	5.0	1.0	1.3
EC (µS/ cm)			370	19.4	195.6	600.	36.0	153.8	1653	27.0	259.7	401	12.8	85.6	2200	42.0	1056	1470	28.0	336.3	150	22	57.8
Salinity (PSU)			1.0	0.0	0.2	0.3	0.0	0.1	0.8	0.0	0.1	0.2	0.0	0.0	1.1	0.0	0.5	0.7	0.0	0.2	0.1	0	0.0
Turbidity (NTU)	1	5	1.2	1.1	1.1	2.0	1.5	1.8	1.9	0.7	1.2	3.7	0.9	2.3	3.1	0.9	1.9	1.5	1.0	1.2	5.9	1.1	3.5
Chloride (mg/L)	250	1000	81	5.8	41.6	92	7.5	34.1	354.9	8.0	56.9	110	3	22.9	437.4	10.3	192.0	329.9	9.0	78	42.5	6.5	15.7
Total Hardness (mg/L)	200	600	42	3	13.3	148	3	24.8	320	2.0	33.4	20.0	2	7.5	310	10	181	230	5.0	53.2	10	2	4.1
Ca Hardness (mg/L)			27	2	6.3	92	2	13.9	200	1.0	20.3	8.0	1	3.3	210.0	5	103.9	120.0	2.5	28.9	5.0	1	2.2
Mg Hardness (mg/L)			15	1	6.8	56	1	10.1	120	1.0	13.1	12	1	3.9	120.0	5	76.6	110.0	2.0	24.4	5.0	1	2
Free Residual Chlorine (mg/L)	0.2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDS (mg/L)	500	2000	184	10	101.7	306	20	81.8	840	14	132.7	204	8.0	44.7	928	22	452.4	752	20.0	171.6	78	14	30.8
TSS (mg/L)			0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0
Fluoride (mg/L)	1	1.5	0.4	0.4	0.4	0.5	0.4	0.5	0.7	0.3	0.4	0.0	0.0	0.0	0.9	0.3	0.5	0.9	0.7	0.8	0.4	0.4	0.4
Sulphate (mg/L)	200	400	15.7	15.7	15.7	35.7	35.7	35.7	73.9	73.9	73.9	0.0	0.0	0.0	113.3	2.2	64.0	97.3	2	55.3	0	0	0

Parameters	Standard values as per IS-		DW-1 (Oil Jetty 7)			DW-2 (Port & Custom Building)			DW-3 (North Gate)			DW-4 (Workshop)			DW-5 (Canteen Area)			DW-6 (West Gate 1)			DW-7 (Sewa Sadan -3)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Nitrate (mg/L)	**45**		26	3.7	12.5	4.2	0.5	1.8	7.5	1.3	4.6	2.4	2.4	2.4	8.8	3.4	5.8	5.7	1.3	2.8	2.1	2.1	2.1
Nitrite (mg/L)			0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.2	0.2	0.2	0	0	0
Sodium (mg/L)			86	5	34.5	38.5	7	21.2	178.6	9.7	38.0	42.6	5.7	18.0	319.6	12.0	118.4	197.5	8.8	44.1	15.1	5.5	9.6
Potassium (mg/L)			0	0	0	0	0	0	0	0	0	0	0	0	5.8	5.8	5.8	0	0	0	0	0	0
Hexavalent Chromium (mg/L)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odour (TON)	**Agreeable**			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Arsenic (mg/L)	**0.01**	**0.05**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cadmium (mg/L)	**0.003**		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Copper (mg/L)	**0.05**	**1.5**	17.3	0	5.8	8.4	0.0	2.8	6.2	0.0	3.1	11.1	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iron (mg/L)	**0.3**		0.6	0	0.3	0.2	0.2	0.2	0.2	0.0	0.1	0.2	0.2	0.2	0.2	0.0	0.1	0.2	0.0	0.1	0.1	0.1	0.1
Lead (mg/L)	**0.01**		3.1	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manganese (mg/L)	**0.1**	**0.3**	0.1	0	0.1	0	0	0	0.5	0.5	0.5	0.1	0.1	0.1	0	0	0	0.5	0	0.2	0	0	0
Mercury (mg/L)	**0.001**		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Chromium (mg/L)	**0.05**		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zinc (mg/L)	**5**	**15**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Coliform* (MPN/ 100ml)	**Shall not be detected**		630.0	5.0	118.0	12500.0	5.0	1629.3	250.0	10.0	100.7	50.0	5.0	24.0	144500	5.0	17137	4350	5.0	1407	23500	2.0	3963.3

Table 22B: Drinking Water Quality for the Monitoring period

Parameters	Standard values as per IS		DW-8 (Nirman Building)			DW-9 (Custom Building)			DW-10 (Port Colony Kandla)			DW-11 (Wharf Area/ Jetty)			DW-12 (Hospital Kandla)			DW-13 (A.O. Building)			DW-14 (School Gopalpuri)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH	6.5-8.5		8	7	7.5	8	6.2	7.3	7.9	6.82	7.31	8.3	6.85	7.71	7.75	6.62	7.224	8.5	7.2	7.61	8.2	7.08	7.56
Colour (Hazen)	5	15	5.0	1.0	2.3	5.0	1.0	2.0	5.0	1	2	10	1	3.083	5	1	1.67	5	1	1.33	10	1	3.28
EC (µS/ cm)			2000	40.0	403.8	2900.0	48.0	492.9	3100	105.4	554.9	2460	55	980.1	269	47	141.2	1412	23.2	187.2	1467	43.3	412.15
Salinity (PSU)			1.0	0.0	0.2	1.5	0.0	0.2	1.6	0.05	0.283	1.2	0.02	0.42	0.13	0.03	0.072	0.71	0.02	0.151	0.73	0.03	0.22
Turbidity (NTU)	1	5	3.6	1.1	1.8	4.7	1.0	2.8	2.2	0.95	1.575	3.79	1	2.09	2	1.02	1.57	9.9	0.9	3.67	13.9	0.5	5.48
Chloride (mg/L)	250	1000	499.9	10.0	93.1	689.8	12.5	108.7	504.8	21.99	75.52	404.8	13.54	173.9	67.98	12.5	31.79	307.4	7.5	44.28	332.4	11.5	93.83
Total Hardness (mg/L)	200	600	280.0	4.0	61.8	480	6.0	80.2	340.0	3	62.83	320	15	176.4	30	3	17.84	240	1.5	70.3	270	2	82.64
Ca Hardness (mg/L)			140.0	2.0	31.8	240	3.0	38.7	190.0	2	33.5	170	5	91.30	17	2	9.67	120	1	31.12	140	1.5	42.96
Mg Hardness (mg/L)			140.0	2.0	30.1	190	3.0	37.5	150.0	1	29.32	150	10	84.76	14	1	8.167	120	0.5	33.15	130	2	43.6
Free Residual Chlorine (mg/L)	0.2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDS (mg/L)	500	2000	1012	22.0	205.2	1522	24.0	255.8	1064	54	165.4	872	29	403.8	138	24	73.17	718	14	101.9	742	22	218
TSS (mg/L)			2.0	2.0	2.0	12.0	2.0	7.0	2.0	2	2	2	2	2	0	0	0	0	0	0	12	8	10
Fluoride (mg/L)	1	1.5	0.0	0.0	0.0	1.5	0.6	1.1	0.5	0.416	0.433	1.06	0.367	0.57	1.108	1.108	1.108	0	0	0	0.35	0.15	0.25
Sulphate (mg/L)	200	400	100.8	45.5	73.2	142.0	41.5	80.0	115.6	3.17	59.39	134.7	1.97	59.51	0	0	0	108.7	108.77	108.7	113.4	11.55	56.304
Nitrate (mg/L)	45		4.5	1.1	2.6	5.6	2.4	3.8	7.5	1.04	3.68	8.49	3.78	5.929	2.023	1.42	1.752	3.392	1.524	2.585	4.48	1.382	2.38

Parameters	Standard values as per IS		DW-8 (Nirman Building)			DW-9 (Custom Building)			DW-10 (Port Colony Kandla)			DW-11 (Wharf Area/ Jetty)			DW-12 (Hospital Kandla)			DW-13 (A.O. Building)			DW-14 (School Gopalpuri)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Nitrite (mg/L)			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.201	0.11	0.147	0	0	0	0	0	0	0	0	0
Sodium (mg/L)			109.5	9.2	39.4	396.2	8.0	75.4	105.8	11.98	37.65	356.5	12.8	106.5	31.35	11.59	20.22	83.91	8.66	21.44	173.5	6.24	46.666
Potassium (mg/L)			0	0	0	13.6	13.6	13.6	7.0	2.6	4.8	0	0	0	0	0	0	0	0	0	0	0	0
Hexavalent Chromium (mg/L)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odour (TON)	Agreeable			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Arsenic (mg/L)	0.01	0.05	0	0	0	0	0	0	0	0.007	0.007	0.005	0.0039	0.004	0	0	0	0	0	0	0.015	0.015	0.015
Cadmium (mg/L)	0.003		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0.005	0.005	0.006	0.006	0.006
Copper (mg/L)	0.05	1.5	6.8	0	3.4	0	0	0	10.2	0.005	2.049	0	0	0	9.257	0.005	3.57	0.008	0.0079	0.008	0	0	0
Iron (mg/L)	0.3		0.1	0.1	0.1	0	0	0	0.3	0.0001	0.16	0.17	0.0001	0.092	0	0	0	0.13	0.13	0.13	0.0001	0.0001	0.0001
Lead (mg/L)	0.01		0.2	0	0.1	0	0	0	0	0.0033	0.003	0.004	0.0038	0.004	0.0028	0.003	0.003	0.002	0.002	0.002	4.27	4.27	4.27
Manganese (mg/L)	0.1	0.3	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.05	0.05	0	0	0
Mercury (mg/L)	0.001		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Chromium (mg/L)	0.05		0	0	0	0	0	0	0	0	0	0	0	0	0.0122	0.012	0.012	0.006	0.006	0.006	0	0	0
Zinc (mg/L)	5	15	0	0	0	0.6	0.6	0.6	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Coliform* (MPN/ 100ml)	Shall not be detected		240.0	2.0	114.7	12050	4.0	1826	37080	35	5374	25550	5	3329	140	4	47.2	685	20	166.7	4900	15	636.4

Table 22C: Drinking Water Quality for the Monitoring period

Parameters	Standard values as per IS		DW-15 (Guest House)			DW-16 (E- Type Quarter)			DW-17 (F- Type Quarter)			DW-18 (Hospital Gopalpuri)			DW-19 (Near Vadinar Jetty)			DW-20 (Near Port Colony)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH	6.5-8.5		7.99	6.87	7.35	7.68	6.93	7.28	8.19	6.78	7.46	8.27	7.12	7.6	8.38	7.21	7.685	8.07	7.05	7.435
Colour (Hazen)	5	15	5	1	1.67	5	1	1.67	5	1	1.67	10	1	3.5	5	1	2.333	20	1	6
EC (µS/ cm)			264	34.3	120.22	746	17.79	116.84	1337	15.93	298.6	7930	30.2	1037	537	30	199.7	1736	88.4	427.7
Salinity (PSU)			0.7	0.02	0.113	0.38	0.02	0.06	0.67	0.02	0.16	4.39	0.02	0.55	0.26	0.02	0.100	0.87	0.05	0.235
Turbidity (NTU)	1	5	2.29	0.63	1.27	2.8	0.52	1.50	1.97	1.1	1.66	3.98	0.7	2.03	1.5	1.2	1.35	5.3	0.7	3.25
Chloride (mg/L)	250	1000	60.98	10.5	26.98	124.96	4	24.58	287.41	4	61.99	163.9	9	75.28	66.98	9	27.20	407.37	13	73.15
Total Hardness (mg/L)	200	600	20	2	11.97	180	1.5	22.86	230	2	52.6	195	4	96.25	160	2	44.58	240	20	88.5
Ca Hardness (mg/L)			10	1.5	6.25	80	1	10.77	120	1	28.5	102	2	49.43	80	1.5	21.54	140	10	44.08
Mg Hardness (mg/L)			12.5	1	6.136	100	0.5	13.25	110	1	24.1	100	1	46.79	80	1	25.09	100	8	44.41
Free Residual Chlorine (mg/L)	0.2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDS (mg/L)	500	2000	138	18	62.75	382	10	60.5	682	8	157.5	448	16	198.8	272	15	100.9	882	46	218.5
TSS (mg/L)			0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	12	4	8
Fluoride (mg/L)	1	1.5	0.34	0.34	0.34	0	0	0	0.5	0.37	0.43	0.51	0.38	0.44	0.35	0.35	0.35	1.06	1.06	1.06
Sulphate (mg/L)	200	400	10.62	10.3	10.46	34.35	34.35	34.35	104.64	8.37	41.20	59.94	1.81	40.82	42.2	13.07	31.87	102.92	25.4	48.22
Nitrate (mg/L)	45		5.63	1.12	2.53	1.97	1.97	1.97	6.06	1.19	3.20	16.51	1.17	5.1	15.79	1.82	5.55	18.54	1.06	6.45
Nitrite (mg/L)			0	0	0	0	0	0	0	0	0	0.20	0.11	0.16	0	0	0	1.89	1.89	1.89

Parameters	Standard values as per IS		DW-15 (Guest House)			DW-16 (E- Type Quarter)			DW-17 (F- Type Quarter)			DW-18 (Hospital Gopalpuri)			DW-19 (Near Vadinar Jetty)			DW-20 (Near Port Colony)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Sodium (mg/L)			40.46	14.3	19.38	74.46	7.06	24.85	82.61	5.75	35.30	185.2	7.08	55.81	58.37	6.08	20.49	204.04	7.18	46.23
Potassium (mg/L)			0	0	0	0	0	0	0	0	0	3.2	3.2	3.2	0	0	0	5.85	5.85	5.85
Hexavalent Chromium (mg/L)			0	0	0	0	0	0	0	0	0	0	0	0	0.041	0.041	0.041	0.01	0.01	0.01
Odour (TON)	Agreeable			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Arsenic (mg/L)	0.01	0.05	0.007	0.007	0.007	0	0	0	0.008	0.008	0.008	0.015	0.01	0.012	0.08	0.08	0.08	0	0	0
Cadmium (mg/L)	0.003		0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008	0	0	0	0	0	0
Copper (mg/L)	0.05	1.5	7.24	0.006	2.42	0	0	0	0.012	0.012	0.012	7.3	0.006	3.65	16.25	0.006	7.99	15.403	0.01	3.09
Iron (mg/L)	0.3		0.25	0.0002	0.13	0	0	0	0.52	0.0001	0.213	0.11	0.0003	0.055	1.47	1.47	1.47	0	0	0
Lead (mg/L)	0.01		2.21	0.002	1.10	0	0	0	0	0	0	0	0	0	10.53	0.003	5.26	0.002	0.002	0.002
Manganese (mg/L)	0.1	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.	0.13	0	0.08
Mercury (mg/L)	0.001		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Chromium (mg/L)	0.05		0	0	0	0	0	0	0	0	0	0.006	0.006	0.006	0	0	0	0	0	0
Zinc (mg/L)	5	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Coliform* (MPN/ 100ml)	Shall not be detected		200	5	57.75	7650	5	1669	57000	9	6635	310	5	131	2850	120	1485	130000	10	16647

A: Acceptable, P:Permissible, BQL: Below Quantification limit Turbidity (QL=0.5 NTU), Free Residual Chlorine (QL=2 mg/L), Total Suspended Solids (QL=2 mg/L), Fluoride (QL=0.3 mg/L), Sulphate (QL=10 mg/L), Nitrate as NO_3 (QL=1 mg/L), Nitrite as NO_2 (QL=0.1mg/L), Sodium as Na (QL=5mg/L), Potassium as K (QL=5mg/L), Hexavalent Chromium (QL=0.01 mg/L), Arsenic (QL=0.005 mg/L), Cadmium (QL=0.002 mg/L), Copper (QL=0.005 mg/L), Iron (QL=0.1mg/L), Lead (QL=0.002 mg/L), Manganese (QL=0.04 mg/L), Mercury (QL=0.0005 mg/L), Total Chromium (QL=0.005 mg/L), Zinc (QL=0.5 mg/L), Total Coliforms (QL=1 MPN/ 100ml)

Note: For Total Coliform, one MPN is equivalent to one CFU. The use of either method; MPN or CFU for the detection of bacteria are considered valid measurements for bacteria limits.

8.3 Data Interpretation and Conclusion

Drinking water samples were taken from 20 locations (18 at Kandla and 2 at Vadinar), and their physical and chemical properties were analyzed. The analysis's results were compared with standard values as prescribed in IS 10500:2012 Drinking Water Specification.

Physico-Chemical Parameters:

- **pH:** The pH values of drinking water samples in Kandla were reported to be in the range of **6.24 to 8.5**, with an average pH of **7.5**. In Vadinar, its values ranged from **7.05 to 8.38**, with an average pH of **7.36**. Notably, the pH levels at both project sites fall within the acceptable range of 6.5 to 8.5, as specified under IS:10500:2012.
- **Colour:** The colour varies from 1 to 10 at the monitoring locations in Kandla. Locations DW-11, DW-14 and DW-10 showed the value of 10 Hazen at Kandla. At Vadinar, the color was observed within the range of 1 to 20 Hazen. the Colour levels at both project sites fall within the acceptable range of 1 to 15, as specified under IS:10500:2012, except of one location DW-20 within the monitoring period of April to May 2023
- **Electrical Conductivity (EC):** It is a measure of the ability of a solution to conduct electric current, and it is often used as an indicator of the concentration of dissolved solids in water. During the monitoring period, the EC values for samples collected in Kandla were observed to range from **12.83 to 7930 µS/cm**, with an average value of **708.65** µS/cm. In Vadinar, the EC values showed variation from **30 to 1736 µS/cm**, with an average value of **503.14** µS/cm. It's important to regularly monitor EC levels in drinking water as it can provide valuable information about water quality and presence of dissolved substances.
- **Salinity:** Salinity at Kandla varies from **0.02 to 4.39 PSU** with an average of **0.396** PSU, while at Vadinar, salinity was observed within the range of **0.02** to **0.87 PSU**.
- **Turbidity**: The Turbidity values of drinking water samples in Kandla were reported to be in the range of **0.5 to 13.9 NTU**, with an average of **2.32**. In Vadinar, its values ranged from **0 to 5.3**, with an average **2.21**. Notably, the Turbidity levels at both project sites fall within the acceptable range of 1 to 5 NTU, as specified under IS:10500:2012, except DW-7, in the monitoring period of July to August 2023, DW-13 in the monitoring period of May to June 2023 and DW-14 in the monitoring period of September to October and October to November 2023. On all this location most of the time Turbidity observed Below Quantification Limit
- **Chlorides:** The chloride concentrations in Kandla varied from **3 to 689.78 mg/L**, with an average value of **116.85** mg/L. At Vadinar the chloride concentration was observed within the range of **9** mg/L to **407.37** mg/L, with an average value of **99.45** mg/L. Thus, the chloride levels at both project sites fall within the Permissible limit of 1000 mg/L, as specified under IS:10500:2012.
- **Total Hardness (TH):** The concentration of Total Hardness varies from **1.5 to 480 mg/L**, with an average concentration of **88.68** mg/L. While at Vadinar, the observed values were within range of **2 to 240** mg/L. at both study areas Total Hardness found

to be within the Permissible limit norm of 600 mg/L as specified by IS:10500:2012 and is not harmful for local inhabitants.

- **Total Dissolved Solids (TDS):** Monitoring TDS is crucial because it provides an indication of overall quality of the water. During the monitoring period, the TDS concentrations in Kandla were observed to vary in a wide range i.e., between **8** to **1522** mg/L, with an average concentration of **264.4** mg/L. which is within the permissible limit. while in Vadinar, it ranged from **6** to **882** mg/L, with an average of **255.75** mg/L. It is important to note that the TDS concentrations in both Kandla and Vadinar fall well within the Permissible limit of 2000 mg/L.
- **Fluoride:** The concentration Fluoride varies from **0** to **1.477** mg/L, with an average concentration of **0.44** mg/L. While at Vadinar Fluoride concentration was varies within range of **0** to **1.06** mg/L**,** with an average concentration of **0.708** mg/L**.** The Fluoride concentration was found to be **BQL** in majority of the monitoring location at Kandla and Vadinar. at both study areas Fluoride found to be within the Permissible limit norm of 1.5 mg/L as specified by IS:10500:2012
- **Sulphate:** The concentration Sulphate varies from **0** to **141.99** mg/L, with an average concentration of **45.67** mg/L. While at Vadinar Sulphate concentration was varies within range of **13.07** to **102.92** mg/L**,** with an average concentration of **43.94** mg/L**.** During monitoring period in Kandla and Vadinar, the sulphate concentrations were found to be within the acceptable limits i.e., 200 mg/L as per the specified norms.
- **Nitrate:** The concentration Nitrate varies from **0** to **25.96** mg/L, with an average concentration of **4.08** mg/L. While at Vadinar Nitrate concentration was varies within range of **0** to **18.54** mg/L**,** with an average concentration of **8.20** mg/L**.** The Nitrate concentration was found to be **BQL** in majority of the monitoring location at Kandla and Vadinar. at both study areas Nitrate found to be within the Acceptable limit norm of 45 mg/L as specified by IS: 10500:2012.
- **Nitrite:** The concentration Nitrite varies from **0** to **0.2** mg/L. While at Vadinar Nitrite concentration was varies within range of **0** to **1.89** mg/L**,** with an average concentration of **0.945** mg/L**.** The Nitrite concentration was found to be **BQL** in majority of the monitoring location at Kandla and Vadinar.
- **Sodium:** During the monitoring period, at Kandla variation in the concentration of Sodium was observed to be in the range of **5.01 to 396.2 mg/L**, with the average concentration of **63.71** mg/L. While at Vadinar, the concentration recorded between **6.08** to **204.4** mg/L, with the average concentration of **57.067** mg/L.
- **Odour:** Odour values recorded 1 TON at all monitoring locations of Kandla and Vadinar.

Metals:

- **Arsenic:** The Arsenic concentrations in Kandla varied from **0 to 0.042 mg/L**. At Vadinar the Arsenic concentration was observed within the range of **0** mg/L to **0.08** mg/L. Thus, the Arsenic levels at both project sites fall within the Permissible limit of 0.05 mg/L, as specified under IS:10500:2012, except on one location at Vadinar DW-19 where Arsenic Concentration found 0.08 mg/L in the monitoring period of November to December 2023. In Kandla and Vadinar, the Arsenic concentrations were recorded

BQL for majority of the locations except the locations DW-2, DW-12, and DW-18 in Kandla and DW-20 In Vadinar.

- **Copper:** The Copper concentrations in Kandla varied from **0 to 17.3 mg/L**. At Vadinar the Copper concentration was observed within the range of **0** mg/L to **16.25** mg/L. Thus, the Copper levels at both project sites fall within the Permissible limit of 1.5 mg/L, as specified under IS:10500:2012, except for locations DW-1, DW-2, DW-4, DW-8, DW-10, DW-12, DW-15, DW-18 in Kandla and on both Locations DW-19 and DW-20 of Vadinar for some samples taken during whole monitoring period. The Copper concentrations were recorded BQL for majority of the locations in Kandla and Vadinar.
- **Iron:** The Iron concentrations in Kandla varied from **0 to 0.64 mg/L**, with an average concentration of **0.10** mg/L. At Vadinar the Iron concentration was observed within the range of **0** mg/L to **1.478** mg/L. Thus, the Iron levels at both project sites fall within the Acceptable limit of 0.3 mg/L, as specified under IS:10500:2012, except for locations DW-1, DW-10, and DW-17 in Kandla and on Location DW-19 of Vadinar for some samples taken during the whole monitoring period. The Iron concentrations were recorded by BQL for the majority of the locations in Kandla and Vadinar.
- **Lead:** The Lead concentrations in Kandla varied from **0 to 4.279 mg/L**, with an average concentration of **0.37** mg/L. While at Vadinar the Lead concentration was observed within the range of **0** mg/L to **10.53** mg/L, with an average concentration of **2.6344**. Thus, the Lead levels at both project sites fall within the Acceptable limit of 0.01 mg/L, as specified under IS:10500:2012, except for locations DW-1, DW-8, DW-14 and DW-15 in Kandla and on Location DW-19 of Vadinar for some samples taken during the whole monitoring period. The Lead concentrations were recorded in BQL for the majority of the locations in Kandla and Vadinar.
- **Manganese:** The Manganese concentrations in Kandla varied from **0 to 0.51 mg/L**, with an average concentration of **0.1** mg/L. While at Vadinar, the Manganese concentration was observed within the range of **0** mg/L to **0.13** mg/L. Thus, the Manganese levels at both project sites fall within the Acceptable limit of 0.3 mg/L, as specified under IS:10500:2012, except for locations DW-3, and DW-6 in Kandla and on Location DW-20 of Vadinar for some samples taken during the whole monitoring period. The Manganese concentrations were recorded BQL for the majority of the locations in Kandla and Vadinar.
- The concentrations of parameters such as **Free Residual Chlorine, Total Suspended Solid, Potassium Hexavalent Chromium** and **the metals (Cadmium, Mercury, Total Chromium and Zinc)** were observed to fall within the Permissible limit at both project sites. Observed "Below the Quantification Limit (BQL)" at majority of the locations during the monitoring period.
- Bacteriological Analysis of the drinking water reveals that **Total Coliforms (TC)** were detected in the range of **0** to **144500** MPN/100ml, with the average of **6964.8** MPN/100ml. While at Vadinar the observed within the range of **0** MPN/100ml to **1,30,000** MPN/100ml, with the average concentration of **25,185** MPN/100ml. And for the rest of the monitoring locations of Kandla and Vadinar were detected "Below the Quantification Limit (BQL)". Reporting such concentration of Coliforms indicates

certain external influx may contaminate the source. Hence, it should be checked at every distribution point. The higher concentration of total coliforms were observed on locations DW-2, DW-5, DW-7, DW-10, DW-11, and DW-17 in Kandla and DW-20 location in Vadinar.

8.4 Remedial Measures

Appropriate water treatment processes should be administered to eradicate coliform bacteria. The methods of disinfection such as **chlorination, ultraviolet (UV), or ozone** etc, apart from that, filtration systems can also be implemented to remove bacteria, sediment, and other impurities.

The following steps can be implemented to ensure that the water being supplied is safe for consumption:

- Regular monitoring should be carried out to assess the quality of drinking water at various stages, including the source, purification plants, distribution network, and consumer endpoints would help in early detection of coliform bacteria or other contaminants in the drinking water.
- It is necessary to carry out a system assessment to determine whether the drinking-water supply chain (up to the point of consumption) as a whole can deliver water of a quality that meets identified targets. This also includes the assessment of design criteria of the treatment systems employed.
- Identifying control measures in a drinking-water system that will collectively control identified risks and ensure that the health-based targets are met. For each control measure identified, an appropriate means of operational monitoring should be defined that will ensure that any deviation from required performance (water quality) is rapidly detected in a timely manner.
- Management and communication plan should be formulated describing actions to be taken during normal operation as well as during incident conditions (such as drinking water contamination) and documenting the same.

CHAPTER 9: SEWAGE TREATMENT PLANT MONITORING

9.1 Sewage Treatment Plant (STP) Monitoring:

The principal objective of STP is to remove contaminants from sewage to produce an effluent that is suitable to discharge to the surrounding environment or an intended reuse application, thereby preventing water pollution from raw sewage discharges. As defined in the scope by Deendayal Port Authority (DPA), Kandla, the STP Monitoring is to be carried out weekly at three locations, one at Kandla, one at Gopalpuri and one STP at Vadinar. The samples from the inlet and outlet of the STP have been collected weekly. The details of the locations of STP to be monitored for Kandla and Vadinar have been mentioned in **Table 23A** as follows:

Frequency of monitoring: weekly

Table 23A: Details of the monitoring locations of STP

Sr. No.	Location Code		Location Name	Latitude Longitude
1.	Kandla	STP-1	STP Kandla	23.021017N 70.215594E
2.		STP-2	STP Gopalpuri	23.077783N 70.136759E
3.	Vadinar	STP-3	STP at Vadinar	22.406289N 69.714689E

The Consolidated Consent and Authorization (CC&A) issued by the GPCB were referred for the details of the STP for Kandla and Gopalpuri. The CC&A of Kandla and Gopalpuri entails that the treated domestic sewage should conform to the norms specified in **Table 23B**. The treated effluent conforming to the norms shall be discharged on the land within the premises strictly for the gardening and plantation purpose. Whereas, no sewage shall be disposed outside the premises in any manner.

Table 22B: Discharge norms (as per CC&A of Kandla STP)

Sr. No.	Parameters	Prescribed limits
1.	pH	6.5-8.5
2.	BOD (3 days at 27°C)	30 mg/L
3.	Suspended Solids	100 mg/L
4.	Fecal Coliform	< 1000 MPN/100 ml

The detailed process flow diagram of the Kandla and Gopalpuri STP have been mentioned in **Figure 3 and 4** as follows:

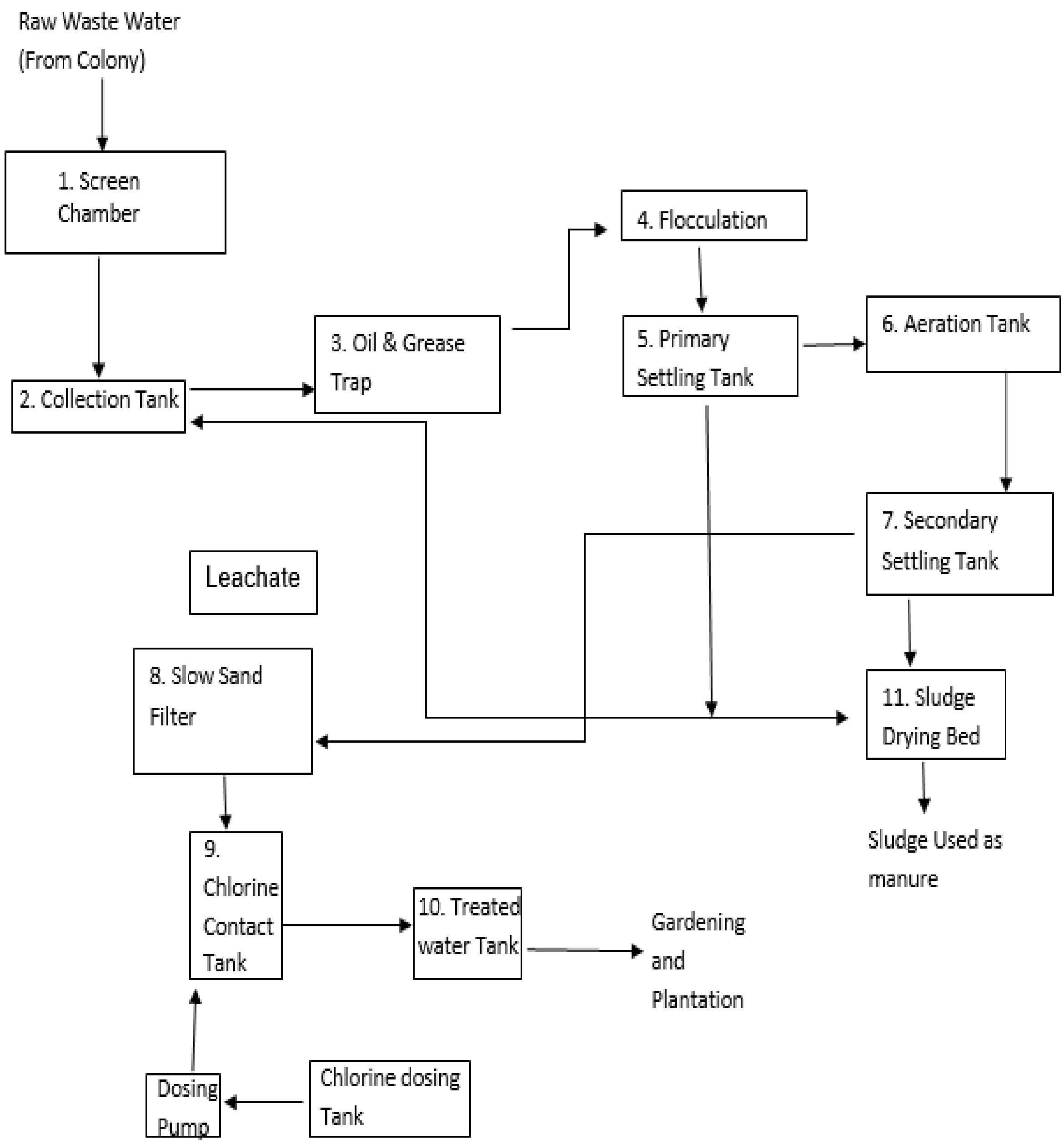


Figure 3: Process flow diagram of STP at Kandla

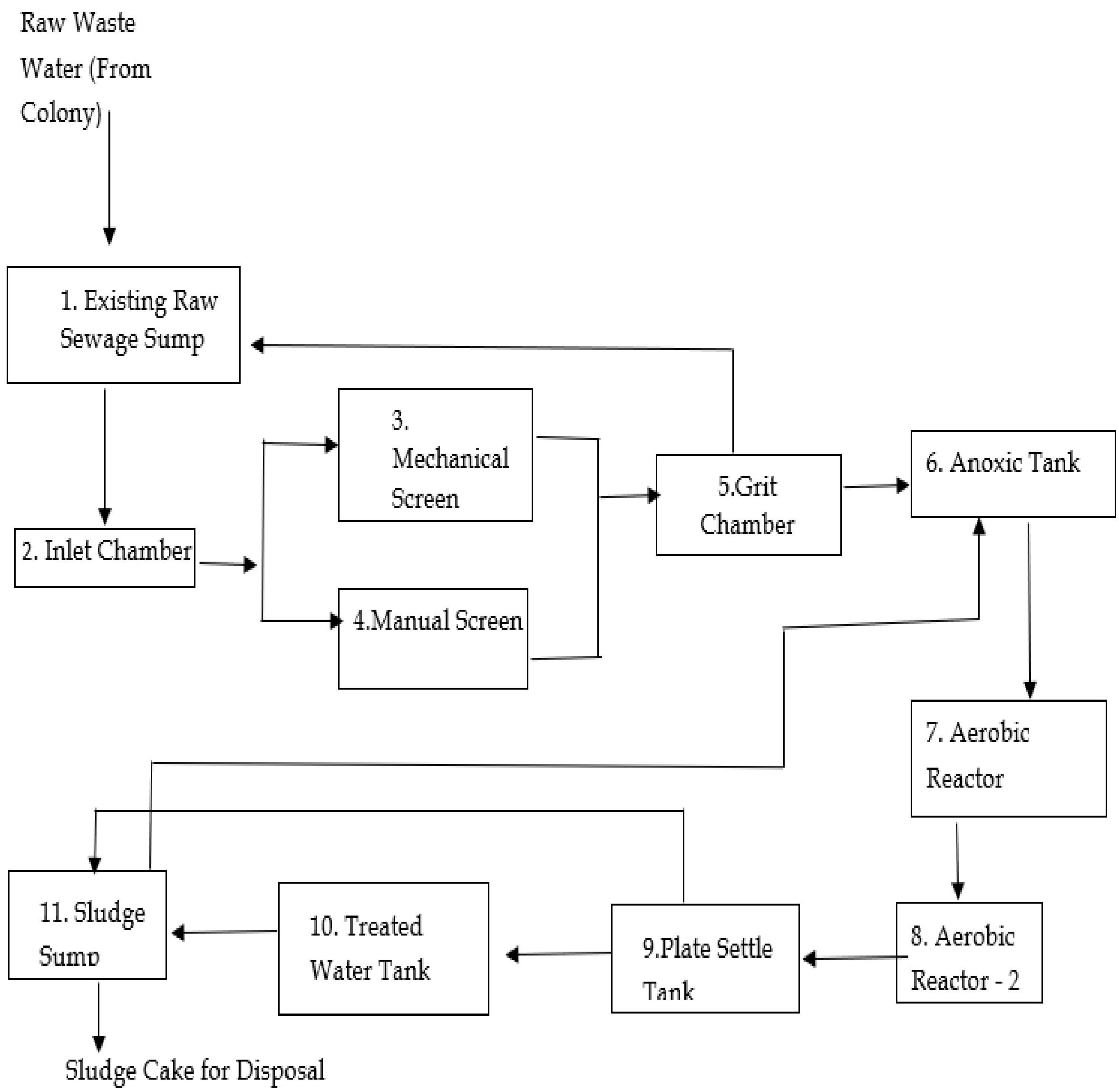


Figure 4: Process flow diagram of STP at Gopalpuri, Kandla

STP at Vadinar

The STP at Vadinar has been built with a treatment capacity of 450 KLD/day. The Consolidated Consent and Authorization (CC&A) issued by the GPCB has been referred for the details of the said STP. The CC&A of the Vadinar STP suggests that the domestic effluent generated shall be treated as per the norms specified in **Table 24**. The treated effluent conforming to the norms shall be discharged on the land within the premises strictly for the gardening and plantation purpose. Whereas, no sewage shall be disposed outside the premises in any manner.

Table 23: Norms of treated effluent as per CC&A of Vadinar STP

Sr. No.	Parameters	Prescribed limits
1.	pH	5.5-9
2.	BOD (3 days at 27°C)	10 mg/L
3.	Suspended Solids	20 mg/L
4.	Fecal Coliform	Desirable 100 MPN/100 ml Permissible 230 MPN/100 ml

Sr. No.	Parameters	Prescribed limits
5.	COD	50 mg/L

The detailed process flow diagram of the Vadinar STP have been mentioned in **Figure 5** as follows:

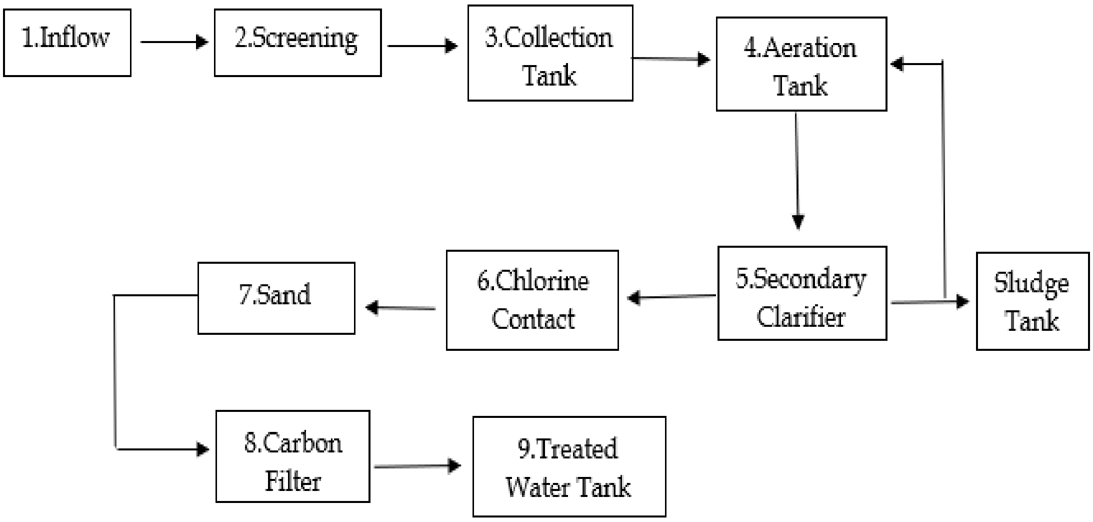


Figure 5: Process flowchart for the STP at Vadinar

The map depicting the locations of STP to be monitored in Kandla and Vadinar have been shown in **Map 14 and 15** as follows:

Map 14: STP Monitoring Locations at Kandla

Map 15: STP Monitoring Locations at Vadinar

Methodology

As per the defined scope by DPA, the sampling and analysis of water samples from the inlet and outlet of the STP's of Kandla and Vadinar are carried out once a week, i.e., four times a month.

The water samples were collected from inlet and the outlet of the STP's and analyzed for physico-chemical and microbiological parameter. Collection and analysis of these samples was carried out as per established standard methods and procedures for the examination of water. The samples were analyzed for selected parameters to establish the existing water quality of the inlet and outlet points of the STP. GEMI has framed its own guidelines for collection of water/wastewater samples titled as 'Sampling Protocol for Water & Wastewater'; which has been approved by the Government of Gujarat vide letter no. ENV-102013-299-E dated 24-04-2014 under the provision of Water (Preservation and Control of Pollution) Act 1974. The sample collection and preservation are done as per the said Protocol. Under the project, the list of parameters to be monitored for the STP have been mentioned in **Table 26** as follows:

Monitoring Frequency

Monitoring is required to be carried out once a week for monitoring location of Kandla and Vadinar i.e., two STP station at Kandla and one STP station at Vadinar. Sample Collected from this location during the monitoring period April 2023 to March 2024.

Table 24: List of parameters monitored for STP's at Kandla and Vadinar

Sr. No.	Parameters	Units	Reference method	Instruments
1.	pH	-	APHA, 23rd edition, 4500- H^+ B, 2017	pH Meter
2.	TDS	mg/L	APHA, 23rd Edition, 2540 C: 2017	Vacuum Pump with filtration assembly and Oven
3.	TSS	mg/L		
4.	DO	mg/L	APHA, 23rd Edition, 4500 C: 2017	Titration Apparatus
5.	COD	mg/L	APHA, 23rd Edition, 5220 B: 2017	Titration Apparatus plus Digester
6.	BOD	mg/L	IS-3025, Part 44, 1993	BOD Incubator plus Titration Apparatus
7.	SAR	meq/L	IS 11624: 2019	Flame Photometer
8.	Total Coliforms	MPN/100ml	IS 1622: 2019	LAF/ Incubator

9.2 Result and Discussion

Analytical results of the STP samples collected from the inlet and the outlet of the STP's of Kandla and Vadinar have been summarized in **Table 26**. Further it was compared with the standard norms specified in the CC&A of the respective STPs.

Table 25: Water Quality of inlet and outlet of STP of Kandla

Sr No.	Parameter	Units	Kandla							Vadinar			
			GPCB Norms (Kandla)	STP-1			STP-2			GPCB Norms (Vadinar)	STP-3		
				Inlet	Outlet		Inlet	Outlet			Inlet	Outlet	
				Avg	Avg	Max	Avg	Avg	Max		Avg	Avg	Max
1.	pH	-	**6.5-8.5**	7.17	7.302	7.65	6.99	7.48	8.88	**5.5-9**	7.19	7.41	8.46
2.	TDS	mg/L	-	3065.7	2069.28	6228	1099.40	1003.3	1814	-	471.61	402.67	482
3.	TSS	mg/L	**100**	183.4	20.97	88	115.17	16.45	46	**20**	38.78	8.42	36
4.	COD	mg/L	-	184.7	32.57	133.1	213.54	25.98	88.4	**50**	138.27	16.18	40.2
5.	DO	mg/L	-	145.91	37.780	277.09	162.29	21.98	76.92	-	115.12	18.69	54.5
6.	BOD	mg/L	**30**	56.82	11.937	52.4	61.75	8.40	18.45	**10**	44.62	6.053	11
7.	SAR	meq/L	-	12.06	9.318	21.04	5.75	5.43	13.1	-	2.71	2.12	3.2
8.	Total Coliforms	MPN/ 100ml	**<1000**	1565.95	1530.66	1600	1537.02	1500.51	1600	**100-230**	1551	1492.3	1600

BQL: Below Quantification limit; Total Suspended Solids (QL=2), Dissolved Oxygen (QL=0.5), Biochemical Oxygen Demand (QL=3 mg/L)

9.3 Data Interpretation and Conclusion

For physicochemical analysis, the treated sewage water was gathered from the Kandla STP, Gopalpuri STP, and Vadinar STP and the analytical results were compared with the standards mentioned in the Consolidated Consent and Authorization (CC&A) by GPCB.

- The average pH at the inlet of STP-1, STP-2, and STP-3 is, respectively, **7.17, 6.99, and 7.19**. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had a maximum pH of **7.65, 8.88, and 8.46** and an average pH of **7.302, 7.48, and 7.41**, respectively. Which conform to their respective stipulated norms of 6.5–8.5 at Kandla and 5.5–9 at Vadinar, respectively.
- The average TDS concentrations at the inlet of STP-1, STP-2, and STP-3 are, respectively, **3065.8, 1099.4, and 471.33** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had a maximum TDS concentration of **6228, 1814, and 482** mg/L, and an average TDS concentration of **2069.3, 1003.3, and 402.67** mg/L, respectively.
- The average TSS at the inlet of STP-1, STP-2, and STP-3 is respectively **183.43, 115.17, and 38.78** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had a maximum TSS of **88, 46**, and **36** mg/L, and an average TSS of **20.974, 16.452, and 8.41** mg/L, respectively. Which conform to their respective stipulated norms of 100 mg/L at Kandla and 20 mg/L at Vadinar, respectively, as mentioned in their respective CCA, except in STP-3 at Vadinar, which exceeds norms in the 3rd and 4th weeks of April 2023.
- The average COD at the inlet of STP-1, STP-2, and STP-3 is respectively **184.7, 213.54, and 138.27** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had maximum COD concentrations of **133.1, 88.4, and 40.2** mg/L, and average COD concentrations of **32.576, 25.97, and 16.18** mg/L, respectively. There are no discharge norms for the COD parameter in STP-1 and STP-2 at Kandla, and they conform to their respective stipulated norms of 50 mg/L at Vadinar as mentioned in their respective CCA.
- The average DO concentrations at the inlet of STP-1, STP-2, and STP-3 are, respectively, **145.91, 162.29, and 115.12** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had a maximum DO concentration of **277.09, 76.92, and 54.5** mg/L, and an average DO concentration of **37.78, 21.98, and 18.68,** mg/L respectively.
- The average BOD at the inlet of STP-1, STP-2, and STP-3 is respectively **56.82, 61.76, and 44.62** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had a maximum BOD of **52.4, 18.45, and 11** mg/L, and an average BOD of **11.93, 8.40, and 6.05** mg/L, respectively. Which conform to their respective stipulated norms of 30 mg/L at Kandla and 10 mg/L at Vadinar, respectively, as mentioned in their respective CCA, except in STP-3 at Vadinar, which exceeds norms in the 3rd and 4th weeks of April 2023.
- The average SAR concentrations at the inlet of STP-1, STP-2 and STP-3 are respectively **12.068**, **5.75** and **2.71** meq/L**.** After treatment, the treated effluent from

STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) having maximum SAR concentration **21.04**, **13.1** and **3.2** meq/L, and having Average SAR concentration **9.31**, **5.46** and **2.12** meq/L respectively.

- The **Total Coliforms** was observed to exceed the norms at the locations of the STP-1 & STP-2 for the treated effluent at Kandla and STP-3 at Vadinar.

During the monitoring period, only Total Coliforms were observed to be exceeding the limits at STPs of Kandla and Vadinar while rest of the treated sewage parameters for STP outlet were within norms as specified under the CCA at both the monitoring sites. Regular monitoring of the STP performance should be conducted on regular basis to ensure adequate treatment as per the norms.

9.4 Remedial Measures:

- The quantum of raw sewage (influent) entering the STP should be monitored by installation of the flow meter. If the quantity of the sewage exceeds the treatment capacity of the treatment plant, then provision of additional capacity of collection sump should be provided.
- The adequacy and efficacy of the stages of Sewage treatment units shall be conducted.
- The results show the presence of total coliforms; hence the method of disinfection (Chlorination) sodium or calcium Hypochlorite can be used.
- Effectiveness of any technology depends on factors such as the specific pollutants in the wastewater, plant size, local regulations, and available resources. There are several processes that may be implemented such as - Advanced oxidation process involve using strong oxidants to break down complex organic compounds. Methods like Fenton's reagent (hydrogen peroxide and iron catalyst) and UV/H_2O_2 treatment can help in reducing COD through oxidation.
- Electrochemical processes like Electrocoagulation (EC) and Electrooxidation (EO) that involve the application of an electric current to facilitate the removal of pollutants through coagulation, flocculation, and oxidation. These methods can be useful for treating sewage containing various pollutants.

CHAPTER 10: MARINE WATER QUALITY MONITORING

10.1 Marine Water

Deendayal Port is one of the largest ports of the country and thus, is engaged in wide variety of activities such as movement of large vessels, oil tankers and its allied small and medium vessels and handling of dry cargo several such activities whose waste if spills in water, can cause harmful effects to marine water quality.

Major water quality concerns at ports include wastewater and leakage of toxic substances from ships, stormwater runoff, etc. This discharge of wastewater, combined with other ship wastes which includes sewage and wastewater from other on-board uses, is a serious threat to the water quality as well as to the marine life. As defined in the scope by DPA, the Marine Water sampling and analysis has to be carried out at a total of eight locations, six at Kandla and two at Vadinar. The marine water sampling has been carried out with the help of Niskin Sampler with a capacity of 5L. The Niskin Sampler is a device used to take water samples at a desired depth without the danger of mixing with water from other depths. Details of the locations to be monitored have been mentioned in **Table 27:**

Table 26: Details of the sampling locations for Marine water

<table>
<tr><th>Sr. No.</th><th colspan="2">Location Code</th><th>Location Name</th><th>Latitude Longitude</th></tr>
<tr><td>1.</td><td rowspan="6">Kandla</td><td>MW-1</td><td>Near Passenger Jetty One</td><td>23.017729N 70.224306E</td></tr>
<tr><td>2.</td><td>MW-2</td><td>Kandla Creek (nr KPT Colony)</td><td>23.001313N 70.226263E</td></tr>
<tr><td>3.</td><td>MW-3</td><td>Near Coal Berth</td><td>22.987752N70.227923E</td></tr>
<tr><td>4.</td><td>MW-4</td><td>Khori Creek</td><td>22.977544N 70.207831E</td></tr>
<tr><td>5.</td><td>MW-5</td><td>Nakti Creek (nr Tuna Port)</td><td>22.962588N 70.116863E</td></tr>
<tr><td>6.</td><td>MW-6</td><td>Nakti Creek (nr NH-8A)</td><td>23.033113N 70.158528E</td></tr>
<tr><td>7.</td><td rowspan="2">Vadinar</td><td>MW-7</td><td>Near SPM</td><td>22.500391N 69.688089E</td></tr>
<tr><td>8.</td><td>MW-8</td><td>Near Vadinar Jetty</td><td>22.440538N 69.667941E</td></tr>
</table>

The map depicting the locations of Marine Water to be sampled and analysed for Kandla and Vadinar have been mentioned in **Map 16 and 17** as follows:

Map 16: Marine Water Monitoring Locations at Kandla

Map 17: Marine Water Monitoring Locations at Vadinar

Methodology

The methodology adopted for the sampling and monitoring of Marine Water was carried out as per the '**Sampling Protocol for Water & Wastewater'** developed by GEMI. The water samples collected through the Niskin Sampler are collected in a clean bucket to reduce the heterogeneity. The list of parameters to be monitored under the project for the Marine Water quality have been mentioned in **Table 28** along with the analysis method and instrument.

Monitoring Frequency

As defined in the scope by DPA, the sampling and analysis of Marine Water has to be carried out once in a month at the eight locations (i.e., six at Kandla and two at Vadinar). For the period April 2023 to March 2024.

Table 27: List of parameters monitored for Marine Water

Sr. No	Parameters	Units	Reference method	Instrument
1.	Electrical Conductivity	µS/cm	APHA, 23rd Edition (Section-2510 B):2017	Conductivity Meter
2.	Dissolved Oxygen (DO)	mg/L	APHA, 23rd Edition, 4500 O C, 2017	Titration Apparatus
3.	pH	-	APHA, 23rd Edition (Section-4500-H^+B):2017	pH meter
4.	Color	Hazen	APHA, 23rd Edition, 2120 B: 2017	Color comparator
5.	Odour	-	IS 3025 Part 5: 2018	Heating mantle & odour bottle
6.	Turbidity	NTU	IS 3025 Part 10: 1984	Nephlo Turbidity Meter
7.	Total Dissolved Solids (TDS)	mg/L	APHA, 23rd Edition (Section-2540 C):2017	Vaccum Pump with Filtration Assembly and Oven
8.	Total Suspended Solids (TSS)	mg/L	APHA, 23rd Edition, 2540 D: 2017	
9.	Particulate Organic Carbon	mg/L	APHA, 23rd Edition, 2540 D and E	TOC analyser
10.	Chemical Oxygen Demand (COD)	mg/L	IS-3025, Part- 58: 2006	Titration Apparatus plus Digester
11.	Biochemical Oxygen Demand (BOD)	mg/L	IS-3025, Part 44,1993,	BOD Incubator plus Titration apparatus
12.	Silica	mg/L	APHA, 23rd Edition, 4500 C, 2017	UV- Visible Spectrophotometer
13.	Phosphate	mg/L	APHA, 23rd Edition, 4500 P-D: 2017	
14.	Sulphate	mg/L	APHA, 23rd Edition, 4500 SO4-2 E: 2017	
15.	Nitrate	mg/L	APHA, 23rd Edition, 4500 NO3-B: 2017	
16.	Nitrite	mg/L	APHA, 23rd Edition, 4500 NO2- B: 2017	
17.	Sodium	mg/L	APHA, 23rd Edition, 3500 Na-B: 2017	Flame photometer

Sr. No	Parameters	Units	Reference method	Instrument
18.	Potassium	mg/L	APHA, 23rd Edition, 3500 K-B: 2017	
19.	Manganese	µg/L	APHA, 23rd Edition, ICP Method 3120 B: 2017	ICP-OES
20.	Iron	mg/L	APHA, 23rd Edition, ICP Method 3120 B: 2017	
21.	Total Chromium	µg/L	APHA, 23rd Edition, 3500 Cr B: 2017	
22.	Hexavalent Chromium	µg/L		UV- Visible Spectrophotometer
23.	Copper	µg/L	APHA, 23rd Edition, ICP Method 3120 B: 2017	ICP-OES
24.	Cadmium	µg/L		
25.	Arsenic	µg/L		
26.	Lead	µg/L		
27.	Zinc	mg/L		
28.	Mercury	µg/L	EPA 200.7	
29.	Floating Material (Oil grease scum, petroleum products)	mg/L	APHA, 23rd Edition, 5520 C: 2017	Soxhlet Assembly
30.	Total Coliforms (MPN)	MPN/ 100ml	IS 1622: 2019	LAF/ Incubator

10.2 Result and Discussion

The quality of the Marine water samples collected from the locations of Kandla and Vadinar during the monitoring period has been summarized in the **Table 29**. The said water quality has been represented in comparison with the standard values as stipulated by CPCB for Class SW-IV Waters.

Table 28: Results of Analysis of Marine Water Sample for the sampling period

Parameters	Primary Water Quality Criteria for Class SW-IV Waters	Kandla																		Vadinar					
		MW-1			MW-2			MW-3			MW-4			MW-5			MW-6			MW-7			MW-8		
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Density (kg/m³)	-	1.02	1.03	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.021	1.02	1.02	1.02	1.02	1.02	1.02
pH	6.5-9.0	6.12	8.32	7.89	7.04	8.36	7.99	7.83	8.33	8.11	7.69	8.31	8.05	7.19	8.48	8.03	6.01	8.31	7.94	7.98	8.2	8.11	7.07	8.22	8.06
Colour (Hazen)	No Noticeable	1	10	5.41	1	20	7.83	1	15	7.16	5	20	9	5	15	7.41	5	20	8.27	1	10	5.66	1	10	5.08
EC (µS/ cm)	-	49700	63600	54282.5	49800	61700	54490.91	50200	60600	53767.75	50400	75300	55689.91	50100	65100	55115.58	15950	61528	50873.17	52200	56900	54239.2	52.119	57500	50312.6
Turbidity (NTU)	-	56.4	310	188.26	33.9	314	206.76	61.8	317	203.81	69	300	216.66	94.5	379	202.5	70.1	346	209.23	3.15	12.5	5.36	3.42	13.8	6.39
TDS (mg/L)	-	24800	44466	36356.3	24900	41922	36679.5	25100	41624	35690.92	25200	64721	38189.5	25000	47159	36938.58	9970	41436	32927.91	25784	38620	35400.16	26882	41790	35965.75
TSS (mg/L)	-	44	436	342.42	26	563	374.58	52	478	340.75	58	924	402.33	80	682	427.66	58	852	387.72	78	341	255.08	151	346	282.33
COD (mg/L)	-	29.2	79.37	49.62	11.98	79.37	47.81	25.41	81	47.68	22.65	81	52.12	31.56	79.37	53.76	22.97	88.8	49.34	21.28	75	50.98	17.92	75	47.63
DO (mg/L)	3.0 mg/L	4.7	6.4	5.76	5.3	6.4	6.07	4.5	6.7	5.87	3.4	6.5	5.85	5	6.6	6.07	5.6	8.4	6.49	4.3	7.6	6.25	4.4	7.9	6.48
BOD (mg/L)	5.0 mg/L	5.24	8.54	7.56	8.4	8.9	8.57	3.74	8.45	6.81	5	8.78	7.755	9.32	9.87	9.57	3.6	11.1	8.64	3.91	7.5	6.51	4.2	7.16	6.16
Oil & Grease (mg/L)	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulphate (mg/L)	-	2056	2937.5	2529.7	2156.32	2897.7	2544.18	2083.7	2925.2	2530.85	2239	3704.9	2879.88	2334.9	2916.8	2652.42	632.62	3612.8	2561.07	1846.3	3225.8	2472.195	2039.9	3236.8	2664.27
Nitrate (mg/L)	-	1.89	5.40	4.28	1.12	5.16	3.75	3.21	5.68	4.17	3.41	5.85	4.64	3.17	6.92	4.21	3.06	6.84	4.06	2.225	5.17	3.56	1.759	5.1	3.39
Nitrite (mg/L)	-	0.12	0.12	0.12	0	0	0	0	0	0	0	0	0	0.11	0.11	0.11	0.13	0.16	0.14	0	0	0	0	0	0!
Phosphate (mg/L)		0.25	1.59	0.82	0.09	1.34	0.69	0.57	1.46	0.96	0.61	2.01	0.92	0.29	1.34	0.76	0.54	1.61	0.81	0.64	0.94	0.79	1.43	1.43	1.43
Silica (mg/L)	-	0.29	3.24	2.12	0.22	4.04	2.24	0.2	3.73	2.19	1.12	3.69	2.54	1.26	4	2.64	0.33	3.74	1.92	0.11	0.96	0.56	0.09	1.86	0.76
Sodium (mg/L)	-	7686	10625	9475.57	7811	10341	9242.42	7763	10308	9347.33	9101	10323	9724.14	8789	10278	9403.67	2086	10722	8042.71	2149.6	9485	6743.97	2349.4	9542	7244.66
Potassium (mg/L)	-	68.35	451.9	318.57	69.27	446.5	303.94	68.57	421	290.60	71.73	543.96	342.71	69.63	423.34	324.92	68.34	442.63	272.9	10.86	421.7	259.6	76.31	518	327.43
Hexavalent Chromium (mg/L)	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	321	321	321	333	333	333
Odour	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Arsenic (mg/L)	-	5.13	5.13	5.13	5.25	5.25	5.25	5.4	5.4	5.4	0	0	0	0	0	0	9.44	12.94	11.19	0.11	1	0.41	0.08	1	0.38
Cadmium (mg/L)	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Copper (mg/L)	-	5.1	6.99	5.8175	0.006	10.9	5.79	0.005	7.7	3.85	5.34	12.01	8.224	0.0067	7.6	5.13	8.07	10.2	9.49	3.4	3.4	3.4	0	0	0
Iron (mg/L)	-	0.69	4.11	1.38	0.21	4.07	1.76	0.37	3.92	1.79	1.02	7.93	2.49	0.98	5.45	2.09	0.43	5.3	2.005	0.01	0.25	0.145	0.08	0.66	0.21
Lead (mg/L)	-	0.002	3.44	2.067	0.0029	3.44	2.29	0.0026	3.06	1.98	0.002	9.68	4.32	0.002	4.65	2.39	0.0029	3.65	2.47	0.0023	2.26	1.035	0.002	2.75	0.96
Manganese (mg/L)	-	0.082	129.91	71.47	0.12	159.78	83.88	0.1085	125.66	74.0	0.096	294.91	93.56	0.074	213.14	74.7	0.11	156.41	80.27	2.39	113.93	39.62	1.97	98.8	34.64
Total Chromium (mg/L)	-	0	0	0	5.62	7.8	6.71	5.67	5.67	5.67	5.14	15.99	12.28	5.11	9.65	7.207	0	0	0	0	0	0	45.75	45.75	45.75
Zinc (mg/L)	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mercury (mg/L)	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Particulate Organic	-	0.51	900	76.22	0.51	35	3.98	0.42	10	1.94	0.58	55	6.03	0.92	30	3.89	0.85	44	5.01	0.47	4.67	1.62	0.32	4.76	1.51

Parameters	Primary	Kandla																		Vadinar					
Carbon (mg/L)																									
Total Coliform* (MPN/ 100ml)	500/100 ml	0.32	1600	159.61	0.16	120	29.76	0.56	108	31.55	0.25	47	14.02	0.35	170	37.19	0.29	50	21.86	0.36	240	39.76	0.39	240	35.28
Floating Material (Oil grease scum, petroleum products) (mg/L)	10 mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	23	23

10.3 Data Interpretation and Conclusion

The Marine water quality of Deendayal Port Harbor waters at Kandla and Vadinar has been monitored for various physico-chemical and biological parameters during the monitoring 2023 at high tide. The detailed interpretation of the parameters in comparison to the Class SW-IV for Harbour Waters is as follows:

- **Density** at Kandla was observed in the range of **1.02 to 1.03 kg/m³**, with the average of **1.022 kg/m³.** Whereas for the location of Vadinar, it was observed in the range of **1.021 to 1.026 kg/m³**, with the average of **1.022 kg/m³**.
- **pH** at Kandla was observed in the range of **6.01 to 8.48**, with the average pH as **7.78**. Whereas for the locations of Vadinar, it was observed in the range of be **7.07** to **8.22**, with the average pH as **7.94**. For the monitoring location of both the study areas, pH was found to comply with the norms of 6.5-8.5.
- **Color** range varied from **1 to 20 Hazen** at all the monitoring locations in Kandla, and for Vadinar, it varied from **1 to 10 Hazen**.
- **Electrical conductivity (EC)** was observed in the range of **15,950 to 75,300 µS/cm**, with the average EC as **54,344.32** µS/cm for the locations of Kandla, whereas for the locations of Vadinar, it was observed in the range of **52,199 to 57,500 µS/cm**, with the average EC as **45,200.67** µS/cm.
- For all monitoring locations of Kandla the value of **Turbidity** was observed in the range of **33.9 to 379 NTU**, with average value of **198.83** NTU. For Vadinar it ranges from **3.15 to 13.8 NTU**, with average of **7.43** NTU. Materials that cause water to be turbid include clay, silt, finely divided organic and inorganic matter, soluble coloured organic compounds, plankton and microscopic organisms. Turbidity affects the amount of light penetrating to the plants for photosynthesis.
- For the monitoring locations at Kandla the value of **Total Dissolved Solids (TDS)** ranged from **9,970 to 64,721 mg/L**, with an average value of **35,171** mg/L. Similarly, at Vadinar, the TDS values ranged from **25,784 to 41,790 mg/L**, with an average value of **34,073** mg/L.

