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MARINE BIODIVERSITY MANAGEMENT PLAN FOR THE PROPOSED GREENFIELD PORT AT VADHVAN, PALGHAR DISTRICT, MAHARASHTRA

Prepared For:

Jawaharlal Nehru Port Authority (JNPA)

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October, 2023

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EXECUTIVE SUMMARY

Introduction

Jawaharlal Nehru Port Authority (JNPA) has been planning to develop a new multi-purpose port at Vadhvan, near Dahanu in Palghar district of Maharashtra. The proposed Greenfield port at Vadhvan having geographical limits between Point A (on the Coast) - Latitude 19° 54' 26'' N and Longitude 72° 40' 34'' E, Point B (on the Coast) - Latitude 19° 57' 59'' N and Longitude 72° 42' 18'' E including banks and shores up to high-water marks and creeks within the line as far as navigable and into the sea, Point C (in territorial waters)- Latitude 20° 0' 0'' N and Longitude 72° 30' 0'' E and Point D (in territorial waters)- Latitude 19° 54' 5" N and Longitude 72° 30' 0'' E is located along the west coast of India, in the state of Maharashtra, which is about 150 km north of JNPA Port. The Vadhvan Port is to be developed as a deep draft all-weather multipurpose port with state-of-art facilities to ensure the least turnaround time for the vessels.

The impact of the proposed port on the marine biodiversity at Vadhvan is assessed by the CSIR-National Institute of Oceanography (CSIR-NIO). The present report establishes the prevailing ecological status of the marine and intertidal environment of the project area and analyses the probable environmental perturbations due to the proposed port project. Based on the assessment of impacts, mitigation measures to minimize these impacts will be implemented by JNPA.

Project information

The proposed port will be developed in two phases. In this model, basic infrastructure of the port necessitating upfront investment such as, breakwater, rail and road linkages, power, water lines, common infrastructure and services will be developed by the port/SPV, whereas all cargo handling infrastructure will be developed and operated by the agencies. The phase 1 development includes a breakwater of total length 12.04 km, dredging of 2.76 M cum, port craft/ Tug berth of 200m, reclamation area inside the port 1472.77 ha with 34.45 M cum in Phase 1, road's 28.8 km, DFC rail yard 227.5 ha. and a parking area of 153 ha. with 60 ha in Phase 1.

In addition to this, the concessionaire will develop the container berth having a length of 4000 m, (4 berths each of 1000 m length) capable of handling up to 24,000 TEU vessel with 18,000 TEU design container vessels. For this, dredging in soil is 0.78 M. cum & in rock is 2.26 M. cum and reclamation of 21.36 M cum has been proposed. Multipurpose berths of 750 m (3 berths each of 250 m), 1 Ro-Ro berth of 250 m, 2 Liquid berths of 200 m, 1 LPG berth of 280 m, 1 LNG berth of 400 m, Fertiliser yard area 18 ha. and IRC railway area of 16 ha. has also proposed in the project.

Prevailing environment

The subtidal studies were conducted in December 2020. A total of 9 subtidal stations and 6 intertidal stations were sampled. Stations VN1, VN2, VN3 and VN4 were between 2 to 5m depth (nearshore region), stations VN5, VN6 and VN7 were in 10 m contour depth (coastal) and stations VN 8 and VN9 were located in 20m depth (offshore) in the study area.

Physical processes

The annual distribution of wave heights and wave period from wave rose diagrams, indicated that the predominant directions of waves in the deep sea were from SW to NW and the waves were less than 1 m, 2 m and 3 m in height for 77, 94 and 98% of the time, respectively. The tides in the region are of the semi-diurnal type. The currents in the region are mainly of monsoon origin and sets in south-westerly and north-easterly direction with a strength of about 2.5 knots (1.25 m/s).

Water quality

During post-monsoon season (December, 2020), the water temperature ranged from 25 − 27.5°C (av. 26.8°C), with the bottom temperature generally being lower than the surface. pH values ranged between 8.1 and 8.2. The salinity ranged between 34.8 and 35.3 PSU during December 2020 and no marked salinity changes were observed between the surface and bottom water column. The suspended sediment (SS) values varied between 11 mg/L to 117 mg/L (av. 52 mg/L) in the sampling stations. Higher values were observed at the bottom water of stations VN8 and VN9 (Offshore segment).

Average water column DO values at nearshore, coastal and offshore stations were 6.7, 6.4, and 6.2 mg/L, respectively, indicating less variable and well-oxygenated conditions prevailing in the region. The PO_4^{3-}-P off Vadhvan ranged between 0.8 and 3.3 µmol/L. NO_3^--N ranged between 7.6 and 14.8 µmol/L (av. 10.2 µmol/L). Nitrite (NO_2^--N) levels were low during December 2020 and ranged between 0.04 and 0.9 µmol/L. The concentration of NH_4^+-N were recorded between 0.8 to 4.5 µmol/L. Phenol concentrations varied between 34.0 and 79.0 µg/L. The concentrations of petroleum hydrocarbons (PHc) ranged between 2.5 and 5.7 µg/L (av. 3.8 µg/L) in the study area.

Sediment quality

Sub-tidal stations were mainly dominated by silt and clay. The silt and clay contents varied within a narrow range of 80 − 87% and 11 − 17%. Heavy metals in the study area were lithogenic in origin. These values may be considered as baseline concentration and can be used for post-project monitoring. PHc concentration of sediment from the subtidal study area were low (0.1−1.1 µg/g wet wt.). Organic carbon (C_{org}) content of sediments within the region off Vadhvan during December 2020 varied within a close limit between 1.3 and 1.9% (av. 1.5%). Sediment phosphorous content off Vadhvan ranged between 604 and 784 µg/g (av.675 µg/g), without much difference among different zones, which indicated relatively lower levels of P.

Assessment of flora and fauna

Microbiology

The total viable count (TVC) of bacteria in the water samples ranged between 10 x 10^2 to 200 x 10^2CFU/mL. The lowest counts were recorded at station VN1 and the highest counts were recorded at station VN7. The TVC count in the sediment samples ranged between 30 x 10^3 to 100 x 10^3CFU/g. Total Coliform (TC), Faecal Coliform (FC), *Escherichia coli* like organisms (ECLO) and *Streptococcus faecalis* like Organism (SFLO) were recorded only in the water samples.

Phytoplankton

In December 2020, the concentrations of chlorophyll *a* ranged from 0.2 to 0.7 mg/m^3 indicating less variable phytoplankton biomass in the study area. Nearshore stations showed comparatively higher values of chlorophyll than coastal and offshore stations. The average concentration of phaeophytin ranged between 0.1 and 1.4 mg/m^3. In general, bottom water recorded higher values of phaeophytin concentration compared to surface waters. Phytoplankton population in surface waters were in the range of 10.2 to 127.4x 10^3 cells/ L and bottom between 11.0 and 151.2x 10^3 cells/L. A total of 36 genera of phytoplankton were recorded from the study region, belonging to 4 major taxonomic groups namely, diatoms, dinoflagellates, cryptophytes and euglenophytes. Diatoms formed the most dominant group, comprised of 24 genera. The most dominant genera were *Thalassiosira* (38.3%), followed by *Cylindrotheca* (10.5%), *Navicula* (7.9%) and *Nitzschia* (5.4%).

Zooplankton

During the present survey, zooplankton biomass ranged from 0.4 to 8.4 ml/100m^3 and the population varied between 11.0 and 110.5 x 10^3 no/100m^3. Both biomass and population were found high at VN2. There was no significant trend observed in the distribution of zooplankton biomass and population from the study area. 22 mesozooplankton groups were identified from the study area with the dominance of copepods (75.0%) in all the stations. Fish larvae, fish eggs and decapod larvae were observed in all the stations.

Macrobenthos

The subtidal benthic macrofaunal standing stock in terms of biomass and population varied from 0.01 to 1.3 g/m^2 and 25 to 100 no/m^2. The faunal composition indicated the dominance of polychaetes (84.9%), followed by amphipods (12.7%) and mysids (2.4%) in the study area. Cossuridae (62.6%) was found to be the dominant polychaete family, which was present at all subtidal stations. The intertidal benthic standing stock in terms of biomass and population varied from 0.002 to 162.4 g/m^2 and 25 to 2875 no/m^2. The highest macrobenthic biomass was observed at IT5 and the lowest was at IT1. Polychaeta (53.8%) were the major group followed by Anomura (16.1%) and Amphipoda (11.3%). In total, 11 polychaete families were observed from the intertidal region with the dominance of Spionidae (21.2%), followed by Capitellidae (16.1%) and Orbiniidae (4.2%).

In the Low water region of IT2, the substratum was comprised of solid rocks with intermittent tide pools, fragments of rocks and stones. The tide pools and part of the rock were smothered with cyanobacterial mats and turf algae. At location IT3, macroalgae, *Ulva* sp. showed a spatial variation and a percent cover between 17.3 ± 24.5%. Other benthic fauna including molluscs, gastropods, and sponges contributed about 0.3%. Low water area of IT4, polychaete worms, bivalves, pseudocorals, crabs and gastropods were present. Midwater region of IT4 macroalgae *Ulva* sp. were the dominant life form accounting for 32.7 ± 3.5%. Other benthic forms including the pseudo coral *Palythoa* sp., gastropods and bivalves collectively contributed 0.8 ± 2.9 % to the total benthic community.

Mangroves

The intertidal regions of the Vadhvan area have the distribution of mangrove species of *Avicennia marina*. Saplings of the *Rhizophora* sp. were also found in the intertidal regions of Jhoting Bhabha Mandir. A survey conducted by the Institute of Remote Sensing, Anna University during May 2021 describes about 98.3 acres of area in the vicinity of proposed port has been classified under CRZ1A. Mangroves at Tadiyala area were surveyed by quadrat method and the density ranged between 40 and 132 no/100m^2.

Other flora and fauna

The shore vegetation includes shrubs and ground covered with grasses. Seagrasses are absent at the site. Poriferan community comprised of sponges. Cnidarian community comprised of sand anemones, *Aiptasia* sp., *Zoanthus* sp., *Zoanthus sansibaricus*, *Zoanthus vietnamensis*, *Palythoa* sp. *Palythoa mutuki Paracyathus* sp. and the presence of hydrozoan colonies (*Pennaria* sp.) were recorded from the study area. Small annelids were present at the lateral margins of the rocky patches. Grapsid crabs and Porcelain crabs were recorded from the rock regions. The molluscan community comprised of gastropods, such as *Indothais* sp., *Thais* sp., *Gyrineum natator, Cantharus spiralis, Indothais sacellum, Clypeomorus* sp, *Nerita* sp. Barnacles such as *Chthamalus* sp and *Megabalanus* sp. were observed in the rocky patches. *Asterina lorioli and Antedon* sp*.,* were also recorded from the rocky crevices, which represent the echinoderm community. The majority of the aforementioned organisms were observed from the rock region of the Shankodar area (19°56'44.78"N, 72°38'14.60"E).

Fishery

ICAR-CMFRI conducted the fishery survey for the proposed project. During their survey, they recorded the occurrence of a variety of finfishes and shellfishes. Fishes (126 species) including 86 species of teleost, 4 sharks, 20 crustaceans and 13 molluscs were reported from the study area.

Reptiles

Olive Ridley turtle (*Lepidochelys olivacea*), Green turtle (*Chelonia mydas*) and Loggerhead turtle (*Caretta caretta*) was reported from the study area by other researchers. However, no sightings of marine turtle were recorded during the present study period.

Birds

The coastal areas of the Palghar district have different marine habitats, like rocky/sandy/muddy intertidal and mangroves for a variety of resident and migratory birds. e-Bird India has recorded 86 species of birds from the Vadhvan region. The main avian fauna recorded during the current study were Lesser egret, Intermediate egret, Pond heron, Black headed ibis, Black winged still and Plovers.

Marine mammals

Published and confirmed records of cetaceans in the coastal waters of Maharashtra state describes the occurrence of 7 species, including *Balaenoptera musculus* (Blue whale), *Balaenoptera physalus* (Fin whale), *Neophocaena phocaenoides* (Finless porpoise), *Sousa chinensis* (Indo-Pacific humpbacked dolphin, *Sousa plumbea* (Indian ocean humpback dolphin), *Globicephala macrorhynchus* (Short finned pilot whale) and *Delphinus capensis* (Long-beaked common dolphin).

Anticipated marine environmental Impacts

The anticipated environmental impacts due to the activities related to the construction, operation and post-operational phases of the proposed port project were identified and described in chapter 5 (section 5.1). The major things covered under this are listed below:

- Port construction and intertidal area reclamation
- Impact of dredging and disposal
- Environmental impact of breakwater system
- Impact of shipping operations on marine environment
- Air pollution from port operations
- Noise and light pollution
- Impact on marine cetaceans
- Impact of cargo handling
- Hazardous materials and oil
- Ship and boat generated wastes
- Introduction of non-native species into marine environment
- Oil spill

Mitigation measures

A number of management techniques and mitigation measures have been developed globally to reduce the impact of dredging activities on the marine environment. Detailed mitigation measures connected with each activity like dredging, sea wall construction, impact on flora and fauna, impact on cetacean community and impact on water quality were identified and presented in section 5.4.

Marine biodiversity management plan

Detailed marine biodiversity management plan is presented in section 6. The broader plan describes the management measures that need to be taken into consideration during the time of port construction and operation phase. The management plan discusses about water quality, sediment quality, flora and fauna, navigational aspects, oil spill, institutional arrangements for marine environmental management**,** approach towards voluntary compliance, MARPOL 73/78, marine monitoring plan and framework for monitoring, cost of marine EMP, disaster management plan and environmental sustainability practices for the proposed greenfield port at Vadhvan. The responsibility of the implementation of the marine biodiversity management plan action lies with the JNPA and construction contractors and the cost could be part of the construction contract.

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COMMON ABBREVIATIONS

Av	Average
B	Bottom
BOD	Biochemical Oxygen Demand (mg/L)
C_{org}	Organic Carbon (%)
CFU	Colony forming unit
DO	Dissolved Oxygen (mL/L)
Eb	Ebb tide
Fl	Flood tide
Min	Minimum
Max	Maximum
ND	Not detected
NG	No growth
NH_4^+-N	Ammonium nitrogen (μmol/L)
NO_3^- -N	Nitrate nitrogen (μmol/L)
NO_2^- -N	Nitrite nitrogen (μmol/L)
PHc	Petroleum Hydrocarbons (μg/L)
PO_4^{3-} -P	Reactive Phosphate (μmol/L)
RB	Rocky Bottom
S	Surface
SS	Suspended Solids (mg/L)
TC	Total Coliforms
TVC	Total Viable Counts

1 Introduction

1.1 Background

India has an approximately 5,423 km long peninsular coastline and is located close to major shipping routes linking East Asia, Europe and the Middle East. Presently, there are 12 major ports and 187 non-major ports in India. The major ports are all Federal Government owned and handled around 54% of India's maritime trade in 2019-20. The cumulative traffic handled by Indian Ports in 2019-20 was about 1,310 million tonnes of which major ports contributed 704.9 million tonnes and non-major ports (minor and intermediate ports) handled 604.8 milliontonnes.

The Government of India initiated the ambitious SAGARMALA project which aimed at capacity enhancement of all major ports by means of increasing the productivity and efficiency through mechanisation of berths, stackyard and effective evacuation of cargo. The development of Vadhvan Port as a satellite port of JNPA is one such initiative of Government of India. This would facilitate larger contribution of major ports in seaborne trade of India.

Maharashtra, with a coastline of 720 km stretching along the Arabian Sea has two major ports. Mumbai and JNPA cater to the hinterland of Maharashtra, North Karnataka, Telangana, Gujarat and secondary hinterland of NCR, Punjab, Rajasthan and Uttar Pradesh. JNPA was developed as a satellite port of Mumbai port and has coped well in becoming the largest container port of the country. The development of Phase 2 of the fourth container terminal is underway, and after its full development, there is little space for further expansion. Apart from that due to the presence of bed rock at or very close the existing bed level, JNPA navigation channel cannot be deepened further economically to handle the future generation of mega container ships drawing draft of 16m or more.

There is a need for a large draft port that will cater to the spill over traffic from JNPA port conceits expanded capacity of 10 million TEUs is fully utilized. With the projected demand for containers to go up, it is necessary to locate a new mega port site which can cater to increased requirement of capacity and also could be developed to handle the future deep draft ships. Considering the above it has been decided to develop Vadhvan port as a satellite port for JNPA.

1.2 Objectives

a) To conduct detailed investigations with respect to water quality, sediment quality and biological characteristics in the study area.
b) To study the concentration of Petroleum Hydrocarbons (PHc) in seawater and sediment in the project location.
c) To study the impact of undersea noise on Cetaceans.
d) To assess the impact of dredging and dumping on the marine ecology around the project site.
e) To Prepare a Marine Environment Management Plan (MEMP) for maintaining a healthy ecosystem around the proposed Vadhvan Port area.

1.3 Approach Strategy

CSIR-NIO has conducted a couple of studies (2006 and 2016) in the vicinity of the proposed project location. The severity of negative impacts of developments in the coastal zone on the associated marine ecology varied widely depending on many factors such as the extent, period and time of disturbance, anthropogenic perturbation, capacity of receiving water to assimilate contaminants and extent of its ecological sensitivity. Prediction of impacts (if any) of activity on marine environmental quality is often achieved by comparing the results of monitoring with the available baseline results. The availability of the previous database with CSIR-NIO over the years would facilitate this comparison. This database would form a general basis to compare with future monitoring studies under this phase.

1.4 Scope of Work

The scope of studies is carefully framed through detailed discussion with JNPA keeping in view the data available with CSIR-NIO. Marine ecology will be assessedin terms of seaweeds, sea grass, mudflats, sand dunes, echinoderms, shrimps, turtles, corals, birds, cetaceans, coastal vegetation, mangroves etc. from the study area. Assessment of marine water quality (at 8-10 locations) for physicochemical, biological parameters will be conducted for below mentioned parameters.

I) Sampling

Sampling would be conducted in the proposed Vadhvan port area and surrounding intertidal regions, keeping in view of the future developmental activities of the proposed port.

II) Parameters for monitoring

a) Water quality

Water quality will be evaluated based on salinity, temperature, pH, Suspended Solids (SS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), reactive phosphate (PO_4^{3-}P), nitrite (NO_2^-N), ammonia (NH_4^--N), sulphides, Petroleum Hydrocarbons (PHc) and phenols. Samples would be obtained at the surface as well as bottom when the depth exceeds 5 m. Otherwise, only surface samples would be obtained.

b) Sediment quality

Sediments from the subtidal and selected intertidal stations would be analysed for texture, organic carbon (C_{org}), phosphorus, selected metals (aluminium, chromium, manganese, iron, cobalt, nickel, copper, zinc, and mercury) and PHc.

c) Biological characteristics

The biological productivity will be estimated in terms of chlorophyll *a*, phytoplankton population and generic diversity; biomass, population and faunal diversity of zooplankton, macro benthos (subtidal and intertidal) and microbial counts [Total Viable Counts(TVC), Total Coliforms (TC)and Faecal Coliforms (FC) etc.].

III) Assessment

Based on the data generated and available for water quality, sediment quality, flora and fauna, the probable impact of reclamation and proposed operations related to the proposed Vadhvan port on the surrounding marine ecology will be assessed.

1.5 Regional Environment

The land close to Vadhvan site is flat and having undulations close to hilly area. The rocky outcrop close to shoreline of Vadhvan can be seen and indicate rocky patches under inter-tidal area. The intertidal zone is wide and extends up to 1.7 km. The beach is sandy. The general terrain of the site area is largely flat with a mild slope.

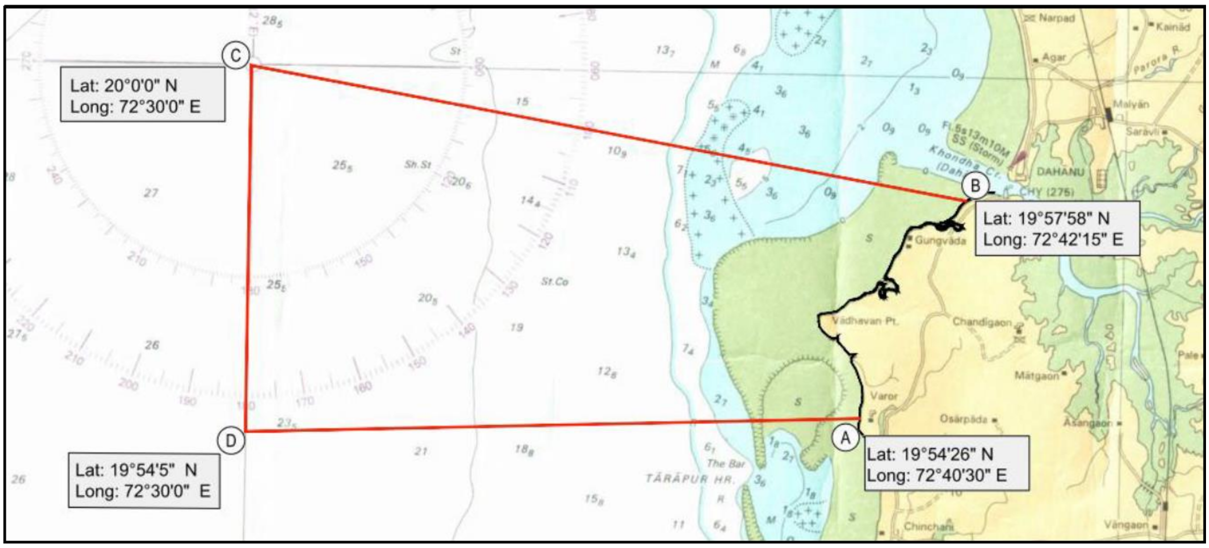


Figure 1.1: Study area

1.6 Meteorological Information

This information has been extracted from previous studies for the project as well as from the West Coast of India Pilot (WCIP) climatological table applicable for the area and the project site.

1.6.1 Rainfall

The average annual rainfall is 3100 mm (2019) with the total number of rainy days of 116 during the year 2019. July to September is the wettest months of the year with an average rainfall in excess of 28 mm per month, with a maximum of 298 mm in July during the southwest monsoon period. February and March are dry months with average rainfall below 1 mm per month.

1.6.2 Temperature

The mean daily maximum temperature is 31ºC and with 34ºC the highest occurring in April. Mean daily minimum temperature is 24ºC and with 18ºC the lowest occurring in December.

1.6.3 Relative Humidity

Relative humidity is generally high and rises to about 85% during the monsoons in the month of August.

1.6.4 Visibility

Visibility is good throughout the year as the region has zero fog days. However, during rains and squalls, the visibility deteriorates.

1.6.5 Cyclone

In general, the west coast of India is less prone to cyclonic storms compared to the east coast. From the information reported by India Meteorological Department (IMD) it is observed from the tracks of the cyclones in the Arabian Sea from 1877 to 2012 that only 10 storms endangering the Mumbai coast have occurred in the above said period i.e. at a frequency of once in 12 years.

1.7 Oceanographic Conditions

This information has been extracted from previous studies for the project area and the project site.

1.7.1 Wind

Wind data for a period of 30 years from 1976 to 2005 were obtained from Indian Meteorological Department (IMD) and analyzed for the grid covering Latitude 18^o – 20^{o}N and Longitude 71^o – 73^{o}E, which centers the area of interest. The distribution of wind speed and direction is presented in Figure 1.2.

The observations represent measurements taken at sea level for every 3 minutes. It may be seen that west is the predominant wind direction and that the wind speed is less than 10 m/s for 88% of the time. The results are also presented in the form of monthly wind roses. It may be seen that the predominant wind is NE-N-NW in January. It gradually shifts towards west and by May it becomes NW to SW. During the months of June, July and August, the wind blows from W to SW. From September the wind direction starts changing and by December, again, the predominant sector becomes NE-N-NW.

It may be observed that during the fair-weather season viz. October to May, the wind speed is less than 6m/s for about 91% of the time. However, during the monsoon season (June to September), the wind speed is less than 8 m/s for only 62% of the time. It may also be seen that during the peak monsoon period (July and August), wind speed of 6 to 13 m/s occurs for about 29% of the time. Wind speed of 13 m/s is seldom exceeded. However, a maximum wind speed of 22.7 m/s has been reported, under normal conditions.

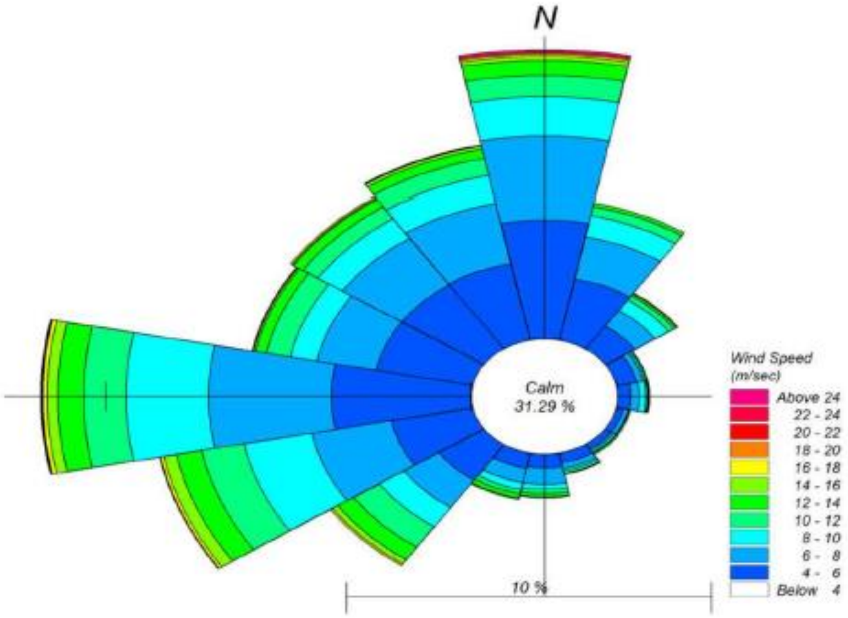


Figure 1.2: Wind rose diagram IMD, 1976 – 2005

1.7.2 Waves

The ship observed wave data were collected from the India Meteorological Department (IMD) for the quadrant bounded by Latitudes 18^{o} to 20^{o}N and Longitudes 71^{o} to 73^{o}E, between 1976 and 2005. The annual distribution of wave heights and wave period is given in the form of wave rose diagrams in Figure 1.3. It may be seen that the predominant directions of waves in the deep sea are from SW to NW. It can also be seen that waves are less than 1 m, 2 m and 3 m in height for 77, 94 and 98% of the time, respectively.

During the pre-monsoon period (January to May) over 92.93% of waves are less than 3 m in height. During the monsoon period (June to September) wave heights are less than 2 m for 85% and less than 3 m for 97% of the time. During the post monsoon period (October to December) wave heights are more than 3 m for 0.9% of the time. The predominant wave directions are in the NW quadrant for pre-monsoon period, from W to SW during the southwest monsoon and from NE to NW in the post-monsoon period. These wave heights applicable for the offshore conditions and wave are completely attenuated as they enter the well protected creek.

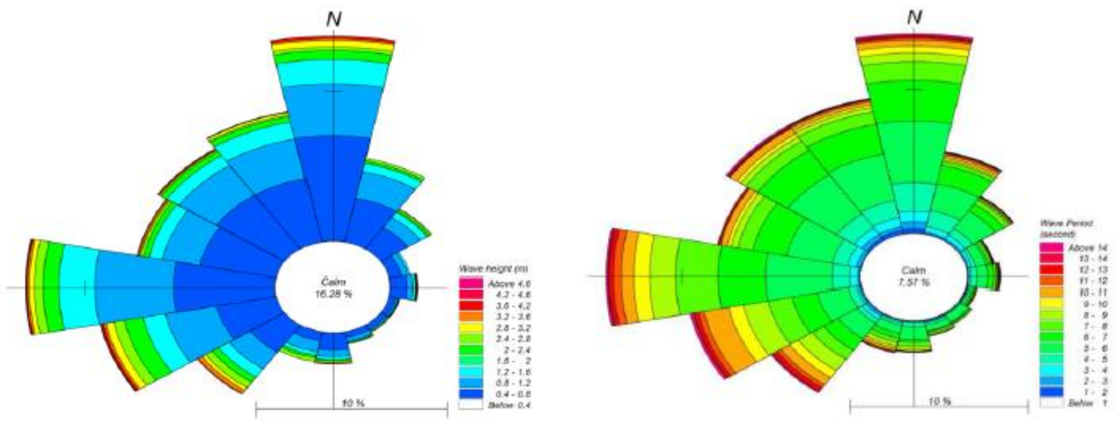


Figure 1.3: Wave rose diagram and Wave period IMD, 1976 – 2005

1.7.3 Tides

The tides in the region are of the semi-diurnal type i.e. characterized by occurrence of two High and two Low Waters every day. Duration of each tidal cycle is between 5 to 7 hours (theoretically 6 hours and 12minutes). There is a marked inequality in the levels of the two low waters in a day. Tide levels in the Vadhvan Port region as per the NHO Chart No. 210 Umargam to Satpati are summarised below.

Description	Tide Levels (m CD)
Mean High Water Spring	+4.7
Mean High Water Neap	+3.7
Mean Sea Level	+2.8
Mean Low Water Neap	+2.0
Mean Low Water Level Spring	+1.2

1.7.4 Current

The currents in the region are mainly of monsoon origin and sets in south-westerly and north-easterly direction with a strength of about 2.5 knots (1.25 m/s).

2 Project Description

2.1 Detailed Project report

JNPA through M/s Progen-Pentacle appointed E&Y to study the traffic potential at the proposed Vadhvan port. E&Y submitted their final report in March 2017. M/s. Progen-Pentacle prepared the Detailed Project Report (DPR) for the proposed Greenfield port in February 2021. The Vadhvan Port is to be developed as a deep draft all weather multipurpose port with state-of-art facilities to ensure the least turnaround time to the vessels. The port is planned to be developed in phases as and when the traffic builds up. The port master plan prepared by M/s Progen-Pentacle is shown in Figure 2.1, envisaging 6000 m container berth to handle the capacity up to 24 M TEUs in 2050, 1000 m multipurpose berth, LNG, LPG, bulk liquid berths and coal berth.

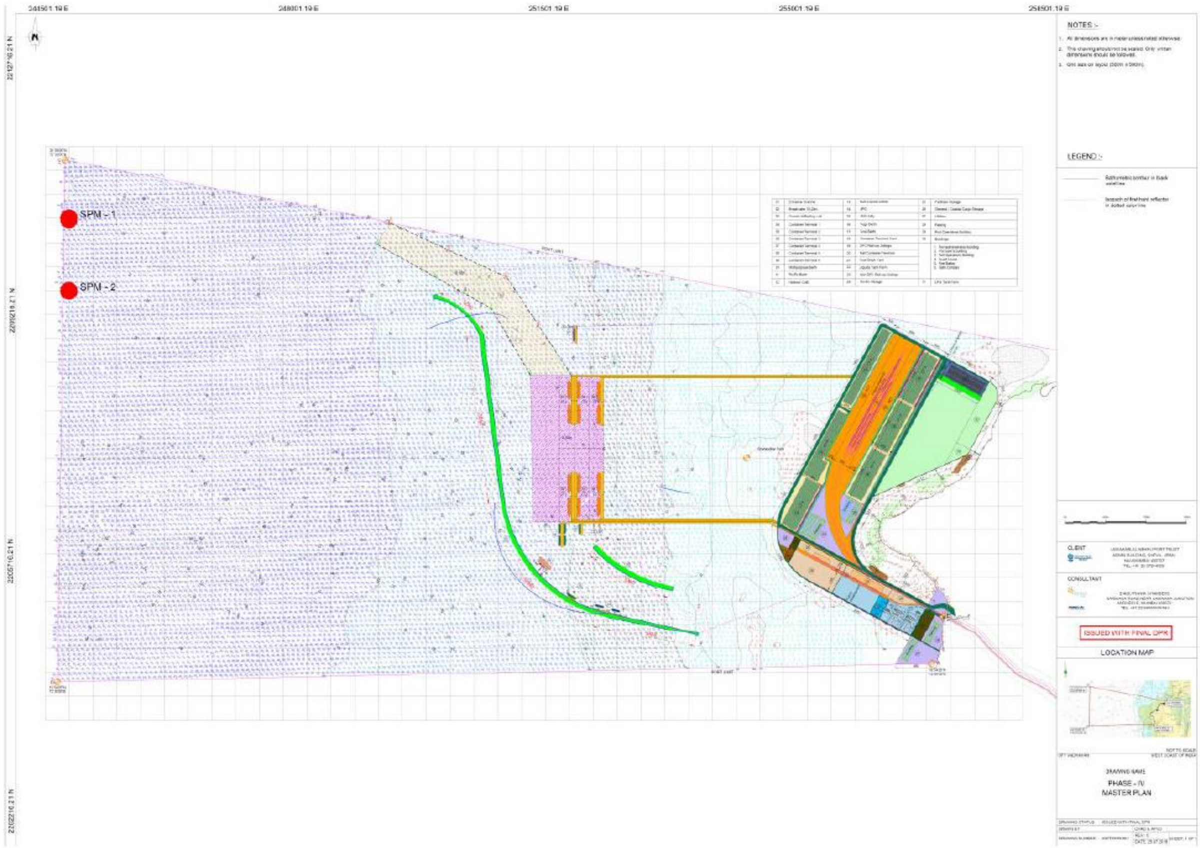


Figure 2.1: Port Master Plan

Subsequently, JNPA approached the Ministry of Shipping, Government of India, for the approval of the proposed port. Considering the Greenfield development, the Ministry advised the changes in the proposed port development considering the futuristic requirement and state-of-the-art development. The Ministry accorded in-principle approval on 13th February 2020 for the port development. After that JNPA carried out detailed engineering through M/s Hoskoning DHV. The modified port master plan layout is as shown below (Figure 2.2).

Figure 2.2: Modified port master plan

2.2 Salient Features of the Proposed Port

Vadhvan Port is planned to be developed by JNPA (Jawaharlal Nehru Port Authority) and MMB (Maharashtra Maritime Board) as Joint Venture Project with equity share of 74% & 26% respectively. The port will be developed in two phases. The proposed port is to be developed on landlord model with the port terminals to be developed on PPP basis. In this model, basic infrastructure of the port necessitating upfront investment such as, breakwater, rail and road linkages, power, water lines and common infrastructure and services will be developed by the port/ SPV whereas all cargo handling infrastructure will be developed and operated by the agencies which are awarded concessions through global tender in an open and transparent manner by the port.

Development of port is consisting of following components:

Inside Port

- Breakwater of total length 10.14 km.
- Dredging 6.98 M cum in Phase I & 21.5 M cum in Phase 2.
- Port craft/ Tug berth of 200 m (1 berth with berthing face of 100 m on each side)
- Total Reclamation area inside the port 1448 ha. with 1162 ha. In Phase 1.
- Road inside the port 32 km
- DFC rail yard 227.5 ha.
- Buildings with area of 23,500 m2.
- Pavement inside port.

Outside of Port Area

- Land acquisition 571 ha. (For road & rail connectivity)
- External road connectivity of 33.4 km, 120 m wide corridor.
- Rail linkage area length 12 km, 60 m wide corridor
- Water pipeline from Suriya river which is about 22 km from port site.
- Power line from PGCIL line/ Tarapur Boisar power station 20 km from port.

Concessionaire (Operator)

- Container terminals including yard storage, equipment, internal terminal pavements, drainage, utilities networks etc., with berth length of 9000 m (4 terminals in Phase – 1 & 5 terminals in Phase 2 each of 1000 m length) capable of handling vessels of 24,000 TEU and above with 24,000 TEU design container vessels.
- Multipurpose berths of 1000 m (4 berths each of 250 m) including equipment, storage yard/ shed.
- 1 Ro, Ro berth of 250 m including storage and onshore facilities.
- 4 Liquid cargo terminals including pipeline and tank farm.

2.3 Setting of Port Location

The proposed port at Vadhvan having geographical limits between Point A (on the Coast) - Latitude 19° 54’ 26’’ N and Longitude 72° 40’ 34’’ E, Point B (on the Coast) - Latitude 19° 57’ 59’’ N and Longitude 72° 42’ 18’’ E including banks and shores up to high-water marks and creeks within the line as far as navigable and into the sea, Point C (in territorial waters)- Latitude 20° 0’ 0’’ N and Longitude 72° 30’ 0’’ E and Point D (in territorial waters)- Latitude 19° 54’ 5” N and Longitude 72° 30’ 0’’ E is located in along the west coast of India in the state of Maharashtra, which is about 150 km north of JN Port. The location of the port is as shown in Figure 2.3. Vadhvan port would be competing mainly with Mundra for its containerized cargo. The natural water depth available at proposed Vadhvan port is more than any competing Indian port and more or equal than competing international ports. It will be able to capture the increasing trend of larger container vessels which none of the existing Indian ports can service, due to which the majority of containers destined or generated from India are being trans shipped or double-handled from competing international ports, resulting in higher import/export cost. Vadhvan port will further enhance India’s ability to handle containerised cargo while establishing a strong supply chain network in Maharashtra.

Figure 2.4 Vadhvan port location

2.4 General

The distinctive features of the location identified are as below:

- A natural water depth of around 20.0 m below CD is available at 10 km from Vadhvan point and 15 m contour is available at a distance of 6 km which will allow safe voyage and mooring for the new generation vessels.
- Land required for port is about 1473 Hectares and is planned from reclamation. A shallow inter-tidal zone between 0.0 and 2.0 m contours is available for reclamation for backyard area development which is ideal and eliminates the scope of land acquisition and rehabilitation. Thus, relief and resettlement or shifting of any house/ dwelling is not required.
- As deep-water depth is available from 6-10 km, New Generation Vessels calling for Deep Draft can be planned without involving cost on dredging.
- Connectivity to NH-8 (Mumbai-Delhi), upcoming Vadodara-Mumbai Expressway, Existing Indian Railways link and upcoming DFC (Dedicated Freight Corridor) is available at short distances for providing connectivity to cargo destinations center in hinterland.
- The Road and Rail Connectivity can be availed through un-habituated areas which do not call for rehabilitation and resettlement.

2.5 Transport Linkages and External Infrastructure

The site is150 km away from Mumbai on Northern side and 150 Km away from Nashik and 180 km away from Surat on Western and Southern side.

2.5.1 Rail Connectivity

Vadhvan is 12 km away from Vangaon Railway Station along Mumbai-Surat Western Rail Link. Further Dedicated Freight Corridor (DFC) is planned to connect Mumbai -Delhi is also 12 km from proposed port location with provision of Rail yard near Vangaon.

2.5.2 Road Connectivity

The port location is 33.4 km away from NH 8 i.e. Mumbai-Delhi 4-lane National Highway and connected with State highway at Tawa Junction. Further Mumbai-Vadodara Expressway is also coming up at a distance of 22 Km from Port location near Ravate.

2.5.3 Power Supply

The required electrical system for the project will consist of:

- The incoming electrical supply at 80 MVA level.
- 220/33 kV substations containing transformers, switchboards, control equipment, etc. to supply the electrical power to various parts of the site at the required voltage levels of 11kV or 6.6 kV & 0.415 kV.
- Control and Monitoring systems.

Two locations of the nearest 220 kV source from PGCIL line and Tarapur Power Boisar Power line are identified to be provided by MSETCL. The PGCIL line and Tarapur Power Boisar Power line located at 20 km (approx.) away from Vadhvan site by overhead 220 KVA HT Line to Vadhvan port site.

2.5.4 Water Supply

Daily water demand for the Phase 1 development is estimated to be around 6.8 MLD (million litres per day) and for the master plan phase, the anticipated demand is at 13.3 MLD. Out of this the potable water demand for port usage is 1.8 MLD in Phase 1 and 2.8 MLD in master plan phase, with the balance being the demand for raw water and supply to port township. A static storage of raw water of 1-day storage is provided for the port while half a day storage is provided for the township.

The water source identified for the port operations is Surya River about 22 km (approx.) away from the proposed Vadhvan Port. Maharashtra Jeevan Pradhikaran (Government of Maharashtra) will be facilitating the required water supply to Vadhvan Port.

3 STUDIES CONDUCTED

3.1 Period of study

The subtidal studies were conducted during December 2020.

3.2 Sampling location

Subtidal sampling stations were selected based on the vicinity of 10 Km radius and bathymetry, from National Hydrographic Office (NHO) Chart 210 to obtain information for the coastal segment likely to be impacted by the proposed project activities. These locations are shownin Figure 3.1. Stations VN1, VN2, VN3 and VN4 fall in between 2 to 5m depth (nearshore region), stations VN5, VN6 and VN7 fall in 10 m contour depth (coastal) and station VN 8 and VN9 were located in 20m depth (offshore) in the study area.

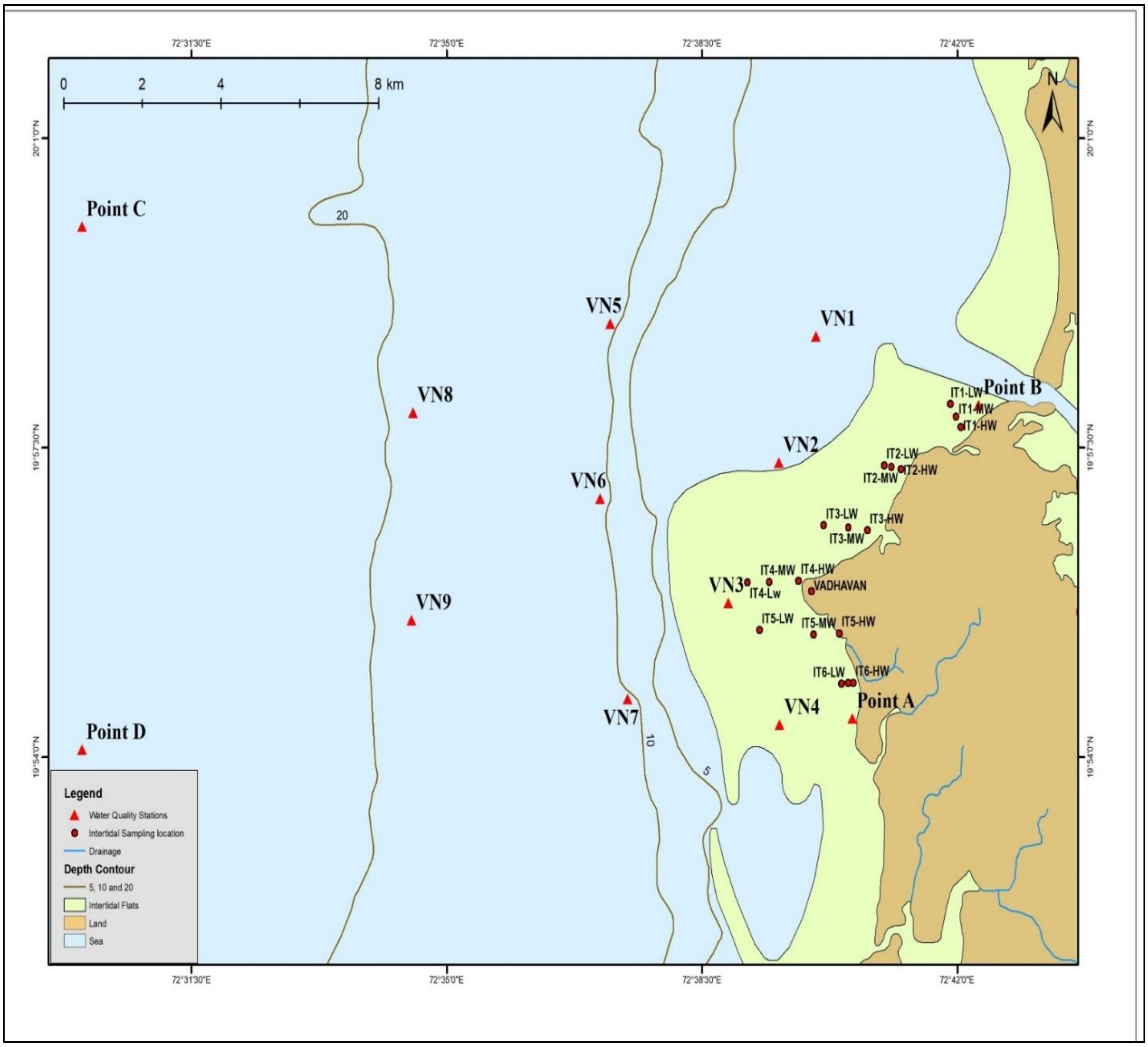


Figure 3.1: Sampling location map

Table3.2A: Details of subtidal stations

Subtidal Station Code	Latitude	Longitude	Type
VN1	19°58'45.50’’ N	72°40'03.98" E	Spot
VN2	19°57'19.87’’ N	72°39'33.53’’ E	Tidal
VN3	19°55'44.45’’ N	72°38'51.80’’ E	Spot
VN4	19°54'21.84’’ N	72°39'34.13’’ E	Spot
VN5	19°58'49.72’’ N	72°38'02.20" E	Spot
VN6	19°56'45.40’’ N	72°37'28.80’’ E	Tidal
VN7	19°54'39.38’’ N	72°37'29.15’’ E	Spot
VN8	19°57'53.64’’ N	72°35'04.40" E	Spot
VN9	19°55'33.76’’ N	72°34'57.59" E	Spot

Table 3.2B: Details of intertidal stations

Intertidal Transect	Station Name	Latitude	Longitude
IT1	Tadiyala	19°58'45.50" N	72°40'03.98" E
IT2	Gungwada	19°57'15.30" N	72°41'13.90" E
IT3	Jhoting Baba Mandir	19°56'33.90" N	72°40'46.20" E
IT4	Vadhvan Point	19°55'59.70" N	72°39'49.40" E
IT5	Tigre Pada	19°55'24.10" N	72°40'23.30" E
IT6	Varor	19°54'50.40" N	72°40'34.40" E

3.3 Water quality

a) Sampling methodology

Surface water samples were collected using a clean polyethylene bucket and Niskin sampler (2.5 L) capacity was used for obtaining bottom water samples. Wherever the water depth exceeded 3m surface and the bottom (1 m above the bed) samples were collected. For shallow regions, only surface samples were collected.

b) Methods of analyses

Majority of the water quality parameters were analysed within 24h of collection in the field laboratory. Colorimetric measurements were made on a Shimadzu (Model 1201) spectrophotometer. Fluorescence spectrophotometer was used for estimating PHc(Shimadzu (Model 5301), Japan). The analytical methods used for various measurements were as follows:

i) pH:

pH meter (Model pH 510 UTECK-pH 700) was used for pH measurement. The instrument was calibrated with standard buffers just before use.

ii) Suspended Solids (SS):

A known volume of water was filtered through a pre-weighed 0.45 μm Millipore membrane filter paper, dried and weighed again (Shimadzu, Model No. BL 220H, Japan).

iii) Salinity:

Salinity was measured using AUTOSAL salinometer (Model 8400B, OSIL, UK). The instrument was standardized with IAPSO standard seawater (OSIL, UK).

iv) DO and BOD:

DO was determined by Winkler method. For the determination of BOD, direct unseeded method was employed. The sample was taken in a BOD bottle in the field and incubated at 27^0 C in the laboratory for 3 days after which DO was again determined. The difference in DO before and after incubation was considered as BOD.

v) Phosphate:

Acidified molybdate reagent was added to the sample to yield a phosphomolybdate complex that was then reduced with ascorbic acid to a highly coloured blue compound, which was measured at 882 nm.

vi) Nitrite:

Nitrite in the 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 colouredazo-dye. The light absorbance was measured at 543 nm.

vii) Nitrate:

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

viii) Ammonia:

Ammonium compounds ($NH3^+$, $NH4^+$) in water were reacted with phenol in presence of hypochlorite to give a blue colour of indophenol. The absorbance was measured at 630 nm.

ix) PHc:

Water sample (1 L) was extracted with hexane and the organic layer was separated, dried over anhydrous sodium sulphate and reduced to 10 ml at 30^0C under low pressure. Fluorescence of the extract was measured at 360 nm (excitation at 310 nm) with Saudi Arabian crude residue as a standard (IOC UNESCO, 1984). The residue was obtained by evaporating lighter fractions of the crude oil at 100^oC.

x) Phenols:

Phenols in water (500 ml) were converted to an orange colouredantipyrine 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.

