राष्ट्रीय पवन ऊर्जा संस्थान
NATIONAL INSTITUTE OF WIND ENERGY
(पूर्व में "पवन ऊर्जा प्रौद्योगिकी केन्द्र" Formerly "Centre for Wind Energy Technology")
(नवीन और नवीकरणीय ऊर्जा मंत्रालय, भारत सरकार Ministry of New and Renewable Energy, Government of India)
नीवे NIWE
(ISO 9001 Certified)

Rapid Environmental Impact Assessment Report-1 GW, Gulf of Khambhat, Off Gujarat coast

Consequent to the approval of Ministry of Defence (MOD), NIWE hereby releases the Rapid EIA (Environmental Impact Assessment) report for understanding the study outcome.

This report has been finalized after having detailed consultation with stakeholders.

This report will provide the confidence to the prospective stakeholders those who are willing to participate under the Model-1 (As per offshore discussion paper).

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Rapid Marine Environmental Impact Assessment of the proposed Offshore Wind Farm in Gulf of Khambhat - off Jafrabad, Gujarat

Prepared for:

National Institute of Wind Energy (NIWE)
Chennai - 600 100

6 January 2020

	सीएसआईआर – राष्ट्रीयसमुद्रविज्ञानसंस्थान **CSIR-NATIONAL INSTITUTE OF OCEANOGRAPHY** **(वैज्ञानिकतथाऔद्योगिकअनुसंधानपरिषद)** **(COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH)** **दोनापावला, गोवाभारत / DONA PAULA, GOA - 403004 India** **फ़ोन/Tel : 91(0)832-2450450/ 2450327** **फैक्स /Fax: 91(0)832-2450602** **इ-मेल/e-mail : ocean@nio.org** **http:// www.nio.org**	

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Executive summary

A. Introduction

National Institute of Wind Energy (NIWE) Chennai is planning to install 1 GW offshore wind farm off the coast of Jafrabad, Gujarat. In this regard, a Rapid Environmental Impact Assessment (EIA) study is to be carried out. The study encompasses the Rapid Marine EIA as per MoEF&CC and international guidelines. Since the CSIR-National Institute of Oceanography (CSIR-NIO) is having scientific expertise, infrastructural and logistic facilities and capability for carrying out such studies, NIWE, Chennai awarded the project to CSIR-NIO based on the proposal of CSIR-NIO to undertake the referred work.

This marine EIA report is based on the site-specific base-line studies carried out in May 2019, encompassing the project domain in the pre-monsoon period and the available secondary data.

The marine EIA study include i) description of the project activities, ii) baseline studies to establish pre-project environmental status, iii) prediction of potential impacts of the project on the marine environment, iv) Environmental Management Plans to reduce environmental impacts, mainly focussed on mitigating significant environmental impacts to acceptable levels and v) Propose a Post-Project Environmental Monitoring Plan for evaluation of the effectiveness of the implemented environmental protection measures.

B. Project description

The proposed 1000MW (1GW) offshorewind energy project site covers 400 sq. Km and is located 23-40 km seaward side from Pipavav port at Gulf of Khambhat off Gujarat coast. The site is accessible from the Pipavav and Jaffrabad Port. NIWE/MNRE (Ministry of New and Renewable Energy) is carrying out extensively wind resource assessment using LiDAR (Light detecting and ranging) based monitoring station at Gulf of Khambhat. The reference geographical coordinates for Lidar location is Latitude: 20° 46’ 36.97” N; Longitude: 71° 40’ 9.89” E.

NIWE has carried out preliminary indicative offshore wind farm layouts (7Dx14D) within the proposed site boundaries based on two typical Offshore wind turbines (6.2 MW & 8.0 MW) representing the present middle & higher range of European Offshore market. Base layouts within the proposed site boundaries have been arrived based on optimization considering the wake loss into account and rule of thumb. "Seven-by-Fourteen" rotor-diameters is one such rule of thumb. Meaning that perpendicularly to the prevailing wind direction, the wind-turbines should be spaced by approximately seven rotor-diameters. In the prevailing wind direction, the distance should be approximately fourteen rotor-diameters. Layout one consists of 162 wind turbines and 125 numbers in layout 2.

Based on the ten years satellite-based mesoscale wind data at 100 m along with the power curve and considered layouts, the expected annual gross production and annual net production including wake loss have been calculated using the industry-standard software tool namely WASP 12.0 (Wind Atlas Analysis and Application Program) developed by the Wind Energy and Atmospheric Physics Department, DTU, Denmark. Total technical losses (grid availability loss, electrical transmission loss, and turbine availability loss) are ~12.5%.

It is proposed to have fixed wind turbines using monopile. The piles are driven into the soil in order to fix the structure to the bottom of the sea. The diameter of the monopiles ranges from 5 to 7 m, and the length of the pile is around 60 m.

C. Description of the environment

The baseline data for assessing the environmental impact include data collected by CSIR-NIO under this EIA project during pre-monsoon season and the secondary data.For assessing the baseline environmental status, an area of ~400 km^2 encompassing the project site was covered. Seawater samples were collected from 40 locations (stations S1-S43) in the project domain and seven locations in the coastal and inter-tidal region for chemical and biological studies in May 2019 (pre-monsoon).

Geological setting of the study area

The Cambay basin is a rift basin and forms the inland extension of the large offshore west coast basin and located on the west-north-west margin platform of the Indian Craton, covering an area of 56,000 sq. Km. the Deccan trap (Cretaceous to Palaeocene age) is the tectonic basement of the Cambay Basin. The sedimentary formation overlying the Deccan trap consists of Alluvial Fans and deltas. The sedimentation in this basin is controlled by pre-rift, syn-rift, and post-rift stages. The Early Tertiary sediments ranging in age from Palaeocene to Early Eocene represent the syn-rift stage of deposition that was controlled by faults and basement highs in an expanding rift system. Seven major riverine systems, including Sabarmati, Mahi, Dhadhar, Narmada, Tapi, Ambika, and Shetrunji, discharge a high quantity of high sediment load of around 0.6×10^8 tons annually into the Gulf of Khambhat which accounts to almost 70% of the total sediment influx to the Gulf. The bottom topography of the Gulf comprises numerous underwater ridges, deep channels, and shoals. Tidal sand bars and ridges with discrete geometries and dimensions are extensively developed in the Gulf. The sand ridges in the outer Gulf region shows an elongate to diamond shape and are hundreds of meters in width and a few kilometres in length. Active dunes on these ridges indicate the presence of sand, and their orientation parallel to palaeo-shorelines supports a tidal origin. Strong tidal currents transport a huge load of sand from fluvial and continental supply to form these sand ridges.

The project area lies in zone-III of the seismic map of India. The peninsula of Saurashtra is a horst, founded between the fractures related to the three intersecting rift trends, *viz,* Delhi (NE-SW), Narmada (ENE-WSW) and Dharwar (NNW-SSE).Saurashtra region is bound by N–S trending Cambay basin in the East, the extension of Narmada geofracture in the south, Kachchh rift to the north, and the major WNW–ESE fault which is an extension of the west coast fault system in the Arabian Sea in the west.The Saurashtra region has experienced random seismic activity at several places such as Junagadh, Jamnagar, Dwarka, Paliyad, Rajkot, Ghogha, and Bhavnagar. A total of 10 earthquakes of a magnitude of 5.0 and above have occurred since 1872. An offshore earthquake occurred on 24 August 1993 of magnitude 5.0 near Rajula.

The bathymetric map of the project area depicts a gradual variation of the seafloor depth ranging from 8 m in the north-east corner to 17.5 m in the south-west corner. Though the seafloor depth is mostly flat with a slope trending north-south orientation, there exists a bathymetric high feature almost in the middle of the project site. The maximum topographic slope on either side of the ridge structure is 1 degree and 0.4 degrees on the landward and seaward side, respectively.

The surficial sediments are mainly coarse-grained in the project area. Sand content is higher in the northeastern part and is lowest in the south-western part. Silt is the second most dominant component and is relatively high in the western part. Clay content is very low at a majority of the station. The seismic survey indicates that it is likely that silty sand ~20 m thick are present on the seabed over the project area.

Climatology

The climatology is based on the data of the nearest observatory of the India Meteorological Department (IMD) at Mahuva. The average air temperature data of 30 years reveals that the highest monthly mean temperature of 41.6 ºC is recorded in April and the lowest monthly mean temperature of 10.1 ºC in January. The monthly mean of relative humidity varies from the lowest of 48% in January and February to 91% in August. The highest value of atmospheric pressure was 1013.9 hPa in January and the lowest of 999.4 hPa in June. The thirty-year monthly means of visibility shows that the morning visibility varies between 4 and 10 km during 94 days and more than 20 km during 211 days in a year. The evening visibility between 4 and 10 km during 102 days and more than 20 km during 224 days in a year. The region receives an average of about 622 mm rainfall in a year, and around 96% of rainfall occurs during the southwest monsoon period (June to September). The number of rainy days in a year has been estimated to be 34.

The measured data of LiDAR monitoring stations from November 2017 to November 2018 shows that at 40 m height, wind speed varied from 0.3 to 18.2 m/s (average value of 6.4 m/s) and at 60 m height, the wind sped varied from 0.2 to 18.5 m/s (average value of 6.6 m/s). At 70 m height, wind speed varied from 0.2 to 18.7

m/s(average value of 6.7 m/s) and at 80 m height, the wind sped varied from 0.2 to 18.6 m/s (average value of 6.8 m/s).At 100 m height, wind speed varied from 0.1 to 18.6 m/s (average value of 6.9 m/s), and at 200 m height, the wind speed varied from 0.3 to 19 m/s with an average value of 7.3 m/s.

From 1960 to 2017, 37 depressions/cyclones crossed within a 4° radius of the project site. The maximum wind speed of these depressions/cyclones was 50 m/sand can cause storm surges up to1.4 m. The 1945 tsunami, generated due to the Makran Earthquake in the Arabian Sea, was the most devastating in the history of the Arabian Sea, and the height of tsunami in Mumbai was 2 m. The estimated arrival time of the tsunami generated at the Makran subduction zone (which is 1060 km from Mumbai) is around 180 minutes. The 2004 Indian Ocean Tsunami was one of the most devastating disasters in modern history, and it affected the southern coasts of India. However, the influence of the 2004 Indian Ocean tsunami along the Pipavav coast was not significant.

Physical Processes

The wave hindcast data for the year 2018 for location 20° 45'N; 71° 45'E shows that the significant wave height varied between 0.3 and 3 m with a mean value of 1.1 m. The mean wave period varied from 3.8 to 12 s, with an average value of 7.1 s. The spectral peak wave period varied from 3 to 20 s with an average value of 10 s. The waves are predominantly from the south-southwest with direction varying from 180 to 240º except in December, during which the waves are from north-east.

The tides measured at 20° 46.615' N; 71° 40.165 'E from 1 December 2018 to 31 January 2019 indicates that the tides vary from -0.62 to 4.32 m. The estimates of mean sea level rise based on the past sea-level data (1878-1994) for Mumbai is 0.78 mm/year.

The coastline between Jaffrabad and Pipavav is under low erosion (<1 m/year) as per the assessment of shoreline changes by the Institute of Ocean Management, Anna University, Chennai,for 38 years from 1972-2010.

Noise and Vibration

Two options were studied in detail, using two sizes of turbine blades with varying numbers of turbines and power output. Simulation results suggest that impacts are restricted to 1 kilometer at the most and will only affect passing marine traffic when in the vicinity of the wind turbines while entering and exiting the ports. No impact is seen on any habitation on the coastline onshore, as the distance is more than 25 times the maximum extent of the wind turbine's low-frequency noise vibrations. The wind turbines are safe for human habitats in the nearest villages to the project as the low frequency noise vibration will not be perceptible by the human habitats.

Wind Wake Analysis

Two options were studied in detail, using two sizes of turbine blades with varying numbers of turbines and power output.The impact is restricted to 14 diameter lengths of the wind turbines at the most and will only affect passing marine traffic when on the leeward side of the wind turbines. Reduction in spacing is possible with staggering the wind turbines in alternate rows and may allow lower costs for foundation. No impact is seen on any habitation on the coastline onshore, as the distance is far beyond the maximum extent of the wind turbine's wind wake.7 x 14 diameter grid is sufficient for avoiding wake losses for the proposed wind farm designs.

Marine Water quality

Dissolved nutrients (nitrite, nitrate, phosphate, and silicate) play an essential role in primary productivity in any aquatic ecosystem and, therefore, also support other aquatic lives. In our present survey, the estimated nitrite concentrations in waters were quite low, with values ranged from 0.06 to 1.0 μmol/l. Even the surface and bottom waters did not show much variation of nitrite concentration. The dissolved nitrate content in most of the water samples varied between 1.0 and 19.4 μmol/l. The concentrations of phosphate and silicate in the same water samples ranged from 0.5 to 2.8 μmol/l and 7.0 to 55.2 μmol/l, respectively.

Biological Productivity and Ecology

The biological parameters considered for the assessment of ecological status in the present study include total bacterial counts, phytoplankton pigments and cell counts, zooplankton standing stock and population, macrobenthic biomass and population and fishery status.

Phytoplankton & Productivity

The values of low chlorophyll concentration in the study area indicate a relatively less productive region in terms of phytoplankton biomass. This possibly is due to the grazing pressure exerted by the mesozooplankton community.

Mesozooplankton Biomass & Abundance

Study region found to be productive in terms of fish larvae and fish eggs contributing ~68% of the zooplankton composition indicating the prevailing environmental condition at the study site to be an ideal site for the fishto spawn in the region.

Benthic Studies

The considerable variation of macrofaunal and meiofaunal abundance was recorded. Nematoda was the most abundant, followed by the Turbellaria, Harpacticoida, Polychaeta, Oligochaeta, Kinorhyncha, Nemertea, Bivalvia Amphipoda.Macrofaunal activity impacts carbon, nitrogen and sulfur cycling, transport, burial and metabolism of pollutants, secondary production including commercial species, and transport of sediments. Complete analysis of subtidal and intertidal benthic macrofauna reveals that the abundance and presence of more macrofauna richness in subtidal regions than of intertidal areas.

Fish and Fisheries

Gujarat has the longest coastline in the country (1600 Km, comprising of 19.71%). The contribution of marine fish catch from Saurashtra has always formed a significant share from the state of Gujarat. Gujarat accounts for contributing about 97% of the total landings of Bombayduck (Jhingran, 1982). Consequently, *dol*net fishery has become synonymous with Bombayduck fishery. Along Navabandar, Rajpara, and Jaffrabad coasts of Saurashtra stated Bombay duck landing contributed of around 31.12% to total *dol* net landings (Ghosh *et al*., 2009).

The coast of Pipavav has a rich diversity of coastal and marine habitats, supporting much biodiversity. A total of five species of marine mammals and a species of reptile were recorded in the study area based on secondary data. According to the Wildlife Protection Act 1972 status, three marine mammal species along with one reptile species are protected under schedule I (Part I) of the act. An experimental beam trawl (bottom trawl) operation was undertaken to assess the benthic fisheries, and the results suggest very low fish representation. This maybe because of high hydrodynamic action in the region that makes the sediment unstable and non-conducive habitat for megabenthic species.

Socio-economic

The localities at coastal places like Jafrabad, Shiyalbet, Pipavav have been evolving as per the source, and available resources, the study area being typically coastal, fishing, and agriculture, can be seen as a prime source of income with the youth wanting to move to the towns for employment. Since past some years fishing at almost the entire coastline of the North West coast of India has been undergoing changes based on many factors like changing methods of fishing and availability of fish catch. The local areas are also reasonably developed in terms of infrastructure, basic services, amenities, hotels, residences, etc.

D. Anticipated Environmental Impacts

The anticipated environmental impacts due to the activities related to the construction, operation, and post-operational phases of the project are highlighted below.

The maximum significant wave height near the project site is 5.9 m, and the corresponding maximum wave height will be around 11 m. Storm surge due to cyclone will be around 1.4 m. Considering these factors, along with the seabed conditions and currents, the structures have to be designed.

For both the wind farm layouts, the model results indicate almost similar sediment movement concerning the present condition. Statistical mean of the bed level change over the model simulation period indicate a marginal increase in bed level of

0.08 m around the monopiles of northern half and decrease in the southern half by the same magnitude. This would suggest marginal accretion around the northern monopiles and erosion (scouring) around the southern ones.

Since the proposed structure is located more than 23 km from the coastline, the construction of the marine structures will not have a significant influence on the shoreline.

Construction Phase

Construction activity destroys the ecology, limiting the ability of the disturbed habitat and nearby areas to function as a nursery area, or feeding ground for all types of marine fauna.Adult fish are likely to move away from or avoid areas of high suspended solids, such as construction sites unless food supplies are increased later on as a result of increases in organic material transformation through heterotrophy and their biomass build-up. The impacts due to vessel traffic for maintenance will be due to exhaust emissions, boat noise emission, grounding/collision of boats, oil spills, and bilge water release.

The project area already has high turbidity due to high currents. Pile driving and vessel movement, as well as construction activity, will have temporary re-suspension of sediment in the water column. This will affect primary productivity and dependent zooplankton community. This impact will not be significant due to already high turbidity and sediment re-suspension.The spillage of oil & grease, as well as other contaminants such as heavy metals, may have long term impacts on the pelagic and benthic organisms. Permanent loss of benthic community in 4808 m^2 area is expected during the construction of monopiles.

This region is known to be visited by dolphins, turtles, birds, and other endangered animals. The construction machinery creates considerable noise and vibration, which may drive away these species and may also negatively impact them.Fisheries in the region will be impacted negatively because, during the construction phase, no plying of vessels and trawling will be allowed to avoid collision risk. This will have negative socio-economic impacts and may affect the fish landing negatively for the local populations.But socio-economy in the region will have overall positive impacts due to the project by the provision of construction jobs for the skilled and semi-skilled local population.

Operational phase

The marine environment is highly corrosive, and suitable coating systems are to be used for the protection of the structures. Maintenance is difficult, and hence coatings are to be applied correctly and under the right conditions. Corrosion in the marine environment is 0.2 to 0.5 mm per year. Considering a design life of 100 years, the additional material thickness of a minimum 50 mm shall be provided as a corrosion allowance for structural members and other components.

During the operation phase, the physical presence of the structures will not have a significant impact on the marine pelagic organisms such as phytoplankton and zooplankton. The impacts of noise and vibrations will not be significant for the local populations. The underwater noise and vibration during the operation phase may negatively affect the larger organisms such as dolphins, whales, and turtles. Electromagnetic emissions from the power generation are also expected to have negative impacts on the organisms. These impacts can be considered of low significance because the core and the buffer zone do not harbor many sensitive species, and many of the critical and sensitive habitats fall outside the buffer zone. Installation of underwater power cables could cause electromagnetic fields and heat emissions, which influence marine organisms, especially fish.

The fisheries in the region may experience some negative impact due to the existence of structures, and fishermen may have difficulty in navigation in the region during the operation phase. The fishery of the region with coastal socio-economic status shall give dependency on this area. Accordingly, the impacts can be weighed.

Socio-economy in the region may have positive impacts due to the project by the provision of jobs for the skilled and semi-skilled local population and increase in facilities, amenities, and infrastructure and socio-economic status in general.

E. Mitigation measures

- During the construction phase, the proposed activities will be notified to mariners and the area, and the route through which the construction material will be transported will be demarcated by marker buoys. Before the commencement of construction activity, residents and fishermen would be advised about the construction, period of construction, and associated activities.

- During the construction phase, temporary colonies of workforce should be established sufficiently away from the High Tide Line. Proper sanitation, including toilets and bathrooms, will be provided to the inhabitants to prevent abuse of the intertidal area. Sewage and other wastes generated in these settlements should not be released to the marine environment.
- Contractors will use the equipment, vessels, boats, and barges that are in good working order, well maintained, and that have some noise suppression equipment (e.g., mufflers, noise baffles) intact and in working order. This will be achieved by making it a component of contractual agreements with the construction contractors. The noise level during piling, transport, and erection of structures, etc. will be kept to a minimum through proper lubrication, muffling and modernization of equipment.
- The vessels engaged in transporting the construction materials would implement a hazardous materials management plan that includes the specification for proper storage and handling of fuels, oil, wastes, and other potentially hazardous materials as well as a plan for containment and clean-up of accidental spills into the marine environment.
- During a cyclone warning, all the persons engaged in construction and maintenance to be evacuated from the project site.
- Negative socio-economic impacts can be minimised by the implementation of best practices in the industry, and adhering to the CSR policies, increase in education, employment, infrastructure development, amenities, and facilities are expected due to the project.

F. Environmental Monitoring Program

The monitoring of critical parameters in the project area is required during the operation phase to ensure that the impacts of the project do not exceed the legal standards. Implementation of the mitigation measures is in the manner as described in the EIA report. Monitoring parameters and duration are presented in the report.

G. Project Benefits

Global carbon dioxide emissions can be significantly reduced by replacing the existing energy sources with renewable energy sources. Currently, renewable energy sources like wind, solar, and biomass contribute only ~5% of the energy source. Wind energy is one of the cleanest energy sources and the proposed project will reduce the atmospheric pollution.

H. Marine Environmental Management Plan

A broad environmental management plan is presented. The responsibility of MEMP action items lies with NIWE and construction contractors, and the cost could be part of the construction contract. Sub-plans for regulating all the activities are formulated to take care of environmental concerns that include Pile Driving Management Plan, Water Quality Management PlanBiodiversity Monitoring Plan, and Vessel Management Plan. A separate team has to be formulated as delineated in the section, and a total budget of Rs 490 Lakhs is assigned for the management plan.

Chapter 1: Introduction

1. INTRODUCTION

National Institute of Wind Energy (NIWE) Chennai is planning to install 1 GW offshore wind farm off the coast of Jafrabad, Gujarat. The map showing the project site is presented in Fig. 1.1. In this regard, a Rapid Environmental Impact Assessment (EIA) study is to be carried out. The study encompasses the Rapid Marine EIA as per MoEF&CC and international guidelines. Since the CSIR-National Institute of Oceanography (CSIR-NIO) is having scientific expertise, infrastructural and logistic facilities and capability for carrying out such studies, NIWE, Chennai awarded the project to CSIR-NIO based on the proposal of CSIR-NIO to undertake the referred work with objective given below.

1.1. Objective

To prepare a marine environmental impact assessment report to assess the impact of the projected development on the marine environment,and subsequently, the report will be provided to various developers by the NIWE to assess the impacts of the project on the environment.The study includes the following components:

- Description of the project activities
- Baseline studies to establish the pre-project environmental status
- Predictions to estimate impacts of the project on the marine environment
- Environmental Management Plans, mainly focussed on mitigating significant environmental impacts to acceptable levels
- Preparation of Environmental Impact Assessment report

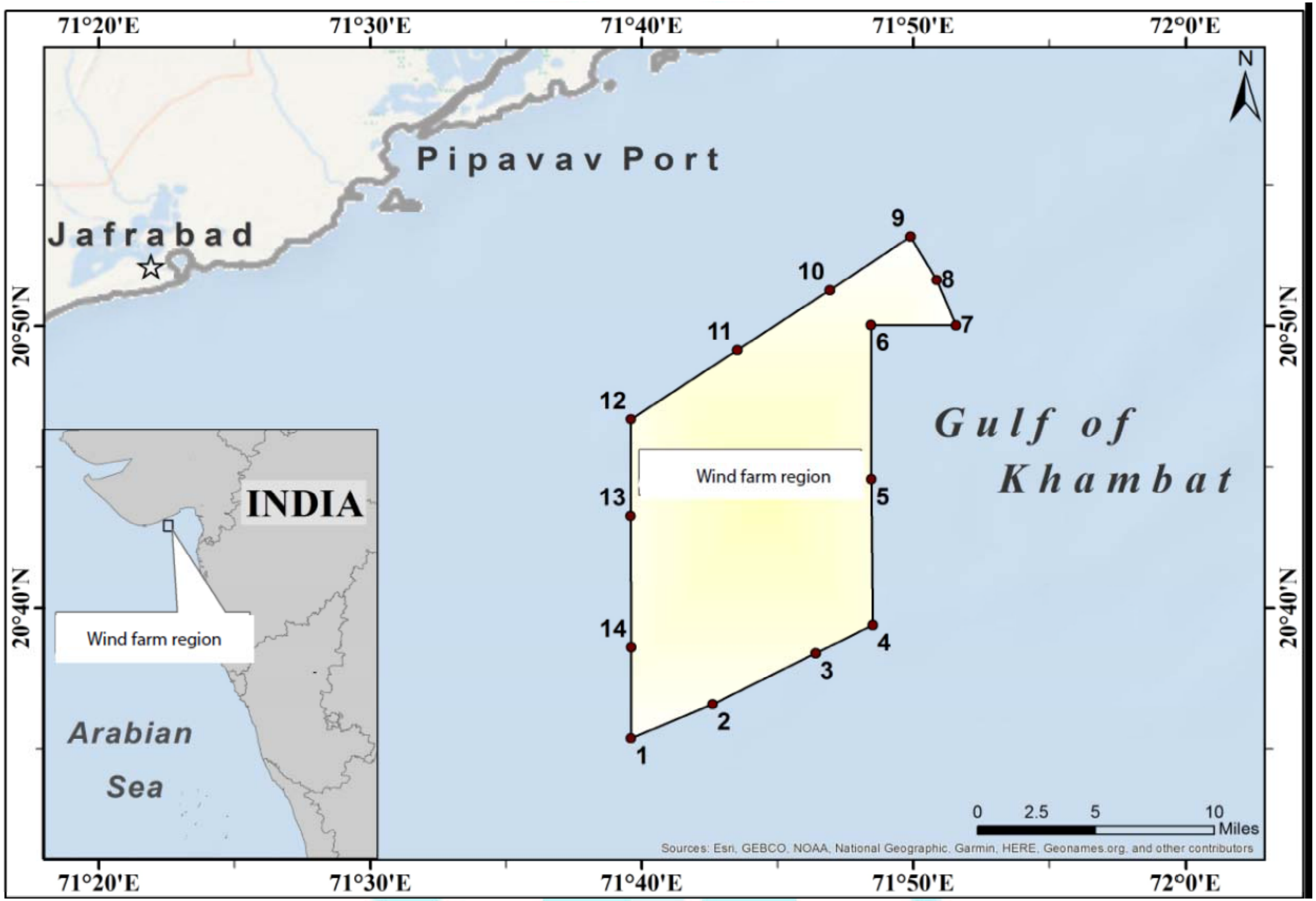


Figure 1.1. Map showing the proposed project site

1.2. Terms of reference

Terms of reference (ToR) for conducting ‘Marine Environmental Impact Assessment (EIA) studieshave been described in the following sections:

a) Project description

Description of the project activities (based on project feasibility study), which are likely to cause environmental effects. Description of the project includes drawings showing project layout, various components of projects, etc.

b)Description of the environment

The data for marine EIA study is collected through field studies, from literature, and interaction with concerned departments. For the EIA study, an area of 10 km radius of the project site is considered. The data/information collected for studying the environmental baseline status are given below.

The meteorological data (air temperature, humidity, and rainfall) from the nearest IMD station for 30 years has-been collected.

Wave data from wave hindcast model from January to 18 December have been used to study the annual wave characteristics. Based on the measurements, the current characteristics are assessed. Numerical modelling is carried out to describe the tides and currents in the project area with and without the proposed wind farm.

The analysis for low frequency noise and vibration modelling is to be measured with the range of impact from the wind farm’s turbine blades and to identify the areas of land and sea where prevalent activities are affected. Background data were reviewed to study the existing available wind, orography, roughness, and temperature data nearest to the proposed location.

The analysis for wind wake modelling is done to measure the range of impact from the wind farm's turbine blades and to identify the areas of land and sea where prevalent activities are affected.Data for wind speed, wind direction, and for multiple heights upto 120 m from 2017 was collected from coastal mast situated off the coast of Jaffrabad and Pipavav located 25 Km away from the shoreline. LIDAR data to be acquired as well for simulation purposes.The Marine Traffic website provides a marine traffic map from the local to a global level with averaged data upto 2017, and live marine traffic mapping was used.

The marine ecology of the site and its surroundings is to be studied through field studies and literature survey. Characterization of the coastal marine waters to be assessed in terms of bacteriology, primary productivity, density, and diversity of phytoplankton, zooplankton, benthic macro-invertebrates, fish, and macrophytes. It is also identified whether the study area forms a part of an ecologically sensitive area or migratory corridor of any endangered fauna.

Assessment of water and sediment quality and ecological studies are based on water and sediment samples collected from 4 to 8 May 2019, 23 to 26 May 2019, and 27 to 28 May 2019.

<u>Physico-chemical parameters</u>

Coastal Waters

- Temperature
- pH
- Salinity
- Turbidity
- Dissolved Oxygen
- BOD
- Nitrite-nitrogen
- Nitrate-nitrogen
- Phosphate-phosphorus
- Silicate-silicon
- Petroleum Hydrocarbons (PHC)

- Trace metals (Cu, Cr, Zn, As, Hg,Pb)

Sediments

- Sediment texture
- Organic carbon
- Total Nitrogen
- Total Phosphorus
- Petroleum Hydrocarbon (PHC)
- Trace metals (Cu, Cr, Zn, As, Hg, Pb)

Biological parameters

Phytoplankton
- Phytoplankton biomass (Chl-*a* &Phaeophytin)
- Total Abundance
- Generic composition
- Density (Total numbers of individual of each species)

Zooplankton
- Total Biomass
- Group Density and Composition of zooplankton groups

Benthic Organisms
Macrobenthos
- Biomass (wet wt, g/m^2)
- Density (Nos./m^2)
- Number and name of each group present
- Total number of each group present

Meiobenthos
- Density (Nos./10cm^2)
- Number and name of each group present
- Total number of each group present

Fisheries

The following data were collected through secondary data sources:
- Dominant ichthyofaunal species inhabiting the study domain
- Analysis of marine fish production

The Socio-economic status to be studied to understand and decides plausible social, financial, legacy, and wellbeing of a proposed venture on local people and their livelihood.Field surveys and observations were made at each sampling village, and the socio-economic status of that region is studied. Primary data,, as well as secondary data, will be collected while considering the aspects such as demography, education, employment, fisherman families and their households, hospitals, primary health centers, and other facilities and amenities in the region.

C) Anticipated Environmental Impacts & Mitigation Measures

With the knowledge of project details, prevailing environment,and intensity of construction activities, potential impacts of the project on the environment are to be identified.Mitigation measures are identified to reduce the adverse impacts if any.

d) Environmental Monitoring Programme & Environmental Management Plan (EMP)

An Environmental Monitoring Programme for monitoring the critical parameters during construction and operation phases of the project are suggested.Marine Environmental Management Plan (MEMP) is developed to selectively mitigate the adverse impacts due to the construction and operation of marine facilities planned for the proposed project. The implementation schedule for adopting mitigation measures is also indicated as a part of the study.The cost involved for implementation of the suggested MEMP is also included.

1.3 Study area

The main focus of the study is to establish the baseline environmental conditions and to identify the possible impacts and to provide a suitable management plan in the project.The sampling was carried out at 47 different coastal stations off Pipavav, Gujarat. The Sampling locations for the study are depicted in Fig 1.2 and Fig. 1.3.

1.4 Geographical Location

The proposed 1000MW (1GW) offshore project site is located in zone ‘B’ of FOWINDidentified zones and located 23-40 km seaward side from Pipavav port at Gulf of

Khambhat off Gujarat coast (Fig. 1.4). The site is accessible from Pipavav and Jaffrabad Port. The Gulf of Khambhat is approximately five km wide at its northern end between the Sabarmati and Mahi river estuaries, and it opens out southwards like a funnel, reaching its maximum width at the south of Gopinath point. The Gulf receives rains during the southwest monsoon (from June to September), the average annual rainfall varies from600 mm on the western side to 800 mm on the eastern side. The proposed 1000MW (1GW) Offshore wind farm project area approximately covers 400 sq.km.The proposed NIWE Wind farm Area would be located more than 23 km offshore Pipavav. The layout of the proposed wind farm area for scoping comprises areas on all sides of the operational Wind Farm. Electricity generated would be transported to the shore by offshore export cables installed within the proposed offshore export cable corridor (Figure 1.4).

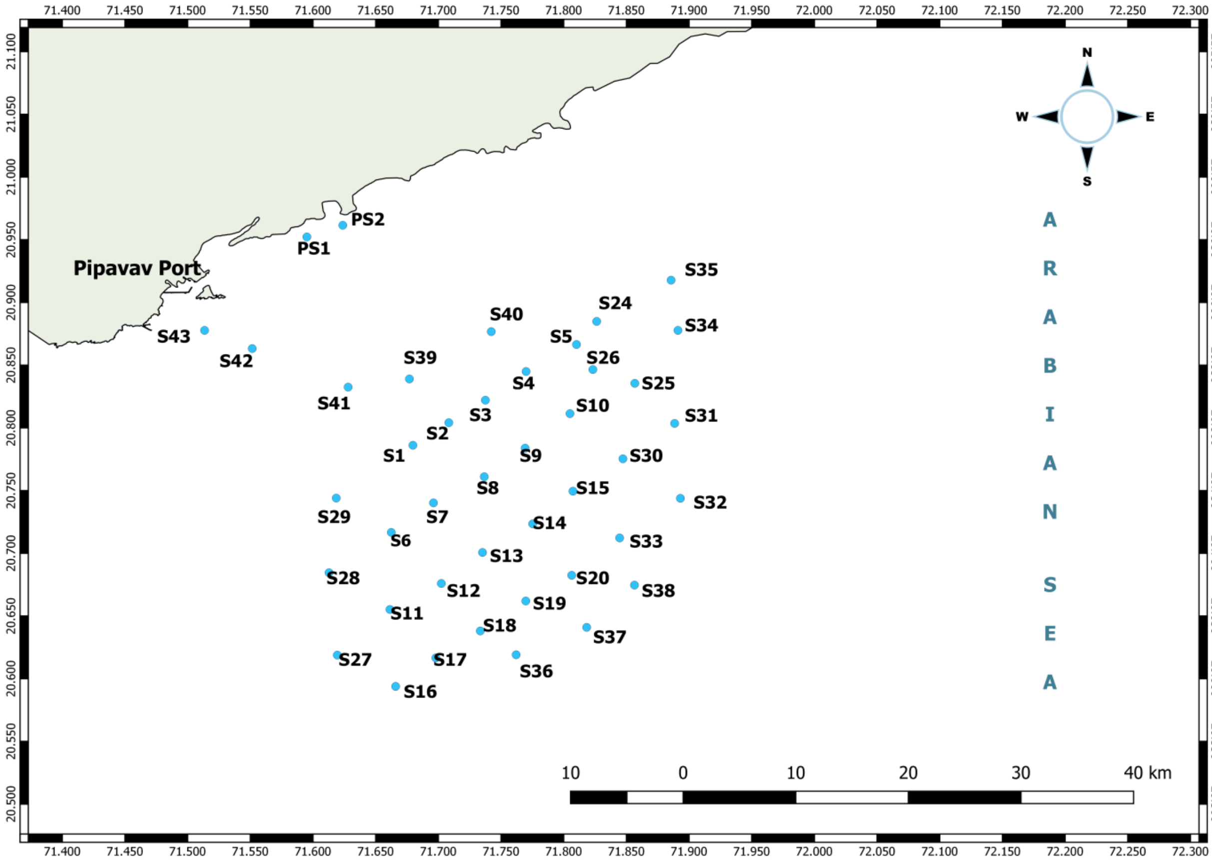


Figure 1.2: Map depicting Sampling Stations in and around the project area.

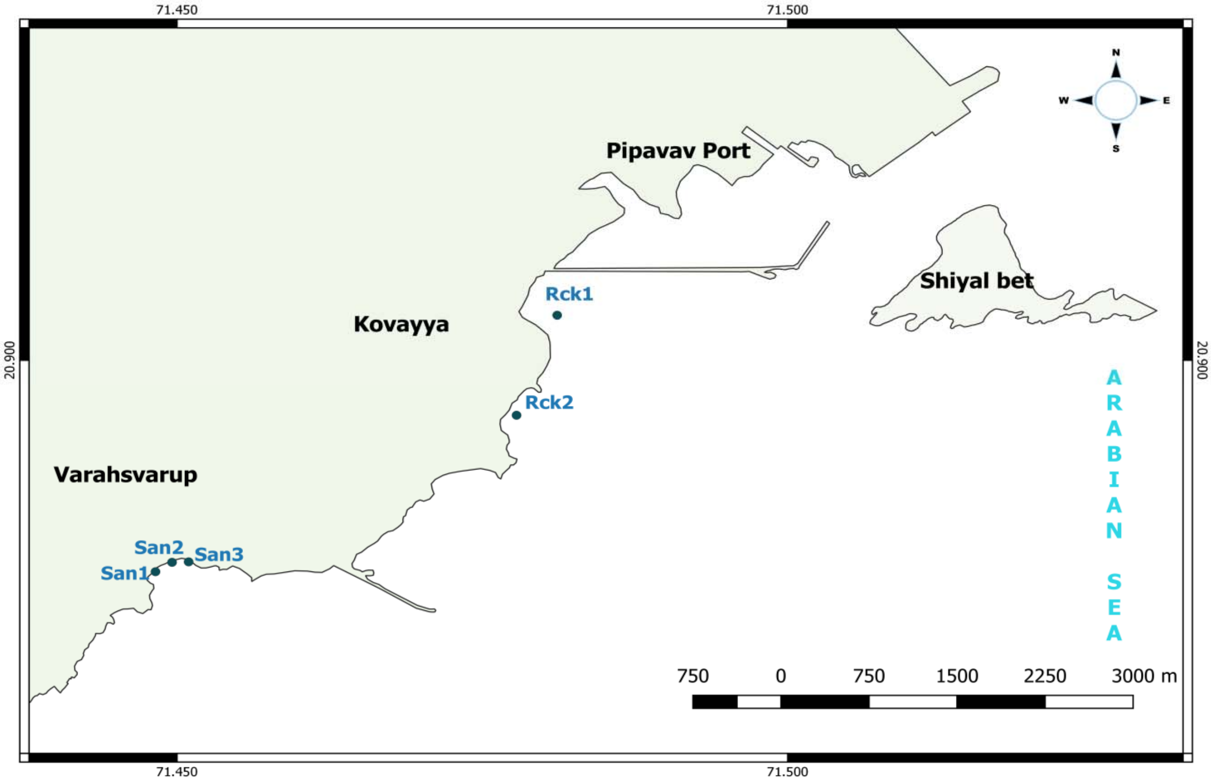


Figure 1.3: Map depicting Intertidal Sampling Stations.

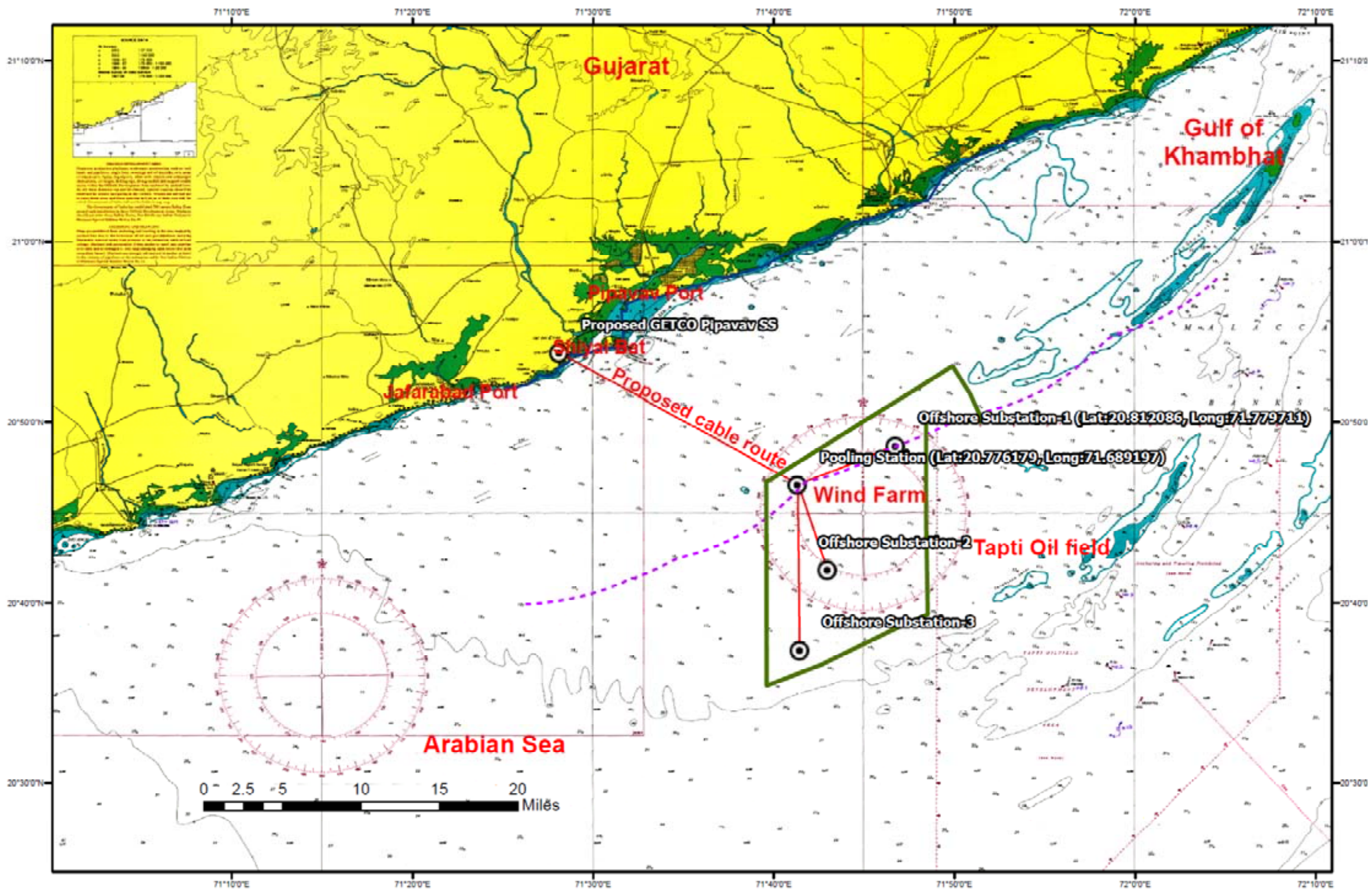


Figure 1.4. Map showing the wind farm location, cable route, and offshore substations

Plate 1.1. Showing the coastal region near the proposed cable landing location

Chapter 2: Project Description

2. PROJECT DESCRIPTION

2.1Site Description

The proposed 1000MW (1GW) offshore project site is located in zone ‘B’ of First Offshore WIND (FOWIND) identified zones and located 23-40 km seaward side from Pipavav port at Gulf of Khambhat off Gujarat coast (Fig. 1.4).The site is accessible from the Pipavav and Jaffrabad Port. The Gulf of Khambhat is approximately five km wide at its northern end between the Sabarmati and Mahi river estuaries and it opens out southwards like a funnel, reaching its maximum width south of Gopnath point. The Gulf receives rains during the south west monsoon (from June to September), the average annual rainfall varies from 600 mm on the western side to 800 mm on the eastern side. Site information is provided in Table 2.1.

Table 2.1 Site information

Site Name	Gulf of Khambhat (Zone–B as identified by FOWIND)
Taluk	Jaffrabad
District	Amerli
State	Gujarat
Water Depth	8-18 m
Minimum distance from the coast	23 km
Nearest Village	Pipavav
Nearest Town	Jaffrabad
Nearest Railway Station	Rajula Junction
Nearest Airport	Diu
Nearest Port	Pipavav/Jaffrabad
Nearest Electrical Sub stations onshore	Ultratech 220kV
CRZ(asper2011notification)	ZoneIV

The proposed 1000 MW (1GW) offshore wind farm project is approximately covers 400 sq.km and is bound by coordinates as given Table 2.2 and Moreover 1.1 illustrates the Offshore wind farm park boundary.

NIWE/MNRE is carrying out extensively wind resource assessment using LiDAR (Light detecting and ranging) based monitoring station at Gulf of Khambhat , Off Gujarat. The reference geographical coordinates for LiDAR location is Latitude: 20° 46’ 36.97” N; Longitude: 71° 40’ 9.89” E (UTM Coordinates – WGS84, 42Q zone 777914.98 m E and 2299758.44 m N). The measurement was commenced in November 2017 and data measurements are underway. The LiDAR is placed on a platform supported on a monopile at 17 m above mean sea level.

Table 2.2 Co-ordinates of the proposed offshore wind farm area

Boundary Point	Latitude		Longitude	
1	20°	35' 23.4724" N	71°	39' 36.0604" E
2	20°	35' 40.3142" N	71°	42' 48.9256" E
3	20°	37' 8.6836" N	71°	46' 32.2712" E
4	20°	38' 33.8318" N	71°	48' 27.8889" E
5	20°	44' 35.4573" N	71°	48' 27.0911" E
6	20°	50' 2.6047" N	71°	48' 26.4892" E
7	20°	50' 2.4566" N	71°	51' 34.0013" E
8	20°	51' 38.8328" N	71°	50' 51.3695" E
9	20°	53' 11.1231" N	71°	49' 52.7061" E
10	20°	51' 17.5642" N	71°	46' 54.6909" E
11	20°	49' 9.3229" N	71°	43' 30.8629" E
12	20°	46' 42.3267" N	71°	39' 35.7641" E
13	20°	43' 16.9636" N	71°	39' 35.0917" E
14	20°	38' 36.9260" N	71°	39' 36.6028" E

.

2.2. Project Layout & Energy Yield

NIWE has carried out preliminary indicative offshore wind farm layouts (7D x 14D) within the proposed site boundaries (400 sq.km) based on two typical offshore wind turbines (6.2 MW & 8.0 MW) representing the present middle & higher range of European offshore market for the simulation study. Using the larger size wind turbines typically reduce the cost of energy and the reference turbine and base layout details as tabulated below in Table 2.3. Base layouts within the proposed site boundaries are shown in Figure 2.1 to 2.2 and have been performed based on optimization considering the wake loss into account and rule of thumb. "Seven-by-Fourteen" rotor-diameters is one such rule of thumb. Meaning that perpendicularly to the prevailing wind direction the wind-turbines should be spaced by approximately seven rotor-diameters, in the prevailing wind direction, the distance should be approximately fourteen rotor-diameters.