- **TSS** values in the studied area varied between **26 to 924 mg/L** at Kandla and **78 to 346 mg/L** at Vadinar, with the average value of **362.69** mg/L and **242.23** mg/L respectively for Kandla and Vadinar.
- **COD** varied between **11.98 to 88.8 mg/L** at Kandla and **17.92 to 75 mg/L** at Vadinar, with the average value as **51.83** mg/L and **47.86** mg/L respectively for Kandla and Vadinar.
- **DO** level in the studied area varied between **3.4 to 8.4 mg/L** at Kandla and **4.3 to 7.9 mg/L** at Vadinar, with the average value of **5.86** mg/L and **6.15** mg/L respectively for Kandla and Vadinar. Which represents that the marine water is suitable for marine life.
- **BOD** observed was observed in the range of **3.6 to 11.1 mg/L**, with average of **7.76** mg/L for the location of Kandla and for the locations of Vadinar, it was observed in the range of **3.91 to 7.5 mg/L**, with an average value of **5.9** mg/L.
- **Sulphate** concentration in the studied area varied between **632.92 to 3704.9 mg/L** at Kandla and **1846.3 to 3236.8 mg/L** at Vadinar. The average value observed at Kandla was **2566.45** mg/L, whereas **2580.87** mg/L was the average value of Vadinar. Sulphate is naturally formed in inland waters by mineral weathering or the decomposition and combustion of organic matter.
- **Nitrate** in the study area was observed in the range of **1.12 to 6.92 mg/L**, with the average of **4.26** mg/L. Whereas for the Vadinar the concentration of Nitrate was observed in the range of **1.759 to 5.17** mg/L, with the average **3.53** mg/L.
- **Nitrite** in the study area was observed in the range of **0 to 0.16 mg/L**, with the average of **0.625** mg/L. Whereas for the Vadinar the concentration of Nitrite was observed Below Quantification Limit During whole monitoring period.
- **Phosphate** in the study area was observed in the range of **0.09 to 2.01 mg/L**, with the average of **0.92** mg/L. Whereas for the Vadinar the concentration of Phosphate was observed in the range of **0.64 to 1.43** mg/L, with the average **1.11** mg/L.
- **Silica** in the study area was observed in the range of **0.2 to 4.04 mg/L**, with the average of **2.19** mg/L. Whereas for the Vadinar the concentration of silica was observed in the range of **0.09 to 1.86** mg/L, with the average **0.724** mg/L.
- In the study area of Kandla the concentration of **Potassium** varied between **68.34 to 543.68 mg/L** and **10.86 to 518 mg/L** at Vadinar, with the average value as **277.71** mg/L and **268.99** mg/L respectively for Kandla and Vadinar.
- **Sodium** in the study area varied between **2,086 to 10,722 mg/L**, with average of **8948.26** mg/L, at Kandla whereas at Vadinar its value recorded within range of **2149.6 to 9542 mg/L,** with the average of **6252.43** mg/L.
- **Odour** was observed 1 for all locations of Kandla and Vadinar.
- **Arsenic** concentration observed to be BQL for majority of location for Kandla and Vadinar except locations MW-1, MW-2, MW-3, MW-6, MA-7 and MW-8 for some instant of time during whole monitoring period.
- **Copper** in the study area varied between **0.005 to 12.01 mg/L**, with average of **6.23** mg/L, at Kandla whereas at Vadinar its value recorded within range of **0 to 3.4 mg/L,**

with the average of **2.04** mg/L, on both project sites during monitoring majority of time Copper found Below Quantification Limit.

- **Iron** in the studied area varied between **0.21 to 7.93 mg/L**, with the average of **2.55** mg/L, at Kandla, and for Vadinar value were recorded within range of **0.01** to **0.66** mg/L, with average value of **0.22** mg/L.
- **Lead** concentration varied **0.002 to 9.68 mg/L**, with an average of **2.41** mg/L at Kandla. At Vadinar location within range of **0.002** to **2.753** mg/L with an average **1.17** mg/L
- **Manganese** in the studied area varied between **0.0748 to 294.91 mg/L**, with the average of **86.57** mg/L, at Kandla and for Vadinar, recorded value were observed within the range of **1.97** to **113.93 mg/L**, with the average of **48.56** mg/L.
- **Total Chromium** in the study area varied between **0 to 15.99 mg/L**, with average of **5.13** mg/L, at Kandla whereas at Vadinar its value recorded **45.76** mg/L at MW-8 in the monitoring period of January to February 2024**,** While on both project sites during monitoring majority of time Total Chromium found Below Quantification Limit
- **Particulate Organic Carbon** in the study area was observed in the range of **0.42 to 900**, with the average value of **65.27**. the maximum spike of 900 is only observed once in the period of April to May 2023 during whole monitoring period. Whereas for the Vadinar, the value observed was Within the range of **0.32** to **4.76**, with the average of **2.22**.
- **Oil & Grease, Nitrite, Phosphate, Hexavalent Chromium, Arsenic, Cadmium, Total Chromium, Zinc, Mercury and Floating Material (Oil grease scum, petroleum products)** were observed to have concentrations **"Below the Quantification Limits (BQL)"** for most of the locations of Kandla and Vadinar, majority of time during whole monitoring period.
- **Total Coliforms** were detected complying with the specified norm of 500 MPN/100ml for all the locations of Kandla and Vadinar, except on location MW-1 in the month of May to June 2023.

During the Monitoring period, marine water samples were analysed and found in line with Primary Water Quality criteria for class-IV Waters (For Harbour Waters).

However, as a safeguard towards marine water pollution prevention, appropriate regulations on ship discharges and provision of reception facilities are indispensable for proper control of emissions and effluent from ships. Detection of spills is also important for regulating ship discharges. Since accidental spills are unavoidable, recovery vessels, oil fences, and treatment chemicals should be prepared with a view to minimizing dispersal. Proper contingency plans and a prompt reporting system are keys to prevention of oil dispersal. Periodical clean-up of floating wastes is also necessary for preservation of port water quality.

CHAPTER 11: MARINE SEDIMENT QUALITY MONITORING

11.1 Marine Sediment Monitoring

Marine sediment, or ocean sediment, or seafloor sediment, are deposits of insoluble particles that have accumulated on the seafloor. These particles have their origins in soil and rocks and have been transported from the land to the sea, mainly by rivers but also by dust carried by wind. The unconsolidated materials derived from pre-existing rocks or similar other sources by the process of denudation are deposited in water medium are known as sediment. For a system, like a port, where large varieties of raw materials and finished products are handled, expected sediment contamination is obvious.

The materials or part of materials spilled over the water during loading and unloading operations lead to the deposition in the harbour water along with sediment and thus collected as harbour sediment sample. These materials, serve as receptor of many trace elements, which are prone to environment impact. In this connection it is pertinent to study the concentration and distribution of environmentally sensitive elements in the harbour sediment. However, human activities result in accumulation of toxic substances such as heavy metals in marine sediments. Heavy metals are well-known environmental pollutants due to their toxicity, persistence in the environment, and bioaccumulation. Metals affect the ecosystem because they are not removed from water by self-purification, but accumulate in sediments and enter the food chain.

Methodology

As defined in the scope by DPA, the Marine Sediment sampling is required to be carried out once in a month at total eight locations, i.e., six at Kandla and two at Vadinar. The sampling of the Marine Sediment is carried out using the Van Veen Grab Sampler (make Holy Scientific Instruments Pvt. Ltd). The Van Veen Grab sampler is an instrument to sample (disturbed) sediment up to a depth of 20-30 cm into the sea bed. While letting the instrument down on the seafloor, sediment can be extracted. The details of locations of Marine Sediment to be monitored under the study are mentioned in **Table 30** as follows:

Table 29: Details of the sampling locations for Marine Sediment

Sr. No	Location Code		Location Name	Latitude Longitude
1.	Kandla	MS-1	Near Passenger Jetty One	23.017729N 70.224306E
2.		MS-2	Kandla Creek	23.001313N 70.226263E
3.		MS-3	Near Coal Berth	22.987752N 70.227923E
4.		MS-4	Khori Creek	22.977544N 70.207831E
5.		MS-5	Nakti Creek (near Tuna Port)	22.962588N 70.116863E
6.		MS-6	Nakti Creek (near NH-8A)	23.033113N 70.158528E
7.	Vadinar	MS-7	Near SPM	22.500391N 69.688089E
8.		MS-8	Near Vadinar Jetty	22.440538N 69.667941E

The map depicting the locations of Marine Sediment sampling at Kandla and Vadinar have been mentioned in **Map 18 and 19** as follows:

Map 18: Marine Sediment Monitoring Location at Kandla

Map 19: Marine Sediment Monitoring Locations at Vadinar

The list of parameters to be monitored under the projects for the Marine Sediment sampling been mentioned in **Table 31** as follows:

Table 30: List of parameters to be monitored for Sediments at Kandla and Vadinar

Sr. No.	Parameters	Units	Reference method	Instruments
1.	Texture		Methods Manual Soil Testing in India January 2011,01	Hydrometer
2.	Organic Matter	%	Methods Manual Soil Testing in India January, 2011, 09. Volumetric method (Walkley and Black, 1934)	Titration apparatus
3.	Inorganic Phosphates	mg/Kg	Practical Manual Chemical Analysis of Soil and Plant Samples, ICAR-Indian Institute of Pulses Research 2017	UV- Visible Spectrophotometer
4.	Silica	mg/Kg	EPA METHOD 6010 C & IS: 3025 (Part 35) – 1888, part B	
5.	Phosphate	mg/Kg	EPA Method 365.1	
6.	Sulphate as SO^{4-}	mg/Kg	IS: 2720 (Part 27) - 1977	
7.	Nitrite	mg/Kg	ISO 14256:2005	
8.	Nitrate	mg/Kg	Methods Manual Soil Testing in India January, 2011, 12	
9.	Calcium as Ca	mg/Kg	Methods Manual Soil Testing in India January 2011, 16.	Titration Apparatus
10.	Magnesium as Mg	mg/Kg	Method Manual Soil Testing in India January 2011	
11.	Sodium	mg/Kg	EPA Method 3051A	Flame Photometer
12.	Potassium	mg/Kg	Methods Manual Soil Testing in India January, 2011	
13.	Aluminium	mg/Kg	EPA Method 3051A	ICP-OES
14.	Chromium	mg/Kg		
15.	Nickel	mg/Kg		
16.	Zinc	mg/Kg		
17.	Cadmium	mg/Kg		
18.	Lead	mg/Kg		
19.	Arsenic	mg/Kg		
20.	Mercury	mg/Kg		

11.2 Result and Discussion

The quality of Marine Sediment samples collected from the locations of Kandla and Vadinar during the monitoring period of April 2023 to March 2024 has been summarized in the **Table 32.**

Table 31: Summarized result of Marine Sediment Quality

Parameters	Kandla																		Vadinar					
	MS-1			MS-2			MS-3			MS-4			MS-5			MS-6			MS-7			MS-8		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Inorganic Phosphate (kg/ha)	16.85	0.86	6.6042	14.37	0.67	8.81	41.2	0.8	16.98	19.44	0.81	9.532	45.1	0.72	14.48	34.6	0.66	15.24	14.5	1.24	5.65	18.51	0.82	5.7325
Phosphate (mg/Kg)	3247.8	290.8	1280.63	2514.7	258.3	1304	3736	226.6	1515	3871	353.7	1287	3741	306.8	1442	14076	578.3	2793.9	3002	152.5	770.24	3477.29	167.93	940.70
Organic Matter (%)	1.42	0.21	0.7875	2.17	0.29	1.13	1.01	0.17	0.593	2.1	0.33	0.975	1.24	0.67	0.911	2.06	0.21	0.915	2.29	0.15	1.04	1.65	0.17	0.89
Sulphate as SO^{4-} (mg/Kg)	905.25	110.2	366.8	1022.25	98.2	370.03	571.64	95.33	275.09	650.25	97.45	268.51	768	87.28	294.27	732	96.38	249.1	296	74.07	126.31	213.4	80.06	132.03
Calcium as Ca (mg/Kg)	13800	1612	3464.3	5800	1259	2836	4200	962	2163	4200	1102	2669	10500	1089	3102	3800	1047	2274.6	3700	2200	2930.9	3974.2	2100	2805.45
Magnesium as Mg (mg/Kg)	1952	1225	1538.53	3050	826.46	1810.84	2136	764	1592.59	3172	866.94	1810.6	2440	1032	1622.80	2745	906.98	1581.95	1952	854	1385.18	14640	1167	2920.83
Silica (g/Kg)	671.25	261.3	479.11	612.51	289.4	481.7	571.5	329.1	444.8	555.2	245.7	392.1	597.1	179.2	418.6	580.4	245.3	436.12	529.8	220.9	377.71	546.08	264.92	426.66
Nitrite (mg/Kg)	0.75	0.12	0.41	0.92	0.13	0.50	0.81	0.08	0.41	0.91	0.01	0.43	0.71	0.11	0.375	0.89	0.07	0.489	0.22	0.07	0.159	0.37	0.04	0.23
Nitrate (mg/Kg)	22.34	5.86	16.58	37.12	7.59	18.29	36.47	4.51	15.50	25.94	4.31	13.99	10.34	5.24	13.17	20.38	6.34	14.52	25.33	9.54	15.36	25.21	4.75	10.52
Sodium (mg/Kg)	7860	3194	4512.43	14688	2453	5318	8612	2072	4550	18308	2612	6435	10520	2063	4665	14076	2072	5639.6	11944	3971	7904.6	13660	2719.42	9536.63
Potassium (mg/Kg)	2610.7	241	1525.98	11580	276	2320	3479	260.7	2126	4208	294	2424	3152	205	1790	3479	236.9	2233.4	3372	699	1876.1	4377	1028	2025.66
Aluminium (mg/Kg)	8371.7	2116	3827.74	10641	1237.1	4465.9	10363.1	1278.5	4370.2	12008.4	1971.2	5025.2	10361.1	1264.58	3891.23	12314.1	1273.22	4384.20	14179.7	358.3	4028.56	19356.55	479.16	4883.52
Mercury (mg/Kg)	4.71	4.71	4.71	10.74	10.74	10.74	41.29	41.29	41.29	6.44	6.44	6.44	15.21	15.21	15.21	34.69	34.69	34.69	0	0	0	0	0	0
Texture	Sandy loam	Sandy loam	Silt loam	Sandy loam	Silt loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Loam	Loam	Loam

11.3 Data Interpretation and Conclusion

The Marine sediment quality at Kandla and Vadinar has been monitored for various physico-chemical parameters during the monitoring April 2023 to March 2024. The detailed interpretation of the parameters is given below:

- **Inorganic Phosphate** for the sampling period was observed in range of **0.66 to 45.12** Kg/ha for Kandla. Whereas for Vadinar the value observed Within range of **0.82** to **18.51** Kg/ha. For Kandla and Vadinar the average value of Inorganic Phosphate was observed **13.77** and **7.74** Kg/ha respectively.
- The concentration of **Phosphate** was observed in range of **226.6 to 3871.15 mg/Kg** for Kandla and for Vadinar the value observed within the range of **152.53** to **3477.29** mg/Kg. For Kandla and Vadinar the average concentration of Phosphate was observed **1616.78** and **1418.5** mg/Kg respectively.
- The **Organic Matter** for the sampling period was observed in the range of **0.17 to 2.17 %** for Kandla with the average value of **0.95**% and for Vadinar the value recorded Within range of **0.15 to 2.29**%, with average concentration as **1.03 %.**
- The concentration of **Sulphate** was observed in the range of **87.28 to 1022 mg/Kg** for Kandla and for Vadinar the value observed Within range of **74.07** to **296** mg/Kg. For Kandla and Vadinar the average value of Sulphate was observed **392.10** and **153.64** mg/Kg respectively.
- The value of **Calcium** was observed in the range of **962 to 13800 mg/Kg** for Kandla and for Vadinar the value observed within the range of **2100** to **3974.5** mg/Kg. The average value of Calcium for the monitoring period was observed **3660.21** mg/Kg and **2951.76** mg/Kg at Kandla and Vadinar, respectively.
- The value of **Magnesium** for the sampling period was observed in the range of **764 to 3172 mg/Kg** for Kandla and for Vadinar the value observed Within the range of **854** to **1952** mg/Kg. For Kandla and Vadinar the average value of Magnesium was observed **1726**.35 mg/Kg and **1440.69** mg/Kg respectively.
- For the sampling period **Silica** was observed in the range of **179.25 to 671.25 mg/Kg** for Kandla with average value **432.83** mg/Kg and for Vadinar the value observed within the range of **220.98** and **546.5** mg/Kg with average **394.35** mg/Kg.
- The value of **Nitrate** was observed in the range of **4.31 to 37.12 mg/Kg** for Kandla with average value **15.47** mg/Kg and for Vadinar the value observed within the range of **4.75** to **25.33** mg/Kg. with average **15.12** mg/Kg.
- The value of **Nitrite** was observed in the range of **0.01 to 0.92 mg/Kg** for Kandla with average value **0.45** mg/Kg and for Vadinar the value observed to be within the range of **0.04** to **0.37** mg/Kg, with average **0.1828** mg/Kg.
- The value of **Sodium** was observed in the range of **2063.3 to 18308 mg/Kg** for Kandla with average value **6647.43** mg/Kg and for Vadinar the value observed within the range of **2719.42** and **13660** mg/Kg, with average **8289** mg/Kg.
- The value of **Potassium** was observed in the range of **205.08 to 11580 mg/Kg** for Kandla with average value **2357.95** mg/Kg and for Vadinar the value observed within range of **699.09** to **4377** mg/Kg, with average **2229.65** mg/Kg.

- The value of **Aluminium**, was observed in the range of **1237.13 to 12314.13 mg/Kg** for Kandla with average value **5509.23** mg/Kg and for Vadinar the value observed within the range of **358.3** to **19356** mg/Kg, with average **7214.30** mg/Kg.
- The value of **Mercury**, was observed in the range of **4.71 to 41.29 mg/Kg** for Kandla with average value **18.84** mg/Kg and for Vadinar the value of **Mercury** was observed "Below the Quantification Limit" at both two locations. During monitoring period majority of time Mercury was observed Below Quantification limit.
- Texture was observed to be "**Sandy Loam**" at location MS-1, MS-2, MS-4 and MS-6 "**Silt loam"** at location MS-3 & MS-5 in Kandla. "**Sandy Loam**" at location MS-7 & "**Silt loam"** at location MS-8 in Vadinar during sampling period.

Heavy Metals

The sediment quality of Kandla and Vadinar has been compared with respect to the Average Standard guideline applicable for heavy metals in marine sediment specified by EPA have been mentioned in **Table 33.**

Table 32: Standard Guidelines applicable for heavy metals in sediments

Sr. No.	Metals	Sediment quality (mg/kg)			Source
		Not polluted	Moderately polluted	Heavily polluted	
1.	As	<3	3-8	>8	EPA
2.	Cu	<25	25-50	>50	
3.	Cr	<25	25-75	>75	
4.	Ni	<20	20-50	>50	
5.	Pb	<40	40-60	>60	
6.	Zn	<90	90-200	>200	
7.	Cd	-	<6	>6	
ND = Not Detected					

(Source: G Perin et al. 1997)

Table 33: Comparison of Heavy metals with Standard value in Marine Sediment

Parameters	Kandla																		Vadinar					
	MS-1			MS-2			MS-3			MS-4			MS-5			MS-6			MS-7			MS-8		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Arsenic (mg/Kg)	5.13	1.09	3.527	4.43	2.11	3.264	6.17	2.06	3.92	5.86	1.28	3.75	5.2	1.75	3.458	5.78	1.98	3.67	5.36	2.04	2.84	5.17	2.5	3.69
Copper (mg/Kg)	5.6	2.13	3.282	11.4	2.14	5.013	8.1	2.08	4.49	9.8	3.48	5.71	12	2.14	5.97	8.9	2.98	4.97	6.13	2.19	4.567	412	2.1	39.05
Chromium (mg/Kg)	64.1	42.12	53.94	67.45	32.74	47.04	73.02	32.41	48.31	83.23	41.08	55.17	59.95	41.87	51.50	104.2	36.71	59.71	59.27	23.18	44.01	104.1	29.7	61.12
Nickel (mg/Kg)	51.4	16.8	31.76	38.9	10.21	23.87	36.41	4.54	22.77	40.87	7.61	27.45	31.86	21.72	25.881	50.78	4.54	25.058	36.21	12.23	22.84	43.66	12.47	29.282
Lead (mg/Kg)	7.05	1.25	5.3	7.45	4.21	5.76	28.73	2.36	6.683	8.25	3.46	5.9	14.22	1.21	6.055	5.01	2.81	7.88	7.94	2.85	4.90	10.58	2.97	5.65
Zinc (mg/Kg)	63.2	35.88	54.63	65.69	32.11	50.455	301.32	23.63	69.545	82.9	18.15	50.86	159.42	19.54	60.65	157.82	23.63	57.7	52.13	11.47	34.6	104.87	13.65	53.8595
Cadmium (mg/Kg)	1.08	0.88	0.98	0.6	0.6	0.6	1.25	0.87	1.1	1.12	0.78	1.022	1.08	0.91	0.995	7.53	0.15	2.302	0	0	0	0	0	0

- **Arsenic** was observed in the range of **1.09 to 6.17 mg/Kg** for Kandla with average value **3.58** mg/Kg and for Vadinar the value observed within range of **2.04** to **5.36** mg/Kg, with average of **3.6** mg/Kg. during monitoring period majority of time arsenic concentration found within moderately polluted class on both study area.
- **Copper** was observed in the range of **2.08 to 12 mg/Kg** for Kandla with average value **5.6** mg/Kg and for Vadinar the value observed within the range of be **2.1** to **8.33** mg/Kg, with average **4.72** mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to copper falls in non-polluted class.
- **Chromium** was observed in the range of **32.41 to 104.24 mg/Kg** for Kandla with average value **55.25** mg/Kg and for Vadinar the value observed within the range of **23.18** to **104.16** mg/Kg, with average **53.57** mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to chromium falls majority of time in moderately polluted and for some instance it location MS-4, MS-6, and MS-8 fall in Heavily polluted class.
- **Nickel** was observed in the range of **4.54 to 51.47 mg/Kg** for Kandla with average value **26.25** mg/Kg and for Vadinar the value observed within range of **12.23** to **43.66** mg/Kg, with average **26.115** mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to nickel falls in moderately polluted class and for some instance it location MS-1, and MS-6 fall in heavily polluted class.

- **Lead** was observed in the range of **1.21 to 28.73 mg/Kg** for Kandla with average value **5.63** mg/Kg and for Vadinar the value observed within the range of **2.85** and **10.58** mg/Kg, with average **5.81** mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to lead falls in not polluted class.
- **Zinc** was observed in the range of **18.15 to 301.32 mg/Kg** for Kandla with average value **73.73** mg/Kg and for Vadinar the value observed within the range of **11.47** to **104.87** mg/Kg, with average **46.997** mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to zinc falls in non-polluted class and for some instance its location MS-1, MS-3, MS-6 and MS-8 fall in Moderately polluted class.
- **Cadmium** was observed in the range of **0.15 to 7.53 mg/Kg** for Kandla with average value **1.325** mg/Kg**.** During the monitoring period majority of time **Cadmium** found BQL, which falls in non-polluted. While exception on one location MS-6 fall within moderately polluted for the duration of July to August 2023. **Cadmium** was observed BQL for all locations at Vadinar during sampling period. With reference to the guidelines mentioned in table 35, the sediment quality with respect to cadmium falls in non-polluted class.

Analysis of the sediments indicates moderate pollution. However, it may be noted that, the sediments are highly dynamic being constantly deposited and carried away by water currents. Hence maintaining the quality of sediments is necessary as it plays a significant role in regulating the quality of the marine water and the marine ecology.

The presence of anthropic activity in the coastal areas has an effect upon the marine water and sediment. One of the primary risks associated with contaminated sediments is bioaccumulation in benthic organisms, which is a route of entry into the food chain. Generally adopted sediment remediation approaches include dredging, capping of contaminated areas, and monitored natural recovery (MNR). Dredging can remove contaminated sediments, but it requires large areas of land for sediment disposal. It is expensive and may cause secondary contamination of the water column during re-suspension. MNR relies on ongoing naturally occurring processes to decrease the bioavailability or toxicity of contaminants in sediment. These processes may include physical, biological, and chemical mechanisms that act together to reduce the environmental risks posed by contaminated sediments. MNR require longer monitoring time and can be even more expensive than for dredging and capping. Capping consists of in situ covering of clean or suitable isolating material over contaminated sediments layer to limit leaching of contaminants, and to minimize their re-suspension and transport. Hence appropriate remedial measures for the polluted sediment sites may be implemented, to reduce the concentration of the heavy metals.

CHAPTER 12: MARINE ECOLOGY MONITORING

12.1 Marine Ecological Monitoring

The monitoring of the biological and ecological parameters is important in order to assess the marine environment. A marine sampling is an estimation of the body of information in the population. The theory of the sampling design is depending upon the underlying frequency distribution of the population of interest. The requirement for useful water sampling is to collect a representative sample of suitable volume from the specified depth and retain it free from contamination during retrieval. Deendayal Port and its surroundings have mangroves, mudflats and creek systems as major ecological entities.

As defined in the scope by DPA, the Marine Ecological Monitoring is required to be carried out once a month specifically at eight locations, six at Kandla and two at Vadinar. The sampling of the Benthic Invertebrates has been carried out with the help of D-frame nets, whereas the sampling of zooplankton and phytoplankton has been carried out with the help of Plankton Nets (60 micron and 20 micron). The details of the locations of Marine Ecological Monitoring have been mentioned in **Table 35** as follows:

Table 34: Details of the sampling locations for Marine Ecological

Sr. No.	Location Code		Location Name	Latitude Longitude
1.	Kandla	ME-1	Near Passenger Jetty One	23.017729N 70.224306E
2.		ME-2	Kandla Creek (near KPT Colony)	23.001313N 70.226263E
3.		ME-3	Near Coal Berth	22.987752N 70.227923E
4.		ME-4	Khori Creek	22.977544N 70.207831E
5.		ME-5	Nakti Creek (near Tuna Port)	22.962588N 70.116863E
6.		ME-6	Nakti Creek (near NH - 8A)	23.033113N 70.158528E
7.	Vadinar	ME-7	Near SPM	22.500391N 69.688089E
8.		ME-8	Near Vadinar Jetty	22.440538N 69.667941E

The map depicting the locations of Marine Ecological monitoring in Kandla and Vadinar have been mentioned in **Map 20 and 21** as follows:

Map 20 Marine Ecological Monitoring: Locations at Kandla

Map 21: Marine Ecological Monitoring Locations at Vadinar

The various parameters to be monitored under the study for Marine Ecological Monitoring are mentioned in **Table 36** as follows:

Table 35: List of parameters to be monitored for Marine Ecological Monitoring

Sr. No.	Parameters
1.	Productivity (Net and Gross)
2.	Chlorophyll-a
3.	Pheophytin
4.	Biomass
5.	Relative Abundance, species composition and diversity of phytoplankton
6.	Relative Abundance, species composition and diversity of zooplankton
7.	Relative Abundance, species composition and diversity of benthic invertebrates (Meio, Micro and macro benthos)
8.	Particulate Oxidisable Organic Carbon
9.	Secchi Depth

Methodology

- **Processing for chlorophyll estimation:**
  Samples for chlorophyll estimation were preserved in ice box on board in darkness to avoid degradation in opaque container covered with aluminium foil. Immediately after reaching the shore after sampling, 1 litre of collected water sample was filtered through GF/F filters (pore size 0.45 µm) by using vacuum filtration assembly. After vacuum filtration the glass micro fiber filter paper was grunted in tissue grinder, macerating of glass fiber filter paper along with the filtrate was done in 90% aqueous Acetone in the glass tissue grinder with glass grinding tube. Glass fiber filter paper will assist breaking the cell during grinding and chlorophyll content was extracted with 10 ml of 90% Acetone, under cold dark conditions along with saturated magnesium carbonate solution in glass screw cap tubes. After an extraction period of 24 hours, the samples were transferred to calibrated centrifuge tubes and adjusted the volume to original volume with 90% aqueous acetone solution to make up the evaporation loss. The extract was clarified by using centrifuge in closed tubes. The clarified extracts were then decanted in clean cuvette and optical density was observed at wavelength 664, 665 nm.

- **Phytoplankton Estimation**
  Phytoplankton are free floating unicellular, filamentous and colonial eutrophic organisms that grow in aquatic environments whose movement is more or less dependent upon water currents. These micro flora acts as primary producers as well as the basis of food chain, source of protein, bio-purifier and bio-indicators of the aquatic ecosystems of which diverse array of the life depends. They are considered as an important component of aquatic flora, play a key role in maintaining equilibrium between abiotic and biotic components of aquatic ecosystem. The phytoplankton includes a wide range of photosynthetic and phototrophic organisms. Marine phytoplankton is mostly microscopic and unicellular floating flora, which are the primary producers that support the pelagic food-chain. The two most prominent groups of phytoplankton are Diatoms (*Bacillariophyceae*) and Dinoflagellates (*Dinophyceae*). Phytoplankton also include numerous and diverse collection of extremely small, motile algae which are termed micro

flagellates (naked flagellates) as well as Cyanophytes (Bluegreen algae). Algae are an ecologically important group in most aquatic ecosystems and have been an important component of biological monitoring programs. Algae are ideally suited for water quality assessment because they have rapid reproduction rates and very short life cycles, making them valuable indicators of short-term impacts. Aquatic populations are impacted by anthropogenic stress, resulting in a variety of alterations in the biological integrity of aquatic systems. Algae can serve as an indicator of the degree of deterioration of water quality, and many algal indicators have been used to assess environmental status.

- **Zooplankton Estimation**

  Zooplankton includes a taxonomically and morphologically diverse community of heterotrophic organisms that drift in the waters of the world's oceans. Qualitative and quantitative studies on zooplankton community are a prerequisite to delineate the ecological processes active in the marine ecosystem. Zooplankton community plays a pivotal role in the pelagic food web as the primary consumers of phytoplankton and act as the food source for organisms in the higher trophic levels, particularly the economically essential groups such as fish larvae and fishes. They also function in the cycling of elements in the marine ecosystem. The dynamics of the zooplankton community, their reproduction, and growth and survival rate are all significant factors determining the recruitment and abundance of fish stocks as they form an essential food for larval, juvenile and adult fishes. Through grazing in surface waters and following the production of sinking faecal matters and also by the active transportation of dissolved and particulate matter to deeper waters via vertical migration, they help in the transport of organic carbon to deep ocean layers and thus act as key drivers of ‘biological pump’ in the marine ecosystem. Zooplankton grazing and metabolism also, transform particulate organic matter into dissolved forms, promoting primary producer community, microbial demineralization, and particle export to the ocean’s interior. The categorisation of zooplankton into various ecological groups is based on several factors such as duration of planktonic life, size, food preferences and habitat. As they vary significantly in size from microscopic to metazoic forms, the classification of zooplankton based on size has paramount importance in the field of quantitative plankton research.

- **Diversity Index**

  A diversity index is a measure of species diversity within a community that consists of co-occurring populations of several (two or more) different species. It includes two components: richness and evenness. Richness is the measure of the number of different species within a sample showing that more the types of species in a community, the higher is the diversity or greater is the richness. Evenness is the measure of relative abundance of the different species with in a community.

1. **Shannon-Wiener’s index:**

   An index of diversity commonly used in plankton community analyses is the Shannon-Wiener’s index (H), which emphasizes not only the number of species (richness or variety), but also the apportionment of the numbers of individuals among the species. Shannon-Wiener’s index (H) reproduces community parameters to a single number by using an equation are as follow:

$$H' = \sum p_i * \ln(p_i)$$

Where, $\sum$ = Summation symbol,

pi = Relative abundance of the species,

ln = Natural logarithm

More diverse ecosystems are considered healthier and more resilient. Higher diversity ecosystems typically exhibit better stability and greater tolerance to fluctuations. e.g., The Shannon diversity index values between 2.19 and 2.56 indicate relatively high diversity within the community compared to communities with lower values. It suggests that the community likely consists of a variety of species, and the species are distributed somewhat evenly in terms of their abundance.

2. Simpson's index:

A reasonably high level of dominance by one or a small number of species is indicated by the range of **0.89 to 0.91**. The general health and stability of the ecosystem may be impacted by this dominance. Community disturbances or modifications that affect the dominant species may be more likely to have an impact. The dominating species determined by the Simpson's index can have big consequences on how the community is organised and how ecological interactions take place.

The formula for calculating D is presented as:

$$D = 1 - \sum (p_i\hat{}2)$$

Where, $\sum$ = Summation symbol, pi = Relative abundance of the species

3. Margalef's diversity index:

The number of species is significantly related to the port's vegetation cover surface, depth, and photosynthetic zone. The habitat heterogeneity is a result of these three elements. Species richness is related to the number of distinct species present in the analysed area. Margalef's index has a lower correlation with sample size. Small species losses in the community over time are likely to result in inconsistent changes.

Margalef's index D_{Mg}, which is also a measure of species richness and is based on the presumed linear relation between the number of species and the logarithm of the number of individuals. It is given by the formula:

$$D_{Mg} = \frac{S-1}{lnN}$$

Where, N = total number of individuals collected

S = No. of taxa or species or genera

4. Berger-Parker index:

This is a useful tool for tracking the biodiversity of deteriorated ecosystems. Environmental factors have a considerable impact on this index, which accounts for the dominance of the most abundant species over the total abundance of all species in the assemblage. The preservation of their biodiversity and the identification of the fundamental elements influencing community patterns are thus critical for management and conservation. Successful colonising species will dominate the assemblage, causing the Berger-Parker index to rise, corresponding to well-documented successional processes. The environmental and ecological features of the system after disturbance may therefore simply but significantly determine the identity of the opportunistic and colonising species through niche selection processes.

The Berger-Parker index is a biodiversity metric that focuses on the dominance or relative abundance of a single species within a community. It provides a measure of the most abundant species compared to the total abundance of all species present in the community. Mathematically, it can be represented as follows:

$$d = \frac{N_{max}}{\mathrm{N}_i}$$

Where, N_{max} = Max no of individuals of particular genera or species

$\sum N_i$ = Total no of individuals obtained.

The resulting value of the Berger-Parker index ranges between 0 and 1. A higher index value indicates a greater dominance of a single species within the community. Conversely, a lower index value suggests a more even distribution of abundance among different species, indicating higher species diversity. The range of the Berger-Parker index can be interpreted as when the index value is close to 0, it signifies a high diversity with a more even distribution of abundances among different species. In such cases, no single species dominates the community, and there is a balanced representation of various species.

5. Evenness index–

Evenness index determines the homogeneity (and heterogeneity) of the species' abundance. Intermediate values between 0 and 1 represent varying degrees of evenness or unevenness in the distribution of individuals among species. Value of species evenness represents the degree of redundancy and resilience in an ecosystem. High species evenness = All species of a community can perform similar ecological activities or functions= even utilization of available ecological niches = food web more stable = ecosystem is robust (resistant to disturbances or environmental changes). Intermediate values between 0 and 1 represent variable degrees of evenness or unevenness.

$$EI = \frac{H}{\ln{(S)}}$$

Where, H= Shannon value

ln(S) = the natural logarithm of the number of different species in the community

Relative Abundance: The species abundance distribution (SAD) from disturbed ecosystems follows even/ uneven pattern. E.g., If relative abundance is 0.15, then the found species are neither highly dominant nor rare.

$$RA = \frac{No. of\ Individuals\ of\ Sp.}{Total\ no. of\ Individual} * 100\%$$

The basic idea of index is to obtain a quantitative estimate of biological variability that can be used to compare biological entities composed of discrete components in space and time. Biodiversity is commonly expressed through indices based on species richness and species abundances. Biodiversity indices are a non-parametric tool used to describe the relationship between species number and abundance. The most widely used bio diversity indices are Shannon Weiner index and Simpson's index.

Monitoring Frequency:

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar. Sample Collected from this location during the monitoring period April 2023 to March 2024.

12.2 Result and Discussion

The details of Marine Ecological Monitoring conducted for the locations of Kandla and Vadinar during the monitoring period has been summarized in the **Table 37.**

Table 36: Values of Biomass, Net Primary Productivity (NPP), Gross Primary Productivity (GPP), Pheophytin and Chlorophyll for Kandla and Vadinar

Sr. No.	Parameters	Kandla						Vadinar	
		ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek- near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
		Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.
1.	Biomass	115	115	96	142	102	121	78	111
2.	Net Primary Productivity	2.91	3.77	3.08	2.99	5.47	2.49	4.16	2.64
3.	Gross Primary Productivity	2.95	3.04	3.73	3.26	2.44	2.85	3.67	3.09
4.	Pheophytin	1.10	1.28	0.80	1.35	0.82	5.81	2.66	2.43
5.	Chlorophyll-a	2.40	1.61	1.72	1.72	2.04	12.43	2.37	3.24
6.	Particulate Oxidisable Organic Carbon	1.34	1.12	1.18	1.51	1.45	1.40	1.26	1.20
7.	Secchi Depth	0.61	0.63	0.56	0.60	0.56	0.62	3.93	2.61

- **Biomass:**
  With reference to **Table 37**, the average concentration of biomass during the monitoring period, for locations ME-1 to ME-6 was reported within the range of **96–142** mg/L, with the lowest biomass present in **ME-3 (near coal berth)** and the highest biomass present in **ME-4 (Khori Creek)** during the sampling period. In Vadinar, the value of biomass was observed at **78** mg/L at ME-7 (near SPM) and **111** mg/L at ME-8 (near Vadinar Jetty) monitoring station.

- **Productivity (Net and Gross)**
  Gross primary productivity (GPP) is the rate at which organic matter is synthesised by producers per unit area and time (GPP). The amount of carbon fixed during photosynthesis by all producers in an ecosystem is referred to as gross primary productivity. During the Monitoring Period, the monitoring location of Kandla reported GPP value in range between **2.44 to 3.73 mg/L/48 Hr** where the highest value recorded

for ME-3 (Near Coal Bearth) and lowest recorded at ME-5 (Nakti creek-near tuna port). In Vadinar, the value of **GPP** was observed **3.67** at ME-7 (Near SPM) and **3.09** mg/L/48 Hr at ME-8 (Near Vadinar Jetty) monitoring station.

Net primary productivity, is the amount of fixed carbon that is not consumed by plants, and it is this remaining fixed carbon that is made available to various consumers in the ecosystem. During the monitoring period of 2023 to 2024 the Net primary productivity of the monitoring location at Kandla from (ME-1 to ME-6) has been estimated to be between **2.49 to 5.47 mg/L/48 Hr**. While in Vadinar, the value of **NPP** was observed **4.16** at ME-7 (Near SPM) and **2.64** mg/L/48 Hr at ME-8 (Near Vadinar Jetty) monitoring station.

- **Pheophytin**

  The level of Pheophytin was detected in the range from **0.8 to 5.81 mg/m^3** where the highest value observed at ME-6 (Nakti Creek (Near NH-8A)) and the lowest value observed at ME-3(Near Coral Breth), While in Vadinar, the value of Pheophytin was observed **2.66** mg/m^3 at ME-7 and **2.43** mg/m^3 at ME-8 monitoring station.

- **Chlorophyll-a**

  In the sub surface water, the value of Chlorophyll-a reported in range from **1.61 to 12.43 mg/m^3**. The highest value observed at ME-6 (Nakti Creek (Near NH-8A)), while the lowest value observed at ME-2 (Kandla Creek). In Vadinar, the value of chlorophyll-a was observed **2.37** mg/m^3 at ME-7 (Near SPM) and **3.24** mg/m^3 in ME-8 (Near Vadinar Jetty) monitoring station.

- **Particulate Oxidisable Organic Carbon**

  During the sampling period, the particulate oxidisable organic carbon falls within the range of **1.12 to 1.51 mg/L** from monitoring location ME-1 to ME-6 at Kandla, whereas for Vadinar, the value of POC observed **1.26** mg/L at ME-7 (Near SPM) and **1.20** mg/L in ME-8 (Near Vadinar Jetty) monitoring station.

- **Secchi Depth**

  In monitoring station of Kandla (ME-1 to ME-6) the level of Secchi Depth was observed between **0.56 to 0.63 ft** whereas at Vadinar, the value recorded at ME-7 i.e. Near SPM is **3.93** ft and in Near Vadinar Jetty is **2.61** ft.

Ecological Diversity

Phytoplankton: For the evaluation of the Phytoplankton population in DPA Kandla and Vadinar within the immediate surroundings of the port, sampling was conducted during the study period. Total 8 sampling locations were studied i.es. sampling locations (6 from Kandla and two from Vadinar).

The details of variation in abundance and diversity in phytoplankton communities is mentioned in **Table 38**.

Table 37: Phytoplankton variations in abundance and diversity in sub surface sampling stations

Genera	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Bacillaria sp.	360	391	271	404	374	521	390	347
Biddulphia sp.	492	340	73	542	315	434	402	274
Chaetoceros sp.	279	379	316	258	627	322	462	394
Chlamydomonas sp.	286	312	147	329	478	456	325	503
Cyclotella sp.	367	443	284	418	454	609	303	378
Coscinodiscus sp.	455	412	290	206	330	376	370	244
Ditylum sp	342	322	124	241	225	205	227	294
Fragilaria sp.	395	381	336	300	355	0	350	360
Bacteriastrum sp.	178	96	52	166	111	252	162	252
Pleurosigma sp.	236	236	129	565	276	675	352	219
Navicula sp.	366	488	472	393	420	332	375	856
Nitzschia sp.	309	272	249	295	366	284	418	435
Synedra sp.	479	328	82	322	144	541	192	327
Skeletonema sp.	270	566	130	0	488	536	521	495
Oscillatoria sp.	341	351	176	251	493	423.5	144	306
Thallassiosira	147	134	64	132	170	224	235	161
Gomphonema sp.	550	495	128	360	600	310	564	500
Planktothrix sp.	140	302	123	411	393	495	272	353
Gyrosigma sp.	410	560	130	750	0	685	400	667
Actinestrum sp.	0	0	0	0	0	500	0	0
Cymbella	500	500	0	550	0	685	700	500
Limnothrix sp.	0	700	0	650	0	800	750	0
Scendesmus sp.	0	0	0	485	0	630	0	0
Mougeotia sp.	0	0	0	8	0	20	0	4
Chlorella sp.	0	0	0	0	0	850	0	0
Density-Units/L	3107.1	3525	3177.3	2918	3073	3704	3357	3576
No. of genera	**20**	**21**	**19**	**22**	**18**	**24**	**21**	**21**

The phytoplankton community of the sub surface water in the Kandla and Vadinar was represented by, Diatoms, green algae and filamentous Cynobacteria. Diatoms were represented by 15 genera; green algae were represented by 1 genera and filamentous Cynobacteria were represented by 1 genera during the sampling period.

The density of phytoplankton of the sampling stations from ME-1 to ME-6 (Kandla) varying from **2918** to **3704** units/L, while for Vadinar its density of phytoplankton observed **3357** units/L at ME-7 and **3576** units/L at ME-8. During the sampling, all communities were contributing in phytoplankton on both location of Kandla & Vadinar except *Gyrosigma sp*, *Actinestrum sp*, *cymbella*, *Limnothrix sp*, *Scendesmus sp*, *Mougeotia sp* and *cholera sp*.

The details of Species richness Index and Diversity Index in Phytoplankton is mentioned in **Table 39**.

Table 38: Species richness Index and Diversity Index in Phytoplankton

Indices	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek- near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Taxa S	13	14	13	14	13	15	14	13
Individuals	3099	3408	3202	2926	3094	3768	3357	3597
Shannon diversity	2.09	2.12	2.05	1.97	1.94	2.02	2.10	1.95
Simpson 1-D	0.86	0.86	0.85	0.83	0.83	0.84	0.86	0.80
Species Evenness	0.92	0.91	0.90	0.89	0.90	0.87	0.90	0.85
Margalef richness	1.03	1.09	1.02	1.00	0.93	1.01	1.07	1.01
Berger-Parker	0.20	0.21	0.22	0.24	0.25	0.24	0.22	0.28
Relative abundance	0.41	0.44	0.38	0.44	0.38	0.41	0.40	0.41

- **Shannon- Wiener's Index (H):** During monitoring period 2023 to 2024, Average Shanon- Wierner's index of phytoplankton communities was in the range of **1.94 to 2.12** between selected sampling stations from ME-1 to ME-6. While for Vadinar, Average Shannon Wiener's index of phytoplankton communities recorded to be **2.10** at ME-7 and **1.95** at ME-8. The apportionment of the numbers of individuals among the species observed higher stability at all monitoring location of Kandla and Vadinar.
- **Simpson diversity index (1-D):** During the monitoring period **2023 to 2024,** average Simpson diversity index (1-D) of phytoplankton communities was ranged between **0.83 to 0.86** at all sampling stations in the Kandla creek and nearby creeks. Similarly, for Vadinar average Simpson diversity index (1-D) of phytoplankton communities was **0.86** at ME-7 and **0.80** at ME-8.
- **Margalef's diversity index** (Species Richness): During the monitoring period **2023 to 2024,** average margalef's diversity index of phytoplankton communities in Kandla and nearby creeks sampling stations was varying from **0.93 to 1.09.** While for Vadinar, average Margalef's diversity index (Species Richness) of phytoplankton communities observed **1.07** at ME-7 and **1.01** at ME-8.

- **Berger-Parker Index (d):** During the monitoring period **2023 to 2024,** average Berger-Parker Index (d) of phytoplankton communities was in the range of **0.20 to 0.25** between selected sampling stations from ME-1 to ME-6. at Kandla creek and nearby creeks.

Average Berger-Parker Index (d) of phytoplankton communities in the sampling stations of Vadinar, was in the range of **0.22** to **0.28.** All the monitoring station signifies a low diversity with an even distribution among the different species.

- The Average **Species Evenness** is observed in the range of **0.87 to 0.92** for all the six-monitoring station of Kandla and for the Vadinar the average species evenness is observed in the range of **0.85** to **0.90**.

- During the sampling period, average **Relative Abundance** of phytoplankton communities was in range of **0.38 to 0.44** between selected sampling stations from ME-1 to ME-6 at Kandla creek and nearby creeks. Whereas for Vadinar the Average relative Abundance value **0.40** at ME-7 and **0.41** at ME-8. thus, it is concluded that the studied species can be stated as neither highly dominant nor rare.

The details of variation in abundance and diversity in zooplankton communities is mentioned in **Table 40**.

Table 39: Zooplankton variations in abundance and diversity in sub surface sampling stations

Genera	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Acartia sp.	2	2	2	2	2	2	3	2
Acrocalanus	2	2	2	2	2	2	2	4
Amoeba	3	2	3	3	4	2	3	2
Brachionus sp.	3	2	2	2	2	3	4	2
Calanus sp.	2	3	3	2	2	3	2	3
Cladocera sp.	2	3	5	2	3	2	3	3
Cyclopoid sp.	5	4	4	4	2	2	4	2
Copepod larvae	2	3	2	3	2	4	2	2
Diaptomus sp.	5	2	4	2	3	2	3	3
Eucalanus sp.	3	2	2	4	3	6	3	4
Mysis sp.	3	9	7	5	1	6	6	8
Oithona sp.	1	2	4	2	1	4	4	9
Paracalanus sp.	8	7	4	8	11	8	9	10
Density Unit/L	24.45	24.91	25.82	26.00	22.91	26.45	27.64	27.36
No. of genera	13	13	13	13	13	13	13	13

A total of 13 groups/taxa of zooplankton were recorded in Kandla and Vadinar during the study period which mainly constituted by *diaptomus*, *copepods*, *brachionus*, *cladocera*, fish and shrimp larval forms. *Amoeba* and *Cyclopoida* had the largest representation at all stations from (ME-1 to ME-8). The average density of Zooplankton of the sampling stations from ME-1 to ME-6 (Kandla) varying from **22.91** to **26.45** units/L, while for Vadinar its average density of zooplankton observed **27.64** units/L at ME-7 and **27.36** units/L at ME-8. During the sampling, all communities were contributing in zooplankton except *Oithana sp.* in Kandla and Vadinar.

The details of Species richness Index and Diversity Index in Zooplankton communities is mentioned in **Table 41**.

Table 40: Species richness Index and Diversity Index in Zooplankton

Indices	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Taxa S	11	13	10	13	10	12	13	10
Individuals	24	57	26	26	23	26	28	27
Shannon diversity	1.77	1.74	1.76	1.79	1.67	1.76	1.79	1.72
Simpson (1-D)	0.79	0.75	0.79	0.79	0.76	0.77	0.79	0.77
Species Evenness	0.78	0.61	0.78	0.79	0.79	0.73	0.82	0.76
Margalef	2.15	2.21	2.07	2.21	2.06	2.34	2.22	2.16
Berger-Parker	0.34	0.42	0.32	0.34	0.35	0.37	0.31	0.35
Relative abundance	34.93	40.08	31.95	37.76	39.98	38.18	39.18	37.27

- **Shannon- Wiener's Index (H):** During monitoring period 2023 to 2024, Average Shanon- Wierner's index of zooplankton communities was in the range of **1.67 to 1.79** between selected sampling stations from ME-1 to ME-6, at Kandla creek and its nearby creeks. While for Vadinar, average Shannon Wiener's index of zooplankton communities recorded to be **1.79** at ME-7 and **1.72** at ME-8. The apportionment of the numbers of individuals among the species observed higher stability at all monitoring location of Kandla and Near SPM (Vadinar).
- **Simpson diversity index (1-D):** During the monitoring period **2023 to 2024,** average Simpson diversity index (1-D) of zooplankton communities was ranged between **0.75 to 0.79** at all sampling stations in the Kandla creek and nearby creeks, for Vadinar average Simpson diversity index (1-D) of zooplankton communities was **0.79** at ME-7 and **0.77** at ME-8.
- **Margalef's diversity index** (Species Richness): During the monitoring period **2023 to 2024,** average margalef's diversity index of zooplankton communities in Kandla and nearby creeks sampling stations was varying from **2.06 to 2.34,** during the sampling period. While for Vadinar, average Margalef's diversity index (Species Richness) of zooplankton communities observed **2.2** at ME-7 and **2.16** at ME-8.

- **Berger-Parker Index (d):** During the monitoring period **2023 to 2024,** average Berger-Parker Index (d) of zooplankton communities was in the range of **0.32 to 0.42** between selected sampling stations from ME-1 to ME-6, at Kandla creek and nearby creeks. Average Berger-Parker Index (d) of zooplankton communities in the sampling stations of Vadinar, was in the range of **0.31** to **0.35.** All the monitoring station signifies a low diversity with an even distribution among the different species.

- The average **Species Evenness** is observed in the range of **0.61 to 0.79** for all the six-monitoring station of Kandla whereas, for the Vadinar the average species evenness was observed in the range of **0.76** to **0.82**, during the monitoring period.

- During the sampling period, **average Relative Abundance** of zooplankton communities was in range of **31.95** to **40.08** between selected sampling stations from ME-1 to ME-6. at Kandla creek and nearby creeks. Whereas for Vadinar the average relative abundance value **39.18** at ME-7 and **37.27** at ME-8, thus it can be concluded that the studied species is stated as neither highly dominant nor rare.

The details of variation in abundance and diversity in **Benthic organism** is mentioned in **Table 42.**

Table 41: Benthic Fauna variations in abundance and diversity in sub surface sampling

Genera	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Thiaridae	2	1	2	2	2	2	1	3
Mollusca sp.	2	1	2	2	3	2	2	3
Odonata sp.	2	1	2	3	2	2	2	3
Lymnidae	2	1	5	2	2	2	3	2
Planorbidae	1	1	2	1	2	2	2	1
Atydae	2	1	2	2	1	2	2	2
Gammaridae	2	1	1	2	1	2	2	3
Portunidae	1	1	1	1	0	1	1	1
Turbinidae	2	1	3	1	1	2	2	2
Palaemonidae	1	1	2	3	3	1	2	2
Diapatra sp.	2	1	3	4	2	4	2	3
Coleoptera sp.	2	1	3	3	0	1	3	2
Crustacea sp.	3	1	3	3	3	3	2	1
Hemiptera sp.	2	1	0	2	2	2	3	2
Tricoptera sp.	2	1	3	4	3	5	2	1
Hydrobidae	1	1	1	2	1	3	0	3
Viviparidae	3	1	0	1	2	2	3	3
Neridae	2	1	2	0	4	2	1	2
Density-m³	10.18	8.82	9.64	10.09	8.5	9.73	9.73	9.55
No of genera	**18**	**18**	**16**	5.00	**16**	**18**	**17**	**18**

Few Benthic organisms were observed in the collected sample by using the Van-Veen grabs during the sampling conducted for DPA Kandla and Vadinar. Majority of the species were found under the Macro-benthic organisms during the sampling period were represented by *Atyde, Palaemonidae, Mollusca sp.*, etc. The average density of benthic fauna was varying from **8.55** to **10.18** m^3.

The details of Species richness Index and Diversity Index in Benthic Organisms is mentioned in **Table 43.**

Table 42: Species richness Index and Diversity Index in Benthic Organisms

Indices	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek- near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg.	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Taxa S	6	7	6	6	7	6	6	6
Individuals	10	9	10	10	9	10	9	10
Shannon diversity	1.55	1.42	1.47	1.50	1.43	1.48	1.43	1.43
Simpson 1-D	0.76	0.73	0.75	0.75	0.73	0.75	0.73	0.74
Species Evenness	0.89	0.89	0.92	0.92	0.90	0.91	0.90	0.89
Margalef	1.92	1.77	1.73	1.81	1.83	1.79	1.76	1.68
Berger-Parker	0.33	0.37	0.33	0.34	0.37	0.34	0.38	0.36
Relative abundance	55.92	57.66	53.67	56.55	60.63	56.18	57.46	51.58

- **Shannon- Wiener's Index (H):** During monitoring period 2023 to 2024, Average Shanon- Wierner's index of benthic organism was in the range of **1.42 to 1.55** between selected sampling stations from ME-1 to ME-6, at Kandla creek and its nearby creeks. While for Vadinar, average Shannon Wiener's index of benthic organism recorded to be **1.43** at ME-7 and ME-8. The apportionment of the numbers of individuals among the species observed higher stability at all monitoring location of Kandla and Vadinar.

- **Simpson diversity index (1-D):** During the monitoring period **2023 to 2024,** average Simpson diversity index (1-D) of benthic organism was ranged between **0.73 to 0.76** at all sampling stations in the Kandla creek and nearby creeks, Similarly, for Vadinar average Simpson diversity index (1-D) of benthic organism was **0.73** at ME-7 and **0.74** at ME-8.

- **Margalef's diversity index** (Species Richness): During the monitoring period **2023 to 2024,** average margalef's diversity index of benthic organism in Kandla and nearby creeks sampling stations was varying from **1.73 to 1.92**. While for Vadinar, average Margalef's diversity index (Species Richness) of benthic organism observed to be **1.76** at ME-7 and **1.68** at ME-8.

- **Berger-Parker Index (d):** During the monitoring period **2023 to 2024,** average Berger-Parker Index (d) of benthic organism was in the range of **0.33 to 0.37** between selected sampling stations from ME-1 to ME-6, at Kandla creek and nearby creeks. average Berger-Parker Index (d) of benthic organism in the sampling stations of Vadinar, was in the range of **0.36** to **0.38**. All the monitoring station signifies a low diversity with an even distribution among the different species.

- The average **Species Evenness** is observed in the range of **0.89 to 0.92** for all the six-monitoring station of Kandla and for the Vadinar the species evenness is observed in the range of **0.89** to **0.90.**

- During the sampling period, **average Relative Abundance** of Benthic organisms was in range of **53.67 to 60.63** between selected sampling stations from ME-1 to ME-6 at Kandla creek and nearby creeks. Whereas for Vadinar the Average relative abundance value **57.46** at ME-7 and **51.58** at ME-8, thus it is concluded that the studied species can be stated as neither highly dominant nor rare.

CHAPTER 13: SUMMARY AND CONCLUSION

13.1 Summary and Conclusion

The report, prepared by the Gujarat Environment Management Institute (GEMI), details the environmental monitoring and management plan for the Deendayal Port Authority (DPA) at Kandla and Vadinar. The monitoring covers the period from April 2023 to March 2024.

The primary objective is to systematically assess and monitor environmental parameters including ambient air, water (drinking and surface), soil, sediment, noise, and ecology to ensure compliance with environmental standards and statutory norms.

Methodology

Environmental monitoring was conducted using standard operating procedures, protocols, and guidelines to ensure accurate data collection. Various parameters were measured, including air quality, water quality, soil characteristics, noise levels, and meteorological data.

Based on the results obtained for both study areas, Kandla and Vadinar, during the monitoring period from April 2023 to March 2024, the following observations are concluded.

- **Ambient Air Quality Monitoring**
  Particulate matter (PM_{10} and $PM_{2.5}$) levels exceeded the national ambient air quality standards (NAAQS) at most monitoring locations, especially at the coal storage area. The high particulate matter levels were attributed to heavy vehicular traffic, loading/unloading of cargo, and dust from unpaved roads. For Gaseous monitoring, sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and carbon monoxide (CO) were generally within the NAAQS limits.
  The noise level was within the permissible limits for the industrial, commercial, and residential zones for daytime and nighttime.

- **DG Stack Monitoring**
  Monitoring of the diesel generator (DG) stacks was conducted at one location each in Kandla and Vadinar. Parameters like suspended particulate matter, SO_2, NO_x, CO, and CO_2 were measured and found to be within the prescribed emission limits.

- **Soil Monitoring**
  The pH in Kandla varies from slightly alkaline to strongly alkaline, while the soil at Vadinar was found to be moderately alkaline. The soil texture was observed as "sandy loam" to "loamy sand" at all the monitoring locations in Kandla, and the soil texture of Vadinar varies from "loam" to "slit loam. Kandla displays higher salinity and nutrient levels, while Vadinar exhibits lower nutrient levels. Vadinar generally shows moderate conditions with higher water holding capacity and more consistent soil composition. The presence of heavy metals such as aluminium, chromium, nickel, copper, zinc, lead, arsenic, and cadmium vary considerably at both study area.

- **STP Monitoring**
  After the effluent treatment in both the study areas, the treated water followed the GPCB discharge norms except for total coliform.

- **Drinking Water Quality Monitoring**
  Drinking water samples were collected from 20 locations across Kandla and Vadinar. Most water quality parameters like pH, color, turbidity, chloride, and total hardness were within the drinking water standards (IS 10500:2012). A few locations showed slightly elevated levels of electrical conductivity, salinity, and total dissolved solids, likely due to the coastal location.

- **Marine Water and Sediment Quality Monitoring**
  Marine water and sediment samples were collected from 6 locations in Kandla and 2 locations in Vadinar. The water quality parameters like pH, salinity, dissolved oxygen, and nutrients were within the acceptable limits for coastal waters. The sediment quality in terms of heavy metals and organic contaminants was also found to be within the prescribed standards.

- **Marine Ecology Monitoring**
  Monitoring of marine ecology was conducted at 6 locations in Kandla and 2 locations in Vadinar. The analysis indicates that both regions exhibit low diversity with an even distribution among species, as evidenced by the Berger-Parker Index and Simpson Diversity Index values. These indices suggest a stable ecosystem where no single species overwhelmingly dominates, nor are any species exceedingly rare. The even distribution of species, coupled with moderate levels of biomass and primary productivity, highlights the resilience of these ecosystems.

Overall, the report concludes that the environmental monitoring conducted by the DPA during the period of April 2023 to March 2024 indicates compliance with the applicable environmental regulations, with some exceptions related to particulate matter levels in the ambient air.