3.4 Sediment quality

a) Sampling Procedure

Subtidal surficial bed sediment from all locations was obtained by a van Veen grab of 0.04 m^2 area. The sample after retrieval was transferred to a polyethylene bag and preserved for further analysis. Intertidal sediment was sampled using a hand shovel.

b) Method of analyses

i) Texture:

Dried sediment (25 g) mixed with deionised water and 10 ml sodium hexameta phosphate (6.2 g/L) was sieved through 63 µm sieve to retain sand and the passed material was dispersed in deionised water (1L). The fraction (20 mL) picked up at 20 and 10 cm depths immediately and after 2 h 30 min, respectively, were considered as silt and clay after drying and weighing.

ii) Metals:

Sediment was brought into solution by treatment with conc. HF-$HClO_4$-HNO_3-HCl on a hot plate and the metals, namely aluminium, chromium, manganese, iron, cobalt, nickel, copper and zinc were estimated by inductively coupled plasma optical emission spectrophotometer (ICP- OES, Perkin Elmer, USA) Optima 7300 DV (Perkin-Elmer, USA) (Loring and Rantala, 1992). The analytical results were authenticated by analyzing certified reference material (PACS-2, NRCC, Canada) with each set of analysis.

For estimation of mercury, the sample was digested with aqua regia, followed by oxidation with potassium permanganate. Mercury was measured by cold vapour AAS technique. FIMS-400 (Perkin-Elmer, USA) was used for the analysis of mercury.

iii) C_{org}:

Total organic carbon C_{org} in the dry sediment was determined by oxidizing organic matter in the sample by chromic acid and estimating excess chromic acid by titrating against ferrous ammonium sulphate with ferroin as an indicator.

iv) Phosphorous:

The sediment was brought into solution by treatment with a mixture of conc. HF-$HClO_4$-HNO_3-HCl acids and phosphorus (P) were estimated as described under Section 3.3 (v).

v) PHc:

Sediment (~100 g) was refluxing with KOH-methanol mixture was extracted with hexane. After removal of excess hexane, the residue was subjected to clean-up procedure by silica gel column chromatography. The hydrocarbon content was then estimated by measuring the fluorescence.

3.5 Flora and fauna

a) Sampling procedure

For microbiological analysis, surface water was collected directly in a sterilised PP bottle. Sediment sample was obtained using van-Veen grab and transferred directly into sterilised polyethylene bag. Polyethylene bucket and Niskin sampler respectively, were used for sampling surface and near-bottom waters for the estimation of phytoplankton pigments and population. Samples for enumeration of phytoplankton cell count were fixed in Lugol's iodine and a few drops of 3% buffered formaldehyde.

Zooplankton samples were collected by oblique hauls using Heron Tranter net (mesh size 200µ, mouth area 0.25 m^2) attached with a calibrated flow meter (General Oceanic, Model-2030R, USA). All collections were of 5 min duration. Samples were preserved in 5% buffered formaldehyde.

Sediment samples for subtidal macrobenthos were collected using a van Veen grab of 0.04 m^2 area. Samples were preserved in 5% buffered formaldehyde- Rose Bengal.

b) Method of analyses

i) Microbiology

The enumeration of Total Viable Count(TVC) was carried out by spread plate method, andother parameters such as total coliforms (TC), Fecal Coliforms (FC), *Escherichia coli* (EC), *Streptococcus faecalis* (SF) were carried out using Membrane filtration techniques (APHA 1998). In brief, 0.1, 1 and 10 mL of water samples were filtered through 0.45 um pore size, 47MM diameter cellulose acetate filters paper (Millipore make). For 0.1 and 1 mL of samples, the volume of water to be filtered was made up to 10ml with sterile phosphate buffer saline (PBS) for evenly distribution across the filter paper during filtration. Bacteria present in the water or sediment samples get retained on the filter surface. The filter was then transferred to a selective media plate as given in the table below for colony development. All of the media plates, except M-FC agar plates, were incubated at 37ºC±1ºC for 24 – 48 h, and final counts of colonies were noted. M-FC agar plates were incubated at 44.5ºC±1ºC for 24–48 h. The number of colonies counted on the membrane is taken to be equivalent to the number of bacterial cells present per volume of the samplefiltered. For sediment samples, 1g of sediment was diluted and thoroughly mixed in 100 mL of PSB saline. 0.1,1 and 10mL of the sample were drawn from 100 mL and filtered through a membrane filter as mentioned above.

Table 3.3A: Culture media used various bacterial types

Sl no	Bacterial type	Culture medium	Manufacture
1	Total Viable Count(TVC)	Zobell Marine Agar (M384)	Hi-media
2	Total coliforms(TC)	Mac ConkeyAgar (MH081)	Hi-media
3	Fecal coliforms(FC)	M-FC Agar (M1122)	Hi-media
4	*Escherichia coli* (EC)	M7HrFC Agar (M635)	Hi-media
5	*Streptococcus faecalis* (SF)	M Enterococcus Agar (M1108)	Hi-media

ii) Phytoplankton

A 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, Trilogy 7200, USA) before and after treatment with dilute acid (0.1N HCl).

Phytoplankton population: Water samples for phytoplankton cell counts were preserved in Lugol's solution with 2% formaldehyde. Enumeration and identification of phytoplankton were made under a compound microscope (Olympus, Model-IX73, Japan) using a Sedgewick-Rafter slide.

iii) Zooplankton

Biomass was obtained by the displacement volume method. Sub-sample (25-50%) was analysed under a Stereo Microscope (Leica, Model: S6D, Germany) for faunal composition and population count.

iv) Benthos

The sediment samples were sieved through a 0.5 mm mesh sieve, and animals retained were preserved in 5% buffered formaldehyde. The total population was estimated as the number of animals in 1 m^2 area and biomass on wet weight basis.

v) Diversity indices

The univariate analysis uses diversity indices,which attempt to combine the data on abundance within a species in a community into a single number. The state of the community can be understood by this method.

i) Shanon-Weiner diversity index

Shanon-Weiner diversity index is used here for comparing species diversity across location and seasons It is denoted by H´(log$_2$).

$$H' (\log_2) = -\sum Pi \ln Pi$$

Where, Pi= S/N

S-Total number of individuals of one species, N-Total number of individuals present in sample, ln – logarithm of base e

ii) Pielou’s evenness index

Pielou’s evenness (1966) is used here to calculate species evenness in the population. It measures the relative abundance that forms the richness of the area. It is denoted by J´.

$$J' = H / \ln \log(S)$$

Where, H- Shanon-Weiner index, S- Total number of species in a sample

4 PREVAILING ENVIRONMENT

4.1 Water quality

The water quality around the sub-tidal regions off Vadhvan was analysed during December 2020 (post-monsoon) to know the environmental condition that prevails in the region. Hydrography and nutrients and oil compounds measured at nine (9) fixed locations covering nearshore, coastal and offshore waters of south Dahanu Creek. Water quality parameters are presented in Table 4.1.1, and their averages, pertaining to different zones like nearshore (VN1, VN2, VN3, and VN4), coastal (VN5, VN6, and VN7), and offshore (VN8 and VN9) were presented in the text.

4.1.1 Temperature

Temperature of water is an important parameter that influences chemical processes such as dissolution-precipitation, adsorption-desorption, emulsification-flocculation, oxidation-reduction etc. Some contaminants such as PHc may be absorbed more at a higher temperature, and the concentration of some materials may enhance due to the increase in solubility at a higher temperature.

As the result of absorption of solar radiation, the temperature of a well-mixed shallow water body varies in accordance with the prevailing air temperature, while that of a water body having restricted mixing a thermal gradient may prevail. Due to natural changes in climatic conditions, the temperature of water fluctuates daily as well as seasonally. These changes often influence the physiological processes and reproductive cycles of aquatic organisms affecting the prevailing community structure and the geographical distribution of species. Temperature also affects aesthetic and sanitary qualities by influencing the self-purification phenomenon of water bodies. An increase in temperature accelerates the biodegradation of organic material both in the overlying water and in the bottom deposits releasing nutrients to the water column, thereby increasing demands of DO when actually DO depletes due to lower solubility.

Water temperature generally regulates species distribution and their composition and activity of life associated with aquatic environment. Since most of the aquatic animals are cold blooded, water temperature regulates their metabolism, ability to survive and reproduce effectively. Hence artificially induced changes such as those by the return of warmer water may alter local communities of the ecosystems. For instance, elevated temperature may affect periphyton, benthic invertebrates and fish in addition to causing shifts in algal dominance. Unnatural short term fluctuation in temperature appears to cause reduced reproduction of fish and invertebrates. Size of harvestable stocks of commercially important fish and shellfish particularly near geographic limits of the fishery; appear to be markedly influenced by slight changes in the long term temperature regime. In extreme conditions, mass mortality of the biota may take place due to thermal shocks. Severe damage generally occurs to lower-order biota while high order organisms may migrate from the affected area. Since generally, the toxicity of a material increases with an increase in temperature, organisms subjected to stress from toxic material are less tolerant to temperature extremes.

An upper threshold limit of 35°C is considered for tropical aquatic species though many may be less tolerant. In the coastal waters of Maharashtra, the annual temperature range is expected to be 20 to 30°C. But in summer, when stagnation condition prevails in the shallow segments, the water temperature may rise to 33 to 35°C in isolated water pools.

Mean water temperature off Vadhvan during December 2020 ranged between 25 − 27.5°C (av. 26.8°C), with bottom temperature generally were lower than the surface (Table 4.1.1) as displayed in the figure below (Figure 4.1.1). The nearshore (stations VN1, VN2, VN3 and VN4), coastal (VN5, VN6 and VN7) and offshore stations (VN 8 and VN9) exhibited average temperatures of 27.1, 26.5, and 25°C, respectively, also closely varied in line with the air temperature. The air temperature averages were 28.1, 27.1, and 25.8°C around the nearshore, coastal and offshore stations, respectively, and decreased from nearshore towards offshore in the region.

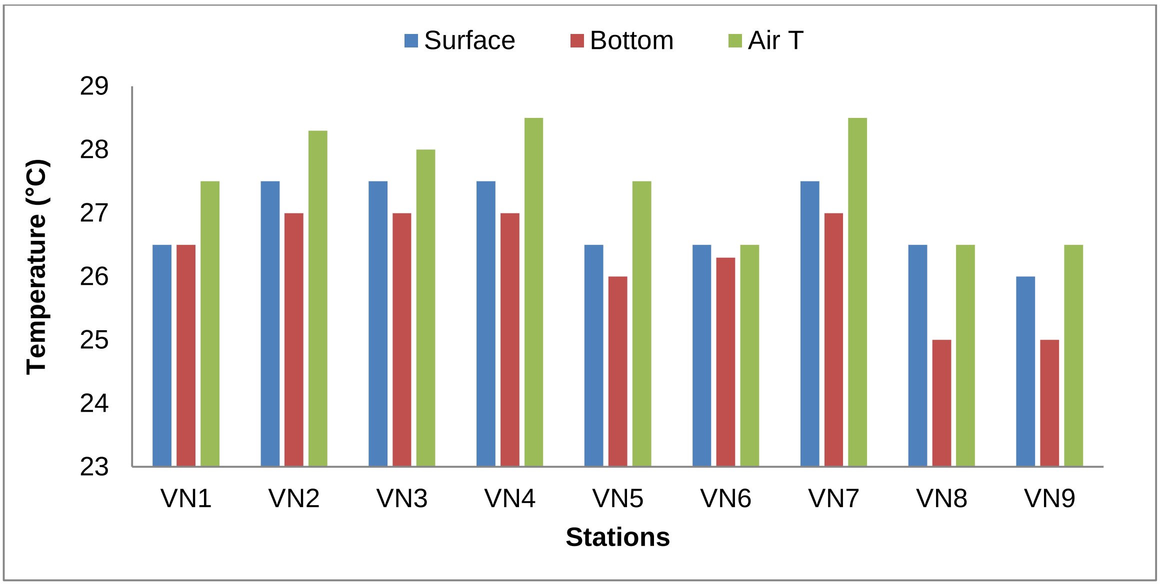


Figure 4.1.1: Distribution of water and atmospheric temperature at different stations of the study area

The average water temperatures at different zones somewhat described general winter conditions. However, the results were based on a snapshot observation during a single day, therefore mainly relevant with air temperature variation. The average water temperature limits did not exceed 35°C (considered as threshold limit for tropical aquatic species). Therefore, it may not have any significant impact on aquatic organisms.

4.1.2 pH

The pH is the measure of hydrogen ion activity in water. It is known as master variable in water since many properties, processes and reactions are pH dependent. The principal system that regulates pH in seawater is the carbonate consisting of CO_2, H_2CO_3, HCO_3^- and CO_3^{2-}, salt content and alkalinity due to borates. Because of the buffering capacity of seawater, generally, seawater pH has limited variability (7.8 -

8.3). In shallow, biologically active tropical waters, large diurnal pH changes from 7.3 to 9.5 may occur naturally because of photosynthesis.

The nearshore influx of freshwater, particularly during monsoon, can affect the buffering effect and the pH often remains below 8. These areas are also vulnerable to pH changes due to release of anthropogenic discharges. For instance domestic and metallurgical effluents can lower the pH, while effluents from textile processing industries may raise pH above 9 particularly in the vicinity of outfalls. These variations are often normalized by tidal mixing in estuaries. A shift in equilibrium of ionic species such as $NH_3 \leftrightarrows NH_4^+$ can enhance its toxicity at higher pH. The Association of metal compounds with water, SS and sediment is largely affected by pH changes. It can cause large shifts in metal complexes influencing toxicity of metals. Though pH range of 5 to 9 is not directly harmful to the aquatic life, such changes can make many common pollutants more toxic. For instance pH range of 5 to 6 may become lethal when CO_2 is liberated from bicarbonates in water.

pH values during December 2020 ranged between 8.1 and 8.2, av. 8.1 off Vadhvan was highlighting alkaline condition. Surface and bottom pH averages were nearly similar, as indicated in the figure below, except in the coastal stations. Average limits of pH were more or less similar around nearshore, coastal, and offshore stations. The average pH is comparable to the pH of the nearshore and coastal waters around the Arabian Sea.

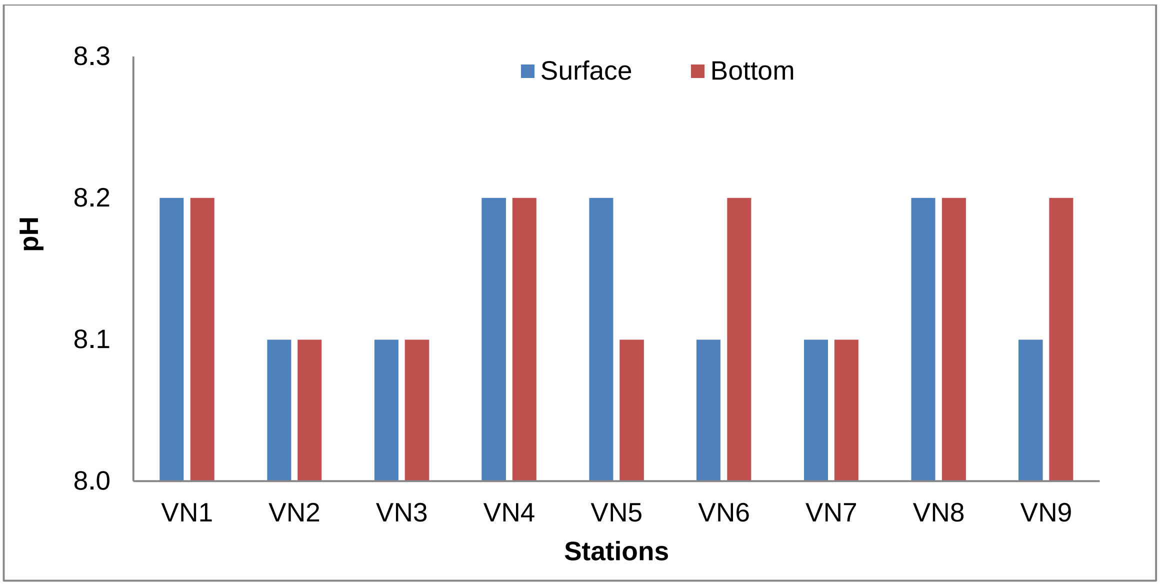


Figure 4.1.2: Distribution of pH at different stations of the study area

Generally, in nearshore and estuarine systems, freshwater mixing, especially during the monsoon season, can affect the buffering effect; thus, pH remains below 8.0. Nevertheless, the lower pH results from runoffs received through rivers, which carry low pH waters. The studied region is far from the riverside, exhibiting typical marine alkaline characteristics during the post-monsoon season. The seawater pH varies between 7.8 and 8.3. In shallow and biologically active tropical waters, diurnal pH fluctuates between 7.3 and 9.5; this is due to the photosynthesis process. The above areas are also vulnerable to pH changes due to the release of anthropogenic discharges. However, the pH range of 5 to 9 is not directly harmful to aquatic life, but such changes can make many common pollutants more toxic. The range of pH observed in this study is indicative of the predominant marine condition.

4.1.3 Salinity

Normally seawater salinity is 35 PSU which may vary depending on the competition between evaporation and precipitation and freshwater addition. Thus for instance, during pre-monsoon evaporation exceeds precipitation leading to salinities higher than 35.5 PSU while during monsoon and post-monsoon the salinities can be markedly lower. In arid areas, salinity values may even exceed 37 PSU due to the absence of freshwater flow and excessive evaporation.

Salinity influences several processes such as dissolution, dispersion, dilution etc., in seawater due to high dissolved salt content and higher density. For instance, DO is relatively low in seawater as compared to freshwater at equivalent water temperature.

Biota is generally acclimatized for a certain range of salinity where they thrive. Hence, wide changes in salinity can result in adaptation with modification and dominance of selected species in the lower order while higher-order biota may migrate. Sudden changes in salinity may cause high mortality of biota, including fish due to salinity shock.

The salinity ranged between 34.8 and 35.3 PSU, averaged at 35.1 PSU during December 2020 in off Vadhvan waters (Tables 4.2.1). There was no marked salinity change observed between the surface and bottom water column at nearshore, coastal and offshore stations of this study, as indicated in the figure below. However, slight salinity variation between surface and bottom (0.2 PSU) in the nearshore station.

The average salinity limits were almost similar; varying within 35.1 - 35.2 PSU indicated typical marine characteristics. Usually, seawater salinity is 35 PSU, which may vary depending on the competition between evaporation and precipitation and freshwater addition. When evaporation exceeds precipitation, salinities get higher than 35 PSU during pre-monsoon. During monsoon and post-monsoon salinities, it can be markedly lower due to the mixing of freshwater. Therefore, the salinity of water in the studied region found to be uniform during the study period.

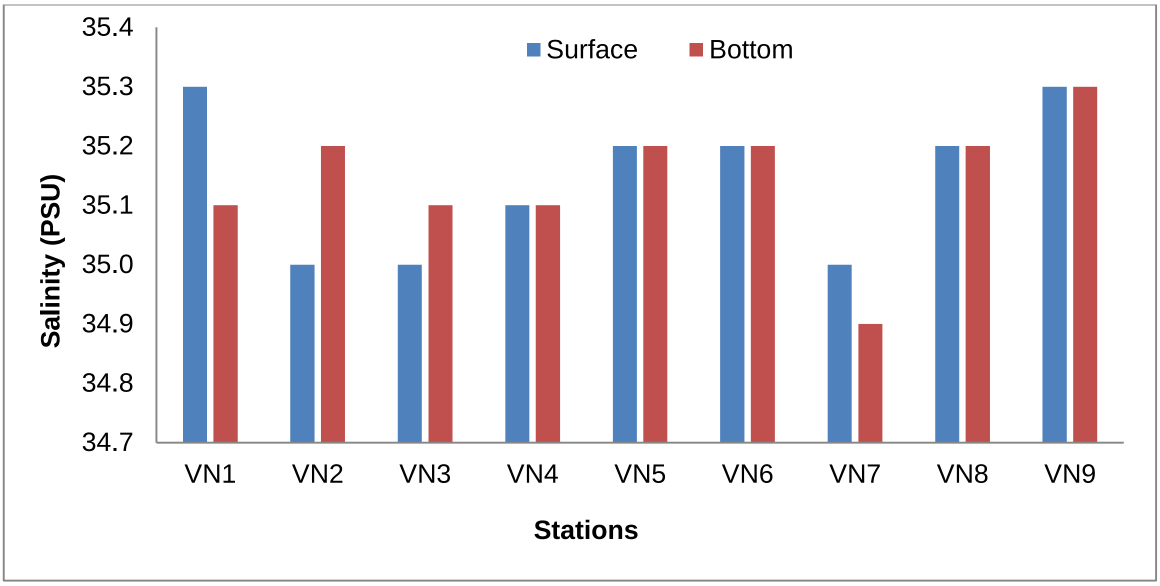


Figure 4.1.3: Distribution of salinity at different stations of the study area

4.1.4 Suspended Solids (SS)

Suspended solids (SS) is the descriptive term used for suspended/ settleable particulate matter in the water column. SS of natural origin mostly contains clay, silt, sand of bottom and shore sediment, and plankton for nearshore regions clay and vegetation matter forms important component of SS. Anthropogenic discharges add a variety of SS depending upon the source. Since the major contribution comes from the disturbance of bed and shore sediments, energy of the region such as tidal currents is the vital influencing factor for SS and typically leads to high values in the bottom water.

The major role played by SS is adsorption of constituents as well as contaminants from the water column. They may get coagulated/ flocculated/ precipitated due to change of matrix. Pollutants such as toxic metals, PHc, pesticides etc. can be adsorbed onto SS and transferred to the bed sediment on settling. The immediate effect of high SS results in an increase in turbidity, which reduces the light intensity and the depth of the photic zone leading to a decrease in primary production and fish food. SS in the water column also adversely affects certain sensitive populations through mortality, reducing growth rate and resistance to diseases, preventing proper development of fish eggs and larvae, modifying natural movement, migration and reduction in the abundance of available food. SS settling on the bed can damage the benthic invertebrate population, block spawning etc. Organic content in SS increases oxygen demand in the water column and its settlement on the bed can make the sediment anoxic.

The SS values varied between 11 to 117 mg/L (av. 52 mg/L) in the stations off Vadhvan; however, this excludes the exceptionally higher values observed at the bottom water of stations VN8 and VN9 (Offshore segment), which were nearly 8-10 times higher than the average (Table 4.1.1). On average, SS value in surface water was lower than that in the bottom water column, as shown in the figure below, also in Table 4.1.1.

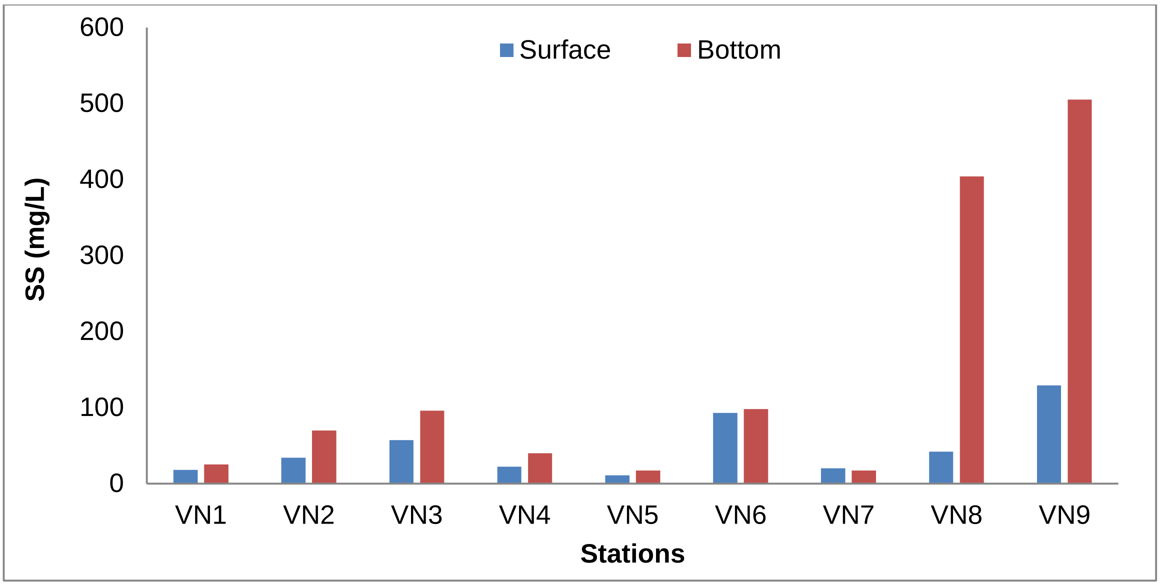


Figure 4.1.4: Distribution of suspended solids at different stations of the study area

The exceptionally higher values of SS were associated with bottom waters at the offshore region, which could relative to localized disturbance and challenging to assess based on this snap-shot observation. The average limits of water column SS increased from nearshore towards offshore, which indicated transport of turbid waters from the nearshore region during the study period. The average SS of nearshore, coastal and offshore water column were 47, 59, and 270 mg/L, respectively, which excluded the exceptionally higher values (404 and 505 mg/L).

SS of natural origin mostly contains bottom sediment residuals, plankton debris from nearshore, and sea bottom. Anthropogenic SS sources are due to the disturbance of sedimentary bed and areal transport of shore sediment during any developmental activities. The immediate effect of SS is an increase in turbidity, which reduces the light intensity and the depth of the photic zone, therefore affect biological productivity. The SS settling on the sedimentary bed can damage the benthic invertebrate population. The organic content in SS increases oxygen demand in the water column, and its settlement on the bed can make the sediment suboxic.

4.1.5 DO and BOD

DO is an important constituent and plays a significant role in protection of aesthetic quality of water as well as maintenance of fish and other aquatic life. Hence it is of considerable interest in water quality investigations that its concentration in water is an indicator of prevailing water quality and ability of a water body to support a well-balanced aquatic life.

Generally, DO is the characteristic of a water body under typical hydrologic, hydrographic, waste loading and environmental conditions. DO in water is replenished through photosynthesis, dissolution from atmosphere and addition of oxygen rich water. Simultaneously it is consumed during heterotrophic oxidation of oxidizable organic matter and respiration by aquatic flora and fauna as well as oxidation of naturally occurring constituents in water. Thus, equilibrium is maintained between consumption and replenishment of DO.

In natural waters the rate of consumption of DO is lower than the rate of replenishment resulting in maintenance of adequate concentrations in water which are often at the saturation level. DO vary in a certain range temporally as well as seasonally depending on the environmental conditions.

Influx of anthropogenic discharges containing oxidizable organic matter and certain pollutants consume DO more than that the water body can replenish creating under-saturation which in extreme cases may lead to onset of septic conditions with mal-odorous emissions thereby degrading the ecological quality. However, in a dynamic coastal environment the impact of such a condition is considerably low because of tidal action and turbulence.

In water body of restricted tidal exchange, the DO may progressively decrease ultimately leading to anaerobic decomposition of organic matter resulting in the release of obnoxious gases such as H_2S, CO_2 and CH_4 in extreme conditions. High concentration of DO, on the contrary support abundant aquatic life. Under conducive conditions addition of excess vegetation growth can lead to eutrophication in enclosed/semi-enclosed water bodies, thereby adversely affecting the ecology.

It is difficult to arrive at the threshold limit of DO for aquatic life, since environmental conditions, waste loading and natural levels of DO vary considerably and the existent composite aquatic life has variable demand for DO depending on their composition, age, activity, nutritional status etc. It has been observed that concentration of DO below 2 mg/L for prolonged time may affect aquatic life since feeding of many organisms is diminished or stopped and their growth is retarded at low DO levels.

The DO levels around nearshore, coastal and offshore stations off Vadhvan ranged between 5.5 to 7.2 mg/L, av. 6.6 mg/L. Similarly, the BOD values ranged at 2.3 - 3.9 mg/L and averaged at 3.2 mg/L during this study (Table 4.1.1).

Overall, the average water column DO values around nearshore, coastal and offshore stations were 6.7, 6.4, and 6.2 mg/L, respectively, remain less variable and highlights well-oxygenated conditions in the region. The variation in average DO, and BOD levels between the surface and the bottom water column are minimal, as indicated in the figures below.

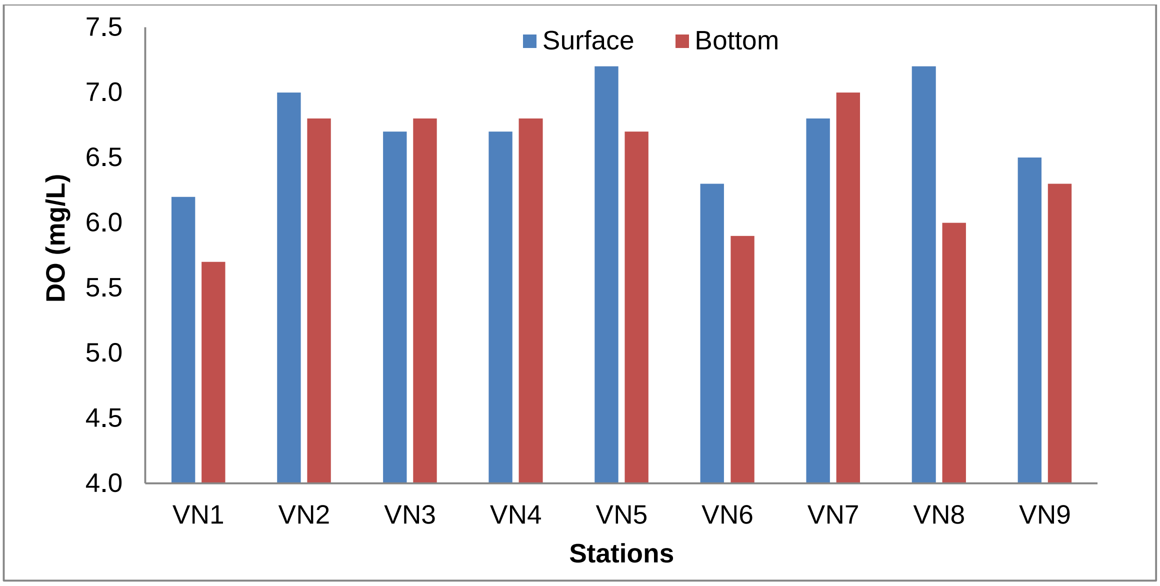


Figure 4.1.5: Distribution of dissolved oxygen at different stations of the study area

Consumption of DO during heterotrophic degradation of oxidizable organic matter creates oxygen demand popularly termed as the Biochemical Oxygen Demand (BOD). Presence of sufficient DO through replenishment keeps this demand low. However, input of oxidisable organic matter more than that a water body can assimilate, enhances BOD, which is the indicator of unfavourable conditions for the aquatic life and aesthetics.

Similarly, the BOD levels were more or less the same, varying between 2.9 to 3.4 mg/L along with the nearshore, coastal and offshore stations. On average, DO, and BOD levels found around the studied region off Vadhvan did not indicate any unfavourable situations that may hamper the biological ecosystem.

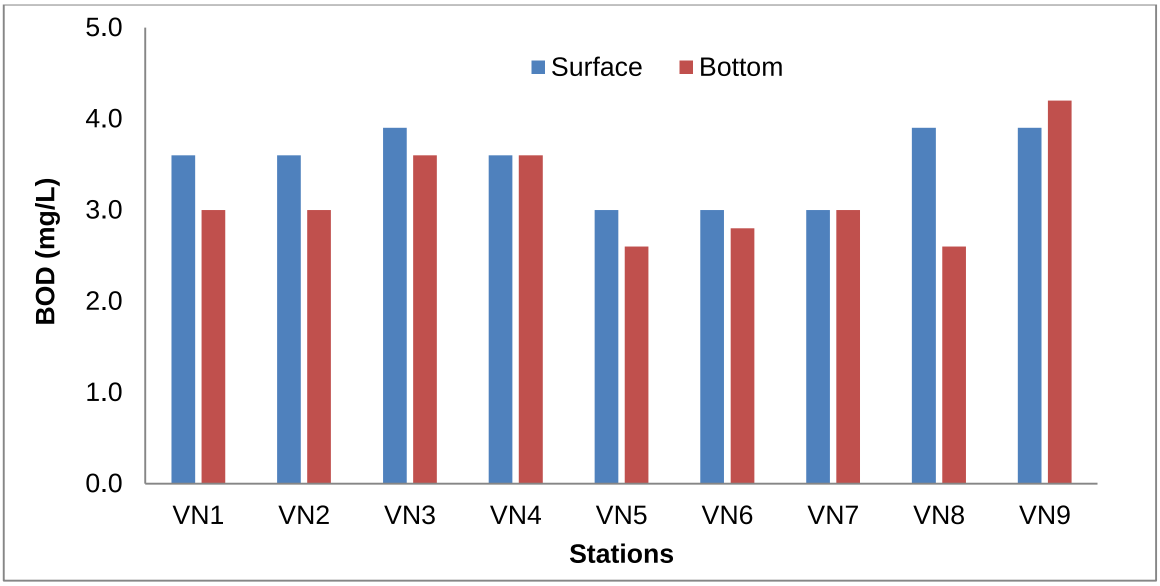


Figure 4.1.6: Distribution BOD at different stations of the study area

4.1.6 Reactive phosphate (PO_4^{3-}-P)

Dissolved nutrients though in low concentrations, are essential for the production of organic matter by photosynthesis. They tend to be efficiently stripped from the surface water through incorporation into the cells, tissues and extra cellular structures of living organisms. Among several inorganic constituents such as phosphate, nitrogen compounds, silicon, trace metals etc. the traditional nutrients namely phosphorus and nitrogen compounds have a major role to play in primary productivity. However, their occurrence in high levels in areas of restricted water exchange can lead to an excessive growth of algae which in extreme conditions result in eutrophication.

Among the several forms of phosphorus namely PO_4^{3-}-P, H_2PO_2, $H_2P_2O_7$, polyphosphoric acid, organic compounds such as phospholipids, phosphonucleotides and their derivatives occurring in seawater, reactive phosphate (PO_4^{3-}-P) accounts for only 10%. Sediment bound phosphate is generally associated with iron, calcium and magnesium which is released to the overlying water column during anoxic conditions.

Phosphorus as phosphate is one of the major nutrients required for plant nutrition and essential for life though the elemental form is particularly toxic and is subject to accumulation. When in excess, it stimulates undesirable plant growth when other nutrients are also available. Sources of phosphate in coastal marine environment are mostly land based. These include domestic sewage, detergents, effluents from agro-based and fertilizer industries, agricultural runoff, organic detritus such as leaves, cattle waste etc. The sources within marine environment are decomposition of algal plant cells, releases through sediment, bacterial action and recycling within the biotic communities.

It is difficult to determine the critical levels of phosphate for optimum growth of aquatic life since they may vary from location to location depending upon phosphorus loading and its distribution. As stated earlier, the levels above certain values, which are the characteristic of a water body, may lead to nuisance growth and cultural eutrophication particularly in a water body having restricted water exchange.

The PO_4^{3-}-P concentrations during December 2020 around nearshore, coastal and offshore stations off Vadhvan ranged between 0.8 and 3.3 µmol/L, averaged at 1.6 µmol/L (Tables 4.1.1). The variation of surface and bottom PO_4^{3-}-P was minimal around the stations as shown in the figure below.

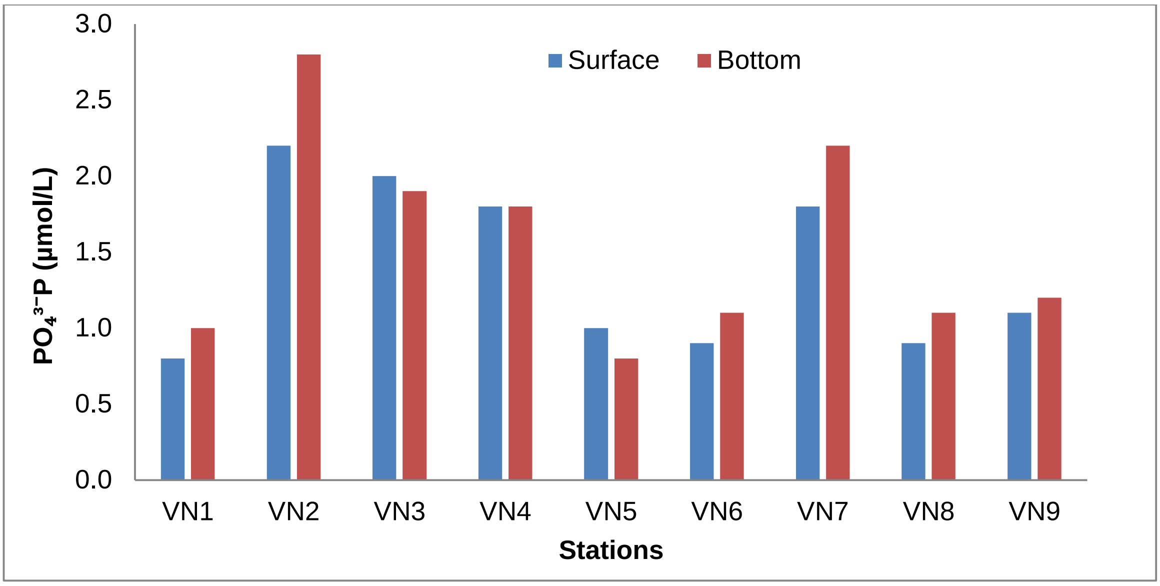


Figure 4.1.7: Distribution of reactive phosphate (PO_4^{3-}-P) at different stations of the study area

The average values of PO_4^{3-}-P at different zones in this study were 2.0, 1.2, and 1.1 µmol/L, respectively at nearshore, coastal and offshore stations off Vadhvan indicated higher average PO_4^{3-}-P in the nearshore region. The average PO_4^{3-}-P concentration in the waters off Vadhvan is in line with the previously observed values along with coastal India.

4.1.7 Dissolved nitrogen

The nitrogen cycle involving elementary dissolved nitrogen, oxides: NO_3^-, NO_2^- and reduced forms: NH_4^+, plays a significant role in sustaining life within the aquatic environment. NO_3^- is the end product of oxidation and the most stable form at pH 7. The principal source of nitrogen in the marine environment is the fixation of atmospheric N_2. NO_2^- occurs in seawater as an intermediate product of NO_3^-reduction in microbial processes, i.e., denitrification at low oxygen level during which NO_2^- transforms into N_2 under anoxic conditions.

(a) Nitrate (NO_3^-- N)

NO_3^--N concentrations within waters off Vadhvan ranged between 7.6 and 14.8 µmol/L, av. 10.2 µmol/L during the study period (Tables 4.1.1). The average NO_3^--N on the surface and bottom were nearly similar, as highlighted in the figure.

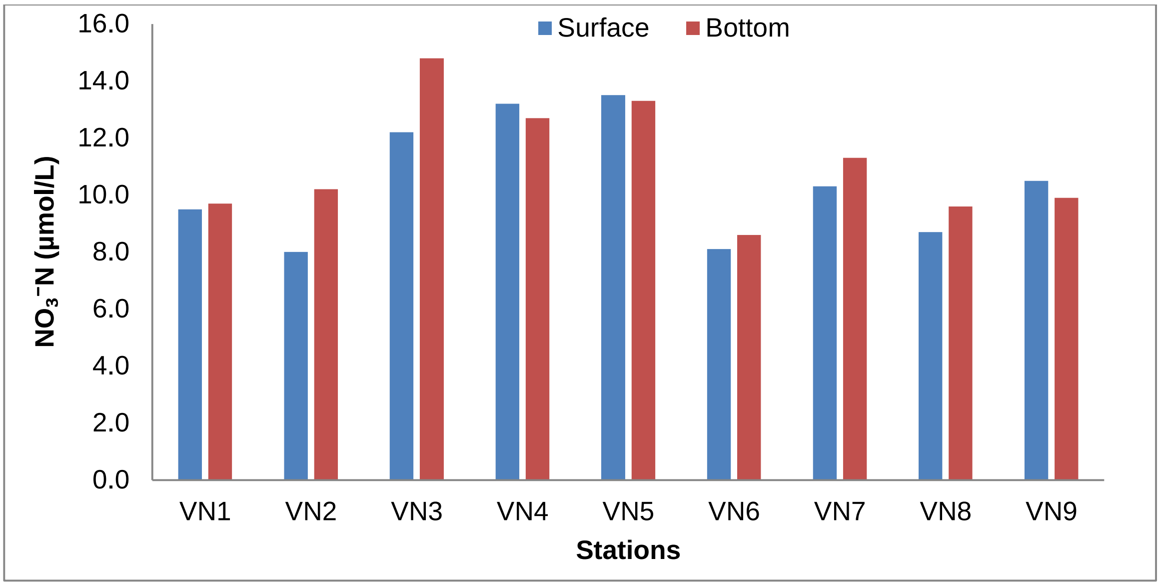


Figure 4.1.8: Distribution of Nitrate (NO_3^-- N) at different stations of the study area

Average water column NO_3^--N around nearshore, coastal and offshore stations off Vadhvan were 10.6, 9.9, and 9.7 µmol/L, generally less variable within the studied region. The limits of NO_3^-- N at different regions of this study compared with the limits found along the coastal region and lower than in the creek and estuarine regions of nearby regions.

(b) Nitrite (NO_2^--N)

The NO_2^--N levels around waters off Vadhvan were low during December 2020 ranged between 0.04 and 0.9 µmol/L averaged at 0.5. The water column average of average NO_2^--N values around nearshore, coastal and offshore stations were 0.3, 0.6, and 0.8 µmol/L respectively.

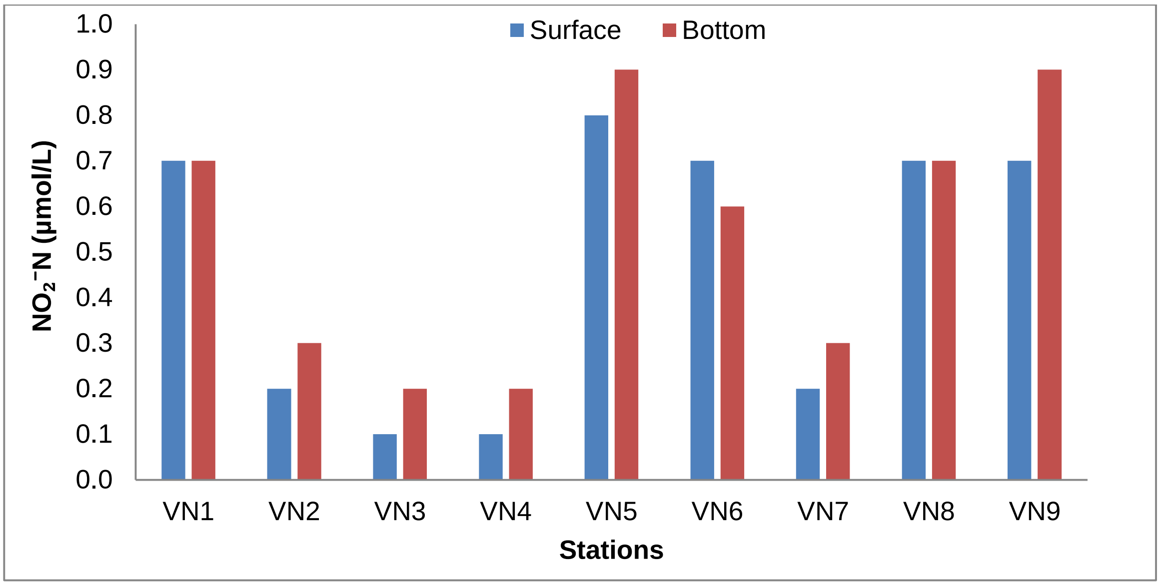


Figure 4.1.9: Distribution of Nitrite (NO_2^--N) at different stations of the study area

The surface and bottom NO_2^--N limits highlighted nearly similar values, as indicated in the figure above. The average limits of NO_2^--N and NO_3^--N found in this study are comparable with their limits found in other west coast systems; however, their further variation is mostly dependent on the seasonal precipitation, and anthropogenic activities lead to their concentration increased over the ambient values.

(c) Ammonium (NH_4^+-N)

The NH_4^+-N is unstable in natural waters, therefore further oxidized to NO_3^--N via NO_2^- -N. The concentration of NH_4^+-N in around waters off Vadhvan widely ranged between 0.8 to 4.5 µmol/L, averaged at 2.3 µmol/L, more or less similar throughout the surface and bottom waters (Table 4.2.1), highlighted in figure 4.1.10.

The average water column NH_4^+-N were respectively 2.4, 2.7, and 3.4 µmol/L around nearshore, coastal and offshore waters off Vadhvan, which increased from nearshore towards offshore. The lower NH_4^+-N around the nearshore region generally associated with higher NO_3^--N. The NH_4^+-N and NO_3^--N are not equivalent forms of dissolved inorganic N in multi-species composing phytoplankton in shallow water bodies. Therefore, a higher organic matter content in the bottom can lead to a more reductive environment where the accumulation of NH_4^+-N forms will be higher than that of NO_3^--N. Around Vadhvan, NO_3^--N was found dominant in the inorganic nitrogen pool; therefore, the reduction of NH_4^+-N can be less effective, evidenced by higher DO in the region.