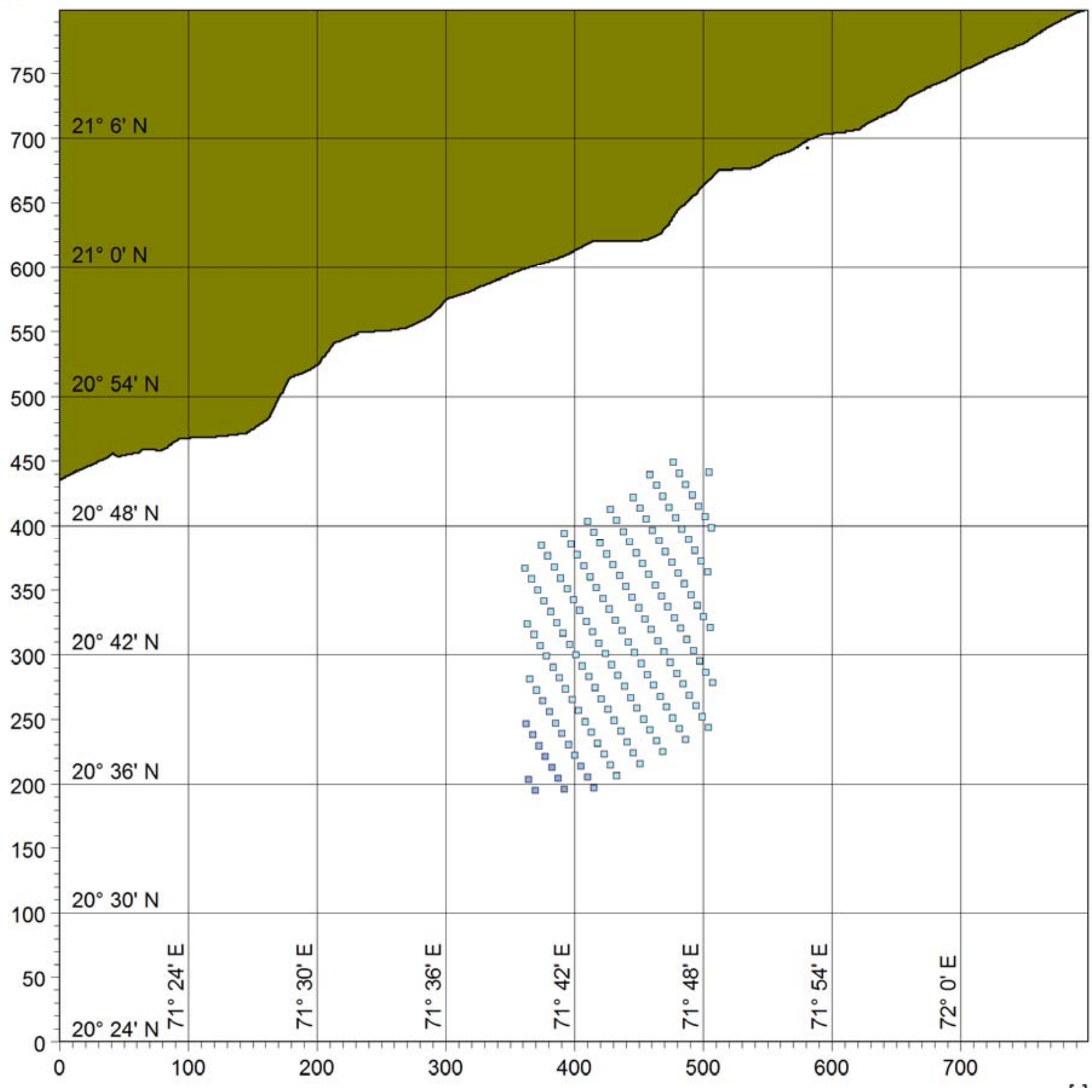


Figure 2.1 Wind farm Layout -1

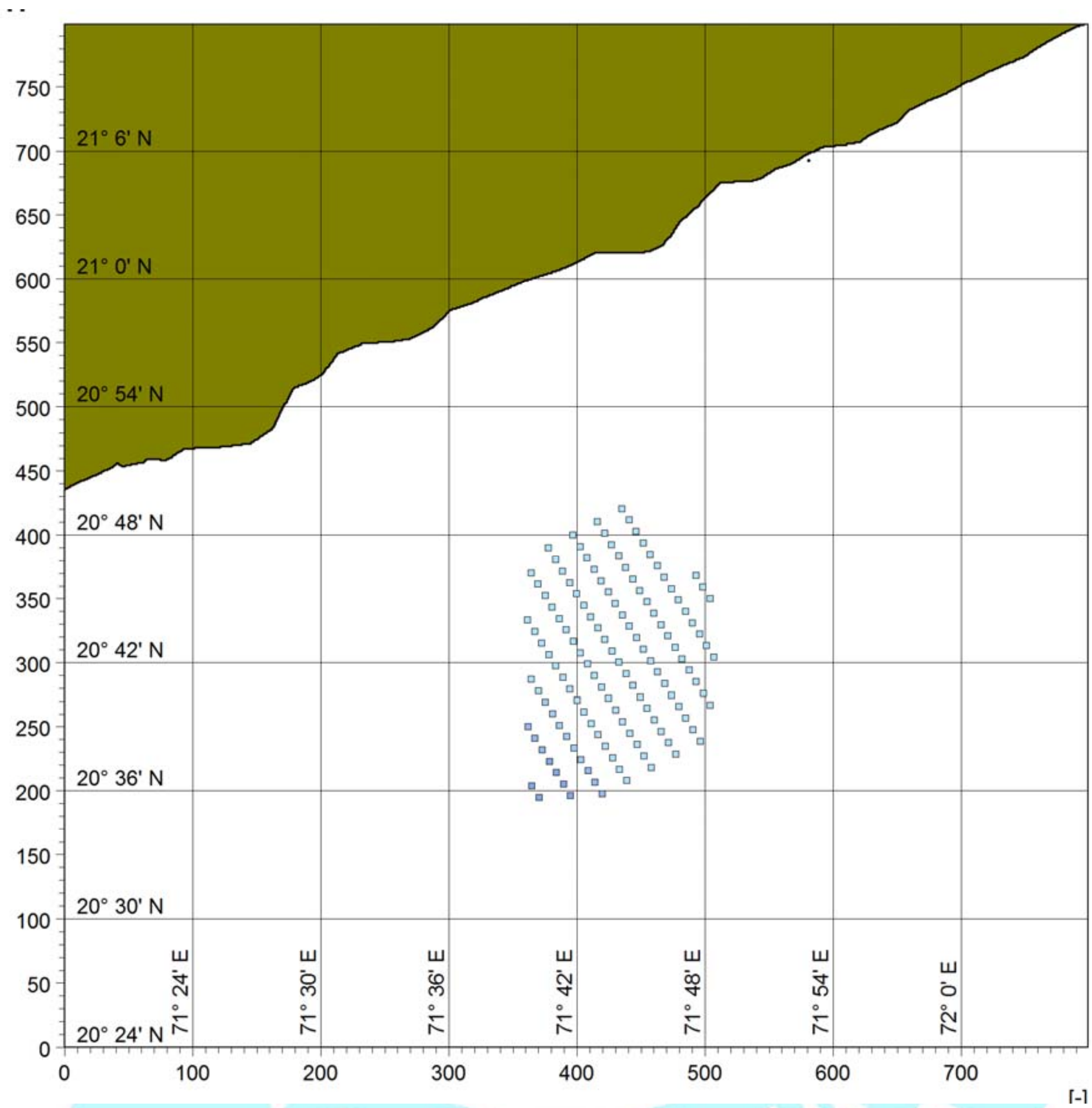


Figure 2.2 Wind farm Layout -2

Table 2.3 Base layout configuration of wind turbines

Option	No.of wind turbines	Capacity (MW)	Rotor diameter(m)	Hub height (m) (m)	Layout Configuration
1	162	6.2 MW	152	100 m	7D x14D
2	125	8.0 MW	164	120 m	7D x14D

Based on the ten years satellite-based meso scale (ERA5–European Centre for Medium-Range Weather Forecast Re-analysis data) wind data at 100 m along with the power curve and considered layouts ,the expected annual gross production (AEP gross) and annual net production including wake loss have been calculated using the tool namely WASP 12.0. The WAsP12.0 model with its wind atlas methodology was used for Micro sitting and generating the spatial wind environment of the Region of Interest. Wind Atlas Analysis and Application Program (WAsP) is a PC-program developed by the Wind Energy and Atmospheric Physics Department, DTU, Denmark for the vertical and horizontal extrapolation of wind data.

For offshore conditions, the PARK2 model has been evaluated and calibrated against a number of data set so factual power production from off shore wind farms. The calibration resulted in are commended / default value for the wake decay constant (0.06).With this wake decay constant, PARK2 was found to produce calculations closer to actual power productions of the offshore wind farms. Therefore, DTU Wind Energy recommends the use of PARK2 with this new default wake decay constant (0.06) for offshore calculations. The PARK2 wake model with awake decay constant of 0.06 corresponding to offshore wind conditions has been applied in this calculation. In order to obtain the estimate p50 (probability of exceedance confidence level) delivered to the grid, the technical losses must be taken into account. In this context, the following standard technical losses are assumed based on standard practice. Table 2.4 shows the standard technical losses.

Table 2.4 Standard Technical Losses

S. No	Standard Technical losses	%
1	Turbine availability loss	5
2	Grid availability loss	5
3	Electrical Transmission loss	3
Total technical losses		12.5

The cumulative energy generation in the p50 level is estimated at 2238.5 GWh/year for 1000 MW (1GW) in consideration of layout-1 (6.2 MW x 162 nos) and Annual Capacity utilization factor (%CUF) is 25.4%. For layout 2, the p50 level is estimated at 2182.6 GW h/year for 1000 MW (1GW) in consideration of layout-2 (8.0MWx125 nos) furthermore, the Annual Capacity utilization factor (%CUF) is 24.9% (Table 2.5).

Table 2.5. Energy Generation (p50) for layout 1 and layout 2

Wind farm Layout-1		
AEP Gross for the 162 WTGs	2884.2	GWh/year
Wake Loss (11.3%)	325.9	GWh/year
AEP net for the 162 WTGs	2558.3	GWh/year
Estimated Technical losses (12.5%)	319.8	GWh/year
P50 AEP for the 162 WTGs	2238.5	GWh/year
P50 AEP / WTG	13.8	GWh/year
CUF (%)	25.4	%
Full load hours	2228.7	Hours
Wind farm Layout-2		
AEPGrossforthe125WTGs	**2781.7**	**GWh/year**
Wake Loss (10.33%)	**287.4**	**GWh/year**
AEPnetforthe125WTGs	**2494.4**	**GWh/year**
Estimated Technical losses (12.5%)	**311.8**	**GWh/year**
P50AEPforthe125WTGs	**2182.6**	**GWh/year**
P50AEP/WTG	**17.5**	**GWh/year**
CUF (%)	**24.9**	**%**
Full load hours	**2182.6**	**Hours**

2.3 Construction details

It is proposed to have fixed wind turbines using monopile. A schematic layout of a monopile is shown in Fig. 2.3. The piles are driven into the soil in order to fix the structure to the bottom of the sea. The diameter of the monopiles ranges from 5 to 7 m, the length of the pile is around 60 m.

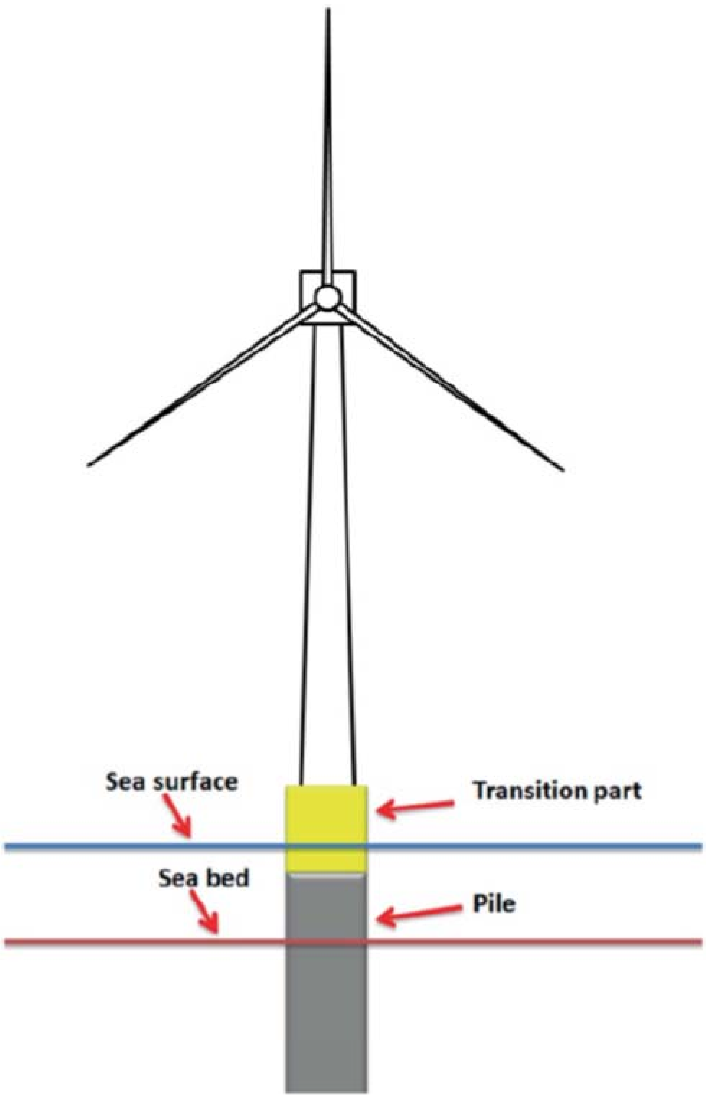


Figure 2.3. Schematic layout of the monopile wind turbine (Karimirad, 2014)

2.4. Power evacuation

A designated government agency will act as a trader for the purchase and sale of wind power from the project. It will enter Power Purchase Agreements (PPA) with the successful bidder, which will be of 25 years duration from the date of commercial operation of the project. The PPA would be backed by an adequate payment security mechanism. The necessary onshore infrastructure for power evacuation from the offshore wind farm will be provided by the Central Transmission Utility / State Transmission Utility. The decision regarding electrical transmission infrastructure from the pooling station in the sea till the point of connection to the onshore substation shall be the responsibility of the developer.

For the study area with large wind farms at distances beyond 20 km from the coast, medium voltage AC cables cannot be used for transmitting power. Hence, an offshore substation has to be installed for transforming the collector system voltages to the HV level for transmission to an onshore substation. The most commonly used design for transmitting large volumes of offshore power to shore is high voltage AC for projects up to 80 km from the shore. HVAC cables can transport considerably more power on a single cable (up to 400 MW on a 220 kV cable). Figure 2.4 depicts the typical layout of an offshore wind farm transmitting power via HVAC cables. The typical voltage for MV collection for offshore wind farms is 33 kV. However, higher MV collection voltages (66 kV) enable small windfarms at larger distances and large wind farms at shorter distances from the shore to transmit power directly to an onshore substation.

Figure 2.4 HVAC transmissions from the offshore wind farm

2.5. Project benefits

Global carbon dioxide emissions can be significantly reduced by replacing the existing energy sources with renewable energy sources. Currently, renewable energy sources like wind, solar and biomass contributes only ~5% of the energy source. Wind energy is one of the cleanest energy sources and the proposed project will reduce the atmospehric pollution.

Chapter 3: Baseline Marine Environment

3. DESCRIPTION OF THE ENVIRONMENT

This chapter presents the baseline data for assessing environmental impact. The baseline data presented include primary data collected by CSIR-NIO under this EIA project during pre-monsoon and post-monsoon seasons and the secondary data. Section 3.1 describes the geological setting of the region, 3.2 seismicity and bathymetry is described in Section 3.3. These two sections are entirely based on secondary data. , The climatology of the regionis based on IMD (India Meteorological Department) data and is described in Section 3.4. The physical processes related to surface waves and tides are presented in Section 3.5. Section 3.6 deals with shoreline changes based on satellite data. Land use land cover of the landfall point is discussed in Section 3.7. Noise and Vibration aspects are covered in section 3.8. Wind wake modelling is presented in section 3.9. Discussion on water and sediment quality is presented in Section 3.10, which is entirely based on primary data collected under this project. The biological characteristics of the region are presented in Section 3.11 to 3.16. Coastal ecology and biodiversity is presented in section 3.17. Socio-economy is in section 3.18.

3.1. Geological setting of the study area

The Cambay basin is a rift basin and forms the inland extension of the large offshore west coast basin and located on the west-north-west margin platform of the Indian Craton, which covers an area of 56,000 sq. Km (Biswas, 1977). The Deccan trap (Cretaceous to Palaeocene age) is the tectonic basement of the Cambay Basin. The sedimentary formation overlying the Deccan trap consists of Alluvial Fans and deltas. The sedimentation in this basin is controlled by pre-rift, syn-rift, and post-rift stages. The Early Tertiary sediments ranging in age from Palaeocene to Early Eocene represent the syn-rift stage of deposition that was controlled by faults and basement highs in an expanding rift system (Balakrishnan *et al*., 1997).The Gulf of Cambay is macro tidal in nature, and the semidiurnal tidal range often exceeds 10m in places. The basin also experiences strong tidal currents with high tides, often rising up to 11m from the normal waterline (Unnikrishnan*et al*., 1999). Seven major river systems including Sabarmati, Mahi, Dadar, Narmada, Tapti, Ambika and Shetrunji deliver a high quantity of sediment load of around 0.6×10^8 tons annually into the Gulf of Khambhat which equates to almost 70% of the total sediment influx to the gulf (Borole, 1988; Rao and Wagle, 1997). The Gulf of Khambhat preserves a record of tidal deposits in both the inner and outer parts of the gulf. The topography of the gulf bottom comprises numerous underwater ridges, deep channels, and shoals. Tidal sand bars and ridges with discrete geometries and dimensions are extensively developed in the Gulf (Saha*et al*., 2016). The sand ridges in the outer gulf region show an elongate to diamond shape and are hundreds of meters in width and a few kilometres in length. Active dunes on these ridges indicate the presence of sand, and their orientation parallel to palaeo-shorelines supports a tidal origin. Strong tidal currents reworked, transported, and re-distributed massive load of sand from fluvial and continental supply to form these sand ridges.

3.2 Seismicity

The project area lies in zone-III of the seismic map of India. Earthquake-prone are as of the country have been identified based on scientific inputs relating to seismicity, earthquakes occurred in the past and tectonic setup of the region. Based on these inputs, the Bureau of Indian Standards (IS 1893 [Part I]:2002) has grouped the country into four seismic zones, *viz*. Zone II, III, IV, and V. Of these, Zone V is seismically the most active region, while zone II is the least. The peninsula of Saurashtra is a horst, founded between the fractures related to the three intersecting rift trends, *viz,* Delhi (NE-SW), Narmada (ENE-WSW) and Dharwar (NNW-SSE).Saurashtra region is bound by N–S trending Cambay basin in the East, the extension of Narmada geofracture in the south, Kachchh rift to the North, and the major WNW–ESE fault which is an extension of the west coast fault system in the Arabian Sea in the West.The Saurashtra region has experienced random seismic activity at several places such as Junagadh, Jamnagar, Dwarka, Paliyad, Rajkot, Ghogha, and Bhavnagar. A total of 10 earthquakes of MC 5.0 have occurred since 1872. An offshore earthquake occurred on 24 August 1993 of magnitude 5.0 near Rajula (Yadav et. Al 2008).

3.3 Bathymetry

The bathymetry chart for the project area is prepared based on the bathymetry survey carried out by CSIR-NIO. The acquired bathymetric data from the survey region was post-processed in HYPACK MAX software, using the Single-beam Editor program to apply various offsets related to the Bathy1500C transducer, SeatexSeapath DGPS antenna, and heave sensor. The method also involves applications of other variables such as vessel offsets, vessel draft, system calibration parameters, heave compensation, and water column sound velocity. Each line data was then edited for filtering out the spurious soundings. The bathymetric data was then reduced to Chart Datum by applying the insitu observed tide data acquired at the mono-pile location with-in the survey region. The horizontal control of the survey was referred to as WGS 84 Spheroid, Universal Transverse Mercator Projection, and plotted on the UTM grid, Zone 42, with Central Meridian 69 degrees E.

The bathymetric map of the project area depicts a gradual variation of the seafloor depth ranging from 8 m in the north-east corner to 17.5 m in the south-west corner (Fig. 3.3.1).Though the seafloor depth is mostly flat with a slope trending north-south orientation, there exists a bathymetric high feature almost in the middle of the project site. The maximum topographic slope on either side of the ridge structure is 1 degree and 0.4 degrees on the landward and seaward side, respectively.

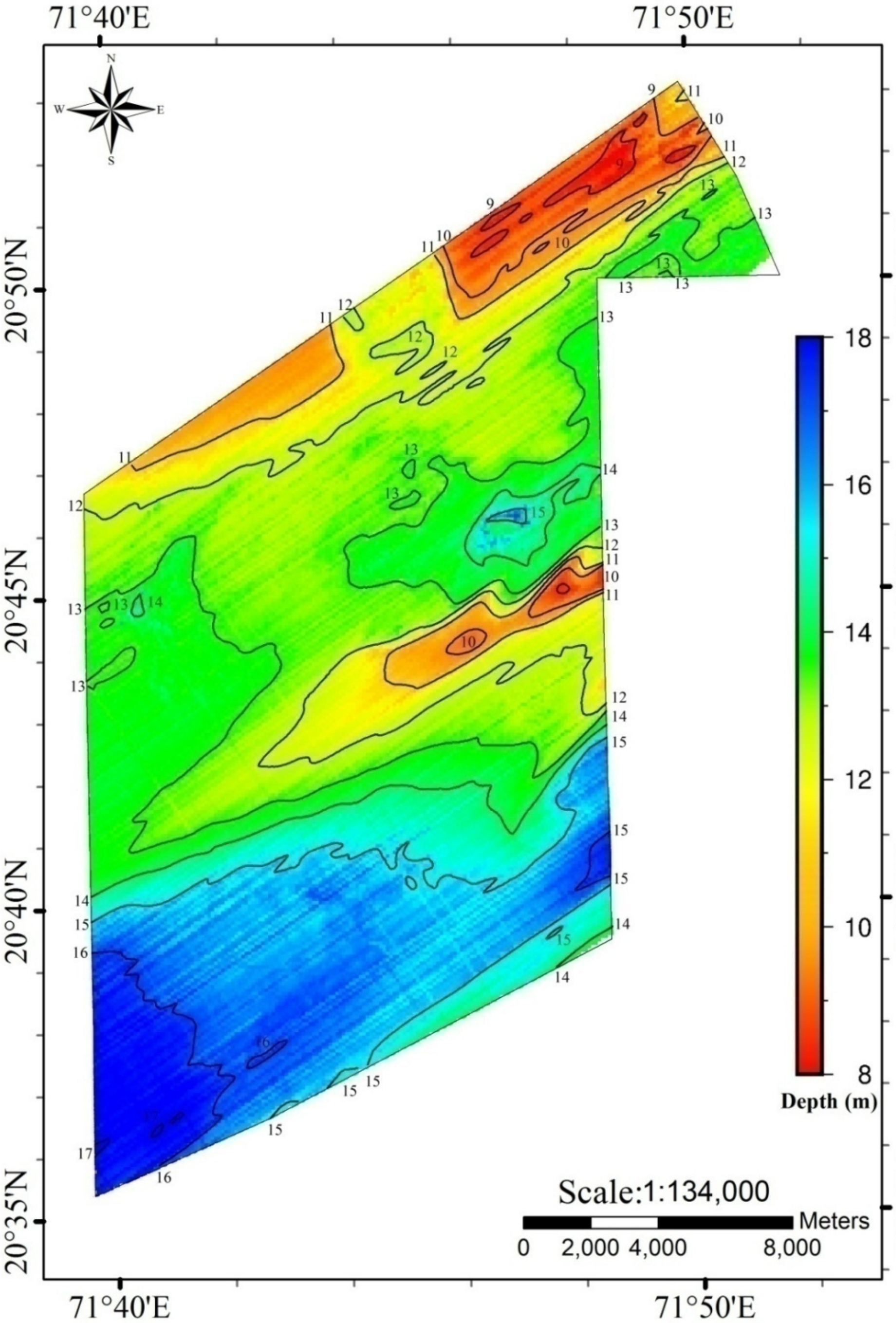


Figure 3.3.1.The bathymetry map of the project area

The surficial sediments are mainly course- grained in the project area. Sand content is higher in the north eastern part and is lowest in the south-western part (Fig. 3.3.2 to 3.3.4). Silt is the second most dominant component and is relatively high in the western part. Clay content is very low at a majority of the station. The seismic survey indicates that it is likely that silty sand ~20 m thick are present on the seabed over the project area.

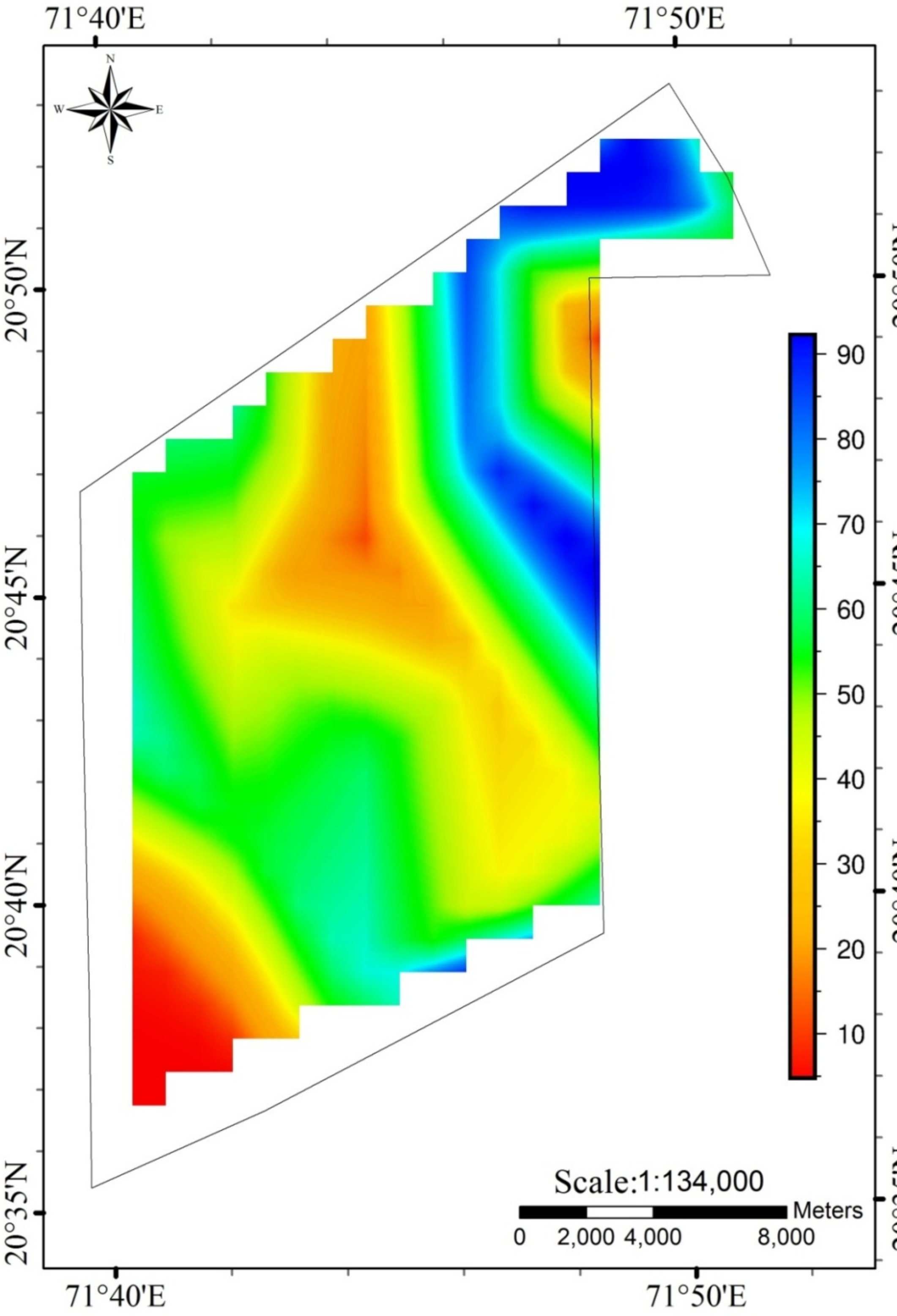


Figure 3.3.2 Distribution of sand content in the surface sediment

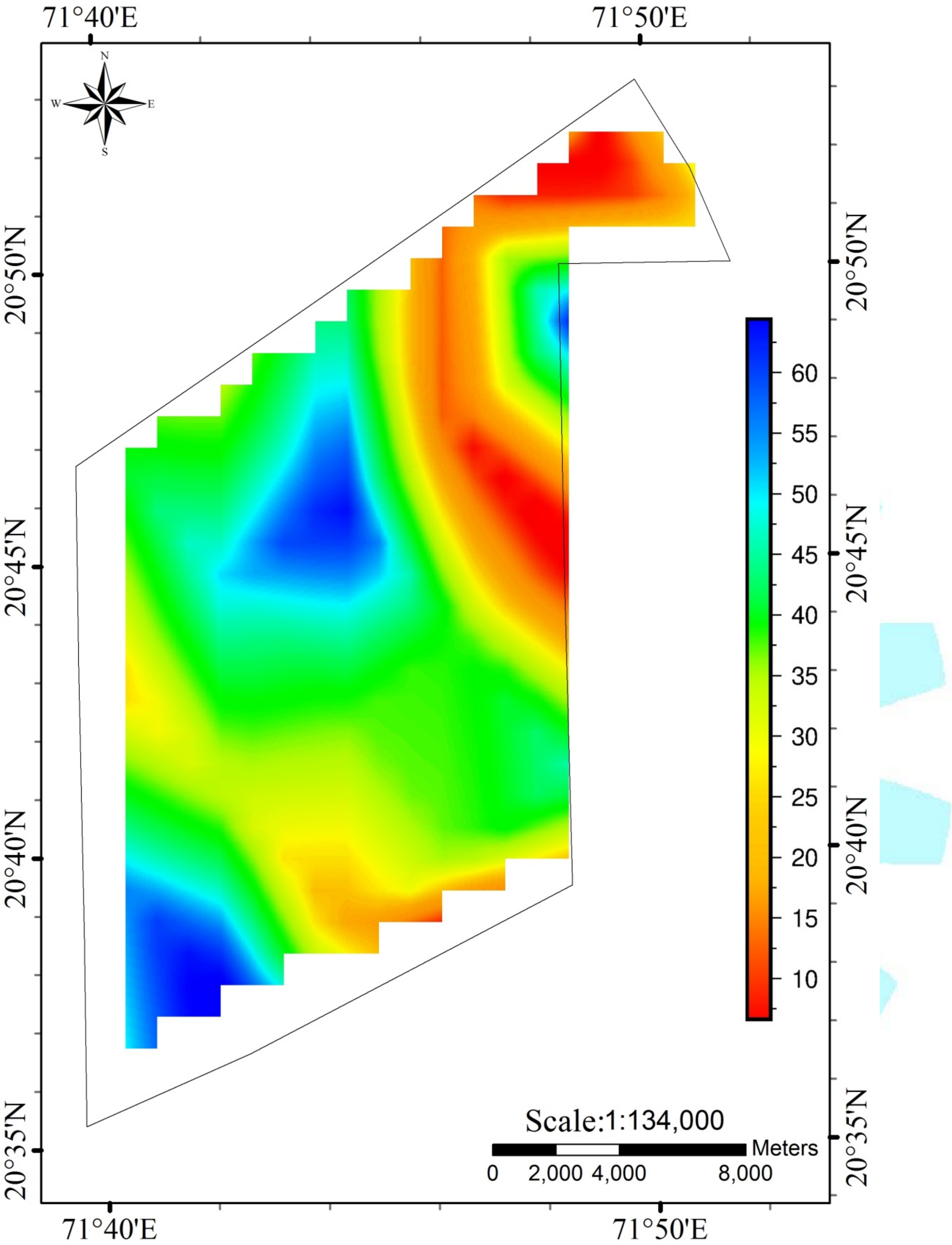


Figure 3.3.3 Distribution of silt content in the surface sediment

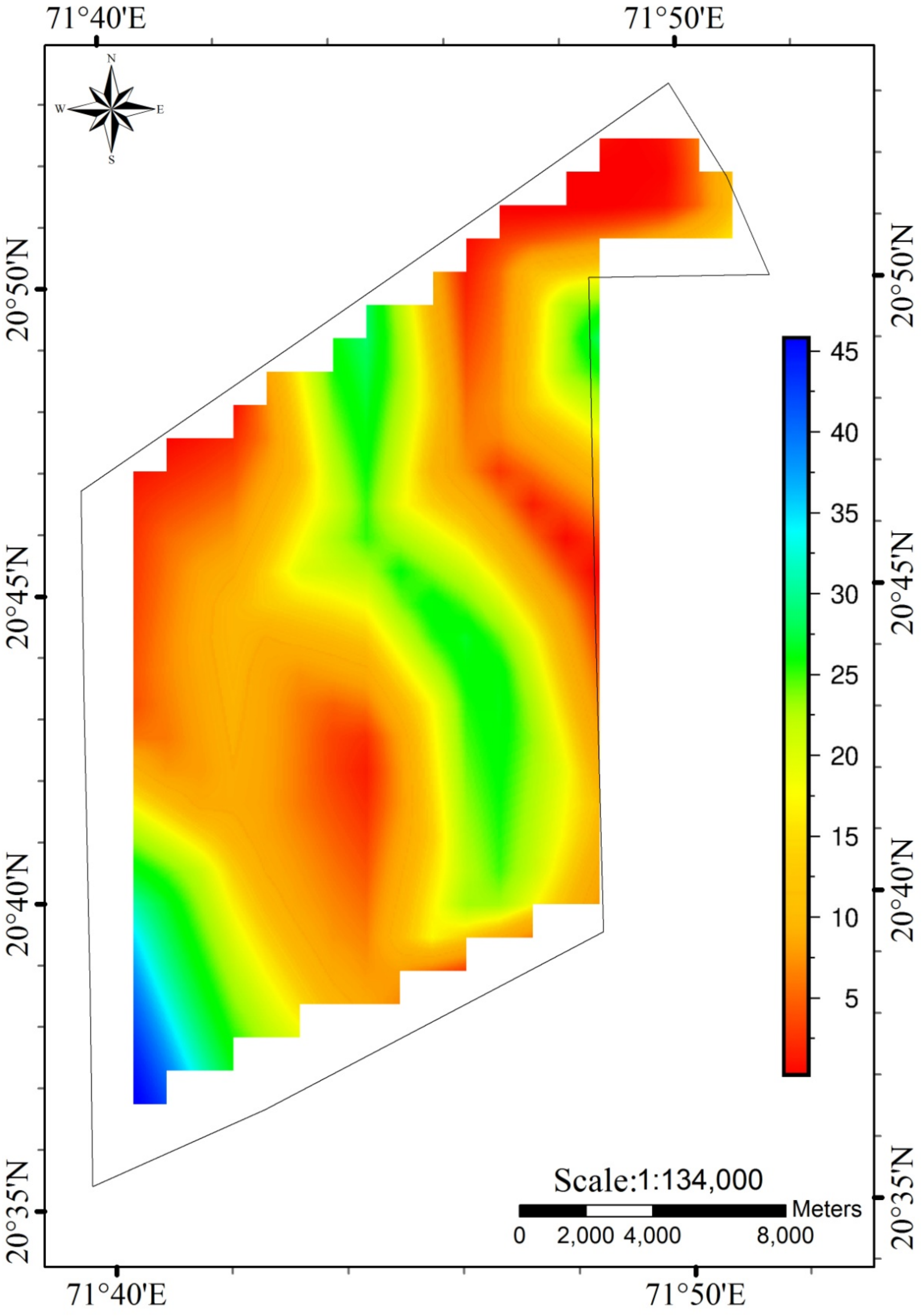


Figure 3.3.4 Distribution of clay content in the surface sediment

3.4. Climatology

3.4.1. Ambient Air Temperature

Analysis of the annual distribution of air temperature at Mahuva, the nearest observatory of India Meteorological Department(IMD), which is 22 km away from the project site,showed seasonal variations. The average air temperature data of 30 years reveals that the highest monthly mean temperature of 41.6 ºC is recorded in April, and the lowest monthly mean temperature is 10.1ºC in January (Table 3.4.1).

Table 3.4.1. Monthly mean air temperature at Mahuva

Month	Monthly maximum (ºC)	Monthly minimum (ºC)
January	33.5	10.1
February	36.7	11.4
March	39.5	14.2
April	41.6	17.7
May	40.8	20.3
June	37.1	23.2
July	34.5	22.9
August	33.6	22.6
September	36.2	21.1
October	37.9	18.4
November	36.4	16.1
December	34.1	11.8

Source – IMD Data

3.4.2. Relative Humidity

The monthly mean of relative humidity varies from the lowest of 48% in January and February to 91% in August (Table 3.4.2).

3.4.3. Atmospheric pressure

The atmospheric pressure variation is within small ranges. The highest value of atmospheric pressure was 1013.9 hPa in January and the lowest of 999.4 hPa in June (Table 3.4.2).

Table 3.4.2.Monthly mean values of Relative Humidity and atmospheric pressure

Month		Relative humidity (%)	Atmospheric pressure (hPa)
January	a)	57	1013.9
	b)	48	1011.0
February	a)	55	1012.4
	b)	48	1009.4
March	a)	59	1010.7
	b)	53	1007.6
April	a)	62	1008.4
	b)	58	1005.3
May	a)	75	1005.7
	b)	66	1002.5
June	a)	83	1002.0
	b)	74	999.4
July	a)	89	1000.7
	b)	81	998.8
August	a)	91	1002.5
	b)	82	1000.3
September	a)	88	1006.1
	b)	75	1003.5
October	a)	70	1009.7
	b)	58	1006.8
November	a)	60	1012.5
	b)	53	1009.6
December	a)	60	1013.8
	b)	51	1010.9
Mean	a)	71	1008.2
	b)	62	1005.4

a) 0830 h. observations b) 1730 h. observations Source - IMD Data

3.4.4. Visibility

The thirty-year monthly means of visibility shows that the morning visibility varies between 4 and 10 km during 94 days and more than 20 km during 211 days in a year. The evening varies between 4 and 10 km during 102 days and more than 20 km during 224 days in a year. (Table 3.4.3).

Table 3.4.3.Monthly mean of visibility

Month		0-1 km	1-4Km	4-10Km	10-20Km	>20Km
January	a)	0.0	1.7	4.4	8.7	16.2
	b)	0.0	0.3	1.7	8.5	20.5
February	a)	0.0	0.9	2.3	7.3	17.5
	b)	0.0	0.0	0.3	6.6	21.1
March	a)	0.0	0.1	2.4	7.4	21.1
	b)	0.0	0.2	0.9	6.1	23.8
April	a)	0.0	0.4	2.2	5.7	21.7
	b)	0.0	0.7	0.5	7.0	21.8
May	a)	0.0	1.2	1.3	8.5	20.0
	b)	0.0	1.5	2.4	9.5	17.6
June	a)	0.2	3.0	4.5	9.5	12.8
	b)	0.1	2.1	3.4	10.6	13.8
July	a)	0.4	4.4	5.8	11.0	9.4
	b)	0.0	3.5	5.3	11.6	10.6
August	a)	0.1	4.3	3.7	11.3	11.6
	b)	0.1	3.1	4.8	11.8	11.2
September	a)	0.1	1.8	3.0	8.6	16.5
	b)	0.0	1.4	1.6	9.6	17.4
October	a)	0.0	0.3	2.8	4.4	23.5
	b)	0.0	0.1	0.8	6.0	24.1
November	a)	0.0	1.6	1.5	5.5	21.4
	b)	0.0	0.8	1.9	7.1	20.2
December	a)	0.0	1.5	4.0	6.0	19.5
	b)	0.0	0.4	1.2	7.3	22.1
Annual Total	a)	0.8	21.2	37.9	93.9	211.2
	b)	0.2	14.1	24.8	101.7	224.2

a) 0830 h. observations b) 1730 h. observations Source - IMD Data

3.4.5 Rainfall

The region receives on an average of about 622mm rainfall in a year, and around 96% of rainfall occurs during the southwest monsoon period (June to September). The number of rainy days in a year has been estimated to be 34 (Tables 3.4.4).

Table 3.4.4.Data on monthly rainfall and rainy days

Month	Rainfall (mm)	No. of rainy days
January	0.7	0.1
February	0.2	0.0
March	6.6	0.2
April	0.1	0.0
May	0.3	0.0
June	112.1	6.0
July	228.4	11.6

August	141.0	9.1
September	114.5	5.7
October	12.7	0.8
November	4.2	0.4
December	1.2	0.1
Annual Total	622.0	34.0

Source – IMD Data

3.4.6 Wind speed

The wind speed for the study area for the year 2018 is estimated from the weather forecast model (WRF) at 40 m, 100 m, and 200 m above mean sea level at six hourly intervals. The wind rose for different periods; February-May, June-September, October-January, and January-December are presented in (Figure 3.4.1). At 40 m height, the wind speed varied from 0.1 to 15 m/s with an annual mean value of 5.8 m/s.At 100 m height, the wind speed varied from 0.4 to 16.6 m/s, with an annual mean value of 6.4 m/s.At 200 m height, the wind speed varied from 0.4 to 17 m/s with an annual mean value of 7 m/s. The measured Lidar data from November 2017 to November 2018 shows that at 40 m height, wind speed varied from 0.3 to 18.2 m/s with an average value of 6.4 m/s and at 60 m height, the wind sped varied from 0.2 to 18.5 m/s with an average value of 6.6 m/s. At 70 m height, wind speed varied from 0.2 to 18.7 m/s with an average value of 6.7 m/s, and at 80 m height, the wind sped varied from 0.2 to 18.6 m/s with an average value of 6.8 m/s.At 100 m height, wind speed varied from 0.1 to 18.6 m/s with an average value of 6.9 m/s, and at 200 m height, the wind sped varied from 0.3 to 19 m/s with an average value of 7.3 m/s.

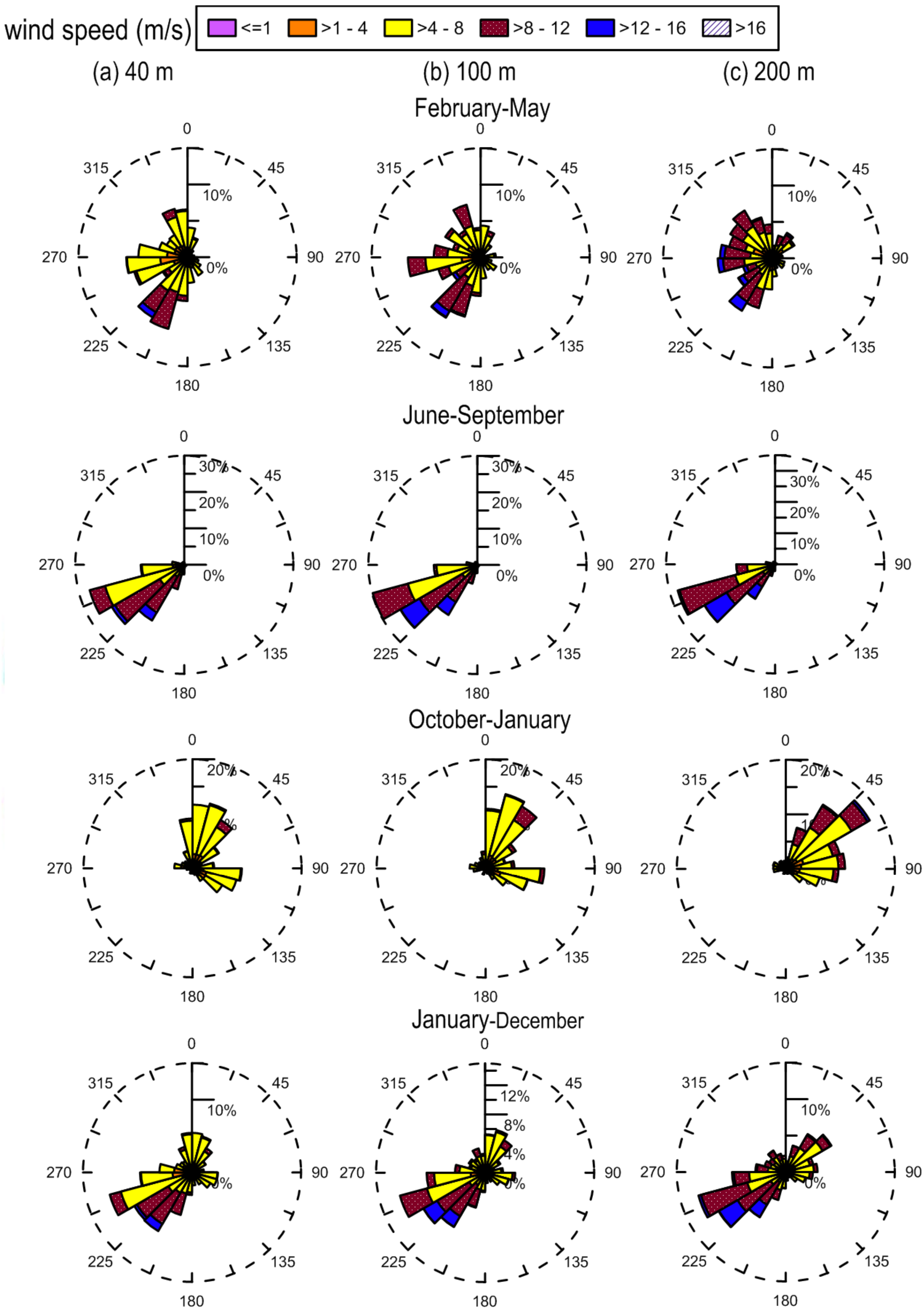


Figure 3.4.1.Rose diagram of winds during periods at different levels of 2018. The left panel is for 40 m, the middle is for 100 m, and the right panel is for 200 m height.

3.4.7. Cyclones

The tracks of the cyclone that occurred in the northern Arabian Sea during 1960 to 2017 have been collected from the Joint Typhoon Warning Center Tropical Cyclone Best-Tracks (http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best_tracks) data, and presented in (Figures 3.4.2 to 3.4.4). From 1960 to 2017, 37 depressions/cyclones crossed within a 4° radius of the project site, and the maximum wind speed of these depressions/cyclones was 50 m/s.

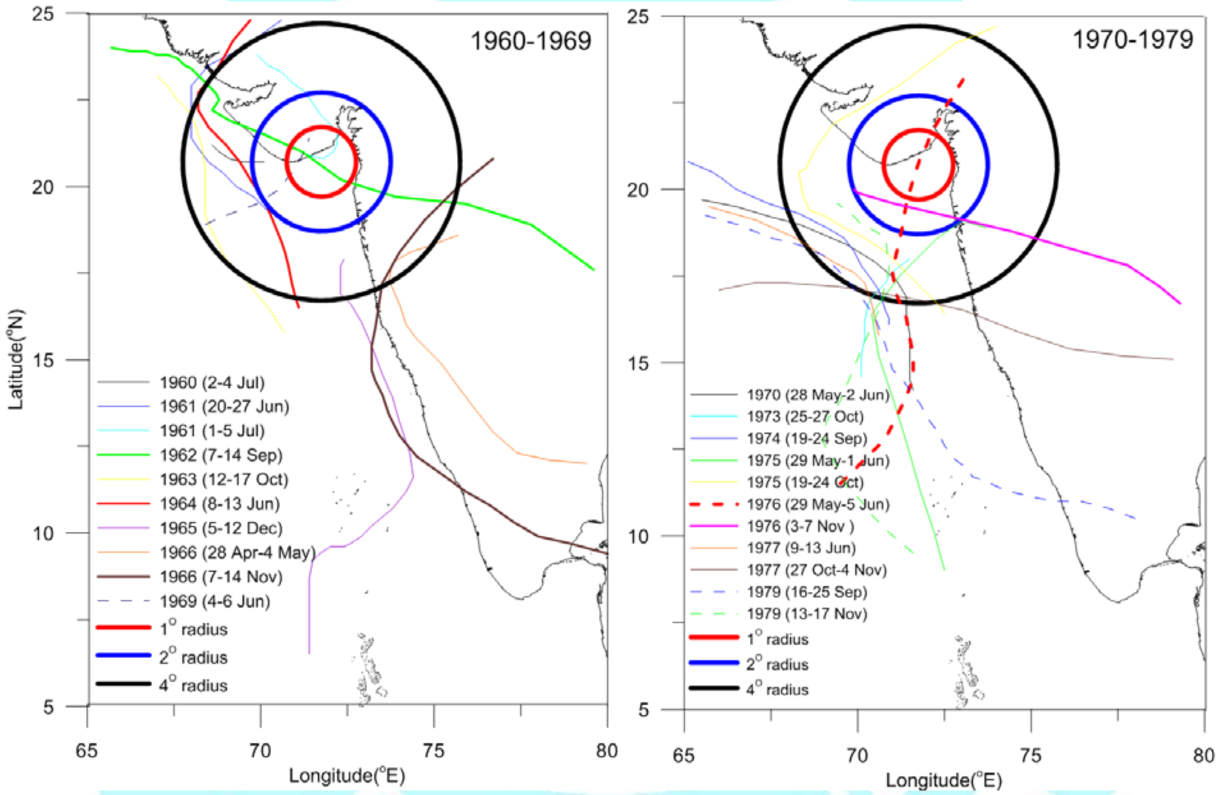


Figure 3.4.2. Tracks of depressions/cyclones within 4° radius of the project location during 1960-1979

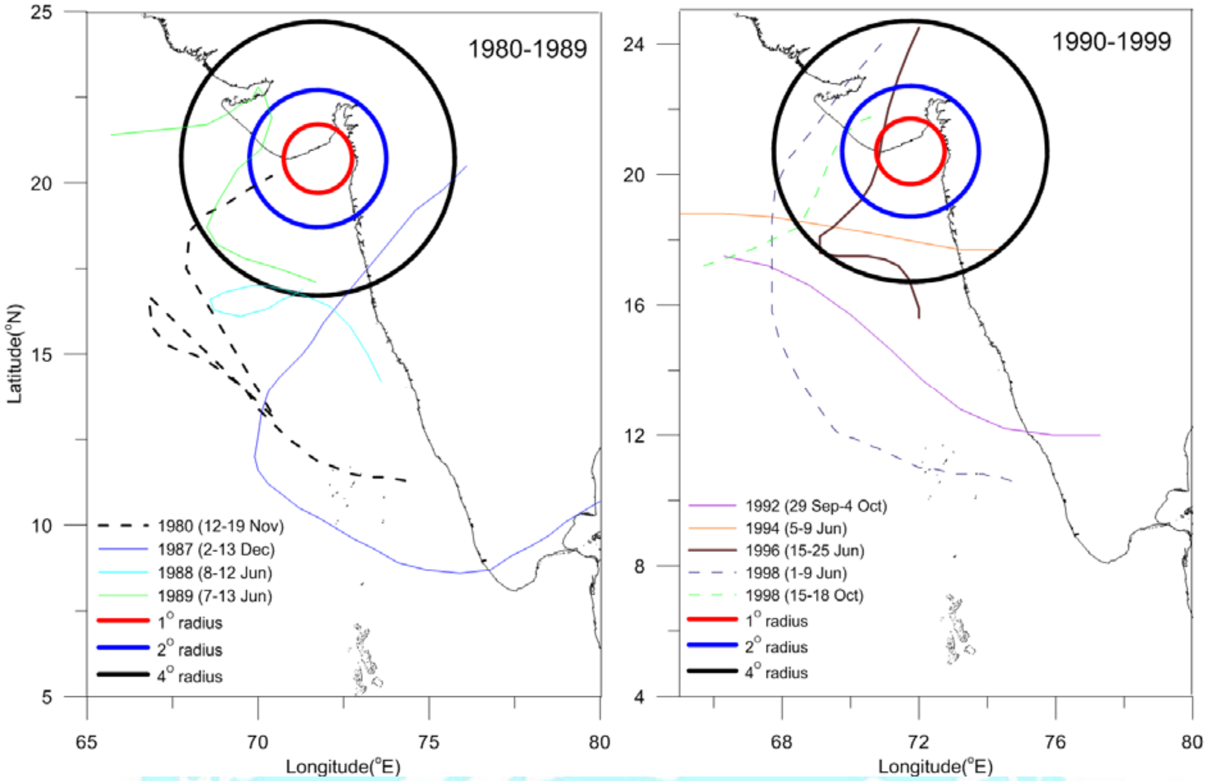


Figure 3.4.3 Tracks of depressions/cyclones within 4° radius of the project location during 1980-1999

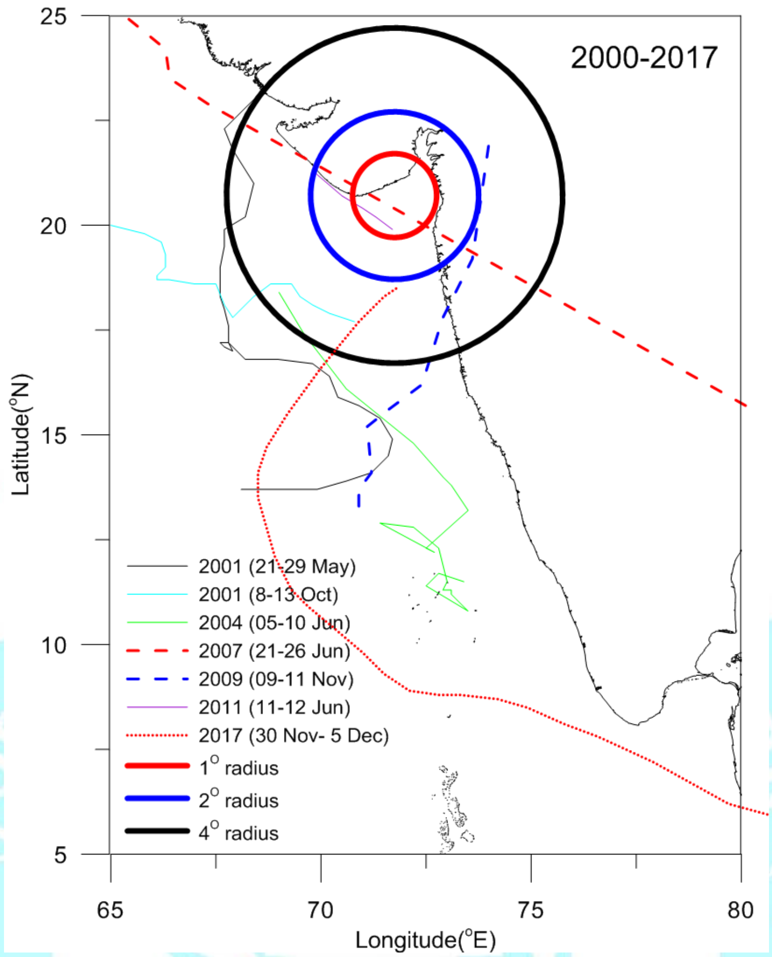


Figure3.4.4.Tracks of depressions/cyclones within 4° radius of the project location during 2000-2017

3.4.8 Storm surge

One of the most significant impacts in the coastal regions by the tropical cyclones is due to storm surges. Storm surges are generated by tropical cyclones by inverse barometric effects in the open ocean region. Surges are barotropic in nature, i.e., they are vertically homogeneous. They propagate towards the shore along with astronomical tides, which are also barotropic. While approaching the shore, they amplify due to the bottom topographic effects and cause damages while striking the coast. Storm surge height depends on the intensity of the wind. For the cyclones which crossed the study area within a 4° radius, the maximum wind speed during 1960-2017 is 50 m/s and can have storm surgesup to1.4 m.