Annexure 1: Photographs of the Environmental Monitoring conducted at Kandla


STP Monitoring


Noise Monitoring


Soil Monitoring


Marine Monitoring


Air Monitoring


Drinking Water Monitoring

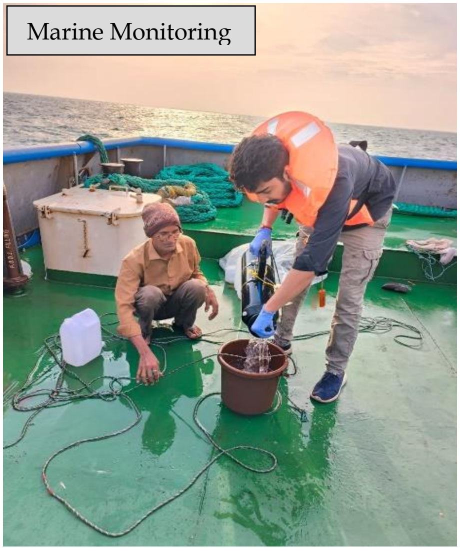
Annexure 2: Photographs of the Environmental Monitoring conducted at Vadinar


Air Monitoring


Noise Monitoring


STP Monitoring


Drinking water Monitoring


Marine Monitoring


Soil Monitoring

Source: GEMI

CHAPTER 14: REFERENCES

References:

(1) National ambient air quality standards central pollution control board, 2009

(2) Ambient Air Quality Standards in respect of Noise,2000.

(3) American Public Health Association 23rd Addition, Standard Methods for Water and Waste water analysis, 2017.s

(4) Indian Standard DRINKING WATER — SPECIFICATION (Second Revision), 2012.

Gujarat Environment Management Institute (GEMI)

(An Autonomous Institute of Government of Gujarat)

'An ISO 9001:2015, ISO 14001:2015 & ISO 45001:2018 Certified Institute

Head Office

Plot No. B 246 & 247, G.I.D.C. Electronic Estate,

Sector-25, Gandhinagar-382024

Laboratory

Plot No. B-64, G.I.D.C. Electronic Estate,

Opp. I.P.R., Sector-25, Gandhinagar-382025

Tel: (+91) 79-23240964 (O), T: (+91) 79-23287758 (Lab), F: (+91) 79-23240965

E-mail: info-gemi@gujarat.gov.in | Website: www.gemi.gujarat.gov.in

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Annexure F

Final report of dredge material study (2022-2023)

Final Report
(2022-23)

Studies on Dredged Materials for the presence of Contaminants

(As per EC & CRZ Clearance accorded by the
MoEF & CC, GoI dated 19/12/2016. Specific condition no. vii)

DPA Work order No. EG/WK/4751/Part (EC&CRZ-1) / 84. Dt. 18.09.2021.

Submitted by

Gujarat Institute of Desert Ecology
P.B. No. 83, Mundra Road
Opp. Changleshwar temple
Bhuj - Kutch, Gujarat – 370001, India

Submitted to

Deendayal Port Authority
Administrative Office Building
Post Box NO. 50, Gandhidham (Kutch)
Gujarat - 370201

Project Team

Project Co-Ordinator **:** Dr. V. Vijay Kumar, Director

S. No	Name & Designation	Role	Expertise
Scientific Personnel			
1.	Dr. K. Karthikeyan Assistant Director	Principal Investigator	Ph.D. in Environmental Sciences – Experience in water and soil studies.
2.	Dr. G. Jayanthi Scientist	Co- Investigator	PhD in Botany; 14 years of Research experience with 5 years of Post-Doctoral experience
3.	Dr. Krushnakant. D. Baxi Scientific Officer	Co- Investigator	Ph.D in Zoology (Marine Biology) with 5 years of experience
Technical Staff			
4.	Ms. Monika Sharma	Team Member	M.Sc. in Environmental Sciences; 7 years analytical experience in soil, water analysis
5.	Ms. Dipti Parmar Scientific Assistant	Team member	M.Sc. in Environmental Sciences; 6 years analytical experience in soil and water analysis.

Dr. V. Vijay Kumar
Director

Gujarat Institute of Desert Ecology

Certificate

This is to state that the **Final Report** of the work entitled, **"Studies on Dredged Material for the Presence of Contaminants"** has been prepared in line with the Work order issued by DPA vide No.EG/WK/4751/Part (EC&CRZ-1) / 84. Dt. 18.09.2021 as per the EC & CRZ Clearance accorded by the MoEF & CC, GoI dated 19/12/2016, Specific Condition No. vii. The work order is for a period of Three years from November 2021 – October 2024 for the above-mentioned study.

This Final report is for the project period from November 2022 - October 2023.

Authorized Signatory **Institute Seal**

PO. Box No. 83, Opp. Changleshwar Temple, Mundra Road, Bhuj (Kachchh) - 370 001, Gujarat (India)
Tel : 02832 - 235025-29
www.gujaratdesertecology.com, E-mail : desert_ecology@yahoo.com

CONTENTS

Abbreviations

AAS	Atomic Absorption Spectrophotometer
Avg	Average
BDL	Below Detectable Limit
C	Celcius
Cd	Cadmium
cm	Centimetre
Cr	Chromium
CWPRS	Central Water and Power Research Station
DPA	Deendayal Port Authority
g/L	Grams per litre
GIS	Geographical Information System
GoK	Gulf of Kutch
GPS	Global Positioning System
GUIDE	Gujarat Institute of Desert Ecology
HCl	Hydrochloric acid
Hg	Mercury
HNO_3	Nitric Acid
$K_2Cr_2O_7$	Potassium Dichromate
kg	kilogram
km	Kilometer
KOH	Potassium Hydroxide
m	meter
max	maximum
min	Minimum
ml	millilitre
MoEF & CC	Ministry of Environment, Forests & Climate Change
Pb	Lead
pH	Potential of Hydrogen
PHc	Petroleum Hydrocarbon
ppm	Parts per million
ppt	Parts per thousands
TOC	Total Organic Carbon
TP	Total Phosphorus
µg	microgram

Project Snapshot : "Studies on Dredged Materials for the presence of Contaminants"

Deendayal Port Authority (DPA) intends to develop seven integrated facilities to meet the increasing cargo handling demands of the port. Ministry of Environment, Forests and Climate Change (MoEF & CC), New Delhi, while according environmental clearance to these developmental initiatives, among other conditions, stipulated to carry out "Studies on dredged materials for the presence of contaminants" as per the EC & CRZ Clearance accorded by the MoEF & CC, GoI dated 19/12/2016, Specific Condition No. vii and the task of carrying out the study was given to Gujarat Institute of Desert Ecology (GUIDE), Bhuj during September 2017 and the study encompasses a detailed study of various physical, chemical and biological characteristics of the sediment. This report covers the study conducted for the period from November 2022 - October 2023.

The data of the present study is detailed out as snapshot below:

S. No	Components of the study	Remarks
1	MoEF & CC sanction letter and details	MoEF & CC's clearance to seven integrated project and specific conditions thereof. Ref. No. F. No. 11-82/2011-IA III; letter dated 19th December 2016. Specific condition No. vii.
2	Deendayal Port letter sanctioning the project	No. EG/WK/4751/Part (EC&CRZ-1) / 84. Dt. 18.09.2021.
3	Duration of the project	Three years (01.11.2021 – 30.10.2024)
4	Period of survey carried out for various components	1st Season study (Winter) 2nd Season study (Summer) 3rd Season study (Monsoon)
5	Survey area within the port limit	Dumping locations of dredged materials as suggested by the CWPRS
6	No of locations sampled within the port limits	Three sampling locations, *i.e.,* Two locations in sub-tidal and one creek location during all the three seasons
7	**Components of the report**	
7.1	Sediment quality (Physico-chemical)	The past three years of data, *i.e.,* 2020-21, 2021-22 and 2022-23 showed that the parameters studied

		such as pH, Salinity, Petroleum Hydrocarbon, Total organic carbon, Sulphur, Lead and Cobalt showed a decreasing trend in the current year (2022-23) when compared to the previous years (2020-21 and 2021-22).
7.2	Sediment quality (Biological)	During Season 1, the diversity indices showed that Shannon Diversity Index ranging from (0.00-1.28) indicated very low diversity. Highest diversity indices were recorded in Offshore (1.28), whereas during Season 2 showed the Shannon Diversity Index ranging from (0.64-1.04) indicated very low diversity. Highest diversity indices were recorded in Cargojetty (1.04). Further, in Season 3, diversity indices showed Shannon Diversity Index ranging from (0.00-1.45) indicated very low diversity and the highest diversity indices was recorded in Cargojetty During this year, the offshore locations recorded a high diversity index.
7.3	Water quality (Physico-chemical)	During the present study, the Offshore location recorded the concentrations of Phenolic compounds and Petroleum hydrocarbons between 14.75-28.83 µg/L and 16.33-59.12 µg/L, respectively. In case of Cargo jetty, the concentration of Phenolic compounds and Petroleum hydrocarbons were within permissible limit set by CPCB, with the maximum values ranging from 26.75µg/L and 28.52µg/L. The average value of PHc was 43.16±33.18 µg/L. The Report also narrates on the comparison of Physico-chemical characteristics of the present study (2022-23) with that of the physico-chemical characteristics of the study conducted during 2020-21 and 2021-22 from all the three different stations (Offshore, Cargo jetty and Phang creek).
7.4	Water quality (Biological)	During the present study, data on Phytopigments such as Chlorophyll and Phaeophytin. the Mean

		Chlorophyll concentrations were ranging between 0.48 – 0.63 mg/m^3, whereas the previous year's data were in the range of 0.53 – 0.73 mg/m^3 during 2020-2021 and 0.32 – 0.62 mg/m^3 during the year 2021-2022. Similarly, Phaeophytin was between 0.26 – 0.41 mg/m^3 during 2020-21 and 0.22 – 0.30 mg/m^3 during 2021-2022 and the current year recorded mean phaeophytin of 0.29 – 0.33 mg/m^3. When the Diversity indices of Phytoplankton is concerned, During first season, it showed the Shannon Index ranged from 2.49 to 3.35, indicating moderate to slightly high level of diversity, during Season 2, it was from 2.01 to 3.20 indicating moderate level to slightly high level of diversity and during Season 3, it was from 1.98 to 3.17 indicating moderate to slightly high level of diversity.
7.5	Management plan	

Chapter 1 Background

Deendayal Port, formerly known as Kandla Port, is a major port in India located in the Kutch district of Gujarat located around 256 nautical miles southeast of the Port of Karachi in Pakistan and over 430 nautical miles north-northwest of the Port of Mumbai (Bombay). Among the twelve major ports of the country Deendayal Port Authority which is located at the tail end of Gulf of Kachchh, is the largest Creek based Ports in the county which is located in the north-western coast of India in the state of Gujarat. DPA caters the maritime trade requirement of many hinterland states and is well connected by the network of rail and road and serves as a gate way port for export and import of northern and western Indian states of Jammu and Kashmir, Delhi, Punjab, Himachal Pradesh, Haryana, Rajasthan, Gujarat and parts of Madhya Pradesh, Uttaranchal and Uttar Pradesh.

It is one of the largest ports in the country and plays a vital role in India's international trade and maritime infrastructure. The port is managed and operated by the Deendayal Port Trust (DPT), which is an autonomous body established under the Major Port Trusts Act, 1963. The Port Authority is responsible for the overall administration, development, and management of the port. The authority consists of a team of professionals and experts who ensure the smooth functioning of the port and its associated activities.

Deendayal Port's journey has started in the year 1931 with construction of RCC Jetty and as of today Deendayal Port has risen to the No. 1 port in India since 2007-08 till date, continuing to be in the same position for the past 14 years and as the largest port of India in terms of volume of cargo handled. About 35% of the country’s total export takes place through the ports of Gujarat in which the contribution by Deendayal port is considerable.

The growth of this port has been contributed not only owing to handling of crude oil imports but also in taking relevant measures to boost non-POL cargo. An assortment of liquid and dry cargo is being handled at Deendayal Port. The dry cargo includes fertilizers, iron and steel, food grains, metal products, ores, cement, coal, machinery, sugar, wooden logs, etc. The liquid cargo includes edible oil, crude oil and other petroleum products. Deendayal Port Authority has shown consistent increase in case of traffic being handled every year and is growing at a fast rate year by year. The port handled a total cargo of 105 MMTPA during 2016-17, 110 MMTPA during 2017-18, 115 MMTPA during 2018-19, 122.5 MMTPA during 2019-2020, 117.5 MMTPA during 2020-21 and 137 MMTPA during 2022-23. During the year 2016, Deendayal Port created history by handling 100 MMT cargos in a year, which is the first of its kind for the Major port category to achieve the milestone.

Especially the cargo traffic handled by the port comprises of Iron scrap, steel, food grains, ore, timber logs, salt extractions, POL products, edible oils and broad range of chemicals compounds. Containerized cargo traffic through this port has also shown a significant growth during the last few years. The dry cargo traffic at the port has been increasing steadily every year at a much faster pace with an average annual rate of growth of around 11.94%. The Port has presently fourteen (14) jetties and six oil terminals and many other allied facilities to handle both dry and liquid cargo. Regular expansion/developmental activities such as addition of jetties, Special Economic Zones, industrial parks, go downs, ship repairing and bunkering facilities and railway lines are underway in order to cope with the increasing cargo handling demands.

Further, a regular expansion of infrastructure and port facilities is under way to cater future logistic requirements. The port has high commercial importance in the Indian maritime trade as it handled 36.1 million tons (17%) of cargo out of total cargo of 213.1 million tons of the maritime cargo of India during 2015. DPT is well connected by the network of rail and road and serves as a gate way port for export and import which caters the maritime trade requirement of many hinterland states including northern and western Indian states of Jammu & Kashmir, Delhi, Punjab, Himachal Pradesh, Haryana, Rajasthan, Gujarat and parts of Madhya Pradesh, Uttaranchal and Uttar Pradesh.

DPT has taken up various activities including Special Economic Zone establishment and proposal to develop a multipurpose cargo terminal and a container terminal at the creek mouth. This entails regular vessel movement, and capital and maintenance dredging of different proportions. Development of multipurpose cargo terminal at Tekra off Tuna and construction of railway over-bridge at the inner end of Nakti creek is sanctioned by the ministry. The cargo terminal will come up very close to the mouth of the Nakti creek and it envisages capital and maintenance dredging to the tune of 12657175 and 1898576 m^3, respectively.

As part of its ongoing expansion, Deendayal Port Authority has taken up Development of 7 Integrated facilities which include development of oil jetty and ship bunkering terminal at old Kandla, a multi-purpose oil terminal near Tuna, upgradation of barge handling facility at Kandla, construction of one rail over bridge and strengthening of existing oil jetties.

1.1. **EC conditions**

The Ministry of Environment, Forest and Climate Change (MoEF & CC), has put up some conditions while according Environmental and CRZ clearance. One of the conditions is to carry out the *"Study on Dredged Material for presence of contaminants"* as accorded by the MoEF&CC,GoI dated 19/12/2016 - Specific condition no. vii)" which states that ***"Dredged materials should be analyzed for presence of contaminants and also to decide the disposal options. Monitoring of dredging activities should be conducted and the findings should be shared with the Gujarat SPCB and Regional Office of the Ministry"***.

1.2. Need of the study

In this regard, DPA has assigned the task of carrying out this particular study to Gujarat Institute of Desert Ecology (GUIDE), Bhuj. GUIDE has received the Work order for this Dredging project with project time period being Three years (01.11.2021 – 31.10.2024). This study on Evaluation of dredging contaminants was conducted Three times in a year at two different dumping locations with the methodical investigation of evaluating physical and chemical characteristics of the bottom sediment from the dumping locations with special reference to pollutants such as heavy metals and petroleum hydrocarbon. Further, the study had objectives including the understanding of the productivity of the sediment and the water by analyzing the planktonic and benthic fauna. Further, based on the results obtained, the management plan is also elaborated which spells out the possible options for managing the dredged materials.

1.3. Selection of sampling locations for 2022-2023

Deendayal Port Authority has assigned the study on the presence of contaminants in the dredged materials for the year 2017-18 based on the locations for the dumping has been suggested by Hydraulic & Dredging Division to DPT on the e-mail dated 24th October 2018. 1. In line with the study conducted during 2017-18, the extension of the study was given in 2018 for a period of three years, *i.e.*, from 2018-2021 and later for a period of three years, *i.e.*, 2021-2024 and the GPS locations of all the locations are mentioned in Table 1.

Table 1: GPS Co-ordinates of sampling locations (2021-22)

Station	Latitude	Longitude
Location 1 (Offshore)	22° 51' 00" N	70° 10’ 00" E
Location 2 (Phang creek)	23° 04' 28" N	70°13’ 28" E
Location 3 (Cargo jetty)	22°56' 31" N	70 13' 00" E

1.4. Port Environment

Rapid industrialization and economic growth in the world has resulted in increased pollution in various environmental matrices such as Air, Water and Soil. The marine environment receives a vast quantity of dredge spoils, sewage waste, industrial effluents and river runoff, markedly affecting the composition and quality of the aquatic environment. The coastal waters are highly at the risk of various pollution due to increase human settlement, establishment of industries, ports and harbours that use seawater and discharge solid and liquid wastes directly into the environment. In general, ports are economic instruments for trade and a vital component in the nation's economy, however, such activities also involve dredging, large-scale construction and its continuous expansion which could affect the marine ecosystems in its vicinity. In a port environment, activities like dredging, continuous movement of vessels and human create major impacts at the marine/coastal environment in its vicinity.

1.5. Study Area

The Port is located at Gandhidham taluka of Kutch district, Gujarat which is the nearest major habitation with a population of 2.49 lakhs as per the 2011 census. The coastal environs in and around the port jurisdiction is characterized by a network of creek systems and mudflats which are covered by sparse halophytic vegetation like scrubby to moderately dense mangroves, creek water and salt-encrusted landmass as major ecological entities. The surrounding environment in a radius of 10 km from the port includes built-up areas, salt pans, human habitations and port related structures on the west and north creek system, mangrove formations and mudflats in the east and south.

1.6. Aim and objectives of the study

The present project is designed considering the scope of work given in the EC conditions with the specific objectives as detailed below and considering the general environmental setting of the entire Gulf. Coastal waters often reveal significant temporal, spatial and seasonal changes with reference to sediment and water environmental and other ecological aspects and such variations should be clearly understood for assessing the prevailing status of a coastal water body. This report covers the monitoring results for the period from November 2021 - October 2022 with specific objectives as follows:

1. To characterize the bottom sediment samples from the dumping grounds for physico-chemical characteristics.
2. To understand the biological characteristics of the marine sediment for benthic faunal density and diversity.

3. To study the physico-chemical characteristics of the marine water from the dumping locations.
4. To estimate the primary productivity (pigments) and the plankton community structures (phytoplankton and zooplankton) in the marine water samples collected near the dumping grounds.
5. To compare the characteristics of the sediment estimated during different seasons to understand the pattern.
6. To suggest suitable management plan for management of the dredged materials.

1.7. Approach Strategy

The work is designed in such a way with an initial reconnaissance survey to understand the sampling location. For this purpose, pre-fixed sampling locations as prescribed by CWPRS were considered and sampling techniques for water and sediment for all the characteristics including physical, chemical and biological aspects were well planned as per standard protocol.

1.8. Sampling frequency

The samples for each season for collection of water and sediment to study different characteristics were sampled at both the locations thrice during the study period. This detailed report represents the outcome of all the Three seasons study in which the first season sampling was conducted for a period of 3 days during January 2022, the second season study was conducted for a period of 3 days during April 2022 and the final season study was conducted for a period of 3 days during September 2022 as per the locations details mentioned in the map as Figure 1 and the glimpses during the sampling locations are presented in Figure 2.

Figure 1: Map showing locations sampling during 2022-23

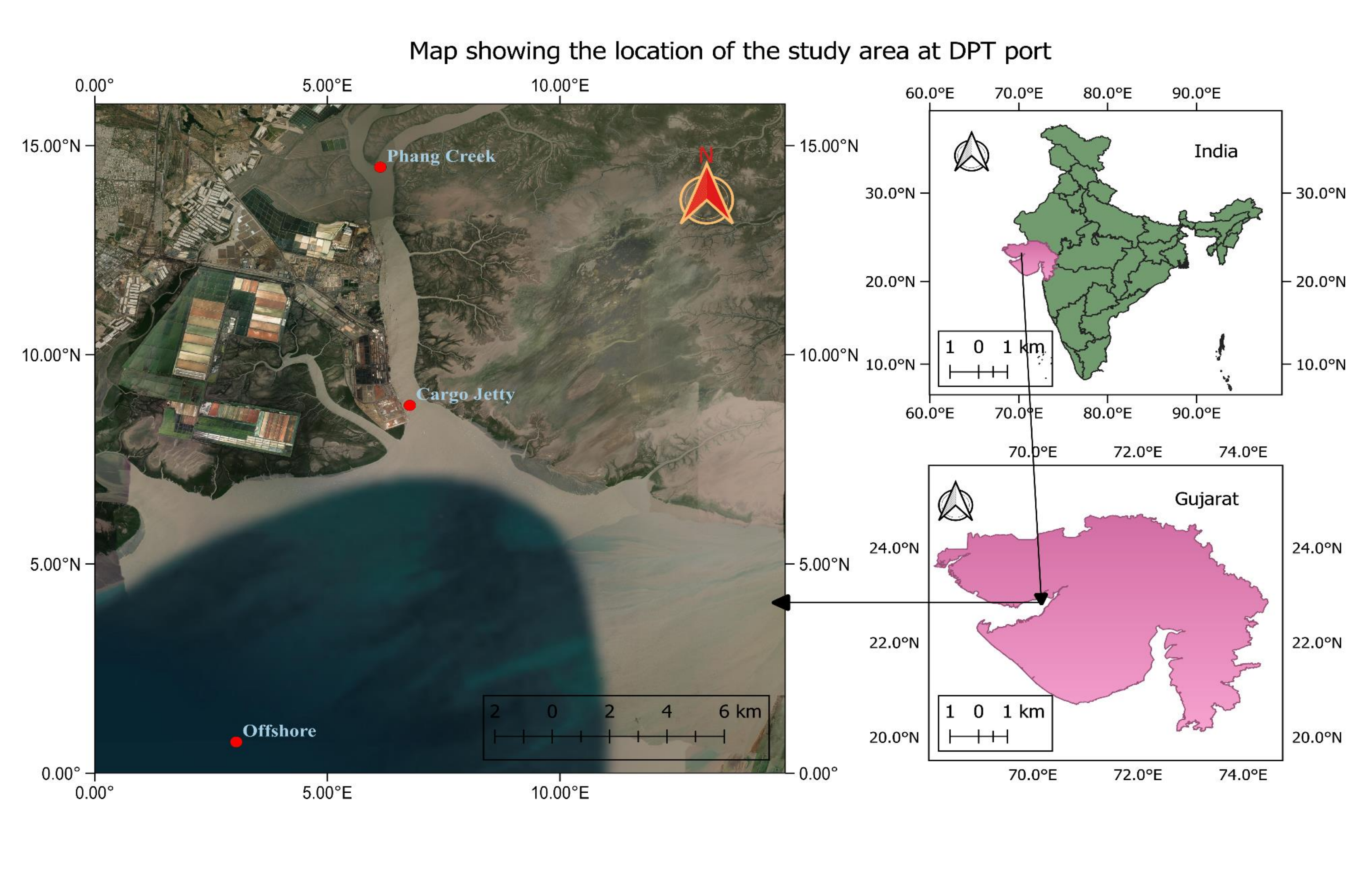

Figure 2: Photograph during sampling at the sampling locations

Chapter 2 Sediment Quality (Physico-chemical)

2.1. Background

Sediments, in general, have strong tendency to accumulate contaminants, especially heavy metals and they possess a very high physico-chemical stability and studying their characteristics usually indicates the optimum health of the marine system (Leoni and Sartori 1996). Sediment characteristics are a determinant factor in contamination of dredged marine environments. This is due to the retention and adsorption of contaminants to sediments by contaminants that have settled on the bottom of marine water bed. Such behavior of adsorption of sediment is highly influence by the sediment texture which is the relative proportions of each class including sand, silt and clay and are commonly referred as soil separates.

Table 2: Physico-chemical and biological characteristics of sediment samples

S. No	Physico-chemical and Biological parameters
1	pH (1: 10 suspension)
2	Salinity (ppt)
3	Petroleum Hydrocarbon (µg/kg)
4	Magnesium (mg/kg)
5	Sand (%)
	Silt (%)
	Clay (%)
6	Total organic carbon (%)
7	Phosphorus (mg/kg)
8	Sulphur (mg/kg)
9	Nickel (mg/kg)
10	Lead (mg/kg)
11	Cadmium (mg/kg)
12	Chromium (mg/kg)
13	Zinc (mg/kg)

14	Copper (mg/kg)
15	Manganese (mg/kg)
16	Cobalt (mg/kg)
17	Macrobenthos Biomass (g/m^2,wet wt); Population (no/m^2) Total Group (no); Major Groups

2.2. Materials and Methods

The sediment samples from the study area were collected for the purpose of characterization employing standard methodology and the analysis of the samples were also performed as per standard protocol and the data of sediment analysis is presented in this Chapter 1. The sediment samples were collected in pre-fixed stations using a Van-Veen type of grab sampler. After collection, the sediment samples were preserved with Rose Bengal and formalin to avoid decomposition of samples and processed for analysis and the samples after collection were brought to the laboratory on the same day of collection and air dried and used for further analysis for the test parameters (Table 2).

2.2.1. pH and Salinity (1: 10 suspension)

pH of the sediment is the measure of H^+ ion activity of the sediment water system. It indicates whether the sediment is acidic, neutral or alkaline in nature. Since ions are the carrier of electricity, the electrical conductivity (EC) of the sediment water system rises according to the content of soluble salts. The measurement of EC can be directly related to soluble salts concentration of the sediment at any particular temperature. Ten gram of the finely sieved sediment will be dissolved in 100ml of distilled water to prepare a leachate. This will be subjected to vigorous shaking using a rotator shaker for 1 hour to facilitate proper homogenization of the suspension. The suspension will be allowed to settle for two 2 hours and the supernatant after filtration will be used for the analysis of pH and salinity using the pH and EC meter (Make: Systronics 361) and Refractometer (Make: Atago). Each sample will be analysed in triplicates and the mean values will be taken into consideration.

2.2. 2. Textural analysis (Sand/Silt/Clay)

Sediments will be collected using Van Veen grab whereas intertidal sediments will be collected using a handheld shovel. After collection, the scooped samples will be transferred to polythene bags, labeled and stored under refrigerated conditions. The sediment samples will be thawed, oven dried at 40ºC and ground to a fine powder before analyses.

For texture analysis, specified unit of sediment samples will be sieved using sieves of different mesh size as per Unified Sediment Classification System (USCS). Cumulative weight retained in each sieve will be calculated starting from the largest sieve size and adding subsequent sediment weights from the smaller size sieves. The percent retained will be calculated from the weight retained and the total weight of the sample. The cumulative percent will be calculated by sequentially subtracting percent retained from 100%.

2.2.3. Total organic carbon

Total organic carbon is the carbon stored in sediment organic matter which enters the sediment through the decomposition of plant and animal residues, root exudates, living and dead microorganisms, sediment biota etc. Total Organic carbon in the sediment is oxidized with potassium dichromate in the presence of concentrated sulphuric acid. Potassium dichromate produces nascent oxygen, which combines with the carbon of organic matter to produce CO_2. The excess volume of $K_2Cr_2O_7$ is titrated against the standard solution of ferrous ammonium Sulphate in presence of H_3PO_4 using Ferroin indicator to detect the first appearance of unoxidised ferrous iron and thus volume of $K_2Cr_2O_7$ can be found out which is actually required to oxidize organic carbon.

Procedure

Percentage of Total organic carbon in the sediment/sediment will be determined by oxidizing organic matter in the sediment samples by chromic acid and estimating excess chromic acid by titrating it against ferrous ammonium sulphate with ferroin as an indicator. The detailed step-by-step procedure is as follows:

One gm of 0.5 mm sieved sediment will be weighed and put into 500 ml conical flask and to which 10 ml of 1N $K_2Cr_2O_7$ will be added with pipette and swirled. Immediately using a burette, 20 ml Conc. H_2SO_4 will be added and mixed gently until sediment and reagents are mixed. The reaction will be allowed to proceed for 30 min in a marble stone to avoid the damage caused due to release of intense heat due to reaction of sulphuric acid. Further, 200 ml of distilled water will be added slowly and 10 ml of concentrated Orthophosphoric acid and about 0.2 gm NaF will be added and allowed the sample and reagent mixture to stand for 1.5 hrs because the titration end point is better visible in a cooled solution. One ml of ferroin indicator will be added into the conical flask just before the titration and then titrated the excess K_2Cr_2O with 0.5 N Ferrous Ammonium Sulphate till the color flashes from yellowish green to greenish and finally brownish red at the end point. Simultaneously a blank test will be also run without sediment sample.

2.2.4. Total Phosphorus

Phosphorus in sediment is commonly performed by Bray's extraction method and in this method, specific-colored compounds are formed with the addition of appropriate reagents in the solution, the intensity of which is proportionate to the concentration of the element being estimated. The color intensity is measured spectrophotometrically. In spectrophotometrically analysis, light of definite wavelength (not exceeding say 0.1 to 1.0 nm in band width) extending to the ultraviolet region of the spectrum constitutes the light source. The photoelectric cells in spectrophotometer measure the light transmitted by the solution.

Fifty ml of the Bray's extractant will be added to 100 ml conical flask containing 5 gm of sediment sample and shaken for 5 minutes and filtered. Exactly 5 ml of the filtered sediment extract will be taken with a bulb pipette in a 25 ml measuring flask and 5 ml of the molybdate reagent with an automatic pipette will be added and diluted to 20 ml with distilled water and shaken well. Further, to this, 1 ml of the dilute Stannous Chloride solution will be added and volume made upto 25 ml mark and shaken thoroughly. The mixture will be kept for color development and after 10 minutes the readings will be taken in the spectrophotometer at 660 nm wave length after setting the instrument to zero with the blank prepared similarly but without the sediment.

2.2.5. Total Sulphur

Sulphur in the sediment extract was estimated turbidimetrically using a spectrophotometer. The standards of sulphur were prepared in series such as 2, 4, 6, 8 and 10 ppm working solution from stock solution. In this, 25ml of solution was added in the volumetric flask separately to each flask and 2.5 ml of conditioning reagent solution was also added followed by 5 ml of extraction solution was added. To this mixture, 0.2-0.3 gm of barium chloride was also added and shaken well and made-up to 25 ml with distilled water and the readings were taken at 340nm spectrophotometer.

The sample was analysed by taking 5g of marine sediment into a 100ml conical flask, to which, 25 ml of 0.15 % CaCl2 solution was added and shaken for 30 minutes. Then this was filtered through Whatman no. 42 filter paper and then 5 ml of sample aliquot was taken in a 25 volumetric flask, to which 2.5 ml of conditioning reagent and 0.2 to 0.3 g of barium chloride powder was added and made up to 25 ml distilled water and shaken well for 2 minutes and the absorbance was read in the same manner as standard solutions.

2.2.6. Heavy metals

Heavy metals are of concern especially as it relates to the environment are Cadmium (Cd), Lead (Pb), Chromium (Cr), Nickel (Ni), Cobalt (Co),Copper (Cu), Zinc (Zn), Manganese (Mn) etc. For the release of mineral elements from sediment and sediments, wet oxidation of samples are generally performed. Wet oxidation employs oxidizing acids (Tri / Di-acid mixtures).

Sediment sample will be weighed to 1.0 gm and taken in 100ml beaker covered with a watch glass and 12 ml of Aqua regia in (1: 3 HNO3 : HCl) will be added and the beaker will be kept in digestion for 3 hours at 100^0c on a hot plate using sand bath and the samples will be evaporated to near dryness and the samples will be kept cool for 5 mins and then 20 ml of 2% nitric acid will be added and kept for 15 minutes in hot plate for digestion and remove from hot plate and cooled and filtered using Whatman

No. 42 mm filter paper and then the final make up to 50 ml with 2 % nitric acid will be made. The extracted sample will be then aspirated to an AAS.

2.2.7. Petroleum Hydrocarbons

Sediment after refluxing with KOH-methanol mixture will be extracted with hexane. After removal of excess hexane, the residue will be subjected to clean-up procedure by silica gel column chromatography. The hydrocarbon content will be then estimated by measuring the fluorescence as per standard method.

2.3. Results on Physico-chemical characteristics of the sediment during Season 1

Sediment is an important characteristic in quantifying the concentration of pollutants in an environment and in fact in comparison to the water quality characteristics sediment characteristics reflects the long-term impact of the particular system. Pollutants get accumulated in the sediment matrix over long period of time according to their chemical persistence and the physico-chemical and biochemical characteristics of the substrata which help in drawing sources of contamination. Further, sediment matrix acts as a sink and sources of contaminants in aquatic systems, chemical analysis for characterization of sediments to provide environmentally significant information about natural and anthropogenic influence on the water bodies. In addition, sediment strata serve as an important habitat for the benthic invertebrates whose metabolic activities contribute to the productivity of the aquatic ecosystem. The above aspects add up to the value to sediments which indicates the ecological health of the marine environment and hence measuring such strata will help us in deriving to a conclusion on the overall environment. Hence, in the present project, the physico-chemical characteristics of the marine sediment collected from the study area was used to ascertain the nature of the marine environment of the coast.

2.3.1. pH (Hydrogen Ion)

pH values play a significant role in marine sediments, influencing various biogeochemical processes and ecosystem dynamics. These values are influenced by various factors, including the carbon, oxygen, nitrogen, phosphate, silicate, sulphur, iron, and manganese cycles. They are closely associated with processes such as heterotrophic respiration, chemoautotrophic activity, photosynthesis, precipitation, and the dissolution of calcium carbonate in marine water and sediments. In our investigation, we conducted measurements of average pH values at different locations. The offshore area exhibited an average pH of 7.84±0.02, the cargo jetty had an average pH of 7.51±0.06, and the Phang creek showed an average pH of 7.46±0.12. Among all the stations, the highest pH concentration of 7.86 was observed at 1B in the offshore, while the lowest pH concentration of 7.33 was recorded in the Phang Creek (refer to Tables 3-5).

2.3.2. Salinity

Salinity levels in marine water and sediment exhibit a wide range, typically spanning from 0 to 36 in most estuaries. Semi-enclosed bays can experience hyper-salinity conditions. The salinity of water is subject to fluctuations influenced by temperature changes, following diurnal and seasonal cycles that correspond to variations in atmospheric temperature. In our study conducted at Deendayal Port, we observed various salinity concentrations at different stations. The highest salinity concentration of 24.47 ppt was recorded at station Control 1 in the offshore region, while the lowest salinity concentration of 5.05 ppt was found at station 2D in the cargo jetty area. The mean ± standard deviation (SD) salinity values were determined to be 21.91±2.18 ppt, 5.98±0.89 ppt, and 17.69±4.81 ppt in the offshore, cargo jetty, and Phang creek, respectively. These findings are summarized in Tables 3-5, where all the data is presented.

2.3.3. Sediment Texture

The sediment texture plays a significant role in determining the physical and chemical properties of the marine sediment, influencing the distribution and abundance of benthic organisms. Understanding the sediment texture at different stations provides valuable insights into the habitat characteristics and ecological dynamics of the marine environment. At the offshore station, the average percentage composition of sand, silt, and clay was found to be 13.48%, 2.68%, and 15.63%, respectively. The cargo jetty station exhibited average percentages of 3.38% for sand, 3.09% for silt, and 1.18% for clay. Similarly, at the Phang creek station, the average percentages were 1.47% for sand, 3.34% for silt, and 4.40% for clay. These findings are summarized in Tables 3-5, which presents the data from all the stations.

2.3.4. Total organic Carbon

Organic carbon in marine sediments primarily originates from the decomposition of animals, plants, and anthropogenic sources such as chemical waste, fertilizers, and organic-rich waste. These sources contribute to the enrichment of the marine environment with organic material, which subsequently settles to the bottom sediments from the water column. This pathway leads to an increase in Total Organic Carbon (TOC) values and can have implications for the faunal communities inhabiting the sediments. In our study, during season three, we investigated the TOC concentrations at different stations. The mean ± standard deviation (SD) TOC percentages were determined to be 0.65±0.11% at the offshore station, 0.86±0.17% at the cargo jetty station, and 0.55±0.12% at the Phang creek station. The TOC concentrations at all stations are presented in Tables 3-5. Understanding the dynamics of organic carbon in marine sediments is vital for assessing the health and ecological integrity of marine environments. It helps in monitoring anthropogenic influences and their potential impacts on the marine ecosystem.

2.3.5. Organic matter

Organic matter serves as the primary reservoir of organic carbon in marine sediments, encompassing the chemical, physical, and biological degradation processes that contribute to the formation of organic material in the marine environment. It consists of a mixture of materials derived from various planktonic and benthic species, forming the ecological foundation for primary producers and consumers in the overlying surface sediment.

In our study conducted during the third season, we investigated the levels of organic matter in different locations. The organic matter percentages ranged from 0.88% to 1.34% in the offshore location, 0.93% to 1.70% at the cargo jetty, and 0.72% to 1.34% in the Phang creek area. These findings are summarized in the below tables (3-5), which illustrates the variation in organic matter content across the studied locations. Understanding the presence and dynamics of organic matter in marine sediments is crucial for assessing the overall health and ecological functioning of marine ecosystems. It provides insights into the cycling of carbon and nutrients, as well as the interactions between different species and trophic levels within the sediment community. Monitoring and studying organic matter in marine sediments helps to comprehend the intricate processes that shape marine environments and their associated biota.

2.3.6. Phosphorus and Sulphur

Phosphorus (P) is an essential nutrient for life and plays a crucial role in regulating primary productivity within marine systems. It serves as a key element in various biological processes. In marine sediments, phosphorus availability influences primary productivity, affecting the growth and development of marine organisms. Sulphur (S), on the other hand, is involved in dissimilatory sulfate reduction by microbial activity, which is a primary pathway for organic matter mineralization in anoxic sea beds. This process leads to the production of sulfide. Subsequently, chemical or microbial oxidation of the produced sulfide forms a complex network of pathways in the sulfur cycle, resulting in intermediate sulfur species and partial conversion back to sulfate.

In our study, we examined the concentrations of phosphorus and sulphur in marine sediments. The highest phosphorus concentration was found to be 46.72 mg/kg at station 1C in the offshore location, while the lowest concentration of 5.53 mg/kg was observed at station 2E in the cargo jetty station. Regarding sulphur, the highest concentration of 29.60 mg/kg was recorded at station 2D in the cargo jetty area, while the lowest concentration of 13.10 mg/kg was observed at station 3C in the Phang creek. The concentrations of phosphorus and sulphur at all stations are presented in Tables 3,4 and 5.

Understanding the levels of phosphorus and sulphur in marine sediments is crucial for comprehending nutrient dynamics and biogeochemical processes in marine ecosystems. These elements influence the availability of essential nutrients and can have implications for primary productivity and the overall functioning of marine ecosystems.

2.3.7. Petroleum hydrocarbon

Petroleum hydrocarbons (PHCs) are a major source of contamination in marine environments, primarily comprising compounds from three classes: alkanes, olefins, and aromatics. These hydrocarbons have low solubility in marine water and tend to adsorb onto particulate matter, leading to their long-term persistence in sediment bottoms. This persistence can have significant negative impacts on benthic aquatic communities within the marine ecosystem.

In our study, we measured the levels of PHCs in different locations. The range of PHC concentrations was found to be 0.98 to 4.31 µg/kg in the offshore area, 0.53 to 5.02 µg/kg at the cargo jetty, and 0.05 to 2.09 µg/kg in the Phang Creek. The highest concentration of PHCs with 5.02 µg/kg was observed at station 2A in the cargo jetty, while the lowest concentration with 0.05 µg/kg was found at station 3B in the Phang Creek.

The presence of petroleum hydrocarbons in marine environments is of great concern due to their potential harmful effects on marine organisms and ecosystems. These contaminants can bioaccumulate in organisms and disrupt their physiological processes, as well as cause long-lasting damage to the benthic communities. Continuous monitoring and mitigation efforts are necessary to prevent and minimize the negative impacts of petroleum hydrocarbon contamination in marine ecosystems.

2.3.8. Magnesium

The flux of dissolved magnesium from the overlying ocean into marine sediments is primarily driven by molecular diffusion. This process occurs as pore water magnesium is depleted during the formation of authigenic minerals within the sediment column. Additionally, direct burial of seawater occurs as sediment accumulates on the seafloor, contributing to the input of magnesium into the sediment. Its concentration in sediments can have implications for nutrient availability, sediment mineralogy, and the diverse organisms inhabiting the sediment environment.

In our study conducted during the third season at Deendayal Port, we determined the concentrations of magnesium at different stations. The average ± standard deviation

(SD) magnesium concentrations were found to be 1079.92±53.34 mg/kg at the offshore station, 1113.42±61.42 mg/kg at the cargo jetty, and 1114.92±36.60 mg/kg at the Phang Creek station. The highest concentration of magnesium with 1154 mg/kg was observed at station 3C in the Phang Creek, while the lowest concentration with 993.50 mg/kg was found at station 1D in the Offshore location.

Understanding the distribution and dynamics of magnesium in marine sediments provides valuable insights into the geochemical processes occurring within the sediment column and their impact on the marine ecosystem. Continuous monitoring of magnesium levels is crucial for assessing the health and ecological integrity of marine environments.

2.3.9. Heavy metals

The study examined the presence of heavy metals in sediment samples collected from various stations at Deendayal Port. The concentrations of heavy metals including nickel (Ni), lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), and cobalt (Co) were determined. Lead, cadmium, chromium, and copper were not detected (below detectable limits, BDL) at all three stations. The highest concentration of nickel was found to be 71.30 mg/kg at station 2E in the cargo jetty area, while the lowest concentration was observed at station 3E in Phang creek, measuring 44.05 mg/kg. Among the three stations, Phang creek recorded the highest concentration of zinc, with 57.50 mg/kg at Control 3, while the lowest concentration was found at station 3D, measuring 32.85 mg/kg. For manganese, the offshore station had the highest average concentration of 1074.17 mg/kg, while Phang creek had the lowest mean concentration of 405.78 mg/kg. The highest concentration of cobalt, 15.18 mg/kg, was observed at the offshore station, whereas the lowest concentration of 7.51 mg/kg was found in Phang creek. The data is presented in Tables 3-5.

Table 3: Physico-chemical characteristics of sediment samples collected from Offshore location

S. No	Parameters	1A	1B	1C	1D	1E	Control 1
1	pH (1: 10 suspension)	7.83	7.86	7.85	7.81	7.85	7.82
2	Salinity	20.11	19.77	24.21	22.81	20.11	24.47
3	Petroleum Hydrocarbon	3.14	0.98	1.36	4.31	1.68	1.44
4	Magnesium	1130.0	1142.5	1079.5	993.5	1066.5	1067.5
5	Sand (%)	55.6	37.7	26.6	35.3	20.3	20.0
	Silt (%)	25.6	21.4	22.0	18.3	19.6	18.9
	Clay (%)	18.8	40.9	51.4	46.4	60.1	61.1
6	Organic matter (%)	1.08	0.93	1.20	1.18	0.88	1.34
7	Total organic carbon	0.63	0.54	0.75	0.69	0.51	0.78
8	Phosphorus	31.14	42.21	46.72	41.80	27.86	31.14
9	Sulphur	27.21	25.35	26.75	23.46	22.92	23.39
10	Nickel	66.75	59.85	67.20	65.30	63.55	67.95
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	BDL	BDL	BDL	BDL	BDL	BDL
13	Chromium	BDL	BDL	BDL	BDL	BDL	BDL
14	Zinc	54.05	52.25	49.70	56.80	46.10	53.45
15	Copper	BDL	BDL	BDL	BDL	BDL	BDL
16	Manganese	1335.00	903.00	1200.50	864.00	1194.00	948.50
17	Cobalt	15.90	12.55	15.95	16.05	16.15	14.50

Table 4: Physico-chemical characteristics of sediment samples collected from Cargo jetty

S. No	Parameters	2A	2B	2C	2D	2E	Control 2
1	pH (1: 10 suspension)	7.61	7.52	7.52	7.49	7.46	7.44
2	Salinity	6.09	5.57	6.18	5.05	7.57	5.39
3	Petroleum Hydrocarbon	5.02	0.53	2.03	1.32	4.97	1.70
4	Magnesium	1159.0	1105.0	1169.0	1090.5	1005.5	1151.5
5	Sand (%)	26.7	26.6	20.1	20.0	19.4	21.5
	Silt (%)	23.3	25.1	30.4	28.7	31.3	27.2
	Clay (%)	50.0	48.3	49.5	51.3	49.3	51.3
6	Organic matter (%)	1.44	1.55	0.93	1.65	1.60	1.70
7	Total organic carbon	0.84	0.9	0.54	0.96	0.93	0.99
8	Phosphorus	31.96	21.92	18.85	24.38	5.53	21.92
9	Sulphur	27.96	25.19	24.33	29.60	21.94	21.32
10	Nickel	BDL	59.25	65.20	57.15	71.30	60.35
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	BDL	BDL	BDL	BDL	BDL	BDL
13	Chromium	BDL	BDL	BDL	BDL	BDL	BDL
14	Zinc	54.10	50.40	55.70	46.30	54.80	48.15
15	Copper	BDL	BDL	BDL	BDL	BDL	BDL
16	Manganese	950.50	444.40	535.00	633.00	1028.00	457.85
17	Cobalt	16.95	16.35	15.45	9.60	15.25	12.60

Table 5: Physico-chemical characteristics of sediment samples collected from Phang creek

S. No	Parameters	3A	3B	3C	3D	3E	Control 3
1	pH (1: 10 suspension)	7.56	7.58	7.43	7.55	7.33	7.33
2	Salinity	17.94	15.67	15.50	10.80	22.64	23.60
3	Petroleum Hydrocarbon	0.17	0.05	0.23	0.37	2.09	0.10
4	Magnesium	1075.5	1064.0	1154.0	1122.0	1137.0	1137.0
5	Sand (%)	9.2	9.4	7.8	6.8	6.4	5.9
	Silt (%)	20.3	19.8	16.0	12.1	19.5	14.6
	Clay (%)	70.5	70.8	76.2	81.1	74.1	79.5
6	Organic matter (%)	0.93	1.34	0.93	0.83	0.72	0.88
7	Total organic carbon	0.54	0.78	0.54	0.48	0.42	0.51
8	Phosphorus	25.20	27.25	21.72	11.27	28.68	18.64
9	Sulphur	14.03	13.28	13.10	14.93	15.91	17.07
10	Nickel	45.65	55.75	46.45	50.95	44.05	49.60
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	BDL	BDL	BDL	BDL	BDL	BDL
13	Chromium	BDL	BDL	BDL	BDL	BDL	BDL
14	Zinc	35.10	37.90	37.90	32.85	39.40	57.50
15	Copper	BDL	BDL	BDL	BDL	BDL	BDL
16	Manganese	380.00	378.20	378.20	378.25	649.00	271.00
17	Cobalt	7.30	11.80	3.90	8.00	7.00	7.05

2.4. Physico-chemical characteristics of the sediment samples during Season 2

2.4.1. pH (Hydrogen Ion)

pH values play a significant role in marine sediments, influencing various biogeochemical processes and ecosystem dynamics. These values are influenced by various factors, including the carbon, oxygen, nitrogen, phosphate, silicate, sulphur, iron, and manganese cycles. They are closely associated with processes such as heterotrophic respiration, chemoautotrophic activity, photosynthesis, precipitation, and the dissolution of calcium carbonate in marine water and sediments. In our investigation, we conducted measurements of average pH values at different locations. The offshore area exhibited an average pH of 7.56±0.26, the cargo jetty had an average pH of 8.02±0.12, and the Phang Creek showed an average pH of 7.71±0.01. Among all the stations, the highest pH concentration of 8.15 was observed at 2A Cargo jetty, while the lowest pH concentration of 7.33 was recorded in 1A Offshore (refer to Tables 6-8).

2.4.2. Salinity

Salinity levels in marine water and sediment exhibit a wide range, typically spanning from 0 to 36 in most estuaries. Semi-enclosed bays can experience hyper-salinity conditions. The salinity of water is subject to fluctuations influenced by temperature changes, following diurnal and seasonal cycles that correspond to variations in atmospheric temperature. In our study, we observed various salinity concentrations at different stations. The highest salinity concentration of 31.41 ppt was recorded at station 2D in the cargo jetty area, while the lowest salinity concentration of 10.26 ppt was found at station 3C in the Phang creek area. The mean ± standard deviation (SD) salinity values were determined to be 20.23±3.05 ppt, 24.94±3.35 ppt, and 13.80±3.70 ppt in the offshore, cargo jetty, and Phang creek, respectively. These findings are summarized in Tables 6-8, where all the data is presented.

2.4.3. Sediment Texture

The sediment texture plays a significant role in determining the physical and chemical properties of the marine sediment, influencing the distribution and abundance of benthic organisms. Understanding the sediment texture at different stations provides valuable insights into the habitat characteristics and ecological dynamics of the marine environment. At the offshore station, the average percentage composition of sand, silt, and clay was found to be 17.72%, 8.47%, and 73.82%, respectively. The cargo jetty station exhibited average percentages of 77.68% for sand, 19.53% for silt, and 2.78%

for clay. Similarly, at the Phang creek station, the average percentages were 17.12% for sand, 6.42% for silt, and 76.47% for clay. These findings are summarized in Tables 6-8, which presents the data from all the stations.\

2.4.4. Total organic Carbon

Organic carbon in marine sediments primarily originates from the decomposition of animals, plants, and anthropogenic sources such as chemical waste, fertilizers, and organic-rich waste. These sources contribute to the enrichment of the marine environment with organic material, which subsequently settles to the bottom sediments from the water column. This pathway leads to an increase in Total Organic Carbon (TOC) values and can have implications for the faunal communities inhabiting the sediments. In our study, during season three, we investigated the TOC concentrations at different stations. The mean ± standard deviation (SD) TOC percentages were determined to be 0.45±0.06% at the offshore station, 0.19±0.04% at the cargo jetty station, and 0.44±0.12% at the Phang creek station. The TOC concentrations at all stations are presented in Tables 6-8. Understanding the dynamics of organic carbon in marine sediments is vital for assessing the health and ecological integrity of marine environments. It helps in monitoring anthropogenic influences and their potential impacts on the marine ecosystem.

2.4.5. Organic matter

Organic matter serves as the primary reservoir of organic carbon in marine sediments, encompassing the chemical, physical, and biological degradation processes that contribute to the formation of organic material in the marine environment. It consists of a mixture of materials derived from various planktonic and benthic species, forming the ecological foundation for primary producers and consumers in the overlying surface sediment.

In our study conducted during the third season, we investigated the levels of organic matter in different locations. The organic matter percentages ranged from 0.62% to 0.82% in the offshore location, 0.25% to 0.41% at the cargo jetty, and 0.56% to 1.08% in the Phang creek area. These findings are summarized in the below tables (6-8), which illustrates the variation in organic matter content across the studied locations.

Understanding the presence and dynamics of organic matter in marine sediments is crucial for assessing the overall health and ecological functioning of marine ecosystems. It provides insights into the cycling of carbon and nutrients, as well as the interactions between different species and trophic levels within the sediment community. Monitoring and studying organic matter in marine sediments helps to comprehend the intricate processes that shape marine environments and their associated biota.

2.4.6. Phosphorus and Sulphur

Phosphorus (P) is an essential nutrient for life and plays a crucial role in regulating primary productivity within marine systems. It serves as a key element in various biological processes. In marine sediments, phosphorus availability influences primary productivity, affecting the growth and development of marine organisms. Sulphur (S), on the other hand, is involved in dissimilatory sulfate reduction by microbial activity, which is a primary pathway for organic matter mineralization in anoxic sea beds. This process leads to the production of sulfide. Subsequently, chemical or microbial oxidation of the produced sulfide forms a complex network of pathways in the sulfur cycle, resulting in intermediate sulfur species and partial conversion back to sulfate.

In our study, we examined the concentrations of phosphorus and sulphur in marine sediments. The highest phosphorus concentration was found to be 61.64 mg/kg at station 1B in the offshore location, while the lowest concentration of 15.56 mg/kg was observed at station 3B in the Phang creek station. Regarding sulphur, the highest concentration of 23.80 mg/kg was recorded at station 1A in the offshore location area, while the lowest concentration of 10.07 mg/kg was observed at station 2C in cargo jetty. The concentrations of phosphorus and sulphur at all stations are presented in Tables 6,7 and 8.

Understanding the levels of phosphorus and sulphur in marine sediments is crucial for comprehending nutrient dynamics and biogeochemical processes in marine ecosystems. These elements influence the availability of essential nutrients and can have implications for primary productivity and the overall functioning of marine ecosystems.

2.4.7. Petroleum hydrocarbon

Petroleum hydrocarbons (PHCs) are a major source of contamination in marine environments, primarily comprising compounds from three classes: alkanes, olefins, and aromatics. These hydrocarbons have low solubility in marine water and tend to adsorb onto particulate matter, leading to their long-term persistence in sediment bottoms. This persistence can have significant negative impacts on benthic aquatic communities within the marine ecosystem.

In our study, we measured the levels of PHCs in different locations. The range of PHC concentrations was found to be 29.12 to 37.42 µg/kg in the offshore area, 27.68 to 48.93 µg/kg at the cargo jetty, and 11.78 to 30.91 µg/kg in the Phang Creek. The highest concentration of PHCs with 48.93 µg/kg was observed at station 2C in the Cargo Jetty, while the lowest concentration with 11.78 µg/kg was found at station 3B in the Phang Creek.

The presence of petroleum hydrocarbons in marine environments is of great concern due to their potential harmful effects on marine organisms and ecosystems. These contaminants can bioaccumulate in organisms and disrupt their physiological processes, as well as cause long-lasting damage to the benthic communities. Continuous monitoring and mitigation efforts are necessary to prevent and minimize the negative impacts of petroleum hydrocarbon contamination in marine ecosystems.

2.4.8. Magnesium

The flux of dissolved magnesium from the overlying ocean into marine sediments is primarily driven by molecular diffusion. This process occurs as pore water magnesium is depleted during the formation of authigenic minerals within the sediment column. Additionally, direct burial of seawater occurs as sediment accumulates on the seafloor, contributing to the input of magnesium into the sediment. Its concentration in sediments can have implications for nutrient availability, sediment mineralogy, and the diverse organisms inhabiting the sediment environment.

In our study conducted during the third season at Deendayal Port, we determined the concentrations of magnesium at different stations. The average ± standard deviation

(SD) magnesium concentrations were found to be 2986.17±355.74 mg/kg at the offshore station, 2250.67±268.30 mg/kg at the cargo jetty, and 3167.50±391.29 mg/kg at the Phang Creek station. The highest concentration of magnesium 3724.50 mg/kg was observed at station 3B in the Phang Creek, while the lowest concentration with 1901.00 mg/kg was found at station 2B in the Cargo jetty.

Understanding the distribution and dynamics of magnesium in marine sediments provides valuable insights into the geochemical processes occurring within the sediment column and their impact on the marine ecosystem. Continuous monitoring of magnesium levels is crucial for assessing the health and ecological integrity of marine environments.

2.4.9. Heavy metals

The study examined the presence of heavy metals in sediment samples collected from various stations at different locations at Deendayal Port. The concentrations of heavy metals including nickel (Ni), lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), and cobalt (Co) were determined. Lead, chromium, copper and cobalt were not detected (Below Detection Limit) at all three stations. Among three stations, Nickel was not detected in the Cargo jetty station. The highest concentration of nickel was found to be 19.00 mg/kg at station 1B in Offshore station, while the lowest concentration was observed at station 3E in Phang creek, measuring 2.20 mg/kg. Among the three stations, 1D station in offshore region recorded the highest concentration of zinc, with 46.50 mg/kg at, while the lowest concentration was found at station 2A of Cargo jetty, measuring 7.50 mg/kg. For manganese, the 1B in offshore station had the highest average concentration of 667.30 mg/kg, while Control 2 in Cargo jetty recorded the lowest mean concentration of 56.20 mg/kg. The highest concentration of cadmium,0.13 mg/kg, was observed in Control 1 at the offshore station, whereas the lowest concentration of 0.05 mg/kg was found at station 3E in Phang creek. The data is presented in Tables 6-8.

Table 6: Physico-chemical characteristics of sediment samples collected from Offshore location

S. No	Parameters	1A	1B	1C	1D	1E	Control 1
1	pH (1: 10 suspension)	7.33	7.55	7.48	7.47	8.08	7.47
2	Salinity	17.89	18.86	20.96	16.84	21.58	25.26
3	Petroleum Hydrocarbon	29.12	29.12	29.41	35.89	33.86	37.42
4	Magnesium	3211.0	2956.0	3211.5	2291.5	3195.0	3052.0
5	Sand (%)	12.8	16.5	16.7	23.9	19.7	16.7
	Silt (%)	7.1	9.4	8.7	7.3	9.1	9.2
	Clay (%)	80.1	74.1	74.6	68.8	71.2	74.1
6	Organic matter (%)	0.72	0.81	0.72	0.82	0.82	0.62
7	Total organic carbon	0.42	0.51	0.42	0.48	0.48	0.36
8	Phosphorus	35.36	61.64	38.39	37.79	39.20	31.12
9	Sulphur	23.80	21.05	22.83	21.90	20.94	21.28
10	Nickel	11.40	19.00	10.35	8.00	12.70	4.05
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	BDL	0.25	0.20	0.25	BDL	0.30
13	Chromium	BDL	BDL	BDL	BDL	BDL	BDL
14	Zinc	41.00	45.95	41.35	46.50	45.15	36.10
15	Copper	BDL	BDL	BDL	BDL	BDL	BDL
16	Manganese	335.90	667.30	508.30	345.60	372.15	545.30
17	Cobalt	BDL	BDL	BDL	BDL	BDL	BDL

Table 7: Physico-chemical characteristics of sediment samples collected from Cargo jetty

S. No	Parameters	2A	2B	2C	2D	2E	Control 2
1	pH (1: 10 suspension)	8.15	8.01	7.8	8.03	8.08	8.03
2	Salinity	23.07	25.09	24.82	31.41	22.37	22.89
3	Petroleum Hydrocarbon	37.29	44.70	48.93	36.74	27.96	27.68
4	Magnesium	2312.5	1901.0	2512.5	2500.5	1941.5	2336.0
5	Sand (%)	81.6	74.8	64.6	76.5	86.5	82.1
	Silt (%)	15.2	19.6	32.0	21.6	12.1	16.7
	Clay (%)	3.2	5.6	3.4	1.9	1.4	1.2
6	Organic matter (%)	0.31	0.25	0.31	0.41	0.36	0.25
7	Total organic carbon	0.18	0.15	0.18	0.24	0.21	0.15
8	Phosphorus	27.48	29.70	22.43	24.85	35.56	20.21
9	Sulphur	12.16	11.71	10.07	12.84	14.34	11.40
10	Nickel	BDL	BDL	BDL	BDL	BDL	BDL
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	0.20	BDL	BDL	0.20	BDL	0.15
13	Chromium	BDL	BDL	BDL	BDL	BDL	BDL
14	Zinc	7.50	BDL	BDL	BDL	BDL	BDL
15	Copper	BDL	BDL	BDL	BDL	BDL	BDL
16	Manganese	102.70	96.80	144.60	64.50	113.60	56.20
17	Cobalt	BDL	BDL	BDL	BDL	BDL	BDL

Table 8: Physico-chemical characteristics of sediment samples collected from Phang creek

S. No	Parameters	3A	3B	3C	3D	3E	Control 3
1	pH (1: 10 suspension)	7.71	7.72	7.71	7.72	7.71	7.69
2	Salinity	13.33	20.79	10.26	12.37	11.66	14.38
3	Petroleum Hydrocarbon	30.91	11.78	21.17	19.59	27.62	17.73
4	Magnesium	3350.5	3724.5	3395.0	2950.0	2648.5	2936.5
5	Sand (%)	12.4	7.1	13.8	12.0	27.8	29.6
	Silt (%)	5.6	3.7	5.5	4.0	10.2	9.5
	Clay (%)	82.0	89.2	80.7	84.0	62.0	60.9
6	Organic matter (%)	0.77	0.56	0.56	0.67	0.87	1.08
7	Total organic carbon	0.45	0.33	0.33	0.39	0.51	0.63
8	Phosphorus	23.84	15.56	16.37	18.18	24.65	19.80
9	Sulphur	17.38	17.41	19.67	20.24	20.38	20.66
10	Nickel	BDL	BDL	BDL	BDL	2.20	BDL
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	0.20	BDL	0.10	BDL	0.05	0.20
13	Chromium	BDL	BDL	BDL	BDL	BDL	BDL
14	Zinc	29.60	31.90	22.70	21.15	37.60	30.70
15	Copper	BDL	BDL	BDL	BDL	BDL	BDL
16	Manganese	310.95	296.50	287.40	167.95	232.25	223.95
17	Cobalt	BDL	BDL	BDL	BDL	BDL	BDL

2.5. Physico-chemical characteristics of the sediment characteristics during Season 3

2.5.1. pH (Hydrogen Ion)

When any characteristics study of water or sediment is concerned, pH is considered to be one of the major variable especially in marine sediments as it influences various biogeochemical processes and ecosystem dynamics. These values are influenced by various factors, including the carbon, oxygen, nitrogen, phosphate, silicate, sulphur, iron, and manganese cycles. They are closely associated with processes such as heterotrophic respiration, chemoautotrophic activity, photosynthesis, precipitation, and the dissolution of calcium carbonate in marine water and sediments. In our investigation, we conducted measurements of average pH values at different locations. The offshore area exhibited an average pH of 7.67±0.14, the cargo jetty had an average pH of 7.732±0.15, and the Phang Creek showed an average pH of 7.67±0.12. The data on individual values at all the locations and stations are given in Table 9-11.