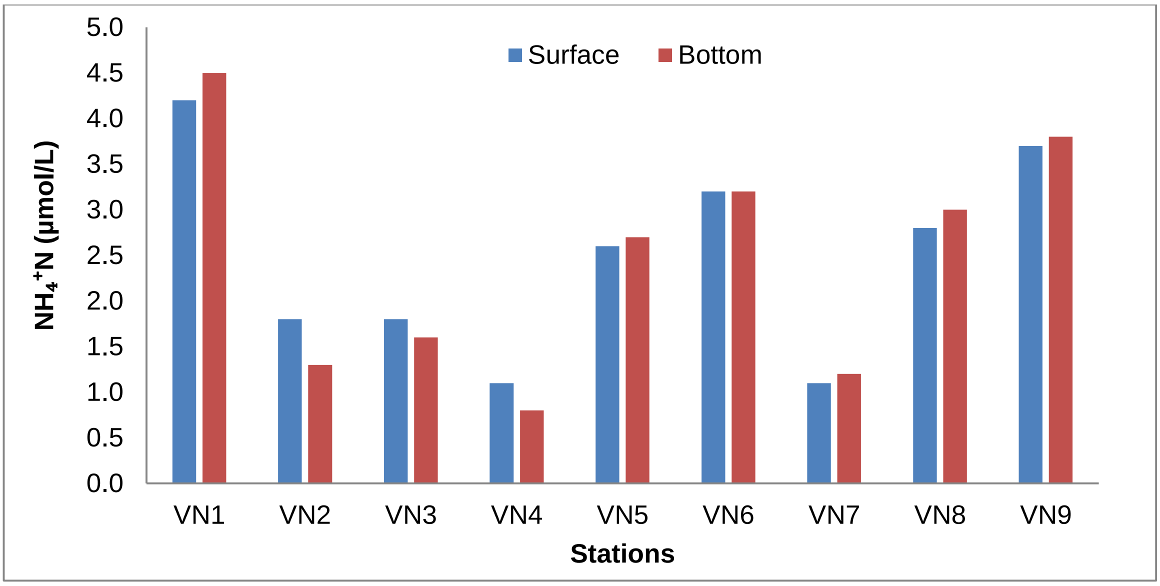


Figure 4.1.10: Distribution of Ammonium (NH_4^+-N) at different stations of the study area

4.1.8 Petroleum hydrocarbon (PHc)

Naturally occurring hydrocarbons in the marine environment are trace amounts of simple forms produced by microbes. PHc derived from crude oil and its products are added to marine environment by anthropogenic activities, namely production of crude oil and its products, transport through pipelines, ship traffic, tankers etc. Prominent landbased sources are domestic and industrial effluents, atmospheric fallout of fuel combustion products, condensed vapours etc.

PHc consists of several hydrocarbons. They are saturated; unsaturated aliphatic; one ring, polyaromatic, fused aromatics; and alicyclic or naphthenic hydrocarbons having a wide range of boiling points. On entering the marine environment, PHc is subjected to several weathering processes during which PHc gets distributed in the water column, evaporates, adsorbs on particulate matter and sinks, gets assimilated by biota, washes ashore etc. Consequently, its high boiling residue may remain in the marine environment till it is biodegraded and/or removed.

The concentrations of PHc off Vadhvan waters varied between 2.5 and 5.7 µg/L, averaged at 3.8 µg/L (Table 4.1.1). The limits of PHc decrease from nearshore to the offshore, varying between 3.3 µg/L and 2.4 µg/L, respectively indicated in the figure above. The levels of PHc found during this study are much lower compared to the adjacent estuarine and creek environment of Mumbai.

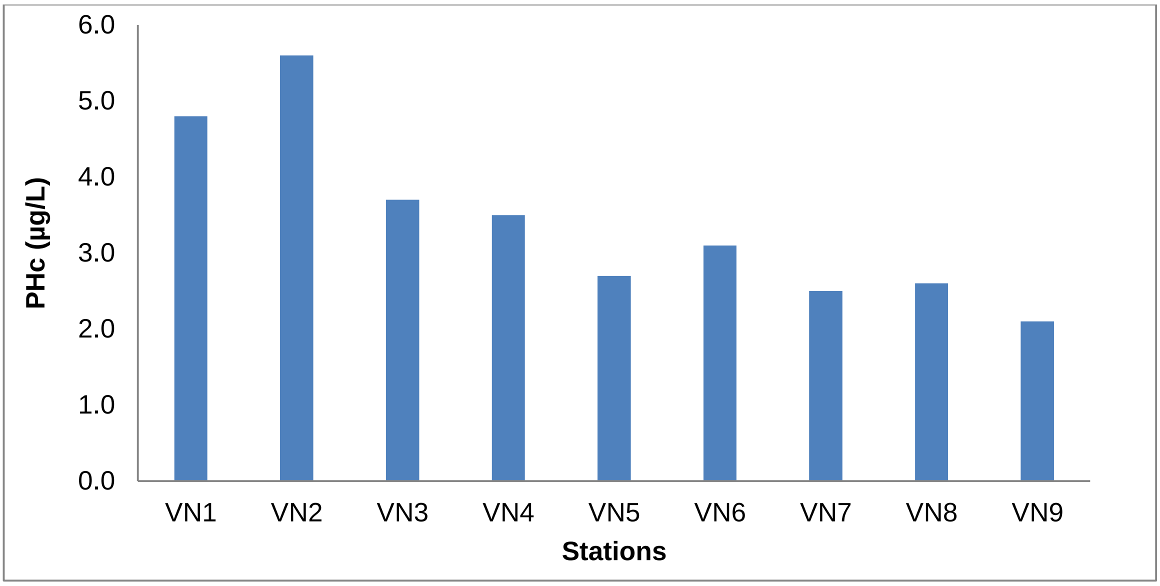


Figure 4.1.11: Distribution of PHc at different stations of the study area

4.1.9 Phenols

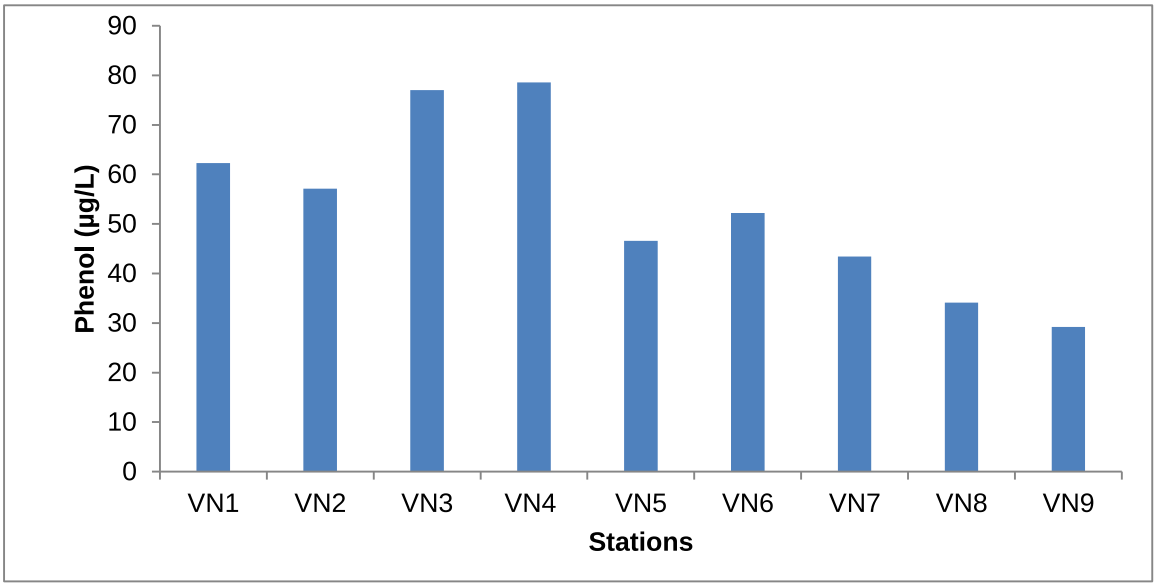
Phenols in the marine environment generally originate through onshore anthropogenic discharges. They are generated as by-products in coke, paper, and pulp processing, coal gas liquefaction, and produced from hydrocarbons in petrochemical industries. They are produced and used on a large scale in fungicides, antimicrobials, wood preservatives, pharmaceuticals, dyes, pesticides, resins etc.

Phenols include a wide variety of derivatives of phenol (C_6H_5OH) such as monohydric, dihydric, polyhydric, one ring, two ring, polyring and fused aromatic. Substitutions of $-CH_3$,-Cl,$-NH_2$ etc. greatly influence reactivity of the molecule; phenol being highly reactive. Some of the commonly known phenols are chlorophenols, cresols and naphthols. Generally, naturally occurring phenols namely thymol, methyl salicylate, polyhydroxy phenols etc. which are lowly reactive compounds are not determined in the water quality parameter. Polyphenols related to catachols are produced by brown algae which on decomposition add phenols in intertidal regions. The High concentration of phenols in marine environment generally originates through onshore anthropogenic discharges. They are generated as by-products in manufacturing processes of coke, paper and pulp processing, coal gas liquification and produced from hydrocarbons in petrochemical industries. They are used on large scale in fungicides, antimicrobials, wood preservatives, pharmaceuticals, dyes, pesticides, resins etc. Hence, they become important constituent of domestic and industrial effluents.

Phenols have broad spectrum toxicity depending upon the substitution. For instance, phenol and O-cresol have LD_{50} (24 h) of 5 and 2 mg/L respectively. Concentration above 200 µg/L may interfere with the aquatic life but significant detrimental effects such as pathological changes in gills and fish tissue are observed at less than 1 mg/L concentration.

Phenol concentrations around Vadhvan waters varied between 34 and 79 µg/L, averaged at 56 µg/L (Table 4.2.1). Phenol limits at the different regions are 65, 49, and 32 µg/L, respectively, in nearshore, coastal and offshore stations, highlighting decreasing levels towards the offshore region as shown in the figure below.

Figure 4.1.12: Distribution of Phenol at different stations of the study area



4.1.10 Chemical Water Quality Index (C_{WQI})

The chemical water quality index (C_{WQI}) using multivariate data is proposed in this study will help to alleviate the information on ecological sustainability status around the sub-tidal regions off Vadhvan. The C_{WQI} is based on the arithmetic average technique described in Brown et al. 1972, later modified and used in various studies (Prati et al. 1971; Gupta et al. 2003; Kachroud et al. 2019). The C_{WQI} is a vital proxy used to classify water quality in the coastal region, therefore helping keep policy makers and the general public aware of the ecological health status of the water body. The arithmetic average approach used in this study is one of the popular methods (Gupta et al. 2003), primarily focused on weighing of selected multivariate parameters in the coastal water. The standard limits for multivariate parameters those categorised as hydrography, nutrient and marine components were adopted from their prescribed limits and observed values around the Indian continental margin. The standard limits (mean and standard deviation) are used and the uncertainties within the seasonal cycle and due to anthropogenic activities were simulated in order to deal with the standard limit variability straight forward manner (Pradhan et al., 2021). Nearly 40 data points for each parameters including the repetitive measurements done during the sampling campaign used as input parameters to infer the C_{WQI}. The quality is evaluated based on the hydrography and nutrients, which primarily support the biological productivity. The marine water quality based on hydrography and nutrient properties primarily responsible for sustainable and healthy ecosystem were scored on a scale as below;

Score	Supportive to biology
0-25	Very bad
26-50	Bad
51- 70	Moderate
71- 90	Good
91 -100	Very Good

The C_{WQI} was calculated using the standard limit of multivariate parameters as follows;

$$C_{WQI} = \sum_{i=1}^{n} \left(\frac{W_i \times Q_i}{W_i} \right) \qquad (1)$$

In above equation, W_i and Q_i are the calculated unit weights and quality ratings of the multivariate parameters, respectively.

The C_{WQI} around off Vadhvan in this study ranged between 61 and 77 (av. 69) during all the campaigns, with disproportional variation between surface and bottom water as indicated in the figure below.

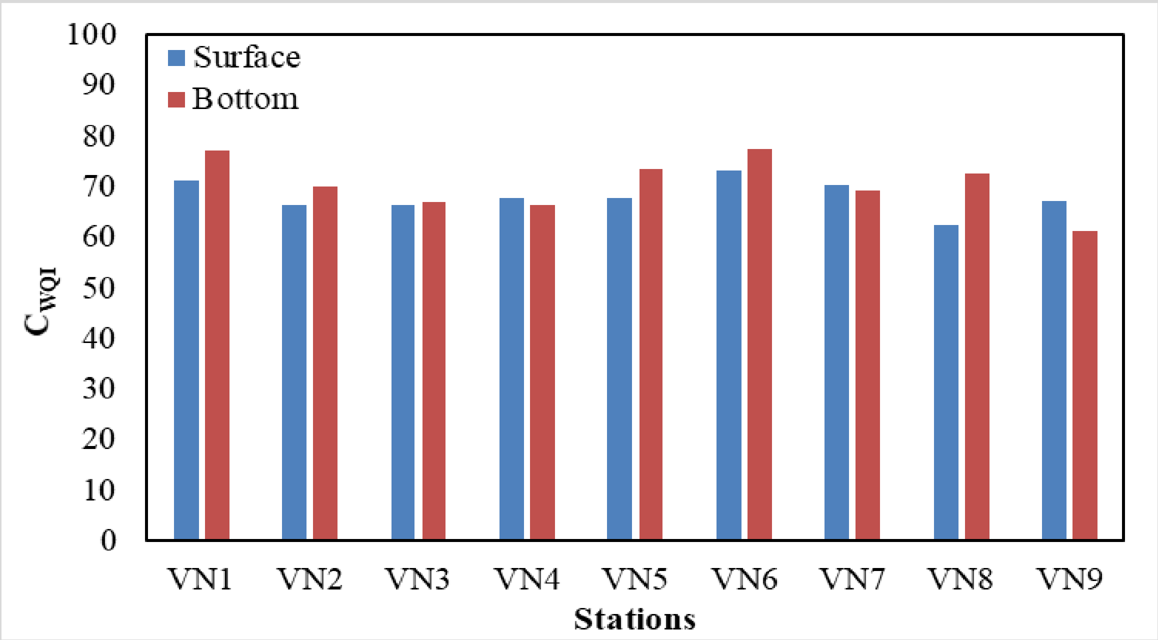


Figure 4.1.13: Chemical Water Quality Index (C_{WQI}) of the study area

Overall, the C_{WQI} off Vadhvan during the study period indicated moderate to good condition of chemical composition in the marine water to support sustainable biota in the region. The C_{WQI} may have varying limits dependent upon the proportional variation in the chemical constituents supporting the biology in the water column at any given point of time, therefore may not directly indicate the pollution status of the water.

4.2 Sediment quality

The sediment in the creek and estuarine environment significantly acts as a sink for suspended particulate matter, often carrying many chemical substances (metals, organic carbon, and pollutants) from the source region. The pollutants are removed through adsorption and attached to the surface of suspended particulate matter. In several instances, even close to effluent release, the metal content in receiving water often decreases to an expected value assessing contamination through water analysis, a difficult task. The concentrations of metals, organic carbon (C_{org}), and pollutants in sediment increase at sinking interfaces depending upon the balance between their receiving fluxes, accumulation, and removal rates. Moreover, the accumulation of metals, C_{org}, and pollutants in sediment can substantially indicate sediment quality essential for healthy benthic ecosystem sustenance.

The sediment samples were collected during December 2020 using a stainless-steel van-Veen grab covering different regions off Vadhvan. Samples from station VN3, VN6 and VN7 were not obtained due to rock bottom. The collected sediments were dried and homogenously ground for the extraction of trace and heavy metal content analysis, except the grain size (texture) and petroleum hydrocarbon (PHc) measured on un−grinded wet sediment results, are presented through Table 4.2.1.

4.2.1 Texture

The bed sediment collected off Vadhvan displayed a wide range of texture properties (clay, silt, and sand), mainly dominated by silt and clay. The percentage of sand was less than 5% on average during December 2020. The silt and clay contents were varied within a narrow range 80 − 87%, averaging at 83% and 11 − 17%, averaged at 15%, respectively at the sampled stations (Table 4.2.1), without showing any significant variations among the stations as indicated in the figure 4.2.1.

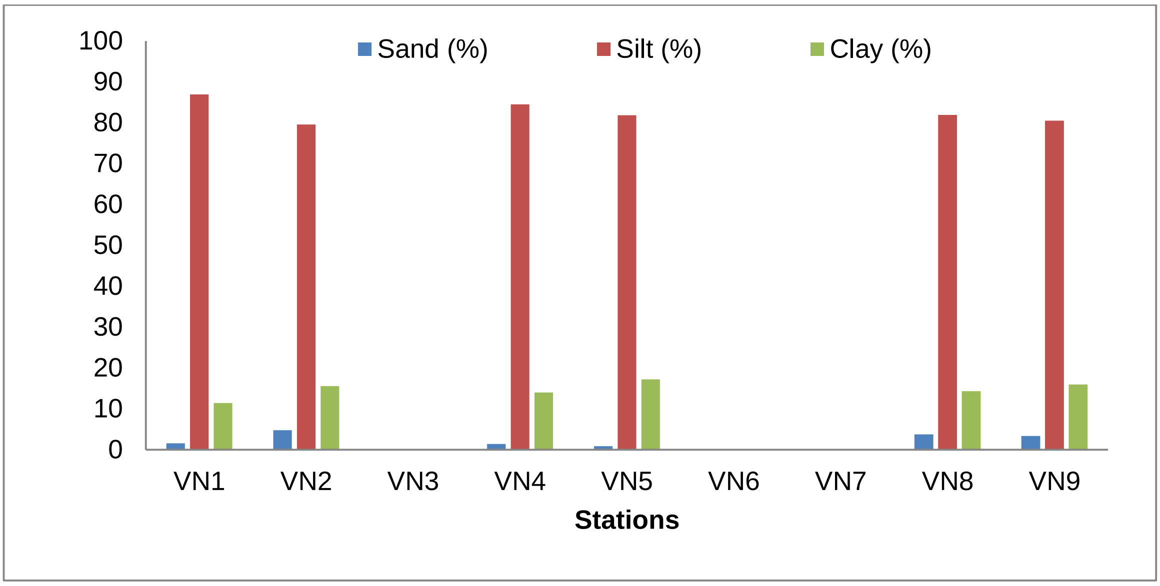


Figure 4.2.1 Sediment texture (%) at different stations of the study area

4.2.2 Metals

Natural sediments always contain heavy metals to a varying degree depending on the source rock and deposition environment. This lithogenic fraction should be accurately known for assessing sediment contamination by heavy metals. The results of subtidal sediment analysis of the present monitoring presented in Table 4.2.1.

The average concentration of metals in sub-tidal sediments from all the different sites off Vadhvan showed extreme variation. Except for Al and Fe, the average contents of metals such as Cr, Mn, Fe, Co, Ni, and Zn showed minimal variability from nearshore towards the offshore region in the study area. The content of Al showed relatively minimum variation might be due to silt dominance. Distribution metals at different stations during this study display in the below figure. Most of the metals show minimal variation in their content. The contents of metals are similar to previously observed values for the same metal along the coastal Arabian Sea. The variations in the concentration of trace metals were probably because of Al and Fe changing levels, which generally influence trace metal-concentration.

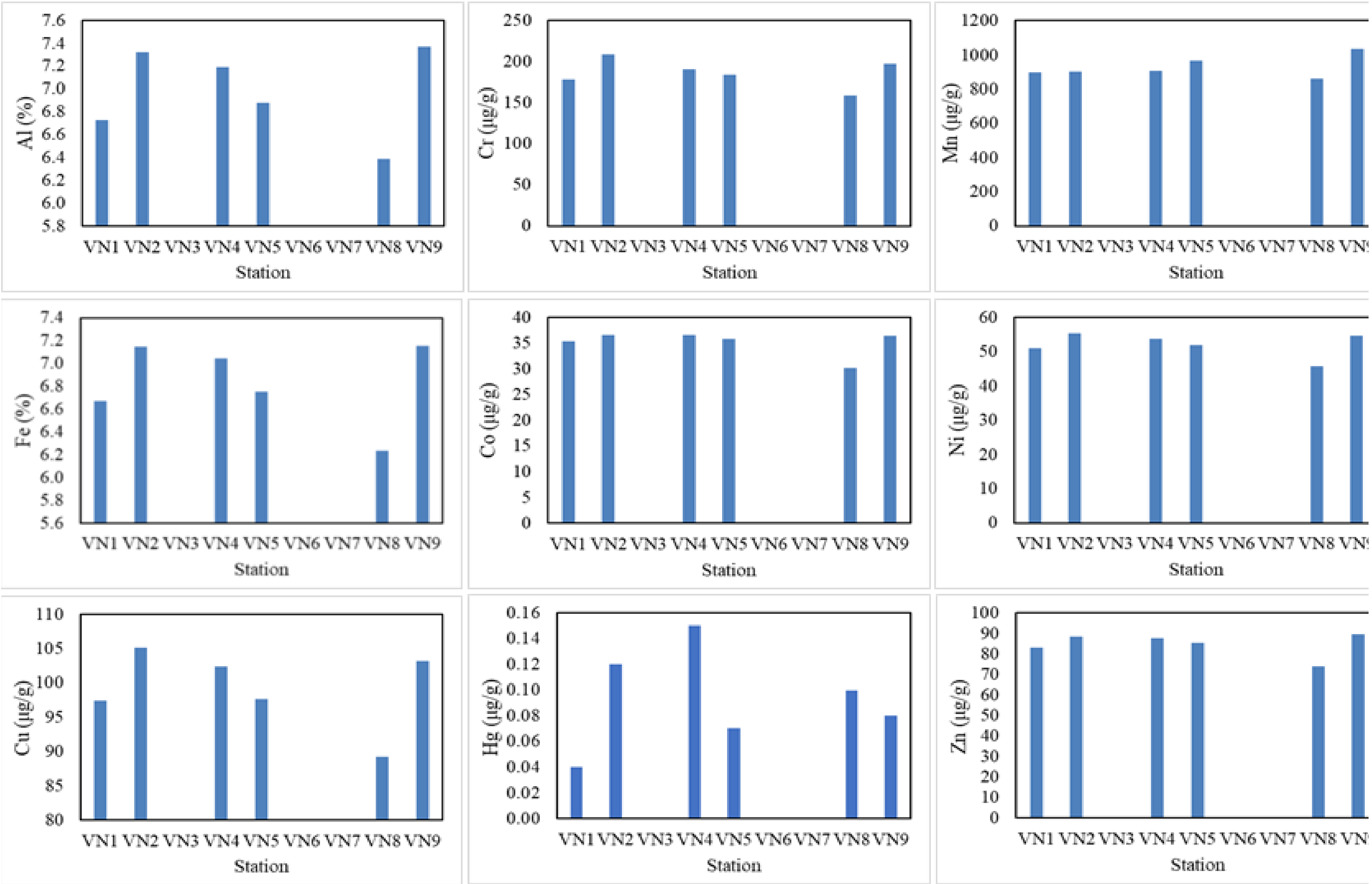


Figure 2.2 Distribution of metals in the sediment from different stations of the study area

4.2.3 Petroleum hydrocarbon (PHc)

The PHc in sediments off Vadhvan can result from the boat and other operational activities related to oil/petroleum products. PHc in the marine environment undergoes degradation by biological activities or dispersion due to physical processes leading to its removal from the sea surface, thereby influencing the water quality. The residue left after the petroleum release is adsorbed by suspended solids and ultimately transferred to the sediment. Hence, sediment in coastal regions influenced by port and petroleum related operations serves as a useful indicator of the cumulative effect of oil contamination. PHc concentration of sediment from off Vadhvan was low and varied from 0.1−1.1 µg/g wet wt., averaged at 0.6 µg/g wet wt. The average value of PHc decreased from nearshore towards offshore, which indicated a minimal impact on marine water by sedimentary PHc as indicated in the figure below.

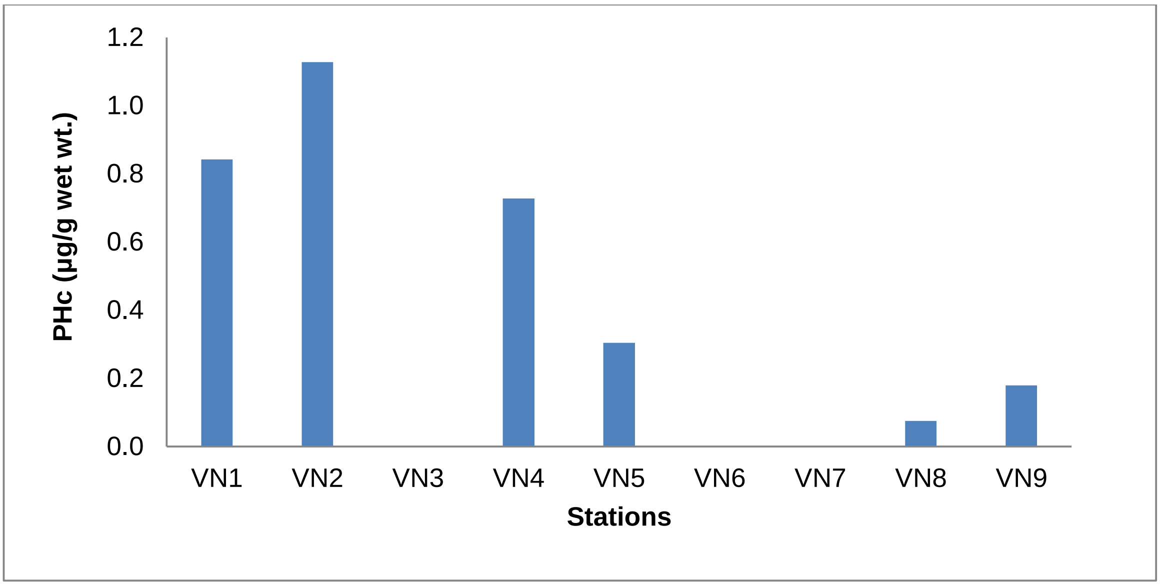


Figure 4.2.3: Concentration of PHc in the sediment from different stations of the study area

4.2.4 Organic carbon (C_{org})

Generally, organic matter in coastal sediments contributed from terrestrial runoff, mainly utilized by the benthic organisms present in the same region. However, anthropogenic organic inputs can increase the content of C_{org} to abnormal levels disturbing the equilibrium of the ecosystem. Organic matter settling on the bed is scavenged by benthic organisms to no small extent. The balance is decomposed in the presence of DO by heterotrophic microorganisms. Hence, DO in sediment-interstitial water is continuously consumed, and anoxic conditions develop if the organic matter is oxidized through oxygen as an oxidant. Such anoxic conditions are harmful to benthic fauna.

The C_{org} content of sediments within the region off Vadhvan during December 2020 varied within a close limit between 1.3 and 1.9% (av. 1.5%; Table 4.3.1). Broadly, the C_{org} contents increased from nearshore towards offshore, indicating their accumulation along the course, as shown in the figure below. The C_{org} contents are in a range similar to C_{org}that is found in nearby creeks and estuary.

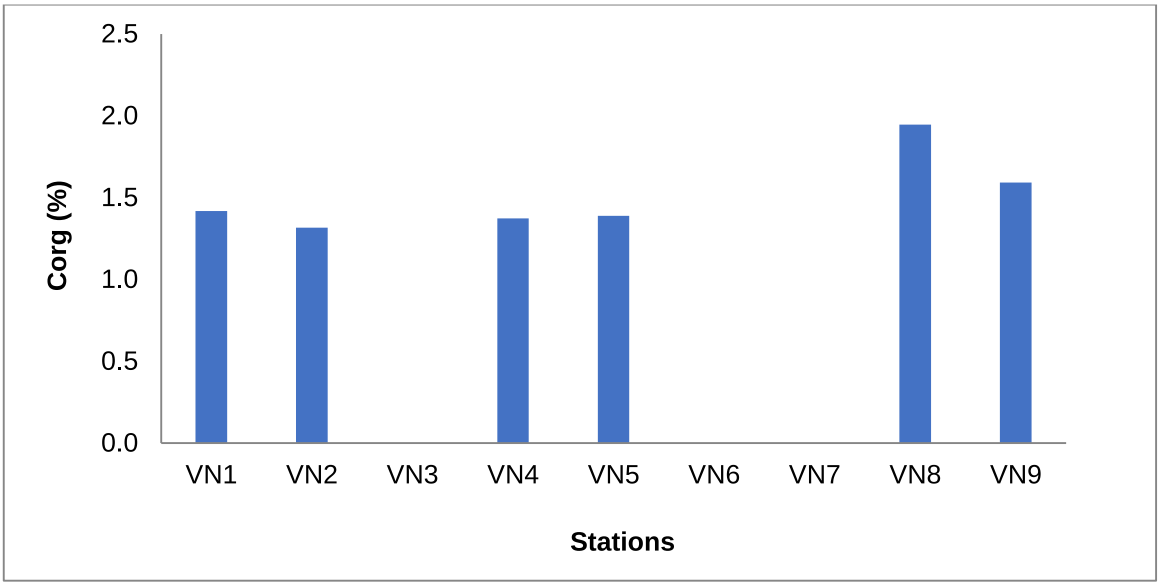


Figure 4.2.4: Distribution of C_{org} in the sediment from different stations of the study area

The content of C_{org} often corresponds to their nature and origin. However, the content itself may not represent any specific source, but compared alongside other parameters such as C_{org} to total nitrogen content ratio and the isotopic signatures, the potential C_{org} sources can be identified.

4.2.5 Total Phosphorus (P)

Lithogenic phosphorus in coastal sediments is derived from geological sources through river flows, while anthropogenic phosphorus results from sewage and industrial discharges, agricultural runoff, etc. Sedimentary phosphorous content off Vadhvan sediment ranged between 604 µg/g and 784 µg/g, averaged at 675 µg/g, without much difference among different zones, which indicated relatively less enrichment of P.

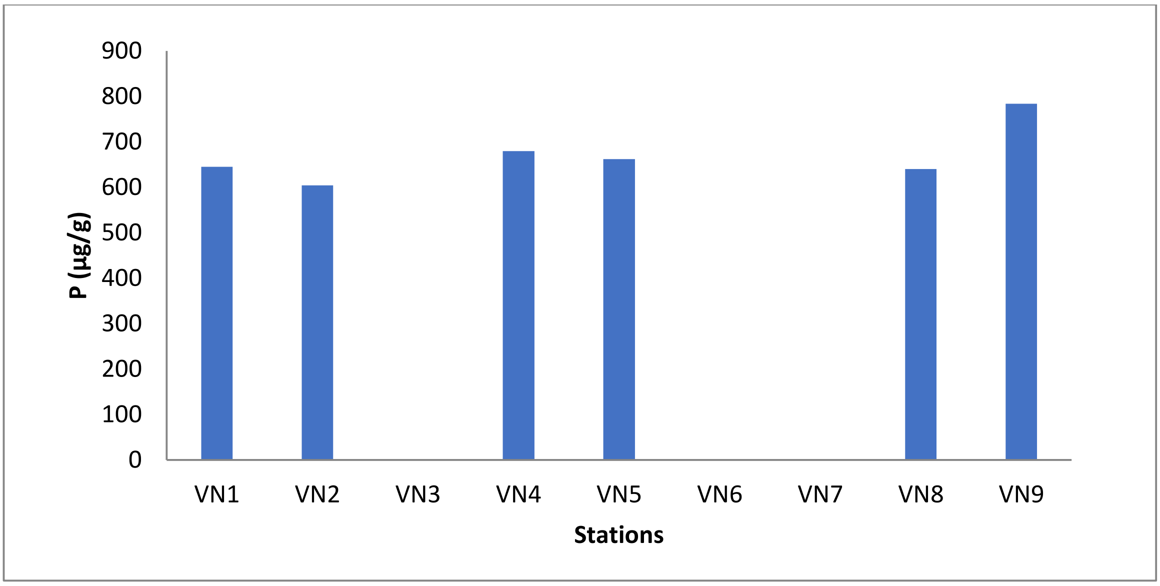


Figure 4.2.5: Distribution of Phosphorous in the sediment from different stations of the study area

The P concentrations in sediments found off Vadhvan are within limits or less than the content generally observed in coastal sediments along India's west coast.

4.3 Flora and fauna

Study of the biological status of a marine ecosystem is an essential prerequisite to assess the existing status and predict the impact due to proposed developments in the coastal zone. Despite many changes in the physico-chemical properties of the water body and sea bed sediment, the ultimate consequences of pollutants may be reflected on the biological system.

Hence, the investigations of an ecosystem and particularly of its communities constitute an important part of any ecological assessment. This can be achieved by selecting a few reliable parameters from a complex community structure. In view of wide variations in biological production in an ecosystem, the biological parameters considered for the present study are microbial parameters, phytoplankton production in terms of pigments, cell count and generic diversity, zooplankton standing stock in terms of biomass, population and total groups, macrobenthos standing stock in terms of biomass, population and faunal groups and fishery.

The phytoplankton pigment, cell count and zooplankton standing stock reflect the primary productivity of water column at the primary and secondary levels. Benthic organisms being sedentary animals associated with the seabed, provide information regarding the integrated effects of stress, if any, and hence are good indicators of early warning of potential damage. Assessment of mangroves, corals and bacteria are considered as part of overall ecological evaluation. A collective evaluation of all the above components is a reliable approach to predict the state of equilibrium of marine life in coastal waters.

4.3.1 Microbiological Aspects

Microbial ecology is on the forefront of developing and applying a new generation of indicators of environmental stress and ecological change. The roles played by marine microorganisms are profound in the overall normal functioning, stability and continuance of the marine ecological processes. Despite their small size marine microorganisms are far more important as they are linked to water column and sediment (benthic) processes. Marine microorganisms occupy the base of the food web, and form food for protozoa, invertebrate larvae and many large zooplankton and regenerate dissolved nutrients for marine photosynthesis and formation of newer organic biomass. Bacteria are major links to many biological and non-biological events in the oceans. As we learn about the diversity of microorganisms and their associated processes, our view of the marine ecosystem is being transformed, and the relevance of microbes to marine resiliency and marine resource management is becoming undeniable. The sheer number of microorganisms act as sentinels for health status within marine ecosystem as well as their vast diversity and different functions has led to the realization of threats from emerging pathogens. In order to bring into focus the importance of marine bacteria at base of the food web, an assessment of their abundance and distribution are essential. The microbial diversity of coastal waters can be influenced by anthropogenic activities also besides oceanic processes.

The principal source of waterborne diseases such as cholera, typhoid and hepatitis is due to contamination of water by sewage and animal wastes. Apart from potable water, bacterial contamination occurs in surface waters such as those used for shell fishing areas, beaches, fisheries and recreational facilities. Though 90% of the intestinal bacterial population dies off within 2 days in natural waters, the remaining 10% decline much more slowly. Coliform bacteria such as *Escherichia coli* and *Faecal streptococci* (Genus: Streptococcus) are the two most important groups of non-pathogenic bacteria found in sewage. Because of number of problems associated with the determination of populations of individual pathogens, non-pathogenic bacteria (such as coliforms) are used as indicators of water pollution. Untreated domestic waste-water has about 3 million coliforms/100 mL. Because pathogens originate from the same source, the presence of high numbers of coliforms indicates potential danger. Bacteriological analyses for present study included the enumeration of total viable bacterial counts (TVC) and coliforms at 9 stations in coastal waters off Vadhvan region. Total Viable Counts (TVC), Total Coliform (TC), *Escherichia coli* like organisms (ECLO) and *Streptococcus faecalis* like Organism (SFLO) were studied.

a) Surface Water

The total viable bacteria in the water samples ranged between 10 x 10^2 to 200 x 10^2 CFU/mL (Table 4.3.1). The lowest counts were recorded at station VN1 and highest counts were recorded at station VN7 as shown in Figure 4.3.1. From the results, it was evident that the offshore stations (VN8 and VN9) recorded lower counts as compared to the nearshore (VN3 and VN4) and coastal station VN7.*Escherichia coli* like organisms (ECLO) were present at most of the nearshore and coastal stations. TC, FC and EC were recorded in stations VN1, VN2 (during both the tides), VN3, VN4, and VN8 and are presented in table 4.3.1. There are many reasons for the high presence of fecal bacterias in the nearshore regions such as, these areas are susceptible to fecal contamination from wastewater, septic leachate, farming drainage, livestock and domestic animals or nonpoint sources of human and animal waste. *Streptococcus faecalis* like Organism (SFLO) was absent at majority of the stations except at station VN2 and VN4.

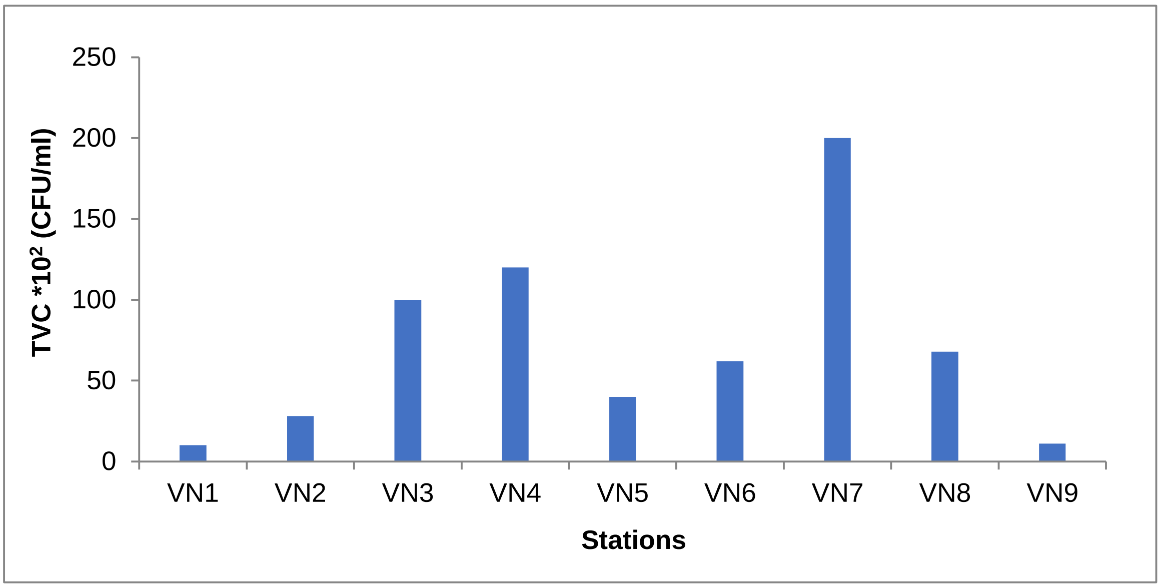


Figure 4.3.1: Distribution of Total Viable Count (TVC) in the surface waters of study area

b) Sediment

The total viable bacterial populations in the sediment samples ranged between 30 x 10^3 to 100 x 10^3 CFU/g (Table 4.3.2). The lowest counts were recorded at stations VN1 and the highest counts at station VN4, as shown in Figure 4.3.2. Other parameters like Total Coliform (TC), Fecal Coliform (FC), *Escherichia coli* like organisms (ECLO) and *Streptococcus faecalis* like Organism (SFLO) were not recorded from the sediments collected from subtidal sampling locations (Table 4.3.2).

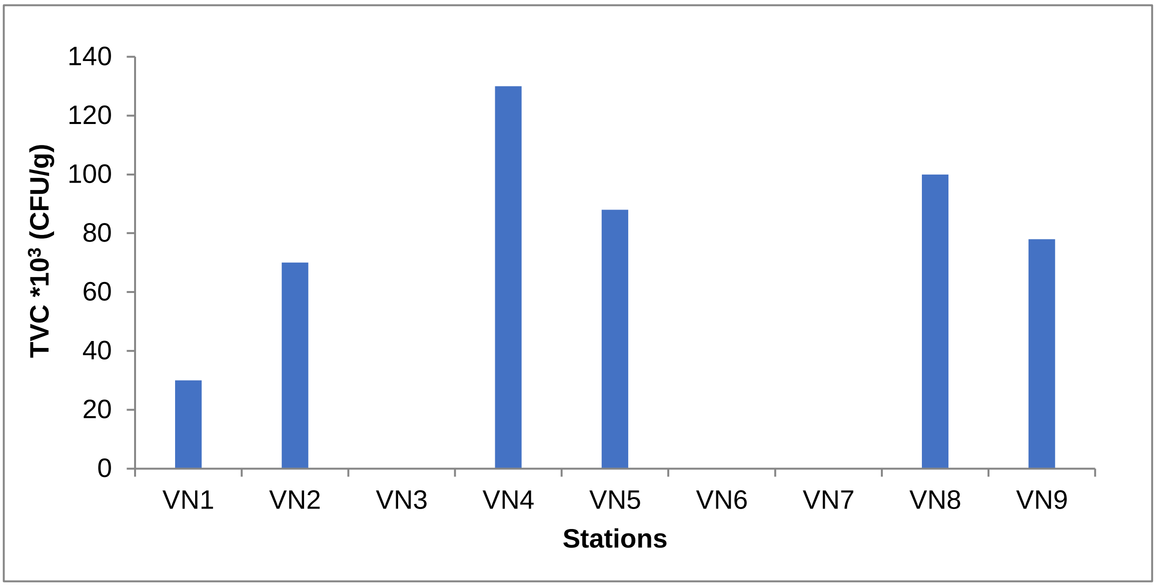


Figure 4.3.2: Distribution of Total Viable Count (TVC) in the sediment of the study area

Based on the results from the microbiological quality of water and sediments, it was observed that the counts of faecal coliforms in some stations were below the detectable limits indicating that the study area was less contaminated by fecal pollution (Table 4.3.1).

4.3.2 Phytoplankton

Phytoplankton forms the vast array of minute and microscopic plants passively drifting in the sea and mostly confined to the photic zone. In an ecosystem, these organisms constitute primary producers forming the first link in the food chain. Phytoplankton are broadly classified as diatoms, dinoflagellates, green algae and blue green algae. Arbitrary size wise classification aremicrophytoplankton (20 - 200 μm), Nanoplankton (2 - 20 μm) and Picoplankton (0.2 - 2 μm). Phytoplankton photosynthesizes thereby assimilating carbon into plant cells and building up mainly carbohydrates and release of oxygen. Other substances such as aminoacids, proteins, lipids and a variety of other components are also incorporated into the living cells.

Phytoplankton in polluted water condition develops noxious blooms, creating offensive tastes and odours or anoxic or toxic conditions resulting in animal death or human illness. Because of their short life cycles, plankton respond quickly to environmental changes, and hence their standing crop in terms of biomass, cell counts and species composition are more likely to indicate the quality of the water mass in which they are found. They strongly influence certain non-biological aspects of water quality such as pH and colour. However, because of their transient nature, and often patchy distribution, their utility as water quality indicators is limited.

In the present study, phytoplankton standing crop was studied in terms of biomass by estimating chlorophyll *a* and phaeophytin and in terms of population by counting total number of cells and their generic composition. The concentration of photosynthetic pigments is used extensively to estimate phytoplankton biomass. Chlorophyll *a* in phytoplankton constitutes approximately 1 to 2% of the dry weight of planktonic algae.

The important chlorophyll degradation products found in the aquatic environments are the chlorophyllids, phaeophorbides and phaeophytins. Undoubtedly much of phaeophytin present in natural waters arises from the grazing activities of zooplankton with the subsequent decomposition of phytoplankton cells. It is widely suggested that chlorophyll is converted also to phaeophytin in nutrient deficient and when phytoplankton is kept in darkness. Marked differences exist between the phytoplankton biomass of different regions of the sea partly due to local climatic conditions and partly to a different grazing pressure/intensity.

A real differences in phytoplankton, apply not only to differences in density, but to distinction in floristic composition. Phytoplankton composition also varies considerably (e.g. during bloom). Thus, a very few species may be overwhelmingly common during blooms, while a large number of species may occur without clear dominance under normal conditions.

In temperate latitudes the estuarine/coastal flora may be exceedingly abundant at certain times of the year. Blooms in some coastal waters may be related to eutrophication, resulting from anthropogenic addition of nutrients. In some coastal areas, however, there is instability and poor light penetration associated with heavy silt load that hampers proliferation of phytoplankton even if the nutrients may be abundantly available.

Table 4.3A: Classification of coastal water productivity based on phytoplankton biomass (Chlorophyll *a*)

Trophic state	**Chlorophyll *a***
Oligotrophic	<1
Mesotrophic	1 - 3
Eutrophic	3 – 5
Hypertrophic	>5

a) Phytopigments

The concentration of chlorophyll *a* recorded from the study area varied in a narrow range of 0.2 to 0.7 mg/m^3 indicating less variable phytoplankton biomass. It was evident from the graph (Figure 4.3.3) that a higher concentration of chlorophyll *a* was observed from the surface waters of station VN2 and lowest in the bottom waters of station VN8. The average surface and bottom values were found to be similar (0.5 mg/m^3). Spatially, nearshore stations showed comparatively higher values of chlorophyll *a* than coastal and offshore stations. Since the average concentration of Chl *a* is 0.5mg/m^3, the environment is found to be oligotrophic.

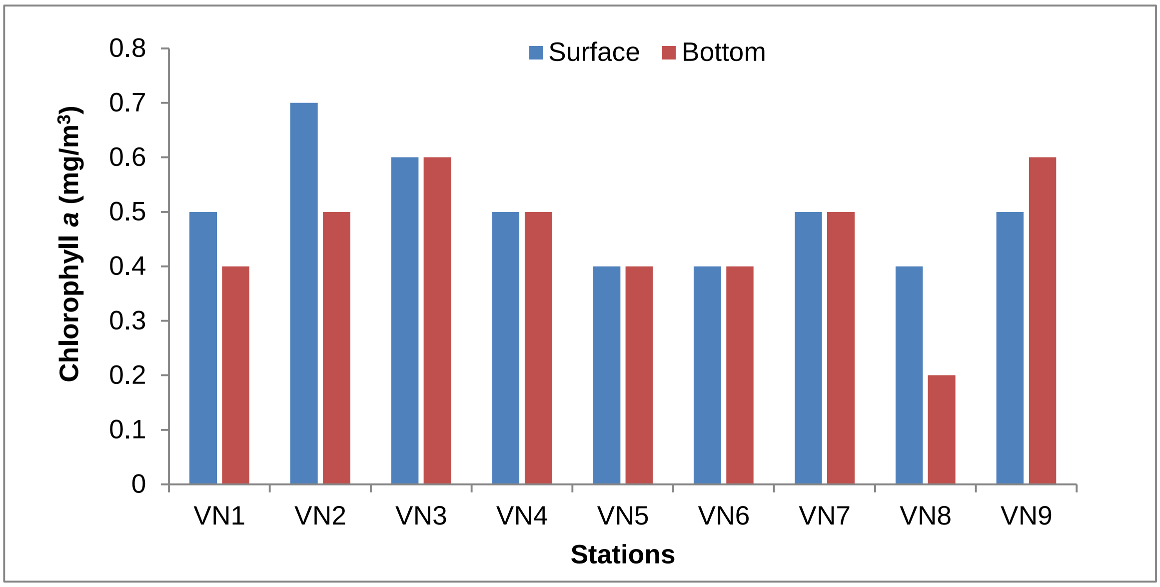


Figure 4.3.3: Distribution of Chlorophyll *a* at different stations of the study area

Phaeophytin is a measure of dead cells and is an indirect indicator of stress conditions leading to the deterioration of chlorophyll *a*. The average concentration of phaeophytin at different stations of study area varied in the range of 0.1 to 1.4 mg/m^3 (Table 4.3.3 and 4.3.4). In general bottom water recorded higher values of phaeophytin concentration compared to surface waters.

Bottom water at station VN9 recorded the higher concentration of phaeophytin and the surface water of station VN4 and VN8 recorded the lowest. On an average a comparable value of 0.3 and 0.5 mg/m^3 were observed in surface and bottom water, respectively.