3.4.9 Tsunami

Tsunami is a series of massive ocean waves caused by submarine earthquakes that set off waves with long wavelengths in water, and the most destructive tsunamis are caused by subduction zone earthquakes, landslides, and volcanic eruption. Makran Subduction zone in the southern part of Pakistan is seismically active, and there have been historical tsunami generic earthquakes from this region in 1765, 24 Jan 1851, and 28 Nov 1945. The 1945 tsunami generated due to theMakran Earthquake in the Arabian Sea was the most devastating in the history of the Arabian Sea. It caused severe damages to the property and loss of life. It occurred on 28November 1945, 21:56 UTC (03:26 IST) with a magnitude of 8.0 (Mw), originating off the Makran Coast of Pakistan. It has impacted as far as Mumbai in India and was noticed up to Karwar Coast, Karnataka (Jaiswal *et al*. 2009), and the height of the tsunami in Mumbai was 2 m. Srivastava *et al*. (2011) estimated the arrival time of the tsunami generated at the Makran subduction zone (which is 1060 km from Mumbai) and found that the tsunami reaches Mumbai in around 180 minutes. The source characteristics considered for the simulation were earthquake of magnitude 9.0 (epicenter: 25° 09'N; 63° 28' 48" E), fault length=377 km, width of fault=190 km, focal depth=25km, displacement=11m.The 2004 Indian Ocean Tsunami was one of the most devastating disasters in modern history, and it affected the southern coasts of India. The influence of the2004 Indian Ocean tsunami along the study area was not significant.

3.5 Physical Processes

The hydrodynamics of the region is mostly controlled by the tides and reversing monsoonal winds.

3.5.1 Waves

Surface waves are generated by the winds blowing over the surface of the sea. Waves are characterized by their height, period and direction. Based on the wave hindcast data for 2018 for location 20° 45'N; 71° 45'E, the wave rose diagram is presented in (Fig. 3.5.1). The predominant wave characteristics during 2018 are presented in (Table 3.5.1). The significant wave height (Hs) varied between 0.3 and 3 m with a mean value of 1.1 m (Table 3.5.1). The mean wave period varied from 3.8 to 12 s with an average value of 7.1 s. The spectral peak wave period varied from 3 to 20 s with an average value of 10 s. The waves are predominantly from the south-southwest with direction varying from 180 to 240º except in December, during which the waves are from north-east (Figure 3.5.1).

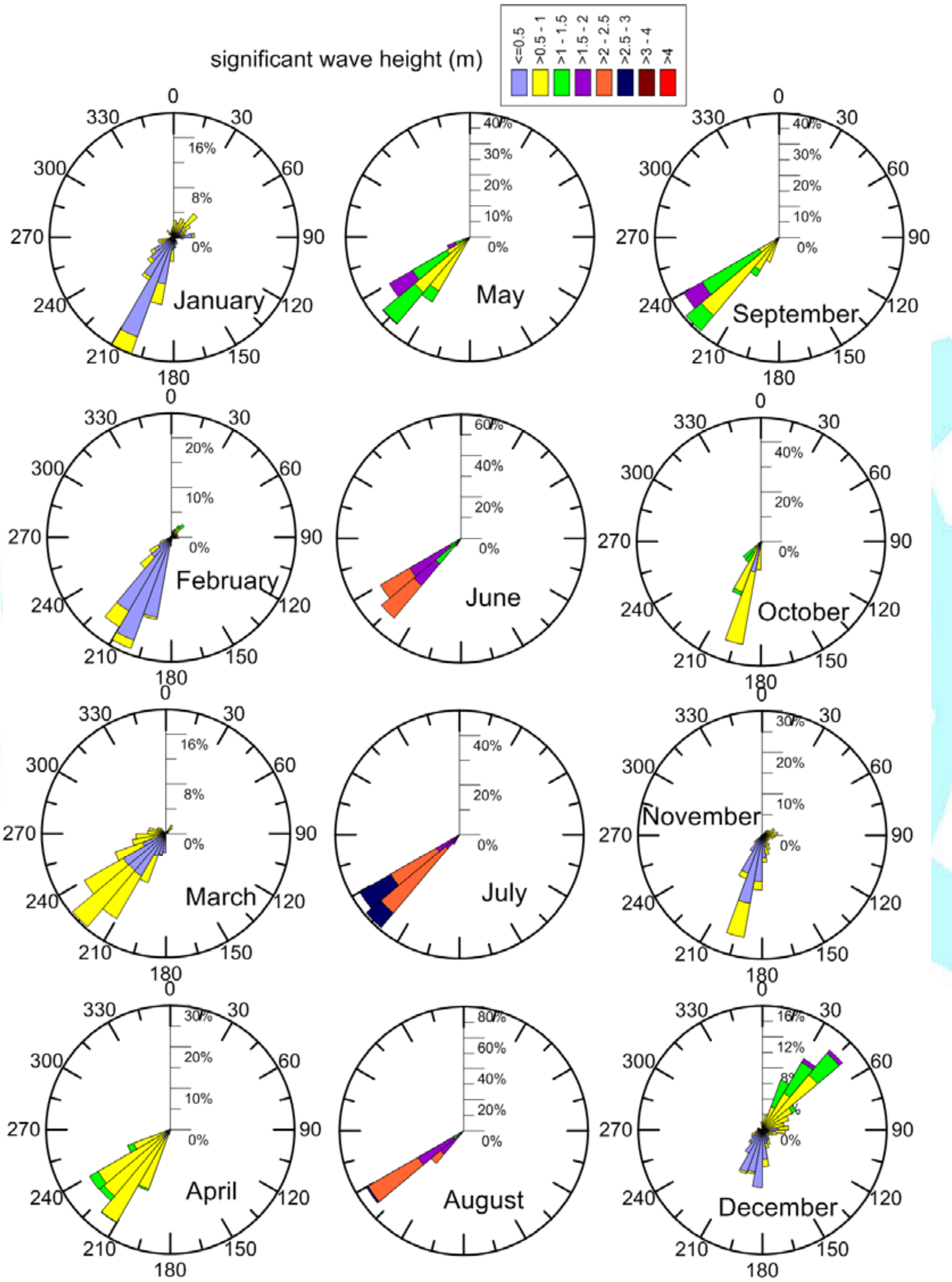


Figure 3.5.1.Wave rose diagram near the study area based on wave hindcast data for the year 2018

Table 3.5.1.Predominant wave characteristics during 2018

Wave parameter	Minimum	Maximum	Average
Significant wave height (m)	0.3	3.0	1.1
Mean wave period (s)	3.8	12.0	7.1
Spectral peak period (s)	3.0	20.0	10.0

The annual maximum significant wave height from 1979 to 2012 based on the model data is presented in (Fig. 3.5.2). The maximum significant wave height is 5.9 m and was in 1998.

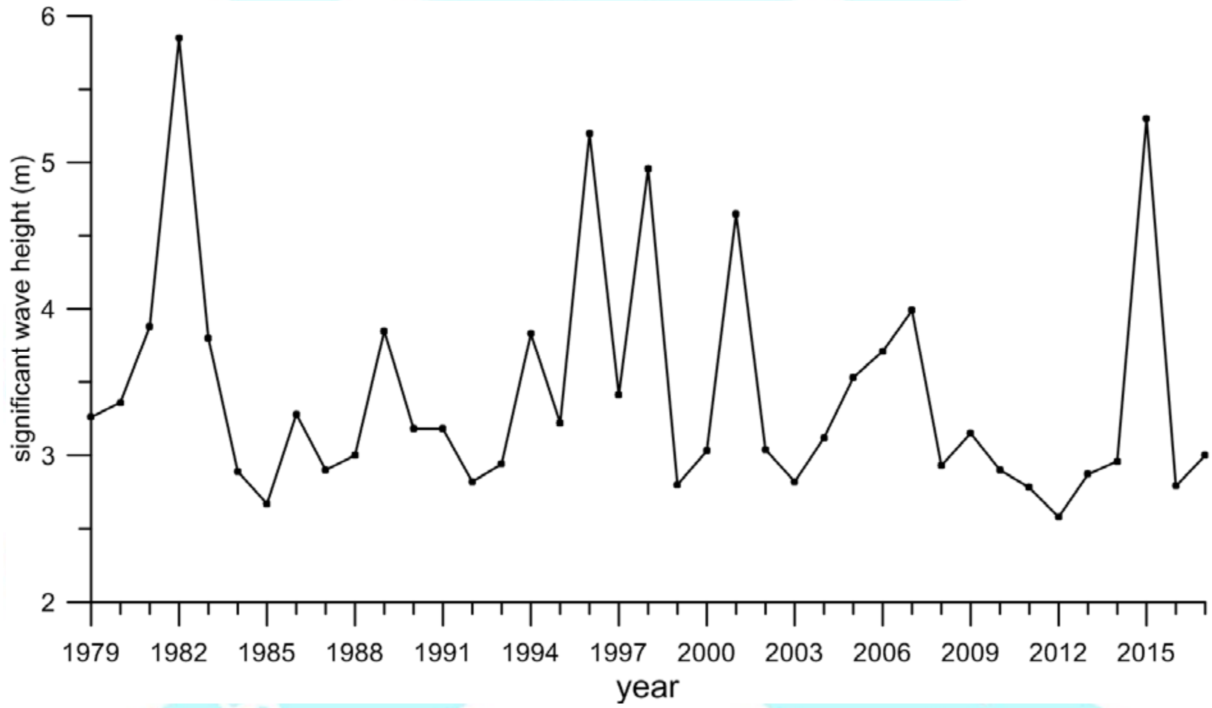


Figure 3.5.2.Plot of annual maximum significant wave height from 1979 to 2017

3.5.2 Tides

The variation of water level during 2019 based on the predicted tide at Pipavav Bandar is presented in (Figure 3.5.3). The tide heights with respect to chart datum at Pipavav Bandar are as follows:

Higher High Water Springs	=	3.92 m
Mean Higher High Water	=	3.19 m
Mean Lower High Water	=	2.37 m
Mean Sea Level	=	1.76 m
Mean Higher Low Water	=	1.16 m
Mean Lower Low Water	=	0.50 m
Lower Low Water Springs	=	-0.01 m
Chart datum	=	0.00 m

The tides measured at 20° 46.615' N; 71° 40.165 'E during 1 December 2018 to 31 January 2019 indicates that the tides vary from -0.62 to 4.32 m (Fig. 3.5.4).

3.5.3 Sea level rise

Analysis of past sea-level measurements, recorded by tide gauges located at various ports in different parts of the world ocean, indicate a mean sea level rise of 1 to 2 mm/year during the last century. These changes are generally attributed to global warming. Various consequences of global warmings, such as the melting of sea ice, volume expansion due to temperature increase in the ocean, etc. can contribute to global sea-level rise. The estimates of mean sea level rise based on the past sea-level data (1878-1994) for the Mumbai region is 0.78 mm/year (Unnikrishnan *et al.*, 2006).

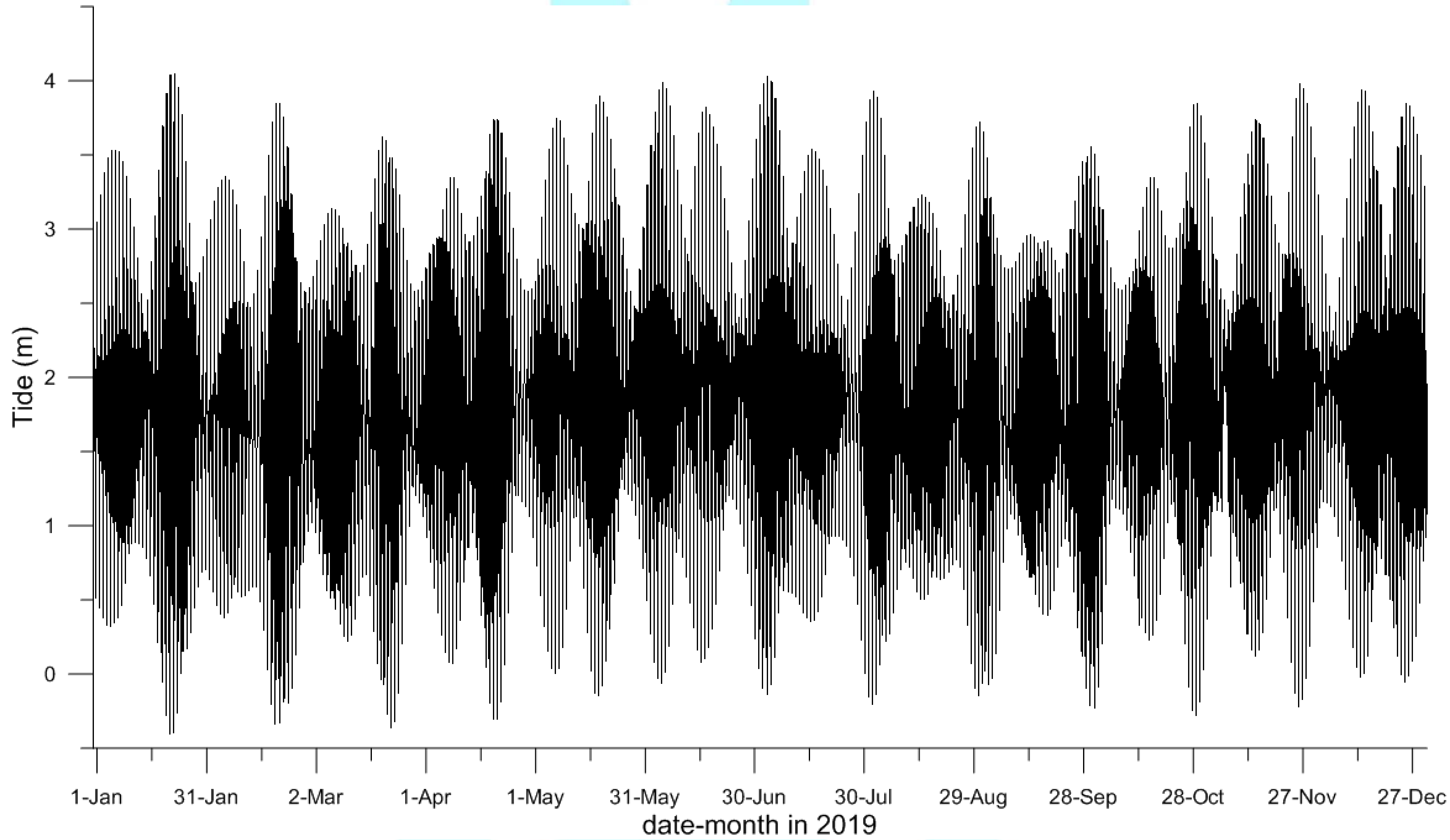


Figure 3.5.3.Variation of the predicted tide at Pipavav Bandar during 2019

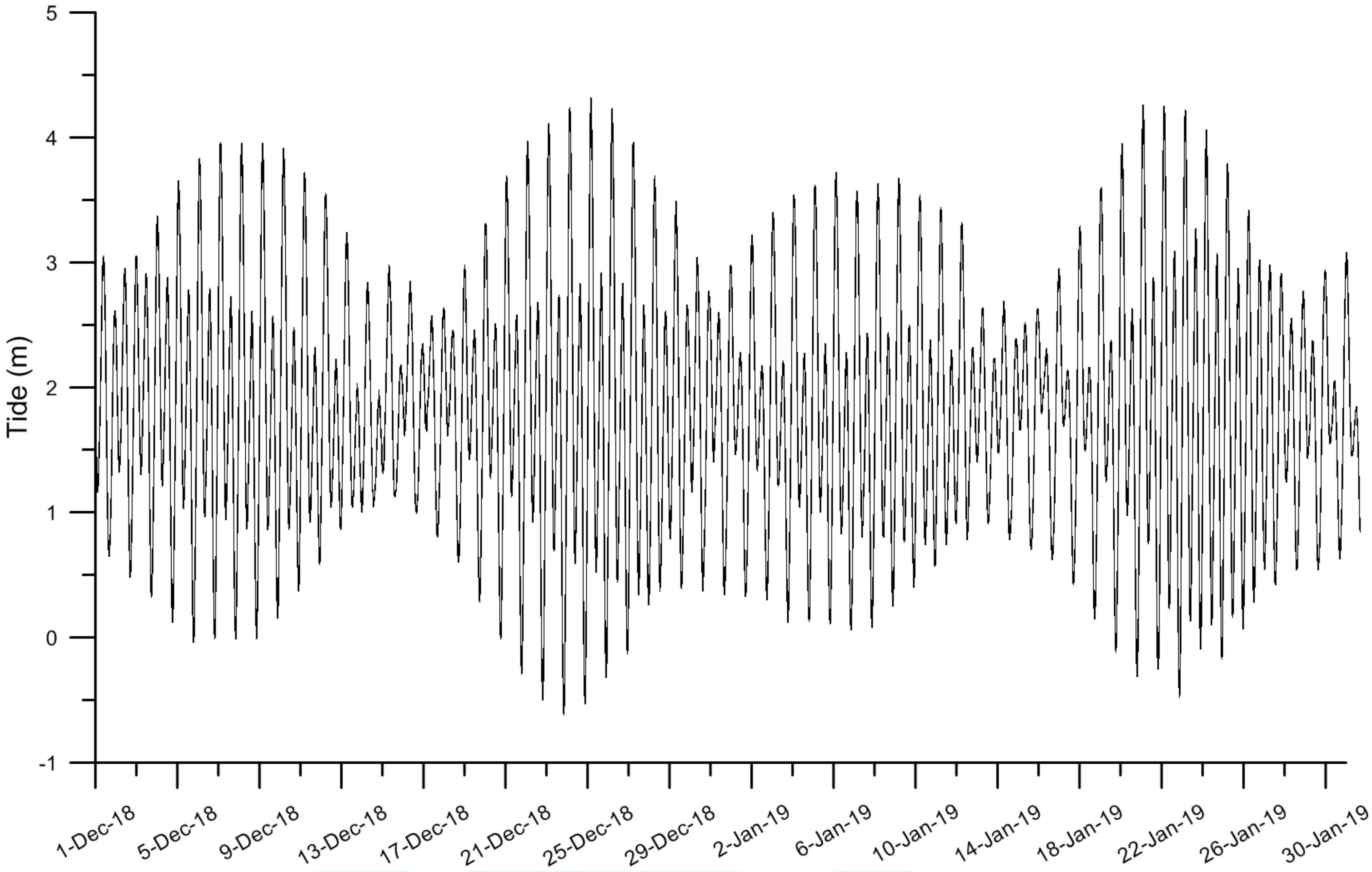


Figure 3.5.4. Variation of tides at 20° 46.615' N; 71° 40.165 'E from 1 December 2018 to 31 January 2019

3.6 Shoreline changes

The coastline between Jaffrabad and Pipavav is under low erosion (<1 m/year) as per the assessment of shoreline changes by the Institute of Ocean Management, Anna University, Chennai,for the period of 38 years from 1972-2010(Fig. 3.6.1). Shoreline change evaluations are based on comparing four to five historical shorelines, archived from satellite imageries for the above time period, with recent shoreline derived from LISS III images and limited field surveys. Base maps were on 1:50,000 scales using the toposheet of the Survey of India and onscreen digitization of coastline using multi-date satellite images on 1:50,000 scale and stored as four different layers in GIS environment for the period between 1972 and 2010. The multi-date shorelines served as input into the USGS digital shoreline analysis model to cast various transects along the coastline. A distance of 300m (in some cases 500m) intervals were assigned to calculate the erosion/ accretion statistics in ArcGIS 9.3 software. The erosion/accretion rates are derived from the "statistical analysis" of multi-date shorelines using the Linear Regression Rate (LRR) of the USGS Digital Shoreline Analysis System.

The assessment of shoreline change during 1990 to 2016 (Kankara et al., 2018) shows that 0.16 km of Amreli district coastline undergone high erosion (> 5 m/year), 0.88 km has moderate erosion (3 to 5 m/year). 22.4 km has low erosion (0.5 to 3 m/year), 18.68 km is stable (<0.5 m/year), 14.50 km has low accretion (0.5 to 3 m/year), 0.34 km has moderate accretion (3 to 5 m/year) and 0.04 km has high accretion(> 5 m/year) (Fig. 3.6.2).

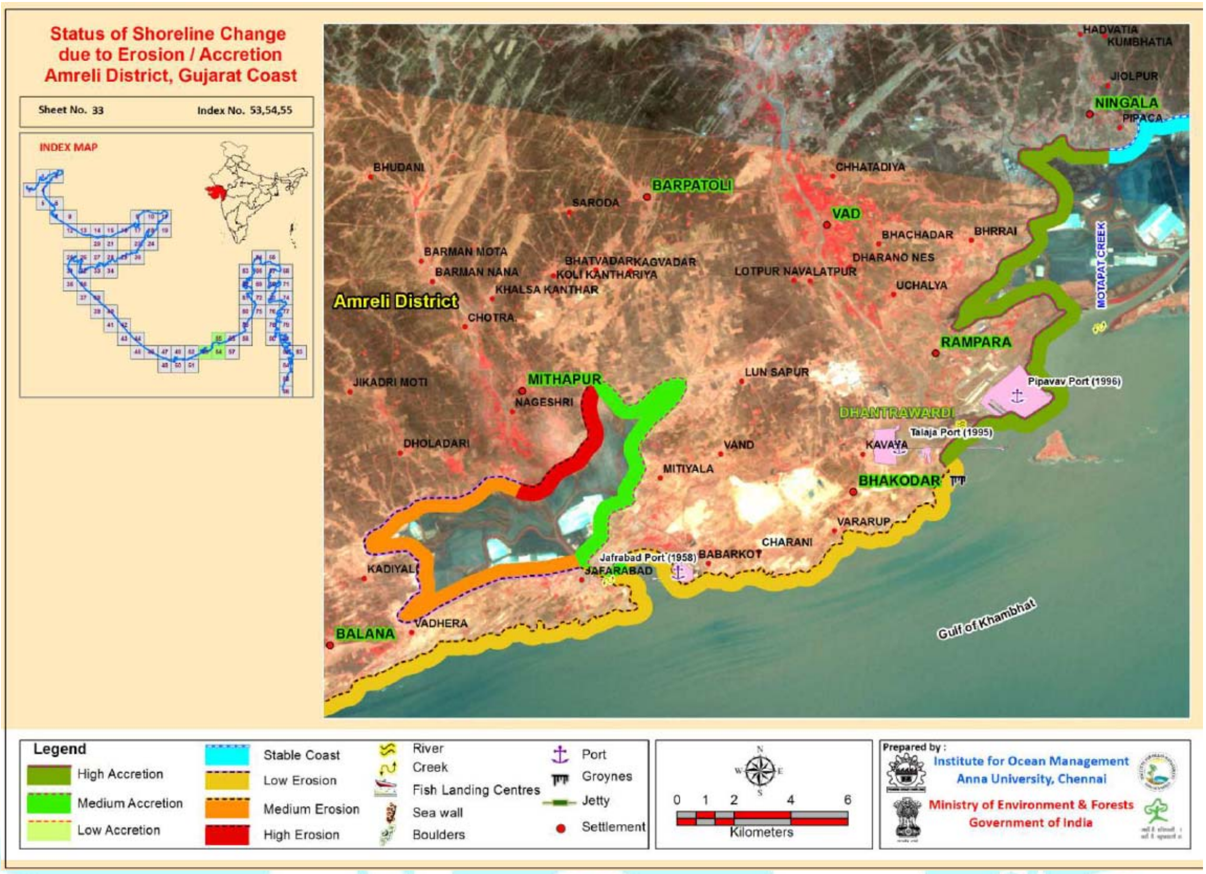


Figure 3.6.1.Shoreline change assessment from 1972 to 2010 (Source:Ministry of Environment and Forests, Government of India).

Figure 3.6.2.Shoreline change of Amreli district from 1990 to 2016 (Kankara et al., 2018)

3.7 Land use & land cover

The region is widely known for its limestone deposits, thus making it a hotspot for industrial growth. India's oneof the largest cement maker Ultratech Cement Ltd has a huge plant in the area known as Gujarat Cement Works. There is a small fishing village situated in the extreme northwest region near of Jaffrabad. On the eastern side lies Port Pipavav India's first private sector port. The region is also bounded with intermittent rocky and sandy shore. Northern Tropical Thorn Forests occupy in the northwest part of the state. They exhibit all stages of the diminution of vegetation to the true climatic desert. Acacia is dominant spp, whose height varies from 4.5 to 10 M. Other species include *Zizyphus* spp., *Caparis* spp.&*Anogeissus* spp. Thin grasses appear during the rainy season, mean annual temperature reach above 31° C & rainfall varies from 250 mm to 750mm. Soils are mostly alluvial or Aeolian on hilly slopes like Arravallies. Several Protected areas are designated to conserve the state's wildlife.The Mitiyala Wildlife Sanctuary is the nearest protected area from the landfall point (substation), which is approximately located at 40 km (Aerial distance). In contrast,Gir national park is located at adistance of approximately 72 km (aerial distance).

Fig. 3.7.1: Depicting Land Cover Land Use in the landfall area (Based on: 10 Km radius from Landfall point).

3.8 Noise and Vibration

Human habitat on land: The analysis for low-frequency noise vibration is carried out to measure the range of impact from the wind farm's turbine blades and to identify the areas of land and sea where prevalent activities are affected. Typically the low-frequency noise vibrations of the wind turbine's blade travel upto a range of 500 m to 3 km. As the site location is over 23 km away from the shore, it is unlikely to have any adverse impact on the baseline environment for habitation on land.

Marine Traffic Routes: The wind-farm also lies very close to the marine traffic routes that connect to Pipavav and Jafarabad ports. This is analysed carefully in the subsequent parts of this report using overlays of the impact zones with baseline information of traffic routes.

Marine Wildlife Habitat: Various species of fish and mammals inhabit in the sea around the proposed site. As the site is located on the edge of the coastal shelf, species living in both shallow and deep water need to be considered in a sensitive manner.

Fishing and Livelihood: Fishingvillages along the coast of Gujarat access the waters around the proposed site for fishing activities. Various sizes of fishing vessels travel across the area and depend on the area for their livelihood.

3.8.1 Methodology

Review of the data available: The following data were reviewed to study the existing available wind, orography, roughness, and temperature data nearest to the proposed location.

Jafarabad Coastal Mast data: The Coastal Mast off the coast of Jafrabad and Pipavav located 23Km away from the shoreline has collected accurate data from 2017 for wind speed, wind direction and for multiple heights upto 120 m.

This location is at the corner of the proposed wind farm and is closest to the actual on-ground readings one can plan for in potential, during operation of the wind farm, and the simulation and analysis.

LIDAR data: This data is collected using state of the art technology and ensures high quality, accurate data for the inputs in the simulation.

Orography of the region: The topography over the sea surface is mostly constant and does not undulate like that of the land where hills and valleys can significantly alterthe wind speeds and directions. This means that the wind is also relatively predictable in its pattern. This data was referenced from the Wind Atlas website (www.globalwindatlas.info), which provides information upto a suitable degree of resolution.

Roughness on the region: The roughness over the sea surface is mostly constant and does not vary like that of the land where farmlands, rocky surfaces, homes, forests, and lakes can significantly alter the wind speeds and directions over the ground level surfaces. This means that the wind is also relatively predictable in its pattern. This data was also referenced from the Wind Atlas website, which provides information up to a suitable degree of resolution (Figs. 3.8.1 and 3.8.2).

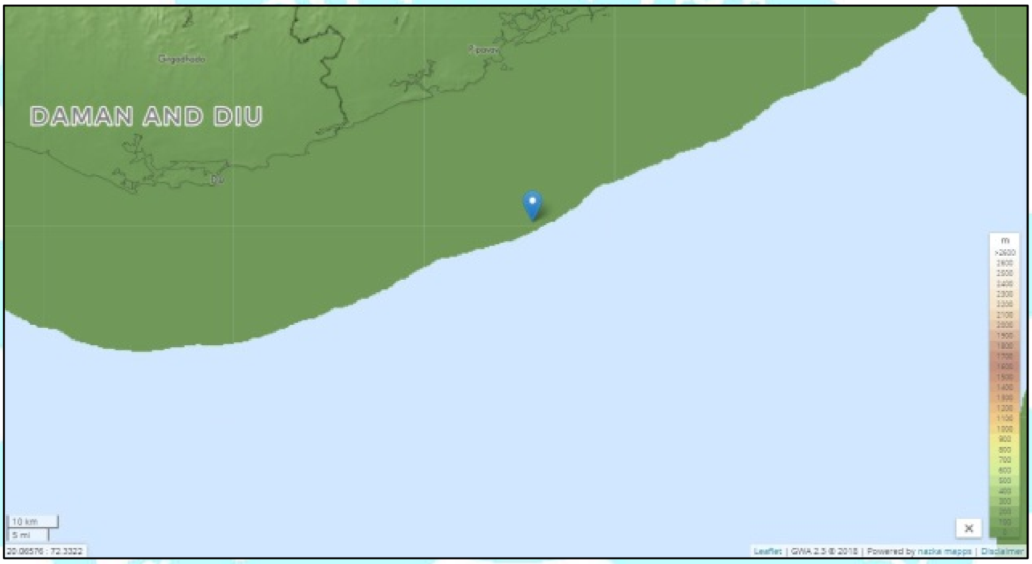
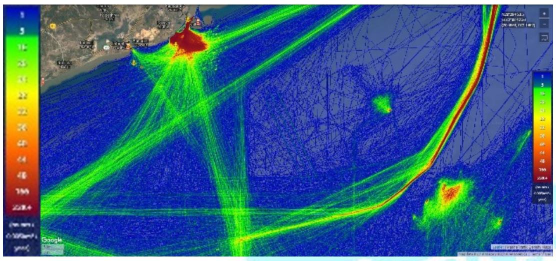


Figure 3.8.1: Map showing the geomorphology of the elevated terrain along the coastal edge of the site.

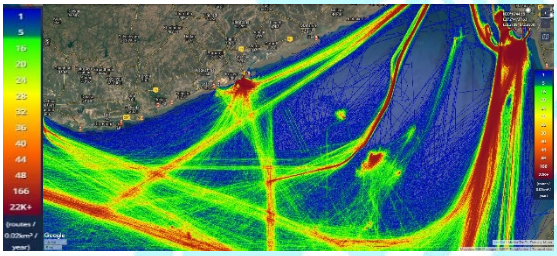
Figure 3.8.2: Roughness data map showing the texture on the sea surface and the terrain along the coastal edge

Marine Traffic in the region

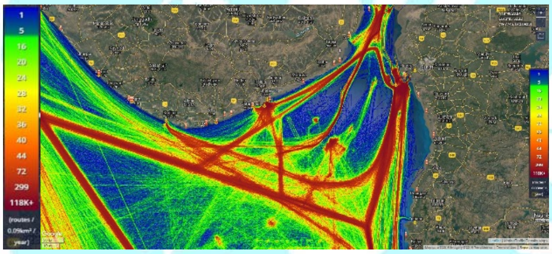
The Marine Traffic website provides a marine traffic map from the local to global level with averaged data upto 2017, and live marine traffic mapping. The underlay for traffic is shown in the subsequent parts of this report at multiple scales (Fig: 3.8.3).



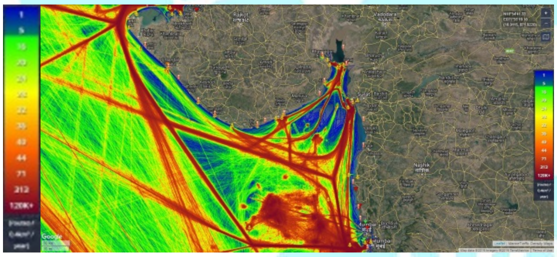
Zoom Level: Z1
Localized map of marine traffic to and from Pipavav Port, and location of the 100 mt MET mast.



Zoom Level: Z2
A wider view of all the ports in the around the proposed site, islands, major marine traffic routes.



Zoom Level: Z3
A view of the Gulf of Khanbhat with densities of marine traffic.



Zoom Level: Z4
Country level view showing marine traffic routes with Pipavav at the center, and radius extending upto Mumbai harbor.

Figure 3.8.3: Marine traffic with different levels

Appropriate wind analysis software for analysis:

a. **WindPRO 3.3**: Comprehensive analysis software for wind with the capability to read wind data, GIS, and Google Earth files and includes databases of wind turbines, MET data, etc.
b. **Q Blade**: Wind Turbine blade designing capabilities with detailed analysis of the performance of the turbine with respect to wake extent and wake losses.

c. **Wind Sim**: Computational fluid dynamics analysis capabilities with more accurate output analysis that linear model analyses.
d. **Aero Dyn** and **MeteoDyn**: Release software scripts by NREL, which can be run using Python or other similar platforms.

Selection of the input parameters required for conducting simulation: Various analyses and studies are being done in the study region to analyses in detail the wind potential of the site. Based on pre-feasibility studies, feasibility studies, onshore and offshore data,a range of observations and analyses have been done.

Selection and referencing of data available in the public domain: Reports available in the public domain include but are not restricted to the following:

1. Offshore Wind Energy in India (NIWE)
2. Wind Solar Hybrid energy Production Analysis Report (National Institute of Wind Energy)
3. First Offshore LIDAR Wind Data Analysis (National Institute of Wind Energy) FOWIND's offshore LIDAR was commissioned on the 2nd of November 2017.
4. Pre-feasibility Study for Offshore Wind Farm Development in Gujarat (FOWIND)
5. Feasibility Study for Offshore Wind Farm Development in Gujarat (FOWIND)
6. Environmental Scoping Report and Consent Register (FOWPI)

3.8.2 Simulation Results

Data sets selected from the available data in the public domain include the Jafarabad Mast data, LIDAR data from the MET mast located offshore, locations from the Pre-feasibility studies, and Feasibility studies by FOWIND and analysis by NIWE for the offshore LIDAR wind data. Parameters of the wind farm simulation Option-1 are shown in (Fig. 3.8.4 and 3.8.5), while parameters of the windfarm simulation Option-1 are shown in (Fig.3.8.6 and 3.8.7).

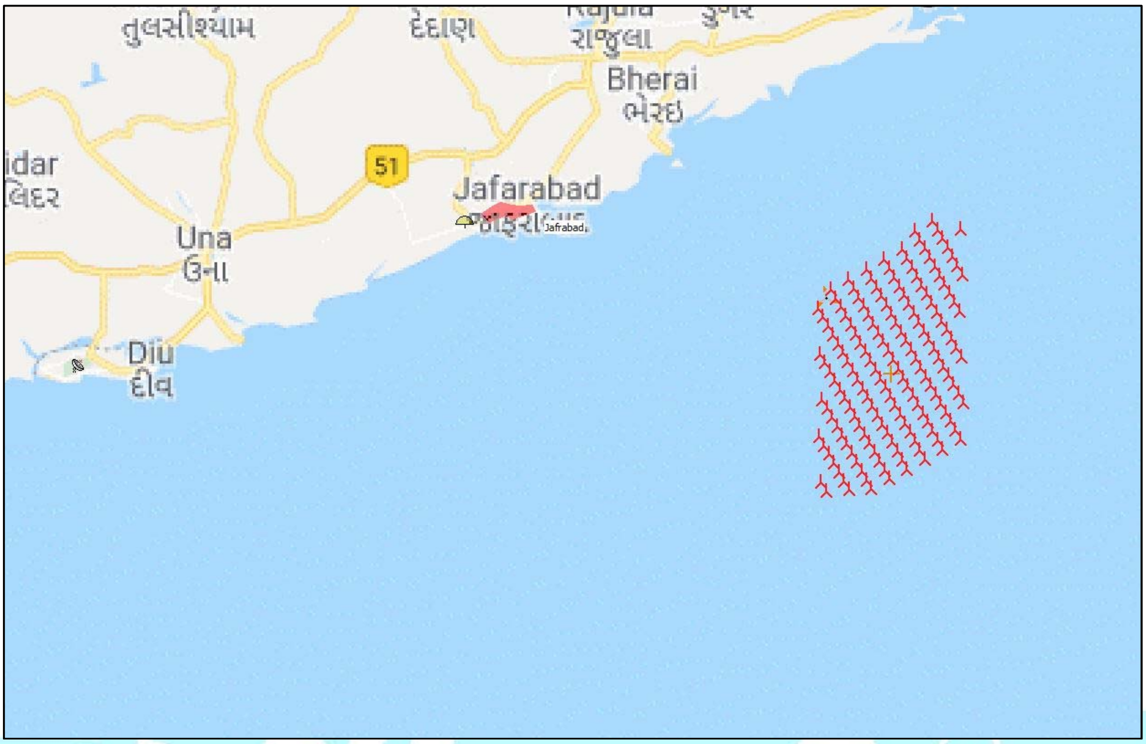


Figure 3.8.4: Location of the Wind Farm from the Shoreline (Option-1)

Option 1

Distance from shoreline

Approximately 23 - 30 kms away from nearest human habitat.

Proposed wind turbine layout

Number of turbines	= 125 nos
Diameter of turbine blade	= 164 meters

Distance between turbines

Blade to Blade dist.	= 6 x 13 Diameter
Mast to Mast dist.	= 7 x 14 Diameter

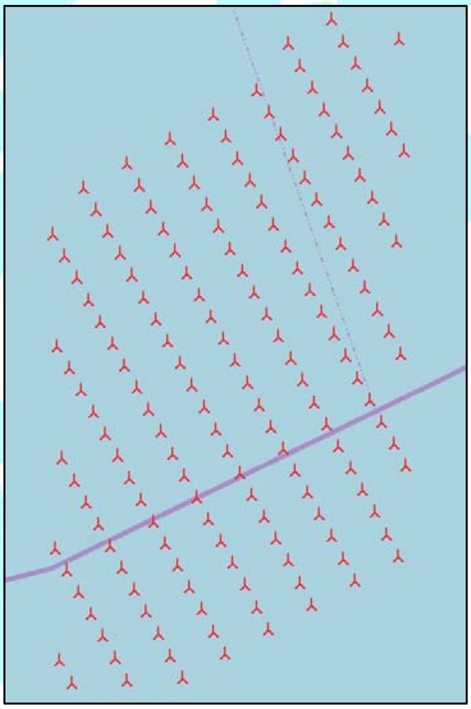


Figure 3.8.5: Wind Turbine Layout (Option-1)

Figure 3.8.6: Location of the Wind Farm Option 2 from the shoreline (Option-2)

Option 2

Distance from shoreline

Approximately 23-30 kms away from nearest human habitat.

Proposed wind turbine layout

Number of turbines = 162 nos
Diameter of turbine blade = 152 meters

Distance between turbines

Blade to Blade dist. = 6 x 13 Diameter
Mast to Mast dist. = 7 x 14 Diameter

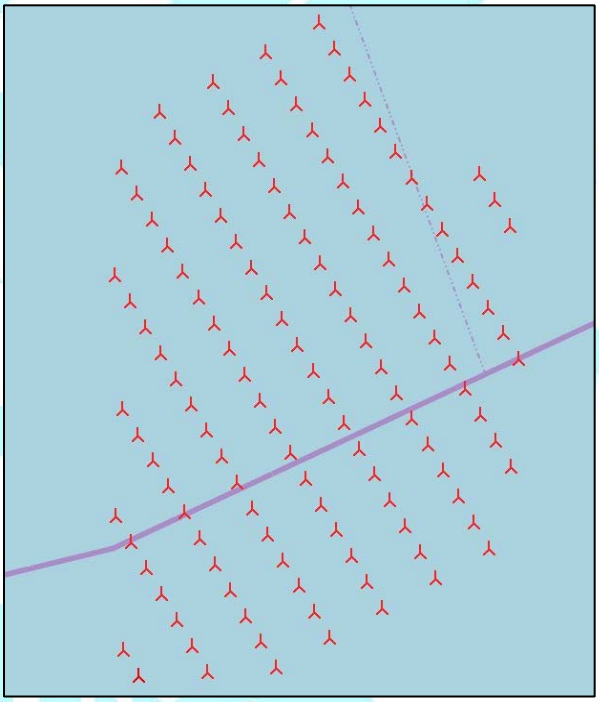
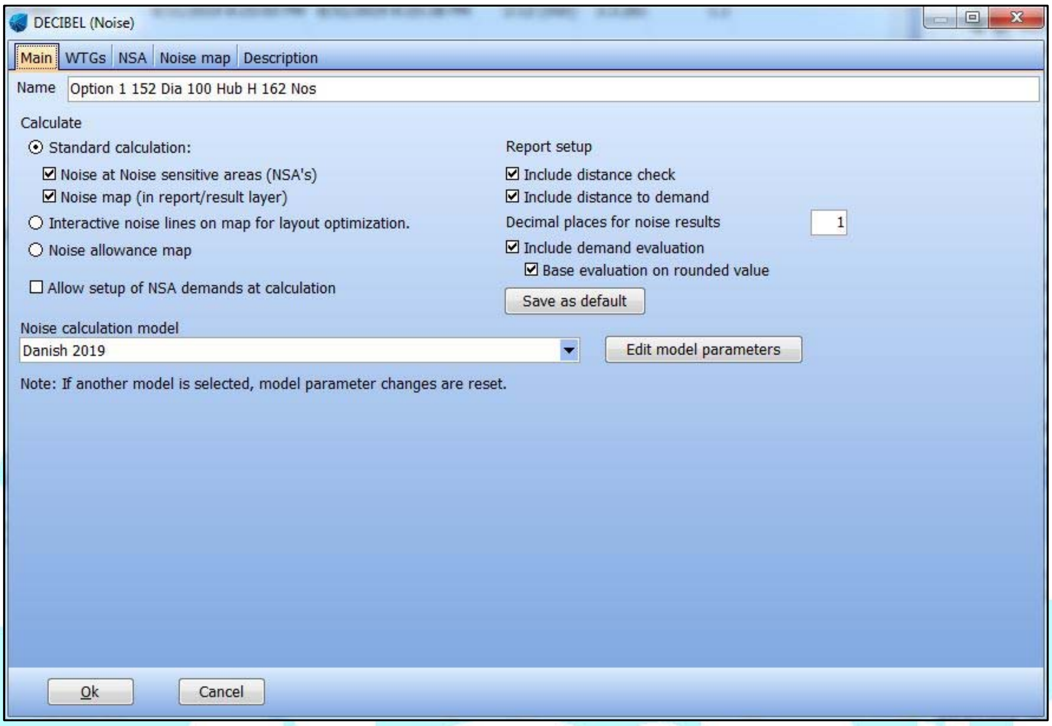
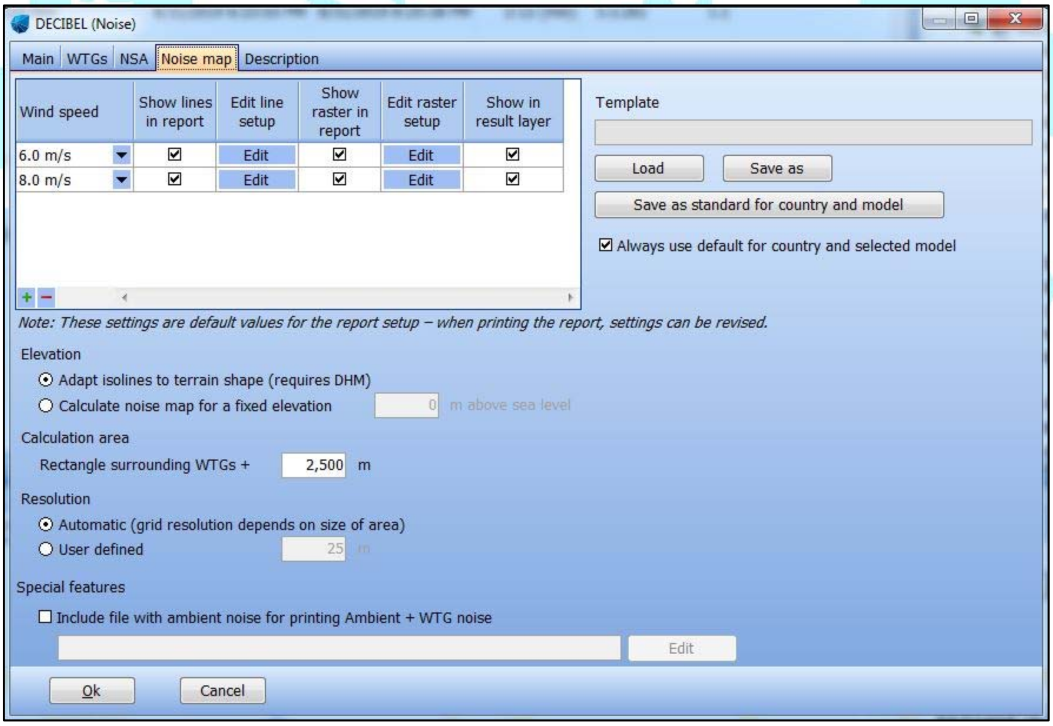


Figure 3.8.7: Wind Turbine Layout (Option-2)

Simulation Inputs for Option 1 (125 turbines)

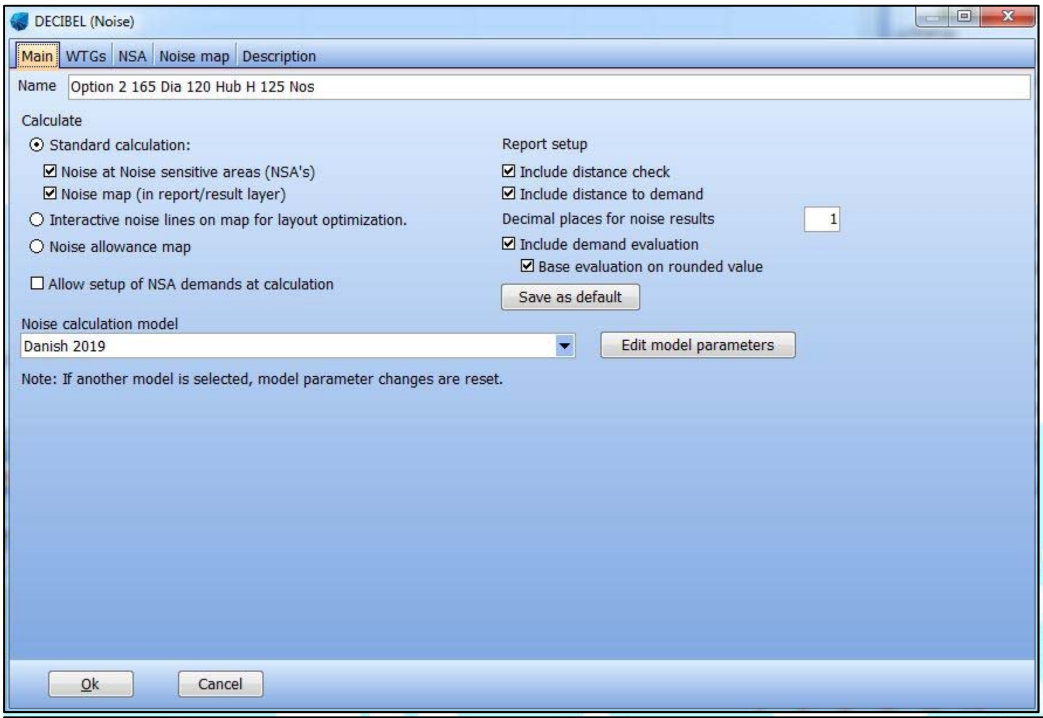
Low Frequency Noise Analysis using the DECIBEL feature in WindPRO 3.3. Input Parameters for Simulation in Wind Pro 3.3 are shown below.