2.5.2. Salinity

The salinity of water is subject to fluctuations influenced by temperature changes, following diurnal and seasonal cycles that correspond to variations in atmospheric temperature. Salinity levels in marine water and sediment exhibit a wide range, typically spanning from 0 to 36 in most estuaries. Semi-enclosed bays can experience hyper-salinity conditions. In the present study, it was observed that a broader range of salinity concentrations at different stations. The highest salinity concentration of 32.35 ppt was recorded at station 2A in the cargo jetty area, while the lowest salinity concentration of 7.44 ppt was found at station 1A in the Offshore area. The mean ± standard deviation (SD) salinity values were determined to be 16.62±4.72 ppt, 21.55±8.46 ppt, and 20.01±1.38 ppt in the offshore, cargo jetty, and Phang creek, respectively. These findings are summarized in Tables 9-11, where all the data is presented.

2.5.3. Sediment Texture

Understanding the sediment texture at different stations provides valuable insights into the habitat characteristics and ecological dynamics of the marine environment. The sediment texture plays a significant role in determining the physical and chemical properties of the marine sediment, influencing the distribution and abundance of benthic organisms At the offshore station, the average percentage composition of sand, silt, and clay was found to be 29.32%, 13.53%, and 57.15%, respectively. The cargo jetty station exhibited average percentages of 23.20% for sand, 22.48% for silt, and 54.32% for clay. In contrary to the previous season, the textural composition was different in Cargo jetty. Similarly, at the Phang creek station, the average percentages were 15.48% for sand, 10.62% for silt, and 73.90% for clay. These findings are summarized in Tables 9-11, which presents the data from all the stations.

2.5.4. Total organic Carbon

Total Organic carbon in sediments primarily originates from the decomposition of animals, plants, and anthropogenic sources such as chemical waste, fertilizers, and organic-rich waste. These sources contribute to the enrichment of the marine environment with organic material, which subsequently settles to the bottom sediments from the water column. This pathway leads to an increase in Total Organic Carbon (TOC) values and can have implications for the faunal communities inhabiting the sediments. In our study, during season three, it was investigated the TOC concentrations at different stations. The mean ± standard deviation (SD) TOC percentages were determined to be 0.28±0.09% at the offshore station, 0.43±0.04% at the cargo jetty station, and 0.38±0.11% at the Phang creek station. The TOC concentrations at all stations are presented in Tables 9-11. Understanding the dynamics of organic carbon in marine sediments is vital for assessing the health and ecological integrity of marine environments. It helps in monitoring anthropogenic influences and their potential impacts on the marine ecosystem.

2.5.5. Organic matter

Organic matter serves as the primary reservoir of organic carbon in marine sediments, encompassing the chemical, physical, and biological degradation processes that contribute to the formation of organic material in the marine environment. It consists of a mixture of materials derived from various planktonic and benthic species, forming the ecological foundation for primary producers and consumers in the overlying surface sediment.

In our study conducted during the third season, we investigated the levels of organic matter in different locations. The organic matter percentages ranged from 0.31% to 0.72% in the offshore location, 0.62% to 0.83% at the cargo jetty, and 0.46% to 0.88% in the Phang creek area. In all the three locations, the minimum concentration of Organic matter recorded in the previous season was lower when compared to the present season and the findings are summarized in the below tables (9-11), which illustrates the variation in organic matter content across the studied locations. Understanding the presence and dynamics of organic matter in marine sediments is crucial for assessing the overall health and ecological functioning of marine ecosystems. It provides insights into the cycling of carbon and nutrients, as well as the interactions between different species and trophic levels within the sediment community. Monitoring and studying organic matter in marine sediments helps to comprehend the intricate processes that shape marine environments and their associated biota.

2.5.6. Phosphorus and Sulphur

Sulphur (S) is involved in dissimilatory sulfate reduction by microbial activity, which is a primary pathway for organic matter mineralization in anoxic sea beds. This process leads to the production of sulfide. Subsequently, chemical or microbial oxidation of the produced sulfide forms a complex network of pathways in the sulfur cycle, resulting in intermediate sulfur species and partial conversion back to sulfate. On the other hand, Phosphorus (P) is an essential nutrient for life and plays a crucial role in regulating primary productivity within marine systems. It serves as a key element in various biological processes. In marine sediments, phosphorus availability influences primary productivity, affecting the growth and development of marine organisms.

In the present study, the highest concentration of sulphur was recorded as 42.82 mg/kg was recorded at station 3B in the Phang creek location, while the lowest concentration of 20.26 mg/kg was observed at station 1B (Offshore location). The concentrations of phosphorus and sulphur at all stations are presented in Tables 9, 10, 11. Similarly, the highest phosphorus concentration was found to be 43.31 mg/kg at two locations such as 1E (Offshore) and 2C (Cargo jetty), while the lowest concentration of 15.39 mg/kg was observed at station 3E (Phang creek). Further, understanding the levels of phosphorus and sulphur in marine sediments is crucial for comprehending nutrient dynamics and biogeochemical processes in marine ecosystems. These elements influence the availability of essential nutrients and can have implications for primary productivity and the overall functioning of marine ecosystems.

2.5.7. Petroleum hydrocarbon

Petroleum hydrocarbons in general have low solubility in marine water and tend to adsorb onto particulate matter, leading to their long-term persistence in sediment bottoms. This persistence can have significant negative impacts on benthic aquatic communities within the marine ecosystem. PHCs are a major source of contamination in marine environments, primarily comprising compounds from three classes: alkanes, olefins, and aromatics. In the present study, the levels of PHCs in different locations were measure. The range of PHC concentrations was found to be 0.74 – 3.45 µg/kg in the offshore area, 1.95 – 4.00 µg/kg at the cargo jetty and 0.02 – 0.80 µg/kg in the Phang Creek. The highest concentration of PHCs with 4.00 µg/kg was observed at station 2D (Cargo Jetty), while the lowest concentration with 0.02 µg/kg was found at station 3B (Phang Creek). The presence of petroleum hydrocarbons in marine environments is of great concern due to their potential harmful effects on marine organisms and ecosystems. These contaminants can bioaccumulate in organisms and disrupt their physiological processes, as well as cause long-lasting damage to the benthic communities. Continuous monitoring and mitigation efforts are necessary to prevent and minimize the negative impacts of petroleum hydrocarbon contamination in marine ecosystems.

2.5.8. Magnesium

Understanding the distribution and dynamics of magnesium in marine sediments provides valuable insights into the geochemical processes occurring within the sediment column and their impact on the marine ecosystem. Continuous monitoring of magnesium levels is crucial for assessing the health and ecological integrity of marine environments. Dissolved magnesium flux from the overlying ocean into marine sediments is primarily driven by molecular diffusion. This process occurs as pore water magnesium is depleted during the formation of authigenic minerals within the sediment column. Additionally, direct burial of seawater occurs as sediment accumulates on the seafloor, contributing to the input of magnesium into the sediment.

Its concentration in sediments can have implications for nutrient availability, sediment mineralogy, and the diverse organisms inhabiting the sediment environment.

In our study conducted during the third season at Deendayal Port, we determined the concentrations of magnesium at different stations. The average ± standard deviation (SD) magnesium concentrations were found to be 2388.75±430.08 mg/kg at the offshore station, 2504.33±771.10 mg/kg at the cargo jetty, and 2479.50±703.17 mg/kg at the Phang Creek station. The highest concentration of magnesium 3577.5 mg/kg was observed at station 3B (Phang Creek), while the lowest concentration with 1201 mg/kg was found at station 2E (Control) in the Cargo jetty.

2.5.9. Heavy metals

In the present study, the sediment samples were examined for the presence of heavy metals from the samples collected from various stations at different locations at Deendayal Port. The concentrations of heavy metals including Lead and Cadmium was not detected in Cargo jetty samples and the metal Lead and Zinc was Below Detection Limit in Phang creek samples. The highest concentration of nickel was found to be 55.15 mg/kg at station 2D (Cargo Jetty), while the lowest concentration of Nickel was observed at station 1A (Offshore) measuring 0.85 mg/kg. Among the three stations, Control station in offshore region recorded the highest concentration of zinc, with 28.85 mg/kg at, whereas all the stations in all the three locations registered the below detection limit of Zinc. In case of Manganese, the 2D in Cargo jetty had the highest concentration of 811.50 mg/kg, while Control 2 in Cargo jetty recorded the lowest mean concentration of 186.35 mg/kg. The highest concentration of cadmium of 6.10 mg/kg was observed in 3A (Phang creek) station, whereas the lowest concentration of 1.00 mg/kg was found at station 1E (Offshore location). The data is presented in Tables 9-11.

Table 9: Physico-chemical characteristics of sediment samples collected from Offshore location

S. No	Parameters	1A	1B	1C	1D	1E	Control 1
1	pH (1: 10 suspension)	7.70	7.44	7.63	7.73	7.85	7.69
2	Salinity	13.82	14.33	13.73	12.62	21.54	23.69
3	Petroleum Hydrocarbon	2.89	3.26	2.89	3.45	2.91	0.74
4	Magnesium	2701.5	2664.5	1903	2786	1798	2479.5
5	Sand (%)	8.3	13.7	16.6	69.0	52.6	15.7
	Silt (%)	2.4	2.9	4.0	26.2	15.6	30.1
	Clay (%)	89.3	83.4	79.4	4.8	31.8	54.2
6	Organic matter (%)	0.41	0.46	0.36	0.31	0.57	0.72
7	Total organic carbon	0.24	0.27	0.21	0.18	0.33	0.42
8	Phosphorus	18.68	17.45	17.86	19.29	43.31	41.26
9	Sulphur	27.41	20.26	22.38	22.47	23.52	37.17
10	Nickel	0.85	BDL	8.75	BDL	38.3	50.65
11	Lead	BDL	BDL	BDL	BDL	BDL	2.8
12	Cadmium	BDL	BDL	BDL	1.35	1.0	BDL
13	Chromium	28.1	22.6	38.6	19.8	69	71.4
14	Zinc	BDL	BDL	BDL	BDL	BDL	28.85
15	Copper	BDL	BDL	4.5	BDL	20.25	25.2
16	Manganese	717.5	510	647	344.1	807	787.5
17	Cobalt	BDL	BDL	BDL	BDL	15.45	6.6

Table 10: Physico-chemical characteristics of sediment samples collected from Cargo jetty

S. No	Parameters	2A	2B	2C	2D	2E	Control 2
1	pH (1: 10 suspension)	7.77	7.54	7.53	7.85	7.84	7.84
2	Salinity	32.35	27.46	22.23	18.36	21.37	7.55
3	Petroleum Hydrocarbon	3.40	1.99	3.06	4.00	2.47	1.95
4	Magnesium	3092	3350.5	2224.5	2330.5	2827.5	1201
5	Sand (%)	9.9	15.5	14.6	12.7	15.5	71.0
	Silt (%)	34.5	7.9	24.2	23.4	25.4	19.5
	Clay (%)	55.6	76.6	61.2	63.9	59.1	9.5
6	Organic matter (%)	0.72	0.77	0.77	0.62	0.72	0.83
7	Total organic carbon	0.42	0.45	0.45	0.36	0.42	0.48
8	Phosphorus	19.70	27.71	43.31	42.49	37.77	17.24
9	Sulphur	37.97	39.58	35.70	36.79	40.64	32.73
10	Nickel	30.95	42.35	39.35	55.15	54.7	BDL
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	BDL	BDL	BDL	BDL	BDL	BDL
13	Chromium	73.15	100.55	85.35	206.7	357.7	16.25
14	Zinc	BDL	BDL	BDL	BDL	BDL	BDL
15	Copper	12.55	19.3	20.3	31.25	69.2	BDL
16	Manganese	772.5	734	796	811.5	768.5	186.35
17	Cobalt	BDL	6.15	BDL	4.2	BDL	BDL

Table 11: Physico-chemical characteristics of sediment samples collected from Phang creek

S. No	Parameters	3A	3B	3C	3D	3E	Control 3
1	pH (1: 10 suspension)	7.63	7.88	7.64	7.68	7.51	7.68
2	Salinity	20.00	17.42	21.45	20.77	20.08	20.34
3	Petroleum Hydrocarbon	0.14	0.02	0.28	0.52	0.80	0.38
4	Magnesium	2304.5	3577.5	2394.5	2415	2773	1412.5
5	Sand (%)	14.8	14.6	7.9	22.4	12.4	20.8
	Silt (%)	6.6	15.8	14.3	10.9	6.3	9.8
	Clay (%)	78.6	69.6	77.8	66.7	81.3	69.4
6	Organic matter (%)	0.62	0.46	0.52	0.88	0.52	0.88
7	Total organic carbon	0.36	0.27	0.3	0.51	0.3	0.51
8	Phosphorus	22.99	20.11	18.06	29.76	15.39	21.55
9	Sulphur	40.82	42.82	38.61	39.29	39.55	34.32
10	Nickel	20.15	1.3	27.2	18.95	5.25	2.55
11	Lead	BDL	BDL	BDL	BDL	BDL	BDL
12	Cadmium	6.1	BDL	BDL	BDL	BDL	BDL
13	Chromium	51.65	45.9	203.75	49.3	36.3	46.1
14	Zinc	BDL	BDL	BDL	BDL	BDL	BDL
15	Copper	8.95	7.3	31.9	11.15	1.65	6.25
16	Manganese	689.5	348.35	738.5	615	696.5	505
17	Cobalt	BDL	BDL	BDL	0.25	BDL	BDL

Table 12: Comparison of the physico-chemical characteristics of the sediment samples of the present study (2022-23) with the previous year data

Parameters	Period of study (in year)								
	2020-2021			2021-2022			2022-2023		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
pH (1: 10 suspension)	7.85	7.78	8.1	8.52	8.77	8.67	7.60	7.76	7.69
Salinity (ppt)	15.70	21.24	10.67	17.58	22.63	21.28	15.19	19.66	19.40
Petroleum Hydrocarbons (µg/kg)	3.24	3.57	1.50	25.55	20.01	20.87	1.74	30.38	1.95
Magnesium (mg/kg)	369.79	488.93	302.24	565.89	459.08	493.16	1102.75	2801.44	2457.53
Sand (%)	32.81	16.58	59.52	61.90	39.23	15.48	20.85	37.51	22.67
Silt (%)	19.43	21.98	19.27	15.46	27.35	15.88	21.89	11.47	15.54
Clay (%)	47.74	61.42	21.22	22.64	33.42	68.63	57.25	51.02	61.79
Total organic carbon (%)	0.35	0.35	0.27	0.95	0.86	0.70	0.66	0.36	0.36
Phosphorus (mg/Kg)	19.68	16.45	12.04	27.28	31.13	19.93	26.56	29.01	26.33
Sulphur (mg/Kg)	18.63	18.42	13.61	69.57	66.10	62.06	21.54	17.78	34.00
Nickel (mg/Kg)	26.02	24.94	21.88	45.84	64.53	48.18	58.83	6.56	27.23
Lead (mg/Kg)	17.95	20.53	50.07	3.58	10.38	8.82	BDL	BDL	2.80
Cadmium (mg/Kg)	1.50	0.911	BDL	0.79	1.08	1.27	BDL	0.19	3.64
Chromium (mg/Kg)	14.28	13.16	29.5	BDL	BDL	BDL	BDL	BDL	84.57
Zinc (mg/Kg)	73.00	74.75	83.59	35.90	51.98	33.45	47.91	26.37	28.85
Copper (mg/Kg)	9.46	14.41	23.7	BDL	BDL	BDL	BDL	BDL	19.46
Cobalt (mg/Kg)	12.05	8.77	19.93	16.25	23.10	19.28	12.35	BDL	5.49

Note: BDL denotes Below Detection Limit.

When the past three years of data is concerned, *i.e.*, 2020-21, 2021-22 and 2022-23, the consolidated mean values of the sediment quality are shown in Table 12. Among the parameters studied, parameters such as pH, Salinity, Petroleum Hydrocarbon, Total organic carbon, Sulphur, Lead and Cobalt showed a decreasing trend in the current year (2022-23) when compared to the previous years (2020-21 and 2021-22).

Chapter 3 Sediment Quality (Sub-tidal Fauna)

3.1. Introduction

The word Benthos comes from the ancient Greek language (βένθος (bénthos) meaning 'the depths (of the sea)'), also called benthon. It is the community of organisms which are mostly live on, in, or near the bottom part of a sea, river, lake, pond or stream and create one typical zone called Benthic zone. Benthos mostly used algae, small microscopic fauna and organic matter (runoff from land) in their diets. Majority affected factors of benthic community are depth of water, salinity, temperature, types of substrates, pre-predation ratio and suddenly change in environmental condition. Now a days different anthropogenic activities affected water ecosystems of earth including substratum habitat. Most of these animals lack a backbone and are called invertebrate animals. Benthic organisms, play an important role as a food source for fish and other higher level of organisms.

Generally benthic community include Mollusca (Gastropods and Bivalves), Coral, Sponges, different types of worms (mostly polychaetes and nematode), Crustacean crabs, other crustaceans, Echinoderms, oysters etc. Some benthos are important predators and scavengers for particular food chain system. The benthic community mainly prefer hard, sandy, muddy and soft bottoms as a living habitat. By the size, Benthos mainly divided into 3 types Macrobenthos (> 1 mm), Meiobenthos (< 1 mm or > 0.1 mm) and Microbenthos (< 0.1 mm). These animals also divided into two types Phytobenthos and Zoobenthos also added base on location Endobenthos, Epibenthos, Hyperbenthos are divided. The benthic community can be considered a black box diverting organic matter into either metabolites or the geosphere (burial) (Wikipedia). The sediments of benthic zone play an important role in providing nutrients for the organisms that live in the benthic zone. The up-down movement of the bottom sediments mainly occurred by these benthic organisms results in a rise of the oxygen concentration of water and hence the overall productivity of the water bodies rich in high level.

The study was conducted in winter season at 3 sites of Deendayal Port Authority with the locations namely, Offshore, Cargo Jetty and Phang Greek.

3.2. Methodology

To studying the benthic organisms, triplicate samples were collected at each station using Van veen grab which covered an area of $0.04m^2$. The wet sediment was sieved with varying mesh sizes (0.5 mm-macrofauna) for segregating the organisms. The organisms retained in the sieve were fixed in 5-7% formalin and stained further with Rose Bengal solution for easy spotting at the time of sorting. The number of organisms in each grab sample was expressed as number/ meter square (No/m^2). All the species were sorted, enumerated, and identified to the advanced taxonomic level possible with the consultation of available literature. The works of Fauvel (1953), Day (1967) were referred for polychaetes; Barnes (1980) and Lyla *et al*. (1999) for crustaceans; SubbaRao *et al.* (1991) and Ramakrishna (2003) for molluscs.

Further, the data were treated with univariate statistical methods in PRIMER (Ver. 6.) statistical software (Clarke and Warwick, 1994).

a) Shannon – Wiener index

In the present study, the data were analyzed for diversity index (H') by following Shannon – Wiener's formula (1949):

$H' = -\sum^{S} Pi \log 2\ Pi$……. i = 1

which can be rewritten as

$$H' = \frac{3.3219\ (N \log N - \sum ni - \log ni}{N}$$

where, H'= species diversity in bits of information per individual

ni = proportion of the samples belonging to the ith species

(number of individuals of the ith species)

N = total number of individuals in the collection and

$\sum$ = sum

b) Species richness(S) was calculated using the following formula given by Margalef (1958)

c) Margalef index (d)

$d = (S-1) / \log N$

d) Pielou's evenness index

The equitability (J') was computed using the following formula of Pielou (1966):

$$J' = \frac{H'}{\log_2 S} \text{ or } \frac{H'}{\ln S}$$

Where, J' = evenness; H' = species diversity in bits of information per individual and S = total number of species.

3.3. Results on Species Composition, Population density and Biomass during Season 1

3.3.1. Location 1 - Offshore site

Different samples of benthic organisms were collected from six sites (1A, 1B, 1C, 1D, 1E and 1- control). A Total of 8 groups (or types of benthos) of Benthic community were recorded in all stations at Offshore sites and they are Bivalves, Crustaceans animals, Dentalium-tusk shell (Mollusca), Gastropods (Mollusca), Pecten sp (Clam-Mollusca) Polychaeta worms (Annelida), Scaphopoda (Mollusca) and Razor clam (Mollusca). Data on Density and Biomass expressed in (Nos/m^2), (gm/m^2) respectively (Table 13).

Highest population density of benthic organisms was recorded in station 1A-Offshore (5600 nos/m^2), whereas lowest in station 1control-Offshore. The density range of all stations varied from 1700 to 5600 nos/m^2. Bivalves, Gastropoda and Razor clam were more abundant among all the benthic organisms. Rarely recorded benthos was *Pecten* sp and Scaphopoda. The highest biomass value (expressed wet weight) of benthic fauna was observed in station 1A-Offshore (20.48 gm/m^2) and lowest value was 1control-Offshore (7.54 gm/m^2) (Table 13). High Biomass values and also density values suggested suitable substratum for benthos and less predator pressure of higher animals. Intermediate association was also one responsible factor for the same.

3.3.2. Cargo Jetty

In Cargo Jetty, frequently observed Benthic groups were Bivalves-Gastropods than Crustacean animals, Dentalium-tusk shell (Mollusca) and Razor clam (Bivalvia). The population density range of 1300 to 2250 nos/m^2 was recorded between all the stations (Cargo Jetty-2A, 2B, 2C, 2D, 2E &2-Control) during the study period. Highest and

Lowest density were recorded in station 2A- Cargo Jetty (2250 nos/m^2) and 2B-Cargo Jetty (1300 nos/m^2) respectively. Polychaeta worms and Scaphopoda were absent in all stations. The Biomass value indicated a highest value in station 2control- Cargo Jetty (10.5gm/m^2) and lowest in 2B- Cargo Jetty (5.85 gm/m^2) (Table 13). Average Biomass value of all station was 8.5 gm/m^2 which indicated the moderate favourable environment condition of biota as well as water quality and substratum (mostly rocky). High density and biomass values of Bivalves and Gastropods also indicated symbiotic and intermediate relation between them or with other invertebrates and suitable rocky substratum or coral reef in bottom of sea (Table 13; Figure 3).

3.3.3. Phang creek

Six Stations of Phang creek were selected for the study namely 3A, 3B, 3C, 3D, 3E and 3-control-Phang creek. In this Phang creek benthic organisms were mostly represented by Bivalves. Other benthic groups were recorded very less numbers and some other are totally absent. The population density was highest in station 3C-Phang creek (900 nos/m^2) and on the other side, lowest density was recorded in 3B-Phang creek (125 nos/m^2). Station 3E-Phang creek comprises highest wet. wt. (17.29 gm/m^2), whereas low at was recorded in3D-Phang creek (1 gm/m^2). Compare to two other sites phang creek area was very poor by benthic communities that might be for pollution and extreme weather events near the creek area or coastal area. Sediment transportation may be one reason for less diversity of benthos.

Overall result of macrofaunal community showed highest population density in 1A-Offshore (5600 nos/m^2) and high biomass was observed (21.44 gm/m^2) at 1E-Offshore. Table 13 showed highest population values of Bivalves in 1A- Offshore (3050 nos/m^2) and lowest value comprised by other groups at various sites including some are totally absent. Less frequently recorded *Dentalium-tusk shell, Pecten sp, Scaphopoda and Razor clam* were preferred rocky substratum and any other hard substrata**.** Compare to Cargo Jetty and Phang creek, Offshore area was containing more diversity and density of benthic organisms and this might be due to relatively stable and less polluted environment provided by open sea area of Offshore site further added that availability of rich food items for benthos. Less anthropogenic activities in that area also one reason behind it. Table 13 showed that average population density and biomass higher in Offshore area where mostly rocky or covered with coral base providing a unique habitat for gastropod, bivalves and other benthic organisms. Lowest density and biomass were observed at Cargo Jetty area and Phang creek (Table 13 and Figure 3) which indicated pollution level or stressful environment, seasonal effect, sediment transportation and also might be some chemical and biological changes in water.

In benthic communities, recorded species at all sites were, *Tellina sp., Clypeomorus bifasciata, Trochus sp, Radix sp, Donax sp Pholas orientalis, Marcia sp, Dentalium sp Dosinia sp, Donax sp, Anadara sp, Turris sp, Pecten sp, Solen, Nereis sp etc*. The percentage of occurrence (Table 13) revealed highest group present was Bivalves (100%) then followed by Gastropoda (77.77%), Razor clam (55.56%), Dentalium-tusk shell (44.44%), Crustacean (33.33%), Polychaeta worms (27.78%), Pecten sp (11.11%) and Scaphopoda (5.56%). Detail status of Population density, Group composition and biomass of the benthic community of all selected sites were depicted in (Table 13) and (Figure 3).

In all the stations, highest percentage composition recorded by Bivalves (59%) followed by Gastropoda (25%), Razor clam (6%), Crustaceans (5%), Dentalium- tusk shell (3%) *and 1%* comprised by Scaphopoda and Polychaeta marine worms. Very less by *Pecten sp* (Bivalvia) 0% indicated very less numbers compare to others (Figure 4). Phytoplankton abundance and their size, zooplankton Body composition, patchy distribution of zooplankton, water currents, ebb and flow tides, and water churning process, changing in structure of muddy, rocky and sandy habitats are the main reasons for biomass and density fluctuation in Benthic communities. In Crustacean most commonly observed species are Crabs and attached Barnacles. Main Mollucsa families recorded Trochidae, Cerithidea, Turritellidae, Tellinidae, Mitridae, Veneridae, Donacidae and Bucciniae etc. *Nereis sp, Capitella sp, Nephtys sp*. like polychaetes (annelids worms) were observed in samples. More number of the broken bivalves, debris, plat items and broken gastropods and small rocks are frequently observed during benthic organism’s study.

3.3.4. Diversity Indices of Benthos Community

Table 14 shows various diversity indices calculation, showed that Shannon Diversity Index ranging from (0.00-1.28) indicated very low diversity. Highest diversity indices were recorded in Station 1A-Offshore (1.28), where moderate value of density and biomass of benthos and other side in 3E-Phang creek diversity indices value was 0 where population density and biomass were very low range. The evenness values ranged between (1.00 to 0.45). The highest evenness value is (1.00) observed in station 3A, 3C and 3E Phang Creek and the lowest evenness index value 0.45 was at station 1D Offshore. Evenness value "1" indicated all organisms occurred in same area or same group. Simpson's Index value ranged between 0 to 0.64 indicated to lower to very less moderate diversity. The Margalef's D value showed a slightly variation of 0.00 to 0.58 indicated normal variation in species/group numbers (Table 14).

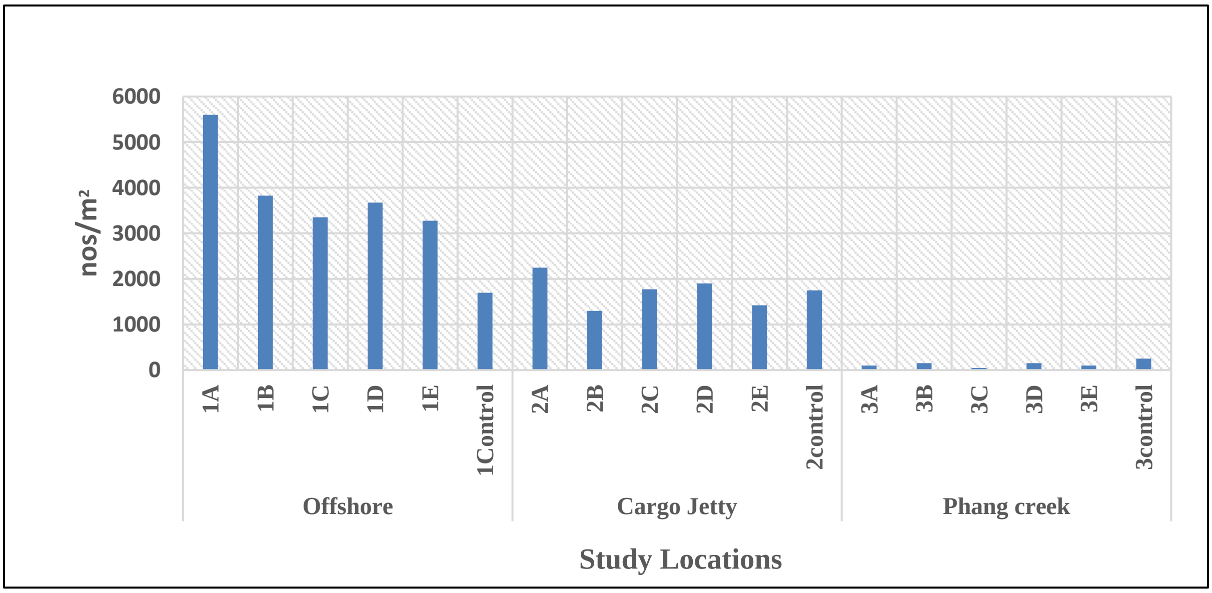

Figure 3. Population density of benthic organisms (nos/m^2) in various sites

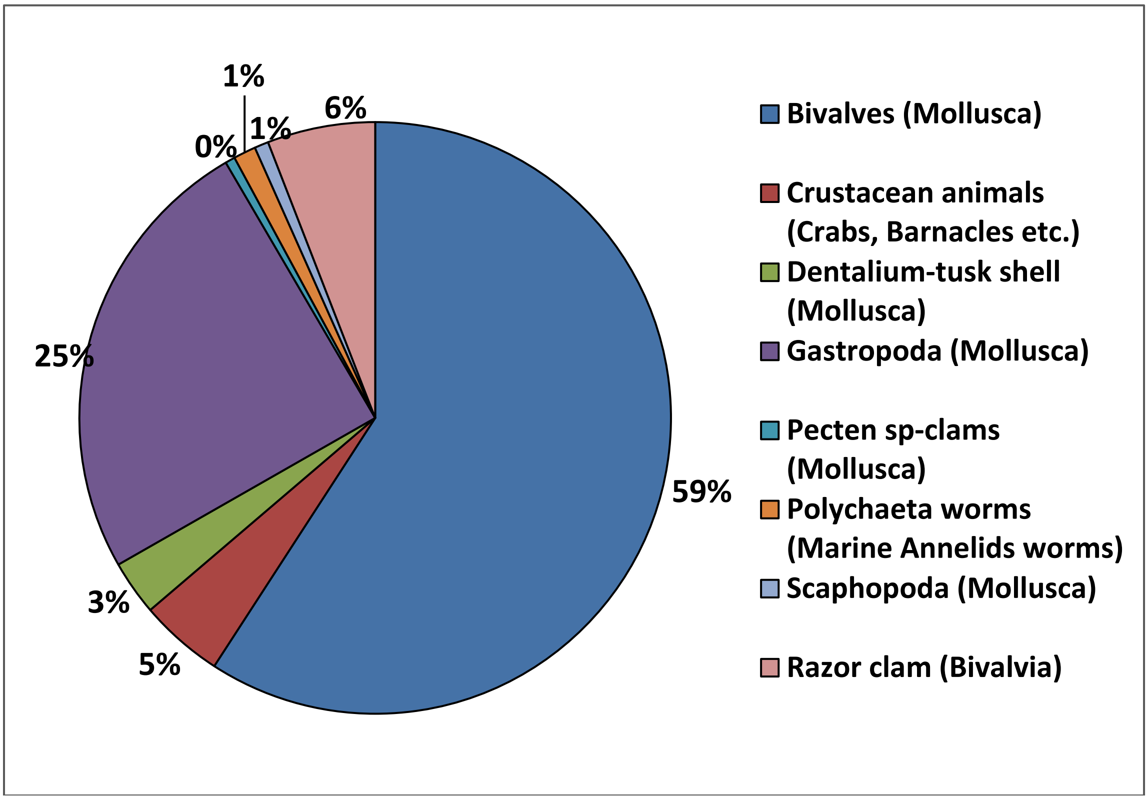

Figure 4. Percentage composition of benthic organisms in various sites.

Table 13. Macrobenthos distribution in different sites of Deendayal Port

Name of Station / Name of Benthic Group	**Offshore**						**Cargo Jetty**						**Phang creek**						**% of Occurrence**
	1A	**1B**	**1C**	**1D**	**1E**	**1-Control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-Control**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-Control**	
Bivalves (Mollusca)	3050	2425	2225	2350	1825	925	1400	775	1050	1075	700	975	50	100	50	125	100	100	100
Crustacean animals (Crabs, Mysis etc.)	400	0	175	250	350	0	0	0	0	0	150	175	0	0	0	0	0	0	33.33
Dentalium-tusk shell (Mollusca)	125	75	0	100	175	75	0	125	0	150	0	150	0	0	0	0	0	0	44.44
Gastropoda (Mollusca)	1350	925	725	725	800	450	550	400	550	575	475	450	0	0	0	25	0	100	77.78
Pecten sp-clams (Mollusca)	0	0	0	75	0	0	0	0	0	0	100	0	0	0	0	0	0	0	11.11
Polychaeta worms (Marine Annelids worms)	0	100	0	100	0	100	0	0	0	0	0	0	50	50	0	0	0	0	27.78
Scaphopoda (Mollusca)	250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.56
Razor clam (Bivalvia)	425	300	225	75	125	150	300	0	175	100	0	0	0	0	0	0	0	50	55.56
Total Population Density Nos/m^2	5600	3825	3350	3675	3275	1700	2250	1300	1775	1900	1425	1750	100	150	50	150	100	250	-
Biomass wet wt gm/m^2	20.48	18	17.19	13.61	21.44	7.54	9	5.85	8.41	9.2	7.89	10.5	0.04	0.09	0.03	0.21	0.05	2.43	-

Table 14. Diversity indices of benthic faunal groups at various station of Deendayal Port -Kandla (Benthos)

Variables	Offshore						Cargo Jetty						Phang Creek					
	1A	1B	1C	1D	1E	1-control	2A	2B	2C	2D	2E	2-contrl	3A	3B	3C	3D	3E	3cont
Taxa_S	6	5	4	7	5	5	3	3	3	4	4	4	2	2	1	2	1	3
Individuals (Nos/m^2)	5600	3825	3350	3675	3275	1700	2250	1300	1775	1900	1425	1750	100	150	50	150	100	250
Dominance_D	0.4	0.5	0.5	0.5	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.5	0.6	1.0	0.7	1.0	0.36
Shannon Diversity	1.28	1.00	0.94	1.14	1.19	1.20	0.91	0.90	0.90	1.04	1.14	1.12	0.69	0.64	0.00	0.45	0.00	1.055
Simpson_1-D	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0.64
Evenness	0.60	0.55	0.64	0.45	0.66	0.67	0.83	0.82	0.82	0.71	0.78	0.76	1.00	0.94	1.00	0.78	1.00	0.96
Menhinick	0.08	0.08	0.07	0.12	0.09	0.12	0.06	0.08	0.07	0.09	0.11	0.10	0.20	0.16	0.14	0.16	0.10	0.190
Margalef	0.58	0.48	0.37	0.73	0.49	0.54	0.26	0.28	0.27	0.40	0.41	0.40	0.22	0.20	0.00	0.20	0.00	0.36

3.4. Results on Species Composition, Population density and Biomass of Macrofauna during Season 2

3.4.1. Offshore

In Offshore region of port, selected six sites were (1A, 1B, 1C, 1D, 1E and 1- control). A total of 4 groups (of benthic community) of animals were recorded in all stations at Offshore sites and they are Razor clam (Mollusca), Other Bivalves, Crustaceans animals, Gastropods (Mollusca). Data on Density and Biomass expressed in (Nos./m^2), (gm/m^2) respectively (Table 15). Dentalium-tusk shell (Mollusca), Polychaeta worms (Annelida) were totally absent in Offshore.

Highest population density of benthic organisms was recorded in station 1 control at Offshore (1600 nos/m^2), whereas lowest in station 1A-Offshore (300nos/m^2). The density range of all stations varied from 300 to 1600 nos./m^2. Bivalves and Gastropoda were more abundant among all the benthic organisms. Rarely recorded benthos was Razor clams. The highest biomass value (expressed wet weight) of benthic fauna was observed in station 1control-Offshore (5.58 gm/m^2) and lowest value was 1C-Offshore (1.3 gm/m^2) (Table 15). High Biomass values and also density values suggested suitable substratum for benthos and less predator pressure of higher animals. Intermediate association was also one responsible factor for the same. Offshore region of sea is always more influences by the Water Currents, Upwelling - Downwelling (Churning process of water) movements of water and that for also same for Nutrients.

3.4.2. Cargo Jetty

In Cargo Jetty, frequently observed benthic groups were Bivalves-Gastropods than Crustacean animal and Razor clam (Bivalve). The population density range of 675 to 1225 nos/m^2 was recorded between all the stations (Cargo Jetty-2A, 2B, 2C, 2D, 2E &2-Control) during the study period. Highest and Lowest density were recorded in station 2B- Cargo Jetty (1225 nos./m^2) and 2control-Cargo Jetty (675 nos./m^2) respectively. Polychaete worms and Razor clams (Bivalve) were absent in all stations. The Biomass value indicated a highest value in station 2A- Cargo Jetty (5.57 gm/m^2) and lowest in 2C- Cargo Jetty (2.51 gm/m^2) (Table 15). Average Biomass and

Population density value of all station were 3.69 gm/m^2, 971 nos./m^2 respectively which indicated the moderate favourable environment condition of biota, water quality as well as substratum (mostly rocky). The population density and biomass of benthic community largely affected by the symbiotic and intermediate relation between them or with other invertebrates and suitable rocky substratum or coral reef in bottom of sea. Availability of Plankton, as a food source, also affected the benthic animals (Table 15 and Fig. 5 & 6).

3.4.3. Phang creek

Six Stations of Phang creek were selected for the study namely 3A, 3B, 3C, 3D, 3E and 3-control-Phang Creek. In this Phang Creek benthic organisms were mostly represented by Bivalves and Gastropoda. Other benthic groups were recorded very less numbers (Dentalium sp) and some other are totally absent. The population density was highest in station 3B-Phang Creek (1175 nos./m^2) and on the other side, lowest density was recorded in 3A-Phang Creek (800 nos./m^2). Station 3control-Phang Creek comprises highest wet. wt (4.52 gm/m^2), whereas low at was recorded in3E-Phang Creek (1.98 gm/m^2).

Overall result of macrofaunal community showed highest population density in 1control-Offshore (1600 nos/m^2) and high biomass was observed (5.58gm/m^2) at 1control-Offshore. Table 15 showed highest population values of Bivalves in 3E-Phang creek (675 nos/m^2) and same highest value of Gastropoda showed in 3control and 3B-Phang creek (550 nos/m^2). The lowest value comprised by other groups at various sites including some is totally absent. Less frequently recorded Dentalium-tusk shell, Razor clam *and* Polychaete worms which indicated extreme weather condition (may be high temperature of summer season) or unfavourable environment condition. Bivalves and Gastropods, dominant groups, were preferred rocky substratum and any other hard substrata**.** Table 15 showed that average population density and biomass higher in Cargo jetty and Phang Creek area where mostly rocky or covered with muddy area providing a unique habitat against high temperature of summer for gastropods, bivalves. Low density and biomass were observed at Offshore (Table 15 and Figure 5) which indicated stressful environment, seasonal effect, more anthropogenic activities and also might be some chemical and biological changes in water.

In benthic communities, recorded species at all sites were, *Umbonium vestiarium Tellina sp., Clypeomorus bifasciata, Trochus sp, Radix sp, Donax sp Pholas orientalis, Turris sp,Marcia sp, Dentalium sp Dosinia sp, Donax sp, Anadara sp, Turris sp, Solen, Nereis sp etc.* The percentage of occurrence (Table 15) was revealed highest group present by Bivalves and Gastropods (100%) then follow Crustacean animals (17 %), Dentalium tusk shell (11%), Polychaete worms (6%) and Razor clams (6%). Detail status of Population density, Group composition and biomass of the benthic community of all selected sites were depicted in (Table 15) and (Figure 6).

In all the stations, highest percentage composition recorded by Bivalves (52%) followed by Gastropods (40%), Crustaceans (3%), Dentalium- tusk shell and Razor clams (2%) *and 1%* comprised by Polychaete marine worms. Phytoplankton abundance and their size, zooplankton Body composition, patchy distribution of zooplankton, water currents, ebb and flow tides, and water churning process, changing in structure of muddy, rocky and sandy habitats are the main reasons for biomass and density fluctuation in Benthic communities. In Crustacean most commonly observed species are Crabs and attached Barnacles. Main Mollucsa families recorded Trochidae, Cerithidea, Turritellidae, Tellinidae, Mitridae, Veneridae, Donacidae and Bucciniae etc. *Nereis sp*, *Capitella sp, Nephtys sp*., like polychaetes (annelids worms) were observed in samples. More number of the broken bivalves, debris, plant items and broken gastropods and small rocks are frequently observed during benthic organism's study.

3.4.4. Diversity Indices of Benthic Community

Table 16 shows various diversity indices calculation, showed that Shannon Diversity Index ranging from (0.64-1.04) indicated very low diversity. Highest diversity indices were recorded in Station 2A-Cargojetty (1.04) where high value of density and biomass of benthos and other side in 3E-Phang creek diversity indices value was 0.64 where biomass was comparatively very low. *The evenness values ranged between (0.80 to 1).* The highest evenness value (1) is observed in station 1D &1E of Offshore and 3B &3C of Phang creek where only Gastropods and Bivalves are present and the lowest evenness index value 0.80was at station 2E-Cargojetty. Evenness value "1" indicated all organisms occurred in same area or same group. Simpson's Index value ranged between 0.45 to 0.63 indicated to lower to very less moderate diversity. The Margalef value showed a slightly variation of 0.14 to 0.32 indicated normal variation in species/group numbers. (Table 16).

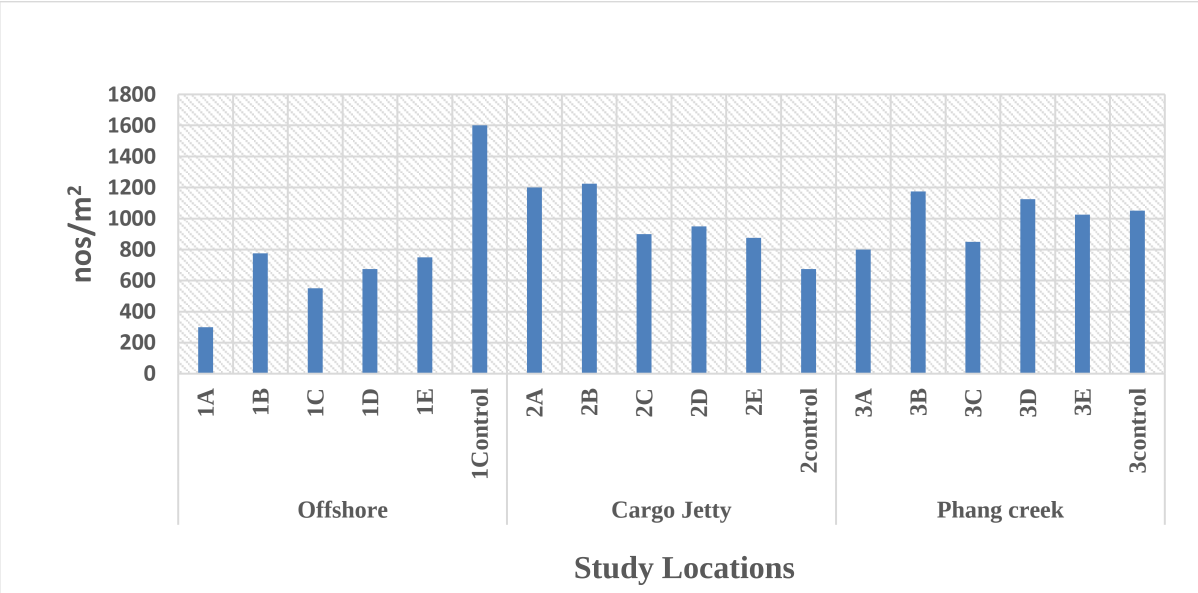

Figure 5. Population density of benthic organisms (nos/m^2) in various sites

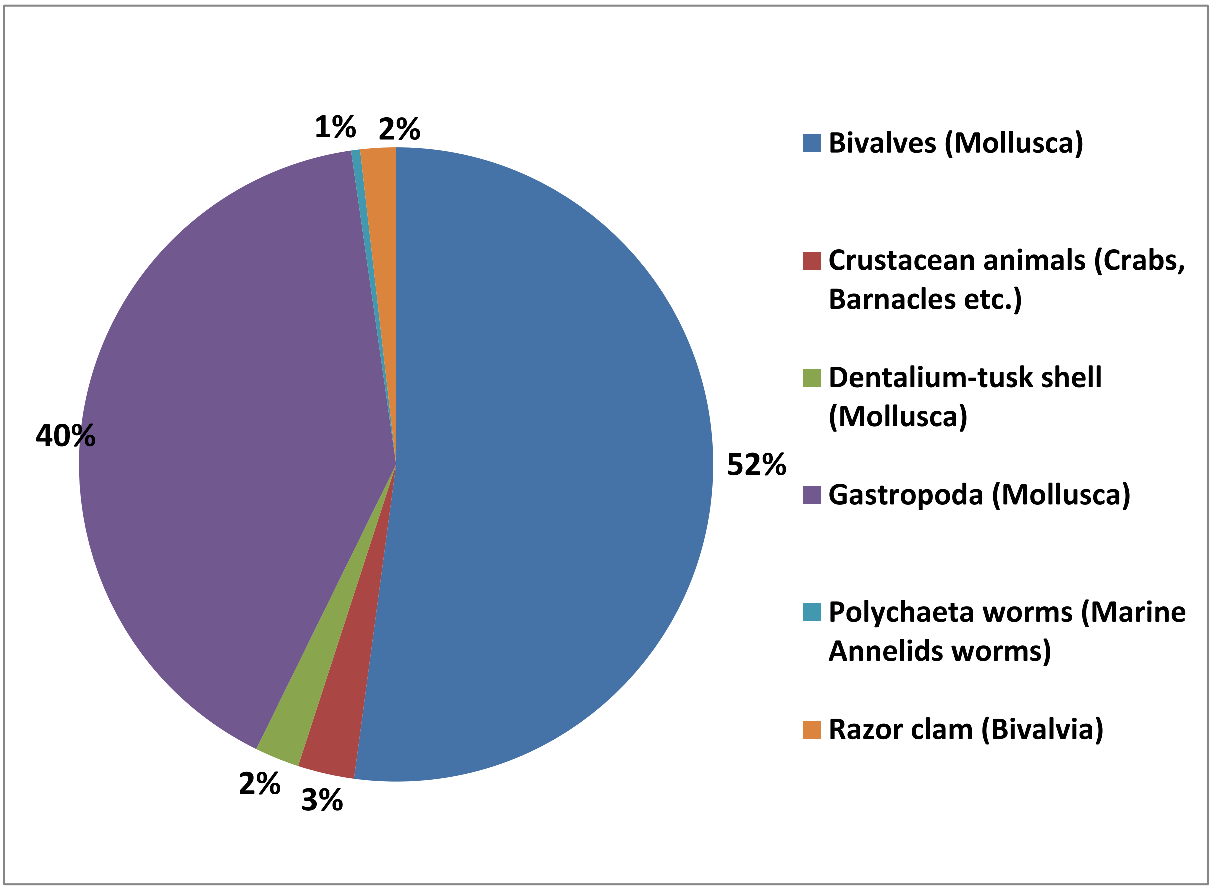

Figure 6. Percentage composition of benthic organisms in various sites

Table 15. Macrobenthos distribution in different sites of Deendayal Port

Name of Station	Offshore						Cargo Jetty						Phang creek						% of Occurrence
	1A	1B	1C	1D	1E	1-Control	2A	2B	2C	2D	2E	2-Control	3A	3B	3C	3D	3E	3-Control	
Name of the Benthic Group																			
Bivalves (Mollusca)	175	125	275	350	400	875	575	600	500	550	525	375	500	625	400	700	675	375	100
Crustacean animals (Crabs, Mysis etc.)	0	150	100	0	0	0	0	225	0	0	0	0	0	0	0	0	0	0	17
Dentalium-tusk shell (Mollusca)	0	0	0	0	0	0	250	0	0	0	0	0	0	0	0	0	0	125	11
Gastropoda (Mollusca)	125	500	175	325	350	425	375	400	400	400	275	300	300	550	450	425	350	550	100
Polychaeta worms (Marine Annelids worms)	0	0	0	0	0	0	0	0	0	0	75	0	0	0	0	0	0	0	6
Razor clam (Bivalvia)	0	0	0	0	0	300	0	0	0	0	0	0	0	0	0	0	0	0	6
Total Population Density Nos/m^2	300	775	550	675	750	1600	1200	1225	900	950	875	675	800	1175	850	1125	1025	1050	-
Biomass wet wt gm/m^2	2.08	3.27	1.3	1.86	3.32	5.58	5.57	4.01	2.51	3.22	4.31	2.57	3.37	3.21	2.22	2.9	1.98	4.52	-

Table 16. Diversity indices of benthic faunal groups at various station of Deendayal Port

Variables	Offshore						Cargo Jetty						Phang Creek					
	1A	1B	1C	1D	1E	1-Control	2A	2B	2C	2D	2E	2-Control	3A	3B	3C	3D	3E	3-Control
Taxa_S	2	3	3	2	2	3	3	3	2	2	3	2	2	2	2	2	2	3
Individuals (Nos./m^2)	300	775	550	675	750	1600	1200	1225	900	950	875	675	800	1175	850	1125	1025	1050
Dominance_D	0.51	0.48	0.38	0.50	0.50	0.40	0.37	0.38	0.51	0.51	0.47	0.51	0.53	0.50	0.50	0.53	0.55	0.42
Shannon Diversity Index (H)	0.68	0.89	1.02	0.69	0.69	1.00	1.04	1.03	0.69	0.68	0.88	0.69	0.66	0.69	0.69	0.66	0.64	0.96
Simpson_1-D	0.49	0.52	0.62	0.50	0.50	0.60	0.63	0.62	0.49	0.49	0.53	0.49	0.47	0.50	0.50	0.47	0.45	0.58
Evenness_e^H/S	0.99	0.82	0.93	1.00	1.00	0.90	0.95	0.93	0.99	0.99	0.80	0.99	0.97	1.00	1.00	0.97	0.95	0.87
Menhinick	0.12	0.11	0.13	0.08	0.07	0.08	0.09	0.09	0.07	0.06	0.10	0.08	0.07	0.06	0.07	0.06	0.06	0.09
Margalef	0.18	0.30	0.32	0.15	0.15	0.27	0.28	0.28	0.15	0.15	0.30	0.15	0.15	0.14	0.15	0.14	0.14	0.29

3.5. Results on Species Composition, Population density and Biomass of Macrofauna during Season 3

3.5.1. Offshore

In Offshore region of port, selected six sites were (1A, 1B, 1C, 1D, 1E and 1- control). A total 6 groups/species (of benthic community) of animals were recorded in all stations at Offshore sites and they are Razor clam (Mollusca), Other Bivalves, Crustaceans animals, Gastropods (Mollusca), Placuna sp (Bivalve), Polychaeta worms and Razor clam (Bivalve). Data on Density and Biomass expressed in (nos./m^2), (gm/m^2) respectively (Table 17). Pholas sp (Bivalve) was totally absent in Offshore.

Highest population density of benthic organisms was recorded in station 1D-Offshore (3225 nos/m^2), whereas lowest in station 1A-Offshore (50 nos/m^2). The density range of all stations varied from 50 to 3225 nos./m^2. Bivalves, Gastropoda and Polychaeta worms were more abundant among all the benthic organisms. Rarely recorded benthos was Placuna sp (Bivalve) and Razor clam (Bivalve). The highest biomass value (expressed wet weight) of benthic fauna was observed in station 1D-Offshore (27.45 gm/m^2) and lowest value was 1A-Offshore (2.06 gm/m^2) (Table 17). High Biomass values and also density values suggested suitable substratum, coral reef substratum, availability of plenty food items and less predator pressure by higher animals. Intermediate association was also one responsible factor for the same. Variation in density and biomass in Offshore region because more influences by the Water Currents, Upwelling - Downwelling (Churning process of water) movements of water and Nutrients availability.

3.5.2. Cargo Jetty

In Cargo Jetty, frequently observed benthic groups were Bivalves, Gastropods, Polychaeta worms than Crustacean animal. The population density range noted between 675 to 1225 (nos/m^2) among all the stations (Cargo Jetty-2A, 2B, 2C, 2D, 2E &2-Control) during the study period. Highest and Lowest density were recorded in station 2E- Cargo Jetty (1800 nos./m^2) and 2B-Cargo Jetty (25nos./m^2) respectively. Placuna sp (Bivalve) and Razor clams (Bivalve) were only seen in 2control-Offshore. The Biomass value indicated a highest value in station 2C- Cargo Jetty (31.75gm/m^2)

and lowest in 2A- Cargo Jetty (1.06gm/m^2) (Table 17). Average Biomass and Population density value of all station were 18.03gm/m^2, 1104 nos./m^2 respectively which indicated the moderate favourable environment condition of biota, water quality as well as substratum (mostly rocky).

3.5.3. Phang creek

Six Stations of Phang creek were selected for the study namely 3A, 3B, 3C, 3D, 3E and 3 Control (Phang Creek). In this Phang Creek benthic organisms were mostly represented by Bivalves, Gastropoda and Polychaeta worms (annelids). Other benthos, *Placuna sp* was recorded very less numbers and Crustacean animals, Pholas sp were totally absent. The population density was highest in station 3Control-Phang Creek (2800nos./m^2) and on the other side, lowest density was recorded in 3B-Phang Creek (50nos./m^2). Station 3E-Phang Creek comprises highest wet wt (58.94 gm/m^2), whereas low value was recorded in3B-Phang Creek (3.07gm/m^2).

Overall result (Offshore, Cargo Jetty and Phang creek) of macrofaunal community showed highest population density in 1D-Offshore (3225nos/m^2) and high biomass was observed (58.94gm/m^2) at 3E-Phang creek. Table 17 showed highest population values of Bivalves in 3Control- Phang creek (2250nos/m^2) and same highest value of Gastropoda showed in 1D-Offshore (550nos/m^2). The lowest value comprised by the *Pholas sp* and Razor clam including some were totally absent in some sites. Some absent or less frequently observed benthos indicated extreme weather condition (may be low temperature of winter season), more stress condition and unfavourable environment condition for their survival. Bivalves and Gastropods, dominant groups, were preferred rocky substratum and any other hard substrata**.** Polychaete worms are preferred sandy-muddy substratum or sandy habitat. Table 17 showed that average population density and biomass higher in Offshore and Phang Creek area where mostly rocky or covered with muddy area providing a unique habitat for benthos. Low density and biomass were observed at Cargo Jetty (Table 17 and Figure 7) which indicated stressful environment, seasonal effect, more anthropogenic activities and also might be some chemical and biological changes in water. The population density and biomass of benthic community largely affected by the symbiotic and intermediate relation between them or with other invertebrates and suitable rocky substratum or coral reef in bottom of sea. Availability of Plankton, as a food source, also affected the benthic animals (Table 17 and Fig. 7 & 8).

In benthic communities, recorded species at all sites were, *Pholas sp*, *Placuna sp, Umbonium vestiarium Tellina sp., Clypeomorus bifasciata, Trochus sp, Radix sp,Nassarius sp, Nerita sp, Donax sp, Turris sp,Marcia sp, Dosinia sp, Donax sp, Anadara sp, Turris sp, Solen*, *Nereis sp, Saccostrea sp, Optediceros breviculum, Euolica sp etc.* The percentage of occurrence (Table 17) was revealed highest group present by Gastropoda (Mollusca) and Polychaeta worms (72%) then follow Bivalves (67%), Crustacean animals (33%), Placuna sp (28%) and both Pholas sp and Razor clam (17%) respectively. Detail status of Population density, Group composition and biomass of the benthic community of all selected sites were depicted in (Table 17) and (Figure 8).

Among all the stations, highest percentage composition recorded by Bivalves (58%) followed by Gastropods (17%), *Pholas sp* (8%), Polychaeta worms (6%), Placuna sp (5%), Crustacean nimals (4%) and Razor clam (2%) (Figure 8). Phytoplankton abundance and their size, zooplankton body composition, patchy distribution of zooplankton, water currents, ebb and flow tides, and water churning process, changing in structure of muddy, rocky and sandy habitats are the main reasons for biomass and density fluctuation in Benthic communities. In Crustacean most commonly observed species are Crabs and attached Barnacles. Main Mollucsa families recorded Trochidae, Cerithidea, Turritellidae, Tellinidae, Mitridae, Veneridae, Donacidae and Bucciniae etc. *Nereis sp, Capitella sp, Nephtys sp* and some unidentified species of polychaeta (annelids worms) were observed in samples. More number of the broken bivalves, debris, plant items , broken gastropods, small pebbles and soil particles are frequently observed during benthic organism’s study.

3.5.4. Diversity Indices of Benthic Community

Table 18 showed various diversity indices calculation, showed that Shannon Diversity Index ranging from (0.00-1.45) indicated very low diversity. Highest diversity indices was recorded in Station 2D - Cargojetty (1.45) where five groups/species of benthos presented whereas, Shannon indices nil (zero) observed in 1A-Offshore, 2A-2B (Cargo Jetty) and 3B- Phang where only one benthic present and density value was very low. Comparatively less Shannon indices value very low in Phang creek area number of benthos group/species present between 1 to 4 nos. The evenness values ranged between (0.69 to 1). The highest evenness value (1) is observed in station 1A(Offshore), 2A-2B (Cargo Jetty) and 3B (Phang creek) where only 1 benthic group present with less population whereas the lowest evenness index value 0.47 was at 3E-Phang Creek. Evenness value "1" indicated all organisms occurred in same area or same group. Simpson's Index value ranged between 0.00 to 0.73 indicated to lower to very less moderate diversity. The Margalef value showed a slightly variation of 0.00 to 0.56 indicated normal variation in species/group numbers (Table 18).