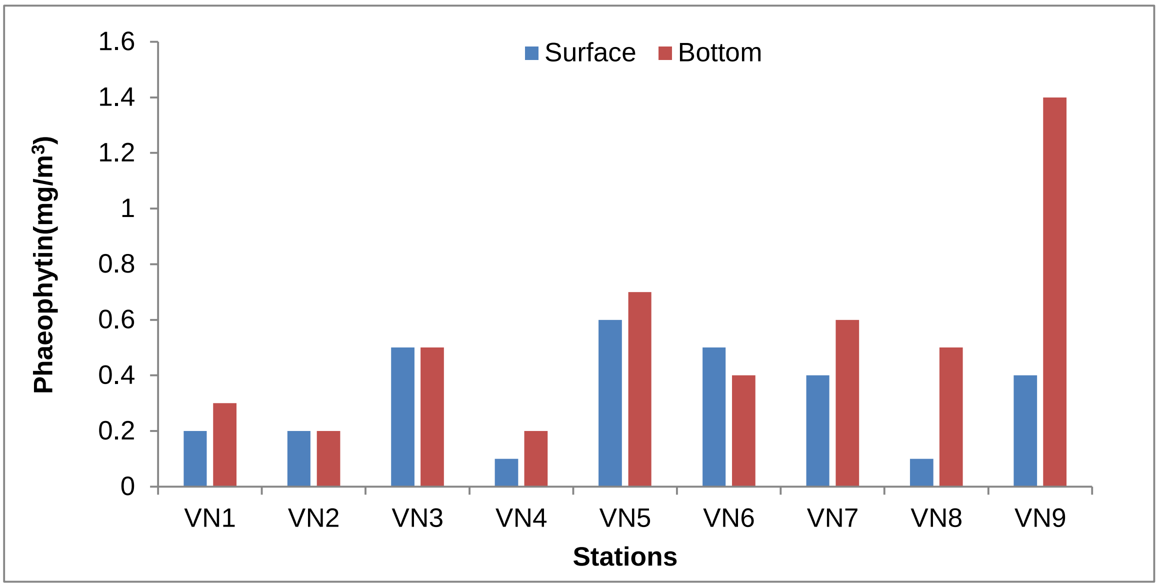


Figure 4.3.4: Distribution of Phaeophytin at different stations of the study area

a) Phytoplankton population

The phytoplankton population in the surface waters widely varied from 10.2 to 127.4x 10^3 cells/ L and in the bottom water from 11.0 to 151.24x 10^3 cells/ L. The highest abundance was found in the station VN7 and lowest in the station VN2. There is an increasing trend of phytoplankton population was observed from nearshore station to coastal stations.

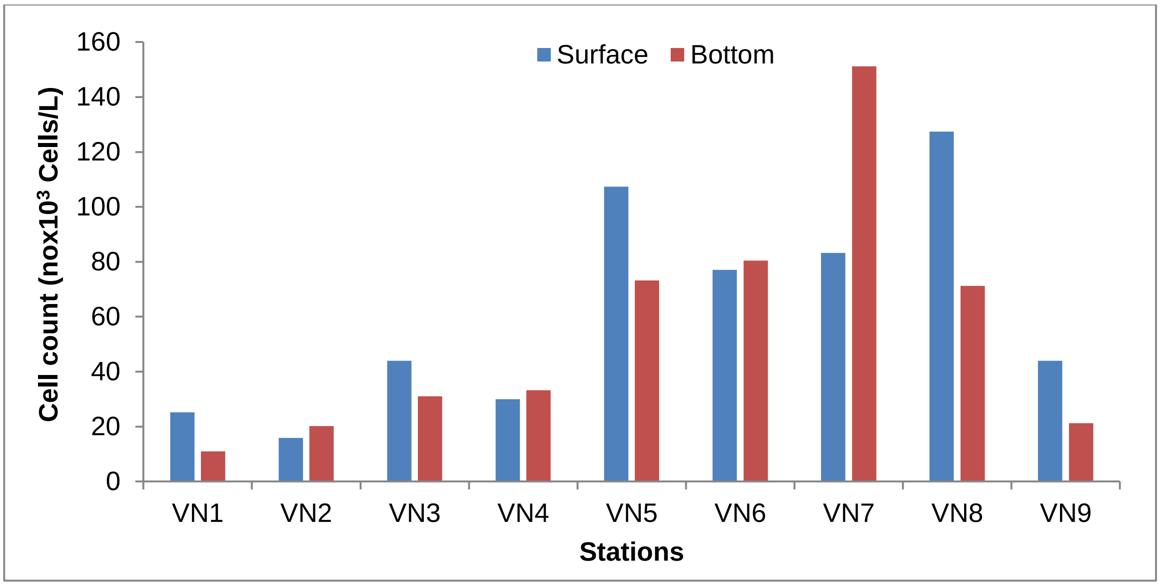


Figure 4.3.5: Distribution of phytoplankton cell counts in the study area

Phytoplankton numerical abundance exhibited a distinctive spatial variation in the study region during the sampling period. A total of 36 genera of phytoplankton were encountered all over the study region, belonging to 4 major taxonomic groups namely, Diatoms, Dinoflagellates, Cryptophytes and Euglenophytes. Of these, diatoms formed the most abundant group, comprised of 24 genera followed by dinoflagellates (9), cryptophytes (2) and euglenophytes (1). Diatoms accounts for the 95% of the phytoplankton genera and dinoflagellates for 4%. In Station VN3, only diatoms were observed. The study area having the dominance of phytoplankton in the genera of *Thalassiosira* (38.37%), *Cylindrotheca* (10.51%), *Navicula* (7.99%) and *Nitzschia* (5.47%). Phytoplankton in the genera *Cylindrotheca, Navicula, Pinnularia* and *Thalassiosira* were observed from all the stations of the study area.

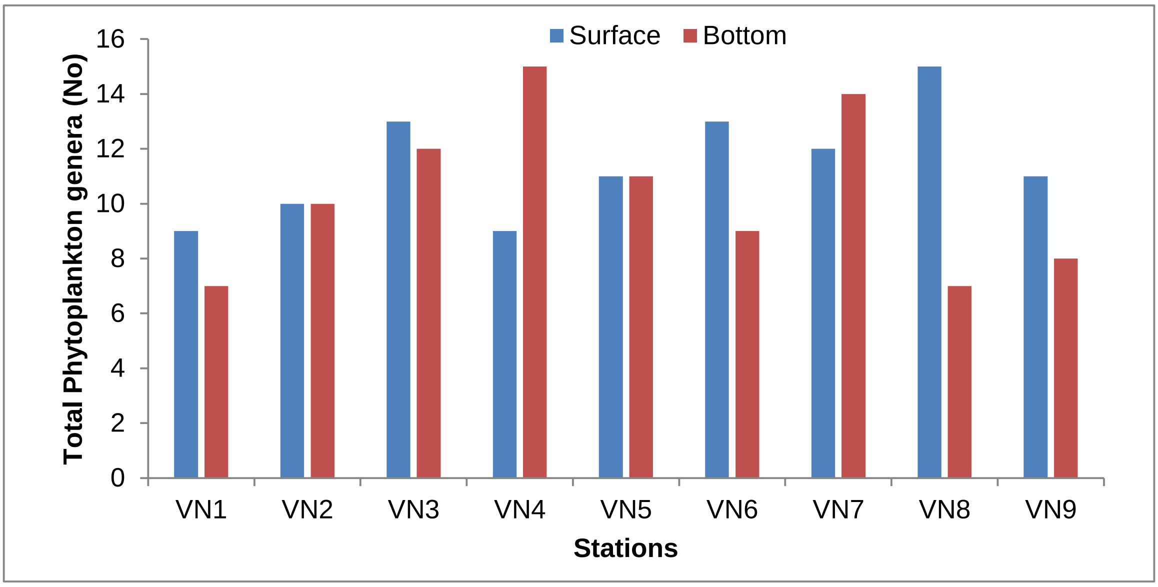


Figure 4.3.6: Distribution of average phytoplankton genera at different stations of the study area

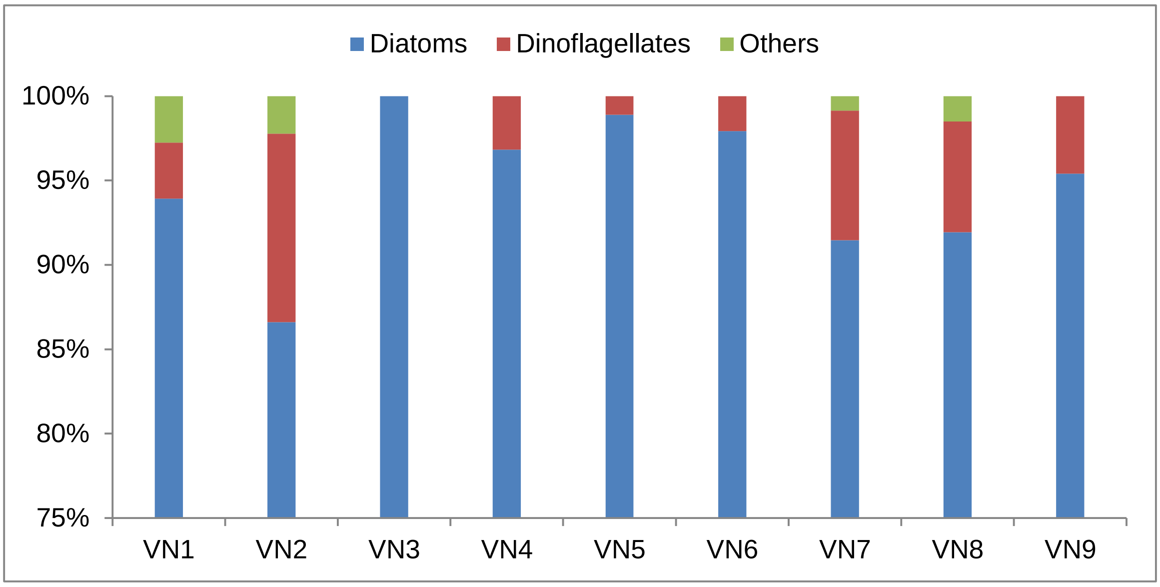


Figure 4.3.7: Distribution (%) of phytoplankton groups at different stations of the study area

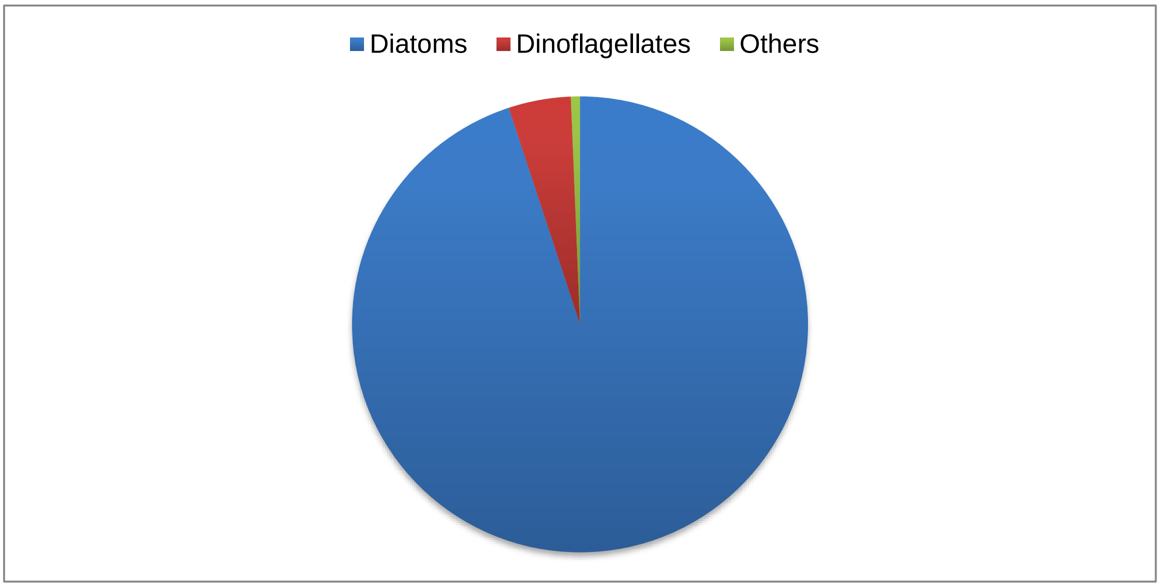


Figure 4.3.8: Distribution (%) of phytoplankton groups at entire study area

Considering the diversity indices of phytoplankton, Shanon-Weiner diversity index of the study area varied in the range 2.4-3.6 with highest value in the station VN2 and lowest in the station VN5. Pielou's evenness index showed the highest value in station VN3 and lowest in the station VN8.

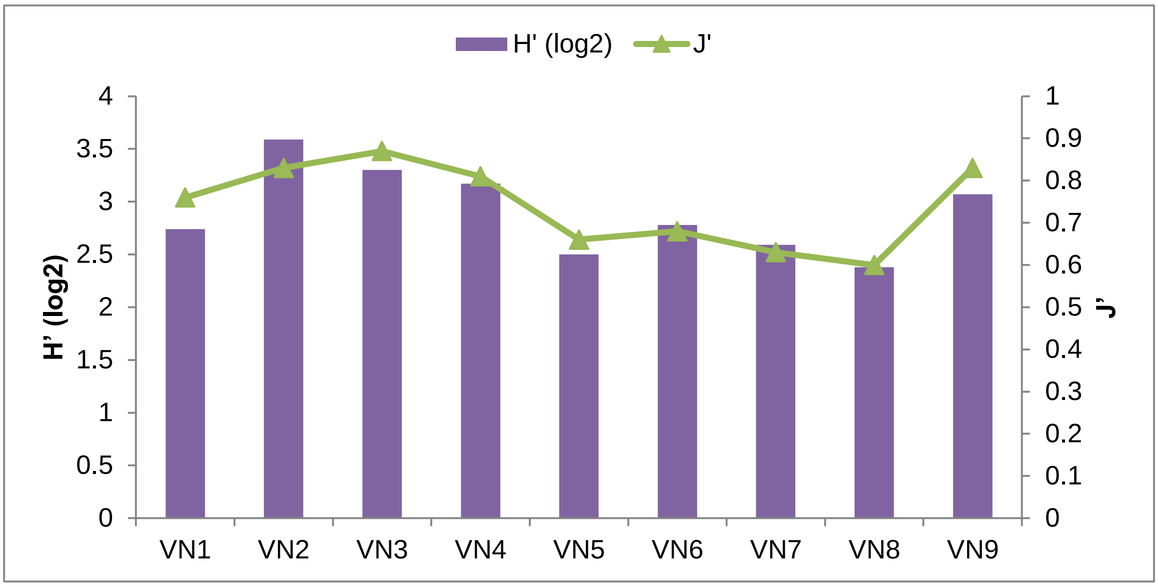


Figure 4.3.9: Diversity indices of phytoplankton in the different stations of the study area

In general, the phytoplankton abundance and generic diversity depend on favourable environmental conditions in the coastal waters. Availability of essential nutrients in adequate quantities and optimum light are the most important factors regulating the phytoplankton abundance. The penetration of light in the euphotic zone and nutrient concentrations in the coastal waters support the healthy growth of phytoplankton.

4.3.3 Mangroves

Mangroves are salt tolerant forest ecosystem of tropical and subtropical intertidal regions of the world. Where conditions are sheltered and suitable, the mangroves may form extensive and productive forests, which are the reservoirs of a large number of species of plants and animals. The role of mangrove forests in stabilizing the shoreline of the coastal zone by preventing soil erosion and arresting encroachment on land by sea is well recognized thereby minimizing water logging and formation of saline banks Mangroves has multi-faceted role in our environment, these are follows:

- Economic benefits (Supports livelihoods in indigenous people)
- Ecological services (carbon sequestration, provide habitat for wide range of fauna etc.)
- Reducing the intensity of Cyclones, Tsunami and Flood
- Coastal protection
- Trapping the sediments

According to the survey conducted by Institute of Remote Sensing, Anna University during May, 2021 about 98.3 acres of area in the vicinity of proposed port has been classified under CRZ1A which include mainly mangroves and other eco sensitive zones.

The intertidal regions of Vadhvan area have the distribution of *Avicennia marina.* Saplings of the *Rhizophora* sp. were also found in the intertidal regions of Jhoting Bhabha Mandir. Published literatures were showing the occurrence of *Sonneratia apetala* and *Aegiceras corniculatum* in the Vadhvan region (Chaudhari& Tosh, 2018). The distribution of mangroves at Tadiyala area were surveyed by quadrat method during the present study period, and is given in the table below:

Table 4.3C: Distribution of Mangroves at Tadiyala region of Vadhvan

Parameters	**Quadrat- 1** (19˚57'44.0"N 72˚41'50.0"E)	**Quadrat- 2** (19˚57'43.6"N 72˚41'49.5"E)
Mangrove species	*A. marina*	*A. marina*
Density(no/100m^2)	40	132
Height (m)	2.08-2.96	1.89-2.97
DBH (cm)	31-70	22-49
SD (no/m^2)	7	16

4.3.4 Zooplankton

Zooplankton are myriads of animal organisms that drift with currents. By virtue of sheer abundance and intermediately role between phytoplankton and fish, they are considered as the chief index of utilization of aquatic biotope at the secondary tropic level. The herbivorous zooplankton is an efficient grazer of the phytoplankton and has been referred to as living machines transforming plant material into animal tissue. The zooplankton can be used as the indicator organisms for the physical, chemical and biological processes in the aquatic body. They occur at different depths and constitute a complicated ecological system.

Zooplankton are characterized by their faunal diversity and include arrays of organisms, varying in size from the microscopic protozoan of a few microns to some jelly organisms with tentacles of several meters long. They have been classified into several groups of size like ultraplankton, nanoplankton, microplankton, macroplankton and megaplankton. The larger planktonic organisms are called micronekton. Besides size, the zooplankton are classified by length of planktonic life (holoplankton - permanent plankton; meroplankton - temporary plankton), habitat (oceanic, neritic, estuarine, brackish and freshwater plankton), depth distribution (pleuston, neuston, epipelagic, mesopelagic, bathypelagic and epibenthic plankton) and feeding pattern (herbivores, omnivores and carnivores).

Zooplankton employs various methods to capture food, but the most common is filter feeding. The herbivores filter the planktonic algae from the water currents generated by tides and waves or by animal itself. The different filters used by zooplanktonic organisms include mucus nets [salps, meshwork secretions (copelates)] and basket work of setae (crustacea).

In contrast with the relative stability of the sea, the estuaries/creeks are dynamic environment, often showing sudden and extensive changes in salinity. The coastal zooplankton species have to be highly adoptive and are reported to show mechanism to detect changes in salinity and DO. They produce resting eggs to tide over unfavorable conditions. The reproduction rates counter mortality. Several zooplankton species show quick maturation, reproduce early, with shorter generation time and low species diversity. The physico-chemical boundaries play an important role in the distribution of zooplankton in the sea as there are usually strong gradients in terms of light, temperature and salinity from surface to bottom layers.

In zooplankton, it is observed that a progressive gradient in diversity from the estuaries to the neritic and open ocean waters. Unlike primary production, there are no direct and simple methods for determining rate of production in zooplankton.

The zooplankton standing stock in different stations of the study area revealed a low range of variation in biomass, population and faunal groups from station to station, indicating moderate to good zooplankton production prevailing in the region. The zooplankton biomass ranged from 0.4 to 8.4 mL/100m^3 and population varied in the range of 11.0 x 10^3/100m^3 and 110.5 x 10^3/100m^3. Both biomass and population were found to be higher in the tidal station VN2 and lower in the station VN4. There is no significant trend observed in the distribution of biomass and population from the study area.

In total, 22 mesozooplankton groups were identified from the study area with the dominance of copepods (75.0%) in all the stations. Non-copepod groups were contributed 25% of the mesozooplankton population. Among them, lamellibranchs found to be dominant taxa contributing the 66% of this population and followed by decapod larvae (25%) and chaetognaths (5%).

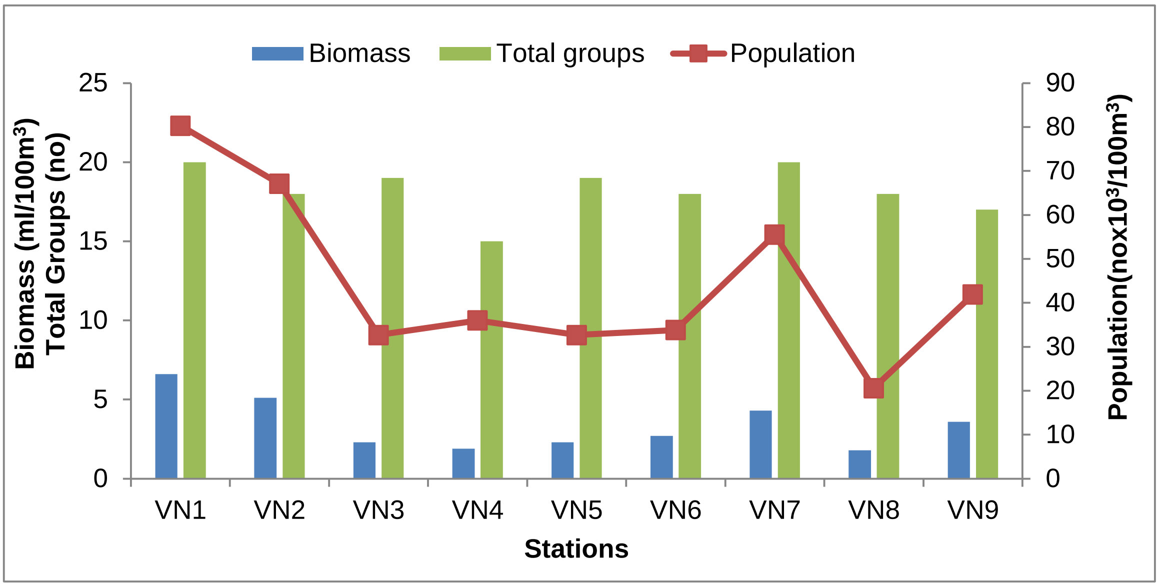


Figure 4.3.10: Distribution of biomass, population and total groups ofmesozooplankton at different stations of the study area

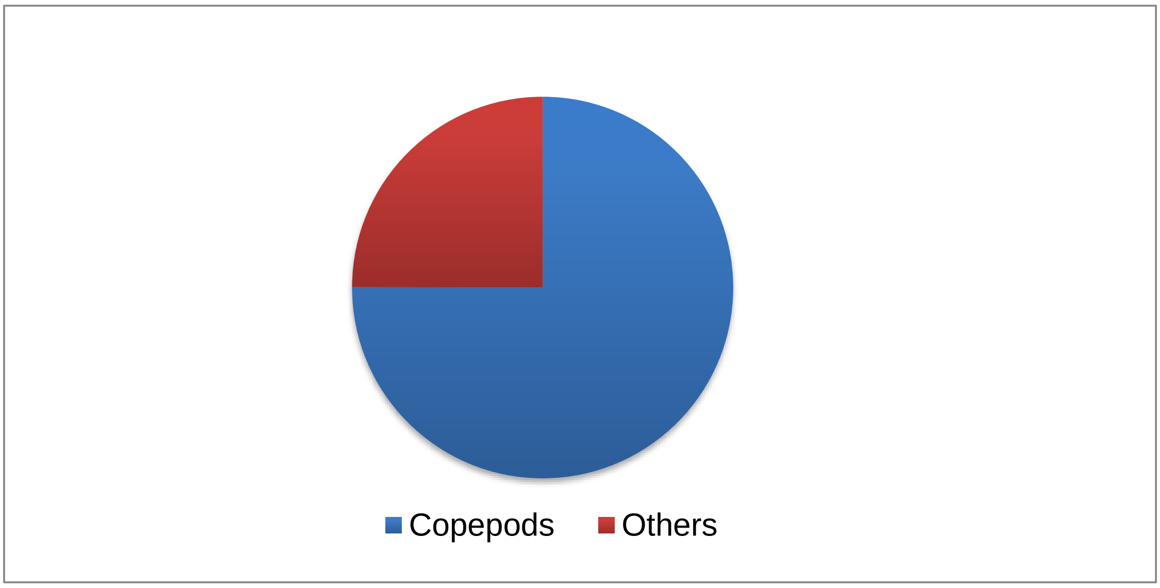


Figure 4.3.11: Percentage composition of major mesozooplankton in the entire study area

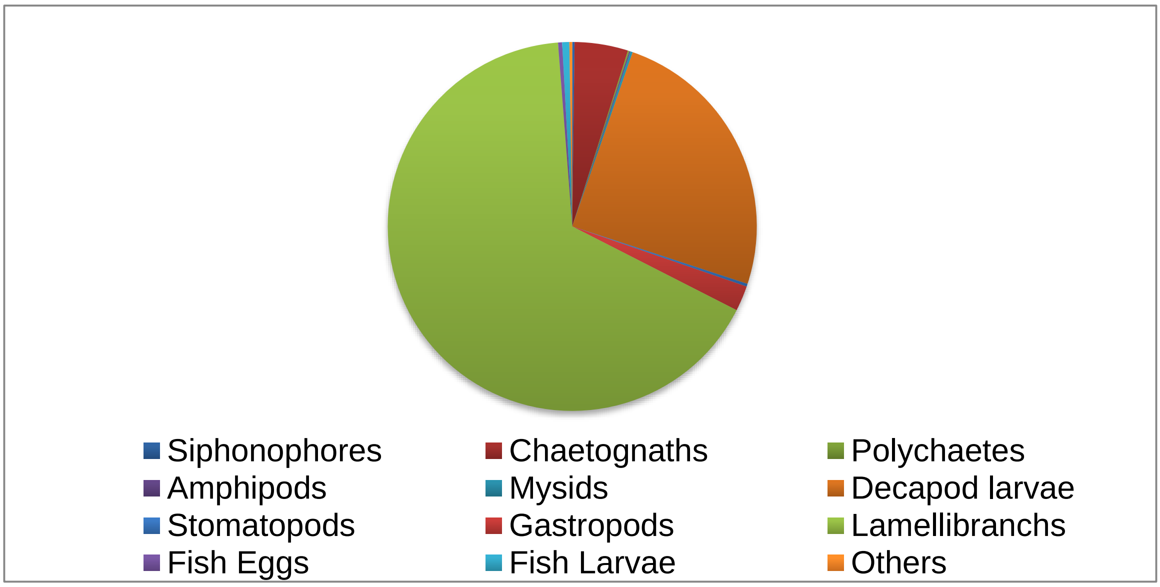


Figure 4.3.12: Percentage composition of non-copepod mesozooplankton in the entire study area

Table 4.3B: Abundance and incidence of decapod larvae, fish eggs and fish larvae in the study area

Stations	Decapod larvae		Fish eggs		Fish larvae	
	Abundance ($no/100m^3$)	Incidence (%)	Abundance ($no/100m^3$)	Incidence (%)	Abundance ($no/100m^3$)	Incidence (%)
VN1	1642-2893 (2268)	100	60-81 (71)	100	6-16 (11)	100
VN2	2006-10305 (6155)	100	113-177 (145)	100	198-245 (222)	100
VN3	1197-4843 (3020)	100	129-134 (132)	100	3-22 (12)	100
VN4	255-1609 (932)	100	1-95 (53)	100	0-95 (47)	50
VN5	863-1724 (1293)	100	2-96 (54)	100	2-4 (3)	100
VN6	2545-3053 (2799)	100	23-96 (60)	100	0-10 (5)	50
VN7	762-1268 (1015)	100	71-85 (78)	100	6-8 (7)	100
VN8	3017-3035 (3026)	100	10-23 (16)	100	22-34 (28)	100
VN9	2936-5469 (4202)	100	10-19 (15)	100	19-23 (21)	100

Decapod larvae were occurred at all the stations with maximum abundance in the station VN2 (av. 6155 no/100m^3) during the study period. Fish larvae and fish eggs were observed in all the stations in variable counts.

4.3.5 Macrobenthos

Depending upon their size, benthic animals are divided into four categories; microfauna, meiofauna and macrofauna. Benthic community responses to environmental perturbations are useful in assessing the impact of anthropogenic perturbations on environmental quality. Macrobenthic organisms which are considered for the present study are animal species with body size larger than 0.5 mm. The presence of species in a given assemblage and its population depends on numerous factors, both biotic and abiotic. The macrobenthic standing stock was studied in the subtidal region in the study area, which is as follows:

a) Subtidal fauna

The subtidal benthic macrofaunal standing stock in terms of biomass and population varied from 0.01 to 1.3 g/m^2 and 25 to 100 no/m^2. Out of 9 station sampled, 3 stations were with rocky substratum (VN3, VN6 and VN7). The highest macrobenthic biomass were observed from the nearshore station VN4 and lowest in the coastal station VN5.Station VN2, VN8 and VN9 revealed the high abundance of macrobenthos in the present study.

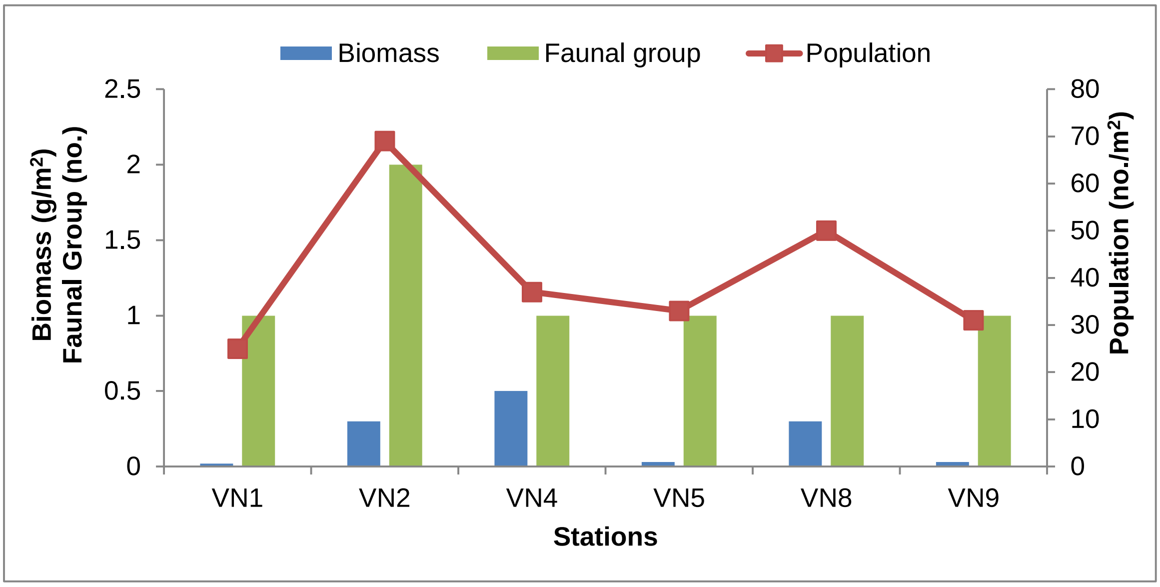


Figure 4.3.13: Distribution of average biomass, population and total groups of subtidal macrobenthos at different stations of the study area

The faunal composition indicated overall dominance of polychaeta (84.9%) followed by amphipoda (12.7%) and mysida (2.4%).

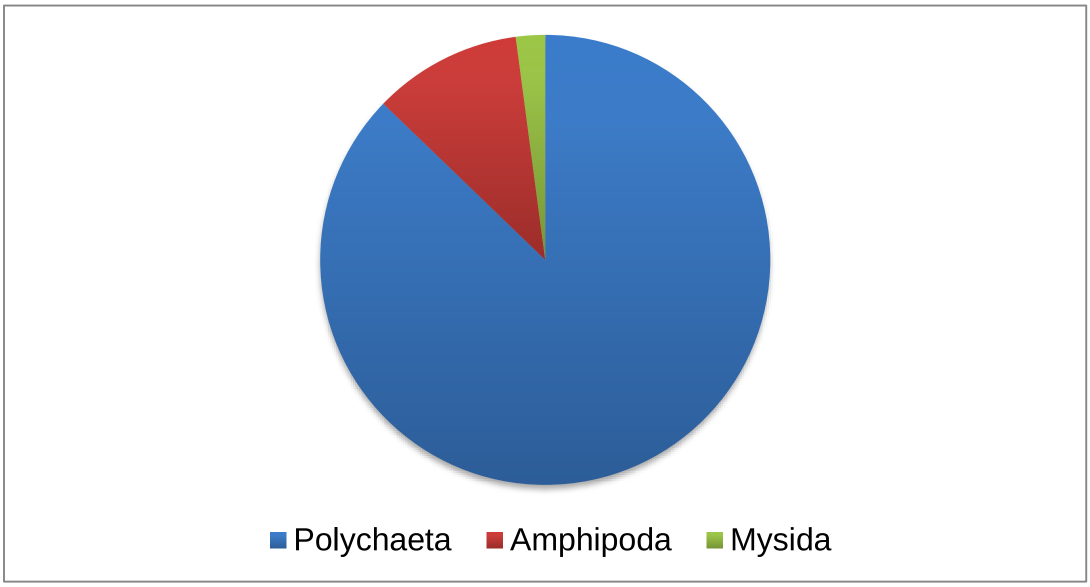


Figure 4.3.14: Percentage composition of macrobenthic groups in the subtidal area

Polychaeta were found to be the dominant taxa in all the stations and in total, they were represented by 7 different families. Cossuridae (62.6%) was found to be the dominant polychaeta family which is present in all the stations. Station VN4 showed the highest diversity of polychaeta comprising of 5 different families.

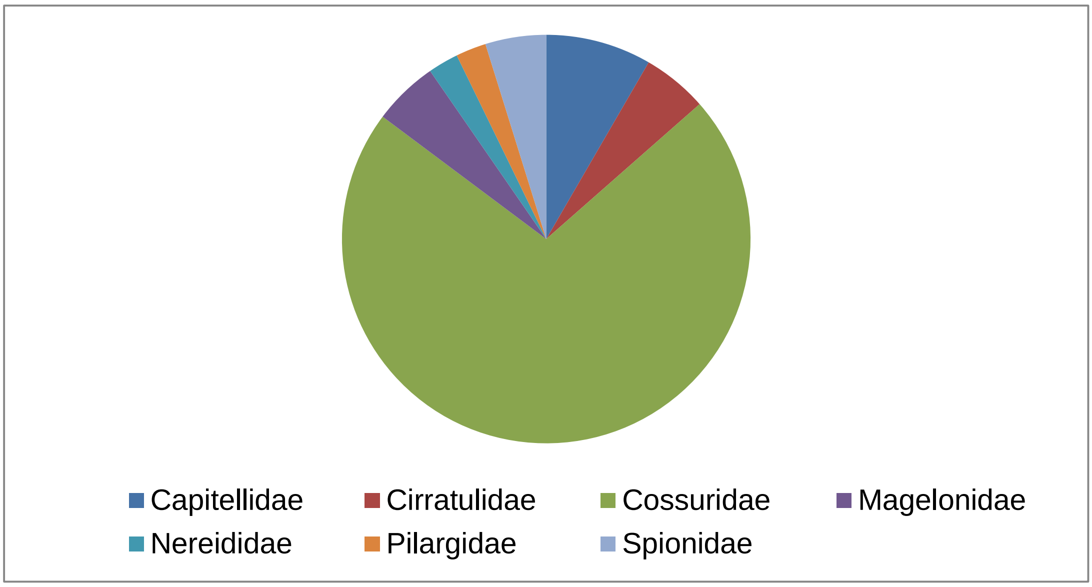


Figure 4.3.15: Percentage composition of polychaeta families in the subtidal area

Shannon-Weiner, H' (log_2) values for the entire sub-tidal area ranged from 0.8 (VN5) to 2.2 (VN4), whereas Pielou's evenness index varied between 0.8 (VN5) and 0.9 (VN2). Both the indices showed lowest values in the station VN5.

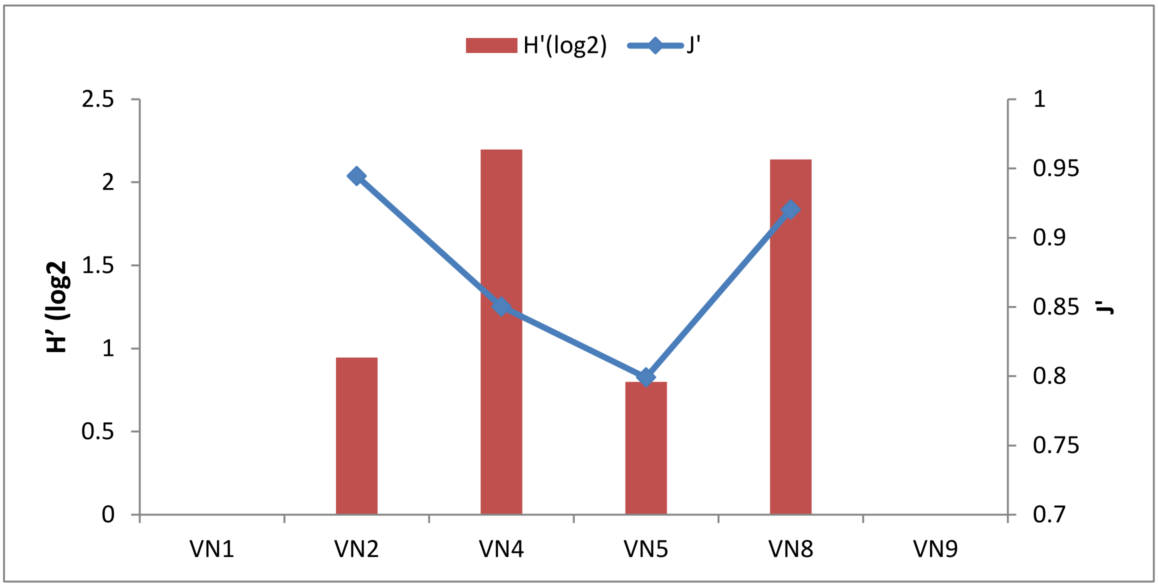


Figure 4.3.16: Diversity indices of macrobenthic groups in the subtidal area

b) Intertidal fauna

The intertidal benthic macrofaunal standing stock in terms of biomass and population varied from 0.002 to 162.4 g/m^2 and 25 to 2875 no/m^2. The highest macrobenthic biomass were observed from the IT5 and lowest in the IT1. IT1 revealed the high abundance of macrobenthos in the present study.

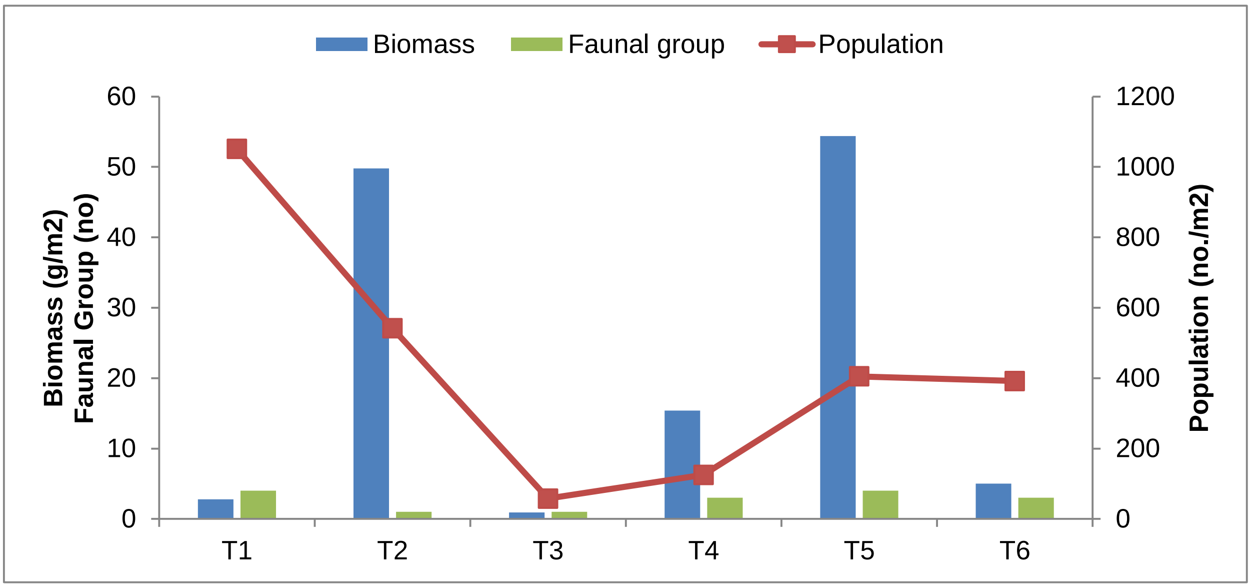


Figure 4.3.17: Distribution of average biomass, population and total groups of intertidal macrobenthos at different transects of the study area

The faunal composition indicated overall dominance of polychaeta (53.8%) followed by anomura (16.1%) and amphipoda (11.3%). In total 11 polychaeta families were observed from the intertidal region with the dominance of Spionidae (21.2%), followed by Capitellidae (16.1%) and Orbiniidae (4.2%). Maximum numbers of polychaete families were observed from IT1 region.

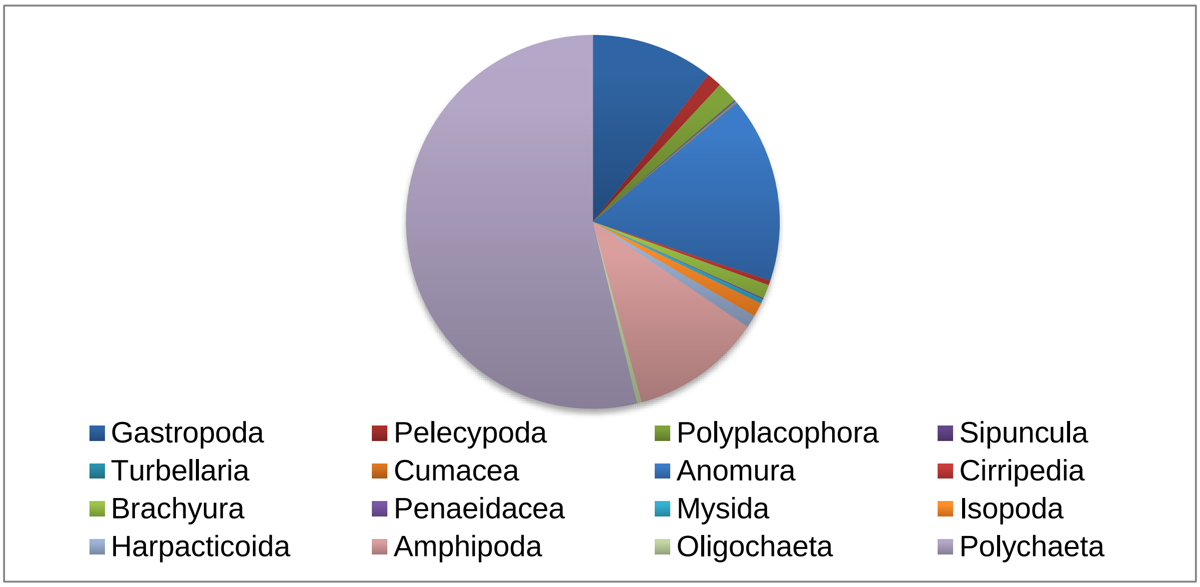


Figure 4.3.18: Percentage composition of macrobenthic groups in the intertidal area

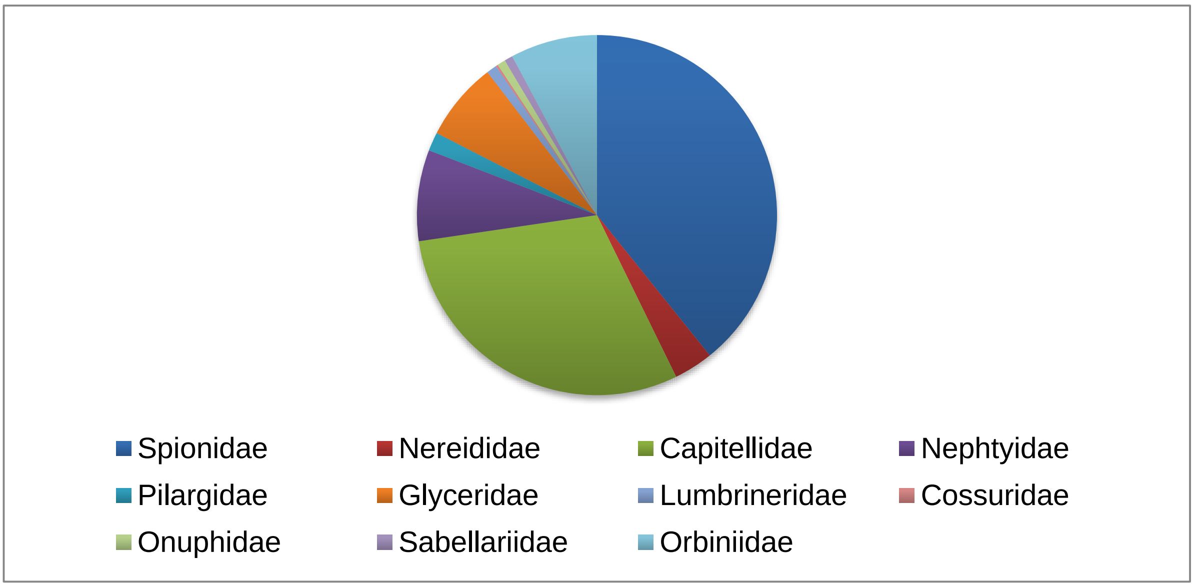


Figure 4.3.19: Percentage composition of polychaeta families in the intertidal area

Shannon-Weiner, H' (log_2) values for the entire inter tidal area is moderately variable in the range between 0.3 (IT2) and 2.7 (IT6), whereas Pielou's evenness index varied between 0.2 (IT2) and 0.9 (IT4). Both the indices were showed lowest values in the transect IT2.

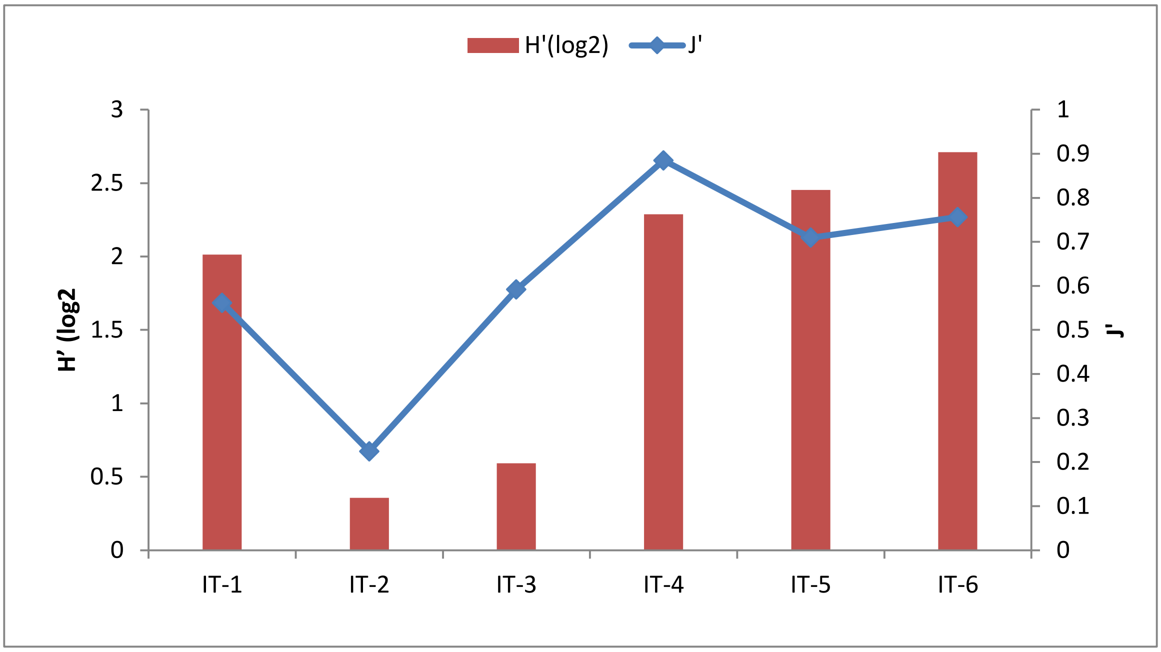


Figure 4.3.20: Diversity indices of macrobenthic groups in the intertidal area

4.3.6 Line Transect Survey for Benthic Biota

Due to the rocky nature of the substrate in many regions in the study area, photo-quadrat method was followed to quantify the relative abundance of different benthic forms at these study sites. In total, three transects (10 m) was laid at middle water and low water areas of each site and ten quadrats (n=10; size = 1 x 1 m) were placed along each transect. Each quadrat was photographed at a fixed height of 1 m using a Nikon W300 camera and the images were processed using Coral point count with excel extension software (CPCe) to calculate the relative abundance of different benthic forms.