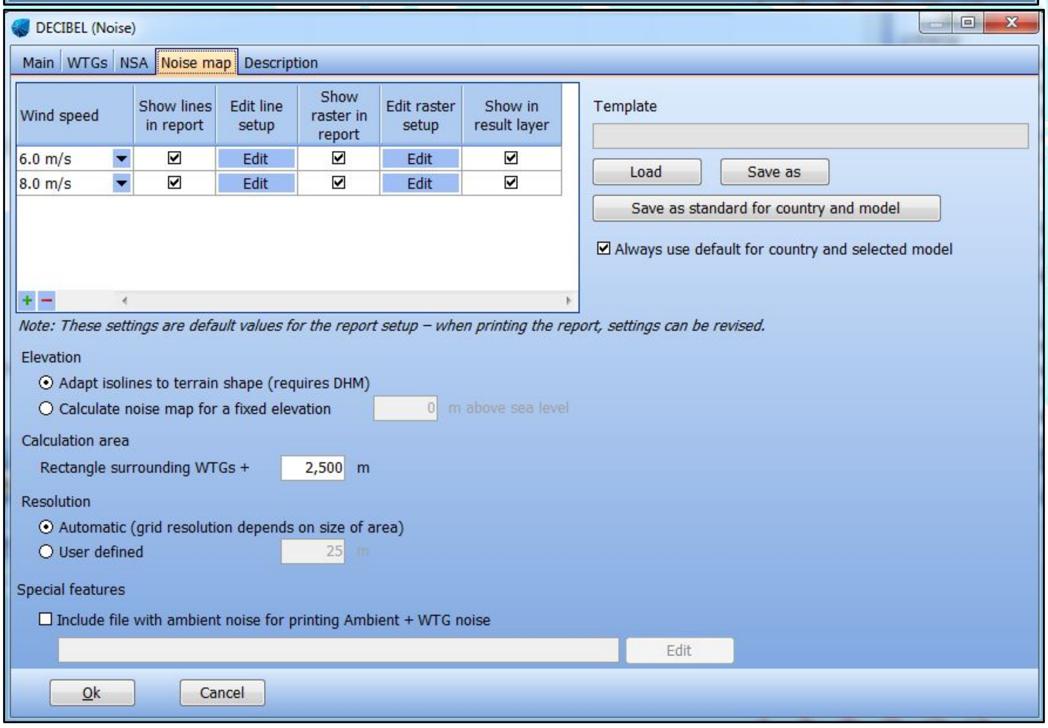




Simulation Inputs for Option 2 (162 turbines)

Low-frequency noise analysis using the DECIBEL feature in WindPRO 3.3. Input parameters for simulation in WindPRO 3.3 are shown below.

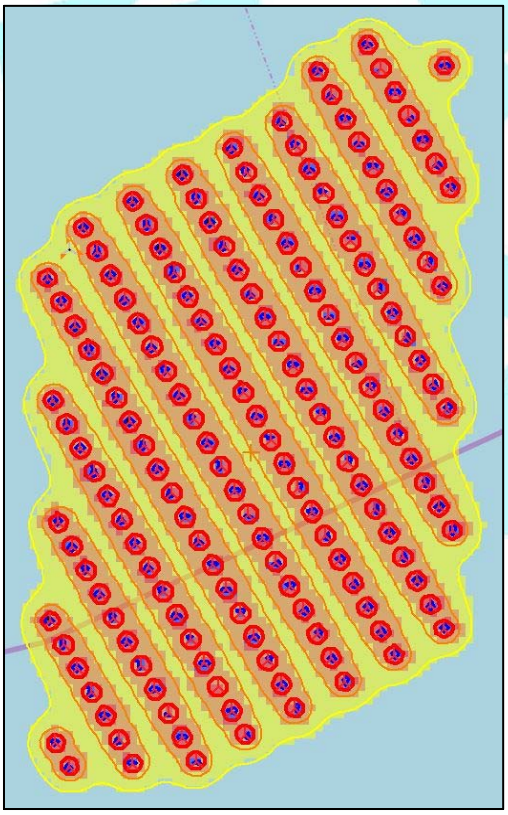


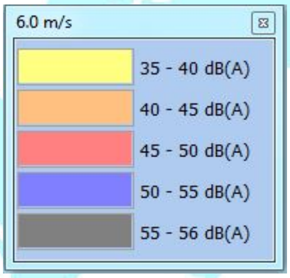


Impact of low frequency noise vibrations

Impact of low-frequency noise vibrations

Wind farms create low-frequency noise that can disturb both human habitation and wildlife. The extent of the vibrations needs to be analysed to identify areas of concern and devise mitigation measures to address the potential conflict with natural or existing patterns of life. Analysis of simulation results for Option 1 at wind speed 6m/s and 8m/s are shown in (Fig 3.8.8 and 3.8.9), while (Table 3.8.1) gives the details of results. Analysis of simulation results for Option 1 at wind speed 6m/s and 8m/s are shown in (Fig 3.8.10 and 3.8.11), while (Table 3.8.2) gives the details of results.

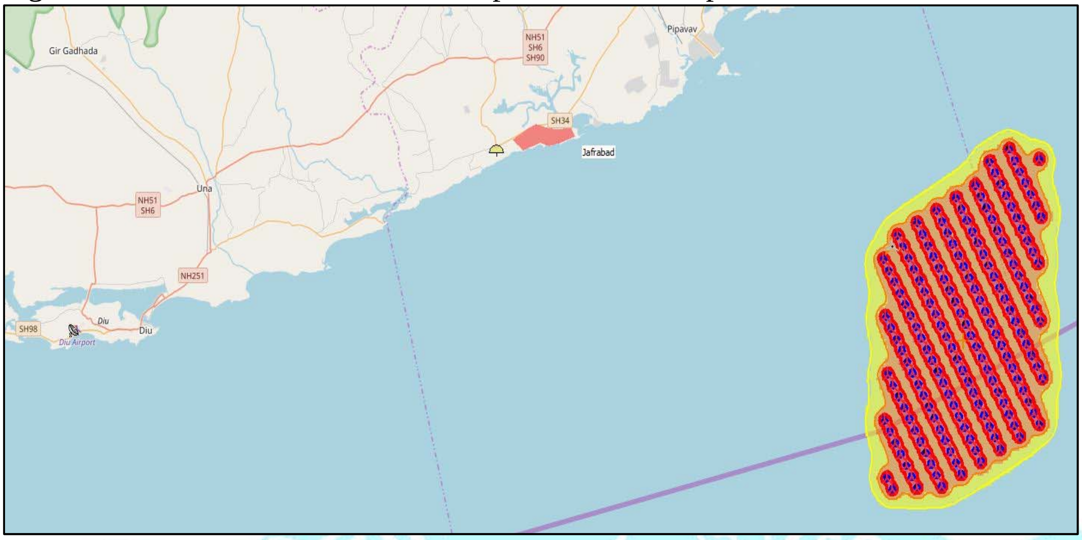


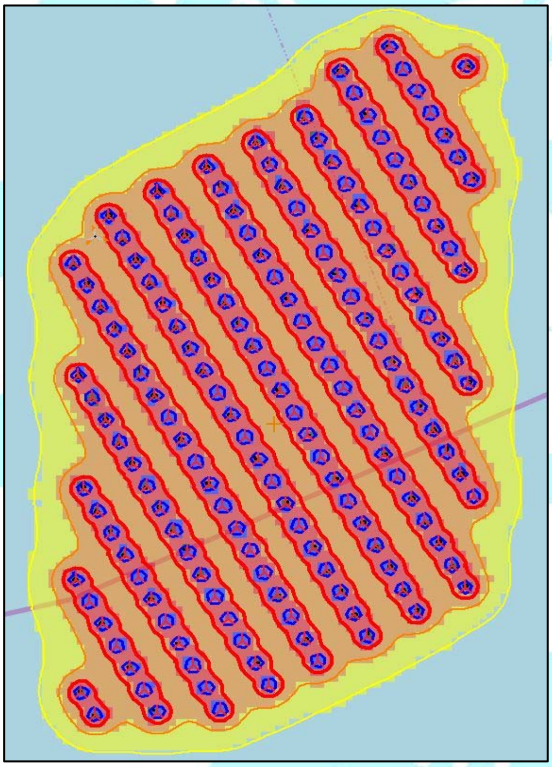


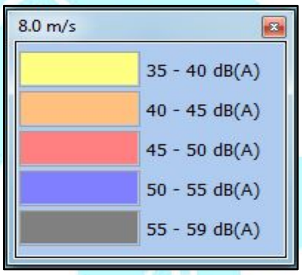
The simulation was run for multiple heights to assess the increase in range of the noise created by the turbines.
Each band signifies the decibel level of sound reaching that area.
Wind speed of 6.0 m/s

Highest decibel level of 56 dB at the wind farm and lowest level of 35 dB at 1.7 kms at the end of the yellow band.

Figure 3.8.8: Simulation Results for Option 1 at wind speed 6m/s







The simulation was run for multiple heights to assess the increase in range of the noise created by the turbines.
Each band signifies the decibel level of sound reaching that area.

Wind speed of 8.0 m/s

Highest decibel level of 59 dB at the wind farm and lowest level of 35 dB at 3 kms at the end of the yellow band.

Figure 3.8.9: Simulation results for Option 1 at wind speed 8m/s

Table 3.8.1: Low Frequency Noise Vibration Result

LF Noise Result 1 - Distance Travelled					
Option 1	**Color Band**				
Wind Speed	**Yellow**	**Orange**	**Pink**	**Blue**	**Black**
6 m/s	1671 m	626 m	390 m	192 m	51 m
8 m/s	3049 m	1380 m	546 m	304 m	145 m

Inference for Option 1

1. Based on the observations of the simulation outputs, we can see that the maximum distance traveled is three kilometers at wind speed conditions of 8 m/s. The range of low-frequency vibrations is from 145 m to 3049 m.
2. As the distance from the land is eight times this length, noise from the wind turbine is not expected to affect any human habitation on land.
3. However, a buffer zone of 3 to 3.5 km, if created around the windfarm, will intersect with marine traffic and marine wildlife routes and will have an impact on them.

This needs to be studied in depth in the subsequent analyses and mitigation measure strategies of the offshore wind farm project

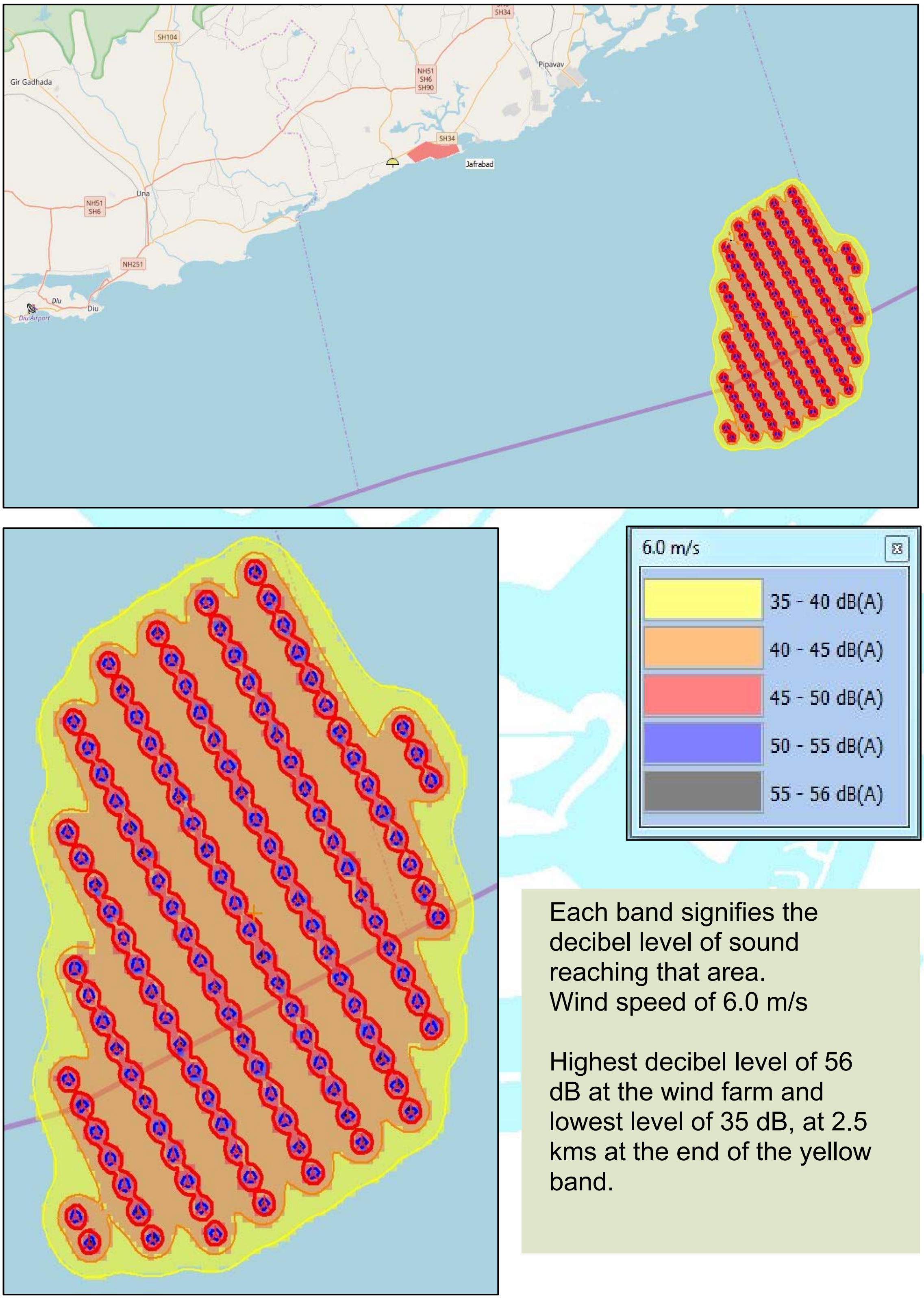
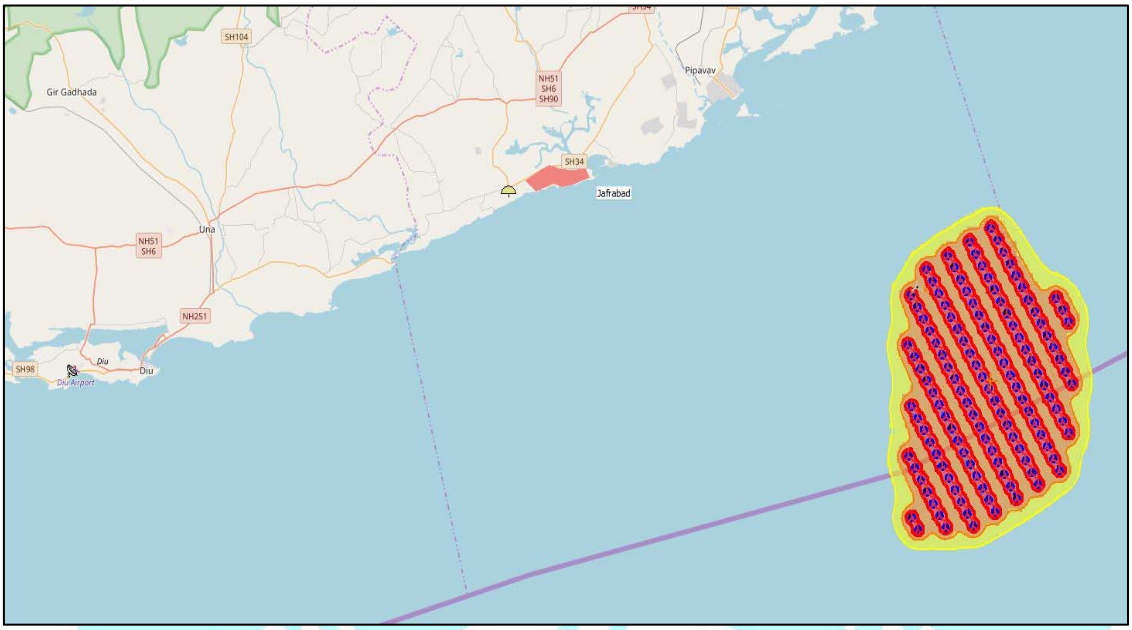
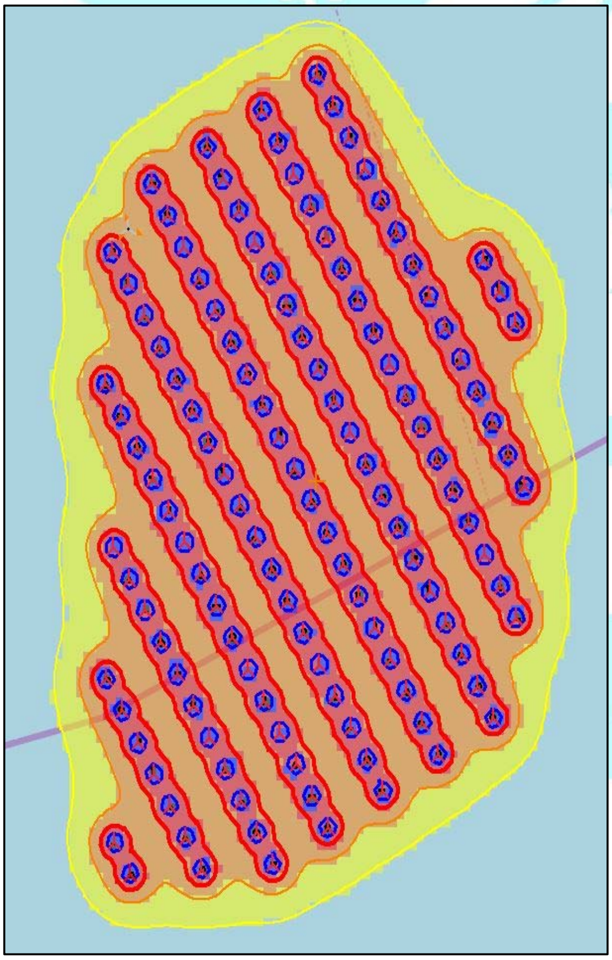
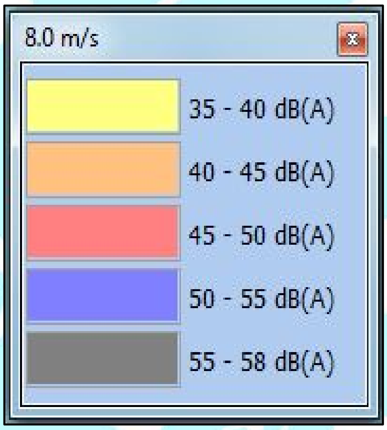


Figure 3.8.10: Simulation results for Option 2 at wind speed 6m/s







Each band signifies the decibel level of sound reaching that area.

Wind speed of 8.0 m/s

Highest decibel level of 58 dB at the wind farm and lowest level of 35 dB at 2.5 kms at the end of the yellow band.

Figure 3.8.11: Simulation results for Option 2 at wind speed 8m/s

Table 3.8.2: Low Frequency Noise Result

LF Noise Result 2 – Distance Travelled					
Option 2	**Color Band**				
Wind Speed	**Yellow**	**Orange**	**Pink**	**Blue**	**Black**
6 m/s	2507 m	947 m	445 m	239 m	68 m
8 m/s	3111 m	1361 m	612 m	536 m	136 m

Inference for Option 2

Based on the observations of the simulation outputs, we can see that the maximum distance traveled is 3.1 kilometers at wind speed conditions of 8 m/s. The range of low-frequency vibrations is from 136 m to 3111 m. As the distance from the land is ~8 times this length, the noise from the wind turbine is not expected to affect any human habitation on land. However, a buffer zone around the wind farm of 3.1 km, if created, will intersect with marine traffic and marine wildlife routes and will have an impact on them. This needs to be studied in-depth in the subsequent analyses and mitigation measures strategies of the offshore wind farm project.

Recommended further analysis

- Analysis of marine traffic with respect to annual low-frequency noise vibration. Further studies with respect to marine traffic routes will be needed to analyse exact time of low-frequency noise vibrations impact on the vessels. The routes may be slightly affected if a buffer zone is maintained around the project to avoid any impact of low=frequency noise vibrations on the marine vessels, communications, and radar.
- Species-specific analysis of Marine Bio-diversity with respect to low-frequency vibrations due to wind turbine noise.

3.9 Wind Wake Modelling

Human habitat on land: The analysis for wind wake is done to measure the range of impact from the wind farm's turbine blades and to identify the areas of land and sea where prevalent activities are affected.Typically the wind turbine's wake travels upto a range of 7 to 8 diameter lengths. As the site location is over 23 km away from the shore, it is unlikely to have any adverse impact on the baseline environment for habitation on land.

Marine Traffic Routes: The wind-farm is located very close to the marine traffic routes that connect to Pipavav and Jafarabad ports. This is analysed carefully in the subsequent parts of this report using overlays of the impact zones with baseline information of traffic routes.

Marine Wildlife Habitat: Various species of fish and mammals exist in the sea around the proposed site. As the site is located on the edge of the coastal shelf, species living in both shallow and deep waters need to be considered in a sensitive manner.

Fishing and Livelihood: Fishingvillages along the coast of Gujarat access the waters around the proposed site for fishing activities. Various sizes of fishing vessels travel across the area and depend on the area for their livelihood.

3.9.1 Methodology

Review of the data available: To study the existing available wind, orography, roughness, and temperature data nearest to the proposed location.

Jafarabad Coastal Mast data: The costal mast off the coast of Jafrabad and Pipavav located 25 Km away from the shoreline has collected data for 2017 for wind speed, wind direction, and for multiple heights upto 120 m. This location is at the corner of the proposed windfarm and is closest to the actual on-ground readings one can plan for in potential, during operation of the wind farm, and the simulation and analysis.

LIDAR data: This data is collected using state of the art technology and ensures high quality, accurate data for the inputs in the simulation.

Orography of the region: The topography over the sea surface is mostly constant and does not undulate like that of the land where hills and valleys can significantly alter the wind speeds and directions. This means that the wind is also relatively predictable in its pattern. This data was referenced from the Wind Atlas website, which provides information upto a suitable degree of resolution.

Roughness on the region: The roughness over the sea surface is mostly constant and does not vary like that of the land where farmlands, rocky surfaces, homes, forests, and lakes can significantly alter the wind speeds and directions over the ground level surfaces. This means that the wind is also relatively predictable in its pattern. This data was also referenced from the Wind Atlas website, which provides information upto a suitable degree of resolution.

Marine Traffic in the region: The Marine Traffic website provides a marine traffic map from the local to a global level with averaged data upto 2017, and live marine traffic mapping. The underlay for traffic is shown in the subsequent parts of this report at multiple scales.

Wind analysis software for analysis

- WindPRO 3.3: Comprehensive analysis software for wind with the capability to read wind data, GIS, and Google Earth files, and includes databases of wind turbines, MET data, etc.
- Q Blade: Wind Turbine blade designing capabilities with detailed analysis of the performance of the turbine with respect to wake extent and wake losses.
- Wind Sim: Computational fluid dynamics analysis capabilities with more accurate output analysis that linear model analyses.
- Aero Dyn and MeteoDyn: Release software scripts by NREL, which can be run using Python or other similar platforms.
- WAsP: Wind wake modelling software with links to WindPRO analysis software.

Input Parameters and Data: Selection of the input parameters required for conducting simulation is mentioned. Various analyses and studies are being done in Gujarat’s Gulf of Khambhat region to analyse in detail the wind potential of the site. Based on pre-feasibility studies, feasibility studies, onshore and offshore data,a range of observations and analyses have been done.The selection and referencing of data available was carried out in the public domain for analysis. Reports available in the public domain include but are not restricted to the following:

- Offshore Wind Energy in India (NIWE)

- Wind Solar Hybrid energy Production Analysis Report (National Institute of Wind Energy)
- First Offshore LIDAR Wind Data Analysis (National Institute of Wind Energy)
- FOWIND's offshore LIDAR was commissioned on the 2nd of November 2017.
- Pre-feasibility Study for Offshore Wind Farm Development in Gujarat (FOWIND)
- Feasibility Study for Offshore Wind Farm Development in Gujarat (FOWIND)
- Environmental Scoping Report and Consent Register (FOWPI)

Data sets selected from the available data in the public domain include the Jafarabad Mast data, LIDAR data from the MET mast located offshore, locations from the Pre-feasibility studies, and Feasibility studies by FOWIND and analysis by NIWE for the offshore LIDAR wind data. Parameters of the wind farm simulation (option 1 and 2) are shown in (Fig. 3.9.1.to 3.9.4).

3.9.2 Simulation Results

Wind turbines extract energy from the wind, and downstream there is a wake from the wind turbine, where wind speed is reduced. As the flow proceeds downstream, there is a spreading of the wake, and the wake recovers towards free stream conditions. The wake effect is the aggregated influence on the energy production of the wind farm,which results from the changes in wind speed caused by the impact of the turbines on each other. The wake effect can lead to the increase of turbulence-induced fatigue loads that reduce the lifetime of WTGs.

Simulation for Option 1

Wind Wake Time step with vector & color range by age – 120-seconds simulation, incident wind at 7 m/s. All the views of simulation option-1 are shown in (Fig 3.9.5 and 3.9.6).

Figure 3.9.3: Location of the Wind Farm from the Shoreline (Option-2)

Distance from shoreline

Approximately 23-30 kms away from nearest human habitat.

Proposed wind turbine layout

Number of turbines = 162 nos
Diameter of turbine blade= 152 meters

Distance between turbines

Blade to Blade dist. = 6 x 13 Diameter
Mast to Mast dist. = 7 x 14 Diameter

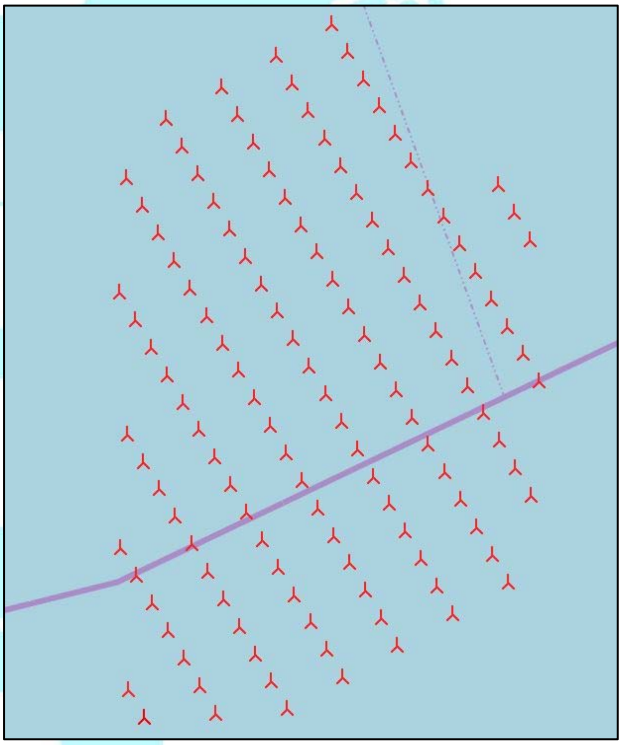


Figure 3.9.4: Proposed Wind Turbine Layout (Option – 2)

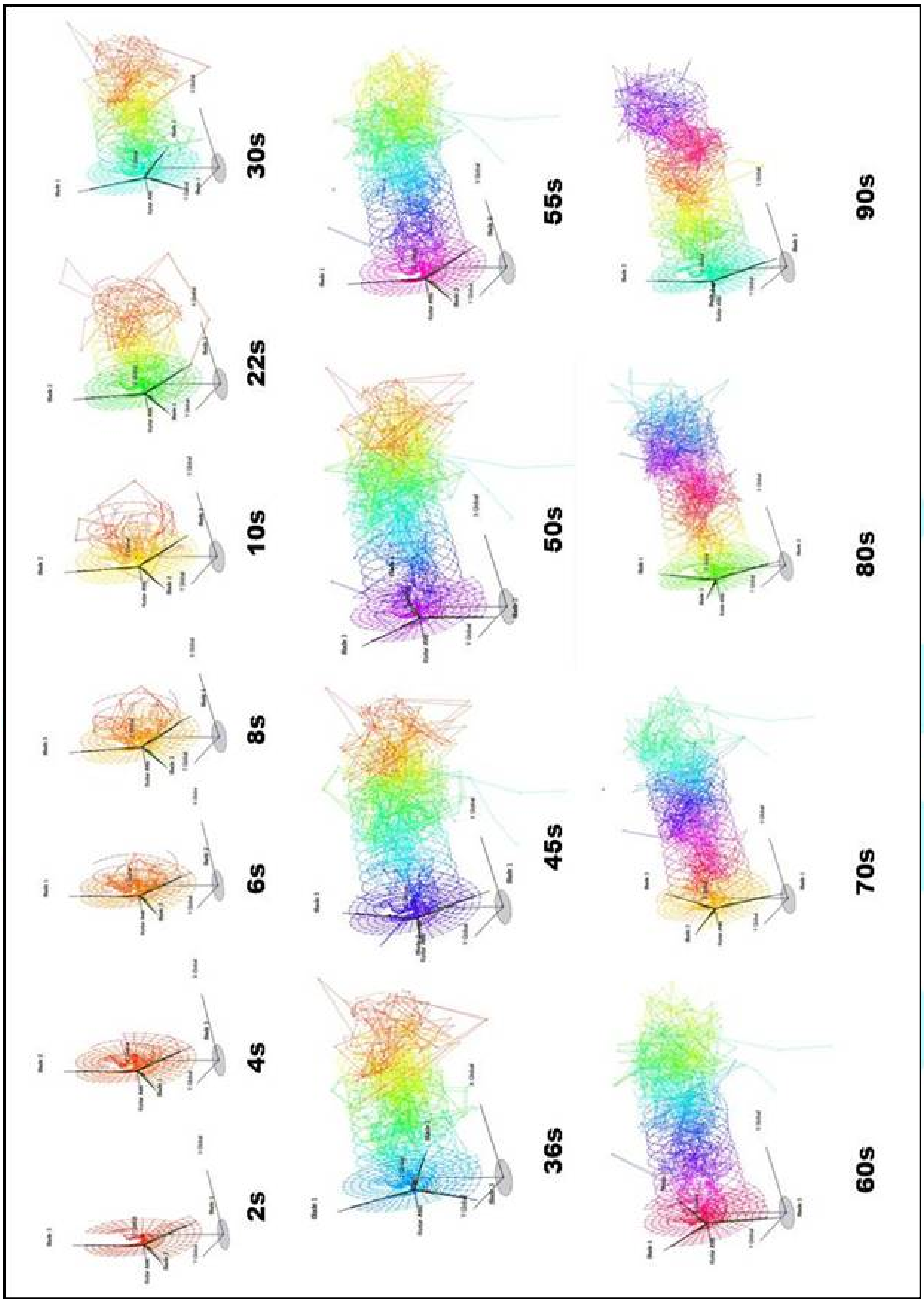


Figure 3.9.5: Simulation for Option 1

Impact Analysis: Simulation for Option 1

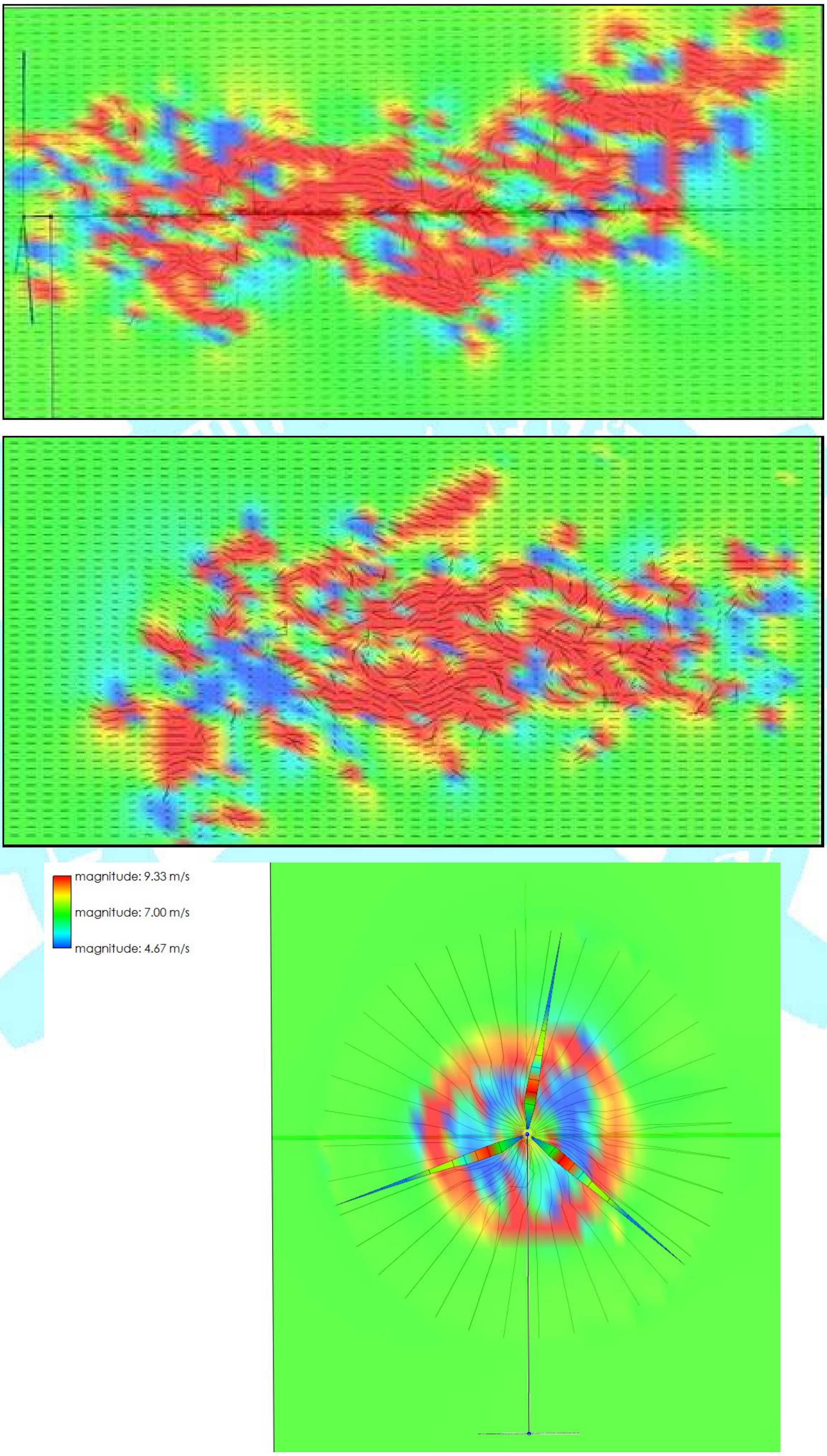


Figure 3.9.6: Side view; Top View and Front View of simulation option-1

Simulation for Option 2

Wind Wake Time step with vector & color range by age – 120 seconds simulation, incident wind at 7 m/s. All the views of simulation option 2 are shown in (Fig 3.9.7 and 3.9.8).

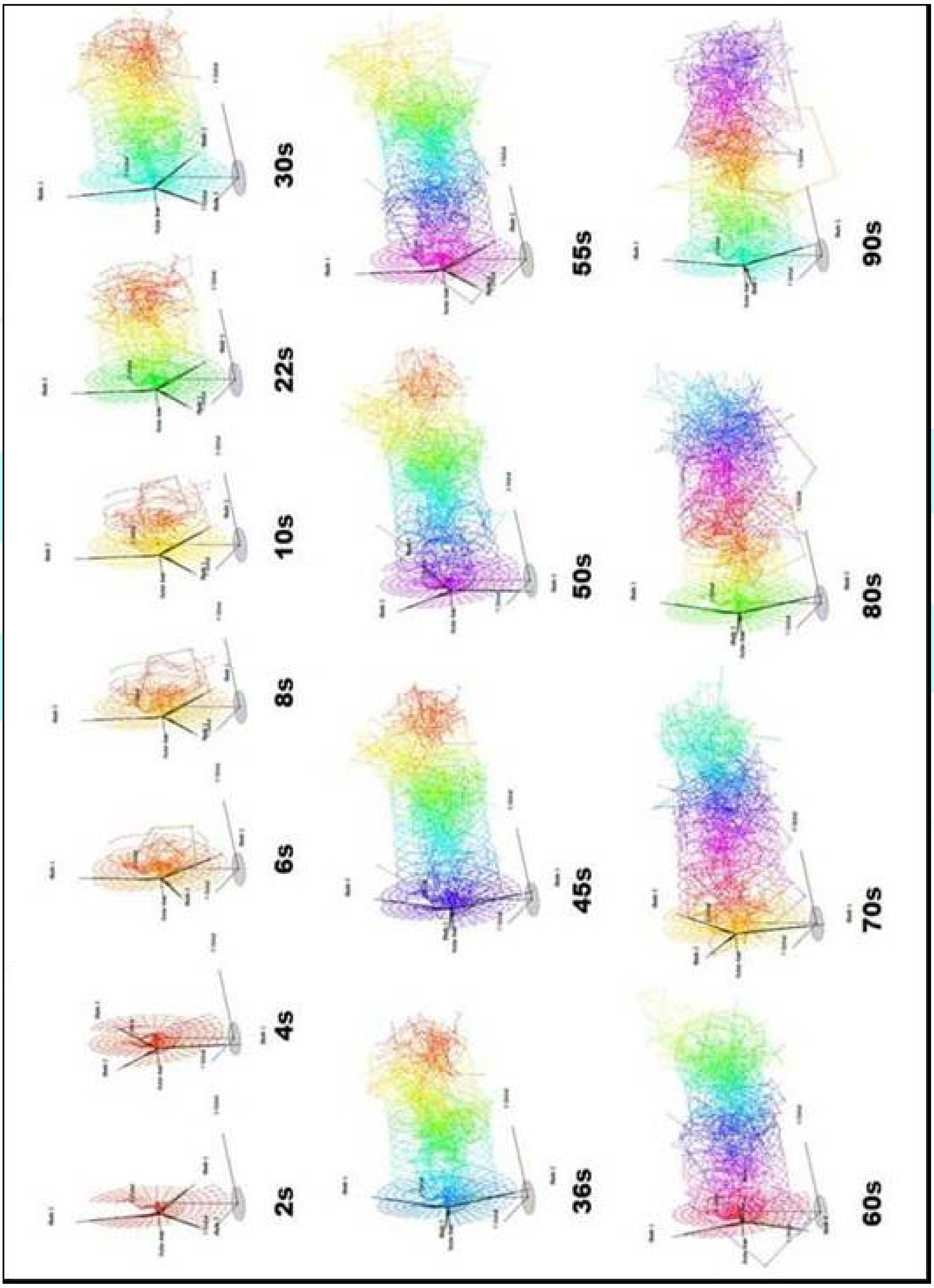
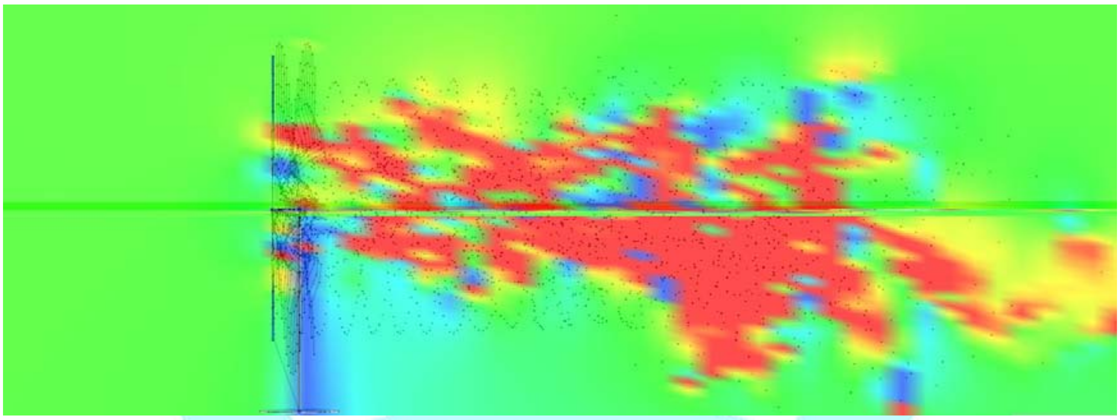
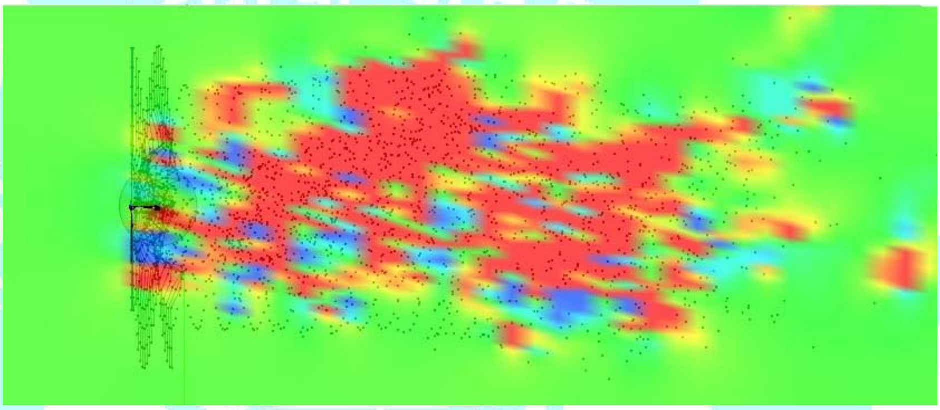
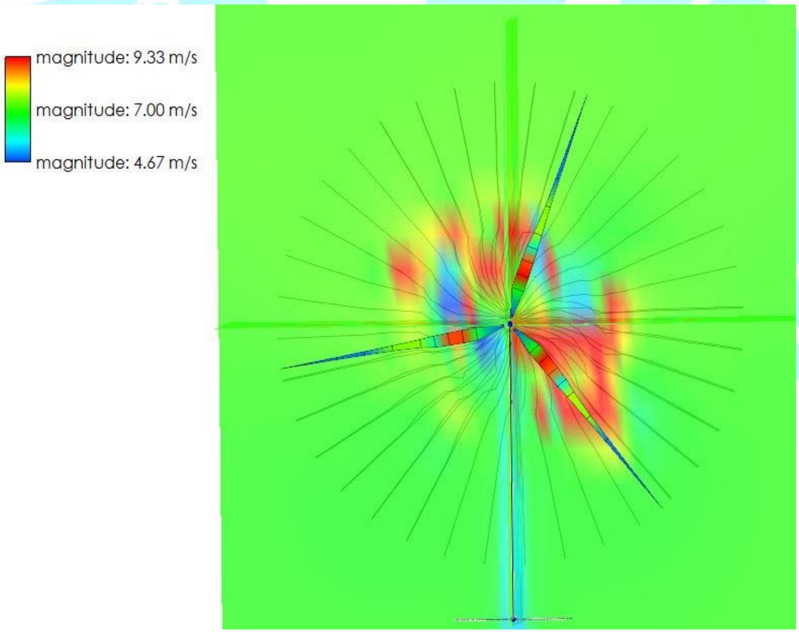


Figure 3.9.7: Simulation for Option 2

Impact Analysis: Simulation for Option 2







Variation in wind speed in the turbine wind wake:

1. Side View
2. Top View
3. Front View

Figure 3.9.8: Side view; Top View and Front View of simulation option-2

Design Analysis Basic Grid

As per standard wind farm design, six diameter lengths must be kept between turbines (blade tip to blade tip). Using this value, a total of seven diameter length has been maintained from mast to mast.

Mast to mast distance = 0.5 turbine dia + 2 dia + 0.5 turbine dia.

In this case, the alternate rows have been highlighted in red and blue, and the distances have been marked for the grid in diameter lengths (Fig 3.9.9).