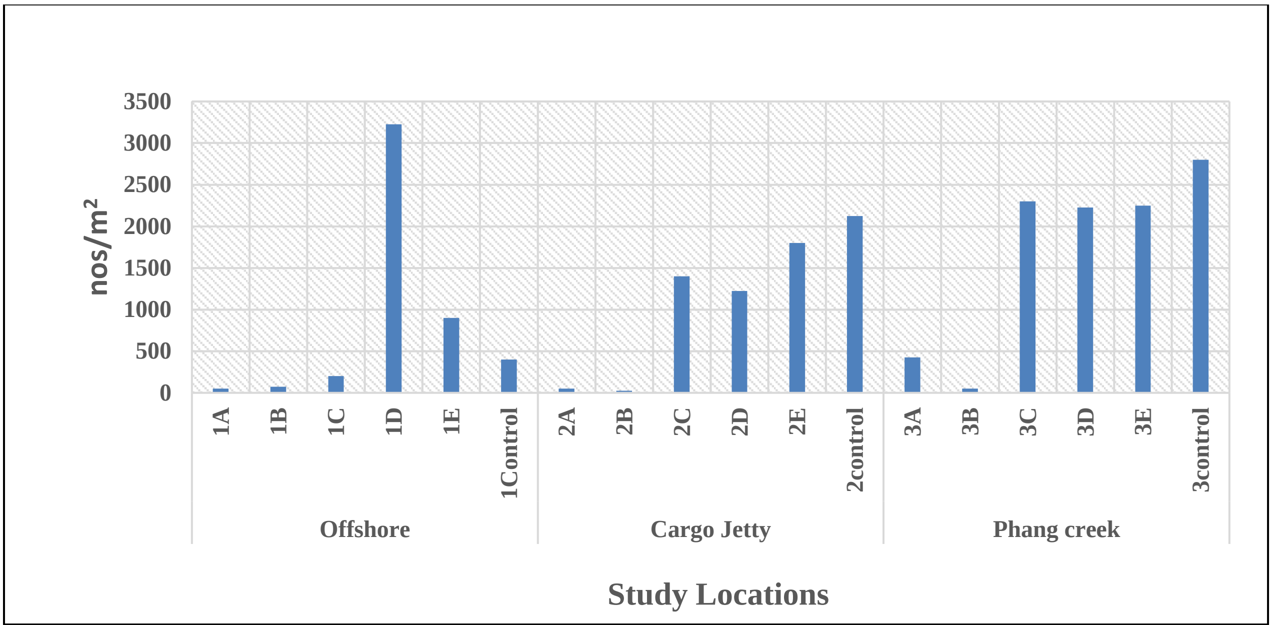

Figure 7. Population density of benthic organisms (nos/m^2) in various sites

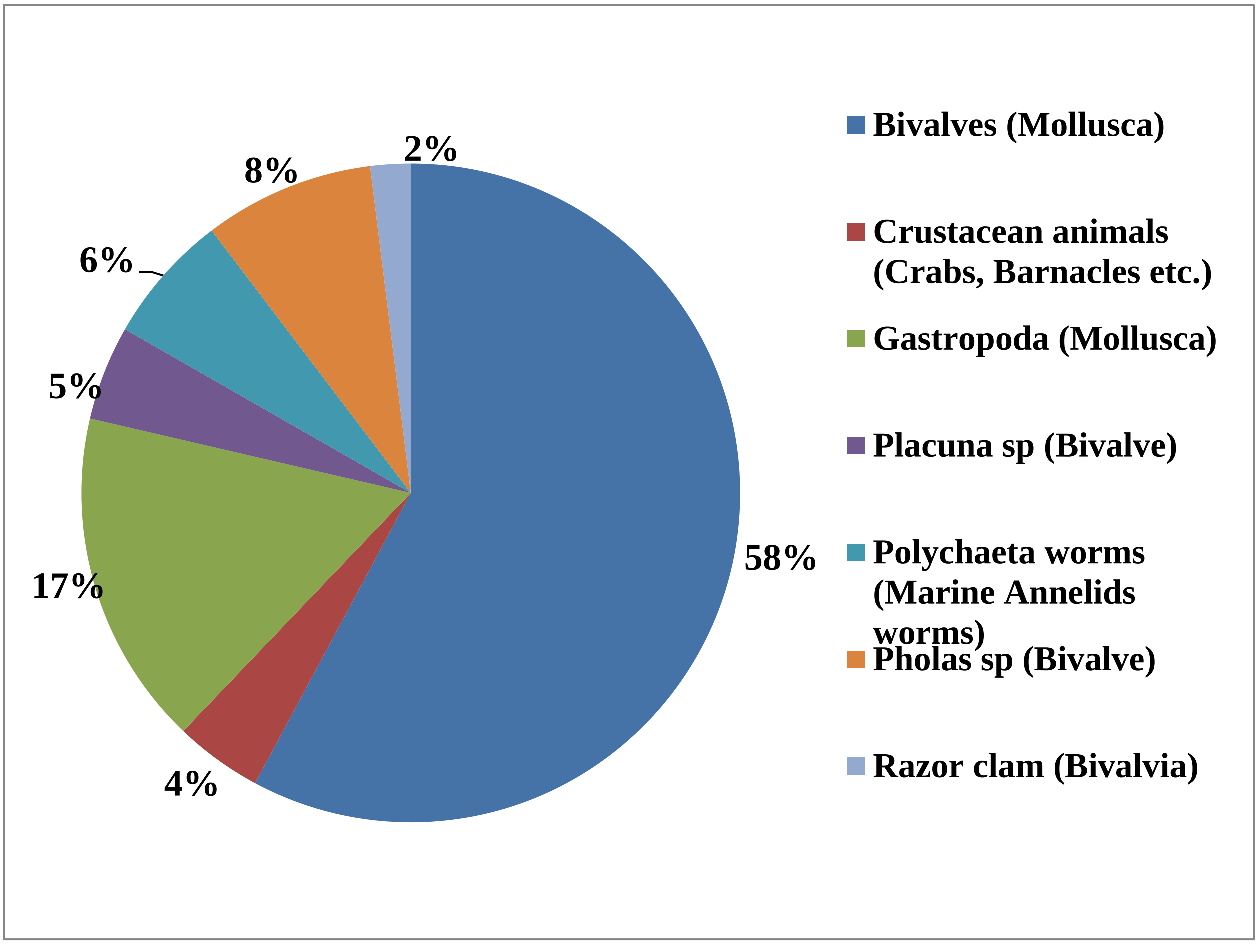

Figure 8. Percentage composition of benthic organisms in various sites

Table 17. Macrobenthos distribution in different sites of Deendayal Port

Name of Station	Offshore						Cargo Jetty						Phang creek						% of Occurrence
	1A	1B	1C	1D	1E	1-Control	2A	2B	2C	2D	2E	2-Control	3A	3B	3C	3D	3E	3-Control	
Name of the Benthic Group																			
Bivalves (Mollusca)	0	0	50	1875	125	0	0	0	550	250	575	900	250	0	1950	1875	1800	2250	67
Crustacean animals (Crabs, Mysis etc.)	0	50	0	300	0	0	0	0	75	125	125	250	0	0	0	0	0	0	33
Gastropoda (Mollusca)	0	0	50	550	250	100	0	0	250	250	300	300	125	0	300	225	350	500	72
Placuna sp (Bivalve)	0	0	0	250	25	0	0	0	0	0	0	550	0	0	0	125	50	0	28
Polychaeta worms (Marine Annelids worms)	50	25	100	0	500	300	50	25	25	100	0	0	50	50	50	0	0	50	72
Pholas Sp (Bivalve)	0	0	0	0	0	0	0	0	500	500	800	0	0	0	0	0	0	0	17
Razor clam (Bivalvia)	0	0	0	250	0	0	0	0	0	0	0	125	0	0	0	0	50	0	17
Total Population Density Nos/m^2	50	75	200	3225	900	400	50	25	1400	1225	1800	2125	425	50	2300	2225	2250	2800	-
Biomass wet wt gm/m^2	2.06	3.05	3.26	27.45	19.66	4.36	1.06	0.85	31.75	19.3	24.65	30.57	5.3	3.07	24.11	32.26	58.94	29.19	-

Table 18. Diversity indices of benthic faunal groups at various station of Deendayal Port

Variables	Offshore						Cargo Jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-cont**
Taxa_S	1	2	3	5	4	2	1	1	5	5	4	5	3	1	3	3	4	3
Individuals (Nos./m^2)	50	75	200	3225	900	400	50	25	1400	1225	1800	2125	425	50	2300	2225	2250	2800
Dominance_D	1.00	0.56	0.38	0.39	0.41	0.63	1.00	1.00	0.32	0.27	0.33	0.28	0.45	1.00	0.74	0.72	0.67	0.68
Shannon Diversity Index (H)	0.00	0.64	1.04	1.23	1.06	0.56	0.00	0.00	1.27	1.45	1.21	1.41	0.92	0.00	0.49	0.54	0.64	0.56
Simpson_1-D	0.00	0.44	0.63	0.61	0.59	0.38	0.00	0.00	0.68	0.73	0.67	0.72	0.55	0.00	0.26	0.28	0.33	0.32
Evenness_e^H/S	1.00	0.94	0.94	0.69	0.72	0.88	1.00	1.00	0.71	0.85	0.84	0.82	0.84	1.00	0.54	0.57	0.47	0.58
Menhinick	0.14	0.23	0.21	0.09	0.13	0.10	0.14	0.20	0.13	0.14	0.09	0.11	0.15	0.14	0.06	0.06	0.08	0.06
Margalef	0.00	0.23	0.38	0.50	0.44	0.17	0.00	0.00	0.55	0.56	0.40	0.52	0.33	0.00	0.26	0.26	0.39	0.25

Chapter 4 Marine Water Quality (Physico-chemical)

4.1. Introduction

The coastal ecosystems harbor a rich diversity of marine flora and fauna because of their higher productivity (Saravanan et al., 2013). These ecosystems are the most precious and vulnerable environments (Jickells, 1998). Rapid urbanization and industrial growth showed a significant impact on coastal ecosystems, such as estuaries and the surrounding coastal areas. The presence of a dense human population in their watersheds contaminates the environment (Jha et al., 2015). Coastal environment reference characteristics are necessary to provide a better management solution for the coastal ecosystem (Barbier Edward et al., 2011). Hence assessing the water for various characteristics will indicate the intensity of pollutants present in such environments.

Considering the above scientific facets on the marine water quality, assessing the marine water for various characteristics will aid in understanding the magnitude of pollutants and also directly indicate the biological quality of the waters as well.

4.2. Materials and Methods

In the present study, the marine water and marine sediment samples were collected using standard protocol and analysis of the same was done following standard methods for marine water and sediment analysis as prescribed by APHA (2012), NIO manual (1982) and ICMAM Manual (2012). Surface water samples for general analysis were collected using a clean polyethylene bucket while an adequately weighted Niskin sampler was used to collect water samples from the bottom. A glass bottle sampler (1 L) was used for collecting water samples at 1 m below the surface. Parameters such as pH, Temperature, Salinity were recorded on spot using hand held meters and the same was also verified in the Laboratory. The water samples collected were stored in refrigerated conditions until further analysis of other parameters. As per the standard protocol, the fixatives and preservatives were added to the samples in case of parameters such as Dissolved Oxygen using Winkler A&B solution immediately, Chemical Oxygen Demand using concentrated H_2SO_4 to bring the <2 pH and preservation using nitric acid for heavy metals. In case of biological characteristics, the marine water samples for planktonic analysis were added with formalin. In general, all the collected water and sediment samples were stored in a sterile, polythene bottles and ziplock bags in an icebox to maintain suitable conditions till it is brought to the Laboratory. The list of parameters (Table 19) and the method adopted for the analysis of samples are detailed below.

Table 19: Physico-chemical and biological characteristics of marine water

S. No	Physico-chemical and Biological parameters
1	pH
2	Salinity (ppt)
3	Total Dissolved Solids (mg/L)
4	Total Suspended Solids (mg/L)
5	Turbidity (NTU)
6	Dissolved Oxygen (mg/L)
7	Bio-Chemical Oxygen Demand (mg/L)
8	Chemical Oxygen Demand (mg/L)
9	Phenolic compound (µg/L)
10	Petroleum Hydrocarbons (µg/L)
11	Oil and grease (mg/L)
12	Cadmium (mg/L)
13	Lead (mg/L)
14	Chromium (mg/L)
15	Copper (mg/L)
16	Cobalt (mg/L)
17	Nickel (mg/L)
18	Zinc (mg/L)
19	Magnesium (mg/L)
20	Chlorophyll (mg/m^3)
21	Phaeophytin (mg/m^3)
22	Phytoplankton Phytoplankton cell counts (no/L) Total Genera (no.) Major Genera
23	Zooplankton Biomass (ml/100m^3) Population (no/100m^3) Total Group (no.) Major Groups

4.2.1. pH and Temperature

A Thermo fisher pH / EC / Temperature meter was used for pH and Temperature measurements. The instrument was calibrated with standard buffers just before use.

4.2.2. Salinity

A suitable volume of the sample was titrated against silver nitrate (20 g/l) with potassium chromate as an indicator. The chlorinity is estimated and from that salinity values were derived using formula.

4.2.3. Total Dissolved Solids (TDS)

The samples were subjected for gravimetric procedure for confirmation of the readings obtained from the hand-held meter. About 100 ml of the water sample was taken in a beaker and filtered which was then dried totally in a Hot Air Oven (105°C). TDS values were calculated using the difference in the initial and final weight.

4.2.4. Total Suspended Solids (TSS)

Hundred ml of the sample was filtered through each pre-weighed filter and placed in the Hot air oven at specified temperature as per the protocol for 1 hour. The filter paper was allowed to cool in a desiccator and obtain a constant weight by repeating the drying and desiccation steps.

4.2.5. Turbidity

The sample tube (Nephlometric cuvette) was filled with distilled water and placed in the sample holder. The lid of the sample compartment was closed. By adjusting the '*SET ZERO*' knob, the meter reading was adjusted to read zero. The sample tube with distilled water was removed and the 40 NTU standard solution was filled in the tube and the meter reading was set to read 100. Other standards were also run. The turbidity of the marine water sample was then found out by filling the sample tube with the sample, and the reading was noted.

4.2.6. Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD)

DO was determined by Winkler's method. For the determination of BOD, direct unseeded method was employed. The sample was filled in a BOD bottle in the field and incubated in the laboratory for 3 days after which DO was again determined and the difference was calculated.

4.2.7. Chemical Oxygen Demand (COD)

A known quantity of sea water was placed in a 50 ml Erlenmeyer flask and to which 3.0 g of silver sulphate was added and kept in a magnetic stirrer for proper mixing at room temperature to remove the chloride interference in the form of Silver chloride precipitate. The sample with white precipitate turned to a fade lilac mixed coloured precipitate is the indication. At this point, mixing of samples was stopped and the flasks were kept at 40° inclined position. Sedimentation of the coloured precipitate was very quick and 20 ml of the cleared sea water was taken carefully from the upper end of the flask bottom after a rest period of 5-10 min. To the 20ml of sea water sample diluted with 150 ml of distilled water, to which 10 ml of standard $K_2Cr_2O_7$ was added, to which 30 ml of Sulphuric acid was added. The tubes were connected to condensers and refluxed for 2 hours at 150 ± 2^0C. After refluxion, the flasks were allowed to cool and titrated against Standard Ferrous Ammonium Sulphate with Ferroin as Indicator. Green blue to wine red is the indication of the end point of the experiment and a blank was run under simultaneous conditions.

4.2.8. Phenolic compounds

Phenols in water (500 ml) were converted to an orange coloured antipyrine complex by adding 4-aminoantipyrine. The complex was extracted in chloroform (25 ml) and the absorbance was measured at 460 nm using phenol as a standard.

4.2.9. Petroleum Hydrocarbons (PHc)

Water sample (1 l) was extracted with hexane and the organic layer was separated, dried over anhydrous sulphate and reduced to 10 ml at 30°C under low pressure. Fluorescence of the extract was measured at 360 nm (excitation at 310 nm) with Saudi Arabian crude residue as a standard. The residue was obtained by evaporating lighter fractions of the crude oil at 120°C.

4.2.10. Oil and Grease

About 500 ml of sample was transferred to the separating funnel and sample bottle was carefully rinsed with 30ml of trichlorotrifluoroethane and add the solvent washings was added to the separating funnel. To this, 5ml of 1:1 HCL was added and shaken vigorously for about 2 minutes If soluble emulsion was formed, then the sample container was shaken for 5 to 10 minutes. Then the layers were allowed to separate and the lower layer (organic layer) was discarded from separating funnel. Then the solvent layer was drained through a funnel containing solvent moistened filter paper into a clean pre weight distillation flask. Then solvent was distilled from distillation flask over a water bath at 70 ^{0}C. Then the residue was transferred using minimum quantity of solvent into a clean pre weighed dried beaker and the beaker was placed on water bath for 15 minutes at 70 ^{0}C and evaporate off all the solvent and it was cooled in desiccators for 30 minutes and weight was taken.

4.2.11 Heavy metals

Heavy metals are of concern especially as it relates to the environment are Cadmium (Cd), Lead (Pb), Mercury (Hg), Chromium (Cr), Arsenic (As), Copper (Cu), Cobalt (Co), Nickel (Ni), Zinc (Zn), Magnesium (Mg) etc. For the release of mineral elements from soil and sediments, wet oxidation of samples are generally performed. Wet oxidation employs oxidizing acids (Tri / Di-acid mixtures).

Soil sample will be weighed to 0.5 gm and taken in 100ml beaker covered with a watch glass and 12 ml of Aqua regia in (1: 3 HNO3 : HCl) will be added and the beaker will be kept in digestion for 3 hours at 100^{0}c on a hot plate using sand bath and the samples will be evaporated to near dryness and the samples will be kept cool for 5 mins and then 20 ml of 2% nitric acid will be added and kept for 15 minutes in hot plate for digestion and remove from hot plate and cooled and filtered using Whatmann No. 42 mm filter paper and then the final make up to 50 ml with 2 % nitric acid will be made. The extracted sample will be then aspirated to an AAS.

4.3. Results on Physico-chemical characteristics of marine water samples of Season 1

During the current year of the study conducted, three locations (Offshore, Cargo Jetty, and Phang Creek) were monitored for physico-chemical characteristics in marine water samples. The data collected from each of these sites is presented in Tables 20 - 22. These results provide valuable information on the specific physico-chemical conditions observed at each location, contributing to our understanding of the environmental factors influencing the marine water quality in these areas.

4.3.1. Location 1 - Offshore location

In the offshore location (Location 1), the recorded data shows that the pH values ranged between 7.82 and 7.89, with an average pH value of 7.86. The salinity of the seawater had a mean value of 39.75±0.45. The maximum Dissolved Oxygen and Biochemical Oxygen Demand was in the order of 5.30 mg/L and 4.40 mg/L respectively. The concentrations of Phenolic compounds and Petroleum hydrocarbons varied between 14.75 to 28.83 µg/L, and 16.33 to 59.12 µg/L, respectively. It is worth noting that the concentration of Petroleum hydrocarbons (PHC) remained below the limit of 100 µg/L set by CPCB. The concentration of oil and grease ranged from 0.40 mg/L to 2.00 mg/L, which is within the acceptable limit of 10 mg/L according to GPCB norms. Additionally, the maximum concentrations of heavy metals were observed for Magnesium (111.60 mg/L), Nickel (2.64 mg/L), Lead (BDL), Cadmium (1.25 mg/L), Chromium (BDL), Zinc (2.41 mg/L), Copper (BDL), Manganese (BDL), and Cobalt (2.06 mg/L), as shown in Table 20.

4.3.2. Location 2 – Cargo Jetty

In the Cargo Jetty location, the mean pH value observed was 7.86±0.02, indicating a slightly acidic condition. The average salinity of the seawater was 39.83±0.38, reflecting the salt content. During Season 3, the maximum values recorded for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) were 5.9 mg/L and 3.5 mg/L respectively (as shown in Table 21). The concentrations of Phenolic compounds and Petroleum hydrocarbons were within permissible limits set by CPCB, with the maximum values ranging from 26.75µg/L and 28.52µg/L. The mean concentration of oil and grease in the marine water samples was 8.8±2.94 mg/L, which falls below the acceptable limit of 10 mg/L according to GPCB norms. Regarding heavy metal concentrations, the mean values for Magnesium, Nickel, Lead, Cadmium, Chromium, Zinc, Copper, Manganese, and Cobalt were 105.17±5.41 mg/L, 2.51±0.46 mg/L, BDL, 0.54±0.23 mg/L, BDL, 1.69±1.14 mg/L, BDL, BDL, 1.77±0.36 mg/L respectively, as presented in Table 21.

4.3.4. Location 3 - Phang Creek

In case of Phang creek near the port, the average pH was recorded as 7.73±0.04. The average salinity of the seawater in the vicinity was found to be 40.66±1.07 ppt, while the TDS which indicates the presence of various anions and cations, had an average value of 38983.91±1072.89 mg/L. Pollution indices such as Dissolved Oxygen and Biochemical Oxygen Demand, Phenolic compounds, and Oil and grease concentrations had maximum values of 5.4 mg/L, 3.9 mg/L, 23.58µg/L, and 6.4 mg/L, respectively. The average value of PHc was 43.16±33.18 µg/L. In case of heavy metals, the mean values for Magnesium, Nickel, Lead, Cadmium, Chromium, Zinc, Copper, Manganese, and Cobalt were 104.60±4.82 mg/L, 2.26±0.59 mg/L, BDL, 0.45±0.20 mg/L, BDL, 1.53±1.78 mg/L, BDL, BDL, 1.42±0.42 mg/L respectively. These values are presented in Table 22.

Table 20: Physico-chemical characteristics of the marine water from sampling location 1 (Offshore)

S. No	Parameters	1A		1B		1C		1D		1E		Control 1	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	25.10	25.00	25.40	25.40	25.80	25.60	26.00	25.80	25.30	25.20	25.10	25.00
2	pH	7.85	7.88	7.82	7.87	7.89	7.86	7.86	7.88	7.88	7.84	7.83	7.86
3	Salinity (ppt)	39.00	39.00	39.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
4	Total Dissolved Solids (mg/L)	39595	40672	38217	38208	41212	41997	37870	38730	38969	40808	40554	40965
5	Turbidity (NTU)	11.8	17.8	5.8	10.1	9.3	4.7	10.4	10.6	10.5	9.4	9	11.3
6	Dissolved Oxygen(mg/L)	5.20	5.30	5.10	5.10	5.20	5.30	4.80	4.80	4.90	5.20	5.30	5.00
7	Bio-Chemical Oxygen Demand (mg/L)	2.80	2.60	3.20	3.00	2.80	2.60	3.80	3.60	4.40	4.00	3.20	3.00
8	Phenolic Compounds (µg/L)	28.83	26.66	15.66	27.66	14.75	18.83	22.25	21.75	22.75	21.91	21.41	22.25
9	Petroleum Hydrocarbons (µg/L)	29.10	39.81	33.30	59.12	55.93	41.38	56.01	47.77	16.33	55.51	35.90	36.79
10	Oil and grease (mg/L)	1.2	0.8	2.0	0.8	1.2	1.2	1.6	1.6	1.6	0.4	0.8	1.2
11	Magnesium (mg/L)	111.05	107.3	101.05	106.65	111.6	104.45	107.9	102.3	102.15	95.85	110.35	106.2
12	Nickel (mg/L)	2.15	2.07	2.51	2.09	1.56	2.19	1.76	2.47	2.64	1.98	2.48	2.41
13	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Cadmium (mg/L)	0.71	0.50	1.25	0.54	0.64	0.69	0.51	0.97	0.85	0.85	1.02	0.65
15	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
16	Zinc (mg/L)	1.25	2.16	2.41	BDL	BDL	0.93	BDL	1.03	BDL	BDL	0.03	BDL
17	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Manganese (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Cobalt (mg/L)	1.41	1.55	1.66	1.91	1.64	1.62	1.02	1.71	2.06	1.62	1.63	1.52

Note: BDL denotes Below Detection Limit.

Table 21: Physico-chemical characteristics of the marine water from sampling location 2 (Cargo Jetty)

S. No	Parameters	2A		2B		2C		2D		2E		Control 2	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	26.5	26.3	27.4	27.3	27.5	27.5	26.8	26.5	27.3	27	27.5	27.3
2	pH	7.89	7.86	7.85	7.87	7.86	7.85	7.88	7.87	7.86	7.86	7.8	7.87
3	Salinity (ppt)	39	40	40	39	40	40	40	40	40	40	40	40
4	Total Dissolved Solids (mg/L)	39662	40011	42114	41756	40663	44892	40642	48273	40203	40242	49009	40176
5	Total Suspended Solids (mg/L)	11.6	10.3	7.5	16.8	4.2	16	17.1	18.2	12.8	10.2	14.7	15.1
6	Turbidity (NTU)	5	5	5	5.9	5.3	4.9	5.1	5	4.8	5.7	5.2	5.3
7	Dissolved Oxygen(mg/L)	2.4	2.2	3.2	3	2.6	2.2	3.5	3.5	3	2.2	2.8	2
8	Bio-Chemical Oxygen Demand (mg/L)	13.08	19.58	16.16	26.75	14.08	11.08	14.58	13	15.66	14.66	14.75	12.16
9	Chemical Oxygen Demand (mg/L)	22.55	22.08	21.55	6.97	19.12	28.52	24.64	18.30	20.52	23.78	2.68	1.46
10	Phenolic Compounds (µg/L)	8.4	14.4	11.2	12	6.8	6	12	7.2	4.8	7.2	9.6	6.8
11	Petroleum Hydrocarbons (µg/L)	106.6	112.4	95.65	108.5	111	101.3	112	103.45	106.35	98	101.35	105.5
12	Oil and grease (mg/L)	2.44	2.81	2.71	2.88	2.70	2.00	2.66	2.47	2.75	3.15	2.25	1.39
13	Magnesium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Nickel (mg/L)	0.325	0.815	0.24	0.975	0.63	0.59	0.265	0.45	0.335	0.83	0.615	0.515
15	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
16	Cadmium (mg/L)	3.45	0.96	2.46	BDL	BDL	1.985	0.37	BDL	BDL	BDL	0.955	BDL
17	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Copper (mg/L)	2.28	2	2.035	1.775	1.56	1.225	1.88	1.995	1.75	1.995	1.845	1
20	Manganese (mg/L)	0.757	0.569	0.695	0.671	0.663	0.520	0.639	0.228	0.324	0.561	0.517	0.425
21	Cobalt (mg/L)	0.344	0.110	0.490	0.200	0.120	0.100	0.790	0.490	0.110	0.240	0.350	0.110

Note: BDL denotes Below Detection Limit

Table 22. Physico-chemical characteristics of the marine water from sampling location 3 (Phang Creek)

S. No	Parameters	3A		3B		3C		3D		3E		Control 3	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	28.3	28	29.1	28.3	28.5	28.3	28.5	28.3	28.1	27.9	28.3	28
2	pH	7.67	7.71	7.69	7.71	7.71	7.7	7.77	7.78	7.77	7.78	7.77	7.79
3	Salinity (ppt)	41	40	42	40	43	41	41	40	41	39	40	40
4	Total Dissolved Solids (mg/L)	38112	39485	41267	39009	37958	38791	39208	37747	37571	39514	40204	38941
5	Total Suspended Solids (mg/L)	11.7	6.4	6.9	9.1	5.5	16.4	6.2	10.4	9.1	9.9	10.9	8.6
6	Turbidity (NTU)	5.4	5.2	5.1	5	4.8	4.8	5.1	5	5	5.1	5	4.8
7	Dissolved Oxygen(mg/L)	3.9	3.2	3.7	3.3	3.1	2.8	3.7	3.6	3.2	3.4	3.1	2.8
8	Bio-Chemical Oxygen Demand (mg/L)	22.75	23.58	13.19	12.91	16.58	18.16	12.25	12.16	13.41	17.41	14.75	15.5
9	Chemical Oxygen Demand (mg/L)	20.00	32.85	27.73	15.47	40.00	31.60	3.41	19.29	89.72	114.14	73.32	50.49
10	Phenolic Compounds (µg/L)	2.0	0.8	2.8	2.8	2.8	3.6	4.4	2.8	4.0	2.4	6.4	2.0
11	Petroleum Hydrocarbons (µg/L)	108.6	106.8	103.7	109.45	111.75	102.1	106.45	100.55	105.75	103.5	103.4	93.2
12	Oil and grease (mg/L)	2.70	2.45	2.38	2.14	1.92	1.76	2.93	1.06	2.45	1.62	2.60	3.13
13	Magnesium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Nickel (mg/L)	0.71	0.565	0.405	0.18	0.115	0.58	0.665	0.44	BDL	0.22	0.53	0.61
15	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
16	Cadmium (mg/L)	BDL	BDL	1.045	BDL	BDL	BDL	4.13	BDL	0.92	BDL	0.045	BDL
17	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Copper (mg/L)	1.67	1.7	1.53	1.585	1.16	1.03	1.825	0.72	1.525	0.67	1.85	1.82
20	Manganese (mg/L)	0.332	0.324	0.603	0.347	0.203	0.350	0.279	0.489	0.339	0.284	0.272	0.150
21	Cobalt (mg/L)	0.242	0.300	0.296	0.245	BDL	0.320	0.200	0.200	0.135	0.157	0.124	0.320

Note: BDL denotes Below Detection Limit

4.4. Physico-chemical characteristics of the marine water samples of Season 2

Throughout the study conducted in the present year, we closely monitored three distinct locations: Offshore, Cargo Jetty, and Phang Creek. A comprehensive analysis of physico-chemical characteristics in marine water samples was conducted at each of these sites. The collected data is thoughtfully presented in Tables 23-25. These findings serve as a significant source of information regarding the precise physico-chemical conditions prevailing at each of these locations. Consequently, they play a pivotal role in enhancing the comprehension of the environmental factors that exert influence on the quality of marine water in these specific areas.

4.4.1. Location 1 - Offshore location

In the offshore location (Location 1), the recorded data shows that the mean value of temperature was recorded as 25.23±0.28°C. The pH values ranged between 7.80 and 7.93, with an average pH value of 7.85±0.04. The salinity of the seawater recorded the mean value as 37.65±2.23 ppt, while the TDS which indicates the presence of various anions and cations, had an average value of 45809.17±672.54 mg/L. Turbidity values ranged from 18.60 to 49.20 NTU. The maximum Dissolved Oxygen and Biochemical Oxygen Demand were in the order of 7.00 mg/L and 3.60 mg/L respectively. The average COD value was determined to be 34.17±3.56mg/L. The concentrations of Phenolic compounds and Petroleum hydrocarbons varied between 11.02 to 46.91 µg/L, and 49.20 to 139.29 µg/L, respectively. It is observed that the concentration of Petroleum hydrocarbons (PHC) was higher than the prescribed limit of 100 µg/L set by CPCB. The concentration of oil and grease ranged from 0.40 mg/L to 2.0 mg/L, which is within the acceptable limit of 10 mg/L according to GPCB norms whereas some samples ex. Additionally, the maximum concentrations of heavy metals were observed for Magnesium (372.20 mg/L), Nickel (4.36 mg/L), Lead (BDL), Cadmium (1.67 mg/L), Chromium (BDL), Zinc (2.18 mg/L), Copper (BDL), Manganese (0.21 mg/L), and Cobalt (1.17 mg/L), as shown in Table 23.

4.4.2. Location 2 – Cargo Jetty

At the Cargo Jetty location, the recorded data shows that the mean value of temperature was recorded as 27.07±0.585°C, and the mean value of pH was observed as 7.873±0.038. The average salinity of the seawater was 37.324±1.686 ppt reflecting the salt content, while the TDS which indicates the presence of various anions and cations, had an average value of 43881.00±2851.613 mg/L. Turbidity values ranged from 23.2 to 57.1 NTU. The maximum values recorded for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) were 6.9 mg/L and 2.9 mg/L respectively (as shown in Table 24). The average COD value was determined to be 38.167±2.623 mg/L. The concentrations of Phenolic compounds and Petroleum hydrocarbons were within permissible limits set by CPCB in most of the samples except a few in case of PHc where some samples recorded a higher value with the maximum values ranging from 56.02 µg/L and 129.5 µg/L respectively for Phenolic compounds and PHc. The mean concentration of oil and grease in the marine water samples was 3.367±2.468 mg/L, which falls below the acceptable limit of 10 mg/L according to GPCB norms. Regarding heavy metal concentrations, the mean values for Magnesium, Nickel, Lead, Cadmium, Chromium, Zinc, Copper, Manganese, and Cobalt were 211.375±40.007 mg/L, 0.692±0.332 mg/L, BDL, 0.687±0.604 mg/L, BDL, 0.732±0.144 mg/L, BDL, 0.155 mg/L and BDL respectively as presented in Table 24.

4.4.3. Location 3 - Phang Creek

In case of Phang creek near the port, the mean value of temperature was recorded as 27.033±0.429°C and the pH value was recorded between 7.86 to 7.96. The average salinity of the seawater in the vicinity was found to be 36.467±1.305 ppt, while the TDS which indicates the presence of various anions and cations, had an average value of 44746.833±1486.111 mg/L. Turbidity values ranged from 7.2 to 10.8 NTU. Pollution indices such as Dissolved Oxygen and Biochemical Oxygen Demand, Phenolic compounds, and Oil and grease concentrations had maximum values of 6.5 mg/L, 3.2 mg/L, 11.32 µg/L, and 5.2 mg/L, respectively. The average value of PHc was 35.609±6.064 µg/L. In case of heavy metals, the mean values for Magnesium, Cadmium and Zinc were 264.142±42.132 mg/L, 0.150±0.268 mg/L, 0.425 mg/L, respectively. These values are presented in Table 25.

Table 23: Physico-chemical characteristics of the marine water from sampling location 1 (Offshore)

S. No	Parameters	1A		1B		1C		1D		1E		Control 1	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	25.40	25.10	25.30	25.10	25.60	25.30	25.70	25.50	24.90	25.10	24.90	24.90
2	pH	7.83	7.82	7.81	7.83	7.91	7.93	7.80	7.86	7.84	7.80	7.83	7.90
3	Salinity (ppt)	36.90	36.90	38.61	36.04	36.04	36.04	40.76	41.19	33.46	39.47	37.33	39.04
4	Total Dissolved Solids (mg/L)	46377	45034	45920	45906	45442	44921	46816	46608	46511	44914	45851	45410
5	Turbidity (NTU)	49.2	47.3	33.9	48.2	35.4	33.6	44.5	41.9	18.8	43.4	18.6	19.3
6	Dissolved Oxygen(mg/L)	7.00	7.00	6.80	6.50	6.80	6.70	6.90	6.80	6.60	6.60	6.30	6.30
7	Bio-Chemical Oxygen Demand (mg/L)	3.10	3.00	2.70	2.40	3.10	2.40	3.60	2.90	2.60	2.70	2.60	2.50
8	Chemical Oxygen Demand (mg/L)	38.00	32.00	36.00	34.00	40.00	32.00	38.00	32.00	36.00	34.00	30.00	28.00
9	Phenolic Compounds (µg/L)	41.02	45.44	26.17	46.91	35.58	24.11	39.65	35.00	14.26	33.67	11.02	11.4.7
10	Petroleum Hydrocarbons (µg/L)	67.25	65.25	139.29	137.55	81.80	79.45	50.85	49.20	61.24	62.95	97.25	98.30
11	Oil and grease (mg/L)	1.2	2.0	0.8	1.2	1.2	0.8	0.4	1.2	1.2	1.2	0.8	0.4
12	Magnesium (mg/L)	292.5	372.2	325	276.3	134.95	252.1	245.75	229	294.2	268.9	227.5	170.4
13	Nickel (mg/L)	BDL	0.85	BDL	BDL	4.36	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
15	Cadmium (mg/L)	0.09	0.09	0.31	0.07	0.88	0.83	0.16	1.67	1.58	0.95	0.10	0.97
16	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
17	Zinc (mg/L)	0.33	0.70	0.12	0.83	1.32	BDL	BDL	BDL	BDL	2.18	BDL	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	BDL	0.21	BDL	BDL	0.02	BDL	BDL	0.02	BDL	BDL	BDL	BDL
20	Cobalt (mg/L)	0.80	0.13	0.40	0.20	1.17	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Note: BDL denotes Below Detection Limit.

Table 24: Physico-chemical characteristics of the marine water from sampling location 2 (Cargo Jetty)

S. No	Parameters	2A		2B		2C		2D		2E		Control 2	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	26.1	26	27.8	27.5	27.3	27.4	27.5	27.3	27.4	27.3	26.8	26.5
2	pH	7.8	7.88	7.88	7.85	7.88	7.9	7.87	7.87	7.82	7.93	7.87	7.93
3	Salinity (ppt)	34.75	38.18	36.47	38.61	37.75	37.75	38.61	36.9	34.75	35.61	38.18	40.33
4	Total Dissolved Solids (mg/L)	445/82	46691	46982	43087	44081	46523	44976	40707	40508	38675	46405	44056
5	Turbidity (NTU)	57.1	55.7	54.3	54.7	55.1	55.7	36.6	36.1	34.2	24.8	28.8	23.2
6	Dissolved Oxygen(mg/L)	6.9	6.8	6.2	6.1	6.8	6.5	6.7	6.4	6.9	6.5	6.2	5.9
7	Bio-Chemical Oxygen Demand (mg/L)	2.7	2.7	2.6	2.6	2.7	2.6	2.6	2.7	2.9	2.7	2.7	2.3
8	Chemical Oxygen Demand (mg/L)	42	38	40	36	40	40	38	36	42	34	36	36
9	Phenolic Compounds (µg/L)	56.02	55.44	38.38	50.73	47.94	45.58	26.91	26.91	26.17	25.58	22.2	19.7
10	Petroleum Hydrocarbons (µg/L)	66.45	65.00	49.20	52.67	129.50	128.35	127.05	128.45	97.85	96.42	81.80	80.00
11	Oil and grease (mg/L)	1.6	5.6	5.2	4	0.8	0.8	7.6	0.8	3.6	1.2	6.8	2.4
12	Magnesium (mg/L)	147.45	208.85	154.2	210.1	219.85	239.35	252.75	263.9	255.3	196.15	161.35	227.3
13	Nickel (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.32	0.94	BDL	BDL	0.82
14	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
15	Cadmium (mg/L)	1.155	0.305	0.875	0.93	1.115	0.055	0.185	1.595	0.12	1.65	0.02	0.24
16	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
17	Zinc (mg/L)	0.81	0.82	BDL	0.565	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	BDL	BDL	BDL	0.16	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
20	Cobalt (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Note: BDL denotes Below Detection Limit

Table 25. Physico-chemical characteristics of the marine water from sampling location 3 (Phang Creek)

S. No	Parameters	3A		3B		3C		3D		3E		Control 3	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	26.5	26.3	27.5	27.4	27.5	27.5	27.1	27	26.8	26.5	27.3	27
2	pH	7.93	7.96	7.87	7.88	7.88	7.87	7.91	7.89	7.94	7.9	7.94	7.86
3	Salinity (ppt)	37.33	35.18	34.32	36.47	36.47	36.47	38.61	38.17	35.18	36.04	35.61	37.75
4	Total Dissolved Solids (mg/L)	43740	41597	43001	45381	46581	45271	44318	44001	46296	46231	45705	44840
5	Turbidity (NTU)	8.5	8.7	8	7.9	7.2	7.2	10.2	8.9	9.7	10.7	10.8	10.7
6	Dissolved Oxygen(mg/L)	6	5.9	5.9	5.6	5.9	5.5	6.1	5.9	6.5	6.2	6.2	5.9
7	Bio-Chemical Oxygen Demand (mg/L)	3.2	2.9	3.2	2.8	2.7	2.2	2.7	2.5	2.4	2.4	2.5	2.4
8	Chemical Oxygen Demand (mg/L)	42	36	36	34	40	38	28	24	32	28	30	30
9	Phenolic Compounds (µg/L)	6.61	6.02	4.11	2.64	3.67	3.67	8.82	11.32	8.23	6.32	11.02	9.55
10	Petroleum Hydrocarbons (µg/L)	35.70	32.00	45.50	45.25	32.95	31.30	28.05	29.95	41.80	40.45	31.61	32.75
11	Oil and grease (mg/L)	4.8	3.6	3.6	1.2	4.0	5.2	2.2	0.8	4.0	2.4	1.6	2.4
12	Magnesium (mg/L)	232.7	292.15	190.65	259.1	243.55	252.55	327.15	209.85	279.15	326.25	264.75	291.85
13	Nickel (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
15	Cadmium (mg/L)	0.055	0.89	0.12	0.005	0.225	0.045	0.01	0.065	0.025	BDL	0.055	BDL
16	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
17	Zinc (mg/L)	BDL	BDL	BDL	0.425	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
20	Cobalt (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Note: BDL denotes Below Detection Limit

4.5. Physico-chemical characteristics of the marine water samples of Season 3

In this third season study conducted in the present year, we closely monitored three distinct locations: Offshore, Cargo Jetty, and Phang Creek. A comprehensive analysis of physico-chemical characteristics in marine water samples was conducted at each of these sites. The collected data is thoughtfully presented in Tables 26 - 28. These findings serve as a significant source of information regarding the precise physico-chemical conditions prevailing at each of these locations. Consequently, they play a pivotal role in enhancing the comprehension of the environmental factors that exert influence on the quality of marine water in these specific areas. The description of the data in each station is detailed as below.

4.5.1. Location 1 - Offshore location

In the offshore location (Location 1), the recorded data shows that the mean value of temperature was recorded as 25.46±0.07°C. The pH values ranged between 7.90 and 8.11, with an average pH value of 7.95±0.06. The salinity of the seawater recorded the mean value as 39.14±3.23 ppt, while the TDS which indicates the presence of various anions and cations, had an average value of 36626.75±2493.75 mg/L. Turbidity values ranged from 6.10 to 16.20 NTU. The maximum Dissolved Oxygen and Biochemical Oxygen Demand were in the order of 7.30 mg/L and 3.20 mg/L respectively. The average COD value was determined to be 39.67±3.80 mg/L. The concentrations of Phenolic compounds and Petroleum hydrocarbons varied between 13.66 to 23.52 µg/L, and 9.53 to 23.80 µg/L, respectively. Both the values are comparatively less than the values recorded during the second season. The concentration of oil and grease ranged from 2.00 mg/L to 10.40 mg/L, which is slightly higher than the acceptable limit (10 mg/L) according to GPCB norms whereas some samples ex. Additionally, the maximum concentrations of heavy metals were observed for Magnesium (317.95 mg/L), Nickel (3.37 mg/L), Cadmium (0.73 mg/L), Zinc (1.18 mg/L), Manganese (0.72 mg/L), and Cobalt (1.03 mg/L), as shown in Table 26.

4.5.2. Location 2 – Cargo Jetty

At the Cargo Jetty location, the recorded data shows that the mean value of temperature was recorded as 25.34±0.051°C, and the mean value of pH was observed as 7.945±0.041. The average salinity of the seawater was 40.288±1.479 ppt reflecting the salt content, while the TDS which indicates the presence of various anions and cations, had an average value of 39291.58±1321.51 mg/L. Turbidity values ranged from 1.5 to 12.1 NTU, which is quite lower than the previous season sample data. The maximum values recorded for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) were 6.8 mg/L and 2.8 mg/L respectively (as shown in Table 27). The average COD value was determined to be 36.167±3.243 mg/L. The concentrations of Phenolic compound were between 7.69 µg/L to 11.08µg/Lwith an mean concentration of 9.498±0.976 µg/L. In case of Petroleum hydrocarbon, all the samples were well within the permissible limits set by CPCB and the maximum recorded concentration was 22.37 µg/L. The mean concentration of oil and grease in the marine water samples was 10.76±4.05 mg/L, which falls below the acceptable limit of 10 mg/L according to GPCB norms. Regarding heavy metal concentrations, the mean values for Magnesium, Nickel, Lead, Cadmium, Zinc and Cobalt were 162.424 mg/L, 0.525 mg/L, 0.090 mg/L, 0.380 mg/L, 3.315, 0.335 mg/L respectively, whereas Chromium, Copper and Manganese recorded a below detection limit in all the sampling points in Station 2 as given in Table 27.

4.5.3. Location 3 - Phang Creek

During the third season sampling in the Phang creek near the port, all the samples were subjected for analysis for various characteristics (Table 28). The mean value of temperature was recorded as 23.90±0.10°C and the pH value was recorded between 7.85 to 7.91. The average salinity of the seawater in the vicinity was found to be 40.00±3.045 ppt, while the TDS which indicates the presence of various anions and cations, had an average value of 40473.08±1043.34 mg/L. Turbidity values ranged from 8.5 to 24.3 NTU. Pollution indices such as Dissolved Oxygen and Biochemical Oxygen Demand, Phenolic compounds, and Oil and grease concentrations had maximum values of 6.6 mg/L, 3.0 mg/L, 12.08 µg/L, and 13.6 mg/L, respectively.

The average value of PHc was 16.858±4.033 µg/L. In case of heavy metals, the Mean±SD values of Magnesium, Nickel, Lead, Cadmium, Chromium, Manganese and Cobalt are 143.361±72.255 mg/L, 1.684±1.201 mg/L, 0.815±0.402 mg/L, 0.365±0.320 mg/L, 0.288±0.313 mg/L, 0.244 ±0.185 mg/L and 0.988±0.495 mg/L. The heavy metals such as Zinc and Copper were in the Below Detection Limits.

The data on Physico-chemical characteristics of the present study (2022-23) is compared with the physico-chemical characteristics of the study conducted during 2021-22 and 2020-2021 of the three different stations (Offshore, Cargo jetty and Phang creek) from DPA region as shown in Table 29.

Table 26: Physico-chemical characteristics of the marine water from sampling location 1 (Offshore)

S. No	Parameters	1A		1B		1C		1D		1E		Control 1	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	25.4	25.5	25.5	25.4	25.5	25.3	25.4	25.5	25.5	25.5	25.5	25.5
2	pH	7.90	7.91	7.91	7.92	7.93	7.95	7.94	7.92	7.99	7.98	8.11	7.99
3	Salinity (ppt)	35.44	42.36	36.74	44.52	37.17	38.47	41.06	42.22	33.28	38.90	38.47	41.06
4	Total Dissolved Solids (mg/L)	37242.00	37602.00	39650.00	38565.00	35347.00	34648.00	34181.00	37863.00	38830.00	37375.00	37502.00	30716.00
5	Turbidity (NTU)	16.2	9.4	8.7	6.1	10.3	7.2	11.3	7.2	13.1	9.7	14.5	9.4
6	Dissolved Oxygen(mg/L)	6.5	6.4	7.3	7.2	6.9	7.2	6.7	7	6.8	6.7	6.6	6.5
7	Bio-Chemical Oxygen Demand (mg/L)	3.20	2.80	2.70	2.60	2.70	3.00	2.70	2.90	2.60	2.40	3.00	2.60
8	Chemical Oxygen Demand (mg/L)	42.00	38.00	46.00	44.00	40.00	38.00	38.00	36.00	42.00	42.00	38.00	32.00
9	Phenolic Compounds (µg/L)	23.52	14.31	14.74	17.48	16.83	17.19	15.17	13.66	15.46	15.53	18.99	15.53
10	Petroleum Hydrocarbons (µg/L)	9.53	13.40	10.12	10.89	15.24	15.07	12.57	13.38	15.30	17.86	21.38	23.80
11	Oil and grease (mg/L)	8.4	5.6	5.6	4.8	3.2	2.0	7.6	6.0	9.8	9.2	10.4	9.6
12	Magnesium (mg/L)	317.95	131.05	195.6	116.4	189.15	59.4	83.8	91.05	229.7	114.8	174.4	210.1
13	Nickel (mg/L)	3.365	1.5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
15	Cadmium (mg/L)	0.725	0.085	BDL	BDL	0.53	BDL	BDL	0.065	0.175	0.46	0.165	0.42
16	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
17	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1.88
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.72
20	Cobalt (mg/L)	1.025	BDL	0.26	BDL	0.2	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Note: BDL denotes Below Detection Limit.

Table 27: Physico-chemical characteristics of the marine water from sampling location 2 (Cargo Jetty)

S. No	Parameters	2A		2B		2C		2D		2E		Control 2	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	25.4	25.3	25.4	25.3	25.4	25.4	25.4	25.3	25.3	25.3	25.3	25.3
2	pH	7.9	7.9	7.98	7.89	8.04	7.96	7.96	7.92	7.95	7.96	7.94	7.94
3	Salinity (ppt)	40.2	38.9	40.63	39.33	39.77	36.87	41.06	40.28	41.49	40.63	42.36	41.93
4	Total Dissolved Solids (mg/L)	38132	37483	38205	37966	38977	38550	41126	38604	40796	40583	40793	40284
5	Turbidity (NTU)	7.2	8.5	7.5	7.2	3.4	1.5	5.4	5.2	4.3	2.8	12.1	7.2
6	Dissolved Oxygen(mg/L)	6.7	6.3	6.7	6.5	6.8	6.3	6.7	6.5	6.6	6.6	6.5	6.4
7	Bio-Chemical Oxygen Demand (mg/L)	2.8	2.7	2.3	2.1	2.7	2.4	2.5	2.5	2.6	2.4	2.7	2.4
8	Chemical Oxygen Demand (mg/L)	42	38	38	36	34	32	40	36	38	32	32	36
9	Phenolic Compounds (µg/L)	7.69	9.28	9.42	8.7	10.35	9.78	8.92	10.28	8.77	8.99	10.71	11.08
10	Petroleum Hydrocarbons (µg/L)	1.24	1.76	3.14	3.88	11.34	14.86	11.27	12.73	18.08	22.37	16.89	12.28
11	Oil and grease (mg/L)	8.8	15.2	16	14	8.4	5.2	15.6	12.4	13.2	7.6	7.6	5.2
12	Magnesium (mg/L)	115.4	131.5	221.35	128.75	202.8	284.55	115.35	122.7	119.85	289.85	36.785	180.2
13	Nickel (mg/L)	0.79	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.26
14	Lead (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.09
15	Cadmium (mg/L)	0.415	BDL	0.41	BDL	BDL	0.16	0.455	BDL	BDL	0.39	BDL	0.45
16	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
17	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	3.315	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
20	Cobalt (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.335	BDL

Note: BDL denotes Below Detection Limit

Table 28. Physico-chemical characteristics of the marine water from sampling location 3 (Phang Creek)

S. No	Parameters	3A		3B		3C		3D		3E		Control 3	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	24.1	23.9	23.9	23.9	23.9	23.8	23.9	23.8	24.1	23.9	23.9	23.8
2	pH	7.88	7.87	7.87	7.86	7.9	7.87	7.91	7.91	7.89	7.86	7.91	7.85
3	Salinity (ppt)	41.37	40.5	40.93	35.72	42.24	37.6	41.8	40.93	43.54	43.11	38.75	33.53
4	Total Dissolved Solids (mg/L)	41347	37562	41230	41231	40507	39904	40906	40506	40293	40064	41362	40765
5	Turbidity (NTU)	12.4	8.5	16.4	19.6	18.9	17.3	11	17.3	24.3	19.2	23.2	15.3
6	Dissolved Oxygen(mg/L)	6.4	6.1	6.4	6.3	6.4	6.3	6.5	6	6.5	6.4	6.6	6.4
7	Bio-Chemical Oxygen Demand (mg/L)	3	2.7	2.6	2.2	2.4	2.3	2.8	2.4	2.8	2.6	2.8	2.7
8	Chemical Oxygen Demand (mg/L)	38	32.0	42	38	44	42	46	40	38	32	34	32
9	Phenolic Compounds (µg/L)	8.92	8.48	11.79	9.06	9.06	8.13	10.86	8.77	8.56	12.08	11.79	9.42
10	Petroleum Hydrocarbons (µg/L)	12.68	11.24	16.29	16.67	10.19	15.78	23.46	22.33	19.02	18.54	17.89	18.20
11	Oil and grease (mg/L)	9.6	6.8	8.8	7.6	7.2	10.4	12.4	7.2	13.6	7.4	5.6	8.4
12	Magnesium (mg/L)	92.55	87.2	92.05	185.7	258.9	91.75	93.2	173.45	206.6	234	180.8	24.13
13	Nickel (mg/L)	0.395	1.535	1.135	2.92	BDL	3.025	BDL	BDL	0.13	2.645	BDL	BDL
14	Lead (mg/L)	0.44	0.88	0.715	1.51	0.35	1.445	0.44	0.69	0.745	1.19	BDL	0.565
15	Cadmium (mg/L)	0.065	BDL	0.435	0.855	BDL	0.09	BDL	0.38	BDL	BDL	BDL	BDL
16	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	0.115	BDL	0.175	0.09	0.22	0.84
17	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	BDL	0.41	BDL	BDL	0.015	0.08	BDL	BDL	BDL	0.31	BDL	0.405
20	Cobalt (mg/L)	BDL	0.585	0.735	1.57	BDL	1.005	0.445	BDL	BDL	1.59	BDL	BDL

Note: BDL denotes Below Detection Limit

Table 29: Comparison of the mean physico-chemical characteristics of the present study (2022-231-22) water data with the data of 2020-21 and 2021-22

Parameters	Period of study (in year)								
	2020-2021			2021-2022			2022-23		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Temperature (^{0}C)	25.18	24.20	25.47	19.31	28.69	32.21	26.92	26.44	24.90
pH	8.12	8.11	8.22	8.11	8.03	7.92	7.82	7.87	7.93
Salinity (ppt)	36.37	37.88	38.20	37.25	39.34	35.07	40.08	37.14	39.81
Total Dissolved Solids (mg/L)	39443.36	40146.57	43872.58	39764.22	41872.28	37427.61	40367.97	44812.33	38797.14
Turbidity (NTU)	33.37	78.86	58.86	65.92	96.76	67.75	10.73	29.41	11.08
Dissolved Oxygen (mg/L)	6.04	5.97	4.81	6.56	5.58	6.39	5.10	6.38	6.58
Bio-Chemical Oxygen Demand (mg/L)	1.32	1.05	0.55	3.61	0.97	1.40	3.09	2.70	2.63
Chemical Oxygen Demand (mg/L)	27.44	29.50	28.50	44.83	40.22	44.17		35.16	38.00
Phenolic Compounds (mg/L)	9.21	12.13	7.77	6.72	13.16	11.71	17.86	25.23	11.93
Petroleum Hydrocarbons (mg/L)	12.47	13.89	30.52	57.30	26.07	2.01	34.37	70.01	14.19
Oil and grease (mg/L)	5.94	3.98	2.76	6.67	2.81	3.00	4.38	2.46	8.79
Magnesium(mg/L)	1997.45	1948.53	3153.30	1510.30	1656.04	246.85	105.12	244.30	155.08
Nickel (mg/L)	0.60	0.50	BDL	1.91	1.37	0.08	2.32	1.64	1.55
Lead (mg/L)	2.11	3.22	7.26	0.701	0.49	3.44	BDL	BDL	0.45
Cadmium (mg/L)	0.08	0.04	BDL	0.46	0.42	0.28	0.59	0.49	0.36
Chromium (mg/L)	0.29	0.68	BDL	0	0	0.00	BDL	BDL	0.29
Zinc (mg/L)	0.22	0.17	0.13	1.02	0.89	0.42	1.51	0.68	2.60
Copper (mg/L)	0.03	0.04	BDL	0	0.169	0.00	BDL	BDL	BDL
Cobalt (mg/L)	0.47	0.14	BDL	1.31	1.46	0.07	1.60	0.53	0.61

Note: BDL denotes Below Detection Limit.

Chapter 5 Marine Water Quality (Biological) - Phytoplankton

5.1. Introduction

"Planet Earth is dominated by the seas". One of the most important natural resources that cover much of the earth's surface is Ocean. First life on earth originated in the oceans. Ocean means continuous body of water and mixing of water. Mixing is the key dynamic character of the ocean. This dynamic character creates currents and exchanges between cold, deep waters and warmer surface waters. Intertidal, subtidal and basin are three main components of see zonation pattern (Davis, 1977).

The 3rd largest ocean of the world is the Indian Ocean. India forms a peninsula surrounded by the Arabian Sea in the west, the Bay of Bengal in the east and the main Indian Ocean in the south. Due to its seasonal weather fluctuations, Arabian Sea is well known for its biological adaptation to environment. Gujarat, western most state of India is part of Arabian Sea. Among all maritime states of India Gujarat has longest coastline of approximately 1600 km. Gujarat coasts having different coastal ecosystems like mangrove, sandy shores, muddy shores, rocky shores, mixed shores, wet sand shore, coral reefs and intertidal mudflats (Brink, 1993; Parasharya and Patel, 2014). Gujarat state is the only state in India bestowed with two gulfs, Gulf of Kachchh and Gulf of Khambhat. The Kachchh second largest district of the country with an area of 45,652 sq.km. Deendayal Port Authority (DPA) one among the 12 major ports of the country and it is located India's western coastal area. It is also called Deendayal Port very near to two famous cities of Gujarat state are Bhuj and Gandhidham. It is a largest Creek based Ports in the country.

Plankton denotes a group of organisms either animals (zooplankton) or plants (phytoplankton). Main phytoplankton in sea water are Diatoms (Tiwari and Nair, 1998; Thakur et al, 2015; Ceaumori et al. 2018), Cocolithophores, Sillicoflagellates, Blue green algae (Cynobacteria) and Dinoflagellates. Diatoms constitute the major part of the phytoplankton in sea water. Zooplankton comprises the second level in the food chain and includes Tintinnids, Foramonifers, Radiolarians, Amphipoda, Copepoda, Calanoida, Chaetognaths, larvae of benthic invertebrates and fish larvae etc. (Gajbhiye and Abidi, 1993; Thirunavukkarosu, 2013; Chakrabarty et al. 2017). The planktonic stages of invertebrates are economically important as a food for pelagic fishes. Zooplankton require a constant supply of oxygen (Dodson, 1992).

Diatoms occur both in the sea water and fresh water as well as in sediment. Marine diatoms are mostly Centric diatoms (Moura et al. 2007). Diatoms are most abundant around 50 meters below the sea surface and are more abundant in the cold waters of high latitudes. Diatoms are divided into two main types based on their shape- the Centric diatoms or Centrales, and the Pennate diatoms or Pennales (Tabassum, 2012). Dinoflagellates have plant like mechanisms such as photosynthetic activity, storage of energy (by synthesis of carbohydrates) etc. The Cyst-forming Dinoflagellates mostly occurred in all marine habitat. They are most primitive eukaryotes. Sometime some Dinoflagellates responsible for Harmful Algal Blooms in sea which causes death of fishes in large numbers. Algal bloom means rapid multiplication of dinoflagellates cells.

The zooplankton may be classified according to their habitat and depth, distribution, size and duration of planktonic life period (Omori and lkeda, 1984). There are the two main classification on base of habitat Marine plankton or Haliplankton and Freshwater plankton or Limnoplankton. Marine plankton further divided in to 3 types' ocean plankton, neritic plankton and brackish water plankton. Oceanic plankton or Off-shore plankton generally found in surface water & continental shelf region water whereas neritic zooplankton means occurring to continental zone to neritic or deep sea (Besiktepe et al, 2015). Brackish water plankton generally inhabiting brackish water like mangrove, estuaries and sea vegetation area.

The factor of size is very important to understanding the classification of both zooplankton and phytoplankton. Based on size various categories of plankton are nanoplankton (2-20 µm), microplankton (20-200 µm), mesoplankton (200 µm-2 mm), macroplankton (2-20 cm), megaplankton (> 20 mm), nanoplankton (2-20 µm) and smallest one is picoplankton (0.2-2 µm).

Understanding of diversity and distribution of marine organisms would not be complete without consideration of abiotic and biotic factors of marine environment. Amongst the various abiotic factors affecting the survival of marine invertebrates in coastal and estuarine regions, salinity and temperature are of primary importance (Rao and

Balasubramanian, 1996; Sreenivasulu et al, 2017). Planktons are affected by changes in biotic & abiotic factors of environment and can rapidly respond to climatic changes. Phytoplankton are primary producers of sea whereas as a primary consumers zooplankton play precious role to control the primary producers in sea. Benthic organisms and Higher vertebrate animals use plankton as a food material in Ocean life. Zooplankton and Phytoplankton are main prey food source for different Fishes. The main food items of Mesopelagic fishes are zooplankton larvae, juvenile fish and many small invertebrate animals.

Population always either stable or fluctuating, depends on environment and economical condition surrounding it (Taylor, 1988; Garzke et al. 2017). Population of plankton and other marine living organisms on which the whole aquatic life depends directly or indirectly is largely governed by the interaction of a number of biological, chemical and physical processes and tolerance to one or more of these conditions (Reid and Wood 1976). The population of plankton diversity largely related Seasonal and Monthly variability in Physical, Chemical and Biological parameters; Interspecific competition among the Zooplankton; Inter-relationship for prey and predator between zooplankton and their mostly predator animals; Grazing ratio of Zooplankton; Suspension of sediment; Fluctuation in Phytoplankton abundance; Waves, Currents and Tidal turbulence effect; Fluctuation in Chlorophyll a and Nutrients; Input of Organic and other Pollution creating sources; Fish potential ratio; Monsoon effect; Suddenly changes in atmosphere; Peak time of every seasons and it’s effect; Vertical migration of Zooplankton; Food selection pattern of predator; Collection time and number of collected samples, mixing of water column, high surf action, Seasonal upwelling and downwelling in water column. Sometimes it is observed that effect of one variable is not similar to another factor or variable. Above all factors are affected population of Plankton either by directly or indirectly.

5.2. Estimation of Chlorophyll and Phaeophytin

Phytoplankton (Chlorophyll a) pigment which is responsible for synthesizing the energy for metabolic activities of phytoplankton through the process of photosynthesis in CO_2 is used and O_2 is released is an essential part to understand the consequence of pollutants due to release in the system. To estimate this, known volume of water (500 ml) was filtered through a 0.45 µm Millipore Glass filter paper and the pigments retained on the filter paper were extracted in 90% acetone. For the estimation of chlorophyll *a* and phaeophytin the fluorescence of the acetone extract was measured using Fluorometer (Turner Design) before and after treatment with dilute acid (0.1N HCL).

5.3. Results on Chlorophyll and Phaeophytin concentration during Season 1

The concentration of phytopigments is inversely proportional to the turbidity of the waters and in general, Kandla waters owing to the high turbidity restricts sunlight penetration essential for nutrient uptake by phytoplankton and thus inhibiting primary production. The concentration of chlorophyll pigment in the water samples ranged from 0.25-1.16 mg/m^3 with a mean ± SD being 0.69±0.29 mg/m^3 in the Offshore (Table 30), 0.32 to 0.79 mg/m^3 with mean ± SD of 0.58±0.13 mg/m^3 in the Cargo Jetty (Table 31) and 0.15 to 0.60 mg/m^3 with mean ± SD being 0.33±0.12 mg/m^3 in the Phang creek location (Table 32).

Another phytopigment estimated was Phaeophytin, which is one of the breakdown products of Chlorophyll was also estimated in the water samples collected from all the three locations and the concentration of Phaeophytin in the marine water samples were in the concentrations such as 0.21-0.66 mg/m^3 with a Mean±SD of 0.39±0.16 mg/m^3 in the Offshore location (Table 30). In case of Cargo Jetty location, the concentration of the secondary pigment was in the range of 0.1 - 0.63 mg/m^3 with a Mean±SD of 0.25±0.17 mg/m^3 (Table 31) and in case of the creek location, the concentration of phaeophytin was almost similar when compared to the other two locations and was ranging between 0.12 – 0.32 mg/m^3 with a Mean±SD of 0.23±0.07 mg/m^3 (Table 32). An optimum ration of Chlorophyll to Phaeophytin of above 1.5 as expected for natural estuarine and coastal waters.