1. IT 2 (Gungawada)

The distribution of different benthic forms at the low water and high water areas were summarized in the figure 4.3.21

Low-water

The substratum is comprised of solid rocks with intermittent tide pools, fragments of rocks and stones. The tide pools and part of the rock was smothered with cyanobacterial mats and turf algae. Barnacles attached to the rocks and gastropods within the tide pools constitute the only marine fauna present in the study site.

Macroalgae belonging to *Ulva* sp. was very low accounting for 0.0015% in one of the transect. In total, solid rocks were the major benthic form accounting for 71.1 ± 10.9% (Mean ± SD) followed by unconsolidated fragments of rocks and stones (20.9 ± 29.1). The cyanobacterial mats and turf algae collective constitute 7.4 ± 3.8% to the total benthic forms.

Mid -water

The substratum is comprised of solid rocks, unconsolidated fragments of rocks with intermittent macroalgae and sand patches. The solid rocks comprised tide pools that serve as a refugium for benthic gastropods and other molluscs. New recruits of the macroalgae Ulva sp. occur in small patches along the tide pools and rocks accounting for 0.22 ± 0.16% of the benthic forms. Similar to the low water area, abiotic forms such as rocks and stones form the major benthic form accounting for 85.3 ± 8.3% and 11.2 ± 11% respectively. The benthic fauna includes the barnacles that were sparsely distributed over the rocks and the molluscs and gastropods in the tide pools that collectively contribute 0.02 % of the benthic forms. Small sand patches were found in between the rocks which constitute 0.9% of the benthic substrate. The cyanobacterial mats were intense around the tide pools.

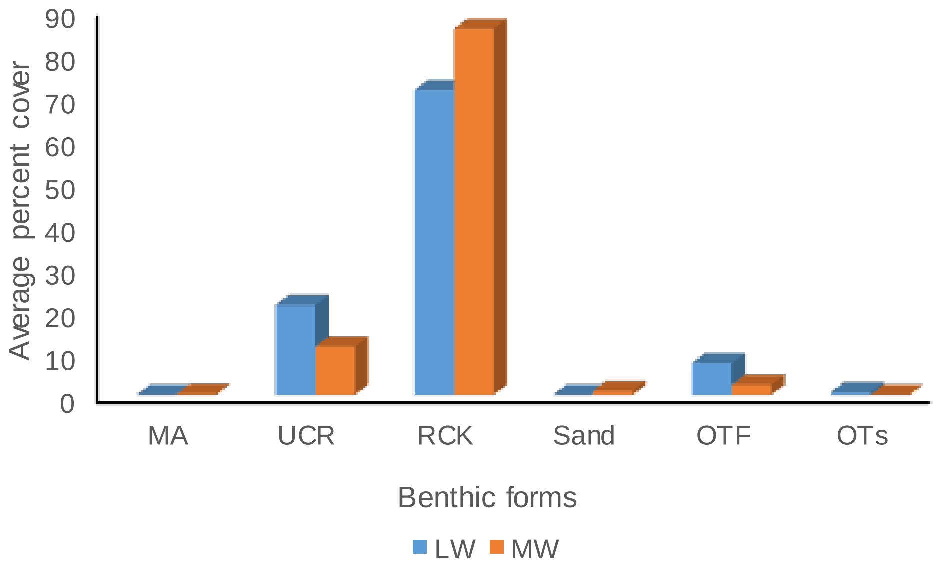


Figure 4.3.21: Average percent cover of different benthic forms at Gungawada site. MA – macroalgae; UCR – Unconsolidated rock fragments and stones; RCK – solid rock; OTF – Other flora; OTs – Other fauna.

2. IT 3 (Jhoting bhabha mandir)

The average percent cover of different benthic forms recorded at the low water and mid water study sites of Jhoting Bhabha Mandir was summarized in the Figure 4.3.22.

Low-water

The substrate is comprised of unconsolidated rock fragments and solid rocks with tide pools that support the growth of macroalgae and other benthic fauna including the bivalves, molluscs and gastropods. The macroalgae Ulva sp. showed a spatial variation in their distribution as the average percent cover of macroalgae varied between a maximum of 17.3 ± 24.5% and none across the transects. In total, macroalgae contribute 6.4 ± 7.5% to the total benthic communities.

The loose fragments of rocks and stones form the major benthic category (54.1 ± 48.6) followed by the consolidated rocks (37.6 ± 38%) that support the attachment and growth of barnacles. Small sand patches constitute 1.5 ± 1.4% of the substrate. Other benthic fauna including molluscs, gastropods, and sponges contribute 0.3% to the benthic communities.

Mid-water

Similar to the low water area, the benthic substratum of the study sites at mid water area was composed of loose fragments of rocks, stones, and consolidated rocks. However, macroalgae distribution was comparatively low in the high water area (0.6 ± 0.8%). Loose stones and small fragments of rocks was dominant benthic form accounting for 72.6 ± 13.5% followed by rocks 23.06 ± 16.7%.

The rocks possess small tide pools that acts as a host for new recruits of macroalgae, bivalves and gastropods that collectively contribute 0.14% of the benthic communities. Small patches of sand occur intermittently constituting 3.6 ± 2.5% of the benthic substrate. A mangrove plant was recorded in one of the transect and it accounts for 0.14% of the total benthic communities.

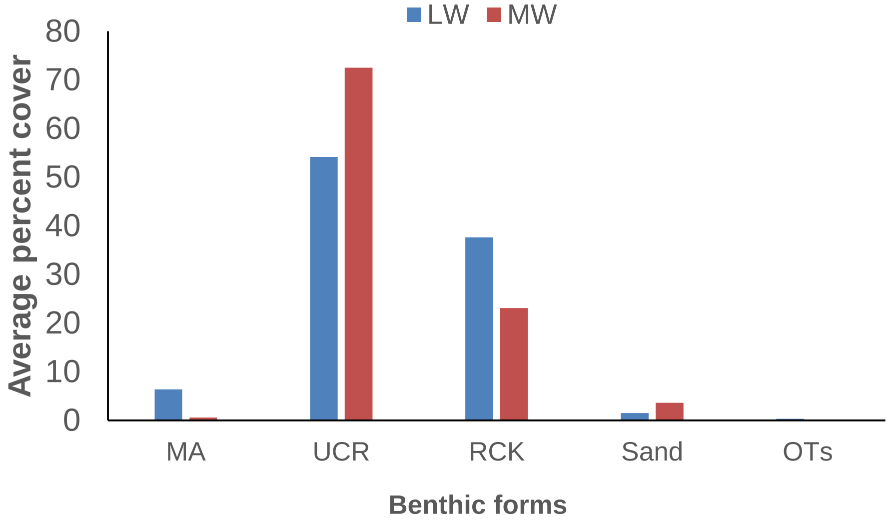


Figure 4.3.22: Average percent cover of different benthic forms at Jhoting Bhabha Mandir site. MA – macroalgae; UCR – Unconsolidated rock fragments and stones; RCK – solid rock; OTs – Other fauna

3. IT 4 (Vadhvan point)

The average percent cover of different benthic forms recorded at the Vadhvan point is summarized in the Figure 4.3.23

Low-water

The substratum is comprised of solid rocks with fragments of stones and small tide pools. Macroalgae was low in abundance accounting for only 0.02% of the benthic communities. The solid rocks constitute the major benthic form (84.6 ± 8.4) followed by fragments of stones (5.2 ± 3.4). The rocks were smothered with patches of cyanobacterial mats that contribute 3.34 ± 1.8% to the total life-forms. Other life forms include Polychaete worms, Bivalves, Pseudocorals, Crabs and Gastropods that collectively contribute 4.3 ± 4.1% to the total benthic communities.

Mid-water

The substrate is comprised of sand interspersed with unconsolidated fragments of rocks and stones with macroalgae attached to them. Among the abiotic forms, sand constitute the dominant benthic category accounting for 36.5 ± 2.2% followed by the unconsolidated fragments of rock (29.4 ± 3.4%). The macroalgae Ulva sp. was the dominant life form accounting for 32.7 ± 3.5% comparatively higher than the other sites. Other benthic forms including the pseudo coral Palythoa sp, Gastropods, and Bivalves collectively contribute 0.8 ± 2.9 % to the total benthic community.

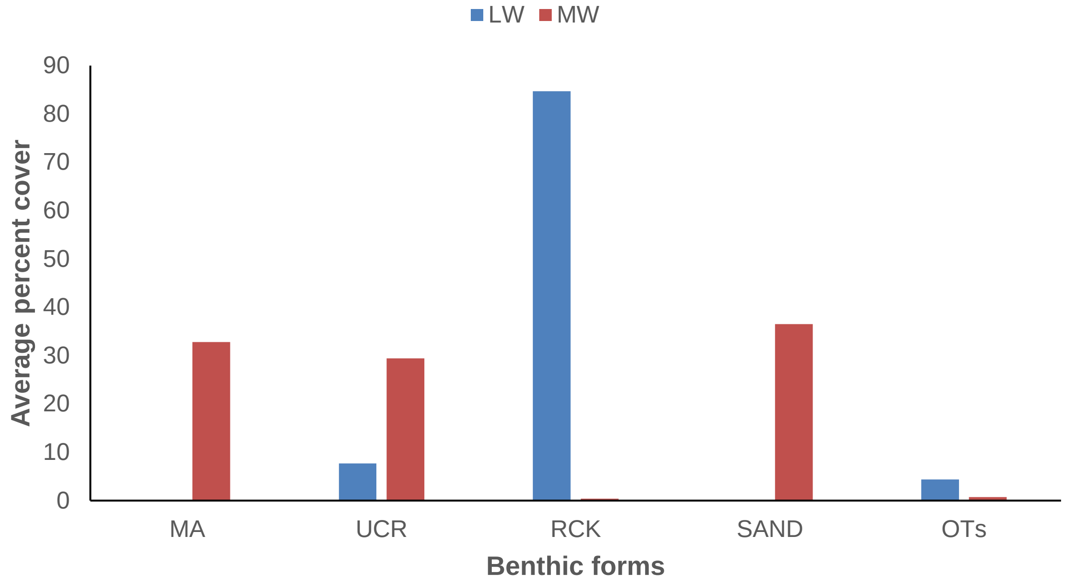


Figure 4.3.23: Average percent cover of different benthic forms at Vadhvan point. MA – macroalgae; UCR – Unconsolidated rock fragments and stones; RCK – solid rock; OTs – Other fauna

4. IT -5 Tigre Pada

Low-water

The substrate was comprised of unconsolidated stones and rocks with intermittent tide pools and sand patches. No major benthic life-forms were recorded within the quadrats except the turf algae that contributes 0.4 ± 0.7%. The abiotic forms such as rocks and stones constitute the dominant benthic category accounting for 50.7 ± 32.8% and 44.7 ± 29.6%. The other abiotic form sand accounts for 2.1 ± 1.8%. The average percent cover of different benthic forms recorded at the study site was summarized in the Figure 4.3.24

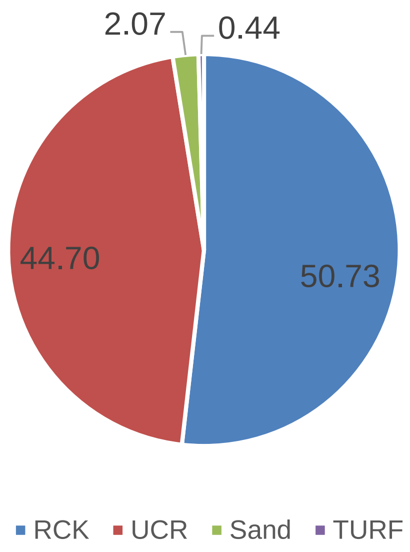


Figure 4.3.24: Average percent cover of different benthic forms recorded at the Tigre pada. RCK – Rock; UCR – Unconsolidated rock fragments

4.3.7 Other Flora and Fauna

Vadhvan coast is in Dahanu taluka of Palghar district, Maharashtra. Vadhvan is surrounded by south and east part by Palghar and Vikramgad taluka, Talasari and Umbargaon taluka towards north. The elevation of the village from sea level is 12 meters. The study area can be conveniently divided into three marine zones. The shore, intertidal zone and sub-tidal zone. The intertidal area mainly with two biotopes viz.,rocky and sandy zones. The substratum is comprised of solid rocks with intermittent tide pools, fragments of rocks and stones.

➢ **Flora**

- **Coastal Vegetation**
  The shore vegetation includes shrubs and ground covered with grasses.
- **Mangroves**
  The intertidal regions of Vadhvan area have the distribution of *Avicennia marina*. Saplings of the *Rhizophora* sp. were also found in the intertidal regions of Jhoting Bhabha Mandir.
- **Sea grasses**
  Sea grasses were absent at the site.
- **Seaweeds**
  The tide pools and part of the rock was smothered with cyanobacterial mats and turf algae. The rocky intertidal area was found rich in sea weed in the genera *Ulva*. New recruits of the macroalgae *Ulva* sp. occur in small patches along the tide pools and rocks.

- **Fauna**
  - **Phylum: Porifera**
    Poriferan community comprised of sponges were observed at the intertidal area.
  - **Phylum: Cnidaria**
    Cnidarian community comprised of sand anemones, *Aiptasia* sp., *Zoanthus* sp., *Zoanthus sansibaricus*, *Zoanthus vietnamensis*, *Palythoa* sp. *Palythoa mutuki* and *Paracyathus* sp. Hydrozoan colonies (*Pennaria* sp.) were present on the lateral margins of the rocky patches. Cnidarians except hydrozoans are listed in Schedule I, Part K of Wild Life (Protection) Amendment Act, 2022.
  - **Phylum: Annelida**
    Presence of small annelids on the lateral margins of the rocky patches.
  - **Phylum: Arthropoda**
    Intertidal area showed the occurrence of Porcelain crabs and Grapsid crabs (*Metopograpsus* sp.). Rocky plate form near infra littoral line was thickly infested with barnacles. They formed a barnacle zone in intertidal area of the site. Barnacles such as *Chthamalus* sp and *Megabalanus* sp. were observed in the rocky patches.
  - **Phylum: Mollusca**
    The solid rocks comprised tide pools that serve as a refugium for various molluscan species. The molluscan community comprised mainly of gastropods such as *Indothais* sp., *Thais* sp., *Gyrineum natator, Cantharus spiralis, Indothais sacellum, Clypeomorus* sp and *Nerita* sp
  - **Phylum: Echinodermata**
    Asterina lorioli and Antedon sp*.,* were present in the rocky crevices of the study area which represents the echinoderm community.

Besides the above, it was observed that abundant invertebrate tubes (unident.) were attached to the rocky outcrops at Shankodhar area (19°56'44.78"N, 72°38'14.60"E). Many of these tubes were inhabited by crustacean groups such as tanaidaceans, amphipods etc. (Plate 15).

4.3.8 Fishery

The proposed port area, and the waters around the navigated channel area partly including the historic fishing areas of fishers of Palghar district. According to the survey and observations made by ICAR-CMFRI during visits to the proposed area and nearby villages revealed the occurrence of variety of fin fishes and shell fishes. They observed a good diversity of fishes (126 species) including 86 species of teleost, 4 shark, 20 crustaceans and 13 molluscs. Most of the fish species collected during June and July were juveniles, smaller than the size at maturity. However, in different months maturity, size and catch composition of fishes differed in different fishing gears.

They also reported that no endemic or protected fishes were recorded in the proposed port area or in the fishery. Common and commercially important fish varieties caught were Bombay duck, non-penaeid prawns, cat fishes, anchovies, pomfrets, seer fishes, lobsters etc.

4.3.9 Reptiles

Shaik (1984) reported the presence of Olive Ridley turtle (*Lepidochelys olivacea*) and Green turtle (*Chelonia mydas*) in Dahanu. A dead female sub adult Loggerhead turtle (*Caretta caretta*) was retrieved from Dahanu beach by WCAWA members. No sightings of marine turtle were recorded during the present study period. All turtles were listed on Schedule I, Part C of Wild Life (Protection) Amendment Act, 2022

4.3.10 Birds

The coastal areas of Palghar district were offers different marine habitats like rocky/sandy/muddy intertidal and mangroves for a variety of resident and migratory birds. The birds use these habitats as their active feeding ground especially during low tide (Plate 16). The main avian fauna recorded during study period are Lesser egret, Intermediate egret, Pond heron, Black headed ibis, Black winged still and Plovers. The detailed check list of birds occurring in the Vadhvan area and birds protected under Wild Life (Protection) Amendment Act, 2022 is represented in the Table 4.3.19.

4.3.11 Mammals

Marine mammals are some of the most amazing living creatures on earth, belonging to three major orders: Cetacea (whales, dolphins, porpoises), Sirenia (manatees and dugong) and Carnivora (sea otters, polar bears and pinnipeds). In India all species of marine mammals are protected under the Wildlife (Protection) Act, 1972 (Rajagopalan and Menon, 2003). The International Whaling Commission created the Indian Ocean Sanctuary (IWC, 1980) for marine mammals, especially for whales (Kannan and Rajagopalan, 2013). This Sanctuary consists of those waters of the northern hemisphere from the coast of Africa to 100°E (including the Red and Arabian Seas and the Gulf of Oman) and those waters of the southern hemisphere between 20°E and 130°E from the equator to 55°S (IWC, 1980). Marine mammals are known from all over the world’s oceans and seas, from estuarine to coastal and oceanic forms. They are widely distributed from poles to the tropics. They play an important role at the top of the food chain in marine ecosystems.

India has one of the richest diversities of cetaceans within the International Whaling Commission’s (IWC) Indian Ocean Sanctuary (IOS). Thirty-one species of cetaceans, including 30 marine species and the Gangesriver dolphin, *Platanista gangetica*) have been recorded. In addition, one sirenian (the dugong, *Dugong dugon*, also Vulnerable) is recorded from Indian waters (Table 4.3.20) There is amplescope for cetacean research in India, and research has indeed gained momentum since the declaration of the IOS in1979.

Published and confirmed records of cetaceans in the coastal waters of Maharashtra state describes the occurrence of 7 species including *Balaenoptera musculus, Balaenoptera physalus, Neophocaena phocaenoides, Sousa chinensis, Sousa plumbea*, (Jog.K et al, 2018) *Globicephala macrorhynchus* and *Delphinus capensis* (Kumarran, R. P., 2012). There are many local reports of stranding and washed ashore cases of other species of cetaceans and they are not included due to lack of published records. All recorded mammals from the study area except *Sousa plumbea* were included in the Schedule I, Part A of Wild Life (Protection) Amendment Act, 2022. Indian Ocean Humpback Dolphin (*Sousa plumbea*) is listed in Schedule II, Part A of Wild Life (Protection) Amendment Act, 2022.

During the present survey no sighting of cetaceans were recorded.

5 ANTICIPATED MARINE ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

5.1 Environmental impacts of ports and harbours

Article 1(4) of the 1982 United Nations Convention on the Law of the Seas (UNCLOS) defines pollution of the marine environment to mean the introduction by man, directly or indirectly, of substances or energy into the marine environment which is likely to result in negative effects on living resources, are hazardous to human health, a hindrance to marine activities including fishing and other legitimate uses of the sea, cause an impairment in quality for seawater uses and the reduction of amenities. As a part of the present study, anticipated environmental impacts associated with the proposed port project have been identified and listed below:

- Port construction and intertidal area reclamation
- Impact of dredging and disposal
- Environmental impact of the breakwater system
- Impact of shipping operations on the marine environment
- Air pollution from port operations
- Noise and light pollution
- Impact of cargo handling
- Hazardous materials and oil
- Ship and boat generated wastes
- Introduction of non-native species into the marine environment
- Oil spill

5.1.1 Port construction and Intertidal area reclamation

Ports contribute significantly to the economy of any Nation; they also pose many adverse effects on the environment. The major environmental effects caused by port activities, berthing ships, and emissions from intermodal transport serving the port hinterland includes localized ambient air pollution, water pollution, noise and light pollution, traffic congestion, the introduction of invasive species, effects on marine ecosystems and impacts of marine accidents and spills.

Reclamation of coastal intertidal land often results in many environmental problems: immediate impact on coastal ecosystems, geological disasters, and the deterioration of marine environmental quality. Reclamation leads to loss of biodiversity, loss of ecosystem-service values, landscape fragmentation and loss of waterbird habitats.

5.1.2 Impact of dredging and disposal

Dredging is a regular activity required in many ports for deepening and maintaining the navigational channels and harbour entrances. The potential effects of dredging can be divided into two. One is the impact of dredging on the dredging site and the second impact of the dredge disposal. Dredged material may come into suspension in the water column because of many activities like disturbance of the substratum, during transport to the surface, overflow from barges or leakage of pipelines, during transport between dredging and disposal sites, and during disposal of dredged material.

Turbidity changes induced by dredging will result in adverse environmental effects when the turbidity generated is significantly larger than the natural variation of turbidity and sedimentation rates in the area. Turbidity created by dredging will cause clogging and smothering effects on filter-feeding organisms such as mussels, oysters, bivalves etc. Dredging may affect the physical environment by changing the bathymetry, altering current velocities and wave conditions which affect the sedimentary regime in the region.

Dredging and disposal of dredged material can lead to a temporary decrease in water transparency, increased concentrations of suspended matter, and increased rates of sedimentation. In the case of contaminated sediment or sediments with high contents of organic matter, dredging and resuspension may also lead to effects on water quality by the release of contaminants leading to an increase in nutrients concentration and reduced dissolved oxygen in the water column.

Physical removal of substratum and associated plants and animals from the seabed and intertidal regions and burial due to subsequent deposition of material is the most likely direct effects of dredging and reclamation projects. New habitats may also be created as a result of the operation, either directly in the dredged area or by the introduction of new habitats on the slopes of a reclaimed area (like hard substratum in the form of breakwaters).

The degree of adverse environmental impacts caused by dredging and disposal depends on the quantity, frequency and duration of dredging, methodology of dredging and disposal, physical dimensions and water depth of the dredging location, grain-size composition, density and degree of contamination of the dredged material, background water quality, seasonal variations in weather conditions (wind and waves), and proximity/distance of ecologically sensitive or economically important areas or species relative to the location of the dredging or disposal site. Depending on these factors, there can be considerable spatial and temporal variation in effects.

5.1.3 Environmental impact of the breakwater system

Coastal defence and armouring structures are deployed on all types of open and sheltered coasts in a wide range of tidal and wave conditions, as well as in onshore and offshore locations. These structures are constructed for protection against erosion and waves and protecting coastal infrastructure. Seawalls are mostly vertical or steeply curved solid structures usually made of concrete, tetrapod's or tightly interlocked stone.

a) Physical Impacts

Any engineered structure placed in a coastal region will alter hydrodynamics and modify the flow of water, wave regime, sediment dynamics, grain size, and depositional processes. For soft-sediment habitats, the loss of original habitat that is covered by the footprint of the seawall is a primary impact, along with the altered coastal hydrodynamic processes in the remaining and adjacent habitats. The effects of these physical changes on subtidal and intertidal benthic communities result in ecological changes on both open and sheltered coasts. On open coasts seawalls and other engineered structures alter the wave regime and modify processes of sediment transport (erosion and deposition).

b) Ecological Impacts

Seawalls introduce new hard substrata that are notably less dynamic than muddy, rocky or sandy habitats. Loss of total benthic subtidal habitat at the area of seawall construction is considered permanent. Structures placed adjacent to soft sediments are likely to have much larger impacts on this adjacent habitat than would be the case if the adjacent habitat was a rocky reef. Loss in habitat types reduces the diversity and abundance of macro-invertebrates. The loss of ecological zones, structural complexity, and habitat types associated with armouring could be expected to directly affect the diversity and abundance of the intertidal and subtidal benthic fauna of sheltered in that region.

Artificial coastal defences transform and often fortify soft shore coastlines into static, hard structures, allowing colonisation by rocky shore species. The impacts of these structures are not only confined to their location. When placed close to harbours or shipping routes, there is a higher risk of invasion by non-native species (neobiota), which could spread along with the breakwater structure. Long term impacts may result from changes to ecological connectivity, which in turn affects biodiversity, as well as the ecosystem services in coastal zones.

5.1.4 Impacts of shipping operations on the marine environment

Ship movements in the coastal region generate waves and propeller-induced turbidity in the water column. Propeller induced turbidity is influenced by a number of variables like depth of water, levels of activity and sediment characteristics. The turbidity caused by these activities decreases the amount of light that penetrates the water column and therefore has a di. This reduction in primary productivity will affect the rest of the ecosystem. The re-suspension of sediments may cause disturbance to sensitive marine animals, particularly due to a smothering effect as the sediments settle. Depending on the quality of the sediments, organic matter, nutrients, and contaminants may be re-released affecting water quality, by the removal of oxygen, for example, canadversely affect the marine animals and plants in the vicinity.

There is an inherent risk of marine accidents occurring where goods are transported by sea. Such accidents may occur if a ship is unsuccessful in its attempt to avoid another vessel or obstruction or by due to a natural calamity. Collision with

Dolphins and porpoises in rare case is an issue when these animals actively seek out moving vessels and swim close alongside in the bow wave which may make them vulnerable to injury from collision. There are a number of incidents recorded in past between the collisions of vessels and marine mammals, where many dead and stranded marine mammals, often porpoises, have shown evidence of propeller damage or massive trauma, indicative of ship collisions.

5.1.5 Air pollution from ports

Ports contribute to various air pollutants that affect the health of people living in nearby communities and contribute to regional air pollution problems. The major air pollutants related to port activities that can affect human health include diesel exhaust, particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NOx), ozone, and sulfur oxides (SOx). Particles directly emitted in the exhaust typically contain mineral ash, metals, black carbon (soot), condensable organics and sulphate. These particles, when leaving the ship stack, are very small (< 0.1 µm). During the ageing of these emissions in the atmosphere, secondary particulate matter is formed when the ship exhaust gases are oxidised and react with other pollutants like ammonia and volatile organics. Shipping also contributes to air pollution with emissions of carbon monoxide and polyaromatic hydrocarbons (PAH). Besides influencing particle formation, nitrogen oxides and VOC emitted by shipping affect tropospheric ozone formation.

5.1.6 Noise and light pollution

Noise associated with shipping and port operations is another major factor that has the potential to cause disturbance to marine animals, including marine mammals, fish and birds. Marine mammals are known to continue to use areas with very high levels of boat traffic and noise. However, there is concern over noise pollution in general which tends to centre on the possible behavioural effects and that in the worse cases marine mammals, fish or birds may be driven away from their home territories. Studies reported that noise and erratic boat movements can distract the feeding behaviour of dolphins and drive them away. Artificial night lighting affects the natural behaviour of many animal and bird species. It can disturb activity patterns and internal clock mechanism in birds.

5.1.7 Impacts of cargo handling

During cargo handling operations in ports & harbours, discharges and emissions do occur. Handling of liquid bulks may require discharge through pipelines, which provides the potential for leaks, emissions and spillages. Sources of atmospheric pollution can stem from cargo vapour emissions. Release of cargoes into the marine environment may have direct environmental effects, as in the case of the loss of toxic substances, or indirect effects, such as the loss of non-toxic organic-rich substances which may result in oxygen depletion on their breakdown. Some dry bulk cargoes have high concentrations of organic material and/or nutrients, such as fertilizers and animal feed, with high biological oxygen demands, large spillages of these may cause localized nutrient enrichment and oxygen depletion. This may result in the suffocation of marine life in the vicinity.

5.1.8 Hazardous material and oil

Hazardous materials at ports include large volumes of hazardous cargo, as well as oil and fuels and hazardous substances used in port activities including vessel, vehicle, and grounds maintenance. Spills may occur due to accidents (e.g. collisions, groundings, fires), equipment failure (e.g. pipelines, hoses, flanges), or improper operating procedures during cargo transfer or fuelling, and involve crude oils, refined products or residual fuels, liquid substances, and substances in packaged form.

5.1.9 Ship-borne waste

Ship-source marine pollutants emanate from cargo carried or waste generated onboard, which usually contains oil or oily mixtures and noxious substances. They accumulate from machinery operation or from the domestic activities of the crew living onboard. Mineral oil in the stern tube lubricating bearings supporting the propeller shaft, contained by shaft seals with certain operational leakage and solid wastes.

5.1.10 Introduction of non-native species into the marine environment

Rapid globalisation and increasing trends of trade, travel and transport in recent decades have accelerated marine biological invasions by increasing rates of new introductions of non-native organisms through various pathways, such as shipping, navigational canals, aquaculture, and the aquarium trade. Shipping plays a major role in the introduction of non-indigenous organisms through ships' ballast water and associated sediments and fouling on ships' hulls. Biological invasions severely challenge the conservation of biodiversity and natural resources. They are considered to be one of the most important direct drivers of biodiversity loss and major pressure on several types of ecosystems, with both ecological and economic impacts. In marine ecosystems introduction of alien marine species may become invasive and displace native species, cause the loss of native genotypes, modify habitats, change community structure, affect food web properties and ecosystem processes, impede the provision of ecosystem services, impact human health, and cause substantial economic losses.

5.1.11 Oil Spill

Oil pollution is considered as one of the major threat to the marine coastal environment, as it causes a variety of deleterious effects across a wide range of habitats and species. The oil possesses a multi-pronged lethality, being a complex mixture of many hydrocarbon compounds with varying physical and chemical properties such as water-solubility, toxicity, and environmental persistence. Most common accidental spills at port and harbour are caused during loading/unloading operation. Bursting of transfer hoses or pipes is another cause. Extreme cases of collision of vessels also are a reason for oil spills.

The extent of damage caused by an oil spill depends upon the quantity of oil spilled, the type of oil involved in the spillage and the oceanographic and meteorological conditions prevailing in the location where the spill has occurred. When the oil spills in large quantity, it temporarily affects the air-sea interaction, thus preventing the entry of oxygen from the atmosphere. The first set of organisms affected is the primary producers like phytoplankton, which is the basis of the marine food chain. The other free-swimming organisms such as fish larvae and fish also get affected. Further, when the oil sinks during the course of time, it affects the benthic organisms such as clams and mussels. The other amenities that are affected include mangrove forests and several marine resources.

Oil spills can also have a serious economic impact on coastal activities and resources of the sea. In most cases, such damage is temporary and is caused primarily by the physical properties of oil creating nuisance and hazardous conditions. The impact on marine life is compounded by toxicity and tainting effects resulting from the chemical composition of oil, as well as by the diversity and variability of biological systems and their sensitivity to oil pollution.

5.2 Construction phase impacts on the marine environment (Marine Water, Sediment Quality and Biota)

Various activities during the construction and operation phase of the project, which are likely to cause an impact on various environmental components. Impacts of the proposed port project on the intertidal and near-coastal environment during the construction phase can be generally classified into impacts on water quality, sediment quality and impacts on various flora and fauna present around the Vadhvan coastal region.

5.2.1 Water Quality

Dredging and reclamation in the intertidal and subtidal area for constructing port, seawall, jetty head, approach trestle, berth pocket and turning circle has high potential to disperse the bed sediment into the water column thereby increasing the suspended sediments in water and degrading the water quality locally. Due to the permanent damage caused to bottom biota, there is a potential risk to fishery resources and may lead to an increase in some undesirable species of biota. This can lead to water quality deterioration and affect adversely on the marine and coastal ecology locally.

The texture of subtidal sediment at the proposed port site is mainly silt (Av. 83.0%) followed by clay and sand (Section 4.2.1). Hence, when the bed is disturbed due to the construction activities the fine particles may remain in suspension, though locally, for some period. The SS generated due to dredging and piling activities could render the water muddy and turbid with an increase in SS, though locally. The changes in salinity due to bed disturbance are not expected.

The discussion in Section 4.2.2 to 4.2.4 gives the results of heavy metals, organic carbon, phosphorus and PHc in sediments. The risk of release of these pollutants entrapped in the sediment to the water is possible when the sediment bed is disturbed during the time of dredging.

Several types of floating platforms such as barges, cranes, ships etc. will be deployed in the area during construction. An accident involving such platforms may lead to the loss of onboard construction material and fuel. In the absence of mitigation and containment measures, the materials may sink to the bed and the fuel spill would deteriorate the water quality of the region. Thus, apart from local transient pulses of SS and deterioration due to accidental spillages, the water quality of the region will not be influenced adversely during the construction phase.

5.2.2 Sediment quality

The sediment dispersed in the water column during the port construction will be localised and temporary, consider if JNPA adopts advanced dredging and piling technologies. The discussion in Section 4.1 indicates that the water quality off the Vadhvan area, which fall in the category of good and moderately good as per C_{WQI} and the sediment are less polluted with petroleum hydrocarbons and heavy metals. Hence, the possibility of releasing the pollutants bounded with the sediments, due to the disturbance of seabed during dredging and piling activities in the coastal region is less expected. Misuse of the intertidal area by the workforce employed during the construction phase, can locally degrade the intertidal sediment by increasing BOD and populations of pathogens, if proper sanitation is not made available to them.

5.2.3 Noise

The impact of anthropogenic underwater sound on marine biota is an important environmental aspect. Sound speed in water is about 4.5 times more than that in air and absorption is less compared to air. Consequently, many marine organisms are very well adapted to emit and receive sound and they use it for a variety of functions such as communication, mating, searching prey, predator, hazard avoidance, and for short- and long-range navigation. In the marine environment, pile driving can produce some of the most intense anthropogenic noises.

There are several factors which affect the type and intensity of sound pressure waves during piling such as the size and material of the pile, the firmness of the substrate, and the type of pile-driving hammer that is used. Piling activity may contribute to the behavioural changes in marine organisms. Studies have shown clear behavioural reactions in fish due to a variety of sounds, sometimes at relatively low received sound pressure levels. Behavioural responses due to piling noise might happen anywhere within the zone of audibility and that the responses could potentially prevent fish from reaching breeding or spawning sites. This could result in long term effects on reproduction and population parameters.

The anthropogenic noise propagation, which is dependent on its frequency, characteristics and duration, may have some impact on certain fishes unless noise control measures are undertaken during construction activities. Fish may leave an area for more suitable spawning grounds or may avoid a natural migration path because of noise disturbances.

5.2.4 Impact on Flora and Fauna

a) Phytoplankton

In general, an increase in turbidity due to dispersion of fine-grained sediment in the water can lead to reduced light transmittance which in turn may influence photosynthesis and consequently may affect the primary productivity. The study area sustains high silt content and thus, an enhancement of suspended sediments during the dredging and piling activities will cause an impact on phytoplankton production resulting in a decrease in phytoplankton standing stock. The degradation of chlorophyll *a* to phaeophytin is also expected due to the enhancement of SS in the region. In general, the recovery of phytoplankton production will be fast after the completion of piling activities.

b) Zooplankton

The zooplankton standing stock in terms of biomass (Av. 3.4 ml/100m^3) and abundance (Av. 44.5 x 10^3/100m^3) in the proposed port area (Table 4.3.9). A good number of fish eggs, fish larvae and decapod larvae are also present in the study area. If the construction activity is prolonged, herbivorous zooplankton may deplete locally due to reduced phytoplankton crop and it will impact the standing stock of zooplankton in the region.

c) Macrobenthos

The impact on the intertidal area by reclamation and subtidal region by of dredging, piling, seawall construction and berth creation on biotic community result mortality due to mechanical damage and complete loss of intertidal habitat in some parts. Proposed constructions would have an adverse impact on the benthic habitats which would be destroyed in the areas directly disturbed. The total area under reclamation is about 1,44,80,000.0m$^{2.}$ In this 1,22,70,000.0m^2 falls in offshore region and 22,10,000.0 m^2 falls in the intertidal region of the study area.

The average values of biomass (21.4 g/m^2,wet. Wt.) and population (429 no/m^2) present at the intertidal segment are worked out to assess the permanent loss of macrobenthic standing stock in the proposed reclamation area in the intertidal segment and approach trestle (Table 4.3.15). The rest of the project activities like sea wall construction, approach trestle, jetty head, berth pocket etc. falls in the subtidal region of the study area. For benthic loss assessment of these segments, the average values of biomass (0.19 g/m^2,wet.wt.) and population (41 no/m^2) for the subtidal region were used (Table 4.3.12). The total benthic biomass loss estimated for the intertidal developments is about 54,317.6 kg and for subtidal is 4,558.56 kg. High loss of benthic fauna as at the intertidal segment because of the large number and diversity of benthic organisms present in that region.

Table 5.1A: Estimation of Macrobenthos loss

Segment	Affected Area (m^2)	Loss of Macrobenthos	
		Biomass (kg)	Population ($nox10^4$)
Reclamation area (Subtidal Region)	1,22,70,000.00	2331.30	50307.00
Reclamation area (Intertidal Region)	22,10,000.00	47294.00	94809.00
Approach Trestle (Intertidal region)	3,28,206.00	7023.60	14080.03
Jetty Head & Unloading Platform (Subtidal Region)	4,98,400.00	94.69	2043.44
Sea wall (Subtidal Region)	17,98,242.00	341.66	7372.79
Dredging in Berth Pocket (Subtidal Region)	29,57,892.00	561.42	12127.35
Dredging in MA/TC/AC (Subtidal Region)	64,71,028.00	1229.49	26531.21
Total	2,65,33,768.00	58876.16	207270.82

d) Mangrove Vegetation

According to the survey conducted by the Institute of Remote Sensing, Anna University during May 2021 about 98.3 acres of area in the vicinity of the proposed port has been classified under CRZ1A which include mainly mangroves and other eco-sensitive zones. The activities proposed to be carried out at the proposed port site are confined to the site and no mangrove cutting is envisaged; therefore, direct impact on the mangroves is not anticipated. The possibility of common indirect impact has been listed:

- **Slippage of fill**: the earth fill used during the construction, intertidal area reclamation spillover, slip down slop and spared out in a fan over the tidal flat. In this cause, the most common impact would be burial of mangroves pneumatophores which may lead to mortality of mangroves.
- **Dust deposition**: dust generated during the operational phase of the proposed port could result in dust being deposited on surrounded mangroves, which can adversely affect on mangrove photosynthesis process.

Mangroves are also threatened by various port-related activities like disposal of wastes, oil spill, change in erosion and deposition patterns etc. The Forest Department and JNPA can take mangrove afforestation programmes, and plans for the protection of the mangroves near the port site. JNPA should further support the mangrove restoration programme near to the project site and adjacent intertidal flats.

e) Fisheries

The proposed port area, and the waters around the navigation channel area partly including the historic fishing areas of fishers of Palghar district. According to the survey and observations made by ICAR-CMFRI a good diversity of fishes (126 species) including 86 species of teleost, 4 shark, 20 crustaceans and 13 molluscs from the study area. Common and commercially important fish varieties caught during the survey were Bombay duck, non-penaeid prawns, catfishes, anchovies, pomfrets, seer fishes, lobsters etc. The detailed impact of fishery and fishing activities has been studied and given in the CMFRI report.

f) Port development activities and their impacts on cetaceans

Conversely, many marine mammal species inhabit coastal regions, where intensive construction activities (including dredging) occurs the direct and indirect impacts on marine mammals are less well understood. As a whole, marine mammals are dispersed widely, but the distribution of individual species and populations is patchy, with certain areas comprising higher animal densities than others. Critical areas that provide ideal conditions for essential activities such as breeding, nursing, or feeding can be vital to a population ability to survive and grow. Interference with these habitats, which could be caused by dredging, may impact local distribution and abundance.

Sound pollution is an area of concern for cetaceans (whales, dolphins, and porpoises), known to be a very vocal taxonomic group, as they are highly dependent on sound for sense, social and sensory biology. Underwater anthropogenic noise is predominantly low frequency, i.e. below 1 kilohertz (kHz), and can reach sound pressure levels1 (SPL) of over 200dB re1µPa at the source. Acoustic masking can cause marine mammals to alter the duration, frequency, or sound level of their acoustic signals. Behavioural changes due to noise exposure to marine mammal can happen at large distances from the source and maybe affect biologically, as they could affect energy expenditure, or limit the amount of time spent feeding or resting. It has been hypothesized that noise impacts have the potential to induce stress. Stress due to noise could reduce the foraging efficiency of marine mammals or increase their susceptibility to disease and the effects of toxins.

Published and confirmed records of cetaceans in the coastal waters of Maharashtra describes the occurrence of 7 species including *Balaenoptera musculus, Balaenoptera physalus, Neophocaena phocaenoides, Sousa chinensis, Sousa plumbea, Globicephala macrorhynchus* and *Delphinus capensis*. Various developmental activities during the construction and operational phase of the proposed port at Vadhvan can cause an impact on the local cetacean diversity, distribution and behaviour.

i.Reclamation of land for developmental activities

Sea bed reclamation involves creating land areas from shallow coastal areas by dumping and filling rock and sediment. Reclamation of shallow seabed to create land for human use is a common practice. This generally occurs by creating a perimeter around the limits of the area to be reclaimed, and then filling in the area with rock, rubble and sand. The materials for filling are often obtained from dredge spoils, but the rockwork that is needed is also often obtained from blasting hillsides in surrounding areas. The filling-in of marine habitats to produce land has the effect of eliminating cetacean habitat. This is irreversible, and while the effects of construction work can be mitigated virtually impossible to mitigate against the effects of complete and total loss of habitat.

ii. Percussive piling

Percussive piling generally consists of a steel pile-driving hammer that falls about 1-2m by gravity, then detonates a fuel-air mixture to drive down the pile with extra force, creating a broadband gunshot like sound. Pile driving can go on almost uninterrupted for days to, in some cases, several months, depending on the substrate, depth, and the number of piles. The lower acoustic frequencies of pile driving can be transmitted for as far as about 40km distance in water deeper than several meters. Because most pile driving energy tends to be below 1000Hz, it is assumed that the activity can be particularly noxious to baleen whales that have acute-low-frequency hearing. However, there is still considerable energy into the single kHz digits, and this is where small-to mid-size toothed whales, such as bottlenose dolphins (*Tursiops* spp.) and humpback dolphins (*Sousa* spp.), for example, produces much communication sound, and are acoustically sensitive.

iii. Dredging activities

Physical injury or mortality from collisions, noise production, and increased turbidity are the main ways dredging can affect marine mammals directly. Collision with vessels is a known cause of injury and mortality in marine mammals. Vessel movement is associated with all stages of dredging, from transit from the extraction site and dumping grounds to operation of the dredger itself. Collision varies, depending on a number of factors, including vessel type, speed, location, species, and behaviour. Data of stranding are useful, but identifying the cause is often based on speculation from injuries, which may not be obvious or could be attributed to a number of sources. Active dredgers are stationary, or move at slow speeds of 1–3 kn if dredging is well managed, avoids critical habitats, times when animals may be distracted, or areas where calves are abundant, risk of collision between marine mammals and active dredgers is minimal.

Marine mammals, particularly cetaceans, are acoustically reliant animals that utilize sound for detecting prey, navigating, and communicating. Reported effects include temporary threshold shift (TTS) or permanent threshold shift (PTS), the latter being considered as auditory injury. Other effects include acoustic masking, which could cause animals to alter the duration, frequency, or sound level of acoustic signals. Masking of important sounds can theoretically impact the reproductive success of individual whales, and in turn, affect population.

In general, dredging produces continuous, broadband sound with main energy below 1 kHz. Sound pressure levels (SPLs) can vary widely, for example, with dredger type, operational stage, or environmental conditions. Studies shows that a cutter suction dredger (CDS) a maximum of received SPL of 149.3 dB re 1 mPa rms was recorded at a distance of 89 m from the dredger, TSHDs has slightly higher noise levels with a maximum broadband source SPL was 189.9 dB re1 mPa at 1 metre. The noise produced by grab dredgers with a measured SPLs at 0.15 km is of124 dB re 1 mPa were recorded at peak frequencies of 0.16 kHz, when the bucket made an impact with the seabed.

Reactions of marine mammals to dredging sound are expected to depend on the types of dredgers used and their state of operation, on the local sound propagation conditions, and the receiver characteristics with regard to the sensitivity and bandwidth of hearing. If anthropogenic noise that produced during dredging operations coincides with species hearing ranges, it has the potential to affect individuals and populations of marine mammals present within the area at the time. Sound levels that marine mammals are exposed to usually are below suspected injury thresholds or PTS, however, TTS cannot be ruled out if marine mammals are exposed to noise for prolonged periods.

During operations of dredging and dumping, an increase in suspended solids concentration and the creation of sedimentation plumes occurs. Sediment plumes have the ability to extend the impact of dredging over larger areas that would otherwise remain unaffected physically. Many researches has been carried out to assess the impacts of suspended sediments on marine organisms, but not all studies have used sediment plume concentrations produced during dredging. Some studies recorded suspended sediment concentrations of 6300 mg/L in the outwash of a suction dredger, while some reported lower concentrations of 80 –340 mg/L (upper water column) and480 –611 mg/L (lower water column) within 100 m of a dredger.

Marine mammals often inhabit turbid environments and many utilize sophisticated sonar systems to sense the environment around them. There are reports that an increase in turbidity may potentially influence humpback dolphin’s prey, and affect the dolphins indirectly by the loss of food supply due to disturbance of the seafloor and increased sedimentation. Moreover, during dredging operations, contaminants such as heavy metals and organochlorines settled on the seabed may be stirred up and redistributed into the water column. This potential contaminant release by resuspension of environmental contaminants may increase their bioaccumulation in dolphins and porpoises through the intake of prey items in the vicinity of the work area. The potential contaminant release should be examined through hazard to health risk assessment.

g) Avifauna

Coastal areas of Vadhvan provide important habitats for many water bird species, especially shorebirds, gulls, herons, stills and plovers. Despite their importance as providers of marine food resources and livelihoods for fishing communities, intertidal areas are been converted into land for agricultural, port construction and industrial estates. The populations of migrating waterbirds and local bird populations that depend on coastal wetlands and intertidal areas will decline in parallel with the losses of these areas. Loss of waterbird habitats can lead to a decline in waterbird numbers, or to the movement of birds to nearby suitable habitats. This can lead to increased densities on other sites and consequent increase in mortality of the displaced birds.