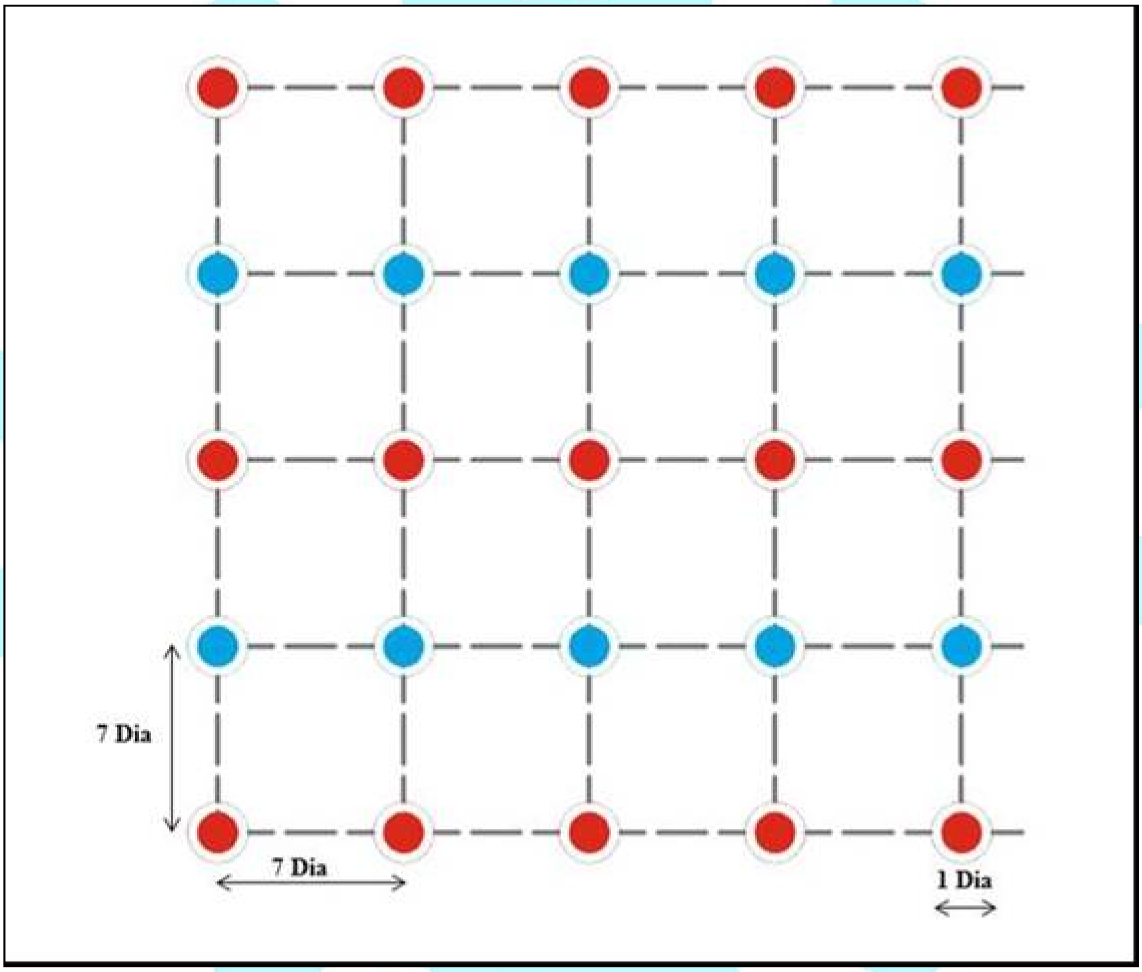


Figure 3.9.9: Basic Grid

Wind Wake Simulation: Impact Analysis

The initial grid studied for wind wake analysis is a seven diameter grid. From the simulation run for both Option 1 and Option 2, we find that the wind wake is in the range of 4 to 5 diameter lengths. The wind will not be uniform after passing through the wind turbine and will affect the wind turbines in the row behind it. Therefore,we can,, predict that the turbines in the 2nd row onwards will receive significant wake losses. The distance between the wind turbines would need to be increased to a greater distance to ensure uniform wind speed is received by all wind turbines (Fig 3.9.10).

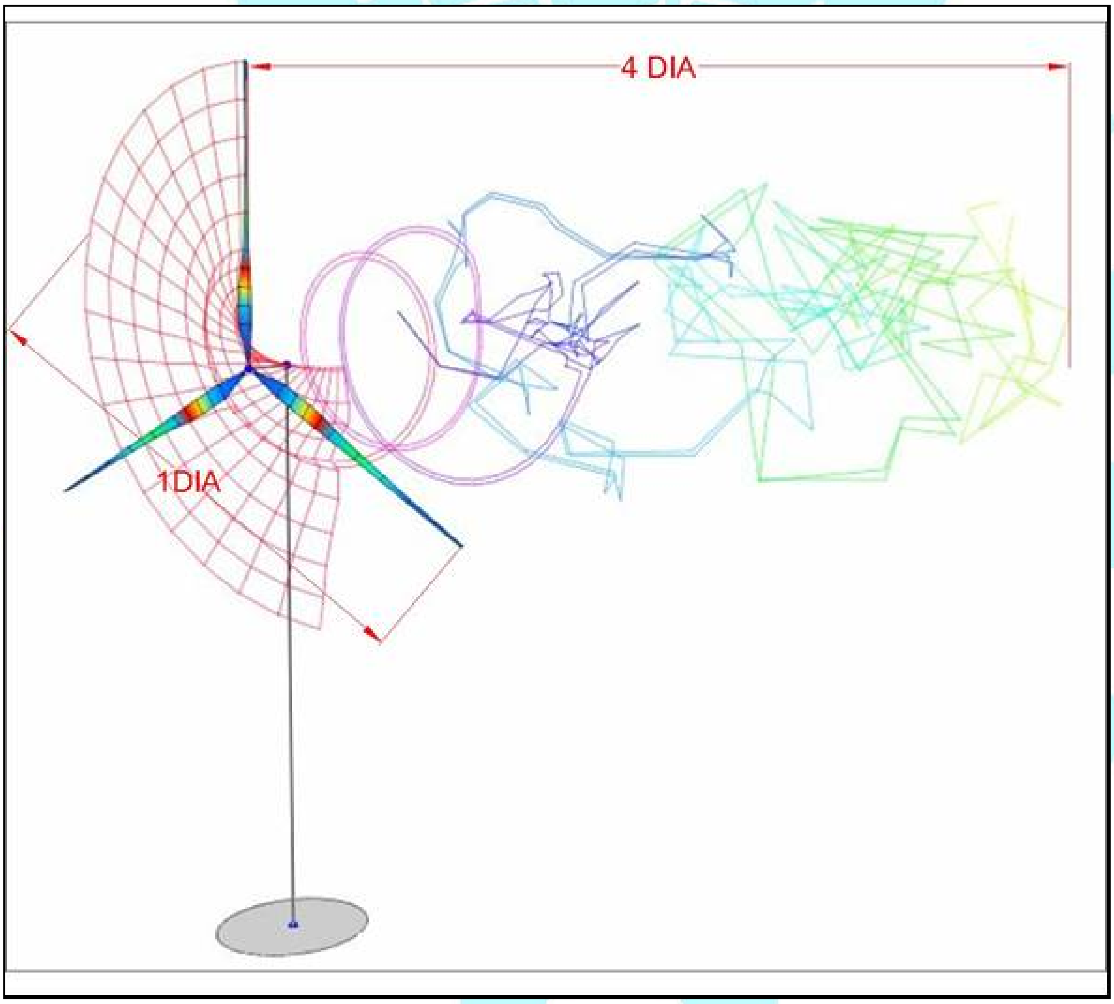


Figure 3.9.10: Impact analysis

Visualization of the wind wake losses in a simple seven diameter grid

The figure shows the wind wake intersecting with the turbines from the second row onwards, indicating a poor performance of the overall wind power generation (Fig: 3.9.11).

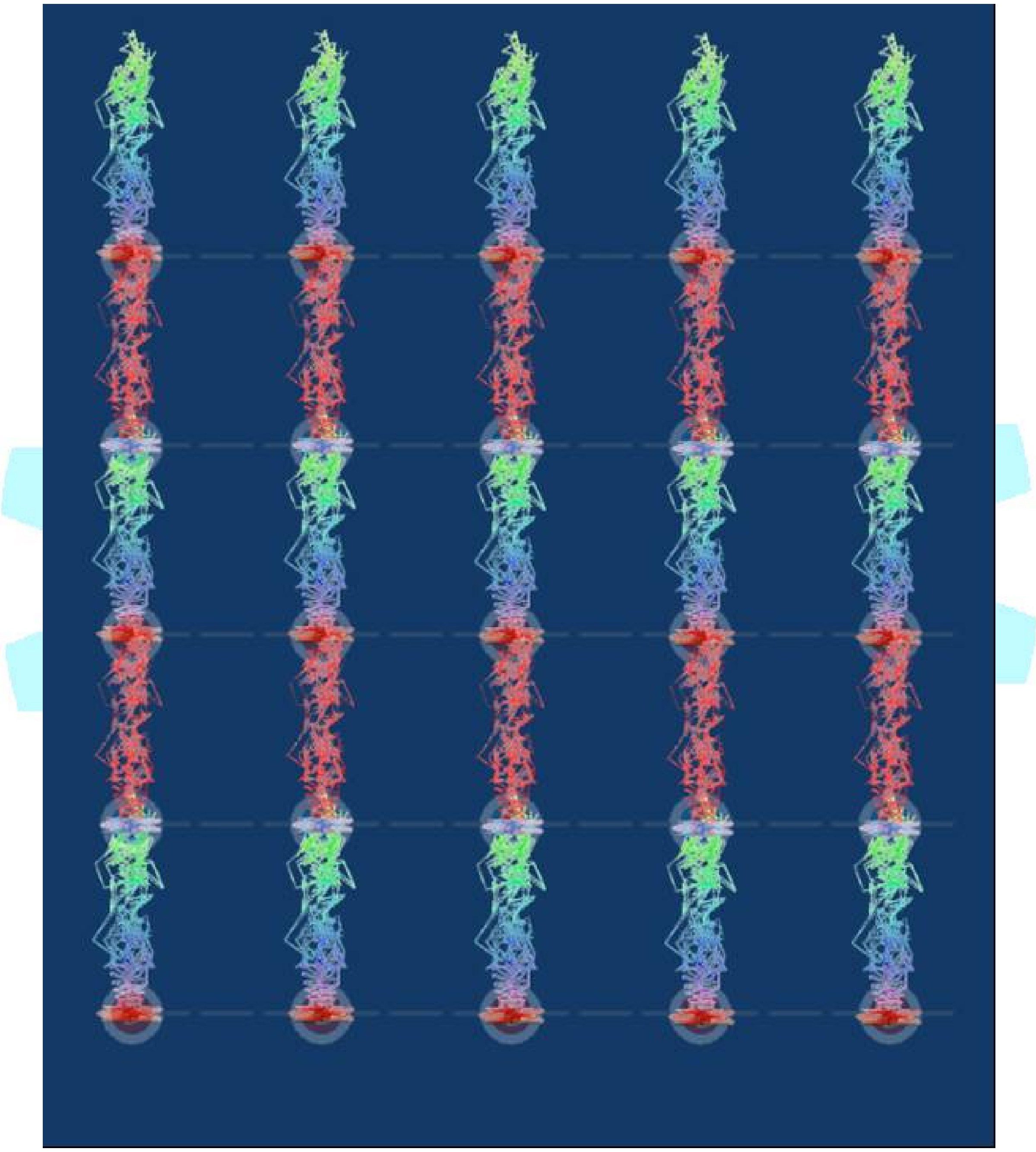


Figure 3.9.11: Visualization of the wind wake losses in a simple seven diameter grid

Recommended: Staggered grid

The image shows a recommended staggered grid where the original grid is staggered by 3.5 diameter lengths. This gives a clear space between two turbines and allows the total wind farm area to remain the same,instead of increasing the wind farm area. This will have significant cost benefits in foundations and also reduces the area of impact of the project on the marine and terrestrial environment (Fig: 3.9.12 and 3.9.13)

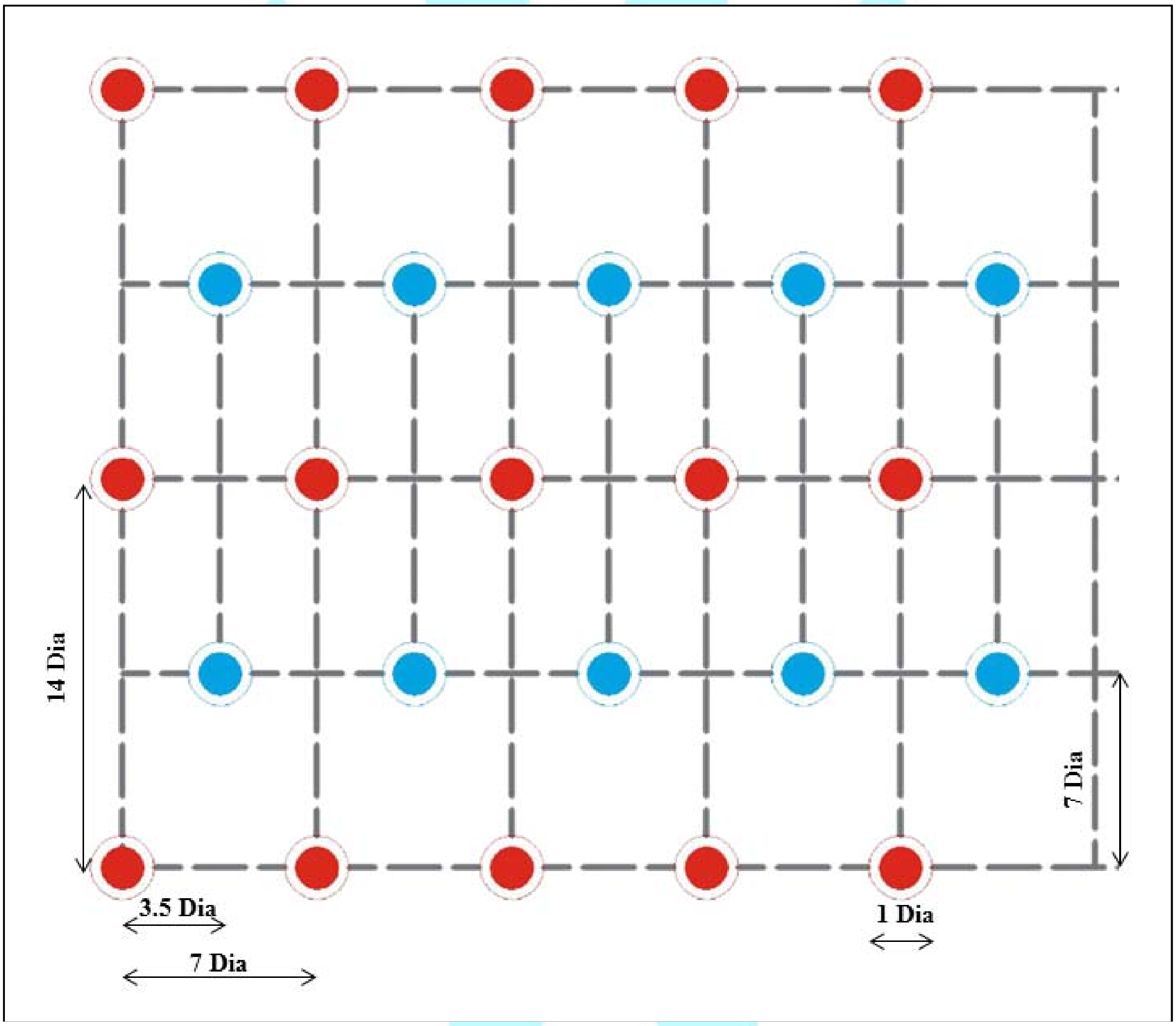


Figure 3.9.12: Staggered grid 7 x 14 diameter spacing

Visualization: Recommended Grid with Wind Wakes

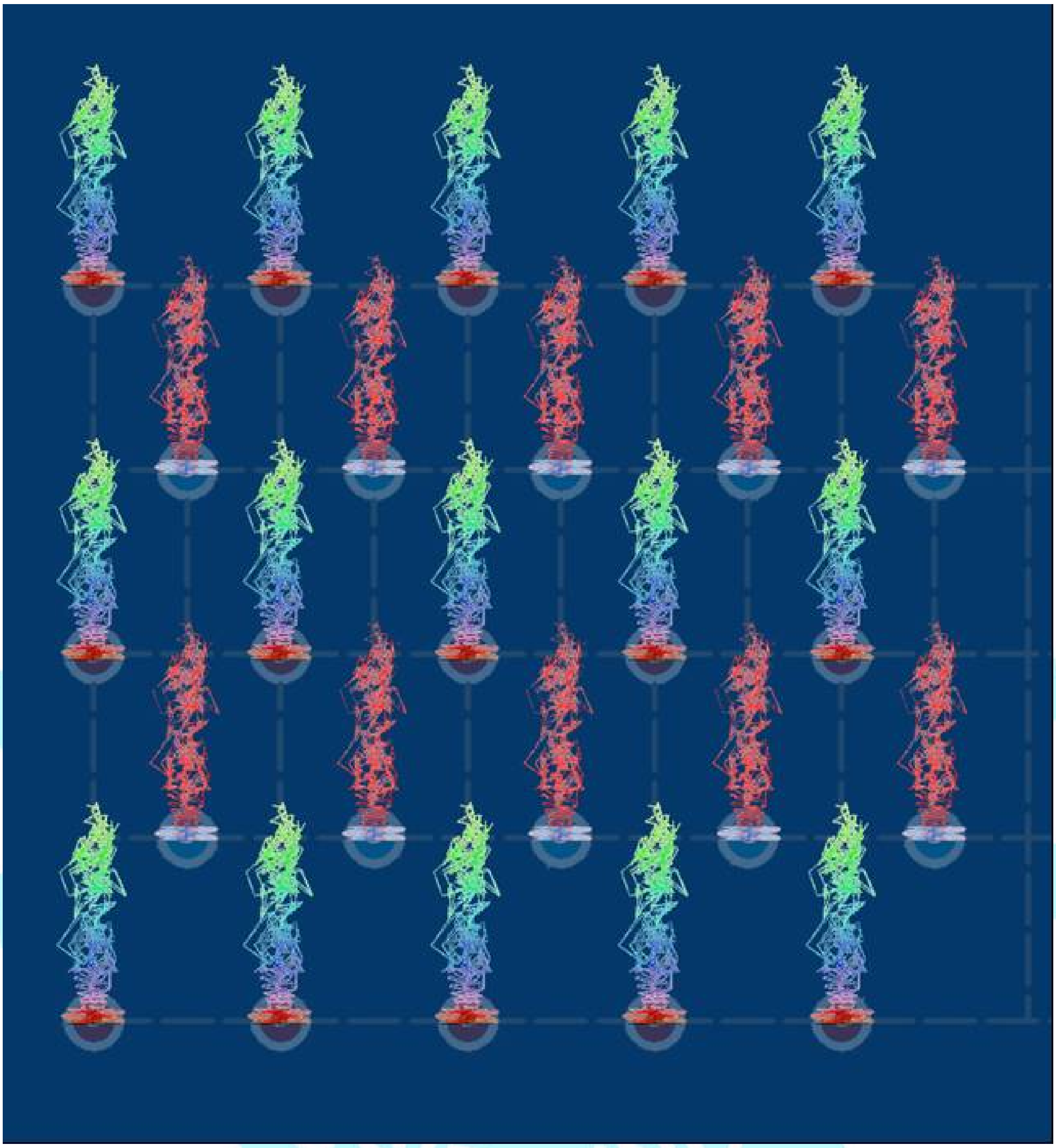


Figure 3.9.13: Recommended Grid with Wind Wakes

Conclusion: The figure shows the wind wake is no more intersecting as there is a 14 diameter gap behind each turbine allowing the wind wake to dissipate completely. This will increase the wind farm's production capacity (AEP) significantly as the wind received on the blades is relatively constant and of higher speeds.

3.9.3 Summary & Conclusions

Two options were studied in detail, using two sizes of turbine blades with varying numbers of turbines and power output. Both options are adjacent to the offshore MET mast, where most accurate offshore data is collected for the Gulf of Khambhat region, ensuring closest to on-ground realistic analysis.

The impact is restricted to 14 diameter lengths of the wind turbines at the most and will only affect passing marine traffic when on the leeward side of the wind turbines. Reduction in spacing is possible with staggering the wind turbines in alternate rows and may allow lower costs for foundation. No impact is seen on any habitation on the coastline onshore, as the distance is far beyond the maximum extent of the wind turbine's Wind Wake.

The wind wake is greatly dependent on wind speeds and air density, which impact the length of the wind wake. 7 x 14 diameter grid is sufficient for avoiding wake losses for the proposed wind farm designs. The wind turbines are safe for human habitats in the nearest villages to the project. The Wind Wake will not be perceptible by the human habitats on land.

Recommended Further Analysis

1. AEP analysis with respect to wind wake and possible wake losses.
2. Analysis of birds flying over the areas where wind wake may extend and possible mitigation measures recommended.

3.10Water and sediment Quality

The Environment Impact Assessment (EIA) study for any development activity is usually carried out to envisage the probable consequences to the natural environment around the developmental site. For such an environmental assessment, it is essential to collect information regarding basic environmental quality around the site of development. EIA study related to any anthropogenic developments or changes in any coastal area also needs systematic investigations on water, sediment, and biological components of that particular area.

3.10.1 Methodology

A reconnaissance survey and sampling was carried out at 40 different coastal subtidal stations. The field sampling was carried out onboard *RV Sindhu*

*Sadhana*from 23th to 26th May 2019.*RV Sindhu Sadhana* features specialised laboratories, including two wet labs, a spacious multipurpose dry laboratory, a computer and data processing lab, and an analytical laboratory (Plate 3.10.1).This 80m long and 17 m wide research vessel is fully equipped with scientific instruments needed for oceanographic research.The details of each sampling station, including location, water depth, and sampling time, are mentioned in (Table 3.10.1). Plate 3.10.2 depicts the sampling methods onboard *RV Sindhu Sadhana.*

At the selected locations,the physio-chemical parameters, including water temperature, salinity, pH, dissolved oxygen, biochemical oxygen demand, and essential nutrients, were investigated to generate necessary information about the quality of water. In addition to the water quality, sediment samples were also investigated for texture, organic carbon, and selective metal contents. At the selected stations, the surface and near-bottom water samples werecollected by using a pre-cleaned Niskin water sampler (Capacity: 5 Liters). Immediately after collection, sub-sampling and the necessary processing of water samples for various water quality parameters were carried out onboard *RV Sindhu Sadhna*. The top layer of sediment samples from all water sampling stations was also collected with a clean van-Veen grab. After collection, the sub-samples for texture, total organic carbon, and metal analyses were stored in Polythene bags, preserved in ice, and then transported to the laboratory for further analyses. The details of the laboratory analyses of water and sediment samples are described in the following section.

Table 3.10.1: Details of the sampling stations in the survey area off Pipavav.

Stations	Date	Latitude N	Longitude E	Depth
NIWE 1	23/05/19	20.78617	71.67971	18
NIWE 2	23/05/19	20.80418	71.708336	17
NIWE 3	23/05/19	20.82213	71.737518	14
NIWE 4	23/05/19	20.84500	71.7700	13
NIWE 5	23/05/19	20.86650	71.81020	11
NIWE 6	24/05/19	20.71669	71.662453	19
NIWE 7	24/05/19	20.74024	71.696114	18
NIWE 8	24/05/19	20.76109	71.736626	18
NIWE 9	24/05/19	20.78386	71.769241	18
NIWE 10	24/05/19	20.81140	71.805	18
NIWE 11	25/05/19	20.65524	71.661362	21
NIWE 12	25/05/19	20.67597	71.7024	20
NIWE 13	25/05/19	20.70071	71.735222	18
NIWE 14	25/05/19	21.72352	71.775246	17
NIWE 15	24/05/19	20.74955	71.807315	18
NIWE 16	25/05/19	20.59390	71.66592	21
NIWE 17	25/05/19	20.61659	71.697968	21
NIWE 18	25/05/19	20.63811	71.733452	20
NIWE 19	25/05/19	20.66201	71.769753	19
NIWE 20	25/05/19	20.68248	71.806389	20
NIWE 24	23/05/19	20.88492	71.826317	14
NIWE 25	24/05/19	20.83556	71.856735	17
NIWE 26	23/05/19	20.84655	71.823273	17
NIWE 27	25/05/19	20.61886	71.619385	22
NIWE 28	24/05/19	20.68455	71.61277	20
NIWE 29	24/05/19	20.74405	71.618538	18
NIWE 30	24/05/19	20.77539	71.847244	20
NIWE 31	24/05/19	20.80360	71.888481	18
NIWE 32	25/05/19	20.74387	71.893105	24
NIWE 33	25/05/19	20.71228	71.84462	21
NIWE 34	24/05/19	20.87780	71.891151	17
NIWE 35	23/05/19	20.91781	71.885666	14
NIWE 36	25/05/19	20.61912	71.762054	21
NIWE 37	25/05/19	20.64099	71.818314	23
NIWE 38	25/05/19	20.67469	71.856445	21
NIWE 39	23/05/19	20.83905	71.676919	16
NIWE 40	23/05/19	20.87679	71.742233	15
NIWE 41	23/05/19	20.83254	71.628021	16
NIWE 42	26/05/19	20.86329	71.551506	18
NIWE 43	26/05/19	20.87790	71.513512	21

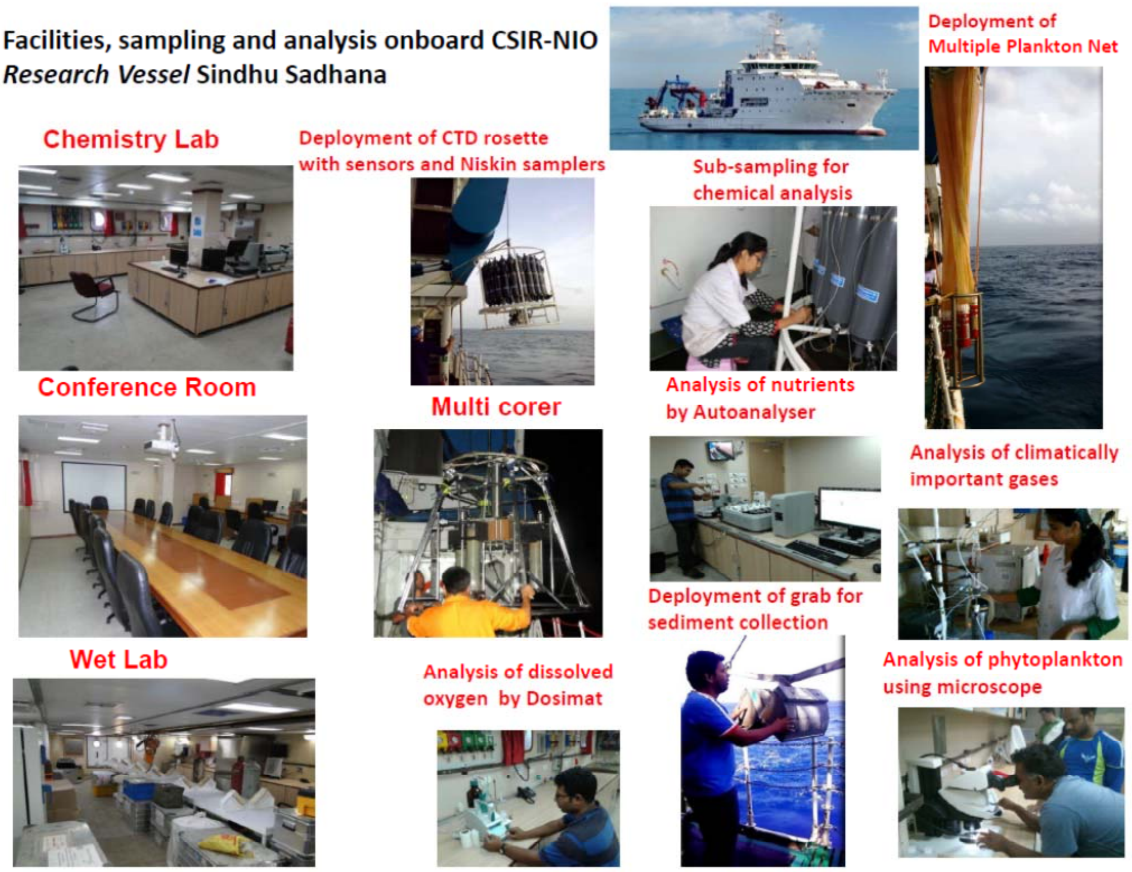


Plate 3.10.1: **Facilities onboard Research Vessel Sindhu Sadhana**

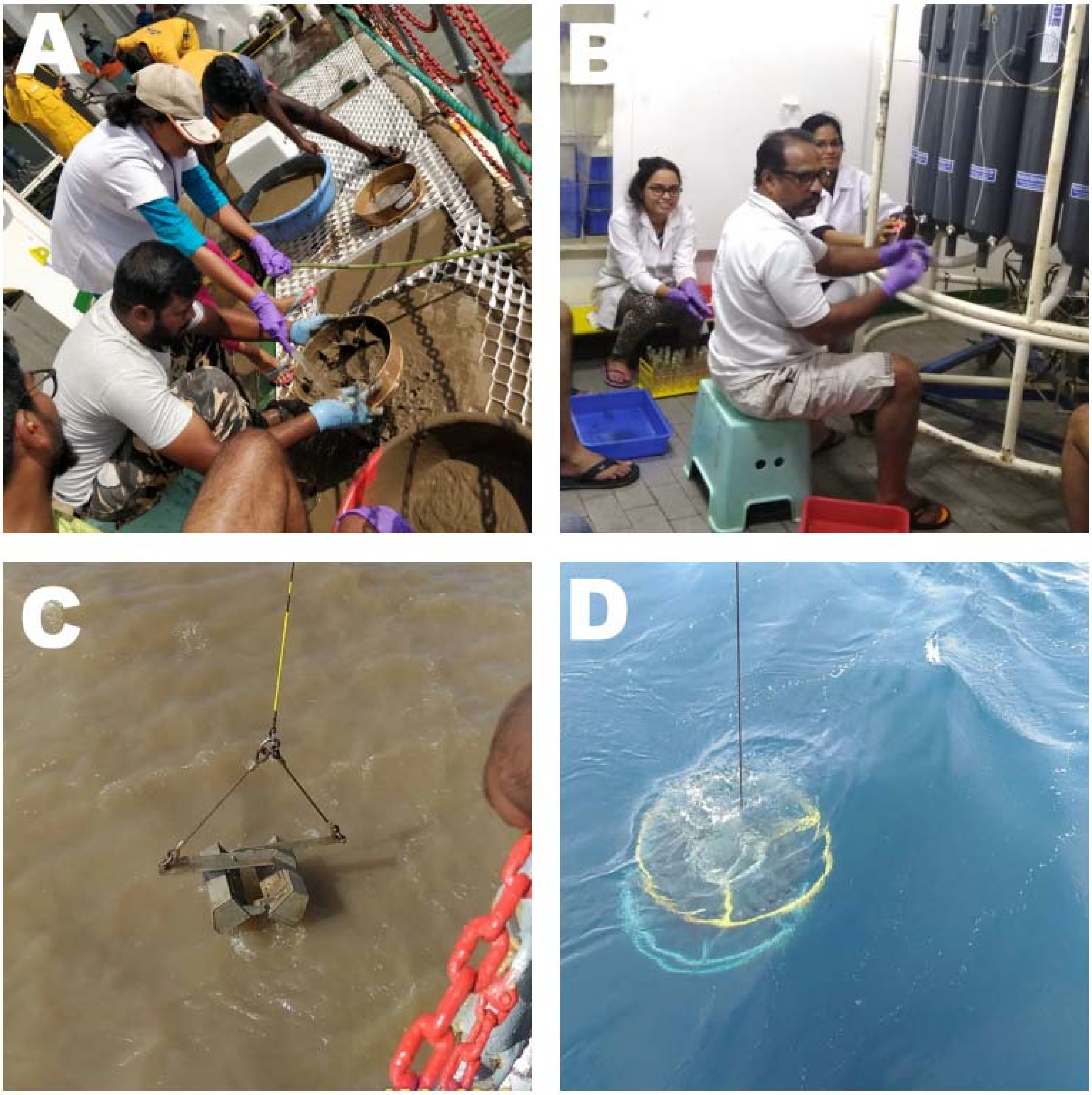


Plate 3.10.2: Depicting sampling methods onboard RV Sindhu Sadhana A-Sediment sieving B-Water sample collection C-Grab in operation D-CTD rosette in operation.

3.10.2 Water quality parameters

pH

At each sampling station, the insitu temperature and salinity in the water column was measured by using a portable CTD. The data for seawater temperature and salinity are presented in degree centigrade (°C) and practical salinity unit (PSU), respectively.

pH

pH of water samples was measured onboard immediately after collection using a portable benchtop, pH meter with an accuracy of ± 0.1 pH units. The pH meter was standardized against standard solutions of pH 4.0, 7.0, and 9.2.

Dissolved oxygen (D.O.)

Dissolved oxygen in the water sample was measured by Winkler's titrimetric method (Grasshoff*et al*., 1983). Samples were collected in D.O. bottles, and then oxygen present in seawater was fixed with Winkler's-A and Winkler's-B reagents immediately after sampling. The precipitate was dissolved with dilute HCl solution, and the liberated iodine was titrated against a standard sodium thiosulphate solution by using an auto-titrator. The endpoint was detected by using starch as an indicator. The estimated D.O. values are presented in mg/l.

Biochemical Oxygen Demand (B.O.D_5)

The seawater samples were collected in B.O.D bottles and incubated in a B.O.D incubator in complete darkness at 20°C for 05 days. After incubation, the residual dissolved oxygen in each water sample was measured by Winkler's method The D.O. values on the 5th day were subtracted from the corresponding initial D.O. concentration to get the B.O.D_5 values and presented in mg/l.

Essential Nutrients

The dissolved nutrients, including nitrite,nitrate, ammonia, phosphate, and silicate in coastal seawater samples, were analyzed by photometric methods described in Grasshoff*et al*., 1983. All the nutrients were analyzed simultaneously by using SKALAR SAN++ Continuous Flow Analyser. The concentrations of each nutrient in water samples are presented in μmol/l.

Total Petroleum Hydrocarbons(TPH):

To analyse TPH from the water sample, 200 ml of water sample was taken in Separating funnel, and 25 ml of Hexane was added to it. Further, it was mixed thoroughly via shaking vigorously for 15-20 min. The organic layer was separated into a clean beaker. This step was repeated twice. To eliminate moisture content, a pinch of Sodium Sulphate is added. Further,the collected organic layer is anaylsed for TPH's using spectrofluorometer.

3.10.3 Sediment quality parameters

Total organic carbon contents:
The dry and powdered sediment sample was treated with a known volume of chromic acid to oxidize all the organic carbon compounds. The excess acid was titrated with standard ammonium ferrous sulfate solution using O-phenanthroline as an indicator following the method described by (El Wakeel and Riley, 1956). The concentration of organic carbon in sediment samples was presented in terms of percentage of sediment weight.

Bulk metal contents:
All sediment samples were dried at 110°C in an oven and then crushed into fine powder by using acid-cleaned agate mortar. The dried and finely powdered sediment samples were entirely digested by using a supra-pure acid mixture (HF:HNO_3:$HClO_4$:7:3:1) at ~180°C. Digested samples were dissolved in diluted (1:1) supra-pure nitric acid solution. Then the final volume was made with Milli-Q® water. These solutions were analysed for selected major and trace metals (e.g., Al, Fe, Ca, Cr, Cu, Ni, Pb, and Zn) with an Inductively Coupled Plasma-Optical Emission Spectroscopy.

3.10.4 Results and discussions

Temperature, salinity,turbidity and DO of the coastal water column:

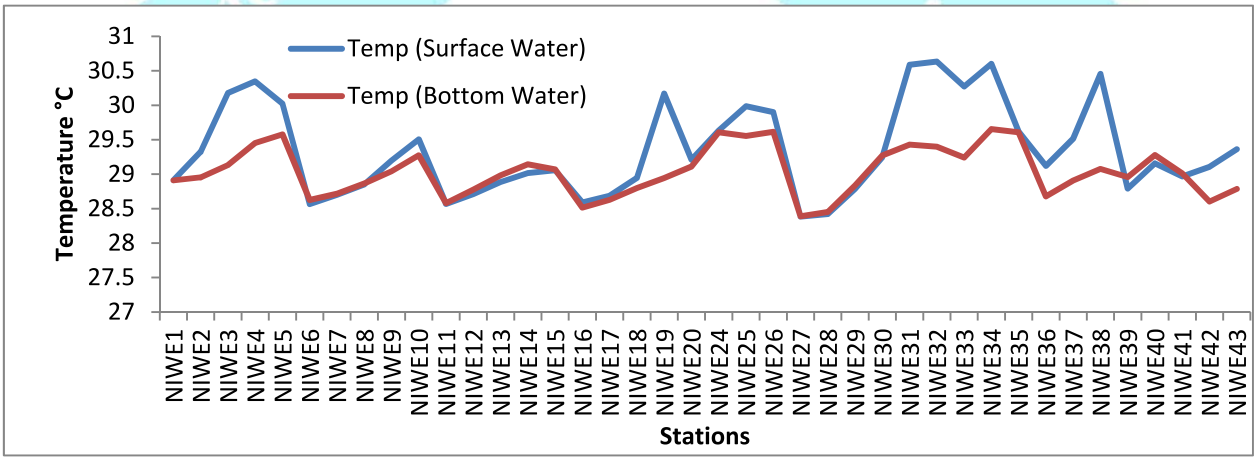


Figure 3.10.1: Spatial variations of temperature in surface and near-bottom waters at the sampling stations off Pipavav.

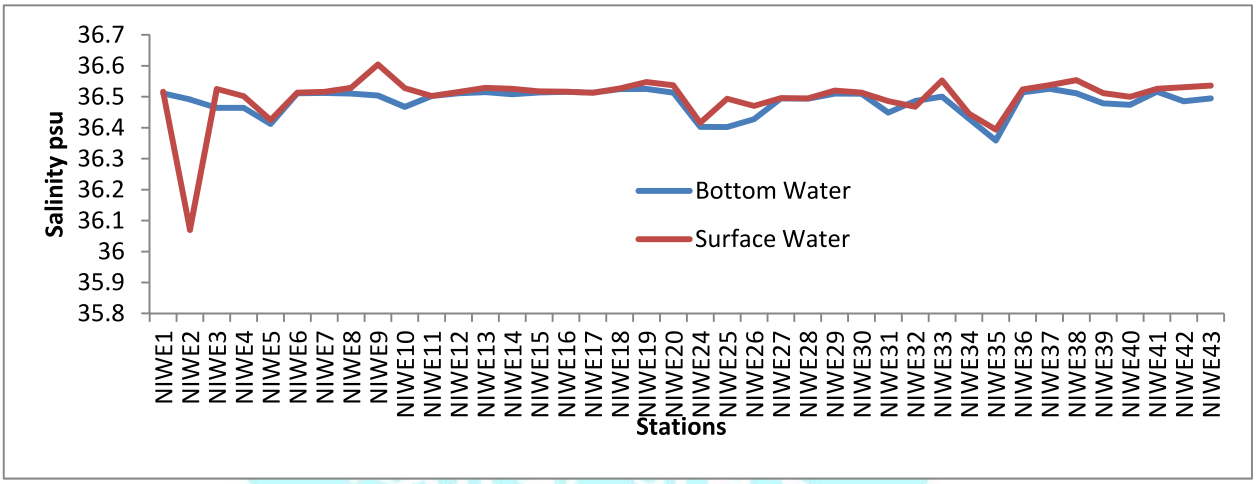


Figure 3.10.2: Spatial variations of salinity in surface and near-bottom waters at the sampling stations in the survey area off Pipavav.

D.O. of water:

The assessment of dissolved oxygen in the water column shows sufficient enrichment of oxygen (>4.0 mg/l; Fig.3.10.3; Table 3.10.2) in all water samples. These values are better than the D.O. levels (i.e., 5.0 mg/L),essential for SW-I type seawater (Environmental Protection Rule, 1986) prescribed for mariculture, salt pans or any ecological sensitive zone. Thus all, the estimated D.O. values can be considered sufficient for the survival of any aquatic life. The spatial distribution of D.O. did not show much variation at different sampling stations in the study area, and notmuch difference was found in D.O. in surface and bottom waters at all other stations (Fig. 3.10.3).

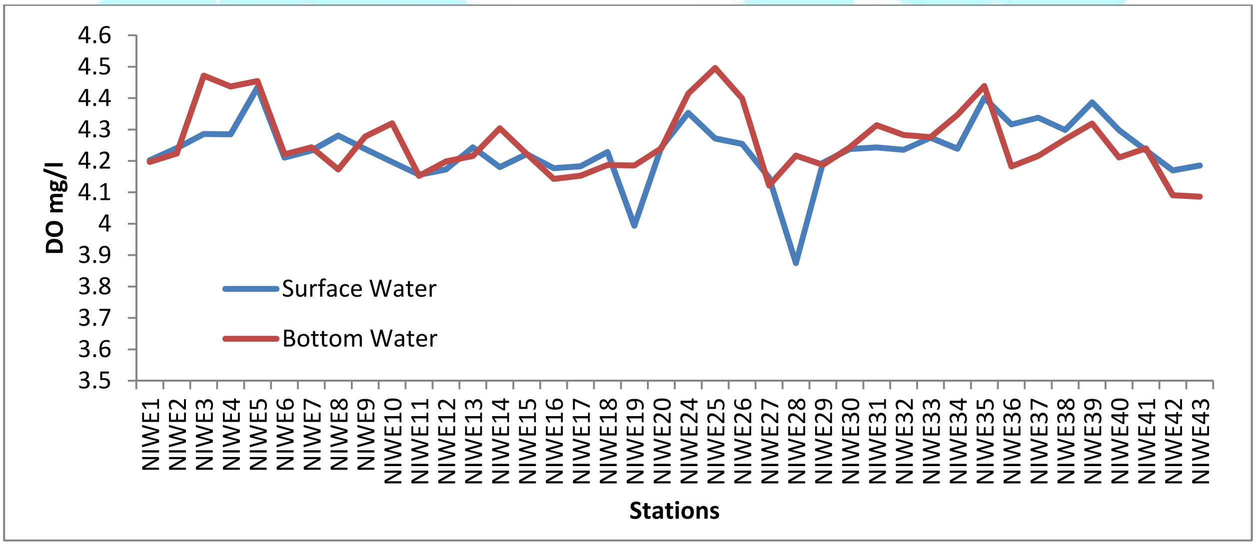


Figure 3.10.3: Spatial variations of dissolved oxygen (D.O.) in surface and near-bottom waters at the sampling stations in the survey area off Pipavav.

Turbidity:

More the load of suspended matters in water more would be the turbidity and which restricts light penetration and productivity within the water column. The suspended loads, the most visible indicator of water quality, can originate from soil erosion, land-based runoff, sewage discharges, stirred bottom sediments, or algal blooms. Distribution of turbidity in the surface waters offPipavav coast found to be more than 25 NTU except a few stations.

Essential nutrients in water:

Dissolved nutrients (nitrite, nitrate, phosphate, Ammonia, and silicate) play an important role in primary productivity in any aquatic ecosystem and, therefore, also support other aquatic lives. However, the concentration of each nutrient should be within certain limits; otherwise, the excess nutrient load can results in hyper nitrification in the water column and which can produce adverse impacts on the ecosystem. In our present survey, the estimated nitrite concentrations in waters were quite low, with values ranged from 0.06 to 1.0 µmol/l (Table 3.10.4). Even the surface and in bottom waters did not show much variation of nitrite concentration (Fig. 3.10.4). The dissolved nitrate content in most of the water samples varied between 1.0 and 19.4µmol/l. The concentrations of phosphate and silicate in same water samples ranged from 0.5 to 2.8 µmol/l and 7.0 to 55.2 µmol/l respectively (Figs. 3.10.5 and 3.10.6; Table 3.10.3.) Ammonium showed a wide range between 0.9 and 4.42 µmol/l (Fig. 3.10.7) in the surface waters.

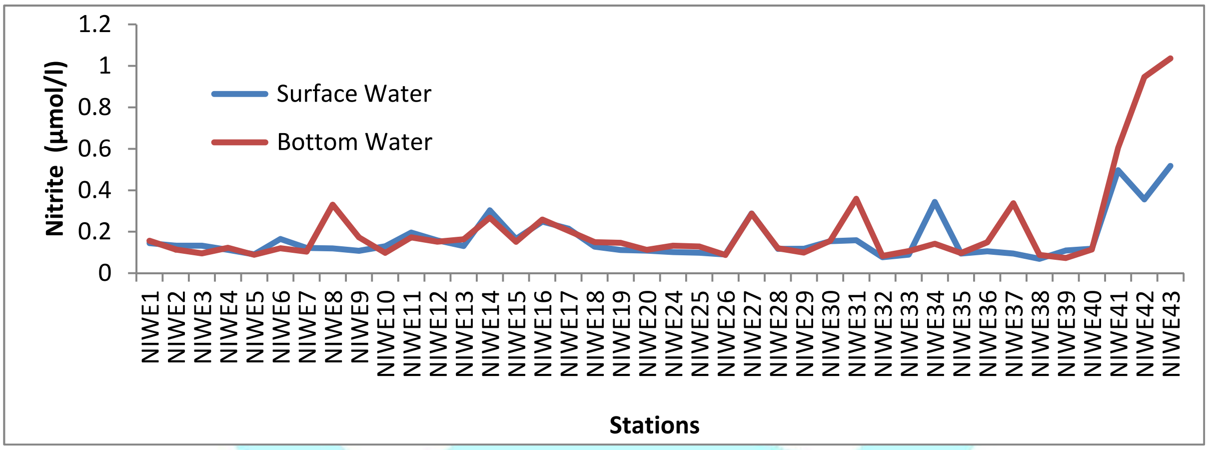


Figure 3.10.4: Spatial variations of dissolved nitrite in surface and near bottom waters at the sampling stations in the survey area off Pipavav.

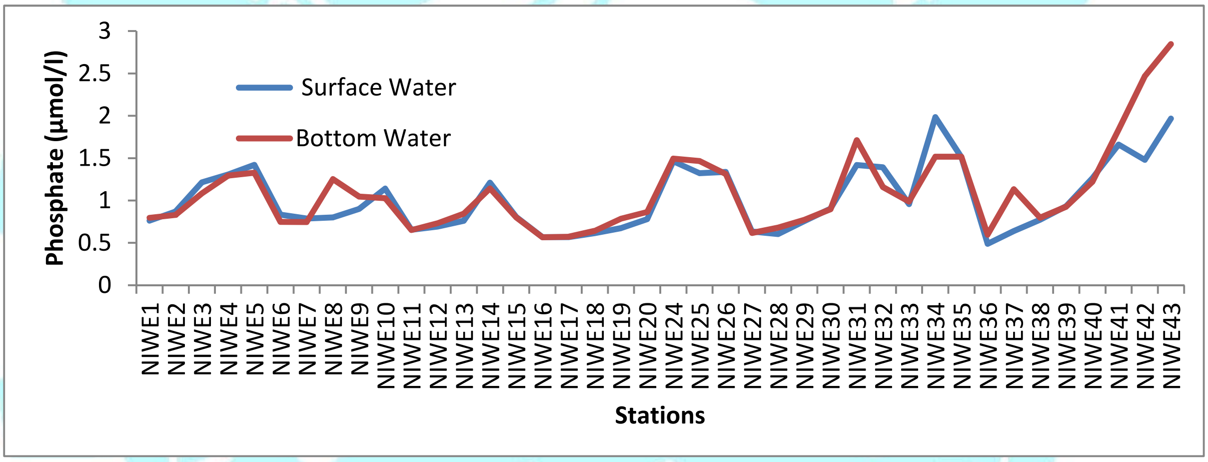


Figure 3.10.5: Spatial variations of dissolved phosphate in surface and near-bottom waters at the sampling stations in survey area off Pipavav

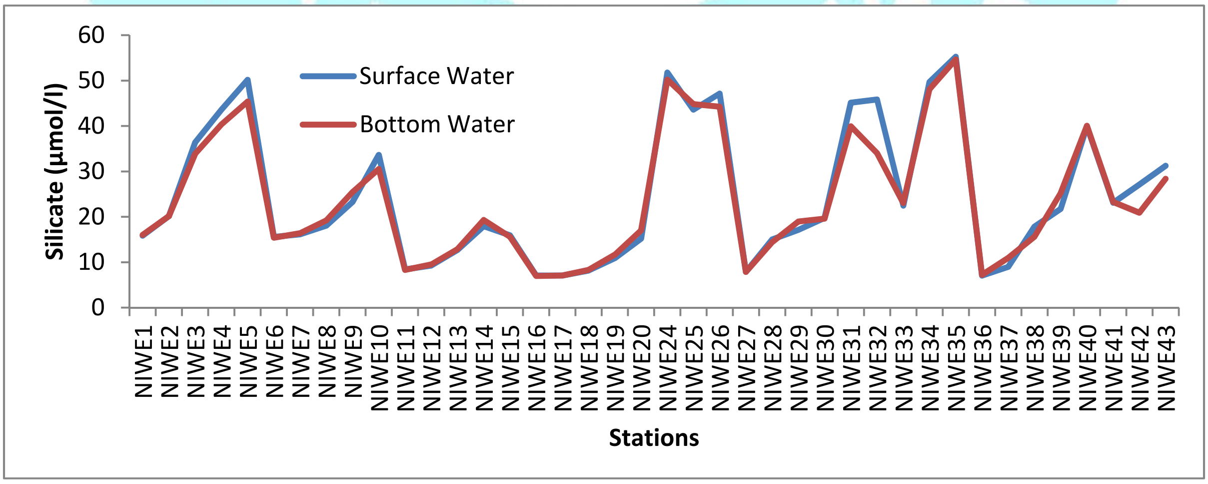


Figure 3.10.6: Spatial variations of dissolved silicate in surface and near-bottom waters at the sampling stations in the survey area off Pipavav.