Table 30: Chlorophyll and Phaeophytin concentration observed in the Offshore site

Parameters	1A		1B		1C		1D		1E		1 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	1.120	0.850	0.537	0.442	0.765	0.750	0.830	0.770	1.160	0.250	0.450	0.380
Phaeophytin	0.350	0.210	0.340	0.420	0.280	0.63	0.660	0.330	0.550	BDL	0.260	0.220

Table 31: Chlorophyll and Phaeophytin concentration observed in the Cargo Jetty site

Parameters	2A		2B		2C		2D		2E		2 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.757	0.569	0.695	0.671	0.663	0.520	0.790	0.490	0.324	0.561	0.517	0.425
Phaeophytin	0.344	0.110	0.490	0.200	0.120	0.100	0.639	0.228	0.110	0.240	0.350	0.110

Table 32: Chlorophyll and Phaeophytin concentration observed in the Phang Creek site

Parameters	3A		3B		3C		3D		3E		3 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.332	0.324	0.603	0.347	0.203	0.350	0.279	0.489	0.339	0.284	0.272	0.150
Phaeophytin	0.242	0.300	0.296	0.245	BDL	0.320	0.200	0.200	0.135	0.157	0.124	0.320

5.4. Chlorophyll and Phaeophytin concentration during Season 2

The concentration of phytopigments is inversely proportional to the turbidity of the waters and in general, waters owing to the high turbidity restricts sunlight penetration essential for nutrient uptake by phytoplankton and thus inhibiting primary production. The concentration of chlorophyll pigment in the water samples ranged from 0.32-0.72 mg/m^3 with a mean ± SD being 0.52±0.15 mg/m^3 in the Offshore (Table 33), 0.229 to 0.845 mg/m^3 with mean ± SD of 0.466±0.205 mg/m^3 in the Cargo Jetty (Table 34) and 0.296 to 0.721 mg/m^3 with mean ± SD being 0.47±0.137 mg/m^3 in the Phang creek location (Table 35).

Another phytopigment estimated was Phaeophytin, which is one of the breakdown products of Chlorophyll was also estimated in the water samples collected from all the three locations and the concentration of Phaeophytin in the marine water samples were in the concentrations such as 0.12-0.76 mg/m^3 with a Mean±SD of 0.37±0.21 mg/m^3 in the Offshore location (Table 33). In case of Cargo Jetty location, the concentration of the secondary pigment was in the range of 0.101 - 0.4 mg/m^3 with a Mean±SD of 0.235±0.089 mg/m^3 (Table 34) and in case of the creek location, the concentration of phaeophytin was almost similar when compared to the other two locations and was ranging between 0.202 – 0.487 mg/m^3 with a Mean±SD of 0.336±0.092 mg/m^3 (Table 35). An optimum ration of Chlorophyll to Phaeophytin of above 1.5 as expected for natural estuarine and coastal waters.

Table 33: Chlorophyll and Phaeophytin concentration observed in the Offshore site

Parameters	1A		1B		1C		1D		1E		1 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.602	0.332	0.323	0.700	0.401	0.441	0.721	0.338	0.652	0.679	0.515	0.52
Phaeophytin	0.486	0.328	0.221	0.120	0.190	0.385	0.173	0.160	0.592	0.762	0.602	0.424

Table 34: Chlorophyll and Phaeophytin concentration observed in the Cargo Jetty

Parameters	2A		2B		2C		2D		2E		2 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.544	0.229	0.641	0.807	0.321	0.481	0.280	0.845	0.442	0.332	0.340	0.324
Phaeophytin	0.282	0.120	0.288	0.400	0.189	0.272	0.101	0.205	0.325	0.218	0.180	0..27

Table 35: Chlorophyll and Phaeophytin concentration observed in the Phang Creek

Parameters	3A		3B		3C		3D		3E		3 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.452	0.430	0.721	0.721	0.339	0.390	0.401	0.512	0.296	0.352	0.496	0.526
Phaeophytin	0.389	0.380	0.339	0.383	0.287	0.289	0.391	0.487	0.214	0.202	0.229	0.442

5.5. Chlorophyll and Phaeophytin concentration during Season 3

The concentration of phytopigments is inversely proportional to the turbidity of the waters and in general, waters owing to the high turbidity restricts sunlight penetration essential for nutrient uptake by phytoplankton and thus inhibiting primary production. The concentration of chlorophyll pigment in the water samples ranged from 0.52 -0.99 mg/m^3 with a mean ± SD being 0.72±0.16 mg/m^3 in the Offshore (Table 36), 0.319 to 0.702 mg/m^3 with mean ± SD of 0.481±0.117 mg/m^3 in the Cargo Jetty (Table 37) and 0.347 to 1.121 mg/m^3 with mean ± SD being 0.695±0.205 mg/m^3 in the Phang creek location (Table 38).

Another phytopigment estimated was Phaeophytin, which is one of the breakdown products of Chlorophyll was also estimated in the water samples collected from all the three locations and the concentration of Phaeophytin in the marine water samples were in the concentrations such as 0.22-0.58 mg/m^3 with a Mean±SD of 0.41±0.1 mg/m^3 in the Offshore location (Table 36). In case of Cargo Jetty location, the concentration of the secondary pigment was in the range of 0.118 - 0.44 mg/m^3 with a Mean±SD of 0.293±0.123 mg/m^3 (Table 37) and in case of the creek location, the concentration of phaeophytin was almost similar when compared to the other two locations and was ranging between 0.128 – 0.432 mg/m^3 with a Mean±SD of 0.299±0.103 mg/m^3 (Table 38). An optimum ration of Chlorophyll to Phaeophytin of above 1.5 as expected for natural estuarine and coastal waters.

Table 36: Chlorophyll and Phaeophytin concentration observed in the Offshore site

Parameters	1A		1B		1C		1D		1E		1 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.583	0.666	0.879	0.576	0.522	0.624	0.721	0.550	0.680	0.980	0.989	0.820
Phaeophytin	0.442	0.578	0.320	0.465	0.217	0.388	0.401	0.420	0.380	0.520	0.320	0.420

Table 37: Chlorophyll and Phaeophytin concentration observed in the Cargo Jetty

Parameters	2A		2B		2C		2D		2E		2 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.571	0.319	0.524	0.589	0.470	0.702	0.319	0.548	0.490	0.347	0.407	0.481
Phaeophytin	0.392	0.432	0.321	0.124	0.344	0.416	0.118	0.440	0.332	0.208	0.128	0.257

Table 38: Chlorophyll and Phaeophytin concentration observed in the Phang Creek

Parameters	3A		3B		3C		3D		3E		3 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.347	0.657	0.664	0.577	0.440	0.771	0.720	0.586	0.887	1.121	0.721	0.847
Phaeophytin	0.131	0.256	0.21	0.394	0.128	0.432	0.319	0.342	0.354	0.266	0.336	0.422

Table 39: Comparison of the mean chlorophyll and phaeophytin concentrations in the present study (2022-23) and the previous year data (20202-21, 2021-22)

Parameters	Period of study (in year)								
	2020-2021			2021-2022			2022 – 23 (Present study)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Chlorophyll mg/m^3	0.530	0.56	0.73	0.32	0.45	0.62	0.53	0.48	0.63
Phaeophytin mg/m^3	0.286	0.26	0.41	0.22	0.30	0.29	0.29	0.31	0.33

During the present year, the data obtained for Chlorophyll and Phaeophytin were compared with the previous year data (Table 39). During the current study, the Mean Chlorophyll concentrations were ranging between 0.48 – 0.63 mg/m^3, whereas the previous year's data were in the range of 0.53 – 0.73 mg/m^3 during 2020-2021 and 0.32 – 0.62 mg/m^3 during the year 2021-2022. Similarly, the Phaeophytin concentration was between 0.26 – 0.41 mg/m^3 during the year 2020-21 and 0.22 – 0.30 mg/m^3 during the year 2021-2022 and the current year recorded the mean phaeophytin concentration of 0.29 – 0.33 mg/m^3.

5.6. Phytoplankton sampling and analysis

Phytoplankton samples were collected in the ten prefixed sampling sites using standard plankton net with a mesh size of 51 µm. Plankton nets are with a square mouth covering an area of 0.900 cm^2 (30cm square mouth) fitted with a flow meter (Hydrobios). Nets were towed from a moving boat for 10 minutes and the plankton adhering to the net was concentrated in the net bucket. Plankton soup from the net bucket was transferred to a pre-cleaned and rinsed container and preserved with 5% neutralized formaldehyde. The containers were appropriately labelled. The initial and final flow meter reading was noted down for calculating the amount of water filtered to estimate plankton density. As per flow meter reading, a total amount of 165 m^3 of water was filtered by the net. One liter of water was separately collected for density estimation to counter check density estimation obtained by the flow meter reading. Quantitative analysis of phytoplankton (cell count) was carried out using a sedge wick-Rafter counting chamber. One ml of soup added to a Sedgwick counting chamber was observed under an inverted compound microscope. The number of cells present in individual cells of the counting chambers (1/1000) was noted and identified up to a generic level. Several observations were fixed to represent the entire quantity of the soup (generally more than30 times) and the recorded data were used to calculate the density (No/l) using the formula, $N = n \times v/V$ (where N is the total no/l; n is an average number of cells in 1 ml; v is the volume of concentrate; V is the total volume of water filtered). The phytoplankton diversity richness and evenness were past software.

5.6.1. Phytoplankton community structure recorded during Season 1

The study was conducted at 3 sites (or regions) at Deendayal Port and near area where dredging activities is going on Creek and the stations are Offshore, Cargo Jetty and Phang Greek.

5.6.1.1. Offshore

In this site, frequently observed species were *Actinocyclus sp, Bacillaria paxillifera colonies, Chaetoceros aequatorialis, Chaetoceros decipiens, Coscinodiscus* *radiatus,Coscinodiscus centrali, Ditylum brightwellii, Gyrosigma sp, Odontella mobiliensis, Odontella sinensis, Pseudo-nitzschia sp chain, Rhizosolenia imbricata, Thalassionema frauenfeldii colony, Thalassionema nitzschioides colony* whereas less observed species were *Amphora sp, Asterionellopsis sp colonies, Ceratium furca, Ceratium fusus, Climacosphaenia moniligera, Dinoflagellated Cyst, Gyrosigma acuminatum, Melosira sp chain, Oscillatoria sp, Rhizosolenia hebeta, Triceratium favus etc.* Total 66 Phytoplankton were recorded in this Offshore area. Highest population density was recorded at site 1D-Offshore (168000 Nos/m^3) and low density recorded at site 1control-Offshore (22880 nos/m^3). The maximum number of species observed in site 1D-Offshore (37 nos.) followed by 1C&1A-Offshore (36 nos.), 1B -Offshore (33 nos), and 1Control-Offshore (20 nos). The population density greatly varied (22880 nos/m^3 to 168000 nos/m^3). Dinoflagellats like *Ceratium furca, Ceratium fusus, Ceratium fusus, Pyrophacus sp and Dinoflagellates cysts* were recorded which are sometimes responsible for Algal Blooms in water. *Oscillatoria sp* and *Synuara sp (alga colony)* were frequently found in this area which indication of some level of water mixing. More number of species were recorded here result indicated may be because of water circulation pattern.

5.6.1.2. Cargo jetty

Total 61 Phytoplankton were recorded in this Cargo Jetty area. The population density greatly varied between 30240 Nos/l to 58080 Nos/m^3. Highest density value recorded at 2E-Cargo Jetty (58080 No/l) and lowest value was at 2D-Cargo Jetty (30240 No/m^3). The highest number of species noticed in the site 2E- Cargo Jetty (38 nos.) where as lowest in 2A-Cargo Jetty (22 nos.) The density and species number, both highest in 2E-Cargo Jetty. In this Cargo Jetty station commonly or frequently observed species were *Coscindiscus radiatus, Coscinodiscus centralis, Fragilaria sp colonies, Planktoniella sol, Pleurosigma sp, Synedra ulna, Thalassionema frauenfeldii colony, Thalassionema nitzschioides colony, Thalassiosira sp, Trieres mobiliensis etc.*

The rarely found species were *Asterionellopsis sp colonies, Bacillaria sp colonies, Campylodiscus sp, Chaetoceros decipiens, Entomoneis sp, Nitzschia longissima, Rhizosolenia alata, Thalassiosira rotula etc. Noctiluca sp* (mostly consider deep sea species) was recorded only in this site of station 2control-Cargo Jetty.

5.6.1.3. Phang Creek

The population density of phytoplankton ranged from 42400 No/l to 79520 No/l same way species availability ranged from 17 to 28 nos. Maximum and minimum value of population density were recorded in site 3A-Phang Creek (79520 nos/m^3) and 3C-Phang Creek (42400 No/m^3) respectively. Highest number of species recorded in site 3E-Phang Creek (28 nos) and lowest in site 3B&3D-Phang Creek (17 nos). Total recorded phytoplankton was 45 in this creek area. *Coscindiscus radiatus, Coscinodiscus asteromphalus, Coscinodiscus centralis, Coscinodiscus sp (Grazing), Pleurosigma sp. Thalassionema nitzschioides colony, Thalassionema frauenfeldii colony, Trieres mobiliensis,* etc. were frequently noticed in samples whereas less observed species were *Hyalodiscus sp, Odontella sinensis, Pseudo-nitzschia sp chain, Thalassiosira ferelineata.*

Overall view of Phytoplankton showed that a total 86 species of Marine phytoplankton were identified during winter season of the year 2022. Among them, 47-Centric diatoms, 26-Pennate diatoms, 6-Dinoflagellates, 1-Blue green algae, 3-Green algae, 1-Silioflagellates and some phytoplankton were unidentified. Plankton identification, both zooplankton and phytoplankton, were done by using relevant identification and taxonomic keys and with standard literatures, monographs and research articles. (Kasturirangan, 1963; APHA, 1992; Mitra et al., 2003;Goswami, 2005; Carling et al., 2004; Mandal, 2004; Hussain & Kalaiyarasi, 2013; Guglielmo et al., 2015; Hussain et al., 2016; Sreenivasulu et al., 2017; NIO,1998; NIO,2002). Some species like *Bellerochea sp chain, Biddulphia sp, Ceratium tripos, Coscinodiscus gigas, Diploneis sp, Gyrosigma acuminatum, Noctiluca sp, Pyrophacus sp, Surirella fastuosa, Dictyocha sp (Silicoflagellates), Dinoflagellated Cyst etc.* were rarely recorded during sample analysis. Input of the fresh water indicated by the presence of some common fresh water species like *Green algae, Oscillatoria sp*. Presence of Silicoflagellates (*Dictyocha sp)* and *Dinoflagellated (Noctiluca sp)* indication of bottom water circulation up to surface water layer in some level. Noctiluca genus is also considering bioluminescent organisms. Highest phytoplankton density was observed at the site 1D-Offshore (168000 No/m^3) and lowest was observed at site 1Control-Cargo Jetty (22880 No/m^3) (Table 40). Total number of highest species observed at site 2E-Cargo Jetty (38 nos) and lowest in site

3B/3D-Phang creek (17 nos). During laboratory analysis some Dinoflagellate species were also recorded like *Ceratium tripos, Ceratium fusus, Ceratium furca, Dinoflagellated cysts, Noctiluca sp and Pyrophacus sp*. Some Blue green algae represented by *oscillatoria sp and other unidentified species*.

The high population density composed by species like *Actinocyclus sp, Coscindiscus radiatus, Coscinodiscus asteromphalus, Coscinodiscus centralis, Fragilaria sp colonies, Navicula sp, Pleurosigma sp, Synedra ulna, Synura sp colony (Algae), Thalassionema frauenfeldii colony, Thalassionema nitzschioides colony, Trieres mobiliensis etc;* (Table 40). This result indicated that genus *Coscinodiscus sp*. *Thalassionema sp and Synedra sp*. were very common with good numbers in all sites. Synura sp colony (Algae) of heterokont algae which are mostly found in freshwater, also recorded in frequently. In some sites, least number of species and low density of phytoplankton might be responsible due to some factors like high pre-predation ratio, marine pollution (anthropogenic pressure), high turbidity, total suspended solids, water current and suddenly changes in environment conditions etc. The individual density of species of sites and all values of phytoplankton density, list of phytoplankton and others shown in Table 40.

5.6.1.4. Diversity Indices of Phytoplankton

According to Table 41, diversity indices calculation for phytoplankton showed that the Shannon Index ranged from (2.49 to 3.35) indicated moderate level to slightly high level of diversity status. High Shannon Index was recorded at 1A-Offshore (3.35) and low at 3B-Phang creek (2.49). Lowest evenness recorded at site 1D-Offshore (0.62) where number of species was 37 and highest density (168000 No/l), whereas highest was in at 1control-Offshore and 2A- Cargo Jetty (0.91) where species number were 20 and 22 respectively. Simpson dominance index ranged from 0.89 to 0.96 where higher value in 1A-Offshore (0.96) and lowest was at in 3B-Phang creek (0.89). Value of Margalef D (1.45 to 3.37) showed more variation in species numbers. (Table 41).

Table 40. Density of Phytoplankton at different sites of Deendayal Port during Season 1

Name of Sites	**Offshore**						**Cargo Jetty**						**Phang Creek**					
	1A	**1B**	**1C**	**1D**	**1E**	**1 control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2 control**	**3A**	**3B**	**3C**	**3D**	**3E**	**3 control**
Genus of Phytoplankton																		
Actinocyclus sp.	4960	2880	6560	16480	9120	640	1440	0	960	1440	2240	4160	0	2720	5920	9920	11360	4640
Amphiprora sp	0	0	0	0	0	0	0	1120	0	0	800	960	0	800	5920	0	0	0
Amphora sp	0	0	0	1600	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterionellopsis sp colonies	0	0	0	960	1120	800	0	0	0	1120	0	0	1280	0	0	0	0	0
Bacillaria paxillifera colonies	1920	960	2560	6240	0	800	0	2080	800	1280	0	1280	0	2080	0	0	960	0
Bacillaria sp colonies	0	0	0	0	0	0	0	0	0	0	960	0	0	0	0	0	0	0
Bellerochea sp chain	0	0	0	0	0	0	0	0	0	0	800	320	0	0	0	0	0	0
Biddulphia sp	0	0	0	0	0	0	0	0	480	0	0	1120	960	0	0	320	480	960
Campylodiscus sp	0	0	0	0	0	0	0	0	640	0	0	0	0	0	0	0	0	0
Ceratium furca	0	640	0	0	960	0	0	0	0	0	640	480	0	0	640	0	800	0
Ceratium fusus	0	800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium tripos	0	0	0	0	0	0	0	960	0	0	0	0	0	0	0	0	0	0
Chaetoceros aequatorialis	1760	6080	3200	1440	7520	640	0	0	0	960	1280	0	0	0	0	0	0	0
Chaetoceros curvisetus	0	0	0	0	0	1120	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros danicus	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros decipiens	1600	6240	960	5920	7040	0	1280	800	0	0	0	0	0	0	0	0	0	0
Chaetoceros sp.	960	0	0	0	6080	960	640	0	0	0	0	0	0	0	0	0	0	0
Climacosphaenia moniligera	0	0	0	1120	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium navicula	0	0	0	0	0	0	0	0	0	0	320	0	0	0	0	0	0	0
Coscindiscus radiatus	4160	2560	10240	3520	7680	640	2560	3520	4000	1920	4160	4800	6400	7680	5280	7680	7360	10240
Coscinodiscus asteromphalus	0	0	6880	25280	13280	0	0	2080	1760	0	5760	5120	6880	3520	3360	4960	5120	5120
Coscinodiscus centralis	6720	3200	2400	17280	0	0	3840	2880	2240	800	5440	960	6720	10880	2080	4960	5920	4640
Coscinodiscus gigas	0	0	0	0	0	0	0	0	0	0	0	0	1600	0	0	0	0	0
Coscinodiscus granii	0	640	0	0	2400	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus oculus-iridis	0	0	5440	0	12640	2560	2080	0	960	800	2400	1600	0	4800	0	0	0	0
Coscinodiscus sp (Grazing)	0	0	0	0	0	0	0	1920	800	0	0	0	3200	0	1600	1440	1440	960
Coscinodiscus sp.	0	0	0	0	0	0	1440	0	0	0	0	0	11520	9280	3520	6880	8320	3680
Coscinodiscus wailesii	3200	0	0	1280	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cylindrotheca sp	0	0	0	1920	1920	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyocha sp (Silicoflagellates)	800	0	640	0	0	0	0	0	0	640	0	640	0	960	0	0	0	0
Dinoflagellated Cyst	0	480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diploneis sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	480
Ditylum brightwelli	1120	0	1120	1120	2240	640	0	1120	0	0	800	480	320	0	0	0	0	640
Entomoneis sp	0	0	640	1920	1600	0	0	1440	0	0	0	0	0	0	0	0	0	0

Fragilaria sp colonies	1120	0	0	6240	5440	1440	1600	0	1440	1920	1120	1280	1440	1280	0	0	0	2240
Frustulia sp	0	0	0	0	0	0	0	0	0	960	0	0	0	0	0	0	0	0
Gren algae (Unidentified)	640	0	1600	3680	0	0	0	0	0	0	0	0	0	0	640	1760	0	800
Gyrosigma acuminatum	0	0	0	1120	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyrosigma sp.	1760	1120	1280	2240	1760	0	0	0	0	960	640	0	1760	0	480	480	160	480
Haslea sp	0	0	0	0	640	0	0	0	0	0	0	0	0	0	0	0	0	0
Hyalodiscus sp	1440	0	0	0	0	0	0	0	480	0	0	1120	0	0	1120	0	0	0
Melosira sp chain	0	0	0	640	0	0	0	0	0	480	480	0	0	0	0	0	0	0
Navicula sp.	960	320	0	1920	1600	0	1920	800	0	0	1280	960	0	0	0	0	0	1440
Nitzschia longissima	960	960	0	0	0	0	0	0	960	0	0	0	0	0	0	0	960	0
Nitzschia sigmoidea	0	0	0	1440	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia sp	0	640	3200	640	0	0	0	0	0	0	640	640	0	0	0	0	800	0
Noctiluca sp	0	0	0	0	0	0	0	0	0	0	0	480	0	0	0	0	0	0
Odontella sinensis	1920	1760	1600	2720	0	0	320	1440	800	0	800	800	0	0	0	0	1440	0
Odontella mobiliensis	640	960	0	6720	1600	0	0	2560	960	0	0	0	0	0	1280	0	1760	4480
Odontella sp	0	0	0	4160	1600	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria sp	0	0	1440	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria sp (Green algae)	0	0	0	0	0	0	0	0	0	0	0	0	800	0	640	0	0	0
Paralia sp chain	0	480	960	0	0	800	0	0	0	0	0	800	0	0	0	0	0	0
Pinnularia sp.	800	0	0	0	0	0	0	0	640	800	800	0	1600	0	0	0	0	0
Planktoniella blanda	0	0	1120	0	1760	0	0	1440	960	0	0	960	1760	0	320	0	1440	1280
Planktoniella sol.	640	0	0	2080	5760	800	1120	800	1920	960	320	1280	2400	0	0	0	0	0
Planktoniella sp	0	0	0	0	0	0	0	0	0	0	800	0	0	0	0	0	0	0
Pleurosigma sp.	0	1440	1920	2880	6240	1440	1440	1280	2240	1120	2560	2560	3200	1120	640	3520	2560	1600
Proboscia alata	800	960	640	800	0	0	1600	0	0	0	1280	0	0	0	0	0	0	0
Proboscia sp	0	0	0	0	0	0	0	0	0	960	1120	800	0	0	0	0	0	0
Pseudo-nitzschia sp chain	1440	1280	7040	3840	5920	0	1600	0	0	2080	960	0	0	0	0	0	1120	0
Pyrophacus sp	0	0	480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia alata	0	0	0	0	0	0	0	0	0	800	0	0	0	0	0	0	0	0
Rhizosolenia hebetata	0	1280	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia imbricata	800	1120	800	2720	0	0	0	0	0	0	0	7680	0	0	0	0	0	0
Rhizosolenia setigera	0	0	0	0	1760	0	1440	0	640	0	2080	0	0	0	0	0	640	0
Rhizosolenia shrubsolei	960	960	1440	0	0	0	0	0	480	0	0	0	0	0	0	0	0	0
Rhizosolenia sp	0	0	960	10240	960	1440	1600	0	0	960	4000	1440	0	0	0	0	3200	1440
Skeletonema sp chain	0	0	0	0	0	480	0	0	0	0	0	0	0	0	0	0	0	0
Surirella fastuosa	800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surirella sp.	0	640	800	0	1280	1760	1600	0	0	0	800	1440	1600	0	320	320	1120	320
Synedra sp	0	480	960	0	0	0	0	0	960	0	0	0	2400	0	0	0	0	0
Synedra ulna	1280	0	4000	4320	6560	800	960	800	960	960	1600	960	3040	1280	1760	2560	3360	4960
Synura sp colony (Algae)	1280	640	1600	1280	1280	0	0	1120	0	0	960	0	3840	0	0	4160	0	480
Thalassionema frauenfeldii	2720	1920	1920	8160	2720	1920	3360	6240	2400	2560	3840	2400	3200	2400	3040	0	4800	5440

colony																		
Thalassionema nitzschioides colony	2080	1600	6880	9120	5600	1760	1120	2560	4480	1920	960	960	3520	1440	960	5760	8640	3200
Thalassiosira ecentrica	0	0	0	0	2560	0	0	0	0	0	1440	0	0	0	0	0	0	0
Thalassiosira ferelineata	1440	800	1280	1120	0	0	0	0	0	0	0	0	1440	0	0	0	2400	0
Thalassiosira leptopus	480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiosira punctigera	2240	0	960	0	4000	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiosira rotula	0	0	0	0	0	0	0	0	1440	0	0	0	0	0	0	0	0	0
Thalassiosira sp.	640	2400	1280	0	7680	0	1440	0	1440	1440	640	800	3520	2720	960	5280	5120	4480
Triceratium broeckii	0	0	0	0	0	0	0	1600	480	800	800	480	1920	1120	0	0	0	0
Triceratium favus	0	0	800	0	0	0	0	800	160	0	640	960	0	0	0	0	800	0
Triceratium sp	0	800	0	0	1440	0	0	640	0	320	0	480	1920	0	320	640	800	320
Trieres mobiliensis	2080	640	0	0	4160	0	960	3040	1280	1120	960	800	1280	1920	1600	3680	480	800
Unidentified	1440	640	1600	3840	0	1440	0	640	960	160	960	320	0	0	0	0	0	0
Density of Phytoplankton (diff. sites wise.) (no/m^3)	**59200**	**48320**	**87200**	**168000**	**145920**	**22880**	**35360**	**43680**	**38720**	**30240**	**58080**	**52320**	**79520**	**56000**	**42400**	**64320**	**83360**	**65120**
Total= 1180640 no/m^3																		
Total No Of Genus/Species=**87**																		

Table 41. Diversity Indices of Phytoplankton at different sites at Deendayal Port during Season 1

Variables	Offshore						Cargo jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-Control**
Taxa_S	36	33	36	37	35	20	22	25	30	27	38	35	27	17	22	17	28	25
Individuals (Nos/m^2)	59200	48320	87200	168000	145920	22880	35360	43680	38720	30240	58080	52320	79520	56000	42400	64320	83360	65120
Dominance_D	0.05	0.06	0.05	0.06	0.05	0.06	0.06	0.06	0.05	0.05	0.05	0.06	0.06	0.11	0.08	0.09	0.07	0.07
Shannon Diversity	3.35	3.18	3.22	3.14	3.27	2.89	2.98	3.02	3.17	3.18	3.34	3.18	3.03	2.49	2.72	2.54	2.91	2.84
Simpson_1-D	0.96	0.94	0.95	0.94	0.95	0.94	0.94	0.94	0.95	0.95	0.95	0.94	0.94	0.89	0.92	0.91	0.93	0.93
Evenness	0.79	0.73	0.69	0.62	0.75	0.90	0.90	0.82	0.80	0.89	0.74	0.69	0.77	0.71	0.69	0.75	0.65	0.69
Menhinick	0.15	0.15	0.12	0.09	0.09	0.13	0.12	0.12	0.15	0.16	0.16	0.15	0.10	0.07	0.11	0.07	0.10	0.10
Margalef	3.19	2.97	3.08	2.99	2.86	1.89	2.01	2.25	2.75	2.52	3.37	3.13	2.30	1.46	1.97	1.45	2.38	2.17

5.6.2. Phytoplankton community structure recorded during Season 2

5.6.2.1. Offshore

In this site, frequently observed species were *Coscindiscus radiatus, Coscinodiscus granii, Coscinodiscus sp, Planktoniella blanda, Synedra ulna, Thalassiosira ferelineata, Thalassiosira sp.,* whereas less observed species were *Biddulphia sp, Coscinodiscus centralis, Diploneis sp, Entomoneis sp, Gyrosigma sp, Nitzschia sigmoidea, Nitzschia sp, Rhizosolenia sp, Thalassiosira ecentrica, etc.* Total 34 Phytoplankton were recorded in this Offshore area. Highest population density was recorded at site 1C-Offshore (16640 nos./m^3) and low density recorded at site 1B-Offshore(8160 nos./m^3).The maximum number of species observed in site 1C-Offshore (18 nos.) followed by 1D and 1control-Offshore (17 nos.), 1A-Offshore (14 nos.),1E-Offshore (13 nos.)and1B-Offshore (12nos).The population density greatly varied between (8160 nos./m^3 to 16640 nos./m^3).*Biddulphia sp, Navicula sp. Oscillatoria sp, Synedra ulna, Fragilaria sp colonies* were recorded which are sometimes considering for pollution indicator species in water. Oscillatoria sp was also recorded in location 1A-1C-Offshorewhich is generally found in freshwater or polluted water indicated mixing of water in some level.

5.6.2.2. Cargo jetty

Total 32 Phytoplankton were recorded in this Cargo Jetty area. The population density greatly varied between 6880 Nos/m^3 to 11200 Nos/m^3. Highest density value recorded at 2E-Cargo Jetty (11200 nos./ m^3) and lowest value was at 2B-Cargo Jetty (6880 nos./m^3). The lowest number of species noticed in the site 2A and 2B- Cargo Jetty (09 nos.) whereas highest in 2E-CargoJetty (15 nos.) The density and species number, both highest in 2E-Cargo Jetty. In this Cargo Jetty station commonly or frequently observed species were *Coscindiscus radiatus, Coscinodiscus centralis, Coscinodiscus sp, Planktoniella blanda, Thalassionema frauenfeldii colonies, etc.* The rarely found species were *Bacillaria paxillifera colonies, Biddulphia sp, Climacosphaenia sp, Cyclotella sp, Green algae, Navicula sp, Noctiluca sp, Thalassiosira punctigera, Protoperidinium sp, etc. The Dinoflagellated cysts like Noctiluca sp*(mostly consider deep sea species) and *Protoperidinium sp* were recorded only in this site of station 2C-Cargo Jetty and 2D-

Cargo Jetty respectively. Unidentified Green algae was also recorded in site 2A-Cargo Jetty.

5.6.2.3. Phang Creek

The population density of phytoplankton ranged from 11680 nos./m^3 to 26080 nos./m^3 same way species availability ranged from 16 to 28 nos. Maximum and Minimum value of population density were recorded in site 3A-Phang Creek (26080 nos./m^3) and 3D-Phang Creek (11680 nos./m^3) respectively. Highest number of species recorded in site 3E-Phang Creek (28 nos.) and lowest in site 3D-Phang Creek (16 nos.). Total recorded phytoplankton was 43 in this creek area. *Actinocyclus sp, Coscindiscus radiatus, Coscinodiscus centralis, Coscinodiscus wailesii, Gyrosigma sp, Odontella mobiliensis, Planktoniella blanda, Synedra ulna, Thalassiosira aculeate, Triceratium sp, etc.* were frequently noticed in samples whereas less observed species were *Bacillaria paxillifera colonies, Bacillaria paradoxa colonies, Ceratium furca, Coscinodiscus oculus-iridis, Diploneis elliptica, Nitzschia sigmoidea, Paralia sulcata colony, Triceratium broeckii etc in* this site. *Ceratium furca, Dinoflagellated cysts*, are sometimes responsible for algal blooms of water recorded which recorded in 3C-Phang Creek

Overall view of Phytoplankton showed that a total 55s pecies of Marine phytoplankton were identified during summer season of the year 2023. Among them,32-Centric diatoms, 17-Pennate diatoms, 3-Dinoflagellates, 2-Blue green algae and some phytoplankton were Unidentified. Plankton identification, both zooplankton and phytoplankton, were done by using relevant identification and taxonomic keys and with standard literatures, monographs and research articles (Kasturirangan, 1963; APHA, 1992; Mitra et al., 2003;Goswami, 2005; Carling et al., 2004; Mandal, 2004; Hussain and Kalaiyarasi, 2013; Guglielmo et al., 2015; Hussain et al., 2016; Sreenivasulu et al., 2017; NIO,1998; NIO,2002) ,etc. Some species like *Bacillaria paxillifera colonies, Bacillaria paradoxa colonies, Campylodiscus sp, Coscinodiscus asteromphalus, Coscinodiscus oculus-iridis, Ditylum brightwelli, Entomoneis sp, Nitzschia sigmoidea, Triceratium favus, Trieres mobiliensis, Protoperidinium sp, etc.,* were rarely recorded during sample analysis. Input of the fresh water indicated by the presence of some common fresh water species like *Green algae, Oscillatoria sp*. Presence of

Dinoflagellated (Noctiluca sp and *Protoperidinium sp)* indication of bottom water circulation up to surface water layer in some level. Noctiluca genus is also considering bioluminescent organisms. Highest phytoplankton density was observed at the site 3A-Phang Creek (26080 nos./m^3) and lowest was observed at site 2B-Cargo Jetty (6880 nos./m^3) (Table 42). Total number of highest species observed at site 3A-Offshore (24 nos.) and lowest in site 2A and 2B-Cargo Jetty (09 nos.).

The high population density composed by species like *Coscindiscus radiates, Coscinodiscus sp, Coscinodiscus centralis, Planktoniella blanda, Synedra ulna, Thalassionema frauenfeldii colonies, Thalassiosira sp, etc.* (Table 42). This result indicated that genus *Coscinodiscus sp*. *Thalassionema sp and Synedra sp.* were very common with good numbers in all sites. In some sites, least number of species and low density of phytoplankton might be responsible due to some factors like extreme hot weather because of summer season, high pre-predation ratio, marine pollution (anthropogenic pressure), high turbidity, total suspended solids, water current and suddenly changes in environment conditions etc. Diatoms, type of phytoplankton, constitute major part in total phytoplankton composition The individual density of species of sites viz. has been depicted in Table 42. All values of phytoplankton density, list of phytoplankton and others shown in Table 42.

5.6.2.4. Diversity Indices of Phytoplankton

According to Table 43, diversity indices calculation for phytoplankton showed that the Shannon Index ranged from (2.01 to 3.20) indicated moderate level to slightly high level of diversity status. High Shannon Index was recorded at 3E-Phang Creek (3.20) and low at 2A-Cargo Jetty (2.01). Lowest evenness recorded at site 3control-Phang Creek (0.69) whereas highest was in at 1A-Offshore (0.95). Dominance_D index ranged from 0.06 to 0.15 where higher value in 2A-Cargo Jetty (0.15) and lowest was at in 3B-Phang creek (0.06). Value of Margalef D (0.89 to 2.70) showed more variation in species numbers. (Table 43).

Table 42. Density of Phytoplankton at different sites of Deendayal Port during Season 2

Name of Sites	Offshore						Cargo Jetty						Phang Creek					
	1A	1B	1C	1D	1E	1 control	2A	2B	2C	2D	2E	2 control	3A	3B	3C	3D	3E	3 control
Genus of Phytoplankton																		
Actinocyclus sp.	0	0	0	960	640	640	1920	0	0	0	480	0	480	1440	800	1280	1760	640
Bacillaria paxillifera colonies	0	0	0	0	0	0	0	0	0	640	0	0	0	320	0	0	320	0
Bacillaria paradoxa colonies	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	480
Biddulphia sp	0	0	0	0	640	0	0	0	0	480	0	0	480	0	0	0	320	0
Campylodiscus sp	0	0	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium furca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	320	0	0	0
Climacosphaenia sp	0	0	0	0	0	0	0	0	0	480	0	0	0	0	0	0	0	0
Coscinodiscus asteromphalus	0	0	0	0	0	0	0	0	0	0	0	0	0	800	0	0	0	0
Coscindiscus radiatus	800	960	0	640	800	800	320	640	320	800	800	1440	1280	1120	1440	1280	960	640
Coscinodiscus centralis	0	0	0	1280	0	0	480	0	480	320	1440	0	960	1120	640	480	480	800
Coscinodiscus granii	1120	0	640	0	1600	960	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus oculus-iridis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	960	0
Coscinodiscus sp	1120	0	1280	640	0	1600	1600	1440	1600	0	1120	0	5280	1280	0	0	800	1440
Coscinodiscus sp (Grazing)	0	0	0	0	0	0	0	0	0	0	0	0	1920	0	0	0	0	0
Coscinodiscus wailesii	0	0	0	0	0	0	0	0	3200	1440	1120	1600	4000	1280	0	960	800	5120
Cyclotella sp	0	0	0	0	0	0	0	0	1120	0	0	0	0	960	640	0	0	0
Diploneis elliptica	0	0	0	0	0	0	0	0	0	0	0	0	0	320	0	0	0	0
Diploneis sp	0	480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ditylum brightwelli	0	0	0	0	0	0	0	0	0	0	320	0	0	0	0	0	0	0
Entomoneis sp.	0	0	0	0	0	640	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria sp colonies	11	0	64	0	0	0	0	0	0	0	0	0	80	32	64	0	0	16

	20		0										0	0	0			0
Green algae	0	0	0	0	0	0	960	0	0	0	0	0	0	0	480	480	0	
Gyrosigma sp.	0	0	800	0	0	800	0	0	0	0	0	0	480	0	0	320	480	480
Hemidiscus sp	0	320	0	320	0	0	0	0	640	0	0	0	640	0	0	0	0	640
Navicula sp.	0	640	0	0	0	640	0	0	0	0	0	320	800	0	0	0	0	640
Nitzschia sigmoidea	0	0	800	0	0	0	0	0	0	0	0	0	0	0	0	640	0	0
Nitzschia sp	0	0	960	0	0	0	0	800	0	0	320	640	0	960	640	0	640	0
Noctiluca sp	0	0	0	0	0	0	0	0	320	0	0	0	0	0	0	0	0	0
Odontella sinensis	800	480	320	480	0	0	0	320	640	0	320	320	0	0	0	0	800	0
Odontella mobiliensis	0	0	0	0	480	0	0	0	0	800	0	0	640	640	480	0	640	960
Oscillatoria sp	640	0	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paralia sulcata chain	0	0	0	0	0	0	0	0	0	0	0	0	640	0	0	0	0	0
Pinnularia sp.	320	0	0	960	0	1120	0	0	0	0	0	0	320	0	0	0	640	0
Planktoniella blanda	800	800	800	480	320	960	480	480	0	0	480	480	480	0	480	960	480	320
Planktoniella sol.	0	0	0	0	0	0	0	0	160	800	0	160	0	0	0	0	0	0
Pleurosigma sp.	0	0	0	960	640	640	0	0	0	0	1120	800	0	640	0	0	320	320
Protoperidinium sp.	0	0	0	0	0	0	0	0	0	480	0	0	0	0	0	0	0	0
Rhizosolenia setigera	640	0	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia sp	0	0	0	320	0	0	0	0	0	320	0	0	0	0	0	0	800	480
Surirella sp.	480	0	960	0	480	640	320	0	0	0	320	320	0	640	1120	320	480	320
Synedra crystallina	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	640	0
Synedra sp	0	0	0	0	1440	0	0	960	0	0	0	0	320	0	0	640	640	480
Synedra ulna	1120	1280	1120	1440	800	640	1120	0	0	640	480	960	960	640	1280	480	960	1120
Thalassionema frauenfeldii colonies	0	640	1600	1280	0	800	0	1280	1440	800	1120	1120	640	0	640	960	960	1440
Thalassionema nitzschioides colonies	0	480	0	0	1120	0	0	0	0	0	0	0	640	0	0	0	0	0
Thalassiosira aculeata	0	0	0	960	640	0	640	0	0	0	0	0	1120	640	320	640	960	0
Thalassiosira ecentrica	0	0	0	0	0	960	0	0	0	0	0	0	0	1280	960	0	960	1440
Thalassiosira	640	800	640	1120	0	800	0	0	0	0	0	480	640	0	1920	640	480	0

ferelineata																		
Thalassiosira punctigera	0	0	800	640	480	0	0	0	0	320	0	0	1120	800	0	0	2400	960
Thalassiosira sp.	800	960	1920	640	0	2560	0	0	**1120**	1120	800	960	0	0	1440	1120	1440	0
Triceratium broeckii	0	0	0	0	0	0	0	0	0	0	0	0	0	320	0	0	0	0
Triceratium favus	0	0	0	0	0	0	0	480	0	0	0	0	0	0	0	0	640	0
Triceratium sp	0	0	0	0	0	0	0	0	0	0	0	0	800	0	800	480	480	0
Trieres mobiliensis	0	0	0	0	0	0	0	480	0	0	0	0	0	0	0	0	0	0
Unidentified	0	320	1440	160	0	1280	0	0	0	0	960	0	640	1120	640	0	0	0
Density of Phytoplankton (diff. sites wise.)(no/m³)	**11040**	**8160**	**16640**	**13280**	**10080**	**16480**	**7840**	**6880**	**11040**	**9440**	**11200**	**9600**	**26080**	**16640**	**15680**	**11680**	**22240**	**18880**
Total= 1180640 no/m³																		
Total No Of Genus/Species=**55**																		

Table 43. Diversity Indices of Phytoplankton at different sites at Deendayal Port during Season 2

Variables	Offshore						Cargo jetty						Phang Creek					
	1A	1B	1C	1D	1E	1-control	2A	2B	2C	2D	2E	2-contrl	3A	3B	3C	3D	3E	3-control
Taxa_S	14	12	18	17	13	17	9	9	11	14	15	13	24	20	19	16	28	20
Individuals (Nos/m^2)	11040	8160	16640	13280	10080	16480	7840	6880	11040	9440	11200	9600	26080	16640	15680	11680	22240	18880
Dominance_D	0.08	0.10	0.07	0.07	0.09	0.07	0.15	0.14	0.15	0.09	0.08	0.10	0.09	0.06	0.07	0.07	0.05	0.11
Shannon Diversity Index (H)	2.59	2.40	2.81	2.72	2.46	2.74	2.01	2.09	2.10	2.54	2.58	2.39	2.82	2.90	2.83	2.68	3.20	2.63
Simpson_1-D	0.92	0.90	0.93	0.93	0.91	0.93	0.85	0.86	0.85	0.91	0.92	0.90	0.91	0.94	0.93	0.93	0.95	0.89
Evenness_e^H/S	0.95	0.92	0.92	0.89	0.90	0.91	0.83	0.89	0.74	0.91	0.88	0.84	0.70	0.91	0.89	0.92	0.88	0.69
Menhinick	0.13	0.13	0.14	0.15	0.13	0.13	0.10	0.11	0.10	0.14	0.14	0.13	0.15	0.16	0.15	0.15	0.19	0.15
Margalef	1.40	1.22	1.75	1.69	1.30	1.65	0.89	0.91	1.07	1.42	1.50	1.31	2.26	1.96	1.86	1.60	2.70	1.93

5.6.3. Phytoplankton community structure recorded during Season 3

5.6.3.1. Offshore

In this site, frequently observed species were *Actinocyclus sp, Bacillaria paxillifera colony, Coscindiscus radiatus, Coscinodiscus granii, Ditylum brightwelli, Rhizosolenia imbricata, Synedra ulna, Thalassionema frauenfeldii colony, Trieres mobiliensis* whereas less observed species were *Amphora sp, Biddulphia sp, Chaetoceros curvisetus, Chaetoceros danicus Corethron sp, Cylindrotheca sp, Green algae (unidentified, Nitzschia sigmoidea, Proboscia alata, Skeletonema sp chain, Thalassionema nitzschioides colony.* Total 56 Phytoplankton were recorded in this Offshore area. Highest population density was recorded at site 1A-Offshore (111040 nos./m^3) and lowest density was recorded at site 1D-Offshore(39200 nos./m^3).The maximum number of species observed in site 1B-Offshore (35 nos.) followed by 1A (33nos.), 1Control (30 nos.), 1C-Offshore (27 nos.), 1D-Offshore (22 nos.) and 1E-Offshore (17 nos.). The population density greatly varied between (39200 nos./m^3 to 111040 nos./m^3). *Biddulphia sp, Navicula sp. Surirella sp, Synedra ulna, Fragilariopsis sp colony, Skeletonema sp chain, Pleurosigma sp.* were recorded which are sometimes considering for pollution indicator species in water. Green algae sp and one algae bunch (group) were also recorded in location 1Control-1C-Offshore respectively which may be indication of freshwater or polluted water mixing with seawater. The *Noctiluca sp, consider* as a Dinoflagellate and Bioluminescence algae, was also recorded in site 1B and 1C of Offshore. Golden brown naked biflagellate algae *Pyrophacus sp* also recorded in site 1B-Offshore.

5.6.3.2. Cargo jetty

Total 54 Phytoplankton were recorded in this Cargo Jetty area. The population density greatly varied between 30080 Nos/m^3 to 100000 Nos/m^3. Highest density value recorded at 2B-Cargo Jetty (100000 nos./ m^3) and lowest value was at 2D-Cargo Jetty (30080 nos./m^3). The lowest number of species noticed in the site 2C-Cargo Jetty (21 nos.) where as highest in 2Control-CargoJetty (32 nos.). In this Cargo Jetty station commonly or frequently observed species were *Coscindiscus radiatus, Coscinodiscus granii, Nitzschia sp, Planktoniella blanda, Pleurosigma sp, Rhizosolenia imbricata,* *Thalassionema frauenfeldii colony, Trieres mobiliensis etc.* The rarely found species were *Bacillaria paxillifera colonies, Biddulphia sp, Chaetoceros curvisetus, Chaetoceros decipiens, Coscinodiscus oculus-iridis, Entomoneis sp, Nitzschia obtusa, Pinnularia sp, Rhizosolenia bergonii, Thalassiosira aculeata etc. The Dinoflagellated like Noctiluca sp*(mostly consider deep sea species) and *Protoperidinium sp* were also observed during microscopic analysis that may be water circulation from deep water to upper surface. Unidentified Green algae was also recorded in site 2A-Cargo Jetty. Some unidentified larva and umidentified species were also recorded.

5.6.3.3. Phang Creek

The population density of phytoplankton ranged from 52960 nos./m^3 to 57440 nos./m^3 same way species availability ranged from 21 to 31 nos. Maximum and Minimum value of population density were recorded in site 3Control-Phang Creek (57440 nos./m^3) and 3A-Phang Creek (52960 nos./m^3) respectively. Highest number of species recorded in site 3E-Phang Creek (31 nos.) and lowest in site 3D/3A-Phang Creek (21 nos.). Total recorded phytoplankton was 47 in this creek area. *Actinocyclus sp, Bacillaria paxillifera colony, Coscindiscus radiatus, Coscinodiscus granii, Fragilariopsis sp colony, Nitzschia sp, Rhizosolenia imbricata, Synedra ulna, Thalassionema frauenfeldii colony, Trieres mobiliensis, etc.* were frequently noticed in samples whereas less observed species were *Biddulphia sp, Chaetoceros peruvianus, Dictyocha sp (Silicoflagellates), Entomoneis sp, Lyrella sp, Odontella sinensis, Pseudo-nitzschia sp Chain, Thalassiosira punctigera, Thalassiosira eccentricA etc. in* this site. *Oscillatoria sp.*(blue Green algae), Green algae *were also recorded*, which are generally found in fresh water and estuarine area.

Overall view of Phytoplankton showed that a total 72 species of Marine phytoplankton were identified during winter season of the year 2024. Among them,43-Centric diatoms, 18-Pennate diatoms, 5-Dinoflagellates, 1-Blue green algae, 3-Green algae and 1-silicoflagellates and one phytoplankton's was unidentified. Some species like *Amphora sp, Biddulphia sp, Campylodiscus sp, Chaetoceros peruvianus, Dictyocha sp (Silicoflagellates), Lyrella sp, Oscillatoria sp.(blue Green algae), Proboscia alata, Pseudo-nitzschia sp Chain, Thalassiosira eccentrica etc.*, were rarely recorded during sample analysis. Input of the fresh water indicated by the presence of some common fresh water species like *Green algae*, *Oscillatoria sp*. Presence of *Dinoflagellated (Noctiluca sp* and *Protoperidinium sp, Pyrophacus sp)* indication of bottom water circulation up to surface water layer in some level. Noctiluca genus is also considering bioluminescent organisms and deep water species. Dictyocha sp (Silicoflagellates) was also recorded in all three station of Kandala region. Highest phytoplankton density was observed at the site 1A-Offshore (111040nos./m^3)and lowest was observed at site 2D-Cargo Jetty (30080 nos./m^3) (Table 44). Total number of highest species observed at site 1B-Offshore (35 nos.) and lowest in site 1E-Offshore (17 nos.).

The high population density composed by species like *Actinocyclus sp, Bacillaria paxillifera colony, Coscindiscus radiatus, Coscinodiscus granii, Fragilariopsis sp colony, Nitzschia sp, Planktoniella blanda, Pleurosigma sp, Rhizosolenia sp, Rhizosolenia imbricata, Synedra ulna, Synedra sp, Thalassionema frauenfeldii colony, Trieres mobiliensis* (Table 44). This result indicated that genus *Coscinodiscus sp*. *Rhizosolenia and Synedra sp.* were very common with good numbers in all sites. In some sites, least number of species and low density of phytoplankton might be responsible due to some factors like extreme cool weather because of winter season, high pre-predation ratio, marine pollution (anthropogenic pressure), high turbidity, total suspended solids, water current and suddenly changes in environment conditions etc. Diatoms, type of phytoplankton, constitute major part in total phytoplankton composition The individual density of species of sites viz. has been depicted in Table 3. All values of phytoplankton density, list of phytoplankton and others shown in (Table 44).

5.6.4.4. Diversity Indices of Phytoplankton

According to Table 45, diversity indices calculation for phytoplankton showed that the Shannon Index ranged from (1.98 to 3.17) indicated moderate level to slightly high level of diversity status. High Shannon Index was recorded at 1B-Offshore (3.17) and low at 2C-Cargo Jetty (1.98). Lowest evenness recorded at site 2B-Cargo Jetty (0.32) whereas highest was in at 2D-Cargo Jetty (0.83). Dominance_D index ranged from

0.05 to 0.32 where higher value in 2B-Cargo Jetty (0.32) and lowest was at in 1B-Offshore (0.05). Value of Margalef D (1.50 to 2.76) showed more variation in species numbers (Table 45).

Table 44. Density of Phytoplankton at different sites of Deendayal Port during Season 3

Name of Sites	Offshore						Cargo Jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1 control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2 control**	**3A**	**3B**	**3C**	**3D**	**3E**	**3 control**
Genus of Phytoplankton																		
Actinocyclus sp	0	4000	2080	1280	1600	4320	640	0	1760	0	480	3360	960	320	1280	2080	2720	2080
Amphora sp	0	640	0	0	0	0	480	1440	0	0	0	0	0	0	0	0	0	0
Bacillaria paxillifera colony	2400	960	1280	960	0	1280	0	0	0	1440	0	1920	2080	2240	2880	0	1600	2240
Bellerochea sp chain	960	0	0	0	1440	0	0	0	0	0	0	0	0	0	0	0	0	0
Biddulphia sp	0	0	0	0	0	1440	0	0	0	0	0	960	0	0	0	0	2880	0
Campylodiscus sp	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	960
Chaetoceros curvisetus	1440	0	0	0	0	0	0	0	0	1920	0	0	0	0	0	0	0	0
Chaetoceros danicus	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros decipiens	8480	6720	0	0	0	0	0	1760	0	0	1120	0	0	0	0	0	0	0
Chaetoceros peruvianus	8160	3520	2080	2560	0	0	0	0	0	0	0	0	0	1440	0	0	0	0
Chaetoceros sp	6400	5280	3360	0	0	1920	800	3360	0	0	0	1120	0	0	0	0	0	0
Climacosphaenia sp	0	0	0	0	0	0	0	0	0	0	0	640	0	0	0	0	0	0
Corethron sp	640	960	0	0	0	0	0	0	0	480	0	0	0	0	0	0	0	0
Coscindiscus radiatus	13920	8480	10880	2720	1920	3520	3200	1440	4320	3360	3200	3360	5920	7520	3360	5440	2080	8480
Coscindiscus sp	0	7520	0	0	0	12480	1600	0	0	0	480	10880	3360	960	0	960	1600	0
Coscinodiscus centralis	0	2720	3840	2560	2240	8480	2560	4320	3840	2080	2240	5920	4960	4160	3360	4960	2720	5920
Coscinodiscus granii	21440	11680	12480	5440	13920	41600	9760	56000	38400	4160	34400	14400	11520	8480	11520	10720	8640	6720
Coscinodiscus oculus-iridis	0	0	0	0	0	0	640	0	0	0	800	0	0	0	0	0	0	0
Coscinodiscus wailesii	0	0	0	0	1120	1120	0	0	0	0	0	0	0	0	0	0	0	0

Cylindrotheca sp	0	1120	0	0	0	0	0	0	0	0	640	0	0	0	0	0	0	0
Dictyocha sp (Silicoflagellates)	0	800	0	960	0	0	0	2240	0	0	0	0	0	800	0	0	800	0
Diploneis sp	0	0	0	0	0	1120	0	0	0	0	0	0	0	0	0	0	0	0
Ditylum brightwelli	2240	1120	1440	1600	0	2240	960	0	0	0	800	0	0	0	0	0	0	0
Entomoneis sp	0	0	0	0	0	0	0	0	800	0	0	0	0	0	800	0	0	0
Fragilariopsis sp colony	1600	1600	1600	0	800	3200	1120	0	0	960	1600	3200	0	0	1920	4160	3200	2400
Frustulia sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	640
Green algae (unidentified)	0	0	0	0	0	640	320	0	0	0	0	0	0	0	320	800	0	1120
Gyrosigma sp.	0	0	640	0	0	640	0	1280	960	0	480	640	0	1440	0	2080	640	1440
Lyrella sp	0	0	0	0	0	0	0	0	0	960	0	0	0	640	0	0	0	0
Melosira sp colony	960	1120	0	480	0	0	0	0	0	0	0	0	0	0	640	0	0	800
Navicula lyra	800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula sp.	0	1760	1760	0	0	800	0	0	0	0	0	640	320	1120	0	2080	0	480
Nitzschia obtusa	0	0	0	0	0	960	0	0	1280	0	0	0	0	1600	1600	0	960	0
Nitzschia sigmoidea	1120	0	0	0	0	800	0	0	1120	800	0	960	0	0	1760	960	0	1440
Nitzschia sp	0	0	800	0	0	1600	960	3520	1920	960	3360	1600	4160	3840	3200	4800	1920	5600
Noctiluca sp	0	1440	1920	0	0	0	0	0	320	0	0	1120	0	0	0	0	0	0
Odontella sinensis	1120	1120	2240	1600	0	0	0	3360	0	0	1760	480	0	0	0	0	0	320
Odontella mobiliensis	2080	1600	0	1280	0	0	0	4160	0	800	0	1280	0	2240	1920	0	2240	2240
Oocystis sp	0	0	0	0	0	0	0	1600	0	0	0		0	0	0	0	0	0
Oscillatoria sp.(blue Green algae)	0	0	0	0	0	0	0	0	0	0	0	1280	0	0	960	0	0	800
Pinnularia sp	0	0	0	0	0	0	800	0	0	0	0	0	0	0	0	0	0	0
Planktoniella blanda	1440	1440	2080	1120	0	2240	480	1600	1120	640	0	1120	0	1440	480	0	480	160
Planktoniella sol	1440	800	1600	0	0	0	0	1920	320	320	0	0	0	0	0	1280	480	0
Pleurosigma angulatum	800	0	0	0	0	0	0	1280	0	0	1600	0	0	0	0	640	800	0
Pleurosigma sp	1440	1920	0	800	1120	1120	960	2240	4480	1120	1600	320	2560	2080	1600	1600	1920	3520
Proboscia alata	1120	0	0	0	0	0	0	0	0	0	0	0	0	960	0	0	0	0
Proboscia sp	1280	0	0	800	0	0	0	1920	0	0	0	960	1600	0	0	0	0	0
Protoperidinium sp	0	0	0	0	0	0	0	0	0	0	0	640	0	0	0	0	0	0
Pseudo-nitzschia sp Chain	0	800	1600	0	0	2080	0	0	0	0	0	1280	0	0	0	0	640	0
Pyrophacus sp	0	1120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia bergonii	0		0	0	0	0	0	0	0	640	0	0	0	0	0	0	0	0
Rhizosolenia imbricata	1280	7520	2080	3360	0	1600	1280	0	1920	1120	1760	960	2080	1600	1600	0	1920	2560

Rhizosolenia setigera	0	7040		1920	2240	2240	0	0	1440	2080	0	0	0	0	960	0	960	0
Rhizosolenia sp	6880	7680	6080	3200	4160	1760	1600	0	2400	2240	2560	0	3200	3200	5600	4960	5280	1920
Skeletonema sp chain	0	1120		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surirella sp.	1120	960	320	0	640	480	480	1440	0	0	640	640	1280	320	1280	1280	640	480
Synedra acus	0	0		0	0	0	0	0	0	1280	0	2560	1600	0	0		960	0
Synedra sp	960	1440	1440	0	2080	0	800	3200	1760	0	0	0	2400	2240	0	1920	1760	1440
Synedra ulna	3840	3520	2240	320	1600	4320	1440	2400	0	960	960	2560	3360	2560	2080	1920	960	3360
Thalassionema frauenfeldii colony	9920	7520	1760	3680	1920	1440	800	1920	5920	1120	4800	1600	0	2560	2560	2880	1920	800
Thalassionema nitzschioides colony	0	0	0	1920	2560	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiosira aculeata	0	0	0	480	1920	1120	960	0	0	0	0	0	640	960	0	640	480	1280
Thalassiosira punctigera	0	0	0	0	0	0	0	0	0	0	0	0	480	0	0	0		0
Thalassiosira eccentrica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	480	0	320	0
Thalassiosira sp.	0	2560	3360	1280	1440	1760	800	0	640	1120	1760	1920	2080	1600	3200	2880	640	0
Trachyneis sp	0	0	0	0	0	0	0	0	0	0	0	0	1120	1440	800	0	0	640
Triceratium favus	0	0	0	0	0	0	0	320	0	640	0	1440	0	800	1120	0	640	0
Triceratium sp	1280	1120	1280	0	0	0	640	0	0	0	0	1120	480	640	0	0	1280	960
Trieres mobiliensis	2080	0	1440	1440	1280	0	1120	800	1280	0	1440	1280	1760	0	2080	2080	2080	1440
Tripos furca	960	960	1600	0	0	0	0	800	0	960	0	0	0	0	0	0	0	0
Tripos muelleri	0	0	0	0	0	1440	0	0	0	0	0	960	0	0	0	0	0	0
Unidentified Larva	0	0	0	0	0	0	0	0	480	0	0	0	0	0	0	0	0	0
Unknown algae group(bunch)	0	0	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unidentified	800	0	0	0	0	800	0	0	800	0	640	0	0	0	640	0	0	1120
Density of Phytoplankton (diff. sites wise.)(no/m^3)	111040	108960	70080	39200	41760	102080	32640	100000	73440	30080	66880	67200	52960	55040	56640	56160	53440	57440
Total= 1241920 no/m^3																		
Total No Of Genus/Species=**74**																		

Table 45. Diversity Indices of Phytoplankton at different sites at Deendayal Port during Season 3

	Offshore						Cargo jetty						Phang Creek					
Variables	**1A**	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-control**
Taxa_S	33	35	27	22	17	30	24	23	21	23	22	32	21	27	27	21	31	29
Individuals (Nos/m^2)	111040	108960	70080	39200	41760	102080	32640	100000	73440	30080	66880	67200	52960	55040	56640	56160	53440	57440
Dominance_D	0.08	0.05	0.08	0.07	0.14	0.19	0.12	0.32	0.29	0.06	0.28	0.09	0.09	0.07	0.08	0.08	0.06	0.07
Shannon Diversity Index (H)	2.90	3.17	2.91	2.88	2.42	2.47	2.71	1.99	1.98	2.95	2.06	2.94	2.70	2.98	2.94	2.76	3.11	3.00
Simpson_1-D	0.92	0.95	0.92	0.93	0.86	0.81	0.88	0.68	0.71	0.94	0.72	0.91	0.91	0.93	0.92	0.92	0.94	0.93
Evenness_e^H/S	0.55	0.68	0.68	0.81	0.66	0.39	0.63	0.32	0.35	0.83	0.36	0.59	0.71	0.73	0.70	0.75	0.73	0.70
Menhinick	0.10	0.11	0.10	0.11	0.08	0.09	0.13	0.07	0.08	0.13	0.09	0.12	0.09	0.12	0.11	0.09	0.13	0.12
Margalef	2.75	2.93	2.33	1.99	1.50	2.51	2.21	1.91	1.79	2.13	1.89	2.79	1.84	2.38	2.38	1.83	2.76	2.56

Chapter 6 Marine Water Quality-Biological (Zooplankton)

6.1. Introduction

Zooplankton are the attractive, various and plentiful group of faunal species living inside the water bodies throughout the world. Most of the zooplankton are microscopic which can drift with the currents. Although most of them can swim, they have no ability to progress against water currents (Alcaraz and Calbet, 2003). They are representatives of all key invertebrate phyla and eventually support to the most marine life. They directly serve as a food resource for various young fish (larvae) and invertebrates such as larvae of squid and lobster, many small planktivorous fish such as sardine and anchovy, and even a few large marine animals such as baleen whales and manta rays etc. They also play important role in food web by indirectly supporting a few large ocean predators such as tuna, sharks etc, which feed upon the small planktivorous fish. In this way they are the major link in the marine life in between phytoplankton and fish including commercially important species, their study is the important part for getting knowledge of the functioning of marine ecosystems (Alcaraz and Calbet, 2003). They are subdivided into holoplankton and meroplankton. Holoplankton are nothing but the permanent members of the plankton which spend their entire lives in the water column while meroplankton are the temporary members. Zooplankton are powerfully approachable to environmental variables such as sunlight, temperature, salinity, pH, dissolved oxygen, food availability etc.