5.2.5 Miscellaneous

Large number of machineries, construction materials and workforce would be brought to the site. A major part of the construction activities such as pre-cast of superstructures, fabrication etc. will be carried out on the land, out of CRZ areas, to minimise the impacts such as spillages, generation of the construction waste etc. at the intertidal area. Left-over solid waste and that generated during dredging, piling and construction period would be a source of nuisance if not cleared from the site. The extent of the impact on marine ecology would also depend on the duration of dredging, piling and construction of the port. If the construction is prolonged due to time overruns or improper planning, adverse influence would increase accordingly.

5.3 Operational phase impacts on the marine environment

Possible marine environmental implications during the operational phase of the port are mostly associated with various emissions to air, ship accidents and grounding due to increasing in traffic at the zone, accidental spills of products handlining in the berth, discharge of wastes from jetty, ships and oil spills. Accidental spillages of these products can result in damage to the environment and assets, the severity of which would depend on the product and the quantity involved, location of spillage, environmental conditions etc.

5.3.1 Emissions to atmosphere

Ports are major sources of air pollutants that affect the health of people living in nearby communities and contribute to regional air pollution problems. The major air pollutants related to port activities that can affect human health include diesel exhaust, particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NOx), ozone, and sulfur oxides (SOx). Particles directly emitted from the exhaust typically contain mineral ash, metals, black carbon (soot), condensable organics and sulphate. Shipping also contributes to air pollution with emissions of carbon monoxide and polyaromatic hydrocarbons (PAH).

5.3.2 Risk of ship accidents

Ship collision or grounding, onboard fire, explosion etc. could lead to bulk releases of oil and cargo to the marine environment. Of these, the first two were more common and often resulted from out of control ship movement. Accidents involving ships were rare, but if occurs it could be ruinous to the local environment if the cargo spilled was crude oil or petroleum product.

5.3.3 Port related wastes

The wastes generated at Port in normal operations include domestic effluent, garbage and solid wastes (debris, leftover plastic items etc.). Liquid and solid wastes if not properly collected and disposed can potentially cause degradation of the terrestrial as well as the marine environment. A site in the vicinity of the jetty will be cordoned and marked as a solid waste collection site. Solid wastes will be segregated at this site and stored separately.

5.3.4 Ship generated wastes

A number of sources of waste generated from jetties can degrade water quality and reduce dissolved oxygen concentrations, including sewage discharges from ships, tugs, recreational and commercial boats etc. The four basic categories of wastes generated by ships, tugs etc. are as follows:

- Oily waste which usually consists of some oil mixed with larger quantities of seawater including fuel residues and sludges.
- Sewage generated by the crew in the ships.
- Garbage originating from the crew, the maintenance of the ship, cargo etc.

The International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL 73/78) prohibits all ships from discharging wastes at sea which could result in pollution of the marine environment. MARPOL 73/78 applies to oil tankers, cruise ships, general cargo and container vessels, tugs, ferries, yachts and small pleasure craft. MARPOL 73/78 requires that ships retain all the wastes on board until reaching port.

5.2.5 Oil spill

Though very rare, bulk releases of petroleum product/fuel could result due to accidents such as ship collision, ship grounding, onboard fire etc. The majority of such accidents have occurred when the ships approach/leave the port through the navigational channel. It has been well established that the human factor remains to be the cause of about 90% of accidents leading to petroleum spills.

If a spill occurs, it would negatively impact the local biota since petroleum products are toxic to marine organisms depending on their composition and volume spilled. Since 30% of the oil gets lost to the atmosphere, rest of the 70% would settle in the water column. This would be settled on the seabed over a period of time.

Spilled petroleum undergoes weathering through processes such as spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation and biodegradation. A lighter product such as naphtha or Motor Spirit (MS) would soon evaporate under tropical conditions while heavy product such as FO would persist in the marine environment for a prolonged period. Thus the impact of a spill on marine biota of the Vadhvan region would critically depend on the nature of the product, volume spilled and the area affected.

i. Mangroves:

Spilled oil if transported to the mangrove area may block the openings of air-breathing roots of plants or interfere with salt balance, harming them. The recovery of mangroves would be slow and may take a few months to years depending on the damage.

ii. Plankton:

An increase in concentrations of dissolved petroleum hydrocarbons (PHc) in water subsequent to a spill could lead to plankton mortality. The recovery of plankton would be however quick through repopulation of the community by fresh recruits from adjacent areas not affected by oil. Eggs and larvae of fishes, crustaceans and molluscs in the spill area would be killed. However, it is unlikely that any localised losses of fish eggs and larvae caused by a spill would have a discernible effect on the size or health of future adult populations.

iii. Benthos:

If the weathered oily mass spreads on intertidal areas mortalities of organisms in the zones of physical contact are expected. Subtidal benthos of shallow waters may also be affected if the sinking residue affected their habitats. The recovery would occur once the oil coating on the intertidal area is washed away by tidal action. Subtidal benthos is unlikely to be impacted significantly since the sinking oil residue would be dispersed widely by strong tidal displacements.

iv. Fishes:

A large oil spill can temporarily reduce the fish catch from the area as fish might migrate from the affected zone. Limited mortality may also occur particularly when the oil concentrations in the water go abnormally high. Often fishes get tainted and unpalatable but become normal when the ambient PHc level approach the baseline.

v. Birds:

The birds are highly sensitive to oil spills and get particularly affected if their habitats are oiled. Oil pollution affects birds in several ways either indirectly by killing or contaminating their nutritional sources, such as plankton, invertebrates and fish, or directly via plumage oiling. The acute effect of oil pollution on birds is on their thermal balance. Oil adheres to the plumage and causes a reduction in the water repellent properties of the plumage, causing water to penetrate into the plumage to displace the insulating layer of air. In water, plumage oiling may cause the heat loss to exceed the bird's heat production capacity leads to hypothermia in birds.

vi. Turtles and mammals:

Marine turtles and mammals are highly sensitive to oil spills and they tend to swim away from the spill site. But direct spillage or ingestion of oil will cause a lethal impact on marine mammals. Contact with viscous oils can lead to long-term coating of the body surface, which may interfere with swimming ability, filtering capabilities in marine mammals.

5.3.6 Behavior of products handling in the berth if accidentally spills

Spillage of various products handling in the port during loading/unloading operations at the berth is considered to be very small and the spill, if it occurs, will be limited mostly to the berth deck or ship deck. In case of any overflow of these products, they will be dispersed in the waters around the berth and the dispersion is expected to be limited to a short distance from the point of spill.

Some of these chemicals are immiscible with water and have a specific gravity less than water and so they float on the surface and get evaporated in a very short time. Some of the chemicals are soluble/miscible in water and they form solutions with varying concentrations with water. Here the dispersion of the chemical pollutant in the surrounding marine environment will be limited to a short distance from the location of the spill (the berth/ship deck) and it is ensured that the dispersion lengths are not long enough so that the shore would be affected. However, many of these chemicals fall under the category of hazardous class as they are highly inflammable and are susceptible for fire risk. In the case of some of the other chemicals being handled at the jetty, they are toxic. The lists of products handled at the jetty are mentioned in the table below:

Sr. No.	Raw Materials / Products	Relative Density at Operating Temperature (g/cm^3)
1	LPG (Propane / Butane)	0.493-0.573
2	White Petroleum Products (Naphtha / MS / HSD / SKO / LDO)	0.7 – 1.0
3	Oils (Furnace, base, lubricant)	-

a) LPG (Propane/Butane)

These petrochemicals are volatile gases at room temperature. Propane and butane are transported safely in gas carriers (ships), barges and pressurized containers for ocean, inland waterway, and coastal shipments. Vessels are specially equipped to carry liquefied gases and typically operate as dedicated service. For small quantities, pressurized containers are preferred whereas fully refrigerated ships are used for large size cargoes.

These are having a normal service temperature less than the ambient (cryogenic service). Hence any leaks/spills of these chemicals will immediately get dispersed into the atmosphere (as they will be in a gaseous state at room temperature) and there will be no impact on the marine environment. These chemicals will not be in the sea nor do they impact the shore.

The primary hazard associated with the leaks of these petrochemicals is their high flammability. Leakages of propylene and butadiene, therefore, are serious fire hazards with severe consequences. The vapours of propylene and butadiene are heavier than air and may accumulate and travel along the ground to a significant distance to an ignition source, resulting in a flesh fire. Liquefied gases of these chemicals produce a visible fog when spilled or leaked. In a fire situation, conditions can develop which could lead to explosion and further fire propagation. The expansion of the liquefied propylene and butadiene gases in closed containers that are exposed to fire can lead to Boiling Liquid Expanding Vapour Explosions (BLEVEs). The Threshold Limit Value (TLV) for propylene for humans is 500 ppm based on asphyxia and potential for upper respiratory tract irritation.

b) White Petroleum Products and Oils

These are petroleum hydrocarbons having a specific gravity less than 1 (i.e. less than that of water/seawater). They are the only chemicals which when any spill occurs will form a spill/slick on the sea surface, float on the sea and undergo weathering processes.

5.3.7 Impact of vessel movements on cetaceans

Increased vessel traffic at the Vadhvan area can potentially increase the chance of dolphins and porpoises being killed or injured by vessel collisions. Vessel traffic can also result in acoustic disturbance to dolphins and porpoises. Small cetaceans are acoustically sensitive, and noise from vessel traffic could cause behavioural disturbance to them. Since dolphins and porpoises rely on their echolocation to navigate their surroundings, detect and capture prey, and to communicate with one another, sound is vital to their survival (especially for mother–calf pairs).

However, humpback dolphins mainly produce lower-frequency, broad-band clicks in the range of 8 to 422 kHz during foraging, while finless porpoises generally exhibit narrowband, high-frequency ultrasonic pulses with peak energy of 142 kHz. In comparison, large vessel traffic generally produces low-frequency sounds of less than 1 kHz. Therefore, the expected acoustic disturbance from large vessels is well below the primary acoustic range for humpback dolphins and finless porpoises. Nevertheless, they may still need to alter their diving and surfacing patterns to avoid collisions with marine vessels. This could result in some short-term behavioural disturbance to the dolphins and porpoises or they may even be displaced from their preferred habitats.

5.4 Mitigation Measures

It is important that certain environment protection measures are conceptualized and strictly implemented at the setting up of the proposed port project so that the negative impacts during construction and operational phases are reduced to a minimum in order to protect the biodiversity of the project area and avoid anthropogenic shocks.

5.4.1 Mitigating measures for reducing the impact of dredging activities

A number of management techniques and mitigation measures have been developed to reduce the impact of dredging activities on the marine environment. Methods like tidal dredging, physical barriers, environmental dredging techniques and so forth, which may be used to mitigate the effects of dredging on sensitive organisms and on ecosystems. In hydraulic dredging techniques, the dredging rate can be adapted by increasing the amount of water pumped up relative to the amount of sediment that is dredged, which can help to reduce the extent of turbidity plumes. Examples of other environmentally less damaging dredging equipment include encapsulated bucket lines for bucket chain dredgers, closed clamshells for grab dredgers, auger dredgers, disc cutters, scoop dredgers and sweep dredgers.

Adoption of sub-suction dredging, which allows for lowering of the seafloor by extracting sediment from deeper layers without disturbing the top layer is also a good option for dredging in the berth pocket and turning circle. Mitigating measures applied in other cases include confined land-disposal, turbidity modeling (plume prediction), turbidity thresholds, minimizing the duration of dredging, seasonal restrictions, limiting over-dredge quantities, the establishment of no-spud zones, use of silt screens, prohibiting dredging near the Shankodar (19°56'44.78"N, 72°38'14.60"E) which is having comparatively high biodiversity in the study area, stopping dredging when turbidity thresholds are exceeded. Protection of an environmentally very sensitive area like Shankodar with silt screens may in some cases be viable, but only if the physical conditions of the site (esp. waves and currents) allow their effective use. The use of a silt screen, however, clearly limits the output level of the dredger, lengthens the execution period, and increases the costs of the project.

5.4.2 Mitigation measures to reduce the impact on sea wall construction

The detrimental effects of sea walls cannot always be avoided, certain nature-based adaptations can be made to mitigate or reduce these effects. Nature-based measures should ideally be considered to limit the construction costs and to allow their implementation over larger spatial scales. Seawalls can be built or altered to enhance habitat diversity and complexity, without affecting the coastal safety offered, by maximising surface roughness and introducing microhabitats. To ensure minimal physical and environmental effects, recommended design guidelines and standards like Shore Protection Manual (CERC, 1984), The Rock Manual (CIRIA, 2007), Coastal

Engineering Manual (USACE, 2002), Manual on wave overtopping of sea defences and related structures (Euro top, 2018) etc. should be followed.

Numerical models predicting the shoreline response to seawalls can help to optimise designs for mitigating physical changes on the adjacent coast. Moreover, monitoring of the physical impacts throughout the lifetime of the structure is important to identify unintended morphologic and hydrodynamic changes. The morpho dynamic effects of foreshore structures can be reduced or mitigated in different ways. The undermining of structures due to scour can be prevented by appropriate scour protection design. However, although typical scour protections of rock or concrete would create new habitat, they would not compensate for the loss of the soft habitat they are placed on but still act as a new medium for the growth. Alternatively, structures of porous materials could produce less scour than impermeable structures. The impacts of erosion could be minimised in the design phase by increasing the structure porosity or in the dimensioning of the structures.

Some heterogeneity is already present at coastal defences due to the construction procedure, such as holes/grooves in armour units, which retain water, or gaps between rocks or concrete blocks. Additional heterogeneities can also be incorporated in the design, for example, by adding tiles with different textures and microhabitats. Drill-cored artificial rock pools can be an affordable, effective way to enhance the biodiversity of intertidal coastal structures. The rock structures should be constructed of both soft and hard rocks, since the weathering of carbonate rocks takes place faster than igneous rocks, thus creating additional surface roughness. Mixed rock sizes provide different habitats that can lead to greater species diversity and abundance. Artificial reef structures, for example, Reef balls and WADs, have been built in many countries with this purpose. These elements are mound-shaped, concrete modules that imitate natural rocky heads, providing a habitat for a variety of marine organisms and increasing local biodiversity.

5.4.3 General practices followed during the construction phase

i)Subtidal environment

The possible impacts during the construction phase can be minimised or avoided by adopting the following measures:

- The barges or vessels involved in the dredging and construction work and the equipments like cranes involved in the construction work will be in a proper condition with no leakages of oil, petrol, diesel, grease which can lead to leakage of pollutants to the sea.
- The movement of the construction barges carrying construction materials and machineries should be well planned that the navigational channel should not be crowded with too many vessels so that the accidents and subsequent spillages of materials and fuel are avoided.
- During construction, the site will be well illuminated to compensate shading of natural sunlight penetration.

- The water quality may have depleted levels of oxygen due to the impact of construction and hence, aeration peddling systems can be released at various spots around the marine water area to provide aeration.
- The impacts of hammering during piling can be minimised using bubble curtain extending from water surface to the bottom. The curtain is expected to reduce underwater noise levels by approximately 10dB on an average.
- Turbidity monitoring can be performed periodically to ensure compliance with water quality standards. If at any time the turbidity levels are estimated to be approaching the turbidity exceeds criterion the work can be suspended temporarily.
- If required silt curtains, as well as careful selection of the dredging method, could be implemented in minimizing dispersal of resuspended sediments.
- Temporary colonies of the workforce etc. should be established sufficiently away from the CRZ areas and proper sanitation including toilets and bathrooms should be provided to the inhabitants to prevent abuse of the intertidal area.
- Sewage and other wastes generated in these settlements should be properly treated and disposed of, to avoid any impact on the marine/land environment.
- No waste should be directly released into the marine environment.
- The workers should be provided with fuel to discourage them from cutting mangroves or any other vegetation.
- Periodic monitoring of construction works to notice and report any adverse events.

ii) Flora and Fauna

The permanent destruction of macrobenthos along the intertidal area and subtidal area selected for construction of port, sea wall and berths, the impact on the marine ecology during the construction phase is inevitable in the proposed project. The key factor in minimising the other adverse impacts mentioned earlier due to construction would be a reduction in the construction period at the site and avoidance of spillage of activities beyond the specified geographical area, which should be kept to a minimum. The dredge spoil generated after trench filling in the intertidal region should be removed and properly disposed of.

Workforces employed during construction often misuse the intertidal and supratidal areas. This should be avoided by establishing the temporary colonies of workers sufficiently away from the constructing sites and proper sanitation should be provided to them to prevent abuse of the intertidal region. The noise level during the transport and construction of marine facilities should be kept to a minimum.

The intertidal and nearshore subtidal areas should be restored to their original contours once the construction activities are completed. General clean-up along the corridor areas should be undertaken and discarded materials including excavated soil should be removed from the site and the aesthetic quality of surroundings restored on completion of the construction phase.

iii) Mitigation and management of mangroves

Mangrove conservation will only be successful when backed up by sound data and broad knowledge, understanding and awareness of the need for mangrove conservation. Research and maintenance of accessible, long-term databases on mangrove coverage, management and protection, value and their response to pressures are essential for sound policy and management decision-making.

- Discharge of wastes/wastewater during the construction and operation would not be allowed.
- A mangrove buffer zone of 50 m is to be marked with signboards and flags from the proposed port boundary to the mangrove proper to avoid unnecessary trespassing by construction workers.
- Awareness will be given to workers about the importance of mangroves and the involvement of local communities in their conservation.
- The sensitive ecosystems such as mangroves, intertidal flats around the proposed site should be marked on maps and periodically monitored (At least once a year) to ascertain their health.
- **Mangrove monitoring**: Mangroves in the project area need to be periodically monitored during the project activity. Regular assessment to detect the mangrove health condition.
- **Sediment monitoring:** monitoring of sediment within the mangrove community will provide an easy way of find potential impact.
- **Mangrove planting:** Mangroves are well adapted to natural phenomena such as (erosion and accretion, storms and floods) and quickly recover from this disturbance without the need for planting. In contrast, human interventions will lead to permanent changes which may create conditions that are unsuitable for the natural regeneration of mangroves. In this kind of environment, mangrove planting is important for its conservation. Planting is the most favourable method, it can be done using seeds, propagules or seedlings; the latter can be from nurseries or transplanted from other sites.
- **Reduction of dust**: For the reduction of the dust formation due to construction activity viz. sprinkling of water, etc.
- **Reforestation:** It refers to planting trees in areas that were previously forested and where the site conditions have not been degraded since the removal of mangrove cover. It’s a part of the mangrove silviculture technique.
- **Rehabilitation:** It means to convert a degraded system to a more stable condition.In sites where mangrove habitat loss or degradation has occurred to such an extent that natural processes can no longer self-correct or self-renew, appropriate, site-specific and affordable rehabilitation or restoration methods are needed.

- **Restoration:** It's a process that aims to return a system to a pre-existing condition whether or not this was pristine.
- **Afforestation:** Establishing a forest by planting trees on the land that was not previously forest.

5.4.4 Mitigation measures to reduce the impact on the cetacean community

i. Temporal and geographic closures

The most obvious way to reduce or eliminate the impacts of various disturbing activities is to plan those activities to occur in places or at times when the animals of interest are not present. Even when the animals are present, temporal or geographic closures that restrict the activities to lower density areas/times or to less sensitive areas/periods may be useful. Measures should take in the account about small-scale patterns of distribution, seasonal shifts in density, diurnal patterns, and calving seasonality. Geographic closures may be harder to implement, as most small cetaceans do not have 'nursery areas' in the sense that most fishes do.

ii. Monitored exclusion zones

Intermittent construction activities have a potential to cause serious behavioural disturbance or even physical harm to small cetaceans, monitored exclusion zones can help to reduce the chances of impacts. The idea here is that only dolphins within close range of the activity of interest are at risk, and therefore it should be possible to avoid the activity when dolphins are nearby. An important aspect of using this mitigation technique effectively is to have an independent observer to monitor the exclusion zone. The observer should be someone who is trained in dolphin and porpoise detection and should use binoculars from an elevated platform with unobstructed visibility to aid detection. The use of passive acoustic monitoring can also greatly increase the effectiveness of such exclusion zones, by adding another way to detect animals that may be underwater or surface cryptically.

iii. Bubble curtains and jackets

Bubble curtains and various iterations (termed ''jackets'' for small curtains directly around noise-making equipment and ''screens'' for curtains enclosed in a foam-like mesh) have since been used in a number of industrial applications, especially to help direct fishes and to reduce sounds of percussive piling and drilling activities. Such air-induced screening tends to be valuable in reducing noise towards seals, dolphins, and porpoises, especially when human-made sounds are loud and stationary in areas of important marine mammal habitat.

iv. Acoustic decoupling of noisy equipment

Construction machinery, such as compressors and generators, that are placed onto the steel hulls of barges are particular culprits. By placing such equipment on rubber or foam mats, or by using pneumatic rubber wheels under such machines, they can be 'acoustically- decoupled' to an extent.

v. Vessel speed limit and restrictions

All vessel captains working in the area should undergo training to educate them about local cetaceans, as well as guidelines for safe vessel operations in the presence of dolphins and porpoises. Vessels traversing through the work areas should also be required to use predefined and regular routes to reduce disturbance to cetaceans due to vessel movements. Studies have found that most bowhead whales avoid drillship or dredging noise with broad-band (20-1000Hz) received levels around 115dB re1µPa, levels that could occur 3-11km from typical drilling and dredging vessels.

vi. No-dumping policies

A no-dumping policy is simply a policy prohibiting the dumping of wastes, chemicals, oil, trash, plastic or any other substance that would potentially be harmful to dolphins and their habitat in the work area.

vii. Silt curtains

To avoid allowing suspended solid and environmental contaminants to be resuspended back into the water column during dredging and dumping operations, silt curtains should be used around the work area wherever feasible.

viii. Cetacean density monitoring

The most important mitigation measure is to conduct surveys to monitor the density and behaviour of the cetaceans before, during, and after the proposed port development. This is often overlooked in mitigation plans, but it is an effective way to find if the mitigation measures that have been put into place have been effective in protecting these animals from disturbance and maintaining their habitat quality.

viii. Miscellaneous

Regulators have often sought to establish a particular noise level that would trigger management action, such as temporary shut-down of the noise source until the cetacean moves away. Such a noise level has been very difficult to determine, particularly as there is such a wide variety of responses between species, situations, and noise sources. Some examples are warning blasts and staggered charges, which are designed to have the effect of warning marine mammals of louder and/or more dangerous sounds to come, giving them the chance to leave the area voluntarily.

5.4.5 General practices followed during the operational phase

Possible discharges from ships that could be a source of water pollution are bilge water, oily wastes, sewage, garbage and other residues in a ship. Spills of oils, lubricants, fuels and other oily liquids may be the other sources of water pollution. Discharges and spills of these wastes can cause problems of oil pollution, floating garbage, unsanitary conditions, odour and degradation of water quality. Biodegradation of oil generates polymerized oil particles and toxic aromatic fractions using dissolved oxygen in the water and it indirectly causes damage to the bottom biota and habitat. Some oils contain carcinogenic contaminants and these are reported.

Harbour authorities make an important contribution to reducing the risk of such events by undertaking their responsibilities as conservancy authorities. Furthermore, here response plans have been drawn up, an appropriate, coordinated approach to any incident will ensure that any potential damage to the environment is limited, particularly where hull ruptures and loss of cargo or fuel spillage occur.

- The proper measure should take to preserve the flora and fauna in the buffer area and surrounding area, that it would not be impacted or deteriorated by the port activities.
- Proper traffic management should be in place to reduce noise and air pollution.
- Comprehensive and easy to implement Standard Operating Procedure (SOP) will be made for each category of cargo in order to avoid spillages.
- SOPs will address safe conditions of wind, tide, visibility etc under which operations would be permissible.
- The operating staff at the berth will be trained in such operations and also to handle emergencies.
- For improved environmental safety and leak prevention, loading arms will be equipped with the following accessories:
  - Hydraulic Coupler which allows rapid connection and disconnection of the arm to the tanker/pipeline flange.
  - PERC installed between two disco valves to allow quick disconnection from the tanker/pipeline without draining of the arm.
  - Limit switches that define 3D working envelope giving alarm at three stages.
  - Emergency Shut Down (ESD).
- SOPs will be developed for every facet of operational OSCP that will include notification; strategy for combating depending on oil/chemical type, quantity involved and area of spill impact; deployment of booms to contain and to protect sensitive habitats, mainly mangroves; deployment of skimmers; on board and shore storage of recovered oil; strategy for shoreline cleaning and storage of oil contaminated sediment; use of dispersants; final disposal of recovered oil and contaminated sediment; closure of operation; dissemination of information to public and media etc.
- The oil spill combating equipment will be stored in the vicinity of the oil berth and a suitable vessel will be always kept stand by for quick response during loading/unloading operations of petroleum and while providing bunker.
- Mock drills involving the deployment of critical oil spill containment and recovery equipment will be held at least once in 3 months.
- The oil spill combating equipment will be inspected regularly as recommended by the manufacturers and records of inspection will be maintained.
- Water drawl sources shall be identified and its impact shall be predicted. Similarly, wash water discharge into sea and impact prediction can be carried out.

- Adequacy of outfall in mitigating the adverse impacts shall be ensured by suitable study. Appropriate regulations on ship discharges and effluent from ships and provision of reception facilities are indispensable for proper control of emissions; detection of spills will be done for regulating ship discharges.
- To handle the spills recovery vessels, oil fences and treatment chemicals with a view to minimizing dispersal can be considered.
- Periodical clean-up of floating wastes is also necessary for the preservation of port water quality.
- The port will be fully prepared and geared up to meet emergencies such as fire due to leakages of these highly inflammable chemicals.
- Emergency responders will be properly trained and equipped in accordance with OSHA’s standards on emergency response and emergency fire protection.
- OSHA's standard for the chemicals handling in the berth requires engineering controls and work practices that comply with the OSHA PELs (Personal Exposure Levels).
- Respiratory protection and Chemical Protective Clothing (CPC) to prevent contact with chemicals will be available at the berth.
- Gas monitors with provisions for alarms set at specific concentrations will be installed at strategic locations on the berth and harbour.
- The transportation of propane and butane will meet the requirements of the International Maritime Organization (IMO) as specified in the International Maritime Dangerous Good Code and MARPOL 73/78.
- Reception facilities to be provided to receive residues and oily mixtures generated from ship operations according to the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL) as per 1978 Protocol (MARPOL, 1973/78).
- The oily and hazardous waste generated at the port will be adequately stored and given to MPCB approved recyclers.

6 MARINE BIODIVERSITY MANAGEMENT PLAN (MBMP)

6.1 Introduction

Indian sub-continent is assumed to be the fastest growing and emerging global economy of the 21st century. Within the coastal zone, there are number of sensitive habitats, including the estuaries, mangroves, coral reefs, sea-grass beds, and oceanic islands. These habitats support a wide spectrum of biota whose abundance and distribution varies both spatially and temporally. These habitats have been exploited for food and aesthetic purposes with no apparent ill effects till large-scale mechanisation began to be introduced. Increasing human population coupled with the greater need for development has led to intensive exploitation of coastal areas and various fishery resources and has caused considerable impacts to many habitats. The coming decade will see unprecedented growth in port and shipping activities. Of the multiple modes of transport, India is mainly dependent on its ports and harbours for trade and navigation. In such a scenario, the proposed port will immensely support the growing transportation needs of the country.

Many places in the coastal waters of India have become danger-prone zones. Stress due to anthropogenic pollution is the principal cause of biodiversity degradation and ecosystem deterioration in coastal waters. Coastal waters are the beds or nursery grounds of many marine flora and fauna, including finfishes and shellfishes, the most influencing commodity for human population growth. Due to the over-exploitation and mismanagement of coastal ecosystems, these marine resources have been considerably declined. Managing a complex ecosystem to balance the delivery of all of its services is at the heart of ecosystem-based management. But, how can this balance be accomplished amidst the conflicting demands of stakeholders, managers, and policymakers? In marine ecosystems, several common ecological mechanisms link biodiversity to ecosystem functioning and to a complex of essential services. As a result, the effects of preserving diversity can be broadly beneficial to a wide spectrum of important ecosystem processes and services, including fisheries, water quality, recreation, and shoreline protection.

A management system that conserves diversity will help to accrue more 'eco-service capital' for human use and will maintain a hedge against unanticipated ecosystem changes from natural or anthropogenic causes. Although maintenance of biodiversity cannot be the only goal for ecosystem-based management, it could provide a common currency for evaluating the impacts of different human activities on ecosystem functioning and can act as a critical indicator of ecosystem status.Significant advances in techniques and technologies have been made in recent years in toreduce environmental impacts, like the Environmental ManagementSystem (EMS) under ISO 14000. The following sections provide the management plans to be implemented for conserving the water quality, sediment and marine biodiversity of the intertidal and subtidal regions within and the immediate vicinity of the proposed greenfield port at Vadhvan.

Objectives of MBMP:

- To identify the anticipated environmental issues which can affect marine water quality and marine biota during construction and operational periods of the proposed project
- To provide guidelines and procedures for implementing mitigation measures
- Develop an institutional framework for marine environment and biodiversity management
- Take immediate action when unpredictable impacts occur
- Monitor the effectiveness of mitigation measures
- Implementation of environmental sustainability in ports

6.2 Components of Marine Biodiversity and Environment Management Plan

The anticipated marine environmental impacts on the prevailing marine water quality and biodiversity around Vadhvan and mitigation measures for reducing the environmental impacts of the proposed greenfield port project have been discussed in detail in Chapter 5.

The following specific marine biodiversity and environmental management aspects are discussed in this section:

- Summary of project activities, associated impacts and mitigation measures in the marine sector
- Priority sites identified around the port for marine biodiversity management
- Institutional arrangements for marine environmental management
- Mechanism for implementation of mitigative measures in the marine segment
- Approach towards voluntary compliance
- Management sections cover under MARPOL
- Legal framework
- Cost of Marine Environment Management Plan
- Marine Environment Monitoring During Construction and Operational Phase
- Disaster Management Plan (DMP)
- Environmental sustainability in Ports

Table 6.1: Proposed port developmental activities, associated impacts and mitigation measures in a nutshell

No.	Port activities	Marine compartment likely to affect	Impacts on the marine environment if no mitigation measures are implemented	Mitigation measures proposed	Responsible agency for implementation
Construction Phase					
1	➢ Dredging ➢ Disposal of dredge spoil ➢ Seawall construction ➢ Intertidal/subtidal reclamation	Marine water and sediment quality	Turbidity increase Increase in suspended organic matter DO depletion	Check turbidity levels and use baseline data as the reference value ✦ Adoption of a sustainable dredge management plan ✦ Disposal of dredged material in approved dumping ground ✦ Ensure dumping of excess/unusable dredge the material would be uniform ✦ Discharge of waste into the sea is strictly prohibited ✦ Implementation of oil spill control SOPs ✦ Slop tanks on barges and boats for collection of liquid, solid and hazardous waste ✦ Adoption of environmental friendly dredgers and technologies for dredging and construction ✦ Minimise the spill on the marine environment ✦ Adoption of scientific methods such as containment system to retain the solid inside the reclamation area	JNPA/ assigned contractor
		Marine biota	Decrease in primary productivity Decrease in zooplankton biomass Benthic biota loss Noise related issues Impact on marine mammals		

			Mangrove conservation	✦ Application of temporal and geographic closures ✦ Bubble curtains and jackets around noise-making equipment ✦ Acoustic decoupling of equipment ✦ Vessel speed limit and restrictions ✦ Installing silt curtains around sensitive areas ✦ Good mangroves patches were present aroundthe proposed port project site ✦ Avoid any disturbance to this nearby mangrove vegetation ✦ Strict adhering of the marine environment and biodiversity monitoring plans under the environmental monitoring programme	
2	➢ Solid, liquid and hazardous waste handling	Marine water and sediment quality Marine biota	Impact on marine water, sediment and biota due to waste disposal Toxicity from hazardous chemicals	✦ Proper collection of waste generated at the worksite and its disposal as per MPCB and CPCB norms ✦ Adoption of safety measures as per OSHA Standards ✦ Hazardous materials such as oils, paints, compressed gases etc will be stored as per the approved safety norms ✦ Medical facilities including first aid will be made available for the workforce.	JNPA/ assigned contractor
Operation Phase					
1	➢ Shipping operations	Marine water, sediment quality and biota	Releasing of ship waste	✦ Vessels visiting the port shall meet emission standards as per MARPOL 73/78 ✦ Vessels are prohibited from discharging any form of wastewater, bilge, oil wastes,	JNPA/ assigned contractor

			Accidental spillages and leaks from cargo handling	etc. into the near-shore as well as harbour waters ✦ Ships would comply with the MARPOL convention ✦ Facilities for waste reception from vessels Is to be established ✦ Comprehensive and easy to implement Standard Operating Procedure (SOP) will be made for each category of cargo to avoid spillages ✦ A separate de-ballasting pipeline should be provided to receive the washing from the ships	
		Noise and light	Noise and light pollution on marine mammals and birds		
		Air quality	Regional air pollution (SOx, NOx, PAH, VOCs, PM etc.) from vessels		
2	➢ Oil Spills	Marine water, sediment and biota	Deterioration of marine water quality and loss of biota	✦ Implementation of Indian Coast Guard approved Oil Spill Contingency Plan (OSDCP) ✦ Oil spill combating equipment will be stored in the vicinity of the berth and a suitable vessel will be always kept stand by for a quick response ✦ Conducting regular mock drills	JNPA

6.2.1 Priority sites identified around the port for marine biodiversity management

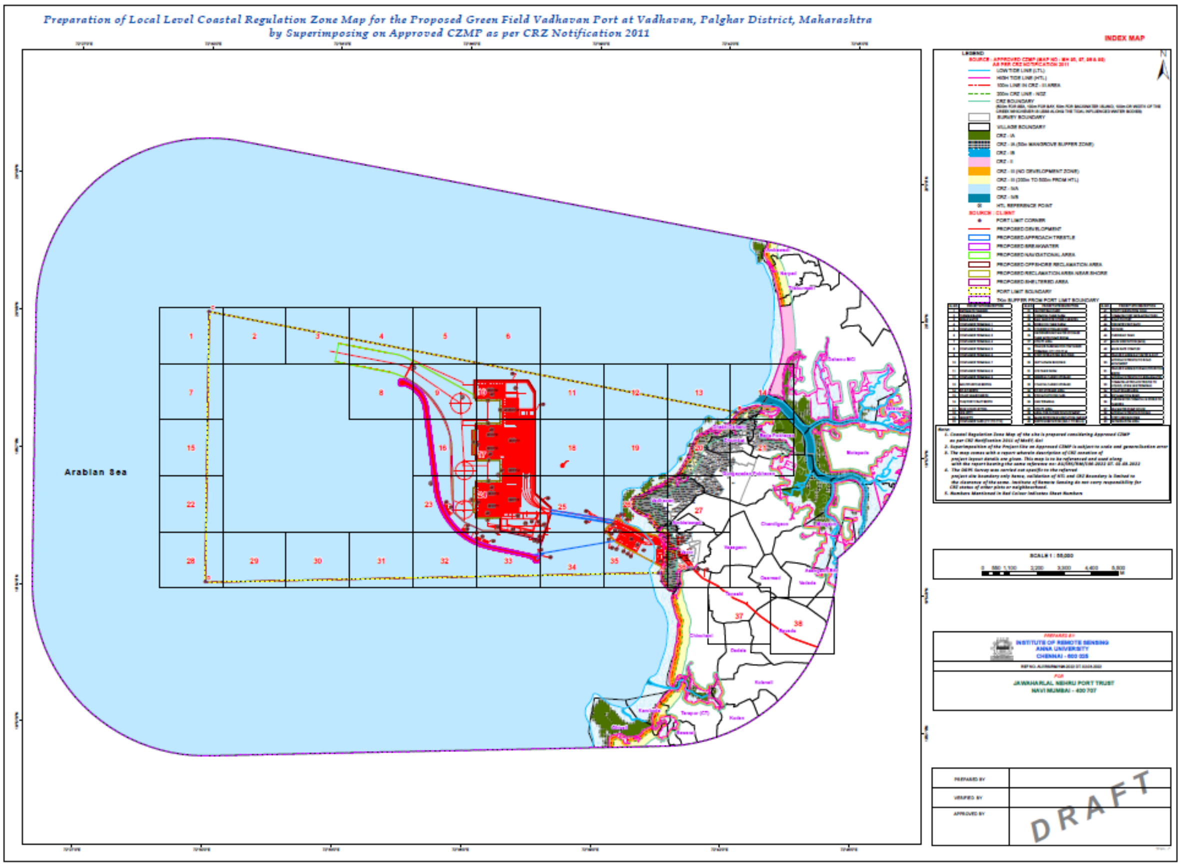
Biodiversity priority sites for management around the proposed greenfield port at Vadhvan was identified into High and Medium classes (Table 6.2). These classes have been ranked based on the biological communities present there. CRZ map prepared by the Institute of Remote Sensing, Anna University has given information about different CRZ classes like CRZ I, II, III and IV in the 7km radius of the proposed port (Figure 6.1). In the CRZ map CRZ I include the zone between HTL and LTL and coverthe ecologically sensitive areas like in the case of Vadhvan, the Shankodar area, mangrove vegetation, Dahanu creek, intertidal sand and muddy beaches etc.

Table 6.2: Priority sites identified in the project vicinity (7km)

Sl No.	Location	Biodiversity importance	Priority Class
Locations inside the proposed port limit			
1	Shankodar Point	Seaweeds Many organisms under the phylum Porifera, Cnidaria, Annelida, Arthropoda, Mollusca and Echinodermata. Presence of abundant (unident.) invertebrate tubes	High
2	Tadiyala	Mangroves Sandy and muddy beach	High
3	Gungwada	Mangroves Sandy and muddy beach	High
4	Jhoting Bhaba Mandir	Mangroves Sandy and muddy beach	High
5	Vadhvan Point	Mangroves Sandy beach and rocky intertidal region	High
6	Varor	Sandy beach	High
Locations outside the proposed port limit			
7	Ambevadi	Mangroves	Medium
8	Dahanu Beach	Sandy beach	Medium
9	Dahanu Creek	Mangroves Intertidal mudflats	High
10	Tarapur Creek	Mangroves Intertidal mudflats	High
11	Chinchani	Sandy beach	Medium
12	Ghivali	Mangroves	Medium

Unclassified sites are not considered priorities for specific management activities within this plan, but this does not mean that it's excluded from the overall conservation plan. Site-specific management actions are targeted to priority sites, as these are anticipated to have the greatest influence on species present over that site.

Figure 6.1: CRZ map of the study area (7km radius)



6.2.2 Site-specific Marine Biodiversity Management

The intertidal areas in the Vadhvan (Shankodar, Tadiyala, Vadhvan point etc.) has good habitats for biota. Many of these regions as having the presence of mangroves, seaweeds, rich molluscan diversity, mud and sand substratum. For e.g. the Shankodar area have the presence of different organisms under different phyla like Porifera, Cnidaria, Annelida, Arthropoda, Mollusca and Echinodermata. Cnidarian groups identified from the study area such as *Aiptasia* sp, *Zoanthus* sp., *Zoanthus sansibaricus* and *Palythoa* sp. were classified under Schedule I, Part K of Wild Life (Protection) Amendment Act, 2022. Dahanu creek and Tarapur creek is having mangrove ecosystems and intertidal mudflats.

Cumulative impacts due to the proposed port in the form of land reclamation, dredging, sewage release can pose a considerable threat to the biodiversity present in these ecosystems. Destruction of marine biota is considered a loss to biodiversity and resource depletion. Due to the presence of different cnidarian and molluscan diversity, the environmental cell of the proposed port can plan and monitor Shankodar area as a site for long term biodiversity monitoring which will eventually lead to the conservation of that area.

Threats to the biodiversity priority areas can be minimized with strict implementation of mitigatory measures proposed (Chapter 5) for each type and stage of activities related to the proposed port development. Adopting a proper management plan for solid waste and oil pollution will help to conserve these locations. For the long term conservation of these eco-sensitive sites, JNPA and its environment cell can implement activities like regular monitoring of these sites, scientific research, eco-restoration and conservation activities of degraded sites and organize public awareness and education programmes.

6.2.3 Community/stakeholder involvement in conservation activities

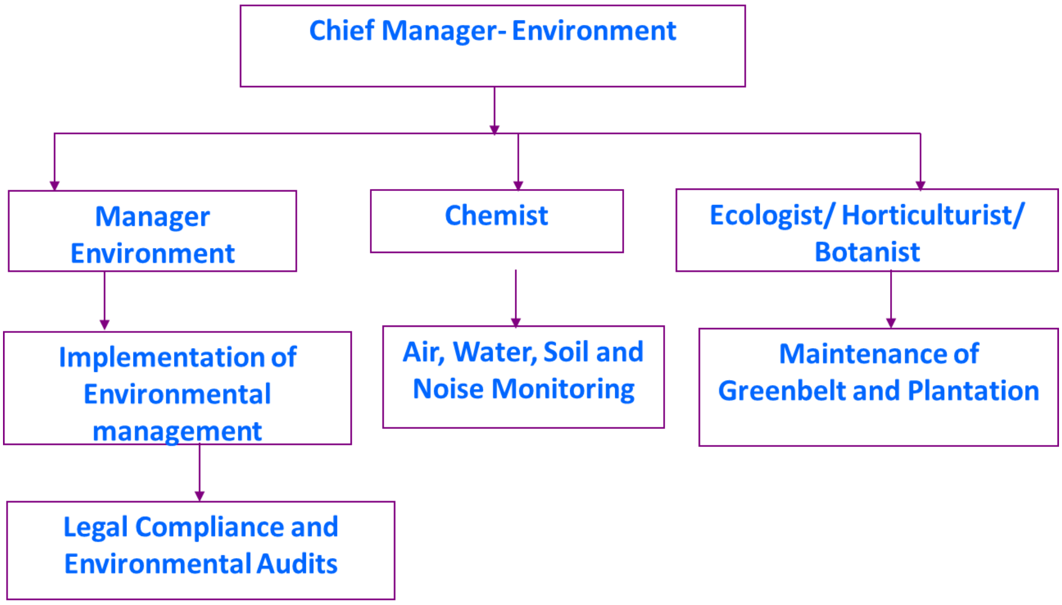
Scientific information and knowledge about the current status of biodiversity, values associated with it and necessary conservation methods will be communicated to the public/stakeholders. Important aspects to be covered under this are given below:

- Importance of natural biodiversity and ecosystem functions and linkages with human survival and well-being
- Biodiversity conservation should be the common aim for ecosystem-based management for all agencies involved in the marine environment
- Setting up objectives for local stakeholders to improve the biodiversity by applying traditional conservation practices
- Maintaining a healthy relationship between port authorities and local stakeholders
- Supporting local communities with incentives for biodiversity conservation and management
- Practicing good governance and sustainable ecosystem management practices involves local participation and transparency
- Conducting outreach programmes and workshops for stakeholder knowledge improvement and conservation of marine life
- Establishing local self-help groups to empower and educate women and local fisherman communities

Based on these concepts local village level stakeholders communities can be established for conservation and restoration of marine ecosystems near the proposed port area. JNPA with through its environmental team can provide financial support fully/partially as part of their CSR activities.

6.2.4 Institutional arrangements for marine environmental management

Institutional arrangements for marine management of the environment fall under the broad categories of project monitoring and post-project monitoring; inspections of machinery; solid, liquid and hazardous waste management; ballast water management; implementation of MARPOL 73/78; Identify environmental aspects for normal, abnormal and emergency conditions; structures and pollution combating equipment; petroleum spill control and combating; ensure implementation of standard operating procedures; evaluate any non-conformity to the environmental standards and green belt development. For this purpose, JNPA should establish an Environment Management Cell (EMC) directly under the control of the Chief Executive and the cell can control the environmental related issues on the marine segment. The model structure for the environment management cell is given below:



Apart from these routine monitoring and inspections, EMC should responsible for arranging training programmes, refresher courses, mock rehearsals etc. The records of all these activities should be maintained as a part of the overall record system. The proposed port should have an operational Tier I Oil Spill Contingency Plan approved by the Indian Coast Guard, which is designed to deal with Tier-I oil spillage and to provide guidance for the initial response to Tier – II and Tier – III oil spills. The plan details the contingency arrangements for responding to actual or threatened oil pollution incidents at the port.

6.2.5 Mechanism for implementation of mitigative measures in the marine segment

For an efficient implementation and supervision of marine environmental and biodiversity management and to mitigate the environmental impacts, which are likely to arise due to the various phases of construction like dredging, reclamation and sea wall construction and during the operational phases of the proposed greenfield port can be achieved through a well-organized institutional mechanism.

Implementation of appropriate marine environmental management plans and SOPs during different work stages is a requirement for the overall success of environment management. The persons assigned to this task should put up the various institutional arrangement needed for the implementation of effective environmental mitigative measures. Existing JNPAs in-house Pollution Control &

Environment Management Cell can take the lead in these aspects of environmental issues.

6.2.6 Approach towards voluntary compliance

JNPA should successfully implement Environment, Health & Safety Management System (EHS MS) based on recognized international standards for environmental and safety management systems like ISO 14001, OHSAS 18001, Social Accountability (SA) 8000 and International Maritime Organisation (IMO) and MARPOL 73/78 guidelines. The main objective behind this is to place a system to assess, monitor and manage various environmental performances in the field of marine, land, air, water, soil and noise which can lead to improve pollution prevention in these segments. Common procedures that can be adopted are given below:

- Identification of various environmental compartments and sensitive areas (classified under CRZ-I) and land, air and water which can be affected by the daily operation of the port
- Find out the major operations that have significant environmental impacts
- Implementation of environmental legislations and policies
- Charting timelines for achieving environmental and biodiversity management goals
- Frame an Environmental Management System

Effective and proper implementation of these objectives is entrusted with JNPA and its environmental management team.

6.2.7 Management sections cover under MARPOL

At an international level, various legal instruments and controls have been provided to encourage regulation and enforcement by flag states, coastal states and port state control. For example, the International Maritime Organization (IMO) convention on Marine Pollution MARPOL 73/78 outlines measures aimed at completely eliminating the wilful and intentional discharge into the seas of oil and noxious or hazardous substances, chemicals, packaging, sewage and garbage. Specifically Annexes I, II, III, IV, V and VI of MARPOL 73/78 identify these sources and by their provision, port authorities are obligated to provide reception facilities for the handling of a range of waste including oil, chemical and garbage. Ports are also required to produce a Port Waste Management Plan (PWMP), including information on the type and location of facilities, notification requirements, details of providers and costs. These plans are to be made available to port users, to ensure that vessels needs are met promptly with no undue delay.