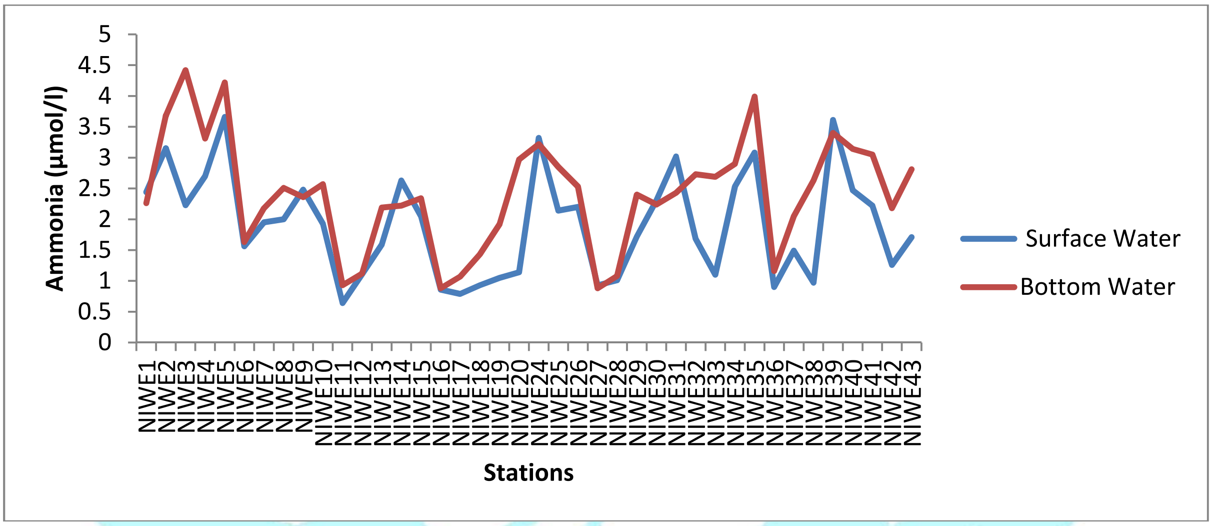


Figure 3.10.7: Spatial variations of dissolved Ammonia in surface and near-bottom waters at the sampling stations in the survey area off Pipavav.

Table 3.10.2: Spatial variation of physico-chemical parameters in coastal seawater quality off Pipavav.

Sampling stations	Water source	Temperature (°C)	Salinity (psu)	D.O. (mg/l)	Turbidity NTU
NIWE-01	Surface	28.91	36.52	4.20	>25
	Bottom	28.91	36.51	4.19	>25
NIWE-02	Surface	29.33	36.07	4.24	>25
	Bottom	28.95	36.49	4.22	>25
NIWE-03	Surface	30.18	36.53	4.28	>25
	Bottom	29.13	36.46	4.47	>25
NIWE-04	Surface	30.35	36.50	4.28	>25
	Bottom	29.45	36.46	4.43	>25
NIWE-05	Surface	30.02	36.43	4.43	>25
	Bottom	29.58	36.41	4.45	>25
NIWE-06	Surface	28.56	36.51	4.21	>25
	Bottom	28.63	36.51	4.22	>25
NIWE-07	Surface	28.70	36.52	4.23	>25
	Bottom	28.72	36.51	4.24	>25
NIWE-08	Surface	28.85	36.53	4.28	>25
	Bottom	28.86	36.51	4.17	>25
NIWE-09	Surface	29.20	36.60	4.23	>25
	Bottom	29.04	36.50	4.27	>25
NIWE-10	Surface	29.51	36.53	4.19	>25
	Bottom	29.27	36.47	4.31	>25
NIWE-11	Surface	28.57	36.50	4.15	15.0992
	Bottom	28.58	36.50	4.15	19.6732
NIWE-12	Surface	28.71	36.52	4.17	22.2708
	Bottom	28.78	36.51	4.19	>25
NIWE-13	Surface	28.89	36.53	4.24	>25
	Bottom	28.98	36.52	4.21	>25
NIWE-14	Surface	29.02	36.53	4.18	>25
	Bottom	29.14	36.51	4.30	>25
NIWE-15	Surface	29.06	36.52	4.22	>25
	Bottom	29.07	36.51	4.22	>25
NIWE-16	Surface	28.59	36.52	4.17	5.2928
	Bottom	28.51	36.52	4.14	10.0866
NIWE-17	Surface	28.69	36.51	4.18	6.1629
	Bottom	28.63	36.51	4.15	10.0381
NIWE-18	Surface	28.95	36.53	4.22	7.6202
	Bottom	28.80	36.52	4.18	>25
NIWE-19	Surface	30.17	36.55	3.99	7.0517
	Bottom	28.94	36.53	4.18	>25
NIWE-20	Surface	29.21	36.54	4.24	17.8458
	Bottom	29.11	36.51	4.24	>25
NIWE-24	Surface	29.63	36.42	4.35	>25
	Bottom	29.61	36.40	4.41	>25

Sampling stations	Water source	Temperature (°C)	Salinity (psu)	D.O. (mg/l)	Turbidity NTU
NIWE-25	Surface	29.99	36.49	4.27	>25
	Bottom	29.55	36.40	4.49	>25
NIWE-26	Surface	29.90	36.47	4.25	>25
	Bottom	29.62	36.43	4.39	>25
NIWE-27	Surface	28.38	36.50	4.14	9.5681
	Bottom	28.39	36.49	4.12	15.7907
NIWE-28	Surface	28.42	36.49	3.87	21.0235
	Bottom	28.45	36.49	4.21	>25
NIWE-29	Surface	28.79	36.52	4.13	>25
	Bottom	28.84	36.51	4.18	>25
NIWE-30	Surface	29.25	36.51	4.23	>25
	Bottom	29.27	36.51	4.24	>25
NIWE-31	Surface	30.59	36.49	4.24	>25
	Bottom	29.43	36.45	4.31	>25
NIWE-32	Surface	30.64	36.47	4.23	10.2789
	Bottom	29.40	36.49	4.28	>25
NIWE-33	Surface	30.28	36.55	4.27	10.4174
	Bottom	29.24	36.50	4.27	>25
NIWE-34	Surface	30.60	36.45	4.23	>25
	Bottom	29.65	36.43	4.34	>25
NIWE-35	Surface	29.62	36.39	4.40	>25
	Bottom	29.61	36.36	4.43	>25
NIWE-36	Surface	29.12	36.52	4.31	6.3342
	Bottom	28.68	36.51	4.18	>25
NIWE-37	Surface	29.51	36.54	4.33	21.3272
	Bottom	28.91	36.53	4.21	>25
NIWE-38	Surface	30.46	36.55	4.29	7.9261
	Bottom	29.08	36.51	4.26	>25
NIWE-39	Surface	28.79	36.51	4.38	>25
	Bottom	28.96	36.48	4.31	>25
NIWE-40	Surface	29.16	36.50	4.29	>25
	Bottom	29.28	36.47	4.21	>25
NIWE-41	Surface	28.97	36.53	4.23	>25
	Bottom	29.01	36.51	4.23	>25
NIWE-42	Surface	29.11	36.53	4.16	>25
	Bottom	28.60	36.49	4.09	>25
NIWE-43	Surface	29.36	36.54	4.18	19.7262
	Bottom	28.79	36.49	4.08	>25

Table 3.10.2: Spatial variation of dissolved nutrients in coastal seawater quality off Pipavav

Sampling stations	Water source	Ammonia (µmol/l)	Nitrite (µmol/l)	Nitrate (µmol/l)	Phosphate (µmol/l)	Silicate (µmol/l)
NIWE-01	Surface	2.44	0.14	2.64	0.76	15.83
	Bottom	2.26	0.16	2.68	0.80	16.03
NIWE-02	Surface	3.15	0.13	4.21	0.87	20.16
	Bottom	3.68	0.11	4.11	0.83	20.15
NIWE-03	Surface	2.23	0.13	10.34	1.21	36.39
	Bottom	4.42	0.10	9.95	1.09	33.89
NIWE-04	Surface	2.7	0.11	13.39	1.31	45.58
	Bottom	3.31	0.12	12.79	1.29	40.34
NIWE-05	Surface	3.66	0.09	17.36	1.42	50.17
	Bottom	4.22	0.89	15.94	1.33	45.39
NIWE-06	Surface	1.56	0.17	2.38	0.83	15.57
	Bottom	1.63	0.12	2.47	0.75	15.41
NIWE-07	Surface	1.95	0.12	2.72	0.79	16.14
	Bottom	2.18	0.10	2.82	0.75	16.39
NIWE-08	Surface	2	0.12	3.30	0.80	18.06
	Bottom	2.51	0.33	3.44	1.25	19.20
NIWE-09	Surface	2.48	0.11	4.98	0.90	23.26
	Bottom	2.36	0.17	5.99	1.05	25.44
NIWE-10	Surface	1.93	0.13	9.20	1.14	33.64
	Bottom	2.57	0.10	9.24	1.03	30.52
NIWE-11	Surface	0.64	0.20	1.59	0.65	8.41
	Bottom	0.93	0.17	1.60	0.65	8.30
NIWE-12	Surface	1.11	0.16	2.00	0.69	9.25
	Bottom	1.12	0.15	2.02	0.73	9.51
NIWE-13	Surface	1.59	0.13	3.05	0.76	12.69
	Bottom	2.19	0.16	3.17	0.84	12.89
NIWE-14	Surface	2.63	0.30	4.83	1.21	17.94
	Bottom	2.22	0.27	5.10	1.14	19.31
NIWE-15	Surface	2.05	0.16	2.89	0.81	15.93
	Bottom	2.34	0.15	2.98	0.80	15.62
NIWE-16	Surface	0.86	0.25	1.03	0.57	7.08
	Bottom	0.88	0.26	1.08	0.57	6.96
NIWE-17	Surface	0.79	0.22	1.08	0.57	7.07
	Bottom	1.07	0.20	1.17	0.57	7.07
NIWE-18	Surface	0.93	0.13	1.49	0.62	8.17
	Bottom	1.43	0.15	1.67	0.64	8.30
NIWE-19	Surface	1.05	0.11	2.44	0.67	10.89
	Bottom	1.92	0.15	2.88	0.79	11.66
NIWE-20	Surface	1.14	0.11	3.79	0.78	15.18
	Bottom	2.97	0.11	4.59	0.87	17.04
NIWE-24	Surface	3.32	0.10	18.00	1.46	51.75
	Bottom	3.22	0.13	17.50	1.50	50.20

Sampling stations	Water source	Ammonia (µmol/l)	Nitrite (µmol/l)	Nitrate (µmol/l)	Phosphate (µmol/l)	Silicate (µmol/l)
NIWE-25	Surface	2.14	0.10	14.29	1.32	43.58
	Bottom	2.85	0.13	15.78	1.47	44.83
NIWE-26	Surface	2.2	0.09	16.04	1.34	47.15
	Bottom	2.53	0.09	15.13	1.31	44.27
NIWE-27	Surface	0.93	0.29	1.38	0.64	7.88
	Bottom	0.88	0.29	1.37	0.62	7.86
NIWE-28	Surface	1.01	0.12	2.00	0.60	15.02
	Bottom	1.08	0.12	1.99	0.68	14.43
NIWE-29	Surface	1.72	0.12	3.57	0.76	17.12
	Bottom	2.4	0.10	3.50	0.77	18.95
NIWE-30	Surface	2.31	0.15	4.19	0.91	19.75
	Bottom	2.24	0.16	4.15	0.90	19.62
NIWE-31	Surface	3.02	0.16	14.93	1.42	45.14
	Bottom	2.43	0.36	13.10	1.71	39.96
NIWE-32	Surface	1.68	0.08	16.69	1.39	45.84
	Bottom	2.73	0.08	11.37	1.16	34.03
NIWE-33	Surface	1.1	0.09	6.28	0.96	22.44
	Bottom	2.69	0.11	6.70	0.99	23.02
NIWE-34	Surface	2.53	0.34	17.37	1.98	49.72
	Bottom	2.9	0.14	16.85	1.16	48.08
NIWE-35	Surface	3.08	0.09	19.34	1.51	55.26
	Bottom	3.99	0.10	19.41	1.15	54.65
NIWE-36	Surface	0.9	0.11	0.80	0.49	7.05
	Bottom	1.16	0.15	1.10	0.60	7.21
NIWE-37	Surface	1.49	0.09	1.59	0.64	8.98
	Bottom	2.05	0.34	2.20	1.13	10.97
NIWE-38	Surface	0.97	0.07	4.47	0.77	17.85
	Bottom	2.63	0.08	4.17	0.80	15.61
NIWE-39	Surface	3.61	0.11	5.34	0.93	27.76
	Bottom	3.4	0.07	5.90	0.93	25.23
NIWE-40	Surface	2.47	0.12	11.77	1.26	39.93
	Bottom	3.14	0.11	11.88	1.22	40.07
NIWE-41	Surface	2.22	0.50	6.37	1.66	23.07
	Bottom	3.05	0.60	6.22	1.84	23.18
NIWE-42	Surface	1.26	0.36	8.33	1.48	27.12
	Bottom	2.18	0.96	5.24	2.47	20.90
NIWE-43	Surface	1.71	0.57	9.36	1.97	31.24
	Bottom	2.81	1.04	7.61	2.85	28.37

Total Petroleum Hydrocarbons (TPH):

Petroleum hydrocarbons are highest at Station NIWE-41, which is nearby the Gujarat coast. The bottom water has more TPHs because of mixing in the water column; more sediment particles were observed in this location (Table 3.10.4).

Surface TPHs value (µgChrsy.eqv/L) = 4.209387 ± 5Bottom TPHs value (µgChrsy.eqv/L) = 11.90724± 5. The minimum TPH is observed at NIWE-40.Surface TPH value (µgChrsy.eqv/L) = 0.346004± 5Bottom TPH value (µgChrsy.eqv/L) = 0.508457± 5.

Table 3.10.3: Variation of Total Petroleum Hydrocarbons at selected 10 locations from the study area.

Station	Water source	Dissolved & Dispersed Petroleum Hydrocarbon (µg Chrsy.eqv/L)
NIWE -01	Surface	3.87
	Bottom	1.94
NIWE- 10	Surface	5.75
	Bottom	6.55
NIWE- 13	Surface	2.47
	Bottom	3.15
NIWE-24	Surface	6.17
	Bottom	6.62
NIWE-27	Surface	2.24
	Bottom	2.24
NIWE33	Surface	2.30
	Bottom	2.39
NIWE-39	Surface	1.47
	Bottom	1.92
NIWE-40	Surface	0.35
	Bottom	0.51
NIWE-41	Surface	4.21
	Bottom	11.91
NIWE-43	Surface	2.11
	Bottom	4.07

Dissolved Trace Metals

The surface seawater samples from 38 locations within the study area were analysed for selective dissolved trace metals (e.g., Al, Cr, Mn, Ni, Cu, Zn & Pb), and the results are presented in the following Table 3.10.5. During field sampling, the surface seawater samples were collected by using pre-cleaned NISKIN samplers. Immediately after collection, each seawater sample was filtered through 0.4µm filter papers by using syringe filters and then acidified at pH< 2.0 with ultrapure nitric acid. These acidified seawater samples were stored in new acid-washed polyethylene bottles and brought back to the shore-based laboratory. The concentrations of dissolved metal wereestimated with a high-resolution ICPMS (Model: *Nu instrument Attom ES*) equipped with micro-nebulizer directly without matrix separation following the method modified after Rodushkin and Ruth, 1997. In this method, each of the acidified seawater samples was further diluted with extra-pure water and analysed with HR-ICPMS using the Rh^{103} solution as an internal standard.

The analytical results showed that the concentrations of trace elements in all these seawater samples were significantly high. The estimated range of values for dissolved Al, Cr, Mn, Ni, Cu, Zn, Pb were found to varies between 0.4- 500 µg/L, 0.2 -64µg/L, 0.1 -95µg/L, 13 -72µg/L, 4.4 -767µg/L, 1.3-1550µg/L, and 0.08 -67 µg/L respectively. Almost all the estimated values of dissolved trace metals were higher than the values commonly found in clean coastal seawaters, and that suggests considerable metal contamination in these waters. At all sampling stations, the water samples were highly turbid, and the metals leached out from the suspended sediment would likely contribute to the dissolved metals. Besides that, the wastewaters from coastal industries also could be another possible source for such higher metal concentrations in seawater. In these results, it has also noticed that the waters from the stations 6, 7, 8, and 9 have exceptionally low metal concentrations as compared to other locations. However, the reason for such low metal concentrations in these stations, located centrally in the sampling area, is not very clear (Table 3.10.5).

Table 3.10.4: Spatial distribution of dissolved trace metals in surface waters.

	Al (μg/l)	Cr (μg/l)	Mn (μg/l)	Ni (μg/l)	Cu (μg/l)	Zn (μg/l)	Pb (μg/l)
NIWE- 1	-	8.7	-	22.7	574.1	169.4	31.8
NIWE- 2	55.9	-	13.7	31.3	527.8	302.9	24.1
NIWE- 3	22.2	-	21.2	35.5	520.4	355.6	25.4
NIWE- 4	99.2	-	13.6	26.8	498.3	152.0	19.3
NIWE- 5	12.2	-	5.9	23.2	488.4	113.5	23.4
NIWE- 6	0.50	0.26	0.09	-	4.45	1.28	0.08
NIWE- 7	0.44	0.32	0.30	-	4.99	3.03	0.11
NIWE- 8	0.54	0.27	0.13	-	4.68	2.68	0.10
NIWE- 9	0.42	0.27	0.13	-	4.67	3.55	0.12
NIWE- 10	124.6	36.7	19.3	30.9	633.7	249.0	32.0
NIWE- 11	203.8	32.9	14.5	22.1	603.1	588.8	6.2
NIWE- 12	56.8	30.2	-	17.6	655.8	219.3	10.2
NIWE- 13	110.1	30.3	0.4	14.3	647.8	154.2	10.5
NIWE- 14	69.8	31.7	-	13.5	658.2	144.3	8.4
NIWE- 15	81.8	33.2	13.6	31.0	637.7	372.1	10.8
NIWE- 16	104.9	33.4	5.2	41.7	638.4	488.9	7.1
NIWE- 17	131.5	35.8	49.8	47.3	658.5	1376.1	11.6
NIWE- 18	119.8	34.5	6.0	18.0	587.7	377.8	37.8
NIWE- 19	120.1	38.0	45.9	34.3	636.3	682.5	32.6
NIWE- 20	194.5	37.7	86.1	60.1	632.3	1550.2	46.6
NIWE- 24	213.9	43.3	52.0	58.1	720.0	670.6	37.9
NIWE- 25	98.0	40.1	42.3	50.9	673.4	588.2	22.2
NIWE- 26	156.6	35.9	10.8	31.1	634.5	487.1	12.7
NIWE- 27	139.3	35.9	2.8	32.0	649.8	309.3	9.8
NIWE- 28	118.4	32.8	27.3	30.4	641.1	581.1	15.8
NIWE- 29	195.8	29.6	25.8	23.8	421.1	273.0	36.1
NIWE- 30	86.0	30.4	-	13.4	319.0	-	20.0
NIWE- 31	321.2	43.9	59.3	47.9	767.1	780.1	62.7
NIWE- 32	172.8	35.5	36.6	26.9	466.9	490.2	47.9
NIWE- 33	165.3	41.1	17.9	24.0	542.3	221.0	35.1
NIWE- 34	497.1	64.2	46.4	69.4	835.1	1243.5	30.2
NIWE- 35	224.3	-	14.9	34.5	503.0	633.8	23.9
NIWE- 37	144.4	41.5	16.8	19.9	653.6	206.2	22.0
NIWE- 38	251.2	44.3	46.6	46.1	641.0	567.8	17.3
NIWE- 39	409.7	44.7	36.4	70.2	675.9	519.4	29.0
NIWE- 41	501.4	43.3	48.6	72.8	710.1	1208.2	32.0
NIWE- 42	201.8	52.1	20.6	72.3	600.8	220.6	66.9
NIWE- 43	443.1	56.0	95.4	64.0	789.6	316.3	55.5

Spatial variation of sediment quality in the coastal area

Texture of surface sediment:

The textural distributions of the sediment samples from all the stations are shown in (Fig. 3.10.8). The relative abundance of sand, silt, and clay in surface sediments are mostly dominated with sand (> 50%), (Except the stations NIWE-9, NIWE-11,NIWE-13, NIWE-15, NIWE-26, NIWE-28, NIWE-32, NIWE-33, and NIWE-34). In these NIWE stations, sediments are coarser and enriched with silt (30 -70%), (Table 3.10.5). The clay contents in all samples were almost uniform (< 30%). Thus on average most of these sediments are characterised as sandy silt types.

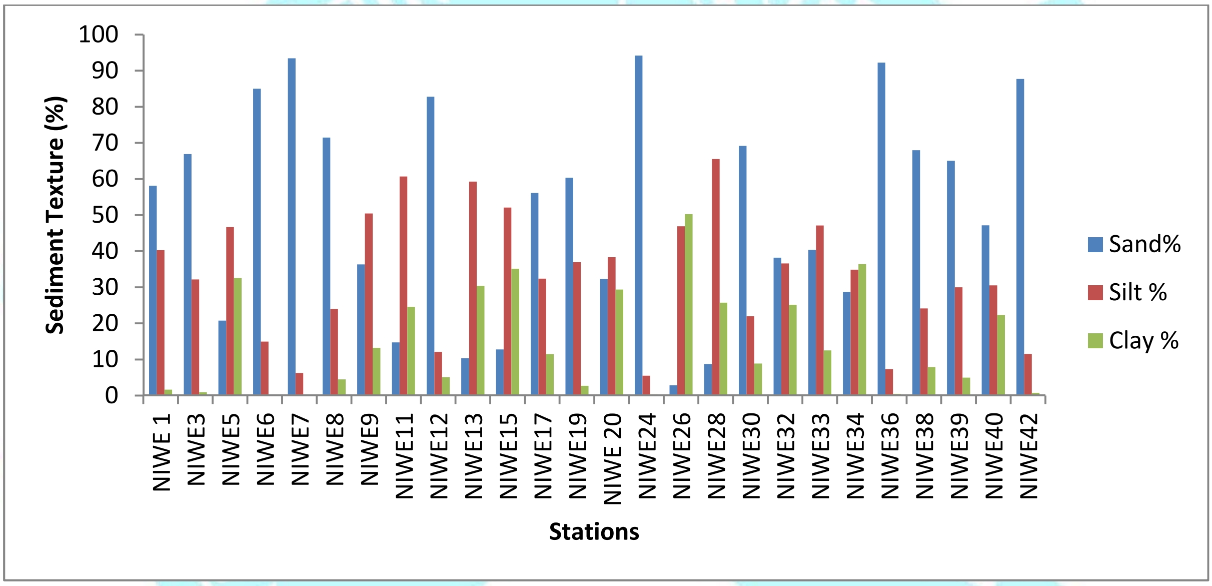


Figure 3.10.6: Spatial variations of sediment texture in the top layer of coastal sediment at the sampling stations in the survey area off Pipavav

Table 3.10.5: Grain-size distribution at selected stations in the area.

Station	Sand%	Silt %	Clay %
NIWE 1	58.10	40.27	1.64
NIWE3	66.91	32.15	0.94
NIWE5	20.75	46.68	32.57
NIWE6	85.00	14.93	0.07
NIWE7	93.42	6.26	0.31
NIWE8	71.49	24.01	4.49
NIWE9	36.33	50.45	13.22
NIWE11	14.71	60.70	24.59
NIWE12	82.77	12.11	5.12
NIWE13	10.33	59.27	30.40
NIWE15	12.79	52.09	35.12
NIWE17	56.13	32.39	11.49
NIWE19	60.36	36.95	2.69
NIWE 20	32.29	38.33	29.38
NIWE24	94.17	5.49	0.35
NIWE26	2.86	46.89	50.25
NIWE28	8.74	65.54	25.72
NIWE30	69.18	21.96	8.86
NIWE32	38.20	36.62	25.17
NIWE33	40.36	47.13	12.52
NIWE34	28.69	34.87	36.44
NIWE36	92.25	7.31	0.45
NIWE38	67.98	24.13	7.90
NIWE39	65.03	29.97	4.99
NIWE40	47.17	30.52	22.31
NIWE42	87.71	11.53	0.76

3.11 Microbiology

Total Viable count (TV-C) - Water and sediment

Water samples were diluted up to 10^{-2} and 10^{-3} for some stations and 0.1 ml of sample was spread plated on Zobell Marine Agar (Hi-media) and Nutrient agar (Hi-media) and incubated at (30 ± 2 °C), for 1-2 days and then bacterial count was noted.

One gram sediment sample was suspended in 9 ml sterile autoclaved seawater. The suspension was vortexed for two minutes. The sediment was then allowed to settle, and serial dilutions were made by serially transferring 1 ml of the sample to 9 ml autoclaved seawater, serial dilutions were carried out up to 10^{-3} for two stations, and 10^{-4} for rest of the stations and 0.1 ml of the sample was spread plated on Zobell marine agar (Hi-media) and Nutrient agar (Hi-media) plates and incubated at (30 ± 2 °C) for 1-2 days.

Indicator bacterial groups

For enumeration of different indicator bacterial groups such as Total Coliforms (TC), *Escherichia coli* like organisms (ECLO), *Salmonella* like organisms (SALO), *Shigella*-like organisms (SHLO), *Proteus*/ *Klebsiella*-like organisms (PKLO) and *Pseudomonas aeruginosa* like organisms (PALO), were quantified using specific media prepared in seawater. The media used for studying the growth and enumeration of different groups of bacteria were procured from Hi-Media and is given below:

Bacterial Group	**Medium**
Total Coliforms (TC)	Mac-Conkey's Agar
Escherichia coli like organisms (ECLO)	
Salmonella like organisms (SALO)	Xylose Lysine Deoxycholate Agar (XLD)
Shigella like organisms (SHLO)	
Proteus/*Klebsiella* like organisms (PKLO)	
Pseudomonas aeruginosa like organisms (PALO)	Cetrimide Agar

Results

Total Viable Counts (TVC)

Total Viable Counts (TVC) in the surface seawater and sediment collected at ten stations off Pipavav region are presented in Table 3.11.1 and 3.11.2.

The heterotrophic bacterial count (CFU/mL) in the surface water ranged from 0.4to 20×10^3 on Nutrient agar and 0.1to 20×10^3 on the ZMA medium. The highest bacterial counts (20×103 CFU/mL) were recorded at station NIWE 13, while the least was at NIWE 03.

The heterotrophic bacterial count (CFU/g) in sediment samples ranged from 0.6×10^3 to 9.0×10^3 on nutrient agar and 33×10^3 to >300 CFU/g on ZMA medium. The highest bacterial count was recorded at station NIWE 29.

Indicator bacterial groups

The distribution in the quantitative abundance of different indicator bacterial groups such as Total Coliforms (TC), *Escherichia coli* like organisms (ECLO), *Salmonella* like organisms (SALO), *Shigella* like organisms (SHLO), *Proteus*/ *klebshiella* like organisms (PKLO) and *Pseudomonas aeruginosa* like organisms (PALO) was done with surface water and sediment samples. However, no growth was observed on any of the differential media used.

Table 3.11.1: Abundance of different indicator bacterial groups in the surface waters (x10^2 CFU/ml) off Pipavav

WATER SAMPLES (CFU/ml)											
DATE	STATION NO.	NA		ZMA		MCA		CA		XLDA	
		10^{-2}	10^{-3}	10^{-2}	10^{-3}	10^{-2}	10^{-3}	10^{-2}	10^{-3}	10^{-2}	10^{-3}
23-05-2019	**NIWE-35**	1×10^3	0	3×10^3	0	NG	NG	NG	NG	NG	NG
23-05-2019	**NIWE-03**	5×10^3	2×10^4	15×10^3	10×10^3	NG	NG	NG	NG	NG	NG
24-05-2019	**NIWE-29**	2×10^3	0	5×10^3	2×10^4	NG	NG	NG	NG	NG	NG
24-05-2019	**NIWE-31**	2×10^3	1×10^4	0	0	NG	NG	NG	NG	NG	NG
		10^{-1}	10^{-2}	10^{-1}	10^{-2}	10^{-1}	10^{-2}	10^{-1}	10^{-2}	10^{-1}	10^{-2}
25-05-2019	**NIWE-13**	4×10^2	1×10^3	1×10^2	0	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-27**	8×10^2	3×10^3	5×10^2	1×10^3	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-18**	11×10^2	1×10^3	14×10^2	0	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-32**	5×10^2	2×10^3	3×10^2	0	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-38**	6×10^2	1×10^3	6×10^2	2×10^3	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-36**	17×10^2	3×10^3	17×10^2	4×10^3	NG	NG	NG	NG	NG	NG

NOTE: NG- NO GROWTH

Table 3.11.2: Abundance of different indicator bacterial groups in the surface sediment (x10^3 CFU/g) off Pipavav

SEDIMENT SAMPLES (CFU/g)											
DATE	STATION NO.	NA		ZMA		MCA		CA		XLDA	
		10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-3}	10^{-4}
23-05-2019	**NIWE-35**	0	0	0	0	NG	NG	NG	NG	NG	NG
23-05-2019	**NIWE-03**	0	0	0	0	NG	NG	NG	NG	NG	NG
24-05-2019	**NIWE-29**	6.25×10^2	25×10^3	>300	>300	NG	NG	NG	NG	NG	NG
24-05-2019	**NIWE-31**	**SAMPLE NOT COLLECTED**									
		10^{-2}	10^{-3}	10^{-2}	10^{-3}	10^{-2}	10^{-3}	10^{-2}	10^{-3}	10^{-2}	10^{-3}
25-05-2019	**NIWE-13**	8.7×10^2	43×10^2	0	0	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-27**	40×10^2	0	0	0	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-18**	5.4×10^2	90×10^2	0	0	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-32**	0	76×10^2	0	46×10^3	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-38**	0	0	0	0	NG	NG	NG	NG	NG	NG
25-05-2019	**NIWE-36**	33×10^2	0	33×10^3	66×10^3	NG	NG	NG	NG	NG	NG

NOTE: NG- NO GROWTH

3.12 Plankton

Phytoplankton

Phytoplanktons are mostly microscopic, single-celled photosynthetic organisms that live suspended in the water. They are the primary producers of the ocean, the organisms that form the base of the food chain. It is vital to study and understand them as they generate about half of the atmosphere's oxygen, as much per year as all land plants. They make most other ocean life possible. The immediate grazers of the phytoplankton carbon are the zooplankton that links phytoplankton biomass to fish. Thus, they together play a critical role in regulating today's carbon cycles.

These two biological parameters were sampled and analyzed under this project. Accordingly, the water samples were collected for biological measurements covering phytoplankton and mesozooplankton analyses from various locations (See Fig. 3.12.1). Samples were analyzed for biomass estimation (chlorophyll a) and identification of the phytoplankton community composition to the genera level. Similarly, mesozooplankton samples collected using HT net (of 200-micron pore size) was processed back to the shore laboratory using the standard protocol. The results of which are discussed below based on representative analyzed samples.

Phytoplankton biomass (Chlorophyll a):

One of the most widely used proxies of phytoplankton biomass is the total chlorophyll-*a* concentration, which varied between 0.22 and 1.09 mg m^{-3} (avg. 0.6) at the surface (1m below the surface). Comparable biomass was also recorded at the near-bottom (0.24-1.67; avg. 0.64 mg m^{-3}), indicatinga very well-mixed water column at the study site (Fig. 3.12.1). However, depth-integrated chlorophyll concentration (Fig. 3.12.2) showed a 10-fold variation with respect to space ranging between 2.75 mg m^{-2} (stn: 3) and 13.64 mg m^{-2} (stn: 10).

Likewise, phytoplankton community composition and abundances (>5micron in size) werealso analyzed following microscopic technique. The composition was found to be primarily dominated by diatoms (specifically pennate forms; 43-88%; avg. 67%) compared to dinoflagellates (12-57%; avg. 33%; Fig. 3.12.3) indicating study site is with enough silicate for the diatoms to proliferate. The vertical distribution also showed relatively higher abundance at the near-bottom compared to the surface. While diatoms were more common at the surface compared to near bottom. Community composition was contributed mainly by numerical abundances of *Bacteriastrum*spp., *Coscinodiscus* Spp. *Thalassiosira* Spp. *Fragillaria* Spp. *Navicula* Spp. *ThalassionemaSpp. Chattonella Spp. Gymnodinium* Spp. *Oxytoxum* Spp. *Protoperidinium* Spp. *Scrippsiella* Spp. Interestingly, *Navicula* Spp. were present in both surface and near-bottom depth (Table 3.12.1).

Mesozooplankton

Zooplankton (>200 microns in size) are a type of heterotrophic plankton that are mostly microscopic and play an important role in the marine pelagic ecosystems in the cycling and export of carbon. In the present study, zooplankton biomass was estimated following displacement technique. At the representative stations (Fig. 3.12.4), biomass values (ml/100 m^3) found to vary from 70 (stn 21) -415 (stn 38) (Avg. 197 ml/100m^3). Zooplankton community composition showed a diverse copepod community contributing to an an average of 30% (Table 3.12.2). Study region found to be productive in terms of fish larvae and fish eggs contributing ~68% of the zooplankton composition indicating the prevailing environmental condition at the study site to be an ideal site for the *fish* to *spawn* in the region.

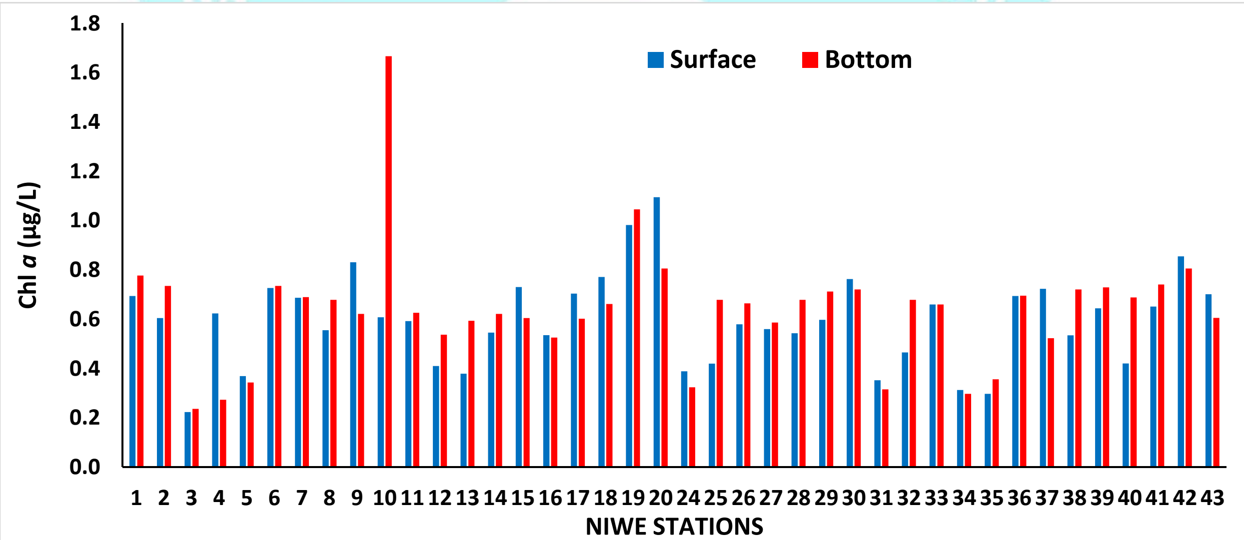


Fig. 3.12.1 Chlorophyll a (µg/L) distribution at the study site.

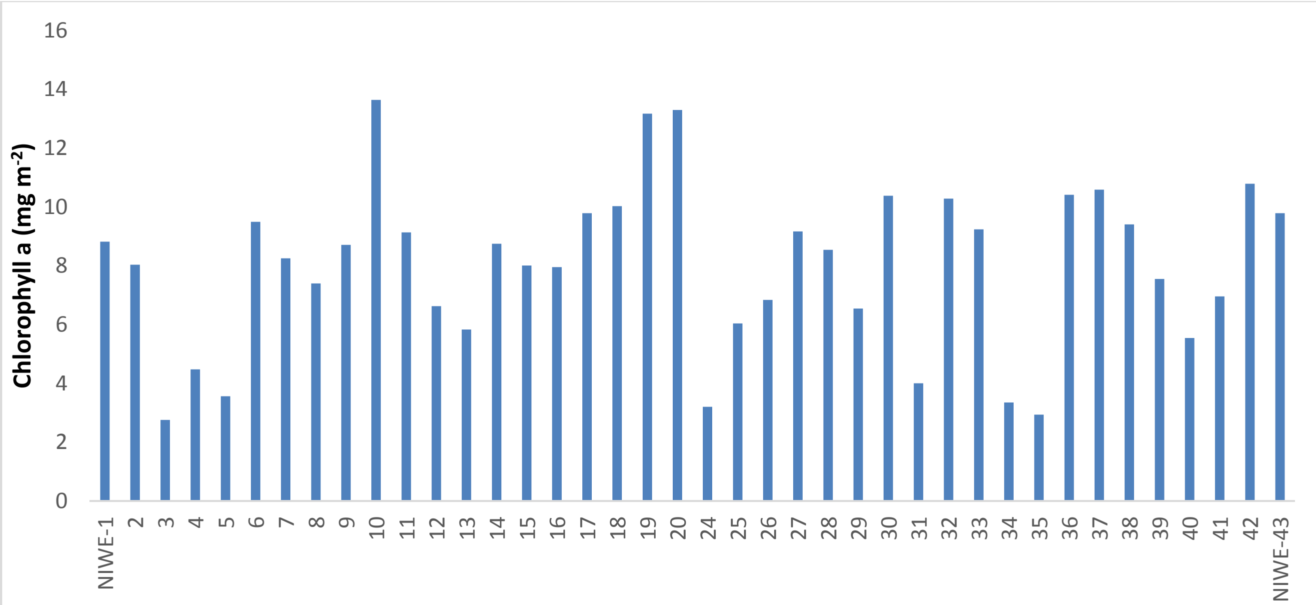


Fig. 3.12.2: Depth integrated Chlorophyll a (mg m^{-2}) distribution at the study site

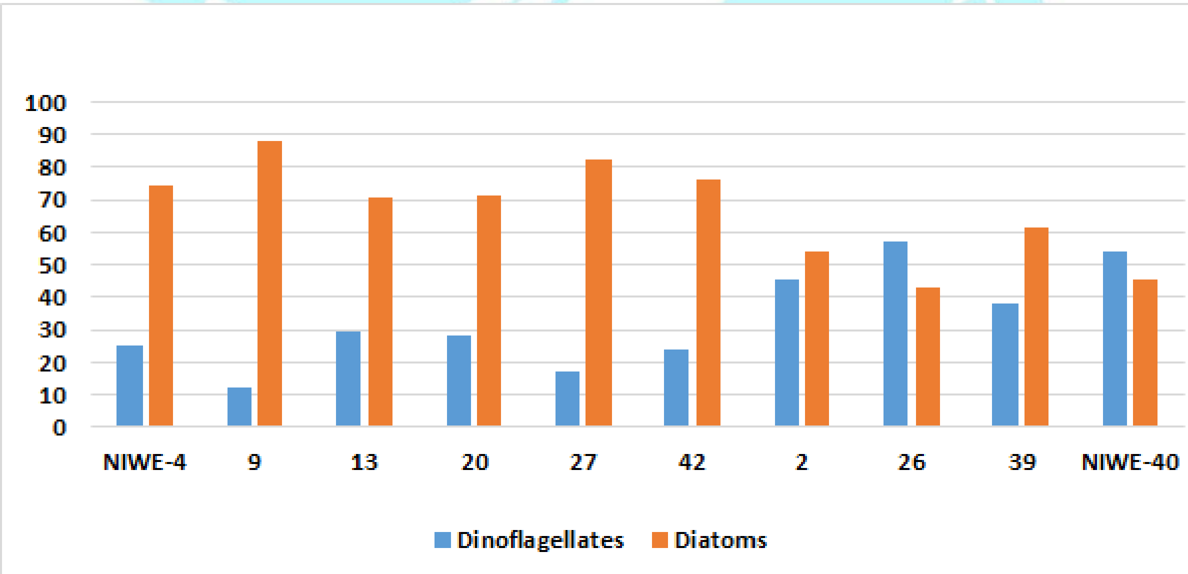


Fig. 3.12.3: Percent diatom and dinoflagellate contribution to the total phytoplankton community composition at the study site

Table 3.12.1: Phytoplankton community composition and abundances (>5micron in size) at the study site

	Surface (1m)-Phytoplankton Composition (Nos/L)						Near Bottom(13m) - Phytoplankton Composition (Nos/L)			
Stations-->	**NIWE-4**	**NIWE-9**	**NIWE-13**	**NIWE-20**	**NIWE-27**	**NIWE-42**	**NIWE-02**	**NIWE-26**	**NIWE-39**	**NIWE-40**
DIATOM (Centric)										
Asteromphalus spp.		576								
Bacteriastrum spp.	2736									
Chaetoceros spp.					136					
Corethron spp.	2128									
Coscinodiscus spp.	304	2496	1400	972		152	2688	4032	3744	2720
Cyclotella spp.	1216		400				896	448	832	1088
Ditylum spp.	304	1344		108	1088					
Guinardia spp.	304			108				448	416	
Hemidiscus spp.										1088
Odontella spp.							896			
Rhizosolenia spp.	304						10752		1248	
Skeletonema spp.								3136		
Thalassiosira spp.	1824			1404	544	608	1792	2240	832	544
DIATOM (pennate)										
Amphora spp.				108		152		448	416	1632
Fragillaria spp.		1344								3808
Licmophora spp.			200		408		2688	1344	1664	1632
Navicula spp.	2736	1152	1400	324	952	1520	5376	1792	6240	6528
Nitzschia spp.	1824		800		408			1344	832	1088
Pleurosigma spp.	912		600		1360	304	2688	1344	832	544
Pseudo-nitzschia spp.		1344			408					
Surirella spp.					544					
Thalassionema spp.	1520	1536	2400	756	1904	1672		1344	416	
DINOFLAGELLATES										
Ceratium spp.				108		152				
Chattonella spp.	912	768	1400		408	152	2688	896		4352
Gymnodinium spp.	304	192	200	648			7168	9856	7488	4352
Gyrodinium spp.				324				3136	416	
Heterodinium spp.							896			
Noctiluca spp.				108						
Oxytoxum spp.	304		800		136		1792	3136	832	5440
Pronoctiluca spp.	304									
Prorocentrum spp.	304		400	324			896	1792	416	544
Protoperidinium spp.	304		200		136		8064	4480		2176
Scrippsiella spp.	3040	384			952	1064	1792	448	1664	7616
Total	**21584**	**11136**	**10200**	**5292**	**9384**	**5776**	**51072**	**41664**	**28288**	**45152**

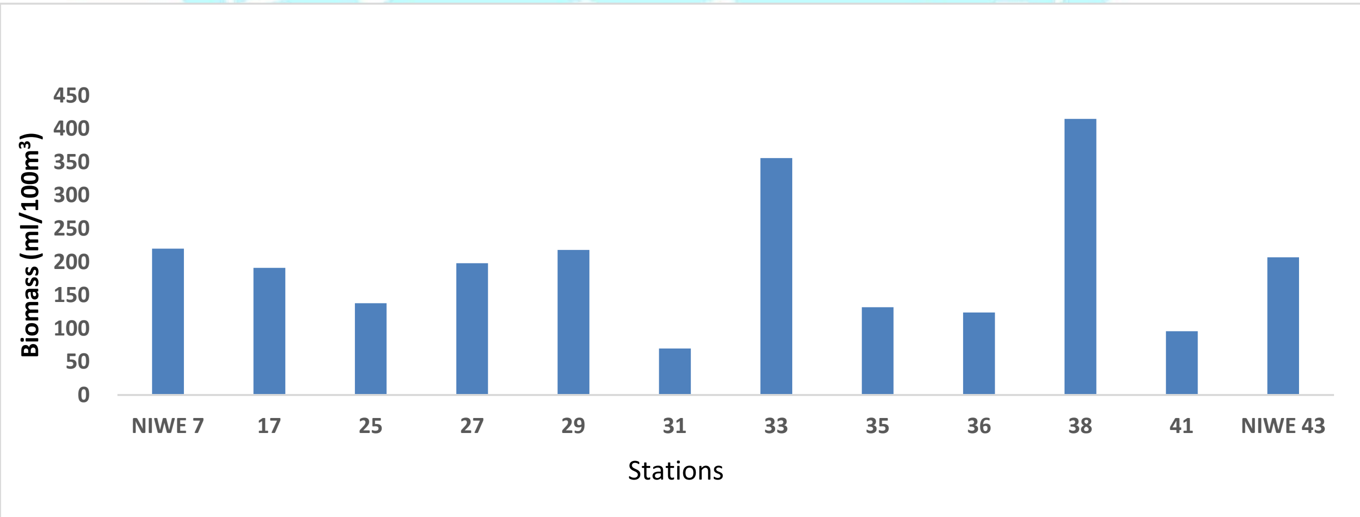


Fig. 3.12.4: Mesozooplankton biomass (ml/100m^3) distribution at the study site.

Table 3.12.2: Mesozooplankton community composition and abundances (>200micron in size) at the study site

Mesozooplankton abundances (Nos. /100m3)				
Stations	NIWE 7	NIWE 25	NIWE 35	NIWE 43
Calanoida				
Paracalanidae	-	7958	-	16210
Acrocalanus spp.	-	21220	-	-
Paracalanus spp.	-	13263	-	5894
calanoid(damaged)	63255	-	51826	53050
Euchaetidae	-	-	-	-
Euchaeta spp.	-	1768	-	2947
Acartiidae	-	-	-	-
Acartia spp.	2259	10610	6797	70734
Pontellidae	-	-	-	-
Lebidocera spp.	-	-	-	13263
Clausocalanidae	-	-	-	-
clausocalanus spp	-	4421	-	8842
Centropagidae	-	-	-	-
Centropages	-	5305	-	10315
Calanidae	-	-	-	7368
Canthocalanus	-	-	-	-
Nanocalanus	-	2653	-	-
Eucalanidae	-	6189	-	16210
Temoridae	-	-	-	-
Temora sp	6777	-	-	2947
Tortanidae	-	-	-	-
Tortanus insularis	-	-	-	1474
Tortanus spp	2259	-	-	-
Cyclopoida				
Oithonidae	-	-	-	-
Oithona spp.	-	-	2549	-
Harpacticoida				
Ectinosomidae	-	-	-	-
Microsettela spp.	-	2653	850	-
Macrosetellidae	-	-	-	-
Macrosettela spp.	-	-	-	-
Tachidiidae	-	-	-	-
Euterpina acutifrons	40664	7958	4248	30946
Clytemnstridae	-	-	-	-
Clytemnstra spp	-	-	-	-
Poicelostomatoida				
Oncedae	-	-	-	-
Onceae spp.	2259	-	1699	-
Corycaecidae	-	-	-	-
Corycaeus asiaticus	-	11494	-	54524
Corycaeus spp.	45182	32714	10195	94312
Copepod naupli	13555	19452	-	103153
Calanoid copepodite	-	14147	-	-
Other Groups				
Chaetognatha	4518	-	1699	29472
Siphonophorae	-	884	-	1474
Decapoda	-	884	2549	-
cladocera	4518	-	-	1474
fish egg	614480	573828	330495	154730
decapod larvae	45182	76923	3398	207781
fish larvae	2259	-	2549	-

3.13 Meiofauna

Meiofauna are the fauna that reside in the sediment and ranged below 300 microns to 40 microns considered as a meiofauna. It includes Nematodes, larvae of polychaetes, Harpacticoid copepods, bivalves, gastropods, larvae of cnidarian, etc. Meiofauna also occupies several "above sediment" habitats, including rooted vegetation, moss, macroalgae fronds, sea ice, and various animal structures, e.g., coral crevices, worm tubes, echinoderm spines (Higgins & Thiel, 1988).Certain taxa are restricted to particular sediment types. Sediments where the median particle diameter is below 125 μm tend to be dominated by burrowing meiofauna. Interstitial groups, e.g.,Gastrotricha and Tardigrada, are typically excluded from muddy substrates where the interstitial lacunae are closed. The sand fauna tends to be slender as it must maneuver through the narrow interstitial openings. In contrast, the mud fauna is not restricted to a particular morphology but is generally larger sized (Coull, 1988).

In general, sediment grain size is a primary factor affecting the abundance and species composition of meiofaunal organisms. Nematodes regularly dominate the meiofauna in sediment biotopes comprising >50% of the total meiofauna. Harpacticoid copepods are usually second in abundance but may dominate in some coarse-grained sediment.

Sampling and analysis

Sediment samples were collected from 40 different subtidal stations in and around the study areaduring the pre-monsoon period (from23rd to 26thMay2019) and 17 Coastal shallow (from 4th to 8th May 2019 and 27th to 28th May 2019)using an acrylic core of 4.5 cm in diameter.Details of the sampling locations are provided in (Fig 1.2 and 1.3).Sediment samples from stations NIWE1,NIWE2,NIWE3,NIWE13, and NIWE 31 could not be collected due to hard substratum. All samples were preserved in 10% formalin mixed with Rose-Bengal seawater solution and stored in polythene bags. In the laboratory, all samples were sieved thoroughly 0.3 mm to remove bigger sized fauna (macrofauna) and then 0.04 mm sized mesh sieve for smaller fauna (meiofauna). The fauna retained on 0.04 mm mesh were considered as meiofauna, which was collected in a beaker and preserved in 5% buffered formalin. The fauna was enumerated and identified up to the group level under the stereo-zoom microscope (Olympus) using the guide Introduction to study of meiofauna (Higgins et al., 1988).