The study was conducted at 3 sites in Deendayal Port area and nearby areas where dredging activities are going on. The three selected study stations are Offshore, Cargo Jetty and Phang Creek.

6.2. Methodology

The present investigation was carried out in the three sampling locations such as offshore dredging, cargo jetty and Phang creek dumping site during January 2022 and September 2022 for three sampling seasons. In each location five replicate samples and one control samples were collected. Zooplankton samples were collected using a standard zooplankton net with a mouth area of 0.25 m^2 fitted with a flow meter. The net was towed from a boat for 5 min with a constant boat speed of 2 nautical miles per hour. The initial and final reading in the flow meter was noted down and the soup collected in the plankton bucket was transferred to appropriately labeled container and preserved with 5% neutralized formaldehyde. To counter-check the zooplankton density values obtained, water samples of 100 Lwere collected and preserved, which was later analysed for zooplankton density. One ml of the zooplankton soup was added to a Sedgwick counting chamber and was observed under a compound microscope. The group/taxa were identified using standard identification keys and their number was counted. Random cells in the counting chamber were taken for consideration and the number of zooplankton was noted down along with their binomial name. This was repeated for five 1 ml samples and the average value was considered for the final calculation. For greater accuracy, the final density values were counter-checked and compared with the data collected by the settlement method. Univariate measures [Shannon-Wiener diversity index (H'), Margalef's species richness (d), and Pielou's evenness (J'), Simpson dominance (D)] were determined using past software.

6.3. Results

6.3.1. Distribution and density of Zooplankton during Season 1

6.3.1.1. Offshore

The Calanoida(unidentified), Clausocalanus sp (Calanoida), Copepoda eggs sacs (egg pouch), Cyclopoida (unidentified), Nauplius larvae of Barnacles, Nauplius larvae of Crustacea, Oithona nana (Cyclopoida), Radiolarian skeletons, Sponge Spicules etc. were the mostly common zooplankton throughout observed in all sites of Offshore area. Highest population density was recorded at site 1D-Offshore (255840 No/100m^3) and lowest density in 1control-Offshore (18080 No/100m^3) where number of species recorded lowest numbers (14). High biomass was observed in the site 1A-Offshore (1.72 ml/100m^3) and low biomass was in site 1D-Offshore (0.81 ml/100m^3). The range of the population density, biomass and number of species were (18080 to 255840 No/100m^3), (0.81 to 1.72 ml/100m^3) and (14 to 47 nos) respectively in all sites. Less observed species are *Acartia sp (Calanoida), Amphorella sp (Tintinnids),* *Arcella sp (Amoebozoa), Eucalanus sp. (Calanoida), Halicyclops (Cyclopoida), Leprotintinnus simplex (Tintinnida), Megacyclops sp (Cyclopoida), Sagitta sp (arrow worm), Thermocyclops sp (Cyclopoida), Tintinnopsis tocantinesis (Tintinnida)* etc. rarely recorded in this station. Total 69 zooplankton was recorded in Offshore area adding that more composition of zooplankton by the Phylum Crustacea (Arthropoda), Tintinnids (Protozoa) and Porifera.

6.3.1.2. Cargo Jetty

The population density of zooplankton varied from 31840 No/100m^3 to 109600 No/100m^3. Maximum density was noticed in site 2control-Cargo Jetty (109600 No/100m^3) and minimum was at site 2A-Cargo Jetty (31840 No/100m^3). Site 2control-Cargo Jetty comprises highest number of species (51 nos) and minimum number of species was observed in site 2A-Cargo Jetty (23nos). Biomass ranged between 1.67 to 3.24 ml/100m^3 where highest biomass noted in site 2B-Cargo Jetty and lowest in 2D-Cargo Jetty. Frequently observed species were *Clausocalanus sp (Calanoida), Cyclopoida (unidentified), Globigerina sp (Foraminifera), Leprotintinnus nordqvistii (Tintinnida), Nauplius larvae of Barnacles, Oithona sp (Cyclopoida), Polychaete larvae (Annelids), Sponge Spicules, Veliger larvae of Bivalve* etc. whereas less observed species were *Acartia sp (Calanoida), Animal Resting egg, Calcarina sp (Foramonifera), Cyphonautes larva (Bryozoan), Harpacticoida (unidentified), Loxostomum sp (Foraminifera), Nodosaria sp (Foraminifera), Rosalina globularis (Foraminifera), Subitaneous eggs of Copepoda, Tintinnopsis tubulosa (Tintinnida)* etc. Total recorded zooplanktons was 81 in Cargo Jetty.

6.3.1.3. Phang Creek

This Creek area was represented by the zooplankton fauna majority of them *Ammonia beccarii (Foraminifera), Calanoida(unidentified), Cyclops sp (Cyclopoida), Cyphonautes larva (Bryozoan), Globigerina sp (Foraminifera), Nauplius larvae of Barnacles, Oithona sp (Cyclopoida), Polychaete larvae (Annelids), Sponge Spicules, Tintinnopsis sp (Tintinnida), Veliger larvae of Bivalve, Zoea larva of Crustaceans etc.* Very less time or rarely recorded species were *Acartia sp (Calanoida), Cirripedia* *(barnacles larvae), Copepoda eggs sacs (egg pouch), Gastrula larva of Sea star, Macrosetella sp (Harpacticoida), Oithona brevicornis (Cyclopoida), Pseudonodosinella sp (Foraminifera), Temora sp. (Calanoida), Tintinnopsis radix (Tintinnida)* etc. The range of zooplankton Biomass was between 1.46 to 2.44 ml/100m^3. Highest Biomass was recorded in site 3D-Phang creek (2.44 ml/100m^3) and lowest in site 3E-Phang creek (1.46 ml/100m^3). Maximum and Minimum species count was at in site 3A-Phang creek (47nos) and 3control/3E-Phang creek (40nos) respectively. Population density was maximum recorded in site 3A-Phang creek (223200 No/100m^3) and minimum in site 3E-Phang creek (129760 No/100m^3).

Overall assessment of zooplankton showed that the total number of 112 Zooplankton recorded during winter season. Out of these (112) zooplankton, 69 zooplankton recorded in Offshore region, 81 zooplankton at Cargo Jetty and 83 zooplankton in Phang Creek region. The recorded zooplankton of all 3 stations mainly representing Phylum Arthropoda (Crustacea), , Protozoa (mainly foraminifera and tintinnids), Porifera (Sponge spicules) and Larva of Echinodermata. Crustacean zooplankton was the dominant due to the dominance of different larval stages which mainly feed on phytoplankton. Generally zooplankton population dynamics and studies emphasize is given up to group level rather than to species level because of microscopic size of zooplankton so owing to the difficulty in identifying the zooplankton as some species are considered as a group or genus level. The most dominant or frequently observed species (all 3 station) were *Cyclopoida (unidentified), Cyclops sp (Cyclopoida), Foraminiferans, Nauplius larvae of Barnacles, Nauplius larvae of Crustacea, Oithona sp (Cyclopoida), Ostracoda, Radiolarian skeletons, Sponge Spicules, Tintinnopsis radix (Tintinnida), Veliger larvae of Bivalve* etc. Overall range of Population density, Biomass and Number of Species were (18080 to 255840 no/100 m^3), (0.81 to 3.24 ml/100m^3) and (14 to 51nos) respectively. Average high biomass noted at Cargo Jetty (2.18) followed by Phang creek (2.06) than Offshore (1.24) (Table 46-48). Highest population density was recorded in site 1D-Offshore (255840 No/100m^3) and lowest was recorded in site 1control-Offshore (18080 No/100m3). Among all recorded zooplankton, majority dominance occurrence was by the Copepoda, Crustacean larvae, Spong Spicules, Foraminifera (Protozoa), Tintinnids (Protozoa), Egg capsules of Littorinids (Mollusca). Maximum zooplankton faunal composition was dominated by the Phylum Arthropoda, Mollusca, Protozoa, Poriffera and Echinodermata. The Chaetognatha and Tunicata groups were only represented by the one species namely *Sagitta sp* and *Oikopleura sp* respectively. In Offshore**,** maximum Occurrence (%) was by the Nauplius larvae of Crustacea (9.09%) and minimum by the Unidentified zooplankton (0.05%). In Cargo Jetty, maximum Percentage of Occurrence (%) by the Sponge spicules (10.12%) and minimum by Tintinnopsis beroidea (Tintinnida) & Nodosaria sp (Foraminifera) (0.05%). In Phang Creek maximum Occurrence (%) was by the Foraminifera (8.67%) and minimum (0.05%) by the Rosalina bradyi (Foraminifera).

During microscopic sample analysis more number of species varieties of foraminifera, sponge spicules and ostracoda were observed. These all three are very important for paleontological study aspects and also for evolutionary, ecological and environmental rebuilding. Some species of Ostracoda, Foraminifera and Sponge spicules are considered in microfossils materials. Some deep-sea species also recorded that is indication of water circulation pattern. Data on zooplankton density, list of zooplankton is shown in Table 46-48.

6.3.1.4. Diversity Indices of Zooplankton

Table 49 shows *diversity indices of zooplankton.* The Shannon-wiener diversity index (H') fluctuated between 2.55 to 3.63 indicated moderate to quite high range of diversity added indication of healthy body of water with a maximum value in site 2control-Cargo Jetty (3.63) where highest species number count (51) and minimum value in site 1control-Offshore (2.55) where species numbers were lowest (14). Range of the evenness was 0.57 to 0.92 where lowest and highest recorded in site 1D-Offshore and 1control-Offshore (0.92) respectively. Range of Simpson index was 0.87 to 0.95. The range value of Margalef indices was 1.33 to 4.31 that means high species number variations.

Table 46. Density of Zooplankton at Offshore site of Deendayal Port during Season 1

Name of Genera/Group	1A	1B	1C	1D	1E	1 Control	Individual total density (no/100m^3)	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	0	0	1920	960	0	0	2880	0.46
Acrocalanus sp (Calanoida)	0	0	0	0	0	1440	1440	0.23
Amphorella sp (Tintinnids)	0	320	0	0	0	0	320	0.05
Arcella sp (Amoebozoa)	0	1280	0	0	0	0	1280	0.21
Calanoida(unidentified)	1280	2560	5120	34560	6720	0	50240	8.08
Cibicides sp (Rotaliida Foraminifera)	0	0	640	2560	0	0	3200	0.51
Clausocalanus sp (Calanoida	2880	4960	3520	15040	11040	0	37440	6.02
Copepoda eggs sacs(egg pouch)	1440	960	2240	7520	3360	0	15520	2.50
Corycaeus sp (Calanoida)	1120	0	640	0	1440	0	3200	0.51
Cyclopoida (unidentified)	1760	4800	6400	17600	13120	1280	44960	7.23
Cyphonautes larva (Bryozoan)	0	640	960	1920	0	0	3520	0.57
Dentalium	640	0	0	0	0	0	640	0.10
Diacyclops sp (Cyclopoida)	1600	640	0	11040	0	0	13280	2.14
Egg capsules of Littorinids	1760	960	1760	1600	0	0	6080	0.98
Eucalanus sp. (Calanoida)	0	0	0	960	0	0	960	0.15
Euterpina sp (Harpacticoida)	800	2560	2560	0	640	1280	7840	1.26
Favella sp (Tintinnida)	0	0	800	1600	0	0	2400	0.39
Foraminifera (unidentified)	2720	0	1280	9280	0	0	13280	2.14
Globigerina sp (Foraminifera)	3200	480	1120	3200	1920	0	9920	1.60
Halicyclops (Cyclopoida)	0	0	1120	0	0	0	1120	0.18
Harpacticoida(unidentified)	960	0	0	0	2080	0	3040	0.49
Heteropoda shells (gastropods)	0	1280	0	2880	1760	960	6880	1.11
Leprotintinnus nordqvistii (Tintinnida)	2080	1440	2880	2080	0	0	8480	1.36
Leprotintinnus pellucidus (Tintinnida)	0	1920	1120	3680	0	2560	9280	1.49
Leprotintinnus simplex (Tintinnida)	0	0	0	0	640	0	640	0.10
Loxostomum sp (Foraminifera)	0	0	0	1280	0	0	1280	0.21
Macrocyclops (Cyclopoida)	0	0	2240	0	0	0	2240	0.36
Megacyclops sp (Cyclopoida)	0	1600	0	0	0	0	1600	0.26
Mesocyclops (Cyclopoida)	0	0	1760	16640	0	0	18400	2.96

Microsetella sp (Harpacticoida)	1120	0	2560	3040	1440	0	8160	1.31
Nauplius larvae of Barnacles	640	2400	2400	8320	8800	640	23200	3.73
Nauplius larvae of Calanoida	960	0	1920	0	5600	640	9120	1.47
Nauplius larvae of Copepoda	0	960	1280	0	3200	0	5440	0.88
Nauplius larvae of Crustacea	2560	6560	4000	31040	12320	0	56480	9.09
Nauplius larvae of Cyclopoida	0	0	4800	0	0	0	4800	0.77
Nonion sp (Foraminifera)	800	0	640	0	0	0	1440	0.23
Oikopleura sp (Tunicata)	0	1120	640	0	2240	0	4000	0.64
Oithona nana (Cyclopoida)	1280	2080	3360	1920	0	0	8640	1.39
Oithona similis (Cyclopoida)	0	1760	3200	4160	1600	0	10720	1.72
Oithona sp (Cyclopoida)	1760	2400	3200	8000	0	1600	16960	2.73
Ophiopluteus Larva (Echinodermata)	0	0	640	1440	1440	0	3520	0.57
Ostracoda	1760	1120	1920	7360	4320	0	16480	2.65
Paracalanus sp (Calanoida)	0	3680	2240	0	4800	1920	12640	2.03
Parvocalanus sp (Calanoida)	0	1440	960	0	2240	0	4640	0.75
Polychaete larvae (Annelids)	0	0	1920	0	3360	0	5280	0.85
Protozoea larva (Crustacea)	960	0	0	2080	0	0	3040	0.49
Quinqueloculina sp (Foraminifera)	800	0	800	0	1600	0	3200	0.51
Radiolarian skeletons	1440	960	2080	1920	4640	0	11040	1.78
Rosalina sp (Foraminifera)	1440	960	800	4320	1120	0	8640	1.39
Rotifera	0	0	800	0	0	0	800	0.13
Sagitta sp (arrow worm)	0	0	0	1120	0	0	1120	0.18
Spirillina sp (Foraminifera)	0	1600	0	1440	320	0	3360	0.54
Spiroloculina sp (Foraminifera)	0	0	800	3360	0	0	4160	0.67
Sponge Spicules	1600	1920	5440	8160	7680	0	24800	3.99
Stentor sp (Protozoa)	0	0	800	0	0	0	800	0.13
Thermocyclops sp (Cyclopoida)	0	0	0	0	3520	0	3520	0.57
Tintinnopsis cylindrica (Tintinnida)	1120	0	0	2880	4160	0	8160	1.31
Tintinnopsis kofoidi (Tintinnida)	0	0	0	1440	0	0	1440	0.23
Tintinnopsis lobiancoi (Tintinnida)	1600	0	1120	0	0	0	2720	0.44
Tintinnopsis orientalis (Tintinnida)	0	0	1280	1280	2560	0	5120	0.82
Tintinnopsis radix (Tintinnida)	960	0	640	1280	3360	0	6240	1.00
Tintinnopsissp (Tintinnida)	0	0	0	0	4160	1600	5760	0.93

Tintinnopsis tocantinesis (Tintinnida)	0	640	0	640	0	0	1280	0.21
Triloculina sp (Foraminifera)	0	0	0	1760	0	0	1760	0.28
Unidentified	0	0	0	320	0	0	320	0.05
Unidentified Crustacea	0	0	0	0	0	640	640	0.10
Unidentified larva	0	0	480	0	6240	0	6720	1.08
Veliger larvae of Bivalve	1120	1120	2080	4960	0	800	10080	1.62
Zoea larva of Decapoda	0	0	0	1760	2560	960	5280	0.85
Total No. Of Genera/Groups =69								
Site-wise Total Density (no/100m^3)	**44160**	**60640**	**96800**	**255840**	**146080**	**18080**	**Total Density =621600**	**100%**
Biomass (ml/100m^3)	**1.72**	**1.25**	**1.27**	**0.81**	**0.94**	**1.45**		

Table 47. Density of Zooplankton at Cargo Jetty site of Deendayal Port during Season 1

Name of Genera/Group	2A	2B	2C	2D	2E	2 Control	Individual total density (no/100m^3))	% of Occurrence (Site-wise)
Acanthocyclops sp (Cyclopoida)	0	0	0	1280	0	0	1280	0.38
Acartia sp (Calanoida)	0	0	0	0	960	0	960	0.29
Acrocalanus sp (Calanoida)	0	0	1280	0	800	800	2880	0.86
Ammonia beccarii (Foraminifera)	0	960	0	640	1440	960	4000	1.20
Ammonia sp (Foraminifera)	0	320	0	0	0	0	320	0.10
Animal Resting egg	0	0	0	0	0	640	640	0.19
Arcella sp (Amoebozoa)	0	0	640	0	1280	800	2720	0.82
Bolivina sp (Foraminifera)	0	0	480	1600	320	800	3200	0.96
Calanoida(unidentified)	0	2240	3200	0	0	0	5440	1.63
Calcarina sp (Foramonifera)	0	0	0	640	0	0	640	0.19
Cibicides sp (Rotaliida Foraminifera)	0	640	640	0	0	0	1280	0.38
Clausocalanus sp (Calanoida)	1600	1600	640	960	800	3360	8960	2.69
Copepoda	0	0	1440	0	0	0	1440	0.43
Copepoda eggs (Individuals)	960	0	0	0	0	1280	2240	0.67
Copepoda eggs sacs (egg pouch)	1440	0	0	1920	1760	4480	9600	2.88
Cyclopoida (unidentified)	1280	1280	800	1600	1600	3200	9760	2.93
Cyclops sp (Cyclopoida)	0	800	1440	1440	0	1600	5280	1.58
Cyphonautes larva (Bryozoan)	0	960	0	0	800	0	1760	0.53
Diacyclops sp (Cyclopoida)	0	0	0	0	1280	1120	2400	0.72
Egg capsules of Littorinids	0	1600	640	0	0	480	2720	0.82
Euterpina sp (Harpacticoida)	0	320	0	960	320	1120	2720	0.82
Eutintinnus apertus (Tintinnida)	0	0	0	0	0	800	800	0.24
Favella sp (Tintinnida)	0	0	0	0	800	0	800	0.24
Foraminifera (unidentified)	1600	6560	5120	4960	5920	4160	28320	8.49
Gastrula larva of Sea star	0	0	0	0	0	320	320	0.10
Globigerina sp (Foraminifera)	1920	1280	1120	1280	800	1440	7840	2.35
Globigerinoides sp (Foraminifera)	0	0	0	0	1920	1120	3040	0.91
Harpacticoida(unid)	0	0	0	0	0	3360	3360	1.01
Heteropoda shells (gastropods)	0	0	800	0	960	2560	4320	1.30

Lagena sp (Foraminifera)	0	0	0	0	0	960	960	0.29
Leprotintinnus nordqvistii (Tintinnida)	960	1440	1600	1600	0	2560	8160	2.45
Leprotintinnus pellucidus (Tintinnida)	0	0	1120	0	0	0	1120	0.34
Leprotintinnus simplex (Tintinnida)	1120	0	0	0	0	0	1120	0.34
Leprotintinnus sp (Tintinnida)	0	800	0	0	0	0	800	0.24
Loxostomum sp (Foraminifera)	0	0	0	0	800	0	800	0.24
Megacyclops sp (Cyclopoida)	0	0	0	800	0	0	800	0.24
Microsetella sp (Harpacticoida)	0	320	0	0	0	960	1280	0.38
Nauplius larvae of Barnacles	800	1280	0	2240	960	1600	6880	2.06
Nauplius larvae of Calanoida	1280	0	1440	0	0	5280	8000	2.40
Nauplius larvae of Copepoda	0	0	800	0	0	0	800	0.24
Nauplius larvae of Crustacea	0	1440	0	1600	2560	7040	12640	3.79
Nodosaria sp (Foraminifera)	0	160	0	0	0	0	160	0.05
Nonion sp (Foraminifera)	800	0	0	800	0	2240	3840	1.15
Oithona attenuata (Cyclopoida)	0	0	0	0	640	640	1280	0.38
Oithona similis (Cyclopoida)	0	2080	1120	0	0	0	3200	0.96
Oithona sp (Cyclopoida)	800	320	1440	640	800	6880	10880	3.26
Ophiopluteus Larva (Echinodermata)	0	0	640	0	0	1120	1760	0.53
Ostracoda	1600	2880	3200	0	4160	3040	14880	4.46
Paracalanus sp (Calanoida)	0	0	0	0	0	1440	1440	0.43
Parvocalanus sp (Calanoida)	0	0	0	0	0	960	960	0.29
Planulina sp (Foraminifera)	0	0	0	0	1120	0	1120	0.34
Polychaete larvae (Annelids)	2080	960	0	2400	1280	2720	9440	2.83
Quinqueloculina sp (Foraminifera)	0	1280	0	1120	1120	2080	5600	1.68
Radiolarian skeletons	1120	2080	1600	1120	2560	5120	13600	4.08
Rosalina globularis (Foraminifera)	0	0	0	0	800	0	800	0.24
Rosalina sp (Foraminifera)	1440	0	800	1280	0	960	4480	1.34
Rosalina vilardeboana	0	0	0	0	0	480	480	0.14
Rotalia (Foraminifera)	0	1440	0	0	0	0	1440	0.43
Rotaliida (Bucella sp-	0	0	640	0	0	0	640	0.19

foraminifera)								
Rotaliida (Foraminifera)	0	0	0	1440	1920	0	3360	1.01
Spirillina sp (Foraminifera)	0	1600	960	0	1120	480	4160	1.25
Spiroloculina sp (Foraminifera)	0	0	960	0	0	2080	3040	0.91
Sponge Spicules	4640	1920	4320	4960	9440	8480	33760	10.12
Sticholonche zanclea (Radiolarians)	0	0	0	0	0	640	640	0.19
Subitaneous eggs of Copepoda	0	0	640	0	0	0	640	0.19
Textularia sp (Foraminifera)	0	0	0	0	1120	0	1120	0.34
Tintinnids (Unidentified)	0	0	0	0	0	4960	4960	1.49
Tintinnids resting cysts (Tintinnida)	0	0	640	800	0	1280	2720	0.82
Tintinnopsis beroidea (Tintinnida)	0	0	0	160	0	0	160	0.05
Tintinnopsis cylindrica (Tintinnida)	0	1120	0	0	1920	1280	4320	1.30
Tintinnopsis karajacensis	0	0	0	0	1440	0	1440	0.43
Tintinnopsis orientalis (Tintinnida)	2400	0	0	0	1120	2080	5600	1.68
Tintinnopsis parvula (Tintinnida)	0	0	0	0	960	0	960	0.29
Tintinnopsis radix (Tintinnida)	480	480	800	800	640	1440	4640	1.39
Tintinnopsis sp (Tintinnida)	800	0	640	640	1120	0	3200	0.96
Tintinnopsis tocantinesis (Tintinnida)	640	0	0	0	800	0	1440	0.43
Tintinnopsis tubulosa (Tintinnida)	0	0	0	800	0	0	800	0.24
Triloculina sp (Foraminifera)	800	0	0	0	800	1920	3520	1.06
Unidentified	0	0	0	1920	480	1920	4320	1.30
Veliger larvae of Bivalve	1280	0	1280	1760	2080	1920	8320	2.50
Zoea larva of Decapoda	0	480	800	0	0	640	1920	0.58
Total No. Of Genera/Groups =81								
Site-wise Total Density (no/100m^3)	**31840**	**40640**	**43680**	**44160**	**63520**	**109600**	**Total Density =333440**	**100%**
Biomass (ml/100m^3)	**1.72**	**3.24**	**1.80**	**1.67**	**2.02**	**2.65**		

Table 48. Density of Zooplankton at Phang Creek of Deendayal Port during Season 1

Name of Genera/Group	3A	3B	3C	3D	3E	3 Control	Total density (no/100m3)	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	0	0	0	3360	0	0	3360	0.32
Acrocalanus sp (Calanoida)	0	1760	640	0	0	0	2400	0.23
Ammonia beccarii (Foraminifera)	1920	2400	4000	1920	1760	960	12960	1.22
Arcella sp (Amoebozoa)	0	0	960	0	2560	1920	5440	0.51
Bolivina sp (Foraminifera)	1760	0	0	3680	0	2080	7520	0.71
Bulimina sp (Foraminifera)	0	2560	2080	0	2080	0	6720	0.63
Calanoida(unidentified)	6080	6080	8960	8320	7360	1920	38720	3.66
Calcarina sp (Foramonifera)	640	0	0	0	320	0	960	0.09
Centropages sp. (Calanoida)	1760	0	0	0	0	0	1760	0.17
Cirripedia (barnacles larvae)	2240	0	0	0	0	0	2240	0.21
Clausocalanus sp (Calanoida)	4320	9120	5120	5920	3200	4320	32000	3.02
Clytemnestra sp (Harpacticoida)	0	0	0	3200	0	1280	4480	0.42
Copepoda	0	1920	0	0	0	0	1920	0.18
Copepoda eggs sacs(egg pouch)	0	0	0	0	2720	0	2720	0.26
Corycaeus sp (Calanoida)	0	0	0	2240	0	0	2240	0.21
Cyclopoida (unidentified)	6560	3840	0	11520	7040	1600	30560	2.88
Cyclops sp (Cyclopoida)	6880	7200	6720	4000	1600	3360	29760	2.81
Cyphonautes larva (Bryozoan)	2880	2400	320	960	0	0	6560	0.62
Diacyclops sp (Cyclopoida)	3040	0	0	3840	0	2240	9120	0.86
Discorbis sp (Foraminifera)	0	0	0	3360	0	0	3360	0.32
Edentostomina sp (Foraminifera)	0	0	0	0	320	480	800	0.08
Egg capsules of Littorinids	7680	7040	960	5920	7840	11040	40480	3.82
Elphidium sp (Foraminifera)	640	0	0	0	0	0	640	0.06
Eucalanus sp. (Calanoida)	3040	0	0	480	0	0	3520	0.33
Euterpina sp (Harpacticoida)	0	2080	2400	6720	1920	1280	14400	1.36
Foraminifera (unidentified)	18240	1776 0	9920	12640	9920	23360	91840	8.67
Gastrula larva of Sea star	0	0	1440	0	960	0	2400	0.23
Globigerina sp (Foraminifera)	6560	8320	4960	7520	1120 0	7520	46080	4.35
Globigerinoides sp (Foraminifera)	0	3520	0	0	0	0	3520	0.33
Harpacticoida(unidentified)	0	2720	6240	0	7840	2560	19360	1.83
Heteropoda shells (gastropods)	0	3200	2080	0	0	0	5280	0.50
Labidocera sp (Calanoida)	0	0	1600	0	960	0	2560	0.24
Leprotintinnus nordqvistii (Tintinnida)	2080	3040	640	0	320	3840	9920	0.94
Leprotintinnus simplex (Tintinnida)	4480	2080	800	0	0	3360	10720	1.01
Loxostomum sp (Foraminifera)	0	0	2080	0	640	960	3680	0.35

Macrosetella sp (Harpacticoida)	0	0	0	3520	0	0	3520	0.33
Megacyclops sp (Cyclopoida)	0	0	3200	3840	0	0	7040	0.66
Microsetella sp (Harpacticoida)	4960	0	1920	6400	960	1280	15520	1.47
Nauplius larvae of Barnacles	4960	3520	3680	2400	1280	1600	17440	1.65
Nauplius larvae of Calanoida	0	7520	2720	7840	3520	11840	33440	3.16
Nauplius larvae of Copepoda	6400	0	0	0	0	0	6400	0.60
Nauplius larvae of Crustacea	0	5920	5280	6720	0	5760	23680	2.24
Nauplius larvae of Cyclopoida	0	8000	0	0	0	3360	11360	1.07
Nauplius larvae of Harpacticoida	0	0	0	0	0	1760	1760	0.17
Nonion sp (Foraminifera)	0	2080	0	0	2560	0	4640	0.44
Oikopleura sp (Tunicata)	960	0	640	0	0	0	1600	0.15
Oithona brevicornis (Cyclopoida)	0	0	3200	0	0	0	3200	0.30
Oithona nana (Cyclopoida)	0	1280	2560	0	0	1920	5760	0.54
Oithona similis (Cyclopoida)	0	960	3200	0	0	0	4160	0.39
Oithona sp (Cyclopoida)	1440	5280	3200	4960	3360	5600	23840	2.25
Ophiopluteus Larva (Echinodermata)	0	0	0	0	640	0	640	0.06
Ostracoda	13280	6720	8320	7680	3200	6880	46080	4.35
Paracalanus sp (Calanoida)	0	3360	800	5920	0	0	10080	0.95
Parvocalanus sp (Calanoida)	1760	4640	2720	3360	1280	1440	15200	1.43
Polychaete larvae (Annelids)	2400	3200	2560	2560	0	640	11360	1.07
Polychaete worms (Annelids)	0	0	0	0	2240	0	2240	0.21
Pontellopsis sp. (Calanoida)	2400	0	0	0	0	0	2400	0.23
Pseudonodosinella sp (Foraminifer)	0	960	0	0	0	0	960	0.09
Quinqueloculina sp (Foraminifera)	1760	0	0	0	0	0	1760	0.17
Radiolarian skeletons	5120	4480	3360	1280	4000	8320	26560	2.51
Rosalina bradyi (Foraminifera)	0	480	0	0	0	0	480	0.05
Rosalina sp (Foraminifera)	0	0	3200	5440	0	5440	14080	1.33
Rotaliida (Foraminifera)	13280	5440	0	0	2240	0	20960	1.98
Sagitta sp (arrow worm)	640	0	0	0	0	0	640	0.06
Spirillina sp (Foraminifera)	1600	3200	2080	320	320	960	8480	0.80
Spiroloculina sp (Foraminifera)	2560	2240	2560	1120	2560	320	11360	1.07
Sponge Spicules	15840	1712 0	9920	8640	1072 0	11680	73920	6.98
Stentor sp (Protozoa)	2240	0	1920	2080	1280	0	7520	0.71
Subeucalanus (Calanoida)	0	960	0	0	0	0	960	0.09
Temora sp. (Calanoida)	15840	0	0	0	0	0	15840	1.50
Thermocyclops sp (Cyclopoida)	1600	0	2400	3520	0	0	7520	0.71
Tintinnids resting cysts(Tintinnida)	0	0	0	960	0	2080	3040	0.29
Tintinnopsis beroidea (Tintinnida)	2560	0	0	0	0	0	2560	0.24

Tintinnopsis cylindrica (Tintinnida)	2720	4160	960	0	3360	640	11840	1.12
Tintinnopsis lobiancoi (Tintinnida)	2080	2400	0	0	0	0	4480	0.42
Tintinnopsis orientalis (Tintinnida)	2560	2080	2240	3360	1760	1760	13760	1.30
Tintinnopsis radix (Tintinnida)	640	0	0	0	0	0	640	0.06
Tintinnopsis sp (Tintinnida)	9280	6080	480	3200	640	1760	21440	2.02
Tintinnopsis tubulosa (Tintinnida)	2080	3360	0	0	1440	0	6880	0.65
Unidentified	8640	0	0	1280	0	0	9920	0.94
Veliger larvae of Bivalve	4160	6720	3840	5920	7360	5120	33120	3.13
Zoea larva of Crustaceans	8640	6880	11840	12640	0	4800	44800	4.23
Zoea larva of Decapoda	0	0	0	0	4480	0	4480	0.42
Total No. Of Genera/Groups =83								
Site-wise Total Density (no/100m^3)	**223200**	**206080**	**150720**	**190560**	**129760**	**159040**	**Total density =**	**100%**
Biomass (ml/100m^3)	**1.79**	**2.23**	**2.04**	**2.44**	**1.46**	**2.42**		

Table 49. Diversity indices of Zooplankton at different sites of Deendayal Port during Season 1

	Offshore						Cargo jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-control**
Taxa_S	30	32	47	43	35	14	23	30	33	30	41	51	47	45	45	41	40	40
Individuals (Nos/m^2)	44160	60640	96800	255840	146080	18080	31840	40640	43680	44160	63520	109600	223200	206080	150720	190560	129760	159040
Dominance_D	0.04	0.05	0.03	0.06	0.05	0.08	0.06	0.06	0.05	0.05	0.05	0.03	0.04	0.04	0.04	0.04	0.05	0.05
Shannon Diversity	3.31	3.23	3.62	3.19	3.27	2.55	2.99	3.13	3.26	3.20	3.39	3.63	3.50	3.56	3.52	3.49	3.32	3.26
Simpson_1-D	0.96	0.95	0.97	0.94	0.95	0.92	0.94	0.94	0.95	0.95	0.95	0.97	0.96	0.96	0.96	0.96	0.95	0.95
Evenness	0.91	0.79	0.79	0.57	0.75	0.92	0.87	0.76	0.79	0.81	0.72	0.74	0.71	0.78	0.75	0.80	0.69	0.65
Menhinick	0.14	0.13	0.15	0.09	0.09	0.10	0.13	0.15	0.16	0.14	0.16	0.15	0.10	0.10	0.12	0.09	0.11	0.10
Margalef	2.71	2.82	4.01	3.37	2.86	1.33	2.12	2.73	3.00	2.71	3.62	4.31	3.74	3.60	3.69	3.29	3.31	3.26

6.3.2. Distribution and density of Zooplankton during Season 2

6.3.2.1. Offshore

Bolivina sp (Foraminifera), Foraminifera (unidentified), Globigerina sp (Foraminifera), Mysida shrimp (Mysids), Sponge Spicules, Tintinnopsis tubulosa (Tintinnida), Zoea larva of Crab etc.were the mostly common zooplankton and throughout observed in all sites of Offshore area. Highest population density was recorded at site 1D-Offshore (44800 nos./100m^3)and lowest density in 1A-Offshore (21600 nos./100m^3) where number of species recorded lowest numbers (13 nos.). High biomass was observed in the site 1E-Offshore (46.51 ml/100m^3) and low biomass was in site 1A-Offshore (20ml/100m^3).The range of the population density, biomass and number of species were (21600 to 44800 nos./100m^3), (20 to 46.51 ml/100m^3) and (13 to 27 nos.) respectively in all sites. Less observed species are *Acartia sp (Calanoida), Bolivinita quadrilateral, Calcarina sp (Foraminifera), Copepoda eggs sac(egg pouch), Cyphonautes larva (Bryozoa) Globigerinita sp (Foraminifera), Rosalina sp (Foraminifera), Tintinnopsis radix (Tintinnida), Triloculina sp (Foraminifera),*

etc. rarely recorded in this station. Total 60 zooplankton was recorded in Offshore area adding that more composition of zooplankton by the Phylum Crustacea (Arthropoda), Tintinnids and Foraminifera (Protozoa) and Sponge Spicules (Porifera)

6.3.2.2. Cargo Jetty

The population density of zooplankton varied from 21920 nos./100m^3 to 46880 nos./100m^3. Maximum density was noticed in site <u>2control-Cargo Jetty</u> (46880 nos./100m^3) and minimum was at site 2C-Cargo Jetty (21920 nos./100m^3). The Sites,<u>2control and 2B -Cargo Jetty</u> comprises highest number of species (24 nos.) and minimum number of species was observed in site <u>2A-Cargo Jetty</u> (14 nos.). Biomass ranged between 11.22 to 46.51 ml/100m^3 where highest biomass noted in site<u>2E-Cargo Jetty</u> and lowest in <u>2cont-Cargo Jetty</u>. Frequently observed species were *Ammonia beccarii (Foraminifera), Calanoida (unidentified), Foraminifera (unidentified, Globigerina sp (Foraminifera), Ostracoda, Sponge Spicules, Veliger larvae of Bivalve, Zoea larva of Crab* etc. whereas less observed species were *Acartia* *ohtsukai, Bolivina sp (Foraminifera), Clausocalanus sp (Calanoida), Elphidium sp (Foraminifera), Jelly fish (Hydrozoa : Cnidaria), Polychaete larvae (Annelids), Spirillina sp (Foraminifera), Tintinnopsis tubulosa (Tintinnida).* etc. Total recorded zooplanktons were 49 in Cargo Jetty.

6.3.2.3. Phang Creek

This Creek area was represented by the zooplankton fauna majority of them were *Globigerina sp (Foraminifera), Leprotintinnus simplex (Tintinnida), Loxostomum sp (Foraminifera), Ostracoda, Sponge Spicules, Tintinnopsis sp (Tintinnida), Veliger larvae of Bivalve, Zoea larva of Crab, Mysida shrimp (Mysids) etc.*Very less time or rarely recorded species were *Acrocalanus sp (Calanoida), Ammonia beccarii (Foraminifera), Bulimina sp (Foraminifera), Cibicides sp (Foraminifera), Copepoda eggs sac(egg pouch), Discorbis sp (Foraminifera), Narcomedusae (Hydrozoa:Cnidaria), Rosalina bradyi, Tintinnopsis kofoidi (Tintinnida), Tintinnopsis parvula (Tintinnida), Tortanus sp (Calanoida)* etc. The range of zooplankton Biomass was between 23.33 to 86.42 ml/100m^3. Highest Biomass was recorded in site 3E-Phang creek (86.42 ml/100m^3) and lowest in site 3B-Phang creek (23.33 ml/100m^3). Maximum and Minimum species count was at in site 3C-Phang creek (31 nos.) and 3control (23 nos.) respectively. Population density was maximum recorded in site 3A-Phang creek (32960 nos./100m^3) and minimum in site 3control (19520 nos./100m^3).

Overall assessment of zooplankton showed that the total number of 96 Zooplankton recorded during summer season. Out of these (96) zooplankton, 60 zooplankton recorded in Offshore region, 49 zooplankton at Cargo Jetty and 69 zooplankton in Phang Creek region. The recorded zooplankton of all 3 stations mainly representing Phylum Arthropoda (Crustacea), , Protozoa (mainly foraminifera and tintinnids), Porifera (sponge spicules). Crustacean zooplankton was the dominant due to the dominance of different larval stages which mainly feed on phytoplankton. Generally zooplankton population dynamics and studies emphasize is given up to group level rather than to species level because of microscopic size of zooplankton so owing to the difficulty in identifying the zooplankton as some species are considered as a group or genus level. The most dominant or frequently observed species(all 3 station) were *Calanoida (unidentified), Egg capsules of Littorinids, Foraminifera (unidentified), Globigerina sp (Foraminifera), Mysida shrimp (Mysids), Ostracoda, Sponge Spicules, Tintinnopsis sp (Tintinnida), Veliger larvae of Bivalve. Zoea larva of Crab*, etc. Foraminiferans belonging to the meroplankton were present at all three station Overall range of Population density, Biomass and Number of Species were (19520 to 46480 no/100 m^3), (11.22 to 86.42 ml/100m^3) and (13 to 31nos) respectively. Average high biomass noted at Phang Creek (53.78) followed by Offshore (32.71) than Cargo Jetty (25.10) (Table 50 - 52). Highest population density was recorded in site 2control-Offshore (46480No/100m^3) and lowest was recorded in site 1control-Offshore (19520 No/100m3). Among all recorded zooplankton, majority dominance occurrence was by the Copepoda, Crustacean larvae, Spong Spicules, Foraminifera (Protozoa), Tintinnids (Protozoa), Zoea larva of Crab, Mysida shrimp (Mysids).Egg capsules of Littorinids (Mollusca).Maximum zooplankton faunal composition was dominated by the Phylum Arthropoda, Mollusca, Protozoa, Poriffera. The Chaetognatha, Tunicata and Cnidaria groups or phylum were only represented by the one species namely *Sagitta sp (arrow worm), Salpa sp, Small Jellyfish* respectively. Small fish and Fish larva, as small plankton, represented the Fish. Veliger larva of Bivalve and Gastropoda shells include in Phylum Mollusca. In Offshore**,** maximum Occurrence (%) was by the Zoea larva of the Crab (21.75%) and minimum by the Ammonia beccarii, *Eutintinnus apertus* and *Elphidium sp* (0.15%). In Cargo Jetty, maximum Percentage of Occurrence (%) by the Zoea larva of the Crab (47.50%) and minimum by *Spirillina sp* (foraminifera) and *Tintinnopsis beroidea* (0.08%).In Phang Creek maximum Occurrence (%) was by the Foraminifera (9.98%) and minimum (0.10%) by the *Corycaeus sp.*.

During microscopic sample analysis more number of species varieties of Foraminifera, Sponge spicules, Crustacean larva and Tintinnids were observed. These all three are very important for paleontological study aspects and also for evolutionary, ecological and environmental rebuilding. Some species of Ostracoda, Foraminifera and Sponge spicules are considered in microfossils materials. Some deep sea species also recorded that is indication of water circulation pattern. Data on zooplankton density, list of zooplankton is shown in Table (50 - 52).

6.3.2.4. Diversity Indices of Zooplankton

Table 53 *shows* diversity indices of zooplankton. The Shannon-wiener diversity index (H') fluctuated between 1.65 to 3.37 indicated moderate to quite high range of diversity added indication of healthy body of water with a maximum value in site 3C-Phang Creek (3.37) where highest species number count (31) and minimum value in site 2D-Cargo Jetty (1.65) where species number was 19 (nos.). Range of the evenness was 0.27 to 0.94 where lowest and highest recorded in site 2D-Cargo Jetty (0.27) and 3C-Phang Creek (0.94) respectively. Range of Simpson index was 0.58 to 0.96. The range value of Margalef indices was 1.20 to 3.02 that means high species number variations.

Table 50. Density of Zooplankton at Offshore site of Deendayal Port during Season 2

Name of Genera/Group	1A	1B	1C	1D	1E	1 Control	Individual total density (no/100m^3)	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	0	0	0	640	0	0	640	0.30
Ammonia beccarii (Foraminifera)	0	0	0	0	320	0	320	0.15
Arcella sp (Amoebozoa)	640	0	0	480	0	0	1120	0.53
Bolivina sp (Foraminifera)	640	480	640	1600	0	0	3360	1.58
Bolivinita quadrilatera	0	0	0	0	0	960	960	0.45
Bolivinita sp (Foraminifera)	0	0	480	0	0	0	480	0.23
Calanoida (unidentified)	0	1120	800	320	800	1440	4480	2.11
Calcarina sp (Foraminifera)	0	0	0	480	0	0	480	0.23
Centropages sp (Calanoida)	0	480	0	0	0	0	480	0.23
Cibicides sp (Foraminifera)	0	0	0	0	0	640	640	0.30
Copepoda (Unidentified)	800	0	0	0	0	0	800	0.38
Copepoda eggs sac(egg pouch)	0	0	0	0	0	960	960	0.45
Corycaeus sp (Calanoida)	0	480	960	0	0	0	1440	0.68
Crustacea (unidentified)	0	960	0	0	0	0	960	0.45
Cyclopoida (unidentified)	0	0	800	640	0	0	1440	0.68
Cyphonautes larva (Bryozoa)	0	640	0	0	0	0	640	0.30
Cypris larva (Barnacle larva)	0	0	0	480	0	0	480	0.23
Egg capsules of Littorinids	0	0	800	320	0	0	1120	0.53
Elphidium sp Foraminifera)	0	0	0	320	0	0	320	0.15
Eponides sp (Foraminifera)	0	0	800	0	0	0	800	0.38
Eutintinnus apertus (Tintinnida)	0	0	0	0	0	320	320	0.15
Foraminifera (unidentified)	1600	2560	3520	10880	6080	5120	29760	14.00
Gastropoda shells	0	480	0	0	0	0	480	0.23
Gastrula larva of Sea star	0	640	0	1120	0	0	1760	0.83
Globigerina sp (Foraminifera)	1120	1920	800	2880	1120	0	7840	3.69
Globigerinita sp (Foraminifera)	0	0	1120	0	0	0	1120	0.53
Globigerinoides sp (Foraminifera)	0	640	0	0	0	1120	1760	0.83
Harpacticoida (unidentified)	0	0	0	320	0	480	800	0.38
Lagena sp (Foraminifera)	0	480	0	0	0	0	480	0.23
Larva (Unidentified)	0	0	0	1280	0	0	1280	0.60
Mysida shrimp (Mysids)	7200	10720	4320	5280	8320	2080	37920	17.83
Nauplius larvae of Barnacles	0	0	0	0	0	480	480	0.23
Nauplius larvae of Calanoida	0	0	0	0	0	480	480	0.23
Nauplius larvae of Copepoda	0	0	0	0	480	0	480	0.23
Nauplius larvae of	0	0	960	640	800	0	2400	1.13

Crustacea								
Oithona sp (Cyclopoida)	0	0	640	0	0	0	640	0.30
Ostracoda	0	0	0	1440	0	640	2080	0.98
Tintinnids (Unidentified)	0	1120	0	0	0	0	1120	0.53
Paracalanus sp (Calanoida)	640	0	640	0	0	0	1280	0.60
Parvocalanus sp (Calanoida)	0	0	640	0	0	0	640	0.30
Radiolarian skeletons	0	0	0	2400	800	0	3200	1.50
Rosalina sp (Foraminifera)	0	0	0	480	0	0	480	0.23
Sagitta sp (arrow worm)	960	0	0	0	0	640	1600	0.75
Spirillina sp (Foraminifera)	0	0	0	0	0	640	640	0.30
Spiroloculina sp. (Foraminifera)	0	0	480	0	0	0	480	0.23
Sponge Spicules	800	7520	2880	3680	1760	1600	18240	8.58
Subeucalanus (Calanoida)	640	0	0	0	0	0	640	0.30
Tintinnids (Unidentified)	0	0	2080	0	0	0	2080	0.98
Tintinnopsis beroidea (Tintinnida)	0	0	0	480	800	640	1920	0.90
Tintinnopsis cylindrica (Tintinnida)	640	1120	0	800	0	960	3520	1.66
Tintinnopsis karajacensis (Tintinnida)	0	0	0	0	480	0	480	0.23
Tintinnopsis parvula (Tintinnida)	0	0	0	480	320	0	800	0.38
Tintinnopsis radix (Tintinnida)	640	0	0	0	0	0	640	0.30
Tintinnopsis sp (Tintinnida)	0	0	0	2240	320	3040	5600	2.63
Tintinnopsis tubulosa (Tintinnida)	0	1120	0	1280	320	2400	5120	2.41
Tintinnopsis corniger (Tintinnida)	0	0	0	0	0	640	640	0.30
Triloculina sp (Foraminifera)	0	960	0	0	0	640	1600	0.75
Veliger larvae of Bivalve	0	800	0	1280	320	480	2880	1.35
Zoea larva of Crab	5280	9920	4320	2560	9920	14240	46240	21.75
Unidentified	0	0	0	0	0	800	800	0.38
Total No. Of Genera/Groups =60								
Site-wise Total Density (no/100m^3)	21600	44160	27680	44800	32960	41440	**Total Density =212640**	**100%**
Biomass (ml/100m^3)	**20**	**41.67**	**33.13**	**29.09**	**46.51**	**25.86**		

Table 51. Density of Zooplankton at Cargo Jetty site of Deendayal Port during Season 2

Name of Genera/Group	2A	2B	2C	2D	2E	2 Control	Individual total density (no/100m^3))	% of Occurrence (Site-wise)
Acartia ohtsukai	0	480	0	0	0	0	480	0.23
Acartia sp (Calanoida)	0	640	0	960	320	1120	3040	1.44
Acrocalanus sp (Calanoida)	0	0	0	480	640	800	1920	0.91
Ammonia beccarii (Foraminifera)	0	480	0	640	320	480	1920	0.91
Bolivina sp (Foraminifera)	0	0	480	0	0	480	960	0.46
Calanoida (unidentified)	640	2720	960	1600	2080	800	8800	4.17
Calcarina sp (Foraminifera)	0	0	0	0	0	0	0	0.00
Canthocalanus sp (Calanoida)	960	800	0	0	0	0	1760	0.83
Centropages sp (Calanoida)	0	640	0	800	0	0	1440	0.68
Cibicides sp (Foraminifera)	0	1120	0	0	0	0	1120	0.53
Clausocalanus sp (Calanoida)	0	0	960	0	0	0	960	0.46
DiCyclops sp (Cyclopoida)	0	0	0	480	0	0	480	0.23
Egg capsules of Littorinids	2400	960	1600	1280	1440	1920	9600	4.55
Elphidium sp (Foraminifera)	0	320	0	0	0	0	320	0.15
Eutintinnus sp (Tintinnida)	0	0	0	640	0	0	640	0.30
Fish larva	0	640	800	0	960	1120	3520	1.67
Foraminifera (unidentified)	1920	4320	1120	1760	1120	3680	13920	6.60
Gastrula larva of Sea star	1120	1280	0	0	0	0	2400	1.14
Globigerina sp (Foraminifera)	800	800	1120	800	320	800	4640	2.20
Globigerinoides sp (Foraminifera)	0	0	0	0	480	160	640	0.30
Harpacticoida (unidentified)	0	0	0	0	0	160	160	0.08
Jelly fish (Hydrozoa : Cnidaria)	0	0	320	0	0	0	320	0.15
Larva (Unidentified)	0	640	0	0	0	0	640	0.30
Leprotintinnus pellucidus (Tintinnida)	0	0	1600	0	0	0	1600	0.76
Loxostomum sp (Foraminifera)	640	0	0	0	160	0	800	0.38
Microsetella sp (Harpacticoida)	0	0	0	0	640	0	640	0.30
Mysida shrimp (Mysids)	0	0	0	0	960	1760	2720	1.29
Nauplius larvae of Barnacles	0	0	0	0	480	320	800	0.38
Nauplius larvae of Crustacea	0	960	0	480	1120	1120	3680	1.75
Oithona sp (Cyclopoida)	0	0	0	640	0	0	640	0.30
Ostracoda	320	800	320	0	320	640	2400	1.14
Paracalanus sp (Calanoida)	0	0	0	480	0	960	1440	0.68
Parvocalanus sp	0	0	0	0	1280	640	1920	0.91

(Calanoida)								
Polychaete larvae (Annelids)	640	0	0	0	0	0	640	0.30
Radiolarian skeletons	320	1440	0	0	0	0	1760	0.83
Rosalina sp (Foraminifera)	0	480	160	0	0	320	960	0.46
Sagitta sp (arrow worm)	800	0	0	1120	0	0	1920	0.91
Salpa sp (Tunicata)	0	640	0	0	0	0	640	0.30
Spirillina sp (Foraminifera)	0	0	0	0	0	160	160	0.08
Sponge Spicules	4160	4160	1600	1280	2240	2400	15840	7.51
Subeucalanus (Calanoida)	0	0	0	0	800	0	800	0.38
Tintinnids (Unidentified)	0	0	0	0	0	960	960	0.46
Tintinnopsis beroidea (Tintinnida)	0	0	0	160	0	0	160	0.08
Tintinnopsis cylindrica (Tintinnida)	0	640	0	0	0	0	640	0.30
Tintinnopsis karajacensis (Tintinnida)	0	0	0	0	0	320	320	0.15
Tintinnopsis sp (Tintinnida)	0	1280	1760	1760	960	0	5760	2.73
Tintinnopsis tubulosa (Tintinnida)	0	320	0	0	0	0	320	0.15
Veliger larvae of Bivalve	1280	0	480	800	160	800	3520	1.67
Zoea larva of Crab	9920	640	8640	28800	27200	24960	100160	47.50
Total No. Of Genera/Groups =49								
Site-wise Total Density (no/100m^3)	**25920**	**27200**	**21920**	**44960**	**44000**	**46880**	**Total Density =210880**	**100%**
Biomass (ml/100m^3)	**28.74**	**30.61**	**17.86**	**15.63**	**46.51**	**11.22**		

Table 52. Density of Zooplankton at Phang Creek site of Deendayal Port during Season 2

Name of Genera/Group	3A	3B	3C	3D	3E	3 Control	Total density (no/100m3)	% of Occurrence (Site-wise)
Acartia amboinensis	480	0	0	0	0	1120	1600	1.01
Acrocalanus sp (Calanoida)	0	320	0	0	0	0	320	0.20
Ammonia beccarii (Foraminifera)	0	0	0	320	0	0	320	0.20
Arcella sp (Amoebozoa)	0	0	0	0	320	0	320	0.20
Bolivina sp (Foraminifera)	480	0	0	320	0	480	1280	0.81
Bolivinita sp (Foraminifera)	640	0	0	0	0	0	640	0.40
Bulimina marginata	0	640	0	0	0	0	640	0.40
Bulimina sp (Foraminifera)	0	0	320	0	0	0	320	0.20
Calanoida (unidentified)	800	0	640	0	640	320	2400	1.51
Centropages sp (Calanoida)	0	0	640	0	640	640	1920	1.21
Cibicides sp (Foraminifera)	0	0	0	960	0	0	960	0.60
Clausocalanus sp (Calanoida)	480	640	800	0	0	0	1920	1.21
Copepoda (Unidentified)	0	800	640	0	0	0	1440	0.91
Copepoda eggs sac(egg pouch)	0	960	0	0	0	320	1280	0.81
Corycaeus sp (Calanoida)	0	0	0	160	0	0	160	0.10
Cyclops sp (Cyclopoida)	640	0	0	0	0	0	640	0.40
Discorbis sp (Foraminifera)	0	0	0	320	0	0	320	0.20
Egg capsules of Littorinids	320	0	800	1280	0	800	3200	2.02
Elphidium sp (Foraminifera)	320	0	0	0	0	0	320	0.20
Fish	0	0	480	640	320	0	1440	0.91
Foraminifera (unidentified)	3360	3360	1120	2240	4640	1120	15840	9.98
Gastrula larva of Sea star	0	0	0	0	320	0	320	0.20
Globigerina sp (Foraminifera)	960	800	320	1280	960	960	5280	3.33
Globigerinita sp (Foraminifera)	1120	0	800	0	1120	0	3040	1.92
Globigerinoides sp (Foraminifera)	0	800	0	0	0	0	800	0.50
Harpacticoida (unidentified)	0	0	0	0	160	320	480	0.30
Lagena sp (Foraminifera)	0	480	0	0	0	0	480	0.30
Larva (Unidentified)	0	0	640	0	0	0	640	0.40
Leprotintinnus pellucidus (Tintinnida)	0	960	640	0	640	960	3200	2.02
Leprotintinnus simplex (Tintinnida)	800	640	480	640	800	800	4160	2.62
Leprotintinnus sp (Tintinnida)	640	0	800	2880	0	0	4320	2.72
Loxostomum sp (Foraminifera)	0	0	640	800	960	960	3360	2.12
Mysida shrimp (Mysids)	0	0	0	1920	5920	2720	10560	6.65
Narcomedusae (Hydrozoa:Cnidaria)	0	0	0	320	480	0	800	0.50
Nauplius larva of Cyclopoida	0	0	0	0	320	0	320	0.20
Nauplius larvae of Barnacles	0	800	960	0	640	0	2400	1.51

Nauplius larvae of Calanoida	0	0	0	960	0	0	960	0.60
Nauplius larvae of Copepoda	1120	0	640	0	0	0	1760	1.11
Nauplius larvae of Crustacea	0	640	0	640	0	480	1760	1.11
Nonion sp (Foraminifera)	480	320	640	0	0	0	1440	0.91
Oithona sp (Cyclopoida)	0	480	480	480	0	0	1440	0.91
Ophthalmidium sp (Foramonifera)	0	0	0	0	320	0	320	0.20
Ostracoda	1920	800	800	640	800	320	5280	3.33
Crustacea (Unidentified)	0	0	640	0	0	0	640	0.40
Parvocalanus sp (Calanoida)	0	480	0	640	320	0	1440	0.91
Radiolarian skeletons	0	0	0	640	800	0	1440	0.91
Rosalina bradyi	0	0	0	480	0	0	480	0.30
Rosalina sp (Foraminifera)	0	0	480	0	0	800	1280	0.81
Rotaliida (Foraminifera)	0	0	0	0	320	0	320	0.20
Rotifera	0	0	640	0	0	0	640	0.40
Sagitta sp (arrow worm)	0	0	0	0	480	0	480	0.30
Spirillina sp (Foraminifera)	640	320	0	0	0	0	960	0.60
Spiroloculina sp. (Foraminifera)	960	640	320	0	640	0	2560	1.61
Sponge Spicules	2400	2720	1120	1440	3040	1760	12480	7.86
Subeucalanus sp (Calanoida)	0	320	0	0	0	0	320	0.20
Textularia sp (Foraminifera)	0	800	0	0	0	0	800	0.50
Tintinnids (Unidentified)	800	0	0	0	0	0	800	0.50
Tintinnids radix (Tintinnida)	0	0	0	0	0	640	640	0.40
Tintinnopsis beroidea (Tintinnida)	960	640	0	0	0	0	1600	1.01
Tintinnopsis cylindrica (Tintinnida)	0	1120	0	800	0	0	1920	1.21
Tintinnopsis estuariensis (Tintinnida)	800	960	640	640	0	1120	4160	2.62
Tintinnopsis kofoidi (Tintinnida)	0	0	640	0	0	0	640	0.40
Tintinnopsis parvula (Tintinnida)	800	0	0	0	0	640	1440	0.91
Tintinnopsis sp (Tintinnida)	1920	1600	480	1120	0	0	5120	3.23
Tintinnopsis tubulosa (Tintinnida)	1920	1440	800	1120	2080	480	7840	4.94
Tintinnopsis minuta (Tintinnida)	0	0	320	0	0	0	320	0.20
Tortanus sp (Calanoida)	800	0	0	0	0	0	800	0.50
Veliger larvae of Bivalve	640	800	0	1120	480	960	4000	2.52
Zoea larva of Crab	5760	1760	1440	1120	4320	800	15200	9.58
Total No. Of Genera/Groups =69								
Site-wise Total Density (no/100m^3)	**32960**	**27040**	**20800**	**25920**	**32480**	**19520**	**Total density =158720**	**100%**
Biomass (ml/100m^3)	**55**	**23.33**	**51.28**	**47.14**	**86.42**	**59.52**		

Table 53. Diversity indices of Zooplankton at different sites of Deendayal Port during Season 2

	Offshore						Cargo jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-control**
Taxa_S	13	20	19	27	16	24	14	24	15	19	21	24	28	29	31	28	27	23
Individuals (nos. /m^2)	21600	44160	27680	44800	32960	41440	25920	27200	21920	44960	44000	46880	32960	27040	20800	25920	32480	19520
Dominance_D	0.19	0.15	0.09	0.10	0.20	0.15	0.20	0.08	0.19	0.42	0.39	0.30	0.07	0.05	0.04	0.05	0.09	0.06
Shannon Diversity Index(H)	2.07	2.32	2.64	2.76	2.00	2.51	2.08	2.87	2.17	1.65	1.72	2.02	3.03	3.16	3.37	3.14	2.77	2.98
Simpson_1-D	0.81	0.85	0.91	0.90	0.80	0.85	0.80	0.92	0.81	0.58	0.61	0.70	0.93	0.95	0.96	0.95	0.91	0.94
Evenness	0.61	0.51	0.73	0.59	0.46	0.51	0.57	0.73	0.58	0.27	0.27	0.31	0.74	0.82	0.94	0.83	0.59	0.86
Menhinick	0.09	0.10	0.11	0.13	0.09	0.12	0.09	0.15	0.10	0.09	0.10	0.11	0.15	0.18	0.21	0.17	0.15	0.16
Margalef	1.20	1.78	1.76	2.43	1.44	2.16	1.28	2.25	1.40	1.68	1.87	2.14	2.60	2.74	3.02	2.66	2.50	2.23

6.4. Distribution and density of Zooplankton during Season 3

6.4.1. Offshore

*Calanoida (unidentified), Egg capsules of Littorinids, Foraminifera (unidentified), Mysida shrimp (Mysis larva), Nauplius larvae of Barnacles, Nauplius larvae of Crustacea, Ostracoda, Sponge Spicules etc.*were the mostly common zooplankton and throughout observed in all sites of Offshore area. Highest population density was recorded at site 1E-Offshore (94400 nos./100m^3) where number of species was highest (31 nos.) and lowest density in 1D-Offshore (33280 nos./100m^3) where number of species recorded lowest numbers (16 nos.). High biomass was observed in the site 1C-Offshore (22.46 ml/100m^3) and low biomass was recorded in site 1E-Offshore (12.77 ml/100m^3).The range of the population density, biomass and number of species were (33280 to 94400 nos./100m^3), (12.77 to 22.46 ml/100m^3) and (16 to 31 nos.) respectively in all sites. Less observed species are Ammonia sp (Foraminifera), *Bolivina sp (Foraminifera), Cyphonautes larva (Bryozoan), Elphidium sp (Foraminifera), Embryonic development egg, Lagena sp (Foraminifera), Leprotintinnus simplex (Tintinnida), Oithona brevicornis (Cyclopoida), Ophiopluteus Larva (Echinodermata), Sagitta sp (arrow worm), Spirillina sp (Foraminifera),* etc. rarely recorded in this station. Total 57 zooplankton was recorded in Offshore area adding that more composition of zooplankton by the Phylum Arthropoda(Crustacea), Tintinnids and Foraminifera and Sponge Spicules (Porifera).