6.2.8 Legal Framework

Many acts and laws were established to regulate the activities and prevention of pollution in the coastal regions of India. The environment management cell of the proposed port has to see the implications of these during the time of construction and operation of the port. Some of the important ones are given below:

- Indian Ports Act, 1908
- Coast Guard Act, 1950
- Merchant Shipping Act, 1954
- Wildlife Protection Act, 1972
- Maritime Zone Act, 1974
- Water (Prevention and control of pollution) Act: 1974
- Forest Conservation Act, 1980
- The Environmental Protection Act, 1986
- Hazardous Waste Management Act, 1989
- Coastal Regulation Zone's (CRZ) Notification, 1991
- National Environmental Tribunal Act, 1995
- The National Environment Appellate Authority Act, 1997
- Biodiversity Act, 2002

Convention and policies to which India is a signatory

- United Nations Convention on the Law of Sea (UNCLOS)
- Ramsar Convention, 1971
- MARPOL 73/78
- Convention on Migratory Species, 1979
- Convention on Biological Diversity (CBD), 1992
- Basel Convention, 1992
- International Union for Conservation of Nature (IUCN)

6.2.9 Cost of Marine Environment Management Plan

The responsibility of MEMP action items lies with Jawaharlal Nehru Port Authority and their construction contractors. The cost could be a part of the construction contract rates and prices. The item-wise break-up of various activities of EMP is listed below. The list is not exhaustive, it gives a broad idea of the various items for which funds need to be allocated in the cost estimate of an MEMP. The funds to be allocated for the various heads are given below:

Personnel	
➢ Instrument/boat hiring	Rs. 30.0 lakhs annually
➢ Training	Rs. 10.0 lakhs annually
Marine Environmental Monitoring (Involvement of thirdparty monitoring)	
➢ Water, sediment quality and marine biota	Rs. 120.0 lakhs annually
➢ Shoreline change monitoring	Rs. 75.0 lakhs annually
➢ Stakeholder's/community programmes for biodiversity conservation	Rs. 50.0 lakhs annually

6.2.10 Marine Environment Monitoring During Construction and Operational Phase

The monitoring plan during the construction and operational phases of the project includes the parameters to be monitored, number of sampling locations, sampling frequency, duration, implemental agency and guiding standards, as summarized in Table 6.2A.

6.2.10.1Baseline studies

As a first important step towards the maintenance of the health of the marine ecology of the study area, critical locations are to be carefully selected around the project as monitoring sites for periodic health checks with respect to water quality, sediment quality and flora and fauna. The results presented in this report are adequate to identify the monitoring sites. The parameters to be monitored are listed below.

i) Water Quality: Water samples near-surface and bottom for temperature, pH, SS, salinity, DO, BOD, dissolved phosphate, nitrate, nitrite, ammonia phenols and Petroleum hydrocarbons.

ii) Sediment Quality: Sediment from sub-tidal and intertidal regions to be analysed for heavy metals, organic carbon, texture and petroleum hydrocarbons.

iii) Flora and Fauna: Biological characteristics are to be assessed based on primary productivity, phytopigments, phytoplankton populations and their generic diversity, biomass, population and group diversity of zooplankton, biomass, population and group diversity of benthos, fishery diversity, mangrove diversity & assessment and regular monitoring of the marine mammal’s population around the port area.

iv) Survey along the coastline: Survey to be carried out to assess the shoreline changes and the nearby locatedcreek geomorphology if any.

v) Assessment: The results of each monitoring should be carefully evaluated to identify changes if any, beyond the natural variability identified through baseline studies.Gross deviation from the baseline may require a thorough review of operations at the berth to identify the causative factors leading to these deviations and accordingly, corrective measures to reverse the trend will be necessary.

Acomprehensive marine quality-monitoring program with periodic investigations at predetermined locations (8-10) by a competitive agency is a practical solution to ensure quality data acquisition. This can be a continuation of the study designed for baseline quality. The parameters listed in the baseline study are to be included in the post-project monitoring program. The results of each monitoring should be carefully evaluated to identify changes if any, beyond the natural variability identified through baseline studies.

Table 6.3 A Monitoring Framework

Sr No	Project activity/stage	Monitoring indicator	Frequency	Responsibility
1	Construction	Reclamation area	Once - at time of detailed alignment survey and design	JNPA
		Sea wall alignment and location	Once - at time of detailed alignment survey and design	JNPA
		Alignment of sheet piles	Once - at time of detailed alignment survey and design	JNPA
		Noise during construction	Once – during construction machinery specification	JNPA and assigned contractor
		Oil spill containment and spill cleanup	Once – Built-in product specification	JNPA
		Sewage disposal system	Once – in tender specification	JNPA
		Fire prevention and fire protection equipment Monitoring	Once – in tender specification	JNPA
		Hazardous materials management plan	Once – in tender specification	JNPA
		Water quality monitoring	Every two weeks	JNPA and assigned contractor
		Discharge from construction vessels	Every two weeks	JNPA
2	Operation and Maintenance	Effectiveness of Training programs and plan	Once in a year	JNPA
		Water, sediment and marine biota monitoring	Twice in a year	JNPA and assigned contractor
		Shoreline change monitoring	Once in a year	JNPA and assigned contractor

6.2.11 Disaster Management Plan (DMP)

Disaster is an unpleasant sudden event of such a magnitude that may cause extensive damage to life or property due to natural calamities like an earthquake, flood, cyclones, landslides, lightning etc. The purpose of DMP is to give an approach to detailed organizational responsibilities, actions, reporting requirements and support resources available to ensure effective and timely management of emergencies.

6.2.11.1 Purpose of Disaster Management Plan

- Design contingency plan, taking into account the accident scenario and natural disasters.
- Safeguard personnel to prevent injuries or loss of life by protecting them from the hazard and evacuating from the site on short notice.
- Obtain early warning of emergency conditions so as to prevent impact on personnel, assets and environment.
- Ensure safety of people, protect the environment and safeguard commercial considerations.
- Ensure immediate response to an emergency situation with an effective communication network and organized procedures.
- Provide guidance to help stakeholders to take appropriate action to prevent accidents and to mitigate adverse effects of accidents that do nevertheless occur.
- Minimize the overall impact of the event at the berth.

6.2.12 Disaster Management Cycle

The Disaster Management Cycle (DMC) has a significant role to play. The four stages of the disaster management cycle have their own importance in terms of their implementation during, after and before the occurrence of any disaster.

a) Mitigation

Mitigation activities actually eliminate or reduce the probability of disaster occurrence, or reduce the effects of unavoidable disasters. Mitigation measures include OSHA standards, SOPs, MARPOL regulations, building codes; vulnerability analyses updates; zoning and land use management; building use regulations and safety codes; preventive health care; and public education.

b) Preparedness

The goal of emergency preparedness programs is to achieve a satisfactory level of readiness to respond to any emergency situation through programs that strengthen the technical and managerial capacity of governments, organizations, and communities. These measures can be described as logistical readiness to deal with disasters and can be enhanced by having response mechanisms and procedures, rehearsals, developing long-term and short-term strategies, public education and building early warning systems. Preparedness can also take the form of ensuring that strategic reserves of food, equipment, water, medicines and other essentials are maintained in cases of national or local catastrophes.

c) Response

The aim of emergency response is to provide immediate assistance to maintain life, improve health and support the morale of the affected population. Such assistance may range from providing specific but limited aid, such as assisting refugees with transport, temporary shelter, and food, to establishing semi-permanent settlement in camps and other locations. It also may involve initial repairs to damaged infrastructure. The focus in the response phase is on meeting the basic needs of the people until more permanent and sustainable solutions can be found. Humanitarian organizations are often strongly present in this phase of the disaster management cycle.1

d) Recovery

As the emergency is brought under control, the affected population is capable of undertaking a growing number of activities aimed at restoring their lives and the infrastructure that supports them. There is no distinct point at which immediate relief changes into recovery and then into long-term sustainable development. There will be many opportunities during the recovery period to enhance prevention and increase preparedness, thus reducing vulnerability. Ideally, there should be a smooth transition from recovery to on-going development.

6.2.13 Environmental sustainability in ports

Due to the problems of climate change as well as the increasing requirements for the logistics and transportation industry, environmental sustainability has become one of the key cornerstones on the agenda of many maritime ports. The environmental impacts of ports are quite significant, especially due to the various sources and forms of port-related emissions, such as those from seagoing vessels, heavy-duty trucks, and cargo-handling equipment. Apart from that, the port community consists of various actors and stakeholders with different perspectives and interests in terms of environmental sustainability.

The term environmental sustainability describes a broad concept, it is important to first identify key areas in the context of maritime ports. There are six core areas comes in this category. First, environmental objectives, pursuing a green strategy, as well as performance indicators, measuring the success of management efforts, need to be defined. The green strategy takes stakeholder interests, public policies and regulations, and social responsibility into account. Given this foundation, various practices and instruments exist to achieve various environmental objectives. Continuous improvement can be obtained by auditing, measuring, and monitoring the progress as a feedback function on the one hand, and by facilitating an alignment between the strategy, projects, operations, and technology. Thereby, new technological developments and advancements in the port infrastructure, for instance, may create new opportunities for adapting port strategies, business models, and operations.

6.2.14 Environmental objectives

A clear definition of strategic objectives is required to determine a coherent green strategy in accordance with the overall port strategy, stakeholder interests, external regulations and policies, and social responsibility.

- **Landlord function**: This involves the management of port-related areas and activities in a way that negative environmental effects are mitigated. Environmental implications must be considered in port related decisions and actions, such as the selection and management of tenants, infrastructure and construction, master planning, dredging, and connectivity (e.g., hinterland transport).
- **Regulatory function:** This subsumes controlling, auditing, and policy functions to not only ensure safety and security within the port but also environmental protection. The latter involves the regulation of environmental matters as well as implementation, monitoring, and sanctioning in case environmental requirements are not fulfilled.
- **Operator function:** This traditionally covers the provision of port services with respect to the physical transfer of goods and passengers between sea and land, the provision of technical-nautical services (pilotage, towage, and mooring) and a range of ancillary services. In this regard, the port needs to ensure that the environmental impact is minimized, such as by improving energy efficiency and conservation, as well as when selecting and managing subcontractors.
- **Community manager function:** A coordinating function for stakeholder management and for maintaining good relationships within the port community. Regarding this role, the port needs to facilitate environmental awareness, stimulate and ensure the adoption of green practices, coordinate environmental activities, and increase the visibility of the green efforts within the port and in public.

6.2.15 Environmental performance indicators

To measure, monitor, and report the performance and trends of environmental activities, resulting from the implementation of a green strategy, environmental performance indicators must be specified. Measuring and reporting those indicators serve as a feedback loop for port governance and management. A comprehensive set of indicators for maritime ports falls under the categories of environmental indicators specified in ISO 14031, the indicators are grouped as follows.

- **Management performance indicators (MPIs):** A set of indicators devoted to evaluating the efforts made by the port towards the implementation of an environmental management system (EMS) which is used to organize and manage environmental programs in the port. This involves, for example, indicators to assess the implementation of processes for auditing, monitoring, budgeting, training and awareness, communication, and emergency planning.
- **Operational performance indicators (OPIs):** Allow the assessment of port operations in terms of resource consumption, noise, waste management, and port development.
- **Environmental condition indicators (ECIs):** These indicators are used to measure and analyze the quality and state of environmental conditions, such as with respect to the quality of air (e.g., regarding GHG emissions like CO_2,

SO_x, NO_x), water, soil, and sediments. Indicators to show the status of specific flora and fauna species are also contained in this category.

6.2.16 Policies and regulations

A port policy can be regarded as an essential governance instrument for implementing green objectives and regulating port activities of individual actors. As environmental policies and regulations may impose substantial costs, a balance between environmental quality and economic feasibility must be sought. The government is responsible for making public policies and regulations at the local, regional, national, and supranational level, whereas the national authorities are, in some cases, the local enforcement authority of international conventions, such as regarding IMO (International Maritime Organization) conventions. Group policy measures for establishing a “green transport corridor” according to related incentives.

- **Economic incentives:** To promote energy-efficient transport, better utilization of resources, and the use of advanced environmental technologies. Common examples include tax incentives, extended gate hours, pricing strategies such as port due discounts for eco-friendly ships, penalizing and restricting access to ports, and financial incentives for modal shifts.
- **Legal incentives:** Regulations that hinder unwanted intensive transport activities or reduce/ban polluting technologies in certain. areas (e.g., low-emission zones, emission control areas), e.g., to improve access for other port actors. Examples include the Clean Truck Program in US ports (e.g., Port of Los Angeles and Long Beach) and the application of specific access rules for trucks in the Port of Rotterdam (Netherlands), where only trucks with certain emission standards can enter.
- **Supporting incentives**: Involves investments and grants for promoting the adoption and development of eco-friendly infrastructure, procedures, and technologies. Examples are truck replacement programs to facilitate the use of clean energy engines. This may also include investments in infrastructure (e.g., equipment for cold ironing, clean bunkering, renewable energy) and information technology. An example is the Maritime Singapore Green Initiative (MSGI), which has provided huge grants within several programs for reducing the environmental impact of port-related activities.
- **Voluntary incentives**: By participating in voluntary programs, companies may benefit from better public perception and might get free access to technical innovations and best practices. Often, policy-makers use voluntary incentives to test potential policies, which may reduce the transition time for participants in case the policy is implemented.

6.2.17 General management practices

Ports have been early adopters of EMS as a systematic approach to manage and certify port operations. Taking into account well-defined standards and performance indicators, the overall goal is to enhance the environmental performance, fulfillment of compliance obligations, and achievement of environmental objectives

(ISO 14001). Eco Ports has developed a basic EMS designed to facilitate the environmental certification and specifically adapted to the needs of maritime ports. It is built from elements of the ISO 14001 system, facilitates environmental certification, and can be implemented by applying the port environmental self-diagnosis method (SDM) and implementing the port environmental review system (PERS), allowing the port to apply for a certificate.

An environmental management information system (EMIS) further supports the management in obtaining, processing, and distributing relevant environmental information in response to internal and external requirements (e.g., regulations, policies, and stakeholder interests). Environmental risk analysis is another responsibility of ports to identify, assess, and prioritize risks associated with environmental duties and liabilities for environmental damage. As seen in Europe, a mutual collaboration between the port sector, research institutes, and specialist organizations fully supported by the ESPO, has paved the way for an improved concept of port environmental management. Moreover, an international working group, in collaboration with the International Association of Ports and Harbours (IAPH) and the World Association for Waterborne Transport Infrastructure (PIANC), is working on guidelines for sustainable reporting.

6.2.18 Infrastructure and technologies

The improvement of port infrastructure and the use of innovative port technologies can lead to enormous energy savings and reduced emissions. This includes energy-efficient vehicle and handling technologies, such as battery-powered automated guided vehicles (AGVs) or electric rubber-tired gantries, as well as the development of an improved transport infrastructure using intelligent transportation systems (ITSs) to mitigate traffic congestion and facilitate intermodal transportation. The environmental impacts of infrastructure projects, such as regarding dredging activities and techniques need to be considered.

6.2.19 Planning and optimization

Besides adapting port governance and management practices and investing in innovative infrastructure and technologies, an enormous potential for making port operations more eco-efficient lies in the consideration of environmental aspects while planning and optimizing port operations and activities. This not only involves the internal activities of individual port actors, but also the coordination and collaboration among different actors along the logistics chains. Mitigating the environmental impact means explicitly considering ECIs in the planning and optimization phase. To reduce energy consumption and better utilize available resources, several concepts have been introduced in recent years regarding landside operations, for example, the implementation of gate/truck appointment systems. Moreover, slow steaming and the management of vessel arrivals for reducing the fuel consumption of seagoing vessels.

Decision-makers usually cannot only take environmental objectives into account; often, a good trade-off between economic and environmental goals needs to be found, leading to multicriteria decision problems. Gaps in the theoretical deviation and implementation of multi objective decision support systems in maritime logistics, taking into account environmental sustainability, has to be identified for every ports for a more greener and sustainable port operations.

7 DISCLOSURE OF CONSULTANTS ENGAGED

CSIR-National Institute of Oceanography; a constituent laboratory of the Council of Scientific & Industrial Research under Ministry of Science and Technology, Government of India; is a premier oceanographic research institute of the country. Institute has the necessary expertise supported by equipment and infrastructural facilities to carry out the marine survey and EIA studies. Consultants worked in this project are the regular staff of CSIR-NIO and are listed below.

Name of consultant	Specialization	Nature of consultancy rendered
Dr. Rakesh P.S.	Biological Oceanography, Marine Pollution and Eco-toxicology	Project co-ordinator, coordinated work related to biological parameters and Biodiversity impact assessment studies and EMP
Dr. C. Mohandass	Marine Microbiology, & Molecular Biology	Associate project leader and Marine microbial biodiversity studies
Dr. Soniya Sukumaran	Biological oceanography, Benthic Biodiversity & Ecology	Associate project leader and co-ordinated the work part related to biological oceanography and Ecology
Dr. Umesh Kumar Pradhan	Chemical Oceanography and Marine Pollution	Associate project leader and co-ordinated the work components related to water and sediment quality
Dr. Manikandan Balakrishnan	Coral Biodiversity	Coral, Intertidal Ecology and diversity studies
Dr. Haridevi C.K.	Biological Oceanography, Phytoplankton Ecology	Marine biodiversity and plankton ecology of the area
Dr. Abhay B. Fulke	Marine Microbiology	Marine microbial biodiversity studies
Mr. Udayakrishnan P. B	Chemical Oceanography	Marine chemistry studies

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Table 4.1.1: Water quality at sub-tidal region off Vadhvan during December 2020

Parameter	Level	VN1	VN2			VN3	VN4	VN5	VN6			VN7	VN8	VN9
		*Avg.	Min.	Max.	Avg.	*Avg.	*Avg.	*Avg.	Min.	Max.	Avg.	*Avg.	*Avg.	*Avg.
Temperature (°C)	S	26.5	27.5	27.5	27.5	27.5	27.5	26.5	26.0	27.0	26.5	27.5	26.5	26.0
	B	26.5	27.0	27.0	27.0	27.0	27.0	26.0	26.0	26.5	26.3	27.0	25.0	25.0
	AT	27.5	28.0	28.5	28.3	28.0	28.5	27.5	25.5	27.5	26.5	28.5	26.5	26.5
pH	S	8.2	8.1	8.1	8.1	8.1	8.2	8.2	8.1	8.2	8.1	8.1	8.2	8.1
	B	8.2	8.1	8.1	8.1	8.1	8.2	8.1	8.1	8.2	8.2	8.1	8.2	8.2
SS (mg/L)	S	18	32	36	34	57	22	11	20	116	93	20	42	129
	B	25	22	117	70	96	40	17	83	113	98	17	404	505
Salinity (PSU)	S	35.3	34.8	35.2	35.0	35.0	35.1	35.2	35.2	35.2	35.2	35.0	35.2	35.3
	B	35.1	35.1	35.2	35.2	35.1	35.1	35.2	35.1	35.2	35.2	34.9	35.2	35.3
DO (mg/L)	S	6.2	6.8	7.2	7.0	6.7	6.7	7.2	6.2	6.5	6.3	6.8	7.2	6.5
	B	5.7	6.8	6.8	6.8	6.8	6.8	6.7	5.5	6.2	5.9	7.0	6.0	6.3
BOD (mg/L)	S	3.6	3.6	3.6	3.6	3.9	3.6	3.0	3.0	3.0	3.0	3.0	3.9	3.9
	B	3.0	3.0	3.0	3.0	3.6	3.6	2.6	2.3	3.3	2.8	3.0	2.6	4.2
PO_4^{3-}-P (µmol/L)	S	0.8	1.5	2.8	2.2	2.0	1.8	1.0	0.8	1.1	0.9	1.8	0.9	1.1
	B	1.0	2.2	3.3	2.8	1.9	1.8	0.8	0.9	1.3	1.1	2.2	1.1	1.2
NO_3^--N (µmol/L)	S	9.5	7.6	8.4	8.0	12.2	13.2	13.5	7.6	8.6	8.1	10.3	8.7	10.5
	B	9.7	8.8	11.7	10.2	14.8	12.7	13.3	8.0	9.1	8.6	11.3	9.6	9.9
NO_2^--N (µmol/L)	S	0.7	0.0	0.3	0.2	0.1	0.1	0.8	0.7	0.7	0.7	0.2	0.7	0.7
	B	0.7	0.2	0.3	0.3	0.2	0.2	0.9	0.6	0.7	0.6	0.3	0.7	0.9
NH_4^+-N (µmol/L)	S	4.2	1.5	2.1	1.8	1.8	1.1	2.6	3.2	3.3	3.2	1.1	2.8	3.7
	B	4.5	1.2	1.4	1.3	1.6	0.8	2.7	3.1	3.3	3.2	1.2	3.0	3.8
PHc (µg/L)	S	4.8	5.5	5.7	5.6	3.7	3.5	2.7	2.9	3.3	3.1	2.5	2.6	2.1
Phenol (µg/L)	S	62.3	56.7	57.6	57.1	77.0	78.6	46.6	52.0	52.5	52.2	43.4	34.1	29.2

*Avg. Values represents average of two readings;Max.and Min. are based on the limits observed during different tides; AT: Air Temperature in °C

Table 4.2.1: Sediment quality at sub-tidal region off Vadhvan during December 2020

Station Code	Sand (%)	Silt (%)	Clay (%)	Al (%)	Cr (µg/g)	Mn (µg/g)	Fe (%)	Co (µg/g)	Ni (µg/g)	Cu (µg/g)	Zn (µg/g)	Hg (µg/g)	C_{org} (%)	P (µg/g)	PHc (µg/g wet wt.)
VN1	1.6	87.0	11.4	6.7	178	897	6.7	35	51	97	83	0.04	1.4	645	0.8
VN2	4.8	79.6	15.6	7.3	209	903	7.2	37	56	105	89	0.12	1.3	604	1.1
VN3	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
VN4	1.5	84.5	14.0	7.2	191	908	7.0	37	54	102	88	0.15	1.4	680	0.7
VN5	0.9	81.8	17.3	6.9	184	966	6.8	36	52	98	86	0.07	1.4	662	0.3
VN6	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
VN7	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
VN8	3.8	81.9	14.3	6.4	159	858	6.2	30	46	89	74	0.10	1.9	640	0.1
VN9	3.4	80.6	16.0	7.4	197	1035	7.2	36	55	103	90	0.08	1.6	784	0.2

NC: No sediment collection during the study period

Table 4.3.1: Microbial counts in surface water (CFU/ml) at Vadhvan during December 2020

Type of bacteria	VN1	VN2		VN3	VN4	VN5	VN6		VN7	VN8	VN9
	Spot	Tidal		Spot	Spot	Spot	Tidal		Spot	Spot	Spot
		Eb	Fld				Eb	Fld			
TVC (*10^2)	10	15	41	100	120	40	40	84	200	68	11
TC	10	10	12	26	10	NG	NG	NG	NG	6	NG
FC	2	6	8	10	6	NG	NG	NG	NG	4	NG
ECLO	1	4	8	8	2	NG	NG	NG	NG	2	NG
SFLO	NG	N	1	NG	2	NG	NG	NG	NG	NG	NG

Table 4.3.2: Microbial counts in sediment (CFU/g) at Vadhvan during December 2020

Type of bacteria	VN1	VN2	VN3	VN4	VN5	VN6	VN7	VN8	VN9
TVC (*10^3)	30	70	RB	130	88	RB	RB	100	78
TC	NG	NG		NG	NG			NG	NG
FC	NG	NG		NG	NG			NG	NG
ECLO	NG	NG		NG	NG			NG	NG
SFLO	NG	NG		NG	NG			NG	NG

NG: No growth; RB: Rocky Bottom

Table 4.3.3: Distribution of Phytopigments (Parenthesis) at different stations of Vadhvan during December 2020

Station	Date	Time & Tide	CHLOROPHYLL		PHAEOPHYTIN		RATIO	
			S	B	S	B	S	B
VN1	02/12/2020	14:45 F.Fl	0.6	0.4	0.2	0.3	2.9	1.4
			0.4	0.3	0.1	0.3	3.1	1.3
VN2	01/12/2020	08:45 Fl-Eb	0.7	0.6	0.1	0.2	6.7	3.0
		13:15 Eb-Fl	0.7	0.5	0.2	0.3	2.9	1.7
VN3	01/12/2020	10:30 Eb-Fl	0.6	0.6	0.5	0.5	1.2	1.3
			0.6	0.7	0.5	0.5	1.2	1.4
VN4	01/12/2020	12:44 Eb-Fl	0.4	0.4	0.1	0.2	3.8	1.8
			0.5	0.5	0.2	0.3	3.0	2.0
VN5	02/12/2020	12:45 Eb-Fl	0.4	0.4	0.7	0.7	0.6	0.5
			0.3	0.4	0.5	0.7	0.6	0.6
VN6	02/12/2020	08:30 Fl-Eb	0.4	0.4	0.4	0.3	1.0	1.1
		13:30 Eb-Fl	0.4	0.4	0.5	0.4	0.8	1.0
VN7	01/12/2020	13:15 Eb-Fl	0.5	0.5	0.4	0.6	1.3	0.9
			0.6	0.6	0.5	0.6	1.3	0.9
VN8	02/12/2020	10:45 Eb-Fl	0.4	0.2	0.1	0.5	5.1	0.4
			0.4	0.2	0.1	0.4	7.0	0.5
VN9	02/12/2020	09:45 Fl-Eb	0.5	0.5	0.3	1.2	1.4	0.4
			0.5	0.7	0.4	1.5	1.4	0.4

Table 4.3.4: Range and average of phytopigments at different stations of Vadhvanduring December 2020

Station	Date	CHLOROPHYLL				PHAEOPHYTIN				RATIO			
		S		B		S		B		S		B	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
		Avg		Avg		Avg		Avg		Avg		Avg	
VN1	02/12/2020	0.4	0.6	0.3	0.4	0.1	0.2	0.3	0.3	2.9	3.1	1.3	1.4
		0.5		**0.4**		**0.2**		**0.3**		**3.0**		**1.3**	
VN2	01/12/2020	0.7	0.7	0.5	0.6	0.1	0.2	0.2	0.3	2.9	6.7	1.7	3.0
		0.7		**0.5**		**0.2**		**0.2**		**4.8**		**2.3**	
VN3	01/12/2020	0.6	0.6	0.6	0.7	0.5	0.5	0.5	0.5	1.2	1.2	1.3	1.4
		0.6		**0.6**		**0.5**		**0.5**		**1.2**		**1.3**	
VN4	01/12/2020	0.4	0.5	0.4	0.5	0.1	0.2	0.2	0.3	3.0	3.8	1.8	2.0
		0.5		**0.5**		**0.1**		**0.2**		**3.4**		**1.9**	
VN5	02/12/2020	0.3	0.4	0.4	0.4	0.5	0.7	0.7	0.7	0.6	0.6	0.5	0.6
		0.4		**0.4**		**0.6**		**0.7**		**0.6**		**0.6**	
VN6	02/12/2020	0.4	0.4	0.4	0.4	0.4	0.5	0.3	0.4	0.8	1.0	1.0	1.1
		0.4		**0.4**		**0.5**		**0.4**		**0.9**		**1.0**	
VN7	01/12/2020	0.5	0.6	0.5	0.6	0.4	0.5	0.6	0.6	1.3	1.3	0.9	0.9
		0.5		**0.5**		**0.4**		**0.6**		**1.3**		**0.9**	
VN8	02/12/2020	0.4	0.4	0.2	0.2	0.1	0.1	0.4	0.5	5.1	7.0	0.4	0.5
		0.4		**0.2**		**0.1**		**0.5**		**6.1**		**0.4**	
VN9	02/12/2020	0.5	0.5	0.5	0.7	0.3	0.4	1.2	1.5	1.4	1.4	0.4	0.4
		0.5		**0.6**		**0.4**		**1.4**		**1.4**		**0.4**	

Table 4.3.5: Distribution of phytoplankton population at different stations of Vadhvan during December 2020

Station	Date	Time & Tide	Cell count (no x 10^3 Cells/ l)		Total genera	
			S	B	S	B
VN 1	02/12/2020	14:45 F.Fl	25.2	11.0	9	7
VN2	01/12/2020	08:45 Fl-Eb	21.6	23.2	12	10
		13:15 Eb-Fl	10.2	17.2	8	10
VN3	01/12/2020	10:30 Eb-Fl	44.0	31.0	13	12
VN4	01/12/2020	12:44 Eb-Fl	30.0	33.2	9	15
VN5	02/12/2020	12:45 Eb-Fl	107.4	73.2	11	11
VN6	02/12/2020	08:30 Fl-Eb	70.0	123.2	12	10
		13:30 Eb-Fl	84.2	37.6	13	8
VN7	01/12/2020	13:15 Eb-Fl	83.2	151.2	12	14
VN8	02/12/2020	10:45 Eb-Fl	127.4	71.2	15	7
VN9	02/12/2020	09:45 Fl-Eb	44.0	21.2	11	8

Table 4.3.6: Range and average of phytoplankton at different stations of Vadhvan during December 2020

Station	Date		Cell count (no x 10^3 Cells/ L)		Total genera (no)		Major genera	
			S	B	S	B	S	B
VN 1	02-12-2020		25.20	11	9	7	*Skeletonema Cylindrotheca Thalassiosira Amphora*	*Thalassiosira Thalassiothrix Navicula Cylindrotheca*
VN 2	01-12-2020	Min	10.2	17.2	8	10	*Thalassiosira Cylindrotheca Amphora Pleurosigma*	*Pleurosigma Cylindrotheca Thalassiosira Amphora*
		Max	21.6	23.2	12	10		
		Av	15.9	20.2	10	10		
VN 3	01-12-2020		44.0	31.0	13	12	*Thalassiosira Cylindrotheca Fragillaria Pinnularia*	*Thalassiosira Navicula Cylindrotheca Fragilaria*
VN 4	01-12-2020		30.0	33.2	9	15	*Fragillaria Cylindrotheca Thalassiosira Pinnularia*	*Thalassiosira Nitzschia Pleurosigma Thalassiothrix*
VN 5	02-12-2020		107.4	73.2	11	11	*Thalassiosira Navicula Cylindrotheca Nitzschia*	*Thalassiosira Nitzschia Fragillaria Skeletonema*
VN 6	02-12-2020	Min	70.0	37.6	12	8	*Thalassiosira Cylindrotheca Navicula Nitzschia*	*Thalassiosira Nitzschia Cylindrotheca Navicula*
		Max	84.2	123.2	13	10		
		Av.	77.1	80.4	13	9		
VN 7	01-12-2020		83.2	151.2	12	14	*Thalassiosira Navicula Peridinium Guinardia*	*Thalassiosira Navicula Cylindrotheca Pinnularia*

VN 8	02-12-2020		127.4	71.2	15	7	*Thalassiosira Cylindrotheca Nitzschia Navicula*	*Thalassiosira Navicula Pseudo-nitzschia Guinardia*
VN 9	02-12-2020		44.0	21.2	11	8	*Thalassiosira Navicula Pseudo-nitzschia Nitzschia*	*Thalassiosira Peridinium Cylindrotheca Pleurosigma*

Table 4.3.7: Percentage composition of phytoplankton population at different stations of Vadhvan during December 2020

Genera name	Stations									
	VN1	VN2	VN3	VN4	VN5	VN6	VN7	VN8	VN9	Av.
Diatoms										
Amphora	2.76	9.97	4.00	0.32	1.33	2.54	2.99			2.66
Bellerochea						0.32	0.85			0.13
Chaetoceros				6.33						0.70
Coscinodiscus		1.66	1.60				0.17			0.38
Cylindrotheca	16.57	15.24	17.33	11.08	5.54	10.16	5.97	6.55	6.13	10.51
Dactyliosolen				3.16					6.13	1.03
Ditylum		1.39	1.60	0.32	0.11	0.38			0.31	0.46
Fragilaria			12.00	15.82	6.09	2.22				4.02
Guinardia					1.11	2.54	4.69	1.51		1.09
Gyrosigma									3.07	0.34
Leptocylindrus						0.44		2.01		0.27
Lithodesmium		1.39	1.33		1.11	0.63		2.01	4.60	1.23
Navicula	6.08	4.16	13.33	4.75	13.29	8.57	8.53	5.54	7.67	7.99
Nitzschia		1.39	5.33	6.33	7.75	12.06	4.69	4.03	7.67	5.47
Odontella		1.39								0.15
Pinnularia	1.66	5.54	9.33	6.33	2.21	2.60	3.84	2.01	3.07	4.07
Pleurosigma	0.55	19.39	5.33	4.75	2.21	0.70		0.30	6.13	4.37
Pseudo-nitzschia						1.27	2.56	4.03	7.67	1.73
Rhizosolenia	2.76	1.39		1.58					4.60	1.15

Skeletonema	33.15		2.13		3.88			3.02		4.69
Surirella		1.39	2.67				0.85			0.54
Thalassionema		1.66		1.27	2.21	3.17				0.92
Thalassiosira	22.10	18.01	21.33	31.65	52.05	46.35	54.61	60.93	38.34	38.37
Thalassiothrix	8.29	4.71	2.67	3.16		3.49	1.71			2.67
Dinoflagellates										
Alexandrium							2.13	2.01		0.46
Ceratium		1.39								0.15
Dinophysis							0.43			<0.1
Gymnodinium							0.43	2.01		0.27
Gyrodinium		2.77								0.31
Oxytoxum								1.51		0.17
Peridinium		1.39			1.11	2.54	4.69	1.01	4.60	1.70
Prorocentrum	0.55									<0.1
Scrippsiella	2.76	4.43		3.16						1.15
Cryptophytes										
Plagioselmis	2.76	1.39								0.46
Teleaulax								1.51		0.17
Euglenophytes										
Eutreptiella							0.85			<0.1

Table 4.3.8: Distribution of Zooplankton of Vadhvan during December 2020

Station (Date)	Time (h)/ Tide	Biomass (ml/100m^3)	Population (nox10^3/100m^3)	Total Group (no)	Major groups (%)
VN1 (02.12.2020)	14:45 F.Fl	7.7	99.7	21	Copepods (90.2) Lamellibranchs(5.9) Chaetognaths (1.8) Decapod larvae(1.6) Gastropods (0.4) Fish larvae (0.1) Others (0.1)
	14:55 F.Fl	5.4	60.9	18	Copepods (83.6) Lamellibranchs (9.5) Decapod larvae(4.8) Chaetognaths (1.6) Gastropods (0.3) Fish larvae (0.1) Others (0.1)
VN2 (01.12.2020)	08:45 Fl-Eb	1.9	23.6	15	Copepods (84.6) Decapod larvae(8.5) Lamellibranchs (5.3) Fish eggs (0.8) Fish larvae (0.5) Chaetognaths (0.1) Others (0.2)
	13:15 Eb-Fl	8.4	110.5	21	Copepods (78.7) Lamellibranchs(10.2) Decapod larvae (9.3) Chaetognaths (0.9) Fish eggs (0.2) Gastropods (0.2) Fish larvae (0.2) Mysids (0.1) Stomatopods (0.1) Others (0.1)
VN3 (01.12.2020)	10:30 Eb-Fl	3.4	47.4	19	Copepods (66.7) Lamellibranchs(21.2) Decapod larvae(10.2) Chaetognaths (0.6) Gastropods (0.4) Mysids (0.4) Fish larvae (0.3) Others (0.1)
	10:40 Eb-Fl	1.3	18.0	18	Copepods (81.8) Lamellibranchs (9.4) Decapod larvae (6.7) Chaetognaths (0.9) Fish larvae (0.7)

					Mysids (0.2) Stomatopods (0.1) Others (0.2)
VN4 (01.12.2020)	12:44 Eb-Fl	3.3	61.0	17	Copepods (79.4) Lamellibranchs (15.8) Decapod larvae (2.6) Gastropods (0.9) Chaetognaths (0.8) Fish eggs (0.2) Fish larvae (0.2) Others (0.1)
	12:54 Eb-Fl	0.4	11.0	13	Copepods (67.5) Lamellibranchs (25.8) Gastropods (3.5) Decapod larvae (2.3) Chaetognaths (0.4) Stomatopods (0.1) Fish larvae (0.1) Polychaetes (0.1) Others (0.1)
VN5 (02.12.2020)	12:45 Eb-Fl	1.7	27.7	19	Copepods (75.2) Lamellibranchs (19.0) Decapod larvae (3.1) Gastropods (1.4) Chaetognaths (1.0) Polychaetes (0.1) Others (0.2)
	12:55 Eb-Fl	2.8	37.7	18	Copepods (60.2) Lamellibranchs (33.5) Decapod larvae (4.6) Chaetognaths (0.8) Polychaetes (0.3) Fish larvae (0.3) Gastropods (0.2) Stomatopods (0.1) Others (0.1)
VN6 (02.12.2020)	08:30 Fl-Eb	1.9	17.3	16	Copepods (73.4) Decapod larvae (14.7) Lamellibranchs (8.7) Gastropods (1.7) Chaetognaths (0.7) Amphipods (0.2) Stomatopods (0.2) Fish larvae (0.1) Siphonophores (0.1) Others (0.1)

	13:30 Eb-Fl	3.4	50.2	20	Copepods (73.2) Lamellibranchs (18.4) Decapod larvae (6.1) Chaetognaths (1.0) Gastropods (0.8) Fish larvae (0.2) Others (0.2)
VN7 (01.12.2020)	13:15 Eb-Fl	4.1	47.9	20	Copepods (63.1) Lamellibranchs (33.1) Decapod larvae (1.6) Gastropods (1.0) Chaetognaths (0.8) Stomatopods (0.2) Fish larvae (0.1) Siphonophores (0.1) Others (0.1)
	13:25 Eb-Fl	4.6	63.0	20	Copepods (59.4) Lamellibranchs (36.2) Decapod larvae (2.0) Gastropods (1.1) Chaetognaths (0.8) Stomatopods (0.1) Fish larvae (0.1) Siphonophores (0.1) Others (0.1)
VN8 (02.12.2020)	10:45 Eb-Fl	1.6	17.3	18	Copepods (71.5) Decapod larvae (17.5) Lamellibranchs (7.5) Chaetognaths (2.5) Siphonophores (0.3) Gastropods (0.2) Fish larvae (0.1) Amphipods (0.1) Fish eggs (0.1) Stomatopods (0.1) Others (0.1)
	10.55 Eb-Fl	2.1	23.9	17	Copepods (79.5) Decapod larvae (12.7) Lamellibranchs (3.9) Chaetognaths (3.2) Siphonophores (0.2) Fish eggs (0.1) Gastropods (0.1) Ostracods (0.1) Others (0.2)
VN9 (02.12.2020)	09:15 Fl-Eb	4.4	47.4	19	Copepods (73.6) Lamellibranchs (12.7) Decapod larvae (11.5) Chaetognaths (1.4) Gastropods (0.2)

					Amphipods (0.1) Siphonophores (0.1) Others (0.2)
	09:25 Fl-Eb	2.7	36.3	15	Copepods (66.2) Lamellibranchs (23.2) Decapod larvae (8.1) Chaetognaths (2.0) Siphonophores (0.2) Stomatopods (0.1) Gastropods (0.1) Fish eggs (0.1) Fish larvae (0.1) Others (0.1)

Table 4.3.9: Range and average (parenthesis) of zooplankton at Vadhvan during December 2020

Station (Date)	Biomass ($ml/100m^3$)	Population ($nox10^3/100m^3$)	Total Groups (no)	Major groups (%)
VN1 (02.12.2020)	5.4-7.7 (6.6)	60.9-99.7 (80.3)	18-21 (20)	Copepods (87.7) Lamellibranchs (7.3) Decapod larvae (2.8) Chaetognaths (1.7) Gastropods (0.3) Fish larvae (0.1) Others (0.1)
VN2 (01.12.2020)	1.9-8.4 (5.1)	23.6-110.5 (67.1)	15-21 (18)	Copepods (79.8) Lamellibranchs (9.3) Decapod larvae (9.2) Chaetognaths (0.7) Fish eggs (0.3) Fish larvae (0.2) Gastropods (0.2) Mysids (0.1) Stomatopods (0.1) Others (0.1)
VN3 (01.12.2020)	1.3-3.4 (2.3)	18.0-47.4 (32.7)	18-19 (19)	Copepods (70.8) Lamellibranchs (18.0) Decapod larvae (9.2) Chaetognaths (0.7) Fish larvae (0.4) Mysids (0.4) Gastropods (0.3) Others (0.2)
VN4 (01.12.2020)	0.4-3.3 (1.9)	11.0-61.0 (36.0)	13-17 (15)	Copepods (77.6) Lamellibranchs (17.3) Decapod larvae (2.6) Gastropods (1.3) Chaetognaths (0.7) Fish larvae (0.1) Fish eggs (0.1) Others (0.1)
VN5 (02.12.2020)	1.7-2.8 (2.3)	27.7-37.7 (32.7)	18-19 (19)	Copepods (66.5) Lamellibranchs (27.4) Decapod larvae (4.0) Chaetognaths (0.9) Gastropods (0.7) Polychaetes (0.2) Fish larvae (0.2) Others (0.1)

VN6 (02.12.2020)	1.9-3.4 (2.7)	17.3-50.2 (33.8)	16-20 (18)	Copepods (73.3) Lamellibranchs (15.9) Decapod larvae (8.3) Gastropods (1.1) Chaetognaths (0.9) Fish larvae (0.2) Stomatopods (0.1) Amphipods (0.1) Others (0.2)
VN7 (01.12.2020)	4.1-4.6 (4.3)	47.9-63.0 (55.5)	20*	Copepods (61.0) Lamellibranchs (34.9) Decapod larvae (1.8) Gastropods (1.0) Chaetognaths (0.8) Stomatopods (0.2) Fish larvae (0.1) Siphonophores (0.1) Others (0.1)
VN8 (02.12.2020)	1.6-2.1 (1.8)	17.3-23.9 (20.6)	17-18 (18)	Copepods (76.1) Decapod larvae(14.7) Lamellibranchs (5.4) Chaetognaths (2.9) Siphonophores (0.2) Fish eggs (0.1) Gastropods (0.1) Fish larvae (0.1) Amphipods (0.1) Others (0.1)
VN9 (02.12.2020)	2.7-4.4 (3.6)	36.3-47.4 (41.9)	15-19 (17)	Copepods (70.4) Lamellibranchs (17.3) Decapod larvae(10.3) Chaetognaths (1.7) Siphonophores (0.2) Gastropods (0.2) Amphipods (0.1) Stomatopods (0.1) Others (0.1)

Table 4.3.10:Percentage composition of zooplankton of Vadhvan during December 2020

Faunal Groups	VN1	VN2	VN3	VN4	VN5	VN6	VN7	VN8	VN9	Av
Foraminiferans	-	-	<0.1	-	-	-	<0.1	<0.1	-	<0.1
Siphonophores	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.2	0.2	0.1
Medusae	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ctenophores	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	<0.1
Chaetognaths	1.7	0.7	0.7	0.7	0.9	0.9	0.8	2.9	1.7	1.2
Polychaetes	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Ostracods	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copepods	87.7	79.8	70.8	77.6	66.5	73.3	61.0	76.1	70.4	75.0
Amphipods	-	<0.1	-	-	<0.1	0.1	<0.1	0.1	0.1	<0.1
Mysids	<0.1	0.1	0.4	<0.1	<0.1	<0.1	<0.1	-	<0.1	0.1
Lucifer sp.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Decapod larvae	2.8	9.2	9.2	2.6	4.0	8.3	1.8	14.7	10.0	6.2
Stomatopods	<0.1	0.1	<0.1	<0.1	<0.1	0.1	0.2	<0.1	0.1	0.1
Heteropods	<0.1	-	-	-	-	-	-	-	-	<0.1
Cephalopods	<0.1	<0.1	-	-	-	<0.1	-	<0.1	<0.1	<0.1
Gastropods	0.3	0.2	0.3	1.3	0.7	1.1	1.0	0.1	0.2	0.6
Lamellibranchs	7.3	9.3	18.0	17.3	27.4	15.9	34.9	5.4	17.3	16.5
Appendicularians	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fish eggs	<0.1	0.3	<0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.1
Fish larvae	0.1	0.2	0.4	0.1	0.2	0.2	0.1	0.1	<0.1	0.2
Isopods	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Marine insects	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pycnogonids	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	-	<0.1

Table 4.3.11: Occurrence of zooplankton of Vadhvan during December 2020

Faunal Groups	VN1	VN2	VN3	VN4	VN5	VN6	VN7	VN8	VN9
Foraminiferans	-	-	+	-	-	-	+	+	-
Siphonophores	+	+	+	+	+	+	+	+	+
Medusae	+	+	+	+	+	+	+	+	+
Ctenophores	+	+	+	+	+	+	+	-	-
Chaetognaths	+	+	+	+	+	+	+	+	+
Polychaetes	+	+	+	+	+	+	+	+	+
Ostracods	+	+	+	+	+	+	+	+	+
Copepods	+	+	+	+	+	+	+	+	+
Amphipods	-	+	-	-	+	+	+	+	+
Mysids	+	+	+	+	+	+	+	-	+
Lucifer sp.	+	+	+	+	+	+	+	+	+
Decapod larvae	+	+	+	+	+	+	+	+	+
Stomatopods	+	+	+	+	+	+	+	+	+
Heteropods	+	-	-	-	-	-	-	-	-
Cephalopods	+	+	-	-	-	+	-	+	+
Gastropods	+	+	+	+	+	+	+	+	+
Lamellibranchs	+	+	+	+	+	+	+	+	+
Appendicularians	+	+	+	+	+	+	+	+	+
Fish eggs	+	+	+	+	+	+	+	+	+
Fish larvae	+	+	+	+	+	+	+	+	+
Isopods	+	+	+	-	+	+	+	+	+
Marine insects	+	+	+	+	+	+	+	+	+
Pycnogonids	+	+	+	-	+	+	+	+	-

Table 4.3.12: Range and average of subtidal macrobenthos at Vadhvan during December 2020

Transect	Date	Biomass (wet wt.; g/m^2)	Population (no./m^2)	Faunal Group (no.)	Major Group
VN1	02/12/20	0 – 0.03 (0.02)	0-50 (25)	0-1 (1)	Cossuridae
VN2	01/12/20	0.02-1.04 (0.3)	25-100 (69)	1-2 (2)	Cossuridae, amphipoda
VN3	01/12/20	ROCKY BOTTOM			
VN4	01/12/20	0.03-1.3 (0.5)	25-200 (81)	1*	Cossuridae, Capitellidae, Magelonidae
VN5	02/12/20	0.01-0.04 (0.03)	25-50 (33)	1*	Cossuridae, Capitellidae
VN6	02/12/20	ROCKY BOTTOM			
VN7	01/12/20	ROCKY BOTTOM			
VN8	02/12/20	0 -1.1 (0.3)	0-100 (50)	0-2 (1)	Cossuridae, Cirratulidae, Pilargidae, Spionidae, mysida
VN9	02/12/20	0 - 0.1 (0.03)	0-100 (31)	0-1 (1)	Cossuridae
Overall Average		0 - 1.3 (0.2)	0-100 (48)	1-5 (1)	Cossuridae, amphipoda

Table 4.3.13: Composition (%) of subtidal macrobenthos at Vadhvan during December 2020

Faunal Groups	VN1	VN2	VN4	VN5	VN8	VN9	Av
Phylum Annelida							
Capitellidae			16.0	24.2			7.3
Cirratulidae					26		4.5
Cossuridae	100	63.8	45.8	75.8	38	100	62.6
Magelonidae			16.0				4.5
Nereididae			7.4				2.1
Pilargidae					12		2.1
Spionidae			7.4		12		4.2
Phylum Arthropoda							
Amphipoda		36.2	7.4				10.7
Mysida					12		2.1

Table 4.3.14: Range and average of intertidal macrobenthos in different water level at Vadhvan during April 2021