Results and discussion

The large variations of meiofaunal abundance were recorded from 40 subtidal stations (Fig3.13.1). A total of nine meiofaunal taxa were found.Nematoda was the most abundant group, followed by Turbellaria, Harpacticoida, Calanoida, Amphipoda, Nauplii, Ostracoda, and Oligochaeta (Table 3.13.1). The highest meiofaunal abundance (11 ind/10cm^2) were recorded at station NIWE20 and lowest (0ind/10cm^2) at station NIWE 1, NIWE 3, NIWE 6, NIWE 29, NIWE 31, NIWE 34, NIWE 40 and NIWE 42 (Table 3.13.1). The percent composition of meiofaunal abundance showed that Nematoda (79%) was dominant among all other meiofaunal groups followed by Turbellaria (9%), Harpacticoida (5%), Calanoida (4%) and Others (3%) with less in abundance respectively (Fig. 3.13.2).

Table 3.13.1: Total meiofaunal abundance (ind/10 cm^2) from the subtidal areas off Pipavav																				
Taxa	NIWE																			
Station	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Nematoda	0	1	0	2	6	0	1	0	1	2	1	2	4	1	1	10	1	4	1	6
Calanoida	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Harpacticoida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Nauplii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligocheta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turbellaria	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	3
Total	**0**	**1**	**0**	**2**	**7**	**0**	**3**	**1**	**1**	**3**	**1**	**2**	**4**	**1**	**1**	**11**	**1**	**4**	**1**	**11**

Table 3.13.1: Total meiofaunal abundance (ind/10 cm^2) from the subtidal areas off Pipavav

Taxa	NIWE																				
Station	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**Total**	**Percentage**
Nematoda	3	3	1	7	3	0	1	0	1	1	0	2	3	5	1	1	0	0	0	1	76	79
Calanoida	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	4	4
Harpacticoida	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	5	5
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Nauplii	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Ostracoda	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Oligocheta	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Turbellaria	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	9	9
Total	**3**	**3**	**1**	**7**	**4**	**0**	**3**	**0**	**1**	**1**	**0**	**2**	**4**	**7**	**3**	**1**	**0**	**3**	**0**	**3**	**96**	**100**

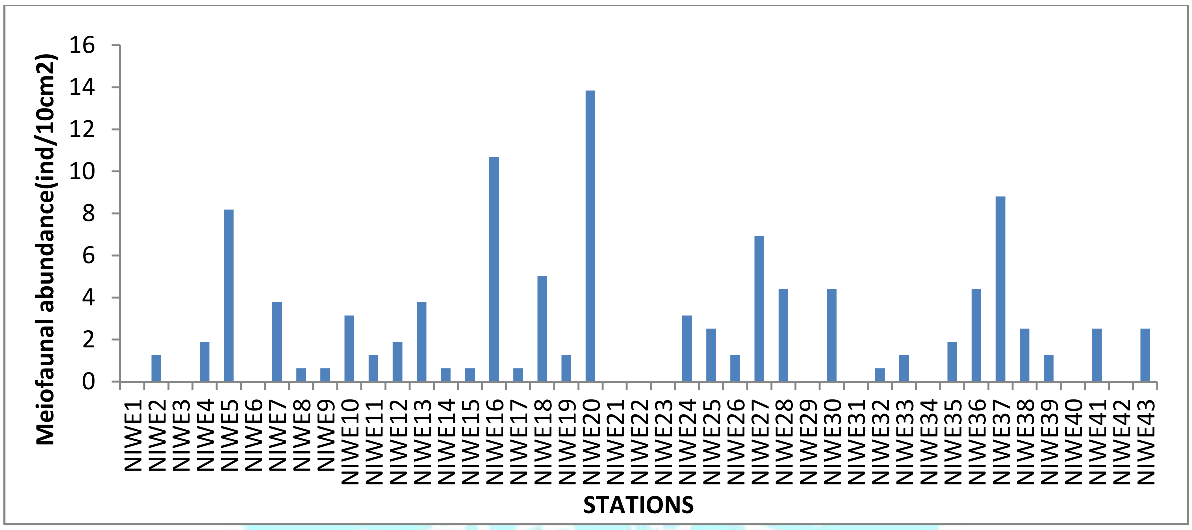


Figure 3.13.1. Station-wise meiofaunal abundance (ind/10 cm^2) Omef Pipavav.

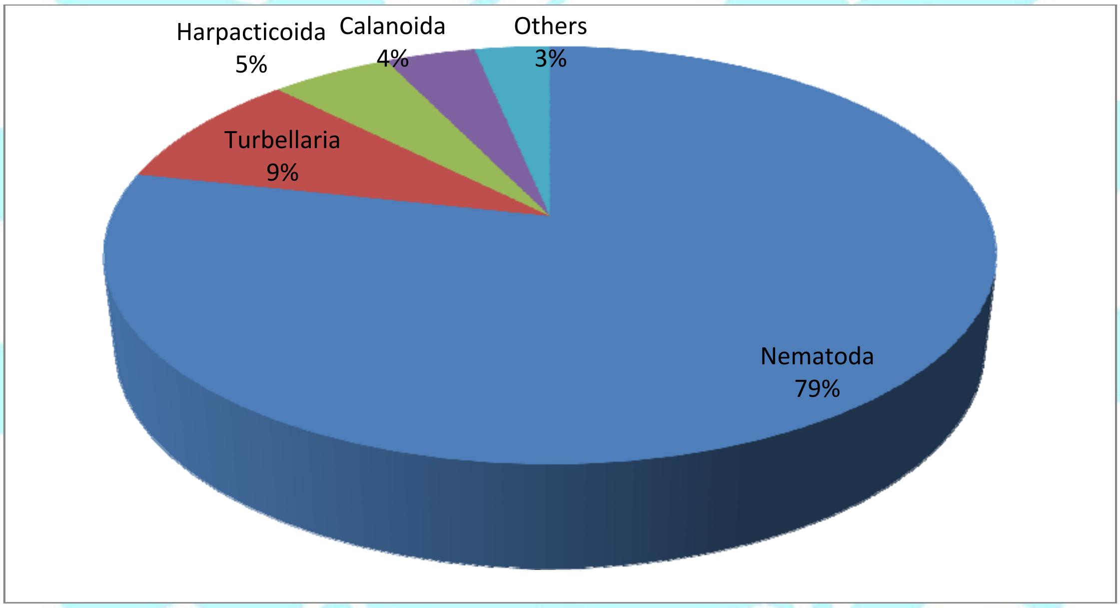


Figure 3.13.2. Percent composition of total meiofaunal abundance Of Pipavav.

Conclusion:

The station Gulf of Khambhat meiofaunal composition revealed that the Nematoda (79%) was the most dominant group followed by Turbellaria (9%), Harpacticoida (5%), Calanoida (4%) and other taxa (3%). The abundance of meiofauna was maximum at station NIWE20 (11 ind/10 cm^2) and the minimum at stationNIWE1, NIWE3, NIWE6, NIWE29, NIWE31, NIWE34, NIWE40, NIWE42 (0 ind/10cm^2).

Shallow Subtidal:

A total of 2 locations in three depths were sampled in the subtidal area, giving a total six sampling stations. Only fauna belonging to Nematoda, Harpactecoida, and Nemertea were found in the sampling stations (Table 3.13.2; Fig.3.13.3). PS 2 at depth 2m had the highest number of organisms (7 ind/10cm^2), and the least was found in PS2 at 10m depth (Fig. 3.13.4). Stations PS1 at 2m and PS1 at 5m had no organisms. Nematodes were the most dominant organisms, with 89% of the total population, while Nemertea was the least, with 4% of the total population (Fig. 3.13.3).

Table 3.13.2: Total meiofaunal abundance (ind/10 cm^2) from the shallow subtidal region.

TAXA	PS1 2m	PS 2 2m	PS 1 5m	PS 2 5m	PS 1 10m	PS 2 10m	TOTAL	AVERAGE	PERCENTAGE
Nematoda	0	6.3	0	1.9	5.7	1.9	15.7	2.6	89
Harpactecoida	0	0.6	0.0	0.6	0.0	0.0	1.3	0.2	7
Nemertea	0	0.0	0.0	0.0	0.6	0.0	0.6	0.1	4
TOTAL	**0**	**7**	**0**	**3**	**6**	**2**	**18**		**100**

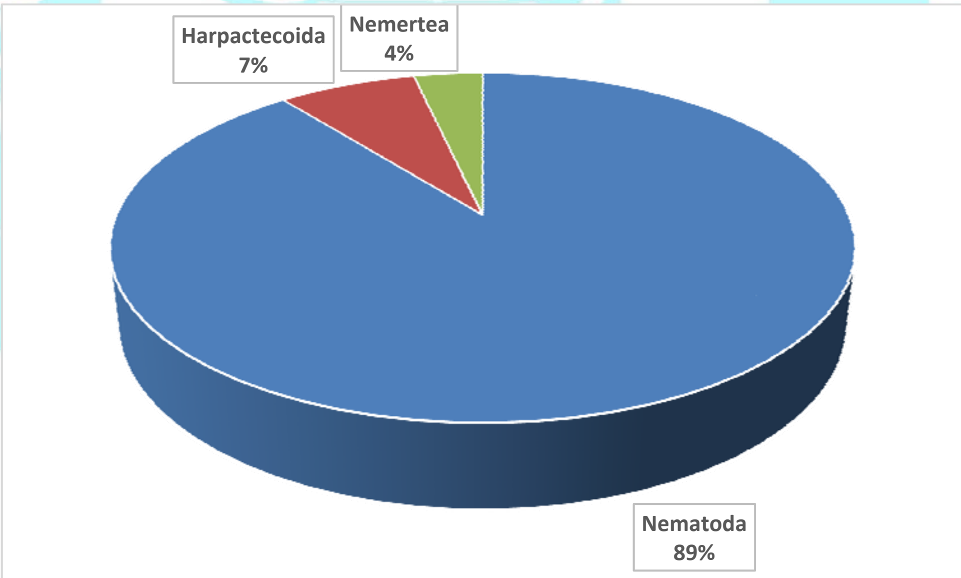


Figure 3.13.3: Percent composition of the total meiofaunal abundance of the shallow sub-tidal region.

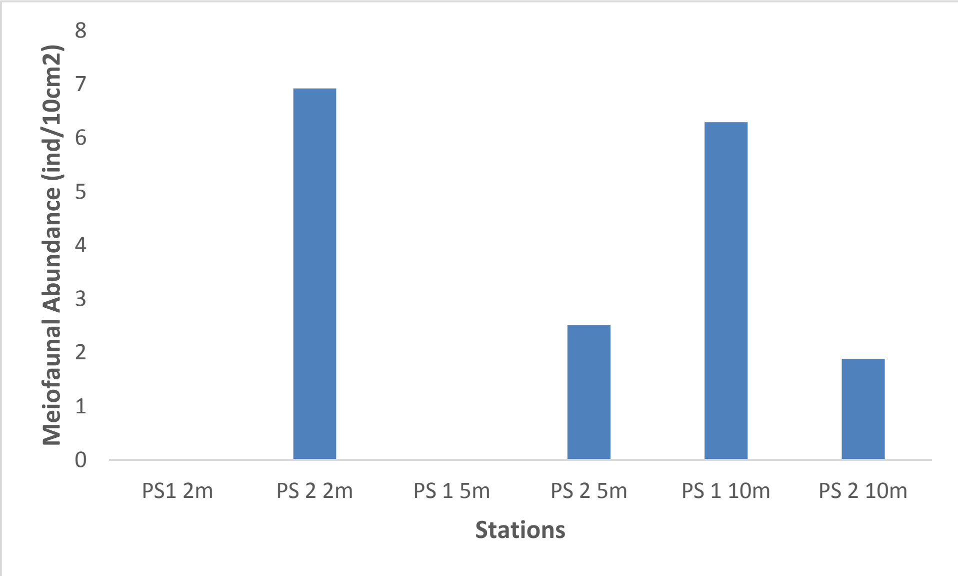


Figure 3.13.4: Station-wise meiofaunal abundance (ind/10 cm^2) of the shallow subtidal region.

Intertidal:

There were a total of 9 stations belonging to high tide, mid-tide, and low tide of three transects. Organisms belonging to 6 groups were found in the study area, which includes, Nematoda, Polychaeta, Harpactecoida, Nemertea, Oligochaeta, and Nauplii, of which Nauplii was the least (0.2% of the total population). Nematoda was the most dominant (70% of the total population) (Table 3.13.3). Mid tidal region of San3 had the most number of organisms (123 ind/10cm^2). In comparison, the high tidal region of San3 had the least number of organisms (12 ind/10cm^2).

Table 3.13.3: Total meiofaunal abundance (ind/10 cm^2) from the Intertidal region

	San 1			San 2			San 3			TOTAL	PERCENTAGE
TAXA	HT	MT	LT	HT	MT	LT	HT	MT	LT		
Nematoda	12	33	43	11	20	25	3	118	24	288	70
Polychaeta	6	0	0	6	1	0	1	0	0	13	3
Harpacticoida	13	9	3	1	5	3	3	3	2	41	10
Nemertea	0	1	2	0	0	3	0	1	4	12	3
Oligochaeta	14	1	1	31	0	0	6	1	6	60	14
Nauplii	0	0	1	0	0	0	0	0	0	1	0.2
TOTAL	**45**	**43**	**50**	**49**	**26**	**30**	**12**	**123**	**37**	**414**	**100**

High tide stations: San2 of the high tide had the highest abundance (49 ind/10cm^2) and the San3 had the least (12 ind/10cm^2). Oligochaeta contributed to the highest density (48% of the total population) and Polychaeta was the least with just 11% (Fig. 3.13.6).

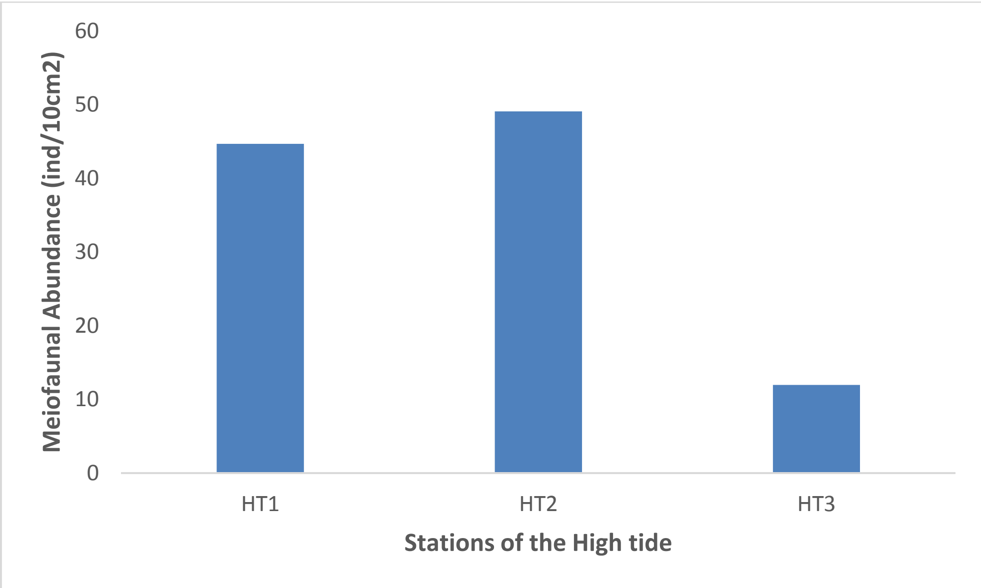


Figure 3.13.5: Station-wise meiofaunal abundance (ind/10 cm^2) of the shallow subtidal region.

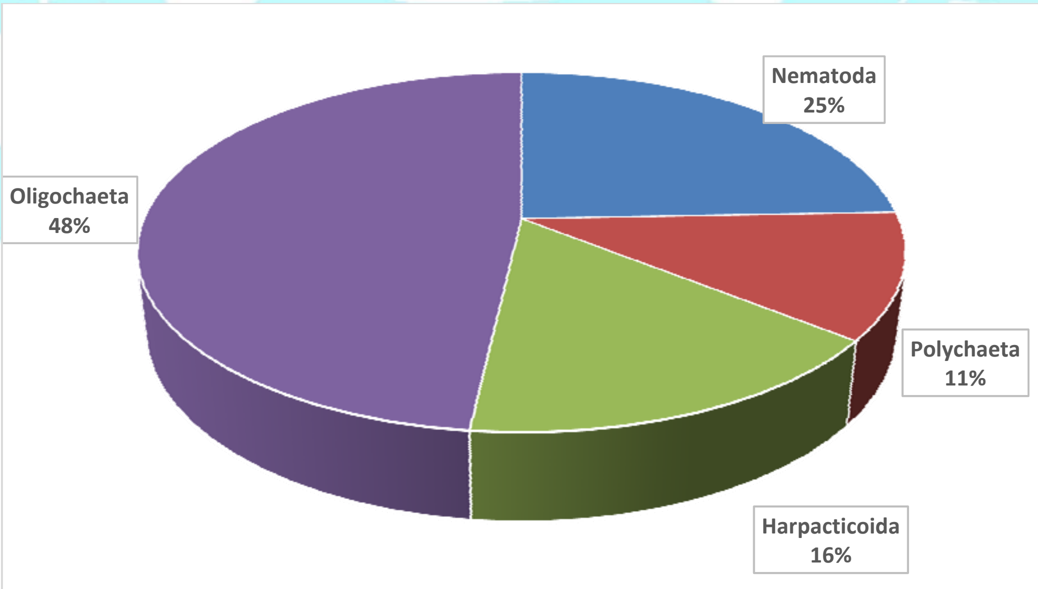


Figure 3.13.6: Percent composition of the totalmeiofaunal abundance of the intertidal region.

Mid-tide stations: San3 -had the most meiofaunal abundance, and San2 had the least (123 ind/10cm^2 and 26 ind/10cm^2 respectively) (Fig. 3.13.7). The group Nematoda was the most dominant contributing to 89% of the total population, followed by Harpactecoida with 8%. The least dominant was Nemertea, Oligochaeta, and Polychaeta, with each contributing to 1% of the total population (Fig. 3.13.8).

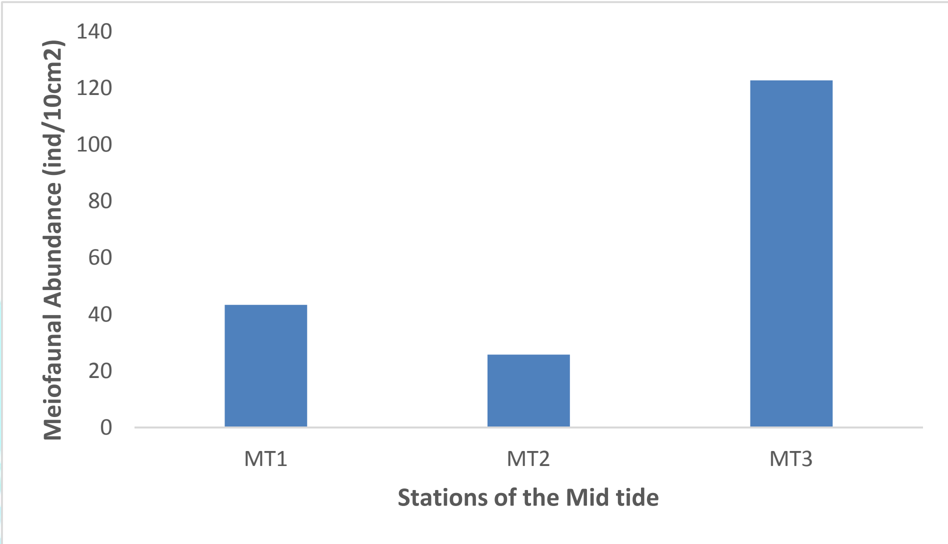


Figure 3.13.7: Station-wise meiofaunal abundance (ind/10 cm^2) of the shallow subtidal region.

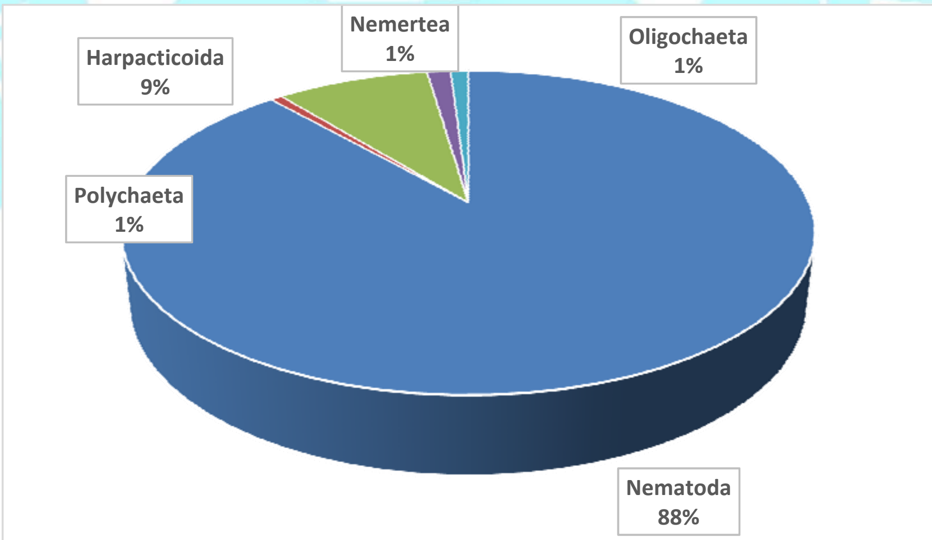


Figure 3.13.8: Percent composition of the total meiofaunal abundance of the intertidal region.

Low Tide stations: San1 of the low tide had the maximum meiofaunal abundance, and San2 had the least (50 ind/10cm^{2}and 30 ind/10cm^2 respectively) (Fig. 3.13.9). Group Nematoda lead the rest in dominance contributing to 79% of the total meiofaunal population, followed by Nemertea with 8%. Both Oligichaeta and Harpactecoida contributed to 6% each of the total population and the remaining 1% was contributed by Nauplii (Fig. 3.13.10).

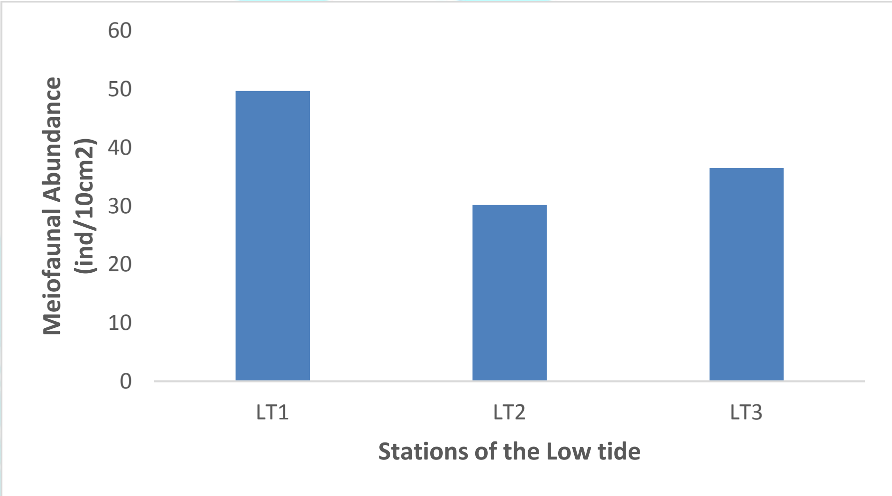


Figure 3.13.9: Station-wise meiofaunal abundance (ind/10 cm^2) of the shallow subtidal region.

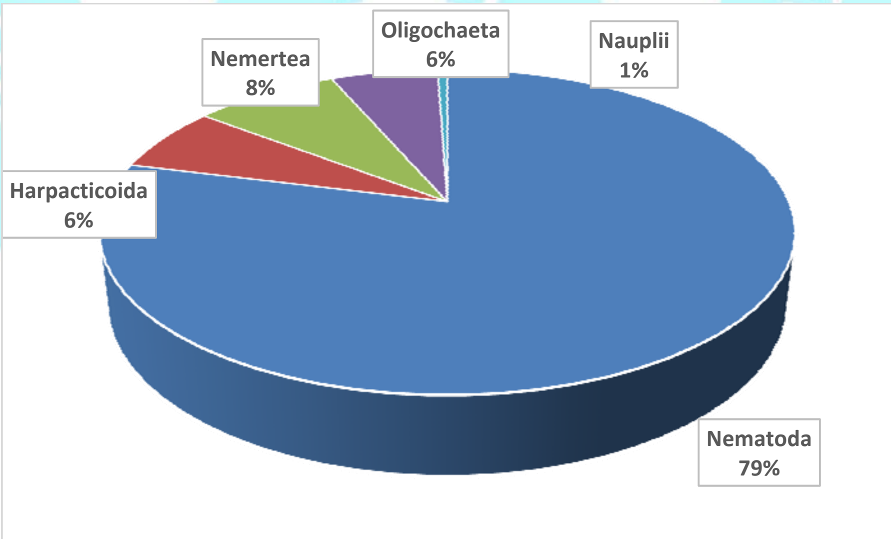


Figure 3.13.10: Percent composition of the total meiofaunal abundance of the intertidal region

3.14 Macrofauna:

Benthic macrofauna are the aquatic animals that live in the seabed in association with sediment. The taxa retain on 0.5mm mesh includes polychaetes, crustaceans, molluscs, gastropods, echinoderms, and many others belong to different minor phyla. Macrobenthos are the food source for many benthic/demersal feeders. Burrowing macrofauna plays a significant role in the ecosystem processes such as bioturbation, nutrient cycling, pollutant metabolism, dispersion, and burial of organic matter. They are also considered to be excellent indicators of the local water quality due to their limited mobility and sensitive nature towards any type of stressed pollution. Hence some of the taxa act as a bio-indicator of the environmental health.

Methodology:

Field sampling:

A total of 40 subtidal stations (from 23rdto 26th May 2019) and 17 coastal shallow locations(from 4th to 8th May 2019 and 27th to 28th May 2019) were sampled for the benthic study.The subtidal sediment samples were generally clayey mixed with silt and sand . In contrast,intertidal sediment were found to be sandy in nature. Details of the sampling locations are provided in (Fig 1.2 and 1.3). Sampling for subtidal was carried out onboard *RV Sindhu Sadhana* in May 2019 using a Van Veen grab, and for intertidal, a Quadrant was used. All the sediment samples were washed separately through a 300µm nylon mesh by using seawater and then transferred to polythene bags and preserved in 10% formaldehyde containing Rose Bengal stain.

Laboratory analysis:

In the laboratory, all the sediment samples were again washed on a 300µm sieve. All the fauna were sorted and preserved in plastic vials containing 5% formaldehyde. The fauna was enumerated and identified up to the group level under the stereomicroscope (Olympus SZX10). Faunal abundance was calculated as individual NO/m^2. The abundance of other fauna such as Oligochaeta, Crustacea, Bivalvia, Echinodermata, Platyhelminth, Nemertea, Sipuncula, and Nematoda were recorded group-wise. Biomass (wet weight) was taken group-wise and expressed as g/m^2.

Result:
A total of 20 taxa belonging to four major and two minor phyla were identified from all the samples. Among all the groups, Crustacea was the most dominant with seven taxa. The dominant groups or order among Crustacea is the Copepoda, where Calanoida (547ind/m^2) and Cyclopoda (80 ind/m^2) were dominant, and crustacean larvae (57ind/m^2) were the second abundant. The second dominant group was the Polychaeta with nine taxa, where the abundance was very less in all the stations. In Polychaeta, *Glycera*sp. (8ind/m^2) was abundant, followed by *Prionospio* sp. (6ind/m^2). Other Crustacea were also found, like Amphipoda (17ind/m^2) and Isopoda (10ind/m^2). Bivalvia, Nemertea, Nematoda, and Chaetognatha were randomly found in all the stations with less in abundance (Table 3.14.1).The minimum macrofaunal abundance of 1ind/m^2 was at station 24, 32, and 35, and a maximum of 108ind/m^2 was at station 37(Table 3.14.1). The macrofaunal abundance was very low in all the stations. In station 8, 9, and 37, the abundance was high due to the increased number of copepods,, and the remaining station showed less faunal abundance (Figure 3.14.1).

The macrofaunal biomass (Wet weight) ranged from 0.00003g/m^2 to 0.23379g/m^2 with the lowest valves at station 12, 15, and 18 and highest at station 17, respectively. The valves plotted in Figureshowed there is a very high variation in the distribution of biomass. An increase in biomass at station 17 contributed by polychaetes, especially *Glycera* sp. due to their larger size (Figure 3.14.2).

The macrofaunal composition showed that the Crustacea was the most dominant group, which contributed among 94%, followed by polychaetes 2% and others (Bivalvia, Nemertea, Nematoda, and Chaetognatha) 2% respectively (Figure 3.14.3).

Shallow Subtidal Macrofauna:
Macrofaunal abundance:
A total of 13 taxa belonging to four major phyla and onr minor phylum were identified among both the stations (PS 1 and PS 2). The sediment sample was collected depth-wise (2, 5, and 10m). Among all the taxa, Crustacea was the dominant group, followed by Polychaeta and Chaetognatha. Among Crustacea, Cyclopoida Copepoda (11756ind/m^2) was dominant, followed by Calanoida (8602ind/m^2) and Amphipoda (7455ind/m^2) and in Polychaeta, threefamilies dominated in which

Spionidae (3727ind/m^2) was the most abundant. Bivalvia, Chaetognatha, and Fish larvae were also reported but with less in abundance (Table 3.14.2). In PS 1 station, the macrofaunal abundance was high at 10m (10895ind/m^2) depth followed 2m (4588ind/m^2) and low in 5 depths (2007ind/m^2). Furthermore, in PS 2 area, the abundance was high at 10m (16056ind/m^2) and low in 5m (573ind/m^2) depth (Table 3.14.2). Compared to both the stations, PS 2 area showed high in abundance as compared to PS 1, and the faunal abundance was high at 10m depth as compared to PS 1 (Figure 3.14.4).The macrofaunal biomass ranged from 0.2652g/m^2 to 0.2867 g/m^2 with lowest at station PS 2 (10m) and highest in PS 1 (10m). High biomass was observed due to the presence of amphipods, polychaetes, and chaetognaths (Figure 3.14.5).The faunal composition showed that Crustacea was the dominant group with 75% of composition from both the stations followed by Polychaeta 11%, Chaetognatha 9%, Fish larvae 4%, and Bivalvia 1% respectively (Figure 3.14.6).

Intertidal Macrofauna:

Intertidal sampling was carried out with three transects {high tide (HT), mid-tide (MT), and low tide (LT)} along the coast. A total of 18 taxa belonging to four major phyla and three minor phyla were identified from the threetransects. Among the taxa, Nematoda was the most dominant group, followed by Oligochaeta and Nemertea. Nematoda showed an abundance of 11024ind/m^{2}followed by Oligochaeta (320ind/m^2) and Nemertea (304ind/m^2),, whereas among Polychaeta, Nereidae family showed an abundance of 128ind/m^2 and Isopoda showed the abundance of 256ind/m^2. I It is also observed that the faunal abundance was high in San1 at low-tide level (Table 3.14.3).A high macrofaunal abundance of (5344ind/m^2) was observed at station San3 at the mid-tide level and low at station San2 high tide level. In San3 station, the abundance was high due to the presence of Nematoda in mid-tide,and low tide level, and the abundance was randomly found in all the three transects (Figure 3.14.7).High biomass was recorded at station San1LT with (0.7392g/m^2) and low at station San1MT, San2HT, and San3LT, respectively. Biomass did not show variation in all the three transects. It varied from tide wise. The faunal abundance goes on decreasing at station San2 to Sab3 (Figure 3.13.8).The macrofaunal composition showed that the Nematoda dominated among all the groups, with 86% followed by Crustacea 6% and others like Oligochaeta 3%, Polychaeta 2%, Nemertea 25 and Others 1% respectively (Figure 3.14.9).

Table 3.14.1: Macrofaunal abundance (Ind/m^2) from the subtidal sampling stations																				
Taxa	NIWE 1	NIWE 2	NIWE 3	NIWE 4	NIWE 5	NIWE 6	NIWE 7	NIWE 8	NIWE 9	NIWE 10	NIWE 11	NIWE 12	NIWE 13	NIWE 14	NIWE 15	NIWE 16	NIWE 17	NIWE 18	NIWE 19	NIWE 20
Cossura sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diopatra sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dipolydora sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Eunicidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magelona sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
*Glycera*sp.	0	0	0	0	0	0	3	0	3	0	0	1	0	0	0	0	0	0	0	0
Onuphis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prionospio sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Sternaspis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1	1	0
Isopoda	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0
Cumacea	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Calanoida copepod	0	0	0	6	3	22	19	82	60	44	7	1	0	33	3	0	0	4	10	15
Cyclopoida copepod	0	0	0	0	0	3	1	10	30	0	0	0	0	0	0	0	0	0	0	0
Crustacean larvae	0	0	0	0	0	1	3	8	1	0	1	0	0	0	0	0	0	6	1	6
Lucifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Bivalvia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertea	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Chaetognatha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	0
Total	**0**	**0**	**0**	**7**	**3**	**26**	**29**	**100**	**96**	**46**	**10**	**4**	**0**	**33**	**3**	**4**	**7**	**15**	**14**	**22**

Continued to next page…

Taxa	NIWE 24	NIWE 25	NIWE 26	NIWE 27	NIWE 28	NIWE 29	NIWE 30	NIWE 31	NIWE 32	NIWE 33	NIWE 34	NIWE 35	NIWE 36	NIWE 37	NIWE 38	NIWE 39	NIWE 40	NIWE 41	NIWE 42	NIWE 43	Total	%
Cossura sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.2
Diopatra sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.2
*Dipolydora*sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.5
Eunicidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.2
*Magelona*sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.2
*Glycera*sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1.1
Onuphis sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.2
Prionospio sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	6	0.7
Sternaspis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0.2
Amphipoda	0	0	0	0	4	0	1	0	1	0	0	0	0	3	0	0	0	0	0	0	17	2.2
Isopoda	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	1	0	0	0	0	10	1.3
Cumacea	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.5
Calanoid copepod	0	17	14	3	7	28	4	0	0	11	19	1	1	76	4	6	1	14	19	12	547	71.9
Cyclopoid copepod	0	0	4	0	3	3	0	0	0	3	0	0	0	10	0	0	0	7	7	0	80	10.6
Crustacean larvae	0	1	0	0	1	0	0	0	0	0	0	0	0	18	0	0	0	0	6	3	57	7.5
Lucifer sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0.4
Bivalvia	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0.5
Nemertea	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.4
Chaetognatha	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.2
Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	8	1.1
Total	**1**	**19**	**21**	**10**	**17**	**32**	**6**	**0**	**1**	**15**	**22**	**1**	**3**	**108**	**4**	**7**	**7**	**21**	**32**	**15**	**760**	**100.0**

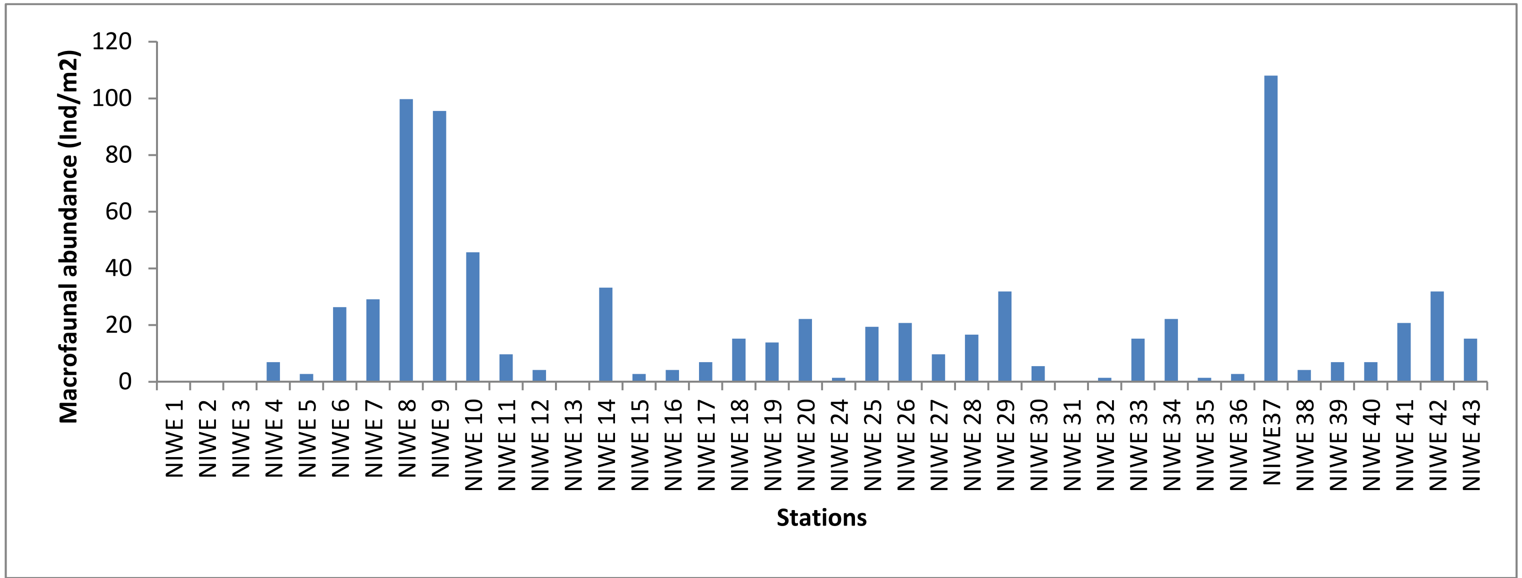


Figure 3.14.1: Graph showing macrofaunalabundance (Ind/m^2) from the subtidal sampling stations

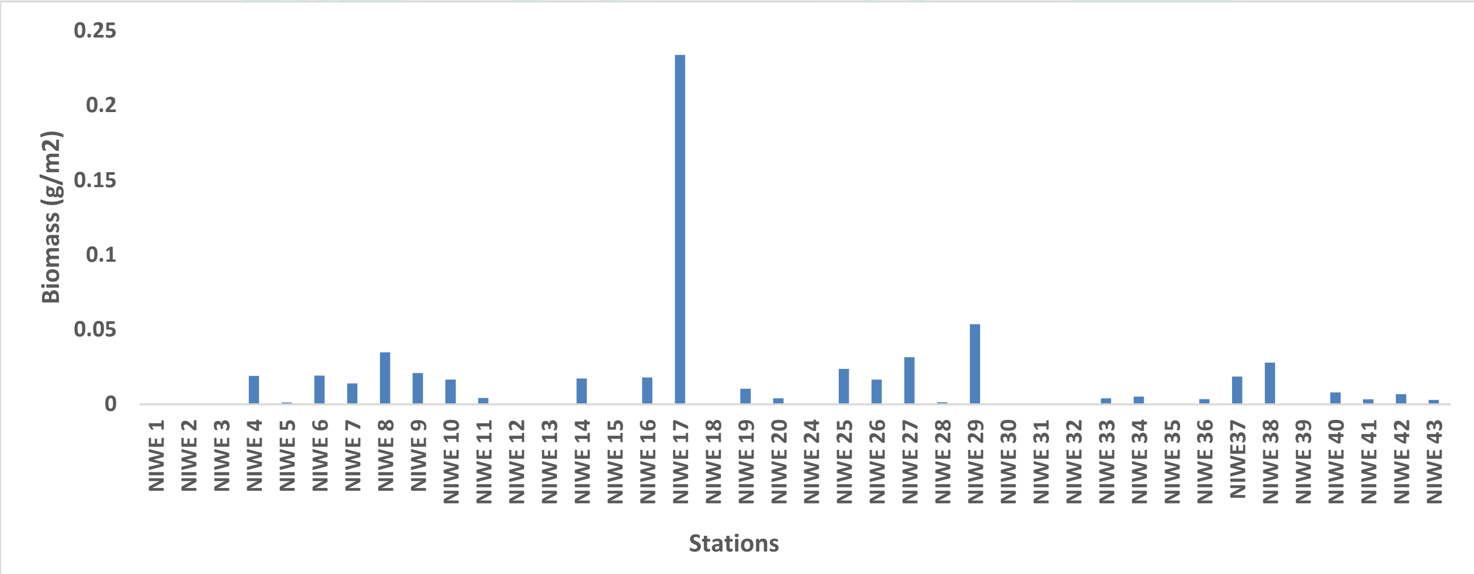


Figure 3.14.2: Graph showing macrofaunal biomass (g/m^2) from the subtidal sampling stations.

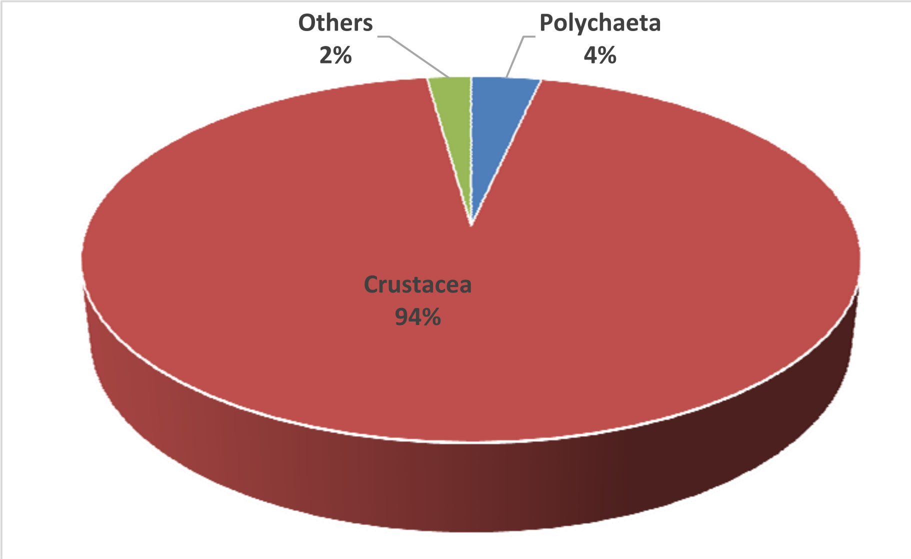


Figure 3.14.3: Percent composition (%) of macrofaunal abundance from the subtidal sampling stations

Table 3.14.2: Macrofaunal abundance (Ind/m^2) from subtidal (PS) sampling stations.

Taxa	PS 1			PS 2			Total	%
	2m	5m	10m	2m	5m	10m		
Spionidae	287	1147	573	0	0	1720	3727	9
Sternaspidae	287	0	0	0	0	0	287	1
Lumbrineridae	0	287	0	0	0	0	287	1
Amphipoda	0	0	3441	0	0	4014	7455	19
Cyclopoida	0	287	1720	1720	573	7455	11756	29
Calanoida	2867	0	2867	2867	0	0	8602	22
Mysis larvae	0	0	0	0	0	573	573	1
Zoea larvae	0	287	0	0	0	0	287	1
Cumacea	287	0	0	0	0	573	860	2
Pycnogonida	0	0	0	573	0	0	573	1
Bivalvia	0	0	573	0	0	0	573	1
Chaetognatha	573	0	1147	573	0	1147	3441	9
Fish larvae	287	0	573	0	0	573	1434	4
Total	**4588**	**2007**	**10895**	**5734**	**573**	**16056**	**39854**	**100**

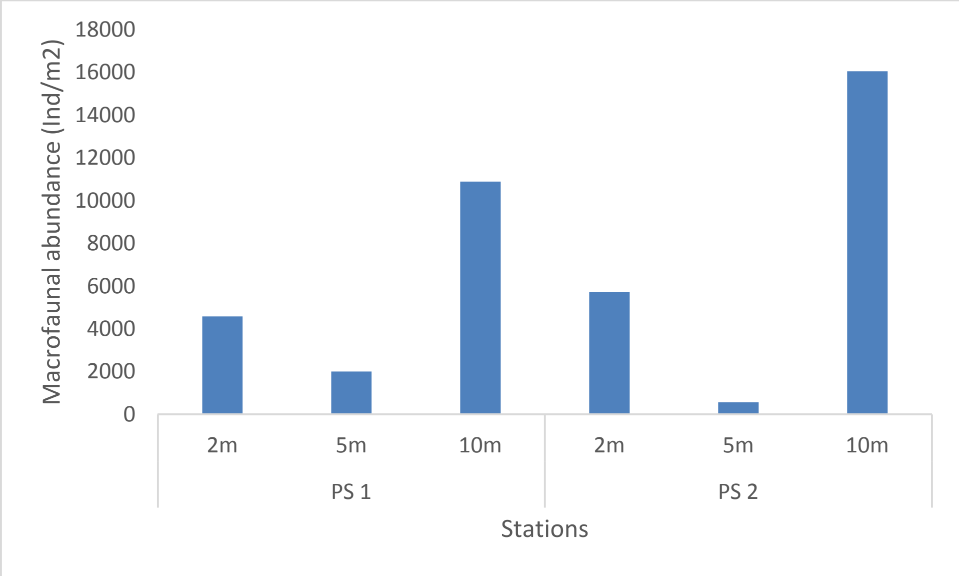


Figure 3.14.4: Graph showing depth- wise macrofaunalabundance (Ind/m^2) from the subtidal (PS) sampling stations

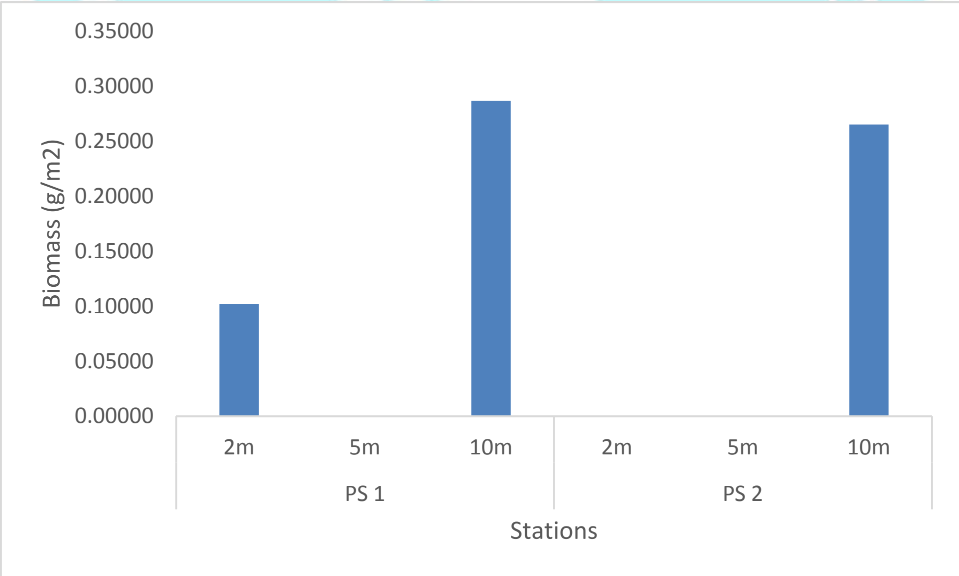


Figure 3.14.5: Graph showing macrofaunal biomass (g/m^2) from the subtidal (PS) sampling stations

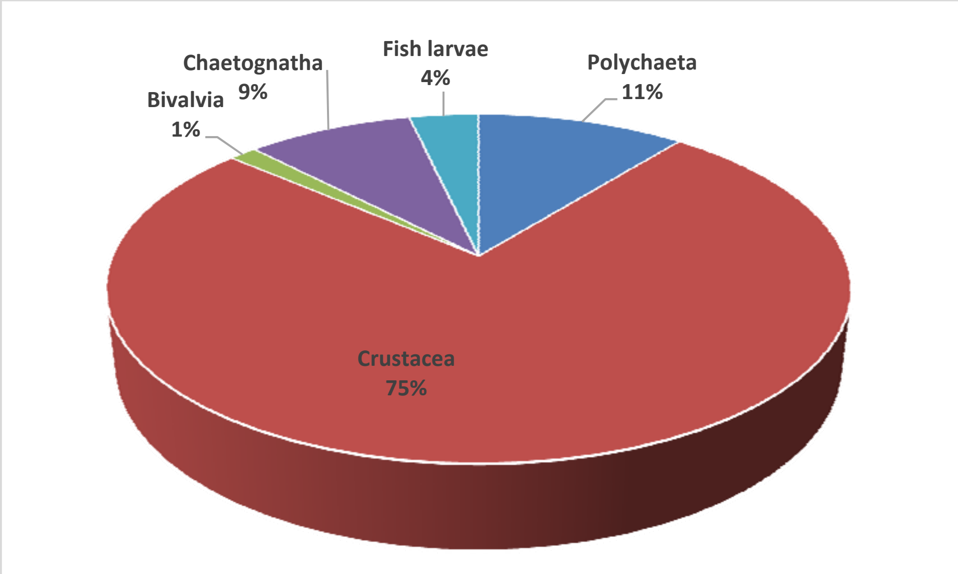


Figure 3.14.6: Percent composition (%) of macrofaunal abundance from the subtidal (PS) sampling stations.