6.4.2. Cargo Jetty

The population density of zooplankton varied from 27040 nos./100m^3 to 92800 nos./100m^3. Maximum density was noticed in site 2control-Cargo Jetty (92800 nos./100m^3) and minimum was at site 2B-Cargo Jetty (27040 nos./100m^3). Maximum number of species (32 nos.) noted at 2Control- Cargo Jetty minimum number of species was observed in site 2B-Cargo Jetty (15 nos.). Biomass ranged between 13.33 to 37.96 ml/100m^3 where highest biomass noted in site2C-Cargo Jetty and lowest in 2A-Cargo Jetty. Frequently observed species were *Acartia sp (Calanoida), Calanoida (unidentified), Egg capsules of Littorinids, Euterpina sp (Harpacticoida), Foraminifera (unidentified), Ostracoda, Protozoea larva (Crustacea), Sponge*

Spicules, Tintinnopsis sp (Tintinnida), Zoea larva of Crab etc. whereas less observed species were *Appendicularia sp (Tunicata), Copepoda eggs sac(egg pouch), Fish larva, Leprotintinnus sp (Tintinnida), Mysida shrimp (Mysis larva), Paracalanus sp (Calanoida), Pontellid nauplius larva (Calanoida), Rosalina sp (Foraminifera), Tintinnopsis cylindrica (Tintinnida), Tintinnopsis orientalis (Tintinnida)*. Total recorded zooplanktons were 49 in Cargo Jetty.

6.4.3. Phang Creek

This Creek area was represented by the zooplankton fauna majority of them were *Calanoida (unidentified), Egg capsules of Littorinids, Foraminifera (unidentified), Leprotintinnus sp (Tintinnida), Nauplius larvae of Crustacea, Ostracoda, Sponge Spicules, Veliger larvae of Bivalve, Zoea larva of Crab etc.*Very less time or rarely recorded species were *Acartia sp (Calanoida)*, *Ammonia sp (Foraminifera), Arcella sp (Amoebozoa), Cibicides sp (Foraminifera), Copepoda (unidentified), Cyclops sp (Cyclopoida), Cyphonautes larva (Bryozoan). Elphidium sp (Foraminifera), Eponides sp (Foraminifera), Harpacticoida (unidentified), Microsetella sp (Harpacticoida), Tintinnopsis radix (Tintinnida)* etc. The range of zooplankton biomass was between 5.63 to 24.17 ml/100m^3. Highest Biomass was recorded in site 3B-Phang creek (24.17 ml/100m^3) and lowest in site 3C-Phang creek (5.63 ml/100m^3). Maximum and Minimum species count was at in site 3E-Phang creek (27 nos.) and 3Control-Phang Creek (22 nos.) respectively. Population density was maximum recorded in site 3A-Phang Creek (54080 nos./100m^3) and minimum in site 3Control-Phang Creek (24960 nos./100m^3).

Overall assessment of zooplankton showed that the total number of 73 Zooplankton recorded during winter season. Out of these (73) zooplankton, 57 zooplankton recorded in Offshore region, 50 zooplankton at Cargo Jetty and 55 zooplankton in Phang Creek region. The recorded zooplankton of all 3 stations mainly representing Phylum Arthropoda (Crustacea), , Protozoa (mainly foraminifera and tintinnids), Porifera (sponge spicules). Crustacean zooplankton was the dominant due to the dominance of different larval stages which mainly feed phytoplankton. More larval stage of crustacean observed in samples that indicated reproduction and development season of animals from larval to mature animal. Generally zooplankton population dynamics and studies emphasize is given up to group level rather than to species level because of microscopic size of zooplankton so owing to the difficulty in identifying the zooplankton as some species are considered as a group or genus level. The most dominant or frequently observed species (all 3 station) were *Calanoida (unidentified), Egg capsules of Littorinids, Foraminifera (unidentified), Nauplius larvae of Barnacles, Ostracoda, Sponge Spicules, Veliger larvae of Bivalve, Zoea larva of Crab,* etc. Foraminifera belonging to the meroplankton were present at all three station. Overall range of Population density, Biomass and Number of Species were (24960 to 94400 no/100 m^3), (5.63 to 37.96 ml/100m^3) and (15 to 32 nos) respectively. Average high biomass noted at Cargo Jetty (20.26 ml/100m^3) followed by Offshore (18.03 ml/100m^3) than Phang Creek (13.90 ml/100m^3) (Table 54 - 56). Highest population density was recorded in site 1E-Offshore (94400 Nos/100m^3) and lowest was recorded in site 3Control-Phang Creek (24960 No/100m3). Among all recorded zooplankton, majority dominance occurrence was by the Copepoda, Crustacean larvae, Spong Spicules, Foraminifera (Protozoa), Tintinnids (Protozoa), Zoea larva of Crab, Mysida shrimp (Mysids).Egg capsules of Littorinids (Mollusca). Maximum zooplankton faunal composition was dominated by the Phylum Arthropoda, Mollusca, Protozoa, Poriffera. The Fish larva (Ichthyoplankton) was also recorded in Cargo Jetty and Phang Creek. The Zooplankton of Chaetognatha, Tunicata, Cnidaria, Amoebozoa and Echinodermata were only represented by the species namely *Sagitta sp (arrow worm), Appendicularioa sp, Hydrotheca colony, Arcella sp. and Gastrula larva of Sea star* respectively. Veliger larva of Bivalve and Gastropoda shells include in Phylum Mollusca. In Offshore**,** maximum Occurrence (%) was by the Zoea larva of the Crab (15.13%) and minimum by the *Caligus sp (Siphonostomatoida)* (0.05%). In Cargo Jetty, maximum Percentage of Occurrence (%) by the Zoea larva of the Crab (44.03%) and minimum by Gastrula larva of Sea star-Echinodermata (0.05%). In Phang Creek maximum Occurrence (25.96%) was by the Zoea larva of the Crab and minimum (0.07%) by the *Textularia sp (Foraminifera)* (Tables 54 - 56).

During microscopic sample analysis more number of species varieties of Foraminifera, Sponge spicules, Crustacean larva and Tintinnids were observed. These all three are very important for paleontological study aspects and also for evolutionary, ecological and environmental rebuilding. Some species of Ostracoda, Foraminifera and Sponge spicules are considered in microfossils materials. Some deep sea species also recorded that is indication of water circulation pattern. Data on zooplankton density, list of zooplankton is shown in Tables 54, 55 and 56.

Plankton identification, both zooplankton and phytoplankton, were done by using relevant identification and taxonomic keys and with standard literatures, monographs and research articles (Kasturirangan, 1963; APHA, 1992; Mitra et al., 2003; Goswami, 2005; Carling et al., 2004; Mandal 2004; Hussain and Kalaiyarasi, 2013; Guglielmo et al., 2015; Hussain et al., 2016; Sreenivasulu et al., 2017; NIO,1998; NIO, 2002).

6.4.4. *Diversity Indices of Zooplankton*

The data in the table 57 shows diversity indices of zooplankton. The Shannon-wiener diversity index (H') fluctuated between 2.13 to 3.05 indicated moderate to quite high range of diversity added indication of healthy body of water with a maximum value in site 3E-Phang Creek and 1E-Offshore (3.05) where maximum number of species noted in their respective site and minimum value in site 2C-Cargo Jetty (2.13) where species number was 23. Range of the evenness was 0.37 to 0.79 where lowest and highest recorded in site 2D/2D-Cargo Jetty (0.37) and 3C-Phang Creek (0.79) respectively. Range of Simpson index was 0.74 to 0.94. The range value of Margalef indices was 1.37 to 2.71 that means high species number variations.

Table 54. Density of Zooplankton at Offshore site of Deendayal Port during Season 3

Name of Genera/Group	1A	1B	1C	1D	1E	1 Control	Individual total density (no/100m^3)	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	1600	0	0	1440	0	640	3680	1.25
Ammonia sp (Foraminifera)	0	0	1280	0	0	0	1280	0.44
Appendicularia sp (Tunicata)	640	480	0	0	0	0	1120	0.38
Arcella sp (Amoebozoa)	480	0	0	640	0	0	1120	0.38
Bolivina sp (Foraminifera)	0	0	0	640	0	0	640	0.22
Calanoida (unidentified)	2240	2240	3200	2880	1920	3520	16000	5.44
Caligus sp (Siphonostomatoida)	160	0	0	0	0	0	160	0.05
Clausocalanus sp (Calanoida)	640	0	1600	0	0	1120	3360	1.14
Copepoda eggs sac(egg pouch)	0	0	1600	0	2240	960	4800	1.63
Corycaeus sp (Calanoida)	0	480	640	0	0	640	1760	0.60
Cyclopoida (unidentified)	0	1280	2400	800	0	800	5280	1.80
Cyclops sp (Cyclopoida)	1120	0	0	0	1120	0	2240	0.76
Cyphonautes larva (Bryozoan)	0	0	640	0	0	0	640	0.22
Egg capsules of Littorinids	2880	4640	9920	3360	3360	2720	26880	9.14
Elphidium sp (Foraminifera)	0	0	0	0	1760	0	1760	0.60
Embryonic development egg	0	0	0	0	640	0	640	0.22
Euterpina sp (Harpacticoida)	640	1600	1600	0	0	1600	5440	1.85
Foraminifera (unidentified)	2080	480	2240	2400	12960	2560	22720	7.73
Globigerina sp (Foraminifera)	0	0	800	0	4000	0	4800	1.63
Harpacticoida (unidentified)	160	640	0	2080	1760	0	4640	1.58
Heteropoda shells (gastropods)	480	0	0	1920	1600	0	4000	1.36
Labidocera sp (Calanoida)	0	480	0	0	0	640	1120	0.38
Lagena sp (Foraminifera)	320	0	0	0	0	0	320	0.11
Leprotintinnus simplex (Tintinnida)	320	0	0	0	0	0	320	0.11
Leprotintinnus sp (Tintinnida)	0	0	0	0	1120	0	1120	0.38
Metis sp (Harpacticoida)	0	800	0	0	0	0	800	0.27
Microsetella sp (Harpacticoida)	0		0	0	2080	0	2080	0.71
Mysida shrimp (Mysis larva)	3200	1280	1600	320	0	640	7040	2.39
Nauplius larvae of Barnacles	2400	3520	3520	3200	4000	3040	19680	6.69
Nauplius larvae of Crustacea	1440	640	4160	0	8960	1440	16640	5.66
Oikopleura sp (Tunicata)	0	0	0	0	0	640	640	0.22

Oithona brevicornis (Cyclopoida)	0	0	800	0	0	0	800	0.27
Oithona sp (Cyclopoida)	0	0	0	0	960	0	960	0.33
Ophiopluteus Larva (Echinodermata)	0	0	640	0	0	0	640	0.22
Ostracoda	1280	1120	0	2400	10240	800	15840	5.39
Paracalanus sp (Calanoida)	960	800	960	0	0	0	2720	0.92
Parvocalanus sp (Calanoida)	0	0	0	0	0	800	800	0.27
Polychaete larvae (Annelids)	640	480	0	0	1120	960	3200	1.09
Pontellid nauplius larva (Calanoida)	0	0	0	640	1440	0	2080	0.71
Protozoea larva (Crustacea)	1120	0	0	0	0	640	1760	0.60
Radiolaria sp	0	0	0	0	960	0	960	0.33
Radiolarian skeletons	0	0	0	0	3360	0	3360	1.14
Rosalina sp (Foraminifera)	0	0	1600	0	1280	0	2880	0.98
Sagitta sp (arrow worm)	0	0	0	0	480	0	480	0.16
Spirillina sp (Foraminifera)	0	0	0	0	1600	0	1600	0.54
Spiroloculina sp (Foraminifera)	0	0	480	0	0	0	480	0.16
Sponge Spicules	3360	1600	2560	3200	2080	1600	14400	4.90
Subeucalanus (Calanoida)	0	320	0	0	0	0	320	0.11
Tigriopus sp (Harpacticoida)	480	0	0	0	0	0	480	0.16
Tintinnida (unidentified)	800	480	0	0	960	0	2240	0.76
Tintinnopsis orientalis (Tintinnida)	1440	0	2560	0	7520	0	11520	3.92
Tintinnopsis radix (Tintinnida)	0	0	0	0	1440	0	1440	0.49
Tintinnopsis sp (Tintinnida)	0	0	0	0	7520	0	7520	2.56
Veliger larvae of Bivalve	640	320	1600	800	3360	1280	8000	2.72
Zoea larva of Crab	4160	10240	11520	6560	1600	10400	44480	15.13
Unidentified	800	0	0	0	960	0	1760	0.60
Unidentified larva	0	640	0	0	0	0	640	0.22
Total No. Of Genera/Groups = 57								
Site-wise Total Density (no/100m^3)	36480	34560	57920	33280	94400	37440	**Total Density =294080**	**100%**
Biomass (ml/100m^3)	**21.02**	**18.99**	**22.46**	**16.67**	**12.77**	**16.30**		

Table 55. Density of Zooplankton at Cargo Jetty site of Deendayal Port during Season 3

Name of Genera/Group	2A	2B	2C	2D	2E	2 Control	Individual total density (no/100m^3))	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	640	160	800	480	480	1120	3680	1.17
Ammonia sp (Foraminifera)	640	0	0	640	0	800	2080	0.66
Appendicularia sp (Tunicata)	0	0	960	0	0	0	960	0.30
Bolivina sp (Foraminifera)	640	0	480	0	0	320	1440	0.46
Calanoida (unidentified)	960	1440	1760	1600	2400	4000	12160	3.86
Calcarina sp (Foraminifera)	0	0	320	0	640	0	960	0.30
Clausocalanus sp (Calanoida)	0	0	800	0	0	800	1600	0.51
Copepoda eggs sac(egg pouch)	0	0	0	640	0	2720	3360	1.07
Cyclopoida (unidentified)	0	0	640	0	640	0	1280	0.41
Egg capsules of Littorinids	2240	2240	4320	5440	5120	7840	27200	8.63
Embryonic development egg	0	0	0	0	0	800	800	0.25
Eponides sp (Foraminifera)	800	0	0	0	0	0	800	0.25
Euterpina sp (Harpacticoida)	1440	800	1120	0	800	2080	6240	1.98
Fish larva	0	0	0	0	320	640	960	0.30
Foraminifera (unidentified)	4800	1440	3200	3200	4480	4160	21280	6.75
Gastrula larva of Sea star	0	160	0	0	0	0	160	0.05
Globigerina sp (Foraminifera)	1120	0	800	960	1120	1280	5280	1.68
Harpacticoida (unidentified)	0	0	0	320	640	1920	2880	0.91
Heteropoda shells (gastropods)	0	0	640	1280	0	960	2880	0.91
Leprotintinnus sp (Tintinnida)	0	0	0	0	1440	0	1440	0.46
Mesochra sp (Harpacticoida)	0	0	0	0	0	480	480	0.15
Metis sp (Harpacticoida)	0	0	0	0	480	0	480	0.15
Mysida shrimp (Mysis larva)	0	0	480	0	0	640	1120	0.36
Nauplius larvae of Barnacles	0	1120	1120	3200	3200	1280	9920	3.15
Nauplius larvae of Crustacea	0	0	0	800	1600	1760	4160	1.32
Ophiopluteus Larva (Echinodermata)	0	0	640	0	0	0	640	0.20
Ostracoda	3200	1440	1600	1440	800	2560	11040	3.50
Paracalanus sp (Calanoida)	0	0	800	0	0	1120	1920	0.61
Parvocalanus sp (Calanoida)	0	1120	0	0	800	960	2880	0.91
Polychaete larvae (Annelids)	480	0	0	0	0	0	480	0.15
Pontellid nauplius larva (Calanoida)	0	0	0	800	0	0	800	0.25
Protozoea larva (Crustacea)	1120	1760	640	1440	1280	640	6880	2.18
Radiolarian skeletons	800	0	0	0	0	1600	2400	0.76

Rosalina sp (Foraminifera)	0	0	0	320	0	320	640	0.20
Sagitta sp (arrow worm)	0	0	0	320	480	640	1440	0.46
Spirillina sp (Foraminifera)	0	0	640	480	800	640	2560	0.81
Spiroloculina sp (Foraminifera)	0	0	0	0	0	640	640	0.20
Sponge Spicules	5920	2240	320	1280	1920	3680	15360	4.88
Subeucalanus (Calanoida)	0	0	960	0	0	0	960	0.30
Temora sp (Calanoida)	0	0	0	480	0	0	480	0.15
Tintinnopsis beroidea	0	0	0	0	0	480	480	0.15
Tintinnopsis cylindrica (Tintinnida)	0	0	0	0	640	0	640	0.20
Tintinnopsis orientalis (Tintinnida)	0	960	0	0	0	0	960	0.30
Tintinnopsis radix (Tintinnida)	0	0	0	0	480	0	480	0.15
Tintinnopsis sp (Tintinnida)	1280	1120	0	640	0	0	3040	0.96
Triloculina sp (Foraminifera)	640	0	0	0	0	0	640	0.20
Veliger larvae of Bivalve	800	960	1120	480	480	800	4640	1.47
Zoea larva of Crab	14080	10080	23360	23680	23360	44160	138720	44.03
Unidentified	0	0	0	640	0	0	640	0.20
Unidentified larva	0	0	0	640	480	960	2080	0.66
Total No. Of Genera/Groups =50								
Site-wise Total Density (no/100m^3)	41600	27040	47520	51200	54880	92800	**Total Density =315040**	**100%**
Biomass (ml/100m^3)	**13.33**	**14.37**	**37.96**	**15.38**	**16.90**	**23.85**		

Table 56. Density of Zooplankton at Phang Creek site of Deendayal Port during Season 3

Name of Genera/Group	3A	3B	3C	3D	3E	3 Control	Total density (no/100m3)	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	1440	1760	0	0	0	800	4000	1.77
Ammonia sp (Foraminifera)	480	0	0	0	0	0	480	0.21
Arcella sp (Amoebozoa)	0	0	0	0	480	0	480	0.21
Bolivina sp (Foraminifera)	320	0	800	320	0	0	1440	0.64
Calanoida (unidentified)	3520	1760	320	960	2240	1440	10240	4.54
Cibicides sp (Foraminifera)	0	0	0	480	0	0	480	0.21
Clausocalanus sp (Calanoida)	1280	960	0	0	1280	640	4160	1.84
Copepoda (unidentified)	0	480	0	0	0	0	480	0.21
Copepoda eggs sac(egg pouch)	1120	0	0	640	1120	960	3840	1.70
Corycaeus sp (Calanoida)	800	0	0	0	640	0	1440	0.64
Cyclopoida (unidentified)	0	0	1440	0	1120	0	2560	1.13
Cyclops sp (Cyclopoida)	800	0	0	800	0	0	1600	0.71
Cyphonautes larva (Bryozoan)	0	800	1120	0	0	0	1920	0.85
Egg capsules of Littorinids	3680	3360	1760	2560	2080	1920	15360	6.81
Elphidium sp (Foraminifera)	320	0	0	0	0	0	320	0.14
Eponides sp (Foraminifera)	0	0	320	0	0	0	320	0.14
Euterpina sp (Harpacticoida)	1120	1440	0	0	0	0	2560	1.13
Fish larva	0	0	0	800	960	0	1760	0.78
Foraminifera (unidentified)	3200	2720	4160	2400	2720	960	16160	7.16
Gastrula larva of Sea star	0	0	640	0	800	0	1440	0.64
Globigerina sp (Foraminifera)	0	480	0	0	800	0	1280	0.57
Harpacticoida (unidentified)	0	1120	0	0	0	0	1120	0.50
Heteropoda shells (gastropods)	0	0	1440	0	960	0	2400	1.06
Hydrocaulus & Hydrotheca colony of Hydrozoa	0	960	0	0	0	0	960	0.43
Lagena sp (Foraminifera)	0	320	480	0	0	0	800	0.35
Leprotintinnus simplex (Tintinnida)	0	480	1760	0	1120	480	3840	1.70
Leprotintinnus sp (Tintinnida)	1280	1280	320	1600	1280	1760	7520	3.33
Medusae of Hydrozoa (Cnidaria)	0	0	0	0	320	320	640	0.28
Metis sp (Harpacticoida)	0	0	0	1120	0	640	1760	0.78
Microsetella sp (Harpacticoida)	0	0	960	0	0	0	960	0.43
Mysida shrimp (Mysis larva)	960	0	0	0	0	0	960	0.43
Nauplius larvae of Barnacles	0	0	0	0	320	640	960	0.43
Nauplius larvae of Crustacea	1280	480	3520	640	1120	800	7840	3.48

Nematoda	0	0	0	0	0	960	960	0.43
Oithona sp (Cyclopoida)	0	0	800	0	0	0	800	0.35
Ophiopluteus Larva (Echinodermata)	0	0	0	640	0	0	640	0.28
Ostracoda	800	320	1920	960	480	800	5280	2.34
Paracalanus sp (Calanoida)	1600	0	0	960	1120	0	3680	1.63
Parvocalanus sp (Calanoida)	0	640	0	800	0	0	1440	0.64
Polychaete larvae (Annelids)	0	0	960	960	0	640	2560	1.13
Protozoea larva (Crustacea)	0	0	0	0	1920	1440	3360	1.49
Radiolarian skeletons	0	800	2240	0	0	0	3040	1.35
Rosalina sp (Foraminifera)	0	0	800	480	0	320	1600	0.71
Sagitta sp (arrow worm)	0	0	0	0	320	1440	1760	0.78
Sponge Spicules	2080	1920	4800	5920	2560	1760	19040	8.44
Subeucalanus (Calanoida)	0	0	0	640	0	0	640	0.28
Textulariasp (Foraminifera)	0	160	0	0	0	0	160	0.07
Tintinnida (unidentified)	1120	0	0	0	0	0	1120	0.50
Tintinnopsisorientalis (Tintinnida)	0	0	2080	800	800	0	3680	1.63
Tintinnopsis radix (Tintinnida)	0	0	0	0	0	480	480	0.21
Tintinnopsissp (Tintinnida)	0	1600	1440	640	1120	0	4800	2.13
Veliger larvae of Bivalve	1280	1280	1600	160	1280	320	5920	2.62
Zoea larva of Crab	24320	13600	1920	7520	5760	5440	58560	25.96
Unidentified	160	480	0	320	0	0	960	0.43
Unidentified larva	1120	0	0	1120	800	0	3040	1.35
Total No. Of Genera/Groups =55								
Site-wise Total Density (no/100m^3)	54080	39200	37600	34240	35520	24960	**Total density =225600**	**100%**
Biomass (ml/100m^3)	**16.98**	**24.17**	**5.63**	**9.87**	**11.94**	**14.84**		

Table 57. Diversity indices of Zooplankton at different sites of Deendayal Port during Season 3

	Offshore						Cargo jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-control**
Taxa_S	28	22	23	16	31	21	18	15	23	24	25	32	23	24	24	25	27	22
Individuals (nos. /m^2)	36480	34560	57920	33280	94400	37440	41600	27040	47520	51200	54880	92800	54080	39200	37600	34240	35520	24960
Dominance_D	0.06	0.13	0.09	0.10	0.06	0.11	0.16	0.17	0.26	0.24	0.21	0.24	0.22	0.15	0.06	0.10	0.06	0.08
Shannon Diversity Index(H)	3.04	2.52	2.73	2.52	3.05	2.62	2.29	2.22	2.13	2.18	2.31	2.31	2.27	2.55	2.94	2.74	3.05	2.80
Simpson_1-D	0.94	0.87	0.91	0.90	0.94	0.89	0.84	0.83	0.74	0.76	0.79	0.76	0.78	0.85	0.94	0.90	0.94	0.92
Evenness	0.75	0.56	0.67	0.78	0.68	0.66	0.55	0.62	0.37	0.37	0.40	0.31	0.42	0.53	0.79	0.62	0.78	0.75
Menhinick	0.15	0.12	0.10	0.09	0.10	0.11	0.09	0.09	0.11	0.11	0.11	0.11	0.10	0.12	0.12	0.14	0.14	0.14
Margalef	2.57	2.01	2.01	1.44	2.62	1.90	1.60	1.37	2.04	2.12	2.20	2.71	2.02	2.18	2.18	2.30	2.48	2.07

Chapter 7 Management Plan

Activity such as Dredging are considered to be a major activity that increases water turbidity and suspended load thereby impacting plankton and productivity. Very high prevailing sedimentation in the Deendayal Port region necessitates huge quantity of maintenance dredging. A typical by product of dredging activities is the resuspension of sediments into the water column, which have effects on marine organisms. Further Dredging related suspended sediment plumes may differ in scope, timing, duration and intensity from those natural conditions, thus potentially causing conditions not normally experienced by the organisms (Snigdha, 2005). Effects of suspended sediments are highly species-specific and can vary greatly (Clarke and Wilber, 2000). Increase in suspended materials in the water column will diminish the light penetration with potential adverse effects on the photosynthetic capability of phytoplankton and other aquatic plants (Iannuzzi et al., 1996).

In general, a comprehensive dredging management plan should be considered for any port environment so as to ensure that the project activities should be carried out with No or a very minimal effects to the environment. Dredging is the activity of removal of the substratum settled at the bottom of the water body. Dredging is carried out to deepen the water column for the smooth transport of vessels in the port area, particularly the navigation canal. The dredging process is intended to remove the soil or sediment which a complex constituted by a mixture of sand, clay and decomposing solid materials and a large number of benthic organisms. Further, in case of a marine environment, various physical characteristics including total suspended solids and turbidity plays a major role in affecting the water column which in turn affects the marine organisms. During dredging activities, there is a high chance of dispersal of suspended sediment load gets mixed up in the water column, thereby increasing the load of TSS.

Over the past few years, dredging has been practiced as a solution to upgrading the infrastructure to enable economic growth of the port and harbors in India however, the programme needs proper planning to achieve the objectives without environmental implications through adoption of proper management plans. Shifting and dislodging the sediment substratum at the bottom of coastal environment no doubt brings habitat loss to the communities which inhabit as well as those found in the water above for quite a long time and the management plan should include the following objectives.

1. Dredging should be undertaken in such a way that it does not harm the marine organisms breeding especially the ones which are economically important.
2. Dredging activities during bad weather conditions should be avoided.
3. Implementation of the use of suction dredger instead of bucket dredger can be a better option.
4. Dewatering of the fines suspended matter through sediment traps can be followed.
5. Dredging activity areas should be screened for the presence of presence of RET Species which are indigenous to the Gulf of Kachchh region.
6. Turbidity curtains, nowadays, are increasingly used during dredging operations as suggested by Researchers (Sawaragi, 1995; Elander and Hammar, 1998; Otoyo, 2003; Dreyer, 2006; Guo *et al*., 2009; Ishizaki and Rikitake, 2010; Ueno, 2010, Trang and Keat, 2010) which could also be attempted based on its operational convenience. Moreover, various other factors such as current speed, water depth and wave heights to be considered as these also play role in the efficiency of Turbidity curtains. Turbidity curtains allow suspended sediments to settle out of the water column in the dredging spot thus minimizing sediment transport towards the shore. Constructed with thermoplastic material, they serve as a primary method to control turbidity in dredging sites. There are various types of curtains like floating, hanging, solid diversion baffles and permeable and impermeable screens. However, they have proved to be an effective method to contain sediment load in ecologically sensitive areas such as mangroves and corals during dredging operations.
7. In order to ameliorate the likely impacts due to sediment load through changes in operational procedure such as appropriately timing the operation in tune with tides and tidal current direction) may be considered.
8. Similar to the current practice being followed, disposal of dredged materials continued to be done only in pre-designated sites.

9. The initial screening for evaluating disposal options is based on physical and chemical analysis for geotechnical character and the presence of contaminants in the sediments. Depending on the physical and chemical character of the dredged material, disposal may be confined, unconfined or treated prior to release in open water, along the shoreline, or on land.
10. Evaluation of the physical/chemical characteristics of dredged material that is dumped at the site to avoid and minimize potential impacts to the marine environment that endanger the health of human through biomagnification and economic loss to the fishery sector.
11. To mitigate potential contaminant passing from the port area, it should be addressed through proper design of storm water handling and treatment facilities; placement of sewage and wastewater outfalls; compatibility of local land use (e.g. proximity of agriculture fields or mining operations), procedures for handling hazardous materials and types of industries permitted to operate in the port area.
12. Many management measures such as enhancing the biodiversity of the intertidal / subtidal areas by means of artificial reef structures and controlling water column turbidity by deploying mechanisms to trap silts arising out of dredging activity may be better options which can be implemented by the port authorities.
13. A program for monitoring the site of dredging as well as the site of dumping the material on regular basis depending the quantity of the material to be disposed, the presence of contaminants at the new site. The main purpose of a disposal site monitoring program is to determine whether dredged material site management practices, including disposal operations, at the site need to be changed to avoid unreasonable degradation or endangerment of human health or welfare or the marine environment.
14. The Bioavailability of the expected contaminants and their toxicity at the different life stages of important bioresources which are commercially important.

15. At the site designation stage, the emphasis is on selecting a site where disposal will not have a significant adverse impact on various amenities such as fisheries, coral reefs, endangered species, or on other uses of the marine environment.
16. There should be proper documentation of all data on the use of the site for inclusion in the site management plan or permits authorizing site usage from the Central and state government authorities.

Further, there are three elements which can act as building blocks for developing site management plans are

a. The disposal site's characteristics, as defined during the site designation process.
b. Compliance with the ocean dumping criteria, including the results of effects-based testing of the proposed dredged material; and
c. The ability to manage the disposal operation and monitor the site for changes.

Site management plans facilitate management action by the statutory bodies and whenever the site management plan is developed, it should be prepared jointly by the concerned bodies as well as the state or local government for managing the ocean dredged material disposal site. The site management plan should provide a clear, concise statement of management objectives and an overview of its purpose and function.

The focus and intensity of site management activities are likely to vary on a case-by-case basis and site management roles and responsibilities may change.

Disposal history information for management plan implementation requires

- Known historical uses of the proposed disposal site.
- Transportation and disposal methods use
- Monitoring findings.
- Enforcement activities.

A monitoring program should have the ability to detect environmental change and assist in determining regulatory and permit compliance. For which the program should be designed to provide the following:

(1) Information indicating whether the disposal activities are occurring in compliance with the permit and site restrictions

(2) Information indicating the short-term and long-term fate of materials disposed of in the marine environment

(3) Information concerning the short-term and long-term environmental impacts of the disposal.

Disposal site monitoring is a key component of site management. Continuous monitoring of all physical, chemical, and biological parameters and resources in and around a typical disposal site is not necessary. Monitoring programs should be structured to address specific questions (null hypotheses) and measure the conditions of key indicators and endpoints, particularly those identified during site designation, or major project-specific issues that arise.

The most effective monitoring programs for ocean disposal sites evaluate the fate and effect of dredged material disposal and its utilization following proper technology such as shoreline strengthening structures, artificial reefs, reclamation and restoration of coastal habitats and beach recharge activities. Discharge point and allowable tolerances in position; Debris removal provisions; Provisions to address spillage, and leakage of dredged material; Inspection and surveillance provisions and Record-keeping and reporting requirements should be incorporated in the plan.

The management plan should consider the anticipated use of the site over the long term, including the anticipated closure date for the site, if applicable, and any need for management of the site after the closure of the site. This can be achieved through Long-term Maintenance Dredging Management Plan (LMDMP) to document the status of responsibilities for managing natural sediment accumulation at the Port, in a way that ensures the safe and efficient operation of the Port and the ongoing protection of local environmental values.

Chapter 8 Conclusion and Recommendation

Dredging activities results in the resuspension of sediment into the water column, which have effects on marine organisms. Further, activities such as Dredging related suspended sediment plumes may differ in scope, timing, duration and intensity from those natural conditions, thus potentially causing conditions not normally experienced by the organisms. Effects of suspended sediments are highly species-specific and can vary greatly (Clarke and Wilber, 2000). Increase in suspended materials in the water column will diminish the light penetration with potential adverse effects on the photosynthetic capability of phytoplankton and other aquatic plants (Iannuzzi et al., 1996).

In this project, with the above scenario, the marine monitoring for the current study period was conducted in the month of December 2022, May 2023 and September 2023 as a three-season study and based on the data gathered, this Final report was prepared. During this period, marine water from the locations was also studied to understand the impact of the dredged material on the water column. The study was conducted in a systematic manner involving standard protocols and the gathered data on the physical, chemical constituents and biological characteristics were used for interpretation.

Overall, comparatively moderate biological community structure of the water and sediment was observed during this study similar to previous years such as 2020-21 and 2021-22. Hence regular monitoring of the sediment matrix and water column of a coastal environment is essential not just to understand the environmental health but will be helpful to find out the pattern and to contrivance appropriate management measures arising due to dredging impacts.

References

Airoldi, L., & Beck, M. (2007). Loss, status and trends for coastal marine habitats of Europe. Oceanography and Marine Biology: An Annual Review, 45, 345–405.

Alcaraz, M.and Calbet, A. (2003). Zooplankton ecology, inMa rine Ecology. Encyclopedia of Life Support Systems (EOLSS), eds C. Duarte and A. Lott Helgueras (Oxford: Developed under the Auspices of the UNESCO, EolssPublishers), 295–318.

Baird, R. and L. Bridgewater, 2017. Standard methods for the examination of water and wastewater. 23rd edition. Washington, D.C.: American Public Health Association.

Barbier Edward, B., Hacker Sally, D., Kennedy, C., Koch, E. W., Stier, A. C., and Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81, 169–193. doi: 10.1890/10-1510.1

Barnes, R D, 1980. Invertebrate Zoology Saunders College, Philadelphia 108pp

Besiktepe, S., Tang, K. W., Mantha, G. (2015). Seasonal variation of abundance and live/dead compositions of copepods in Mersin Bay, northeastern Levantine Sea (eastern Mediterranean). Turk Zool. 39: 494-506. doi:.10.3906/zoo-1405-23.

Bhaskar P. V., Roy R., Gauns M., Shenoy D. M., Rao V. D., Mochemadkar S., 2011. “Identification of non-indigenous phytoplankton species dominated bloom off Goa using inverted microscopy and pigment (HPLC) analysis”, J Earth Syst Sci, pp.1145–1154.

Bhunia, A.B. and Choudhury, A., 1998. Studies on the seasonal abundance and biomass of Crustacean Zooplankton and Chaetognaths in relation to ecological parameter of a tidal Creek (Mooriganga), of Sagar Island (north), Sunderbans, West Bengal. *Indian Journal of. Marine Science 28,* 93-198.

Boyd, S. E., Limpenny, D. S., Rees, H. L., & Cooper, K. M. (2005). The effects of marine sand and gravel extraction on the macrobenthos at a commercial dredging site (results 6 years post-dredging). *ICES Journal of Marine Science*, *62*(2), 145–162.

Brink, K.H. (1993). The coastal ocean progresses effort. Oceanus, 36, pp. 47-49.

Carling, K. J., Ater, I. M., Pellam, M. R., Bouchard, A. M., Mihue, T. B. (2004). A Guide to the Zooplankton of Lake Champlain. Plattsburgh State University of New York. Scientia Discipulorum. 1: 38-66.

Chakrabarty, M., Banerjee, A., Mukherjee, J., Rakshit, N., Ray, S. (2017) Spatial pattern analysis of zooplankton community of Bakreswar reservoir, India. Energ. Ecol. Environ. 2(3): 193-206. doi:. 10.1007/s40974-017-0057-8.

Chattopadhyay, J., R.R. Sarkar & S. Pal 2003. Dynamics of nutrient–phytoplankton interaction in the presence of viral infection. *BioSystems*, 68: 5–7.

Clark, K R and Warwick, R M 1994. Change in Marine Communities, An Approach to Statistical Analysis and Interpretation Natural Environment Research Council, Plymouth Marine Laboratory, Plymouth, pp144.

Cloern J. E., “Phytoplankton bloom dynamics in coastal ecosystems: A review with some general lessons from sustained investigation of San Fransisco Bay”, California. 1996. Rev Geophys, 34(2), pp.127–168, 1996.

Covich, A. P., Palmer, M. A. and T. A. Crowl (1999): The Role of Benthic Invertebrate Species in Freshwater Ecosystems. Bio Science, 49 (2): 119-127.

Davies, O.A., C. C. Tawari and J. F. N. Abowei, 2008. Zooplankton of Elechi Creek, Niger Delta, Nigeria. Environ. Ecol., 26 (4c) : 2346 - 2441.

Davis, B. J. 1977. Distribution and temperature adaptation in the teleost fish genus Gibbonsia. Mar. Bio!. 42: 315-320.

Day, J H 1967. A monograph on the Polychaeta of Southern Africa Pts I and II, Brit Mus Nat Hist, 656, 1-878.

Dekker, R. 1989. The macrozoobenthos of the subtidal western Dutch Wadden Sea. I. 468 Biomass and species richness. Netherlands Journal of Sea Research 23: 57–68.

Desai, S. R, 2008. Subashchandran, MD, Ramachandra TV; Phytoplankton Diversity in Sharavati River Basin, Central Western Ghats. Journal of Sediment and Water Sciences, 2008; 1(1):7- 66.

Descy, J. P, 1993. Ecology of the phytoplankton of river Moselle: Effect of disturbance on community structure and diversity. Hydrobiologia, 249(1-3): 111-116.

Dodson, S. (1992). Predicting crustacean zooplankton species richness. Limnol Oceanogr. 37(4): 848-856.

Dodson, S.I. and Frey, D. G. (2001). Cladocera and other branchiopoda. Ecology and classification of North American Freshwater Invertebrates. Academic Press. London. 850 – 914.

Fauvel, P, 1953 The Fauna of India Including Pakistan, Ceylon, Burma and Malaya Annelida, Polychaeta, Allahabad pp507.

Figueredo, C. C. & A. Giani 2001. Seasonal variation in the diversity and species richness of phytoplankton in a tropical eutrophic reservoir. *Hydrobiologia*, 445: 165-174.

Gajbhiye, S.N. & Abidi, S.A.H. (1993). Zooplankton distribution in the polluted environment around Bombay. Environment Impact on Aquatic & Terrestrial Habitats. pp. 127-142.

Gao, X. & J. Song 2005. Phytoplankton distributions and their relationship with the environment in the Changjiang Estuary, China. *Marine Poll. Bull.*, 50: 327-335.

Garzke, J., Sommer, U., Ismar, S.M.H. (2017). Is the chemical composition of biomass the agent by which ocean acidification influences on zooplankton ecology. Aquat Sci. 79(3): 733-748. doi:. 10.1007/s00027-017-0532-5.

Goswami, S. C. (2005). Zooplankton Methodology collection & identification manual. Published by National Institute of Oceanography, Dona Paula, Goa. Edited by V.K.Dhrgalkar & X.N.Veriecar.

Goswami, S.C and Padmavathi, G. (1996). Zooplankton production, composition and diversity in the coastal water of Goa. *Indian Journal of. Marine Science25*, 91-97.

Gray, J. S. (1997). Marine biodiversity: Patterns, threats and conservation needs. Biodiversity and Conservation, 6, 153–175.

Guglielmo, L., Granata, A., Guglielmo, R. (2015). Class Malacostraca Order Euphausiacea. Revista IDE@- SEA. 86(B): 1-20. ISSN 2386-7183.

GUIDE, (2011). Comprehensive Terrestrial EIA (including Mangroves) for the Proposed Multi-Project SEZ at Kandla. EIA report submitted to Mumbai Regional Centre of National Institute of Oceanography, Dona Paula, Goa.

Hambler, C and Speight, M R 1995. Biodiversity conservation in Britain, science replacing tradition British Wildlife, 6, 137-147yla, P S, S Velvizhi and S Ajmal Khan 1999 A Monograph on the amphipods of Parangipettai coast Annamalai University, India 78.

Harkantra, S. N., A. Nair, Z. A. Ansari and A. H. Parulekar, 1980. Benthos of the shelf region along the West coast of India. *Indian J. Mar. Sci.*, 9: 106-110.

Hussain, S. M., Joy, M. M., Rajkumar, A., Nishath, N. M & Fulmali, S. T. (2016). Distribution of calcareous microfauna (Foraminifera and Ostracoda) from the beach sands of Kovalam, Thiruvananthapur, Kerala, Southwest coast of India.Journal of the Palaeontological Society of India. 61(2). 267-272. ISSN 0522- 9630.

Hussain, S. M., Kalaiyarasi, A. (2013). Distribution of Ostracoda in the Mullipallam Lagoon, near Muthupet, Tamil Nadu, Southeast Coast of India —Implications on Microenvironment. In: Sundaresan J., Sreekesh S.,230 Ramanathan A., Sonnenschein L., Boojh R. (eds) Climate Change and Island and Coastal Vulnerability. Springer, Dordrecht.

Ingole B, Sivadas S, Goltekar R, Clemente S, Nanajkar M, Sawant R, D'Silva C, Sarkar A, Ansari Z (2006) Ecotoxicological effect of grounded MV River

Princess on the intertidal benthic organisms of Goa. Environ /ntemat.32:284-289.

Jagadeesan, L., Jyothibabu, R., Anjusha, A., Arya, P. M., Madhu, N. V., Muraleedharan, K. R., and Sudheesh, K., 2013. Ocean currents structuring the mesozooplankton in the Gulf of Manner and the Palk Bay, southeast coast of India. *Progress in Oceanography*, 110: 27-48.

Jegadeesan, P., 1986. Studies on environmental inventory of the marine zone of Coleroon estuary and inshore waters of Pazhayar, Southeast coast of India. *Ph. D., Thesis*, *Annamalai University*, India.

Jha, D. K., Devi, M. P., Vidyalakshmi, R., Brindha, B., Vinithkumar, N. V., and Kirubagaran, R. (2015). Water quality assessment using water quality index and geographical information system methods in the coastal waters of Andaman Sea, India. Mar. Pollut. Bull. 100, 555–561. doi: 10.1016/j.marpolbul.2015.08.032.

Jickells, T. D. (1998). Nutrient biogeochemistry of the coastal zone. Science 281, 217–222. doi: 10.1126/science.281.5374.217.

Jones, G., and Candy, S. (1981). Effects of dredging on the macrobenthic infauna of Botany Bay. *Marine and Freshwater Research*, *32*(3), 379–398.

Kadam S.S. and L. R. Tiwari, 2012. Zooplankton Composition in Dahanu Creek-West Coast of Ind. Res. J. Rec. Sci., 1(5): 62-65.

Karr, J. R., J D. Allen, and A. C. Benke 2000 River conservation in the United States and Canada. In P. J. Boon, Davies and B. R. Petts, G E (Ed.), Global perspectives on River conservation, pp 3–39 Science, Policy, and Practice. Wiley, New York.

Kasturirangan, L. R (1963). A key for the identification of the more common planktonic Copepoda of Indian coastal waters. Publication No .2. Indian National Committee on Oceanic Research. p. 87.

Krishnamurthy, K. and Santhanam, R. (1975). Ecology of Tintinids (Protozoa: Ciliata) in Porto Novo region. *Indian Journal of. Marine Science 4*, 181-184.

Kumar, A., 1995 Studies of pollution in river Mayurakshi in south Bihar. Indian Journal of Environmental Pollution, 2(1): 21-26.

Levandowsky, M., 1972. An ordination of phytoplankton population in ponds of varying salinity and temperature. *Ecology,* 53(3): 398-407.

Lyla, P S., Velvizhi, S and Ajmal Khan, S 1999. A Monograph on the amphipods of Parangipettai coast Annamalai University, India pp78.

Madin, L.P., Horgan, E.F., and D.K. Steinberg. 2001.Zooplankton at the Bermuda Atlantic Timeseries Study (BATS) station: diel, seasonal and inerannual variation in biomass, 1994-1998. Deep-Sea Research II. 48 (8-9): 2063-2082

Magurran, A 1991. Ecological Diversity and Its Measurement Princeton University Press, Princeton, pp178.

Mahapatro, D R C., Panigrahy, K and Samal, R N 2011. Macrobenthos of shelf zone off Dhamara estuary, Bay of Bengal. J Oceanog Mar Sci 22, pp 32-42.

Mandal, S.K. (2004). Studies on the Effect of Ship Scrapping Industry Wastes on Marine Phytoplankton at Alang, Gujarat, Ph. D thesis. M. K. Bhavnagar University, Bhavnagar.

Margalef, R 1958. Information theory in ecology. Gen Syst, 3, 36–71.

Marine Biology Organization (MBO), 2007. Zooplankton Retrieved from: http://www.marinebio.com/oceans/zooplankton.Askp. 62k, (Accessed on: September 29, 2006).

Martin G.D, P.A. Nisha, K.K. Balachandran and G.V.M. Gupta (2011). Eutrophication induced changes in benthic community structure of a flow-restricted tropical (Cochin backwaters), India. Environ. Monit. Assess. 176(1-4):427-438.

Maurer, D., Watling, L., Kinner, P., Leathem, W and Wethe, C 1978. Benthic invertebrate assemblages of Delaware Bay. Mar Biol, 45, 65-78.

Maya, M. V., M. A. Soares, R. Agnihotri, A. K. Pratihary, S. Karapurkar, H. Naik & S. W. A. Naqvi 2011. Variations in some environmental characteristics including C and N stable isotopic composition of suspended organic matter in the Mandovi estuary. *Environ. Monit. Assess.*, 175: 501–517.

Mees, J. and Jones, M. B. (1997): The Hyperbenthos. Oceanography and Marine Biology: an Annual Review, 35, 221-255.

Mishra, S., and Panigrahy, R. C. (1999). Zooplankton ecology of the Bahuda estuary (Orissa), east coast of India. *Indian Journal of. Marine Science 28,* 297-301.

Mitra A., Davidson, K. and Flynn, K. J. (2003) The influence of changes in predation rates on marine microbial predator/prey interactions: a modelling study. *Acta Oecol* (Suppl. 1), S359–S367.

Mitra, A., Zaman, S., Sett, S., Raha, AK and Banerjee, AK 2014. Phytoplankton cell volume and diversity in Indian sundarban. Ind J Mar Sci 43, 2 208-215.

Moura, A. N., Bittencourt-Oliveira, M. C & Nascimento, E. C. (2007). Benthic Bacillariophyta of the Paripe River estuary in Pernambuco state, Brazil. Braz. J. Biol. 67(3): 393-401.

Murugan, A., 1989. Ecobiology of Cuddalore, Uppanar backwaters, Southeast coast of India. *Ph.D., Thesis, Annamalai University*, India.

Murugesan, P., 2002. Benthic biodiversity in the marine zone of Vellar estuary (Southeast Coast of India). *Ph. D., Thesis Annamalai University*, India, 359pp.

Nair, VR 2002. Status of flora and fauna of Gulf of Kachchh, India NIO, Goa, pp 1-258.

Newell, R. C., Seiderer, L. J., & Hitchcock, D. R. (1998). The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology: An Annual Review*, *36*, 127–178.

NIO, (2002). Status of flora and fauna of Gulf of Kachchh, India. National Institute of Oceanography, Goa.

NIO, 1998. Environmental studies for proposed BPCL jetty and associated facilities at Kandla Part-I Rapid marine EIA, May1998 NIO Mumbai.

NIO. (1980). Technical Report, National Institute of Oceanography, Goa.

Omori, M. and lkeda. T. (1984). Methods in Marine Zooplankton ecology. John Wiley & Sons, New York.

Parasharya D and Patel B. (2014). Spawning aggregation of Melibe viridis Kellart (1858) from Gulf of Kachchh-Western India. International Journal of Scientific and Research Publication, 4(3), ISSN 2250-3153.

Parasharya D and Patel B. (2014). Spawning aggregation of Melibe viridis Kellart (1858) from Gulf of Kachchh-Western India. International Journal of Scientific and Research Publication, 4(3), ISSN 2250-3153.

Parulekar, A. H., Dhargalkar, V. K., and Singbal, S. Y. S. (1980). Benthic studies in Goa estuaries. Part 3. Annual cycle of macrofaunal distribution, production and trophic relations. *Indian J Mar Sci*.

Pearson, T. H. and Rosenberg, R. (1978): Macrobenthic Succession in Relation to Organic Enrichment and Pollution of the Marine Environment. Oceanography and Marine Biology-An Annual Review, 16: 229-311.

Perumal P, Sampathkumar P, Karuppasamy PK (1999) Studies on the bloom-forming species of phytoplankton in the Vellar estuary, southeast coast of India. Ind J Mar Sci 28: 400-403.

Pielou, E C 1966. The measurement of diversity in different types of biological collections. J Theoret Biol 13, 131-144.

Plafkin, J. L., Barber, M. T., Poter, K. D., Gross, S. K. and Highes, R. M. 1989. *Rapid bioassessment protocol for use in streams and rivers for benthic macro invertebrates and fish.* EPA/444/ 4-89/001**.** Office of water regulation and standards. U.S. Environmental Protection Agency, Washingaton DC, USA.

Prabhahar. C., K. Saleshrani & Enbarasan 2011. Studies on the ecology and distribution of phytoplankton biomass in Kadalur coastal zone Tamil Nadu, India. *Curr. Bot.*, **2(3):** 26-30.

Ramakrishna, D A 2003. Manual on identification of schedule molluscs from India 40pp

Ramakrishna, T C R., Sreeraj, C., Raghunathan, R., Raghuraman, P and Yogesh Kumar, J S 2011. An account of additions to the Icthyofauna of Andaman and Nicobar Islands Records of the Zoological Survey of India, Occasional Paper no 326, 1-140 Published-Director, Zool Surv India.

Rao, K.K and Balasubramanian, T. (1996). Distribution of Foraminifera in the Cochin Estuary. J.mar.biol. Ass. India. 38(1 and 2): 50-57.

Reid, G. K, 1961. Ecology in inland waters and estuaries. New York.375

Reid, G. K., Wood, R. D. (1976). Ecology of inland waters and estuaries. Toronto, Ontario, D. Van Nostrand Co., pp. 138–146.

Saravanan, K. R., Sivakumar, K., and Choudhury, B. C. (2013). “Important coastal and marine biodiversity areas of India,” in Coastal and Marine Protected Areas in India: Challenges and Way Forward, ENVIS Bulletin: Wildlife & Protected Areas, Vol. 15, ed. K. Sivakumar (Dehradun: Wildlife Institute of India), 134–188. doi: 10.1007/978-3-642-38200-0_30

Shannon, C E and Wiener, W 1949. The Mathematical theory of Communication Univ of Ilinois Press, Urbana

Sinha B. and M. R. Islam, 2002. Seasonal variation in zooplankton population of two lentic bodies and Assam State Zoo cum Botanical Garden, Guwahati, Assam, Eco.Environ. Cons., 8: 273-278.

Sivasamy, S.N., 1990. Plankton in relation to coastal pollution at Ennore, Madras coast. Indian J. Marine Sci., 19: 115-119.

Sreenivasulu, G., Jayaraju, N., Raja Reddy, B.C.S., Prasad, T. L., Nagalakshmi, K., Lakshmanna, B. (2017). Foraminiferal research in coastal ecosystems of India during the past decade: A review. Geo ResJ. 13: 38–48.

SubbaRao, N V., Surya Rao, K V and Maitra, S 1991. Marine molluscs State Fauna Series 1, Part 3 Fauna of Orissa. Zool Surv India, Kolkata, 1–175.

Tabassum, A. and Saifullah, S. (2012). Centric Diatoms from the North Arabian Sea Shelf of Pakistan. LAP. BOOK Lambert Academic Publishing. ISBN: 978-3-659-28532-5.

Takai N, Mishima Y, Yorozu A, Hoshika A (2002) Carbon sources for demersal fishes in the western Seto Inlan Sea, Japan, examined by delta 13C and delta 15N
analyses. *Limnol Oceanogr*. 47(3):730-741.

Taylor, B. E. (1998). Analyzing population dynamics of zooplankton. Published by the American Society of Limnology and Oceanography, Inc. Limnol.Oceanogr 33(6, part 1): 1266-1273.

Thakur, B., Chavda, C., & Salvi, H. (2015). Phytoplankton diversity at some selected sites of the Gulf of Kachchh, Gujarat, India. Bulletin of Environmental and Scientific Researcch. 4(4): 7-12. ISSN. 2278-5205.

Thangaraja, G. S., 1984. Ecobiology of the marine zone of the Vellar estuary. *Ph. D. Thesis, Annamalai University, India*.

Thirunavukkarasu, K., Soundarapandian, P., Varadharajan, D., Gunalan, B.(2013).Zooplankton Composition Structure and Community Structure of Kottakudi and Nari Backwaters, South East of Tamilnadu. J. Environ Anal Toxicol. 4(1): 200. doi:.10.4172/2161-0525. 1000200

Tiwari, L.R and Nair, V.R. (1998). Ecology of Phytoplankton from Dharmatar creek, West Coast of India. Indian. J. Marine Sci., 27 (3 & 4).

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Annexure G

Detail of CSR activities

CSR Works for the year 2018-19

Sr. No	Activity/Work	Approved Cost (In lakhs)
1.	CSR work to Donate 100 Nos of Computers to Daughters of Martyred Soldiers in the country under the "BETI BACHAO BETI PADHAO" program by Atharva Foundation, Mumbai	24.00
2.	CSR work to Donate ONE (40 Seater) School Bus for Deaf Children Students for the Institute of Mata Lachmi Rotary Society, Adipur	18.00
3.	CSR work to Providing One R.O Plant with Cooler at Panchyat Prathmik Sala, Galpadar Village for the ANARDE Foundation, Kandla & Gandhidham Center.	1.50
4.	CSR work for Providing Drainage Line at Meghpar Borichi village, Anjar Taluka.	25.00
5.	CSR work for Construction of Health Centre at Kidana Village	13.00
6.	CSR work to provide 4 Nos. of Big Dust Bin for Mithi Rohar Juth Gram Panchayat.	3.40
7.	CSR work for Renovation & construction of shed at Charan Samaj, Gandhidham –Adipur.	10.00
8.	CSR Work for Renovation/Repairing of Ceiling of School Building at A. P Vidhyalay, Kandla.	10.00
9.	CSR work for Construction of Over Head Tank & Providing 10 Nos of Computers (for students) of Navjivan Viklang Sevashray, Bhachau, Kutch	9.50
10.	CSR work to Provide Books & Tuition fees for Educational facilities to weaker section children of Valmiki Samaj, Kutch.	2.00
11.	CSR work to provide Water Purifier & Cooler for the ST. Joseph's Hospital, Gandhidham	1.50
12.	CSR work for Construction of Second Floor (Phase – I) for Training Centre of "Garbh Sanskran Kendra" "Samarth Bharat Abhiyan" of Kutch KalyanSangh, Gandhidham	37.00
	Total Approved Work Amount:	154.90 Lakh

CSR Works for the year 2019-20

Sr. No	Name of Scheme	Approved Cost (Rs. In Lakhs)
1.	CSR activities for Providing Drainage line at Nani Nagalpar village.	3.00
2.	CSR activities for Development of ANGANWADI Building at School no- 12 at Ward no 3 & 6 at Anjar.	7.00
3.	CSR activities for Improving the facilities of Garden at Sapna Nagar(NU-4) & (NU-10 B), Gandhidham.	18.00
4.	CSR activities for development of School premises of Shri Guru Nanak Edu. Society, Gim.	30.00
5.	CSR activities for the improvement of the facilities at St JOSEPH Hospital & Shantisadan at Gandhidham	20.00
6.	Consideration of Expenditure for running of St Ann's High School at Vadinar of last five years 2014 to 2019 under CSR.	825.00
7.	CSR activities for development of school premises of Shri Adipur Group Kanya Sala no-1 at Adipur	6.50
8.	CSR activities for development of school premises of Shri Jagjivan Nagar Panchyat Prathmiksala, Gandhidham.	16.50
9.	CSR activities for development of school premises of Ganeshnagar Government high school, Gandhidham.	9.00
10.	CSR activities for improving greenery, increase carbon sequestration and beat Pollution at Kandla, DPT reg.	352.32
11.	CSR activities for providing infrastructures facilities at "Bhiratna Sarmas Kanya Chhatralaya" under the Trust of SamajNav- Nirman at Mirjapur highway, Ta Bhuj.	46.50
	Total Approved Work Amount:	1333.82 Lakh

CSR Works for the year 2020-21

Sr. No	Name of Scheme	Approved Cost (Rs. In Lakhs)
1.	CSR Proposal for earmarking of 15% Funds for National Maritime Heritage Complex, Lothal, Gujarat (NMHC) from allocated CSR Fund of Rs 3.46 Cr	51.90
2.	PM Care Fund	800.00
3.	Other COVID related exp.	188.00
	Total Approved Work Amount:	1039.90 Lakh

CSR Works for the year 2021-22

Sr. No	Name of Scheme	Approved Cost (Rs. In Lakhs)
1.	CSR Activities for providing Water supply pipe line for drinking water facilities for poor people & Fishermen at VANDI Village.	20
2.	CSR activities for providing facilities in Girls Hostel of Kasturba Gandhi Balika Vidhyalay, Gandhidham.	30
3.	CSR works for Construction of Auditorium Hall at RSETI (Rural Self Employment Training Institute) at Bhujodi-Bhuj.	16
4.	CSR works for the providing of SOLAR POWER SYSTEM and other facilities for 0the JEEV SEVA SAMITI at Gandhidham.	9.3
5.	CSR Activities for providing HD projector for KANYA MAHA VIDYALAYA, Adipur	1.5
6.	CSR works for Construction of New Building for Setting up of skill development centre at Rajkot (Sewa Gujarat).	250
7.	CSR Works for Ladies Environment Action Foundation (LEAF) Trust for providing infrastructure to the primary school at Gandhinagar District	46.5
8.	CSR works lor Providing of Furniture for the School "Shri Galpadar Panchayat Prathmic Kumar group Sala" at Galpadar village, Taluka: Gim	5
	Total Approved Work Amount:	378.30 Lakh

CSR Works for the year 2022-23

Sr. No	Name of Scheme	Approved Cost (Rs. In Lakhs)
1.	CSR work for providing One Bore hole with construction one room along with Motor pump at Village MOTI NAGALPAR, Anjar.	18.00
2.	CSR work for Construction of Shamashan bhoomi (Crematorium) at Gandhidham.	49.50
3.	CSR work for providing metallic sheet DOME in Community Hall at Old Sunderpuri for Shri Juni Sundarpuri Maheshwari Samaj at Gandhidham.	15.00
4.	CSR Activities for construction of Samajwadi at village: Rampar, Taluka: Anjar.	15.00
5.	Financial assistance under CSR for providing basic facilities at Gandhidham GSRTC bus station.	25.00
6.	CSR Activities for construction of School Building for physically disabled, deaf & mute children, Shri & Shrimati Chhaganlal Shyamjibhai Virani Behera Munga Shala Trust, Virani Deaf School at Rajkot.	5.00

7.	CSR work for construction of new Administrative staff block for the Maitri Maha Vidhyalaya, Adipur.	80.10
8.	Financial support under CSR for providing 60 seater school bus for "Aadhaar Sankul", Manav Seva Trust, Gandhidham.	25.00
9.	Financial assistance under CSR for Rooftop Solar System & Afforestation under clean energy & sustainable development in 10 villages around DPA	63.72
10.	CSR works for Shree Kachchh Mahila Kalyan Kendra, Bhuj-Kutch	55.00
11.	CSR works for Installation of 125 no. Sanitary Pad Vending Machines at Women Hostels, NGOs etc, in Kutch District.	15.00
12.	CSR Fund for Vadinar Village & surrounding	128.54
13.	CSR Activities for Girls Hostel at Kasturba Gandhi Balika Vidhyalaya At Shinay, Taluka:Gim	33.25
14.	CSR request for Allotment of fund for construction of Community hall at Adipur.	25.00
15.	CSR Request for requirement of funds for renovation work in Sector-7, Gandhidham (Aryasamaj Gandhidham)	30.00
16.	CSR Request for providing"Antim Yatra Bus" & Mortuary Cabinet Morgue" for Adipur-Gandhidham from CSR Funds,	25.00
17.	CSR Request for creation of a Children park at Gandhidham Military Station, Gandhidham	15.00
18.	CSR Request for construction of Toilet block units for Girls & Boys NAV JIVAN VIKLANG SEVA SHREY Bhachau	3.04
19.	CSR Request for laying Synthetic Athletic track in Galpadar and to Provide One E-Kart facility for Conveyance of youths at BSF Campus, Gandhidham	75.00
20.	CSR request for submitted by AAS, Indore for solid waste Management at Gandhidham & Kandla.	60.00
21.	CSR request from Trikamsaheb Manav Seva Trust at Madhapar Near Bhuj for grant for Construction of Community Hall, Compound Wall etc.	40.00
22.	CSR Request for construction of Dome shaped shed at Rampar Village Prathmik Shala, Rampar	24.00
23.	CSR Fund for development of School premises of Shri Guru Nanak Education Society, Gandhidham	4.50
24.	CSR Request for conducting Awareness campaigns on T.B. Prevention & treatment, Mumbai	60.00

25.	CSR Request for fund Under CSR for Railway institute, Gandhidham, Western Railway	5.00
26.	CSR proposal project for Sanitary Pad Making Machine For School Girls.	12.39
27.	CSR funds for requirement of Mentally disabled childrens in Adipur, Kutch	70.83
28.	CSR Funds for support for Procurement of kitchen Equipment & machineries to Serve Mid-day meals to Govt. School children in Bhuj-Kutch	55.31
29.	CSR support for the Junagadh Hospital Project under the CSR Initiatives	30.24
30.	CSR Request for financial Assistance on menstrual Hygiene for girls, Assam-TIPKAI	20.00
31.	CSR Request received from Anjar Education Society to the Extent of Rs 35 Lakhs for Installation of 75 KVA Capacity Solar power system.	35.00
	Total Approved Work Amount:	1118.42 Lakh