Transect	**Date**	**Biomass** (wet wt.; g/m^2)	**Population** (no./m^2)	**Faunal Group** (no.)	**Major Group**
IT-1 HW	31/03/21	0.002-0.036 (0.013)	25	1	Spionidae, Nereididae
IT-1 MW	26/03/21	3.4-10.7 (6.3)	875-2875 (1871)	2-7 (5)	Capitellidae, Spionidae
IT-1 LW	01/04/21	1.7-2.6 (2.0)	1100-1450 (1258)	5-9 (7)	Spionidae, Nephtyidae, Capitellidae
IT-2 HW	02/04/21	0-2.4 (1.2)	0-50 (33)	0-1 (1)	Brachyura
IT-2 MW	09/04/21	98.4	1050	2	Anomura
IT-3 HW	05/04/21	0.8-1.0 (0.9)	25-75 (58)	1-2 (1)	Brachyura, isopoda
IT-4 HW	03/04/21	NIL			
IT-4 MW	26/04/21	30.9	250	6	Polyplacophora, anomura
IT-5 HW	06/04/21	0-0.5 (0.2)	0-25 (8)	0-1 (1)	Gastropoda
IT-5 MW	08/04/21	0.3-0.5 (0.5)	575-725 (633)	4-5 (4)	Amphipoda, Orbiniidae, penaeidacea
IT-5 LW	24/04/21	162.4	575	6	Gastropoda, anomura
IT-6 HW	06/04/21	0.01-0.06 (0.03)	50-275 (133)	2-4 (3)	Harpaticoida, mysida, Isopoda
IT-6 MW	06/04/21	0.2-25.6 (14.0)	50-875 (492)	2-4 (3)	Gastropoda, isopoda
IT-6 LW	08/04/21	0.6-2.1 (1.1)	200-475 (550)	3-5 (4)	Amphipoda, Orbiniidae, Glyceridae

Table 4.3.15: Range and average of intertidal macrobenthos at Vadhvan during April 2021

Transect	**Date**	**Biomass** (wet wt.; g/m^2)	**Population** (no./m^2)	**Faunal Group** (no.)	**Major Group**
IT-1	26/03/21 31/03/21 01/04/21	0.002-10.7 (2.8)	25-2875 (1051)	1-9 (4)	Spionidae, Capitellidae
IT-2	02/04/21 09/04/21	0-98.4 (49.8)	0-1050 (542)	0-2 (1)	Brachyura, anomura
IT-3	05/04/21	0.8-1.0 (0.9)	25-75 (58)	1-2 (1)	Brachyura, isopoda
IT-4	03/04/21 26/04/21	0-30.9 (15.4)	0-250 (125)	0-6 (3)	Polyplacophora, anomura
IT-5	06/04/21 08/04/21 24/04/21	0-162.4 (54.4)	0-725 (405)	0-6 (4)	Gastropoda, amphipoda, anomura
IT-6	06/04/21 08/04/21	0.01-25.6 (5.0)	50-875 (392)	2-5 (3)	Isopoda, Orbiniidae, harpaticoida
OVERALL AVERAGE		0-162.4 (21.4)	0-2875 (429)	0-9 (3)	Spionidae, Capitellidae, anomura, amphipoda, gastropoda

Table 4.3.16: Composition (%) of intertidal macrobenthos at Vadhvan during April 2021

Faunal Groups	IT-1			IT-2		IT-3	IT-4		IT-5			IT-6			Av
	HW	MW	LW	HW	MW	HW	HW	MW	HW	MW	LW	HW	MW	LW	
Phylum Mollusca															
Gastropoda									100.0		52.5		84.4		**10.6**
Pelecypoda		3.3								2.6				1.5	**1.3**
Polyplacophora								30.0			8.7				**1.8**
Phylum Sipuncula															
Sipuncula			0.7												**0.1**
Phylum Platyhelminthes															
Turbellaria													1.7		**0.1**
Phylum Arthropoda															
Cumacea										1.3					**0.1**
Anomura					97.6			30.0			21.7				**16.1**
Cirripedia											4.3				**0.4**
Brachyura				100.0		85.7									**1.2**
Penaeidacea							NIL			1.3					**0.1**
Mysida												18.8			**0.4**
Isopoda						14.3						12.5	10.2	1.5	**1.2**
Harpaticoida												56.3			**1.1**
Amphipoda			6.6		2.4			10.0		55.3	8.7			42.4	**11.3**
Phylum Annelida															
Oligochaeta			2.0												**0.4**
Polychaeta															
Spionidae	33.3	39.4	55.0												**21.1**
Nereididae	66.7	0.7	0.7					10.0			4.3	12.5	3.4	1.5	**1.9**
Capitellidae		49.9	11.9							1.3				1.5	**16.1**

Nephtyidae		4.0	17.9												**4.4**
Pilargidae		0.9	3.3												**0.9**
Glyceridae		0.9	0.7							18.4				21.2	**3.8**
Lumbrineridae		0.9	0.7											1.5	**0.5**
Cossuridae			0.7												**0.1**
Onuphidae								10.0							**0.4**
Sabellariidae								10.0							**0.4**
Orbiniidae										19.7				28.8	**4.2**

Table 4.3.17 Dominant invertebrates of the study area

Sr No	Phylum	Scientific Name	Common name
1	**Cnidaria**	*Aiptasia* sp.*	Glass anemones
2		*Zoanthus* sp.*	Zoanthid
3		*Zoanthus sansibaricus**	Violet zoanthus
4		*Zoanthus vietnamensis**	Pink button zoanthus
5		*Palythoa* sp.*	Zoanthid
6		*Palythoa mutuki**	Zoanthid
7		*Pennaria* sp.	Hydroid
8		*Paracyathus sp.**	Solitary cup coral
9	**Arthropoda**	*Metopograpsus* sp.	Grapsid crab
10		*Pisidia* sp.	Porcelain crab
11		*Chthamalus* sp	Barnacle
12		*Megabalanus* sp.	Acorn Barnacle
13	**Mollusca**	*Indothais* sp.	Rock snail
14		*Thais* sp.	Dog winkles
15		*Gyrineum natator*	Common triton snail
16		*Cantharus spiralis*	Sea snail
17		*Indothais sacellum*	Murex snail
18		*Nerita* sp.	Blotched nerite
19		*Clypeomorus* sp	Sea snail
20	**Echinodermata**	*Asterina lorioli*	Loriol's sea star
21		*Antedon sp.*	Feather star

*Listed in Schedule I, Part K of Wild Life (Protection) Amendment Act, 2022

Table 4.3.18 Marine reptiles of the study area

Sr No	Family	Scientific Name	Common name	Conservation status
1	**Cheloniidae**	*Lepidochelys olivacea**	Olive Ridley turtle	VU
2		*Chelonia mydas**	Green turtle	EN
3		*Caretta caretta**	Loggerhead turtle	VU

*Listed in Schedule I, Part C of Wild Life (Protection) Amendment Act, 2022
VU: Vulnerable, EN: Endangered

Table 4.3.19 Checklist of Birds in the Vadhvan region

Sl No	Common name	Scientific name	Conservation status
1	Indian Gray Hornbill	*Ocyceros birostris*	LC
2	Eurasian Oystercatcher	*Haematopus ostralegus*	NT
3	Black capped Kingfisher	*Halcyon pileate*	LC
4	Greater Coucal	*Centropus sinensis*	LC
5	Asian Koel	*Eudynamys scolopaceus*	LC
6	Alpine Swift	*Apus melba*	LC
7	Asian Palm Swift	*Cypsiurus balasiensis*	LC
8	Greater Sand Plover	*Charadrius leschenaultia*	LC
9	Eurasian Curlew	*Numenius arquata*	NT
10	Lesser Black backed Gull	*Larus fuscus*	LC
11	Painted Stork	*Mycteria leucocephala*	NT
12	Black winged Kite	*Elanus caeruleus*	LC
13	Oriental Honey buzzard	*Pernis ptilorhynchus*	LC
14	Indian Golden Oriole	*Oriolus kundoo*	LC
15	Common Tailorbird	*Orthotomus sutorius#*	LC
16	Red vented Bulbul	*Pycnonotus cafer#*	LC
17	Jungle Babbler	*Argya striata*	LC
18	Chestnut tailed Starling	*Sturnia malabarica*	LC
19	Common Myna	*Acridotheres tristis*	LC
20	Jungle Myna	*Acridotheres fuscus*	LC
21	Pale billed Flowerpecker	*Dicaeum erythrorhynchos#*	LC
22	Rock Pigeon	*Columba livia*	LC
23	Spotted Dove	*Streptopelia chinensis*	LC
24	Lesser Sand Plover	*Charadrius mongolus*	LC
25	Sanderling	*Calidris alba*	LC
26	Common Sandpiper	*Actitis hypoleucos*	LC
27	Great Egret	*Ardea alba*	LC
28	Intermediate Egret	*Ardea intermedia*	LC
29	Little Egret	*Egretta garzetta#*	LC
30	Western Reef Heron	*Egretta gularis#*	LC
31	Cattle Egret	*Bubulcus ibis#*	LC

32	Indian Pond Heron	*Ardeola grayii*	LC
33	White throated Kingfisher	*Halcyon smyrnensis*	LC
34	Green Bee eater	*Merops orientalis#*	LC
35	Coppersmith Barbet	*Psilopogon haemacephalus#*	LC
36	Rose ringed Parakeet	*Psittacula krameri*	LC
37	Black Drongo	*Dicrurus macrocercus#*	LC
38	Ashy Drongo	*Dicrurus leucophaeus#*	LC
39	Indian Paradise Flycatcher	*Terpsiphone paradisi*	LC
40	House Crow	*Corvus splendens*	LC
41	Large billed Crow	*Corvus macrorhynchos*	LC
42	GrayheadedCanaryFlycatcher	*Culicicapa ceylonensis*	LC
43	Pied Bushchat	*Saxicola caprata*	LC
44	Purple rumped Sunbird	*Leptocoma zeylonica*	LC
45	Baya Weaver	*Ploceus philippinus*	LC
46	Scaly breasted Munia	*Lonchura punctulata*	LC
47	House Sparrow	*Passer domesticus*	LC
48	Greater Flamingo	*Phoenicopterus roseus#*	LC
49	Black bellied Plover	*Pluvialis squatarola*	LC
50	Kentish Plover	*Charadrius alexandrinus*	LC
51	Ruddy Turnstone	*Arenaria interpres*	LC
52	Terek Sandpiper	*Xenus cinereus*	LC
53	Gull billed Tern	*Gelochelidon nilotica**	LC
54	Whiskered Tern	*Chlidonias hybrida*	LC
55	Common Tern	*Sterna hirundo*	LC
56	Lesser Crested Tern	*Thalasseus bengalensis*	LC
57	Barn Swallow	*Hirundo rustica*	LC
58	Laughing Dove	*Streptopelia senegalensis*	LC
59	Red wattled Lapwing	*Vanellus indicus*	LC
60	Pheasant tailed Jacana	*Hydrophasianus chirurgus*	LC
61	Curlew Sandpiper	*Calidris ferruginea*	NT
62	Common Snipe	*Gallinago gallinago*	LC
63	Common Greenshank	*Tringa nebularia**	LC
64	Brown headed Gull	*Chroicocephalus brunnicephalus*	LC
65	Asian Openbill	*Anastomus oscitans*	LC
66	Little Cormorant	*Microcarbo niger#*	LC

67	Booted Eagle	*Hieraaetus pennatus**	LC
68	Montagu's Harrier	*Circus pygargus*	LC
69	Long tailed Shrike	*Lanius schach*	LC
70	Rufous tailed Lark	*Ammomanes phoenicura*	LC
71	Ashy crowned Sparrow Lark	*Eremopterix griseus*	LC
72	Oriental Skylark	*Alauda gulgula*	LC
73	Ashy Prinia	*Prinia socialis*	LC
74	Plain Prinia	*Prinia inornata*	LC
75	White browed Bulbul	*Pycnonotus luteolus#*	LC
76	Yellow eyed Babbler	*Chrysomma sinense*	LC
77	Asian Pied Starling	*Gracupica contra*	LC
78	Bank Myna	*Acridotheres ginginianus*	LC
79	Oriental Magpie Robin	*Copsychus saularis*	LC
80	Siberian Stonechat	*Saxicola maurus*	LC
81	Purple Sunbird	*Cinnyris asiaticus*	LC
82	Indian Silverbill	*Euodice malabarica*	LC
83	Western Yellow Wagtail	*Motacilla flava*	LC
84	Paddyfield Pipit	*Anthus rufulus*	LC
85	Tawny Pipit	*Anthus campestris*	LC
86	Black headed Bunting	*Emberiza melanocephala#*	LC

Source: e-Bird India,

*****Listed in Schedule I, Part B of Wild Life (Protection) Amendment Act, 2022,

Listed in Schedule II, Part B of Wild Life (Protection) Amendment Act, 2022.

LC: Least Concern; **NT**: Near Threatened

Table 4.3.20 Check list of marine mammals in India

Sl No	Common name	Scientific name	Conservation status
Order: Cetacea			
Suborder: Odontoceti (Toothed Whales)			
Family: Delphinidae (Marine Dolphins)			
1	Rough toothed dolphin	*Steno bredanensis*(Cuvier, 1828)	LC
2	Indo-Pacific	*Sousa chinensis* (Osbeck, 1765)	VU
3	Indian ocean humpback	*Sousa plumbea*(Cuvier, 1829)	EN
4	Striped dolphin	*Stenella coeruleoalba*(Meyen,	LC
5	Pantropical spotted	*Stenella attenuata*(Gray, 1846)	LC
6	Pantropical spinner	*Stenella longirostris*(Gray, 1828)	LC
7	Long-beaked common	*Delphinus capensis* (Gray, 1828)	LC
8	Indo-Pacific bottlenose	*Tursiops aduncus*(Ehrenberg,	LC
9	Common bottlenose	*Tursiops truncates* (Montagu,	LC
10	Fraser's dolphin	*Lagenodelphis hosei* (Fraser,	LC
11	Melon headed whale	*Peponocephala electra*(Gray,	LC
12	Irrawaddy dolphin	*Orcaella brevirostris*(Owen, 1866)	VU
13	False killer whale	*Pseudorca crassidens* (Owen,	LC
14	Killer whale	*Orcinus orca* (Linnaeus, 1758)	DD
15	Risso's dolphin	*Grampus griseus* (Cuvier, 1812)	LC
16	Short finned pilot whale	*Globicephala*	DD
17	Pygmy killer whale	*Feresa attenuata*(Gray, 1874)	LC
Family: Phocoenidae (Porpoises)			
18	Finless porpoise	*Neophocaena*	VU
Family: Physeteridae (Sperm Whales)			
19	Sperm whale	*Physeter macrocephalus*	VU
20	Pygmy sperm whale	*Kogia breviceps*(de Blainville,	DD
21	Dwarf sperm whale	*Kogia sima* (Owen, 1866)	DD
Family: Ziphiidae (Beaked Whales)			
22	Indo-Pacific beaked	*Indopacetus pacificus*(Longman,	DD
23	Blainville's beaked	*Mesoplodon densirostris*	LC
24	Cuvier's beaked whale	*Ziphius cavirostris*(Cuvier, 1823)	DD
Suborder: Mysticeti (Baleen Whales)			
Family: Balaenopteridae (Rorquals)			

25	Humpback whale	*Megaptera novaeangliae*	EN
26	Blue whale	*Balaenoptera musculus*	EN
27	Bryde's whale	*Balaenoptera edeni*(Anderson,	DD
28	Omura's whale	*Balaenoptera omurai (*Oishi &	DD
29	Fin whale	*Balaenoptera physalus* (Linnaeus,	EN
30	Minke whale	*Balaenoptera*	LC
Order: Sirenia			
Family: Dugongidae (Dugongs)			
31	Dugong	*Dugong dugon* (Müller, 1776)	VU

Source: Marine Mammal **|** Research and Conservation Network of India,
*LC: Least Concern; VU: Vulnerable; EN: Endangered; DD: Data Deficient

Plate 1: Photo showing collection of bottom water sample using Niskin sampler

Plate 2: Photo showing collection of sediment sample using van Veen grab

Plate 3: Photo showing collection of zooplankton using Heron Tranter (HT) net

Plate 4: Photo showing mangrove survey (*Avicennia marina)* at Tadiyala region

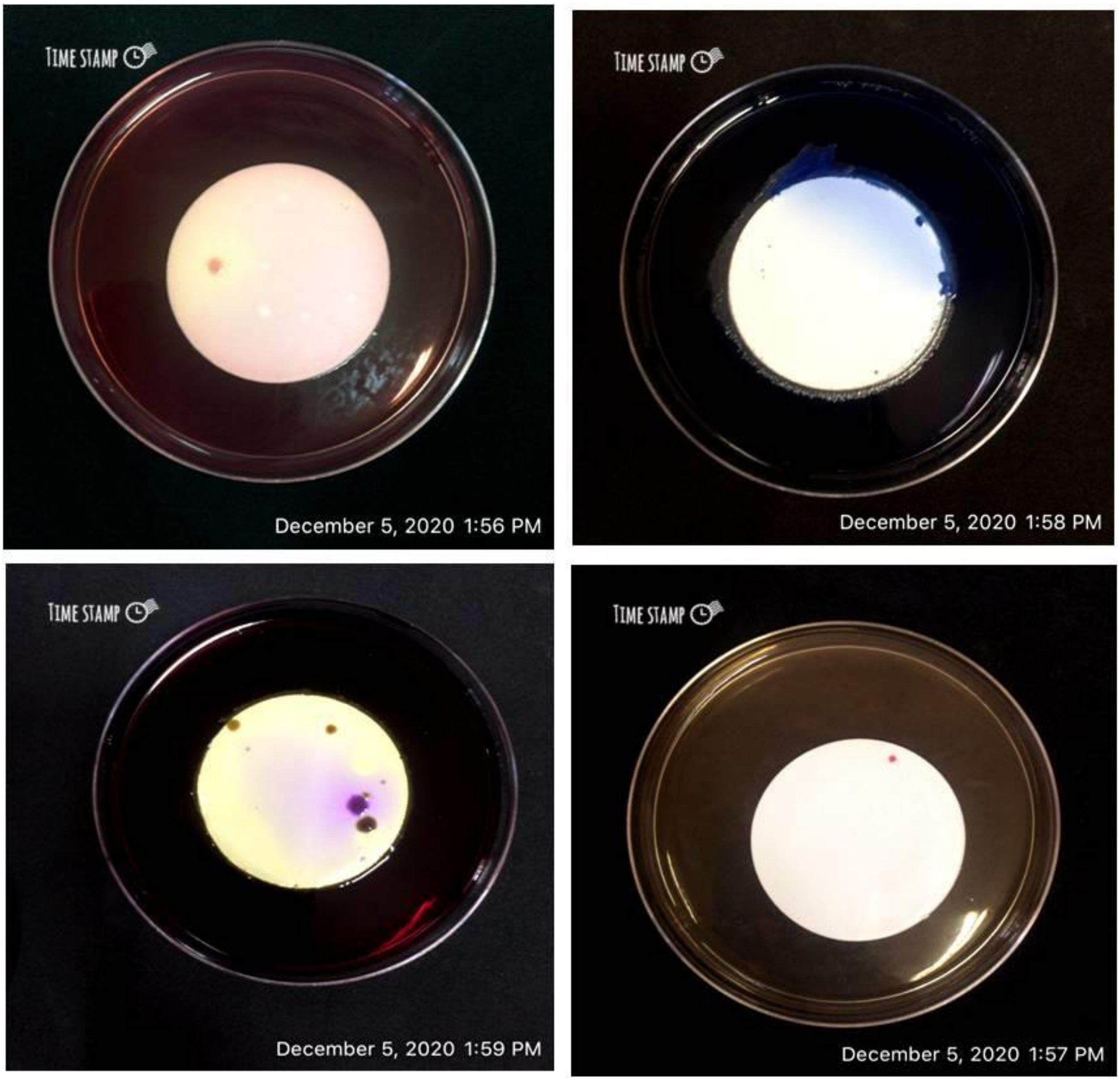

Plate 5: Growth of TC, FC, EC and SF colonies from water samples of Vadhvan on cellulose acetate membrane filters (0.45 um pore sized) on various microbial media after incubation

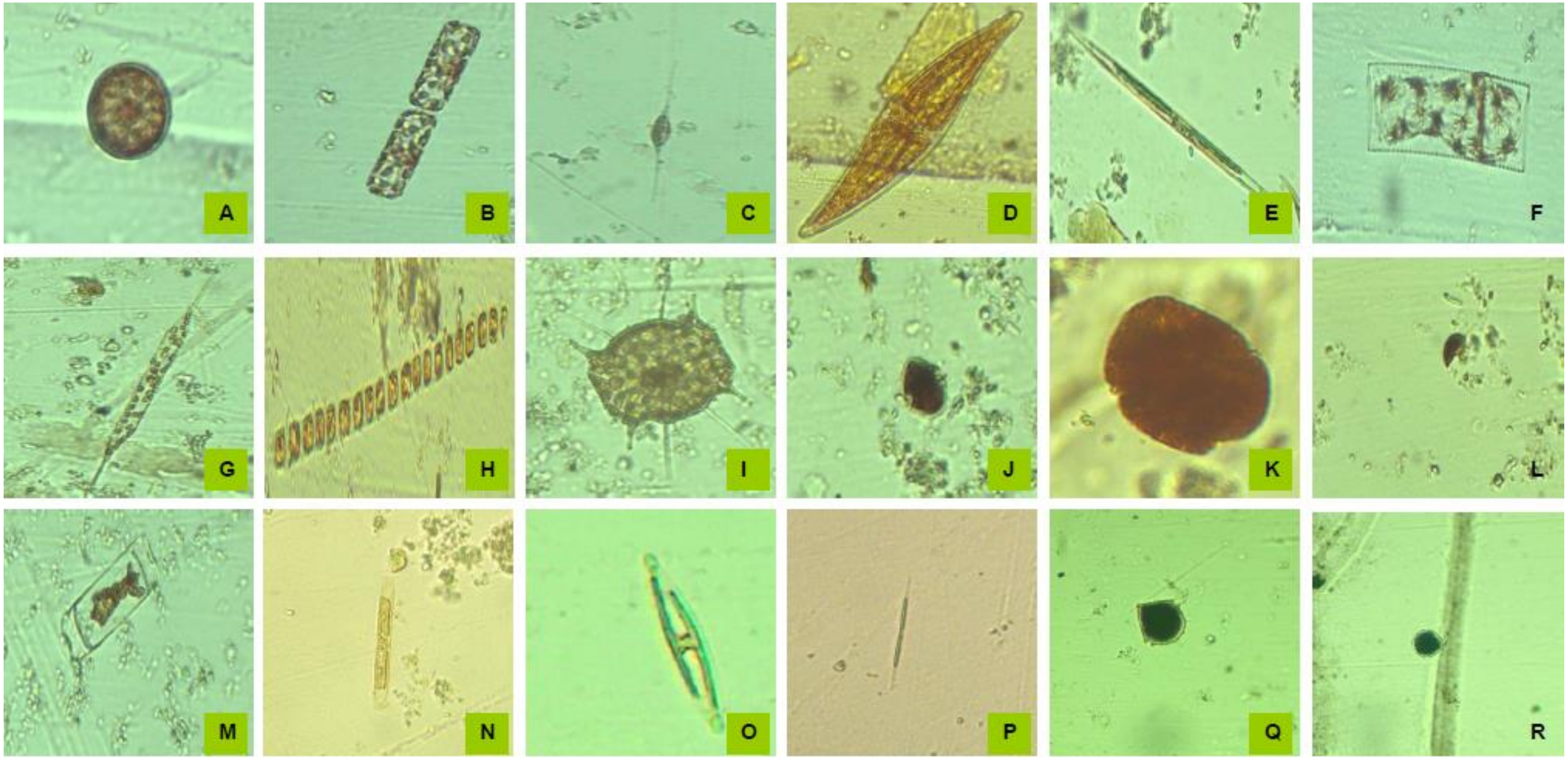

Plate 6: Phytoplankton identified from the subtidal region of Vadhvan

A:*Thalassiosira* sp. **B**:*Dactyliosolen* sp. **C**: *Cylindrotheca* sp. **D**:*Pleurosigma* sp. **E**:*Pseudo-nitzschia* sp. **F**:*Guinardia* sp. **G**:*Rhizosolenia* sp. **H**:*Skeletonema* sp. **I**:*Odontella* sp. **J**:*Alexandrium* sp. **K**:*Gymnodinium* sp. **L**:*Plagioselmis* sp. **M**:*Lithodesmium* sp. **N**:*Pinnularia* sp. **O**:*Navicula* sp. **P**:*Nitzschia* sp. **Q**:*Peridinium* sp. **R**:*Scriippsiella* sp.

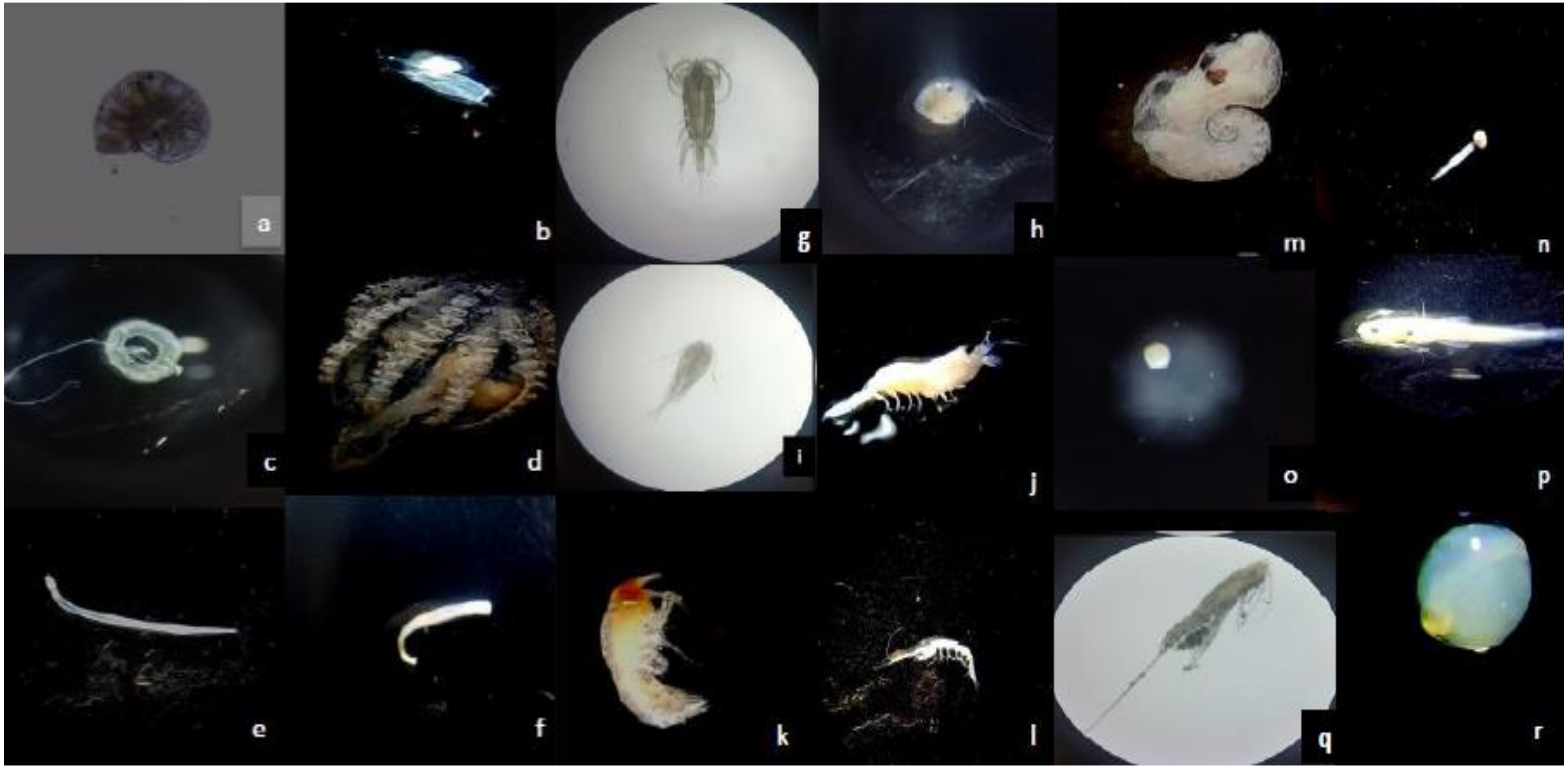

Plate 7: Zooplankton identified from the subtidal region of Vadhvan

a:Foraminiferan, **b**: Siphonophore, **c**: Medusae, **d**: Ctenophore, **e**: Chaetognath, **f**:Polychaete, **g**: Calanoid copepod, **h**: Ostracod, **i**: Cyclopoid copepod, **j**: Decapod, **k**: Amphipod, **l**:*Lucifer* sp, **m**:Heteropod, **n**:Appendicularian, **o**:Lamellibranchs, **p**: Fish larvae, **q**: Harpacticoid copepod, **r**: Fish egg

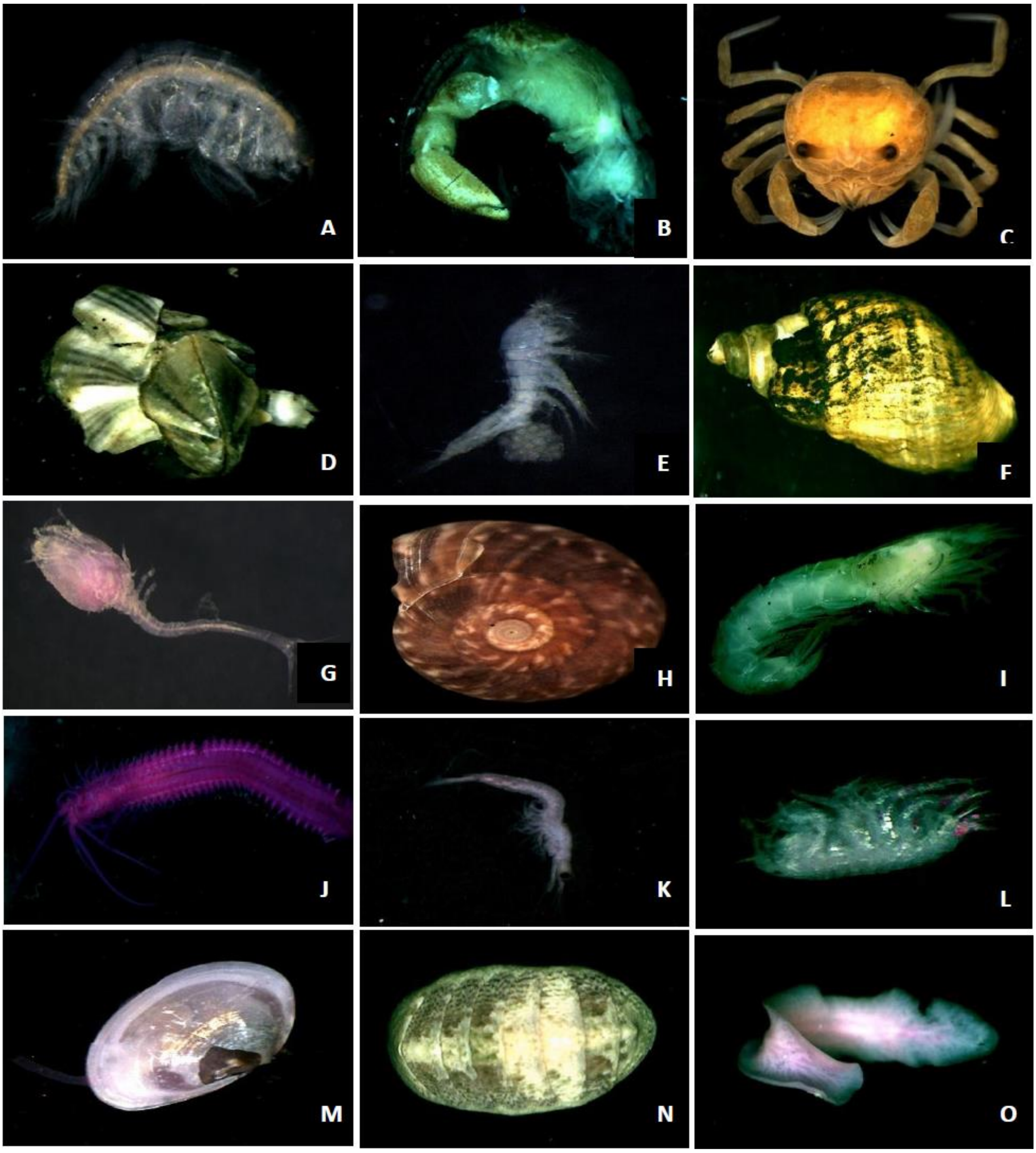

Plate 8: Macrobenthos identified from the intertidal and subtidal region of Vadhvan

A: Amphipoda **B**: Anomura **C**: Brachyura **D**: Cirripedia **E**:Harpacticoida
F: Gastropoda **G**: Cumacea **H**: Gastropoda **I**: Penaeidacea **J**: Polychaeta **K**: Mysida
L: Isopoda **M**: Pelecypoda **N**:Polyplacophora **O**: Turbelleria

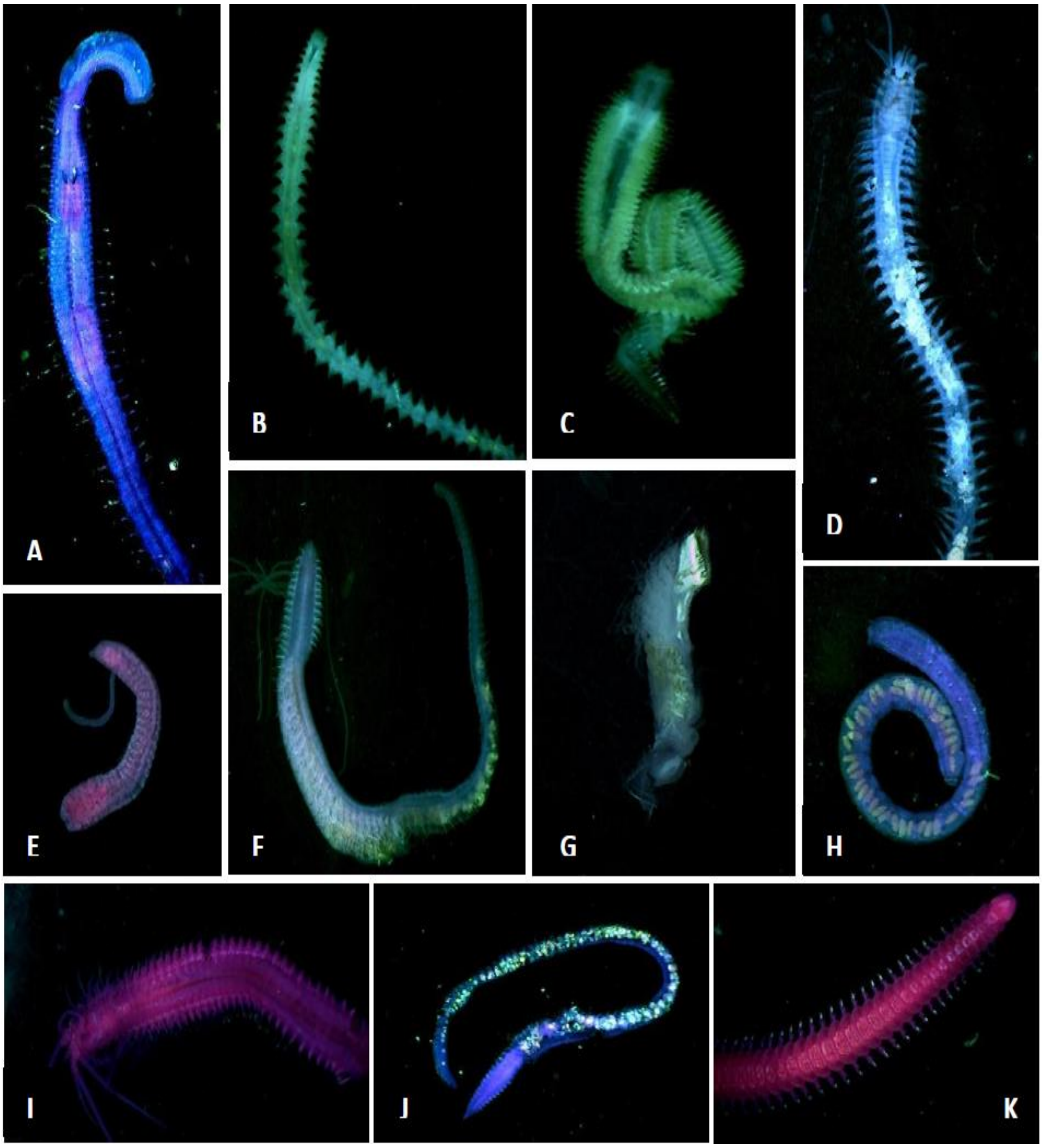

Plate 9: Polychaete families identified from the intertidal and subtidal region of Vadhvan

A: Glyceridae **B**: Nephtyidae **C**: Pilargidae **D**: Nereididae **E**: Cossuridae **F**: Spionidae **G**: Sabellariidae **H**: Capitellidae **I**: Onuphidae **J**: Orbiniidae **K**: Lumbrineridae

Plate 10: *Ulva* sp. occur in small patches along the tide pools and rocks of intertidal region

Plate 11: Sapling of *Rhizophora* sp. found at the Jhoting Bhabha Mandir regio

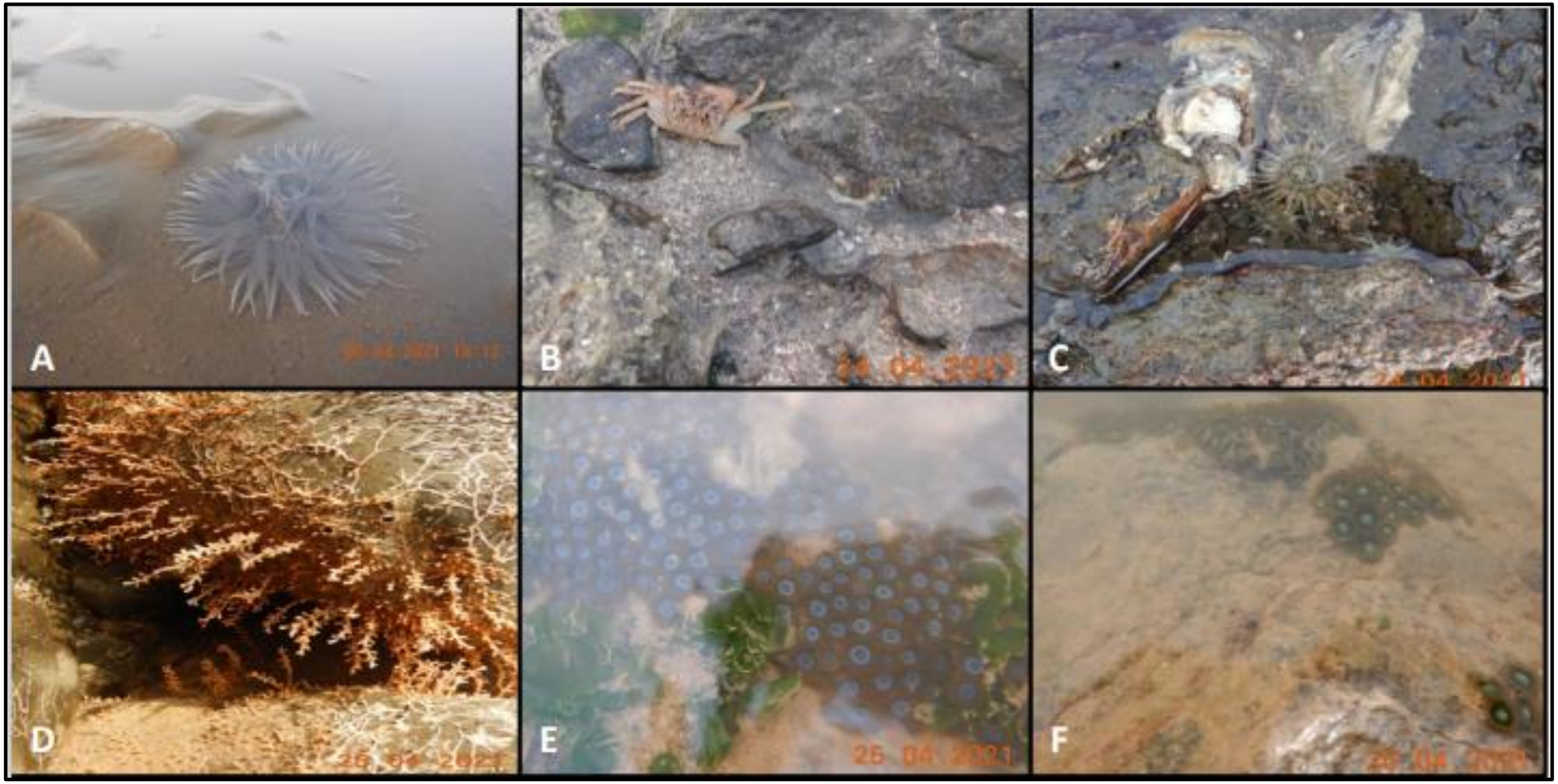

Plate 12: Biota present in the intertidal regions of Vadhvan

A: Sand anemone **B:** *Metopograpsus* sp. **C**: *Aiptasia* sp. **D**: *Pennaria* sp. **E:** *Zoanthus* sp. **F**: *Zoanthus sansibaricus*

Plate 13: Gastropods present in the intertidal regions of Vadhvan

A:*Gyrineum natator* **B**:*Nerita* sp*.* **C**:*Indothais sacellum* **D**: *Thais* sp*.* **E**: *Cantharus spiralis* **F**:*Indothais* sp*.*

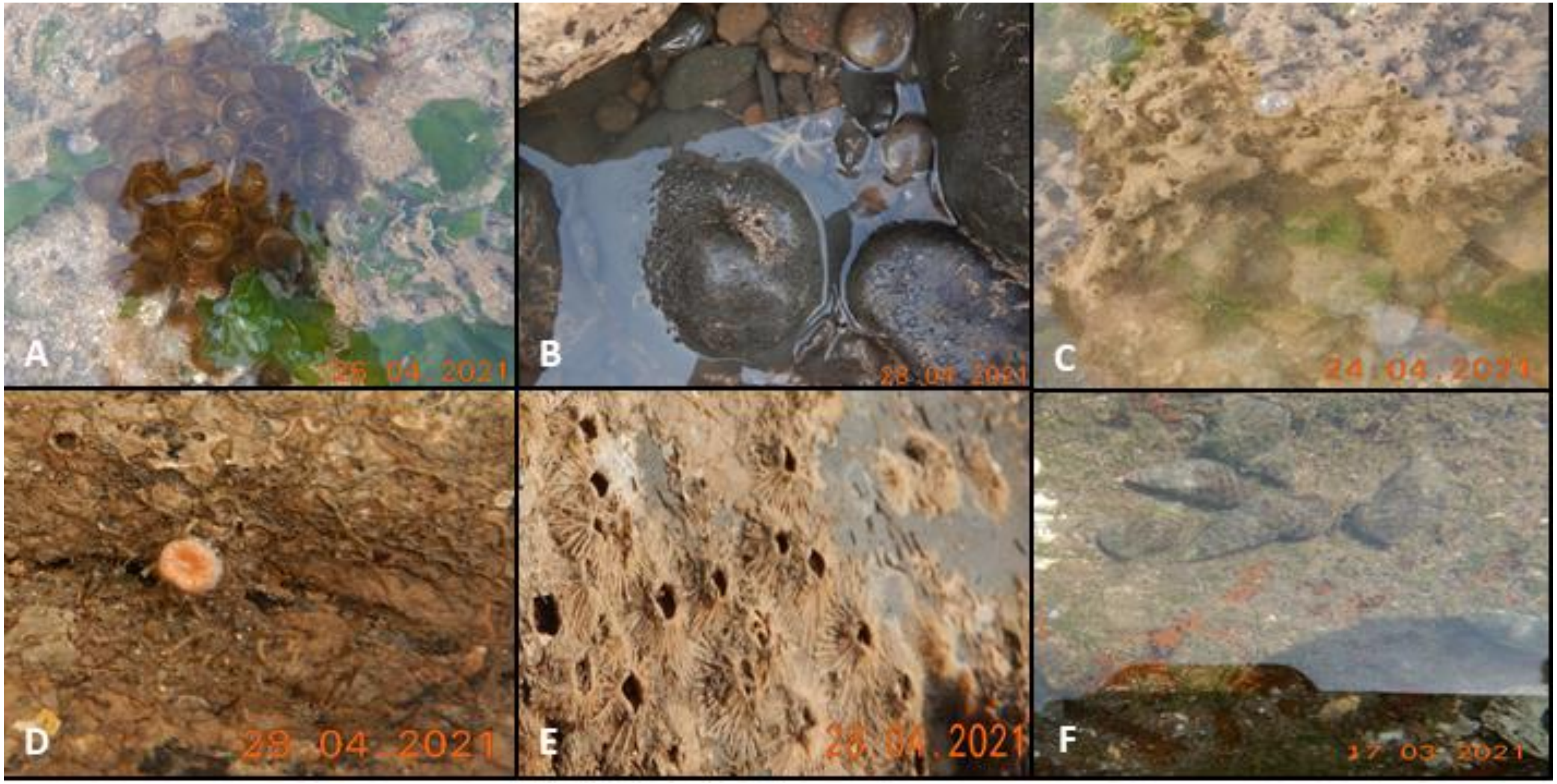

Plate 14: Benthic fauna present in the intertidal regions of Vadhvan

A: *Palythoa mutuki* **B**: Sea lily **C**: Sponges **D**: *Paracyathus* sp. **E**: *Chthamalus* sp **F**: *Clypeomorus* sp

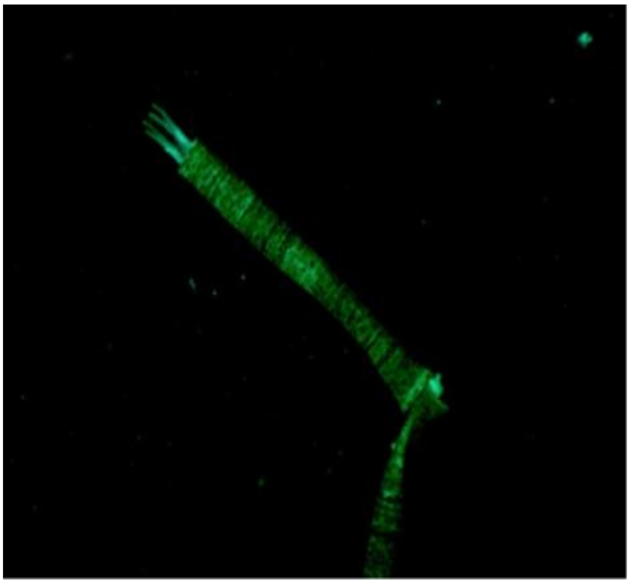

Plate 15: Unidentified invertebrate tubes inhabited by crustacean groups observed in the rocky outcrops of Shankodar area.

Plate 16: Birds feeding at the exposed intertidal area of Vadhvan