Table3.14.3: Macroafuanal abundance (Ind/m^2) from intertidal sampling stations.

TAXA	San 1			San 2			San 3			TOTAL	%
	HT	MT	LT	HT	MT	LT	HT	MT	LT		
Nereidae	0	16	48	0	16	48	0	0	0	128	1.0
Onuphidae	0	0	32	0	0	0	0	0	0	32	0.3
Capitellidae	0	0	64	0	0	0	0	0	32	96	0.8
Amphipoda	0	0	16	0	0	0	0	32	16	64	0.5
Calanoida	0	0	64	16	0	0	0	48	0	128	1.0
Cyclopoida	0	16	64	0	32	0	0	0	0	112	0.9
Harpacticoida	0	0	16	0	16	64	0	0	0	96	0.8
Isopoda	16	16	64	0	0	48	0	96	16	256	2.0
Lucifer	0	0	16	0	0	0	0	0	0	16	0.1
Halacarida	0	0	0	0	0	0	0	16	0	16	0.1
Crustacea larvae	0	0	48	0	0	0	0	0	0	48	0.4
Unknown crustacea	0	0	16	0	0	0	0	0	0	16	0.1
Bivalvia	0	0	0	0	0	16	0	0	0	16	0.1
Gastropoda	0	0	48	0	0	0	0	0	0	48	0.4
Nematoda	112	112	64	16	496	16	0	5136	5072	11024	86.4
Nemertea	48	0	32	80	112	0	0	16	16	304	2.4
Oligochaeta	320	0	0	0	0	0	0	0	0	320	2.5
Turbellaria	0	0	0	0	32	0	0	0	0	32	0.3
Total	**496**	**160**	**592**	**112**	**704**	**192**	**0**	**5344**	**5152**	**12752**	**100.0**

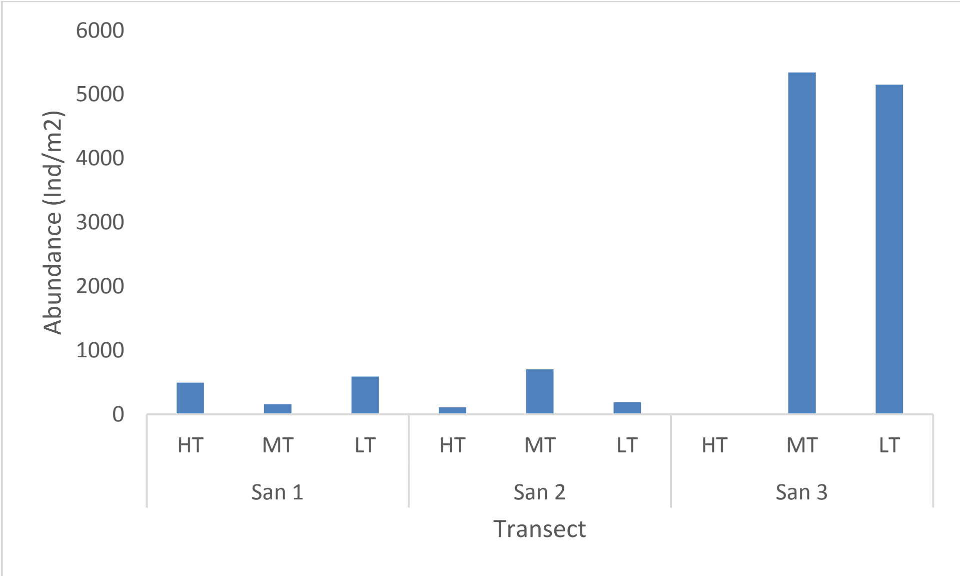


Figure 3.14.7: Graph showing transect- wise macrofaunal abundance (Ind/m^2) from the intertidal sampling stations.

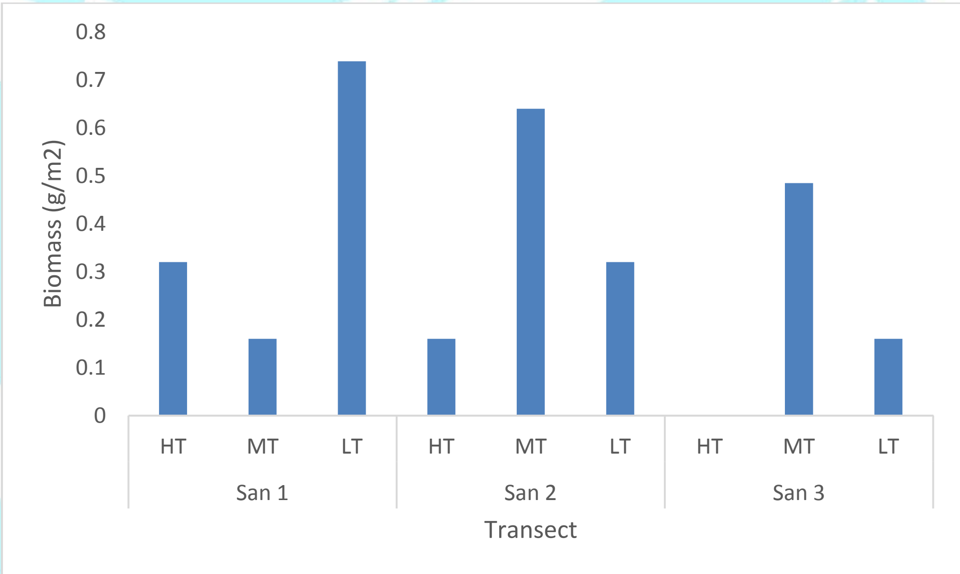


Figure 3.14.8: Graph showing macrofaunal biomass (g/m^2) from the intertidal sampling stations.

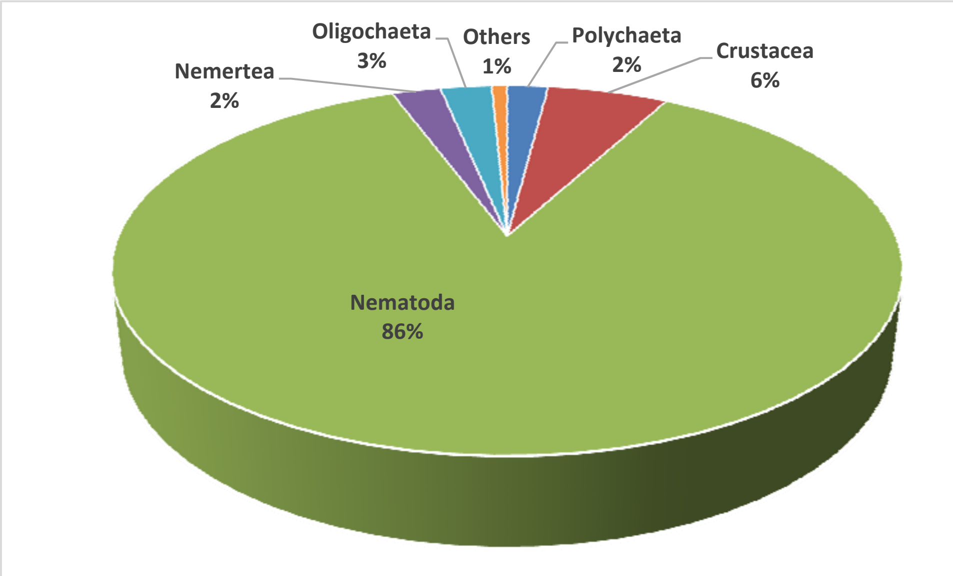


Figure 3.14.9: Percent composition (%) of macrofaunal abundance from the intertidal sampling stations.

Mega benthic fauna of rocky shores:

A rocky shore is an intertidal area of seacoasts where solid rock predominates; these are biologically rich environment and are useful natural laboratory. Vertical zonation applies to all rocky intertidal communities. Zonation is primarily based on sessile species, like algae, barnacles, and mussels. However, some mobile animals also tend to be zoned but with less sharp demarcation.

On rocky shores, the supralittoral zone is inhabited by encrusting black lichens (which are combinations of algae and fungi) and blue-green algae, certain species of *Littorina* (periwinkles) that graze on the vegetation, and relatively large (3-4 cm long) isopods (*Ligia*), primitive insects like *Machilis* may also be present.Just below the supralittoral zone, periwinkles are usually found in extraordinarily dense populations.Barnacles form in the lower littoral zone with thousand per m^2 in density. In many localities, mussels crowd together in dense aggregations below the barnacle zone. There is intense competition for the limited space among the attached algae and sessile animals.

Total two sampling sites were chosen for rocky intertidal study, namely Rck1 and Rck2 (Fig 1.3), where quadrants were put randomly. Various groups of animals were found as algae, gastropods, shrimps, isopods, and crabs. Stump size mangroves of *Avicennia officinalis* were also rarely recorded. 20-30 Turbo spp were recorded in an m^2 quadrate area, whereas 40-50 Cerethidaespp were found aggregated in the

$1m^2$area. Polychaete tubes were found to be sparsely distributed in the quadrate area also Ulva spp showed a similar type of pattern. Organisms encountered are depicted in Plate 3.14.1.

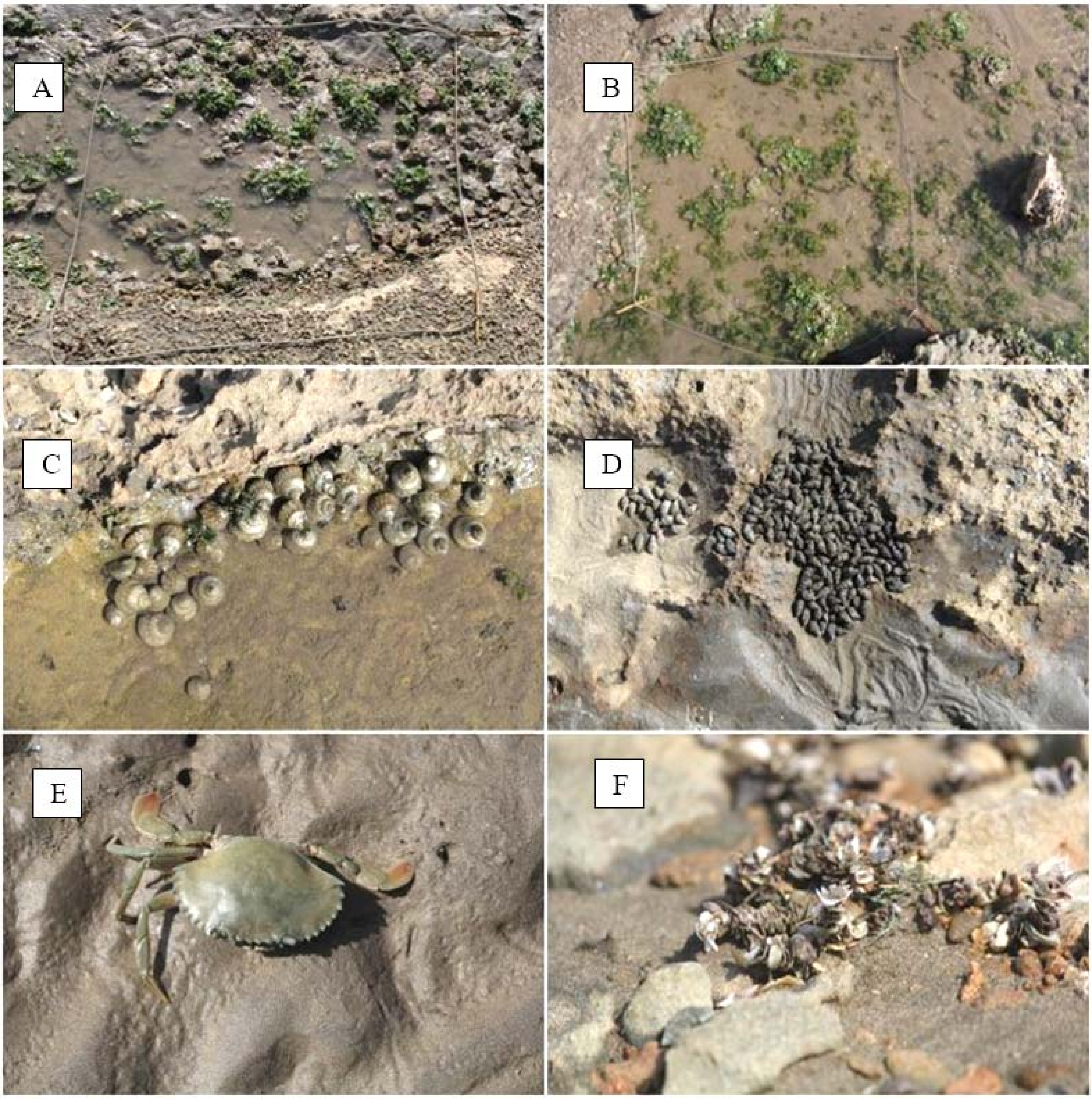


Plate 3.14.1: Depicted organisms encountered in rocky intertidal region. A: Quadrant laid, B: Quadrant aggregated with *Ulva* spp, C: Aggregation of *Trochus* spp, D: Aggregation of *Cerithidea* spp, E: *Scylla serrata* and F: Polychaete tubes.

3.15 Fisheries

Gujarat has the longest coastline in the country (1600 km,comprising of 19.71%). The contribution of marine fish catch from Saurashtra has always contributed to the significant share from the state of Gujarat. However, Saurashtra has around 53% coastline of the state, its contribution in terms of marine fish landings amounts to 90%. *Dol*nets are operated mainly in three regions in Gujarat, viz., Umbergaon to

Kavi (along the Southern Gujarat), Siyalbet to Diu (along the Saurashtra coast) and Takkara to Modhwa (in the Gulf of Kachchh region). Gujarat is accounted for contributing about 97% of the total landings of Bombay duck in India (Jhingran, 1982).

Consequently, *dol*net fishery has become synonymous with Bombay duck fishery. The report along Navabandar, Rajpara, and Jaffrabad coasts ofSaurashtra stated Bombay duck landing contributed of around 31.12% to total *dol* net landings (Ghosh *et al*., 2009). List of Economically important speciesof Dol net fishery is given in (Table 3.15.1).

Table 3.15.1: List of major Economically important species of Dol net fishery inhabiting the study area.

Sr no.	Common Name	Scientific Name
1	Bombay Duck	*Harpadon nehreus*
2	Spotted Seerfish	*Scomberomorus guttatus*
3	Ribbonfish	*Lapturecanthus savala*
4	Golden Anchovy	*Coilia dussumieri*
5	Big Eye Ilisha	*Ilisha megaloptera*
6	Talang Queerfish	*Scomberoides commesonnianus*
7	Bearded Crocker	*Johnius dussumieri*
8	Jew Fish	*Protonibea diacanthus*
9	Bronze Crocker	*Otolitles biauritus*
10	Indian Threadfin	*Polynemus indicus*
11	Silver Pomfret	*Pampus argenteus*
12	Catfish	*Arius dussumieri*
13	Shark	*Scoliodon laticaudus*
14	Ray Fish	*Dasyatis Zugei*
15	Squid	*Loligo durvaucrlli*
16	Kiddi Prawn	*Parapaeneopsis stylifera*
17	Indian Prawn	*Metapereus affinis*
18	Coastal mud Prawn	*Solenocora Crassicornis*
19	Indian White Prawn	*Fenneropenaeus* spp.

(Source: Sikotaria *et al*., 2018)

3.16 Marine Mammals

The coast of Pipavav has a wide variety of coastal and marine habitats supporting a massive amount of biodiversity. Total five species of marine mammals and a species of a reptile were found in the study area during the sampling period (Table 3.16.1.) According to the Wildlife Protection Act 1972 status, three marine mammal species are protected under schedule I (Part I) of the act.

Table 3.16.1: List of Marine Mammals reported from study area.

Sr. No	Common name	Scientific name	IUCN Status	WPA Status
1	Bottle Nosed Dolphin	*Tursiops truncalus*	Least Concern	Schedule I (Part I)
2	Indo-Pacific Humpback Dolphin	*Sousa chinensis*	Vulnerable	Schedule I (Part I)
3	Olive Ridley Sea Turtle	*Lepidochelys Olivacea*	Vulnerable	Schedule I
4	Hump Back Whale	*Megaptera noveaangilae*	Endangered	Not Evaluated
5	Beaked Whale	*Unidentified*	-	Not Evaluated
6	Whale Shark	*Rhincodon typus*	Endangered	Schedule I

3.17 Coastal Ecology and Biodiversity

Avifauna

The most significant ecological concern for operational wind farms is the collision of flying fauna with the rotating wind turbine blades. The proximity of an Important Bird and Biodiversity Areas (IBAs) is, therefore, a more prominent indicator of ecological sensitivity than Protected Areas. The proximity of the Project to IBAs has been presented in (Figure 3.17.1).However, the coastline and a few km inland along the Amreli and Bhavnagar coast have similar habitats consisting of mudflats, flooded areas, and scattered saltpans. The entireGulf of Khambhat western coast can, therefore, be considered potentially significant for migratory birds, and the likelihood of migratory bird congregations being found around the offshore turbine locations is high. It should also be noted that there are similar species found in Gir and Bhavnagar Saltpan IBAs, including the migratory Dalmatian Pelican (*Pelecanuscrispus*) that are likely moving between the IBAs during the course of the migratory season (October to March). Several migratory bird species were identified during the site visit, including Kentish Plover (*Charadriusalexandrinus*), Common Snipes (*Gallinagogallinago*), Black-tailed Godwits (Limosalimosa), Spotted Redshank (*Tringaerythropus*), Little Stint (*Calidrisminuta*) and Greater

Flamingo(*Phoenicopterus roseus*).A list of species from the study area is given in Table 3.17.1 with a description of a few notable species.

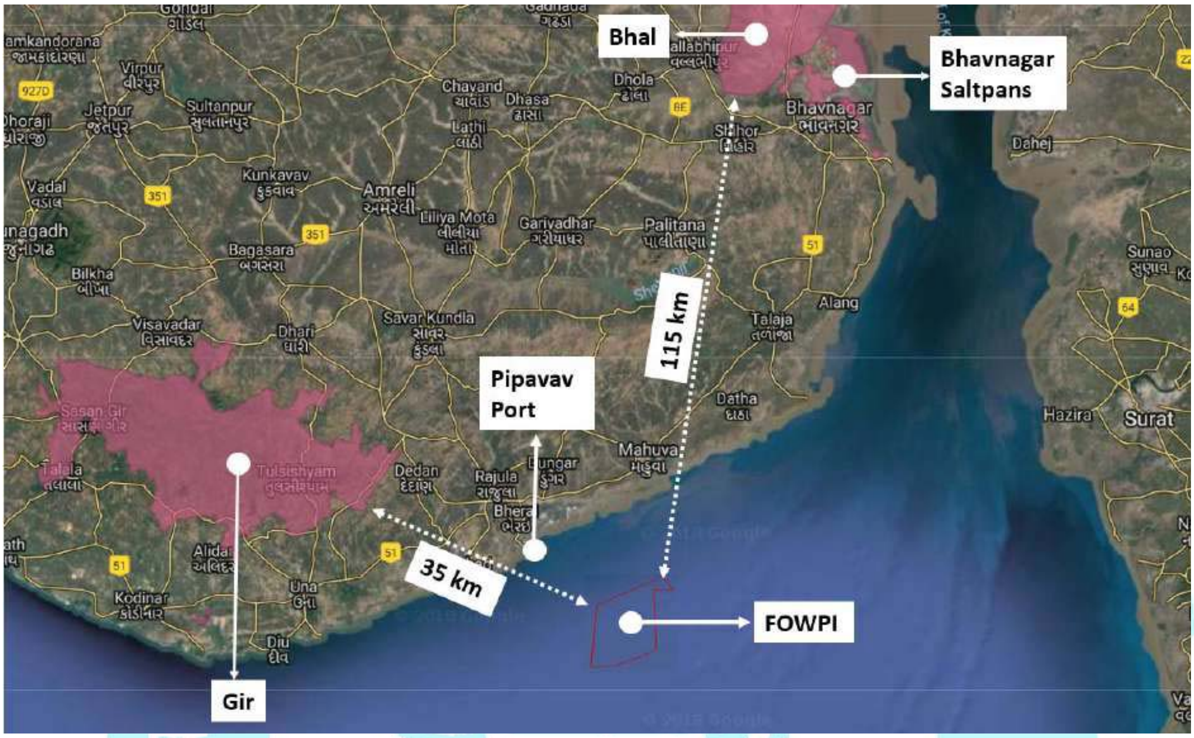


Figure 3.17.1: International Birding Area sites around the project site (Scoping report- ERM, 2019).

Table 3.17.1: List of birds that were observed in Landfall area (Sheyalbet and Pipavav port coast vicinity)

Sr.No	Common Name	Scientific Name	IUCN Status	WPA Status	Migration	Habitat
1	Black headed Ibis	*Threskiornis melanocephalus*	NT	Schedule IV	R	Terrestrial
2	Pied Kingfisher	*Ceryle rudis*	LC	Schedule IV	R	Terrestrial
3	Little Egret	*Egretta garzetta*	LC	Schedule IV	R	Coastal
4	Western reef Egret	*Egretta gularis*	LC	Schedule IV	R	Coastal
5	Black Drongo	*Dicrurus macrocercus*	LC	Schedule IV	R	Terrestrial
6	Red-wattled Lapwing	*Vanellus indicus*	LC	Schedule IV	R	Terrestrial
7	Baya weaver	*Ploceus philippinus*	LC	Schedule IV	R	Terrestrial
8	Common tailorbird	*Orthotomus sutorius*	LC	Schedule IV	R	Terrestrial
9	House Sparrow	*Passer domesticus*	LC	Schedule IV	R	Terrestrial
10	Rock Pigeon	*Columba livia*	LC	Schedule IV	R	Terrestrial
11	Grey Francolin	*Francolinus pondicerianus*	LC	Schedule IV	R	Terrestrial
12	Large grey babbler	*Argya malcolmi*	LC	Schedule IV	R	Terrestrial
13	Laughing dove	*Spilopelia senegalensis*	LC	Schedule IV	R	Terrestrial
14	Crested lark	*Galerida cristata*	LC	Schedule IV	R	Terrestrial
15	Red vented bulbul	*Pycnonotus cafer*	LC	Schedule IV	R	Terrestrial
16	Lesser whistling duck	*Dendrocygna javanica*	LC	Schedule IV	R	Coastal
17	Indian robin	*Copsychus fulicatus*	LC	Schedule IV	R	Terrestrial
18	Plain prinia	*Prinia inornata*	LC	Schedule IV	R	Terrestrial
19	Red naped Ibis	*Pseudibis papillosa*	LC	Schedule IV	R	Terrestrial

20	Little Grebe	*Tachybaptus ruficollis*	LC	Schedule IV	R	Terrrestrial
21	Indian spotbilled duck	*Anas poecilorhyncha*	LC	Schedule IV	R	Terrestrial
22	Common Pochard	*Aythya ferina*	VU	Schedule IV	R	Terrestrial
23	Common coot	*Fulica atra*	LC	Schedule IV	R	Terrestrial
24	Common Myna	*Acridotheres tristis*	LC	Schedule IV	R	Terrestrial
25	Brahminy starling	*Sturnia pagodarum*	LC	Schedule IV	R	Terrestrial
26	Lesser flamingo	*Phoenicoparrus minor*	NT	Schedule IV	W	Coastal
27	Great Thick-knee	*Esacus recurvirostris*	NT	Schedule IV	R	Coastal
28	Whimbrel	*Numenius phaeopus*	LC	Schedule IV	W	Coastal
29	Common Redshank	*Tringa totanus*	LC	Schedule IV	R	Coastal
30	Lesser sand plover	*Charadrius mongolus*	LC	Schedule IV	W	Coastal
31	Great Egret	*Ardea alba*	LC	Schedule IV	R	Coastal
32	Indian Pond heron	*Ardeola grayii*	LC	Schedule IV	R	Terrestrial

Plate 3.17.1: Depicting bird species encountered in study area

<u>Common Pochard</u> (*Aythya ferina*):
A medium-sized diving duck, where the male has a chestnut head, black breast and grey upperparts and flanks, female has brownish head and breast with brownish upperparts and flanks. They are winter visitors and often found in Lakes, rivers, marshes (Plate 3.17.1).

<u>Common Coot</u> (*Fulica atra*):
A member of the rail and crake family, It is Blackish with white bill and frontal shield. It is found in standing freshwater, open water and emergent vegetation.

<u>Brahminy Starling</u> (*Aythya farina)*:
It is a member of the starling family, which includes myna's as well. The adult has a black crest and rufous orange sides of head and under parts, it has a yellowish bill with blue base and blue and yellow skin behind the eye. It is found in dry well-wooded areas and thorn scrubs.

<u>Crested Lark</u> (*Galeridacristata*):

A small bird belonging to the lark family, it has an erect crest with broader rounded wings. It has rufous-buff outer tail feathers and upperwing. It is mostly found in Deserts, semi-desert, dry cultivation, and coastal mudflats.

Plate 3.17.2: Depicting bird species encountered in study area

Grey Francolin (*Galerida cristata*):
It belongs to the Phasianidae family, which also peacocks, partridges, and junglefowl. It is a medium-sized bird with plain buffish face and a buffish white throat with a fine necklace of dark spotting.It has finely barred upperparts and underparts and shows rufous tail in flight. It is mostly found in dry open grass plains and thorn scrubs, often near dry cultivation and stony semi-desert (Plate 3.17.2).

Great Thick-Knee (*Esacus recurvirostris*):
It is a large wader and is a resident in Gujarat and belongs to the stone curlew group. It has a large, slightly upturned black and yellow bill and tallow eye. Its most striking features are white forehead and spectacles contrasting with black ear-

coverts and blackish and whitish bands across wing coverts. It is found in stony banks of rivers and lakes and also in coastal wetlands. IUCN listed this bird as a Near Threatened species.

Lesser Whistling Duck (*Dendrocygna javanica*):
A species of whistling duck, it has a chestnut brown colour with chestnut upper-tail and coverts. It has a dark brown crown. It has a yellow or brown ring around the eye. Its voice is incessant wittering call in flight. While resting clear whistled whi-whee can be heard followed by subduing quacking. Its habitat is Paddyfields, flooded grasslands, freshwater marshes,ponds, and lakes and mostly prefers emergent vegetation and partly submerged trees.

Whimbrel (*Numenius phaeopus*):
It is a winter migrant wader belonging to the curlew genus. It has a shorter bill often with more marked downward kink. It has prominent whitish supercilium and crown stripe with contrasting with blackish eye stripe and sides to the crown, resulting in a more striking head pattern. It feeds mostly from the surface of open mud and also by probing. Its habitat is mainly estuaries, tidal creeks and mangroves.

Plate 3.17.3: Depicting bird species encountered in study area

Baya Weaver (Ploceus *philippinus*):
It is a weaver bird found all over the Indian subcontinent. The male in his breeding form has yellow crown, dark brown ear coverts and throat, unstreaked yellow breast and yellow streaking on mantle and scapulars. Non breeding male, females and juveniles usually have unstreaked buffish underparts, less distinct and buffish supercilium and lacks yellow neck patch. They are mostly found in areas with grassland and scrub with scattered trees (Plate 3.17.3).

Laughing Dove (*Spilopelia senegalensis*):
It is a small slim pigeon with fairly long tail, It has brownish-pink head and underparts. The upperparts are brownish with a bluish-grey band along with the wings. It has checkered neck margin around the neck and has red feets. It is mostly found in dry cultivation and scrub covered hills.

Lesser Sand Plover (*Charadrius mongolus*):
It is a small wader from the plover family of birds. It has long legs and long bill, it has dark greenish legs. The males have grey backs with white underparts. The breast, forehead and nape are of chestnut colour. Female is duller than the male and winter and juvenile birds lack the chestnut colour. It breeds on Tibetian Plateau and spend winters on coastal wetlands.

Western Reef Egret (*Egretta gularis*):
It is a medium-sized heron bird and occurs in dark grey, intermediate and white colour morphs. It has longer and slightly down-curved bill with yellowish or brownish yellowish bill colour. Legs are slightly shorter and thicker and vary from black with yellow feet to being mainly green. Usually solitary while foraging, but occasionally in two's or three's and sometimes with little egrets. It is usually found at seashores, estuaries, mangroves and tidal creeks. Also occasionally at fresh waters.

Table 3.17.2: List of terrestrial mammals found in study area

Sr. No	**Common name**	**Scientific name**	**IUCN Status**	**WPA Status**
1	Asiatic Lion	*Panthera leo persica*	Endangered	Schedule I (Part I)
2	Indian Leopard	*Pathera pardusfusca*	Vulnerable	Schedule I (Part I)
3	Nilgai (bluebull)	*Boselaphus tragocamelus*	Least Concern	Schedule III
4	Indian Gazelle/ Chinkara	*Gazella bennetti*	Least Concern	Schedule I (Part I

5	Bonette Macaque	*Macaca radiata*	Least Concern	Schedule II (Part I)
6	Southern's plain GrayLangur	*Semnopithecus dussumieri*	Least Concern	Schedule II (Part I)
7	Golden Jackal	*Canisaureus*	Least Concern	Schedule II (Part I)
8	Indian flying fox	*Pteropus gigantecus*	Least Concern	Schedule IV
9	Indian fox	*Vulpes bengalensis*	Least Concern	Schedule II (Part I)
10	Desert fox	*Vulpes vulpespusilla*	Least Concern	Schedule I (Part I)
11	Striped Hyaena	*Hyaena hyaena*	Near Threatened	Schedule III
12	Rusty Spotted Cat	*Prionailurus rubiginosus*	Vulnerable	Schedule I (Part I)
13	Spotted deer	*Axis axis*	Least Concern	Schedule III
14	Indian Wild Pig	*Sus scrofaindica*	Least Concern	Schedule III
15	Ruddy Mongoose	*Herpestes smithii*	Least Concern	Schedule II (PartI)
16	Indian Grey Mongoose	*Herpestes edwardsii*	Least Concern	Schedule II (Part I)
17	Five Striped Squirrel	*Funambulus pennatii*	Least Concern	Schedule IV
18	Indian Hare	*Lepus nigricollis*	Least Concern	Schedule IV

Ecologically sensitive Habitats

There are several ecological sensitivities along the western coast of Gulf of Khambhat. The coast is dominated by mudflats, saltpans, mangroves and rocky beaches, all of which can attract a wide variety of migratory birds. The area around Gopnath Beach has been declared an Important Coastal and Marine Biodiversity Area (ICMBA) that is locally significant for migratory bird activity and turtle nesting (Saravanan, 2013). The entire coast can therefore be considered a single migratory pathway with movement of species from Bhavnagar coast in the southwest direction and towards the proposed wind farm site (Ref: Scoping report- ERM, 2019, Fig. 3.17.2.). The location of turtle nesting sites along the Amreli District coast is being report by the Forest Depratment outside the buffer zone wherein three females were reported to visit the district for laying eggs.

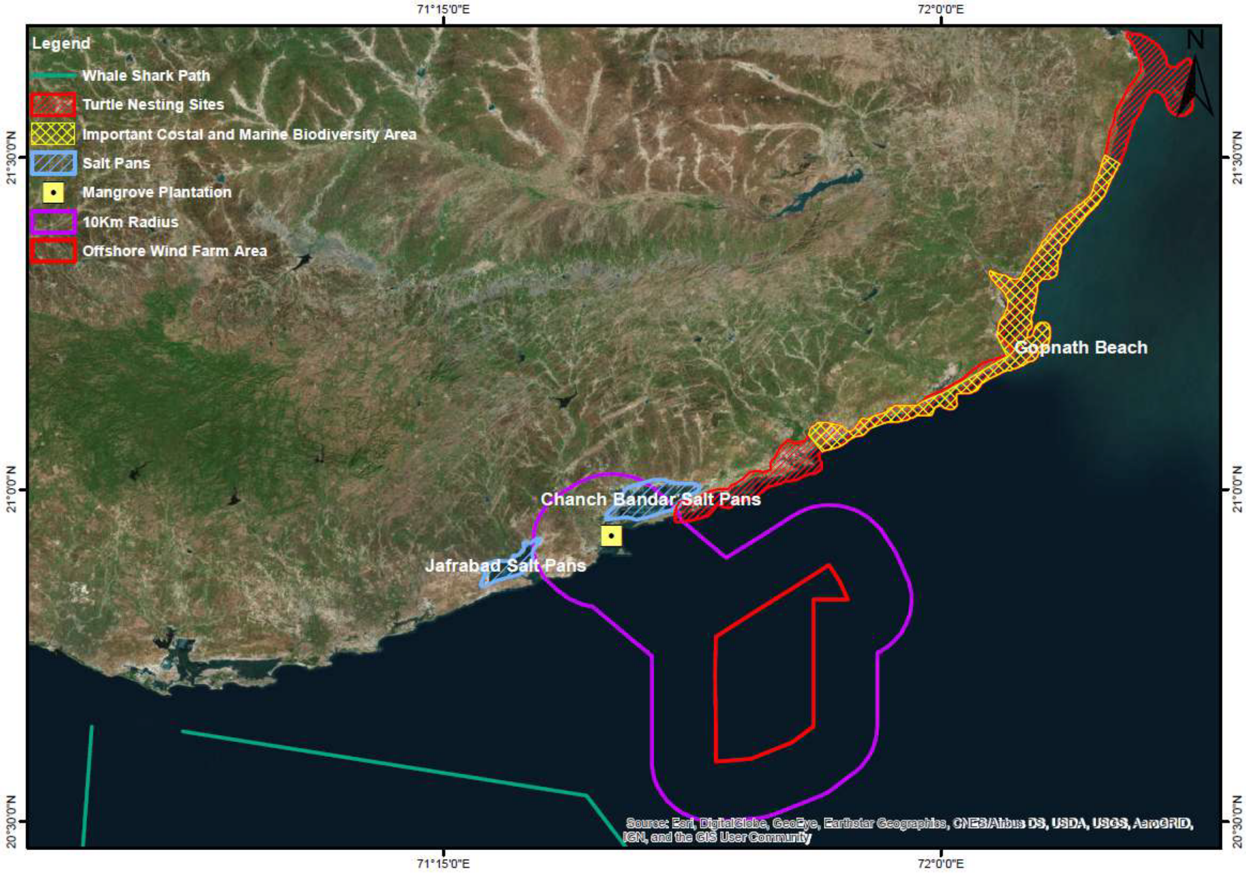


Figure 3.17.2: Ecologically sensitive habitats (Scoping report- ERM, 2019).

3.18 Socio-economy

The Social Impact Assessment (SIA) is a critical segment of the EIA procedure that decides plausible social, social, financial, legacy, and wellbeing impacts, of a proposed venture on local people and their livelihood, gatherings, and networks. Today, SIA has increased acknowledgment that is more extensive since it is currently performed via prepared social researchers that utilize sociology strategies. To foresee the foreseen social effects of an undertaking, sociologists gather information at various phases of a venture utilizing factors. In spite of the fact that utilizing a variable rundown as an agenda is not prompted, in light of the fact that extraordinary, yet essential factors might be found in the SIA procedure, a rundown can give a beginning stage to commentators.

Approach and Methodology

- Village level survey by form filling
- Local Fishermen's interviews with Sarpanch of the village
- Discussion with villagers from coastal villages like Jafrabad and Shiyalbet etc.
- Review of Provided documents from the client, from the local people and from secondary data.

- Review of information on the public domain.
- Reconnaissance of site.

3.18.1 Methodology

A judgmental and purposive sampling method was planned for choosing respondents of various sections of the society i.e. Sarpanch, adult males and females, fishermen, teachers, medical practitioners, businessmen, laborers, unemployed groups etc. Judgmental and purposive sampling method includes the right cases from the total population that helps to fulfill the purpose of research needs. For the process of data collection through primary source following methods are used:

Field survey and observations is made at each sampling village and the socio-economic status of that region is studied. Visits are made at Fisherman families and their Households, hospitals, primary health centers and sub-centers to know the health status of the region. Various Governmental organizations such as Fisheries Department, Census Department visited to collect the requisite details of that region. Structured interview method is used to collect data regarding the awareness and opinion from the samples selected of the various socio- economic sections of the community. Structured interviews involve the use of a set of predetermined questions that includes fixed and alternative questions. The questionnaire mainly highlights the parameters such as income, employment and working conditions, housing, food, water supply, electricity supply, sanitation, health, energy, transportation and communication, education, environment and pollution to assess the standard of living of that particular region and general awareness, opinion and expectation of the respondents about the proposed project. Interview method helps to collect more correct and accurate information as the interviewer is present during the field survey.

Baseline data such as demographic pattern, occupational status, educational, health and other amenities as existing in the study area have been studied. However, wherever the data was not available secondary data from desktop studies has been utilised.

3.18.2 Results

The socio-economic study under Environment Impact Assessment mainly involves the study for villages within 10 and 30 km radius including two Talukas viz. Jafrabad and Rajula as the project site is restricted to the Rampara and Pipavav villages of Taluka Rajula. Geographically Jafrabad coastline is in continuation with the continental shelf of the Gulf of Khambhat and therefore there is presence of smaller hinterland like islands viz, Shiyalbet. The population here majorly can therefore be seen involved in fishing activities. Hence, only the village within a 10 km radius from the Village Shiyal Bet, Taluka Jafrabad and the villages coming under the 30 km radius is considered under the study area.

The assessment has been made with a view to understand all the social aspects of the study area and the changes anticipated due to the proposed project. While allied activities include, livestock, forestry and cotton processing. Very few health and educational facilities are locally available in the villages. Most of the villages depend on the towns for these facilities. Towns are located between 3 to 10 km distances from the villages. The villages in the study area have less than 50% literacy. The sanitation facilities in the villages are not satisfactory.

Fence-line Communities: Fence-line communities are affected/potentially affected communities living in the immediate vicinity of the project footprint and vulnerable to potential offsite implications of onsite hazards.

Shiyal Bet: The settlement of Shiyal Bet is located on an island approx. 500 m south of the APM Terminals jetty. As per Census of India 2011, there are 832 households (5,096 population) in Shiyal Bet. The only access to Shiyal Bet is the Shiyal Bet jetty located adjacent to the Pipavav Port jetty. At the eastern end of Shiyal Bet is a rocky island called Savai Bet, detached at high tide. There is a tomb of a Pir or Muslim Saint called Savai Pir in Savai Bet.

Accessibility: The proposed Project site can be accessed via the Pipavav port. Pipavav port is well connected via road**.** The Port has developed 11 km four-lane expressway, which connects the port to National Highway 8E, which is 455 km in length. National Highway 8E connects Bhavnagar to Dwarka via Somnath and Porbandar. The highway is currently two lanes; however, expansion work of highway from two lane to four lane is being undertaken.

The Pipavav Port is part of several ports that are located in the region including Jafrabad Port and Mahuva Port. Each of these ports is along the shipping navigation channel that connects the western border of the Gulf of Khambhat. In addition to that two jetties are located close to Pipavav port, namely Ultratech Jetty and Shiyal Bet Jetty.

Project Components: The components of the project that will be checked if they are going to impact the settlements of stake holders.

Landfall: The landfall is the location where the export cable touches the shore and connects to an onshore cabling system. Some key points that need to be identified for the landfall:

- Proximity to the Pooling or Grid Substation (depending on the chosen configuration);
- A flat topography to prevent any horizontal drilling at the landfall point;
- Low to no coastal communities to reduce impacts;
- Easy access to the site by construction machinery; and
- No shipping routes or navigation channels along the route.

In discussions with the Pipavav Port Staff, it has been understood that the areas south of the port will not be possible for the landfall point because of the existing dredging and navigation channel. Further north of the port, is the Chanch Bandar salt pan site where permission for landfall will not be provided by the local authority and will receive opposition from communities, as indicated during consultations. The recommended landfall point at this stage of the project is therefore between the port and salt pan area. The demographic details of the three important villages from the study area are given below in Table 3.18.1.

Table 3.18.1 Demographic details of the major fishing villages in the study area.

Sr. No.	Fishing Villages	Fisherman Families	Traditional FF	BPL Families	Fisherfolk Population
1	Jafrabad	1975	1975	602	17780
2	Shiyalbet	832	832	117	5221
3	Vadhera	45	45	24	206

Social attributes of the study region

Places with high human settlement density and infrastructure of the built environments are called urban settlements. The areas away from these kinds of settlements and of characteristics other than that of the town are called rural settlements. In Rajula Taluka majority of the population lives in rural areas, which is about 78% of the total population, whereas 22% live in urban areas. The population of children of the age group 0-6 years that live in a rural region in 20 thousand, which is roughly four times as compared to the urban region.

Primary health centers (PHC) are state-owned rural health care facilities that play an essential role in health promotion and disease prevention. They are equipped to carry out minor surgeries too. There are three PHCs in Rajula Taluka at DungarVavera, and Bherai. There are 16 post offices in Rajula Taluka. Irrigation facilities are proper in Rajula. The primary source of water for irrigation is groundwater. Bus connectivity is present in the district, which provides transport facilities. Continuous electricity is not available in village areas.

The economic aspects of the study area include the economic structure of the people of the surrounding area. It can be predicted that the economic structure of the study area will be improved with time. Maximum people are engaged in agricultural activities and horticulture. Pipavav port has given some employment to the marginal workers of the study area.

Rajula taluka is having the facility of lodges and hotels, which has become a source of employment for the people of surrounding areas.Becoming a source of employment for the local people. It does not fulfill the employment requirements of the people. According to working status, the whole population of the study area is divided into marginal workers, non-workers, primary workers. The Census Department has defined ten categories of workers in primary workers. It consists of cultivators, agricultural, labourer those engaged in livestock, forestry, fishing, mining and quarrying, manufacturing, processing, and repairs of household industries and other services. Workers engaged in the work for a period of less than six month during the reference year falls under marginal workers. Workers engaged in unpaid household duties, e.g., students, retired person, dependents, etc. fall under non-workers.

Almost all the villages have more than 50% of people as non-workers. Rapid industrialization in the last two decades has resulted in significant changes in the occupational profile of the local people. There is an overall trend among the youth to opt for employment in the service sector and move away from the traditional occupation.

It was noted that almost the pukka road facility is available in all villages in the region. The literacy rate of various villages in the study region is from 57 to 83%. Based onthe survey for literacy rate data, it is interpreted that there is a need to promote education among more and more people. There is a need to establish more technical and educational institutes and to generate employment through commercial industries. These commercial institutes may play an employment role in improving the problems related to unemployment.

- The proposed project aims to provide direct or indirect employment opportunities to the eligible population.
- There is a sizeable population residing in the coastal villages along the coastline from Diu to Rajula, who are directly dependent on offshore fishing activities.The prime fish species playing a major role in providing income to these people is the Bombay Duck (*Harpodon nehereus*). There is a specific population that is also involved in Cotton farming and as labours in Salt pans.
- The proposed project shall bring change in the lives of the residents. However, it should not be overlooked about the damages that can be faced by the fishing community in case there are any restrictions or changes in their fishing business.

3.18.3 Conclusion:

The localities at coastal places like Jafrabad, Shiyalbet, Pipavav have been evolving as per the source. Available resources, the study area being typically coastal, fishing, and agriculture, can be seen as a prime source of income with the youth wanting to move to the towns for employment. Since past some years fishing at almost the entire coastline of the northwest coast of India has been undergoing changes based on many factors like changing methods of fishing and availability of fish catch. The fish catch statistics have been showing fluctuations accordingly. The local areas are also being developed in terms of infrastructure, basic services, amenities, hotels, residences, etc. However, for the progressive development of an area, what is normally considered as a center of development can be something that leads to making changes in the lifestyle of the locals and providing them with income opportunities. Activities like proposed ‘Wind farms’ can bring in employment opportunities in this scenario.

- The proposed cable landfall site and the villages in the core zone (5km) and buffer zone (15km) are mainly dependent on the fishery as their livelihood. Therefore, the areas will be considered in the village level survey as fishing villages.
- It is observed that the coastal villages of Jafrabad from Diu to Rajula hold a direct relationship with the fishery along the coastline, pre-dominantly Bombay Duck, as it forms most of the catch.
- Amongst all the villages Jafrabad, Vadhera, Shiyalbet are primarily involved in the fishery of Bombay duck. Species are primarily caught with the bag-net, better known as "dol" net of 35 – 60 m length and with a cod-end mesh of 20 mm.
- The operation of the dol net is timed to a strong tidal current at depths ranging from 20 – 30 m or deeper.
- The proposed project is to be executed at a 23 km distance from the coast. During the construction activity, there will be a temporary displacement of fauna due to construction activities.
- The fishermen will need to pass through the area of the proposed 'Wind Farm' to reach offshore fishing grounds. The **right of way or navigation for the fishermen should hence be protected** along with the compliances for the **Safety of Windfarms**.
- It is therefore recommended to educate the local fishermen about the proposed project activities during construction and operation phases and plan as per the schedule related to the fishery of the area.

Chapter 4: Numerical Modelling

4. NUMERICAL MODELING OF HYDRODYNAMICS AND SEDIMENT TRANSPORT

4.1. Introduction

Winds, waves, and currents are the important driving forces that generate several oceanic phenomena in the coastal and open ocean. In this present work, the currents and sediment transport are analysed to ascertain the impact of monopiles to be installed for the windfarm. The studies covered under numerical modelling are;

- Estimation of Gulf of Khambhat (GoK) waves and hydrodynamics using MIKE-SW and MIKE21 FMHD
- Estimation of waves, hydrodynamics and sediment transport for the study area using MIKE21 coupled model (SW, FMHD and ST)
- Estimation of the impact of monopiles on the hydrodynamics and in the sediment transport

The CFSv2 analyzed winds are used as input to the Indian Ocean wave model, and WRF (Weather Research Forecasting) model winds are used for the other domains. Various data used to validate the model results are presented in Table 4.1. In order to understand the prevailing coastal circulation, waves, and sediment transport in the study area, three model domains have been considered. These model domains are presented in Figures 4.1, 4.2, and 4.3.

Table 4.1. Data used for the model validations.

Equipment	Longitude (°E)	Latitude (°N)
LIDAR	71°41.182'	20°45.318'
Wave Rider Buoy	71°40.999'	20°45.794'
Tide gauge	71°40.165'	20°46.615'
Current Meter	71°40.846'	20°46.028'

4.2. Wind modelling

4.2.1 Model details

The Weather Research and Forecast (WRF) model was developed as a collaborative effort of several research organizations and Universities in the USA. It is a fully compressible, non-hydrostatic atmospheric model with a large number of physics options regarding cumulus parameterization, cloud microphysics, radiation, planetary boundary layer (PBL), and surface layer processes. The model also includes multiple nesting and four-dimensional data assimilation options, which enable us to hindcast meteorological conditions realistically. There are two dynamic solvers in the WRF system: the Advanced Research WRF (ARW) solver (originally referred to as the Eulerian mass or “em”) and the NMM (Nonhydrostatic Mesoscale Model) solver. The WRF–ARW solver is based on a fully compressible, primitive equation, non-hydrostatic Euler equations, with terrain following, hydrostatic pressure vertical coordinate system. The horizontal grid follows the Arakawa-C grid methodology. The third-order Runge–Kutta scheme is used as the time integration scheme in the solver. The spatial discretization is based on second- to sixth-order schemes.

The model has the computational capability to handle different nesting options—two-way, one-way and two-way moving nests, analysis, and observation nudging. The FNL analyses come from NCEP’s Global Data Assimilation System, which runs four times a day in 1°×1° horizontal resolution, 6-hour interval data serve as initial and lateral boundary conditions to the model. As the representation of coastlines and orography greatly depends on the spatial resolution of topography data, horizontal grid spacing of 10 minutes is used to set up the model. The WRF preprocessing system (WPS) of the WRF model reads and interpolates the global model fields and land surface static data onto the target model domain grid. However, the functionality of the WPS has to be expanded to handle the horizontal staggering map projection. These interpolated atmospheric and static fields serve as input to the WRF initialization package, which outputs the initial and boundary conditions to the WRF model for the final forecast. These WRF winds are used for wave modelling of the area of interest in the present study.

4.2.2Model Validation

In order to simulate atmospheric parameters for the GoK region, WRF model setup with 3 km gridded domain (Lat 19°N to 22.5°N and Long 70.25°E to 73.25°E) has been used and the wind data generated at one hour interval for November 2017 to February 2019. In order to validate the accuracy of WRF modeled winds, WRF wind velocity components were compared with LIDAR winds (November 2017 to December 2018), and are presented in Figure 4.4. The comparison is very good, and these WRF winds are further applied in the wave and Hydrodynamic (HD) models in the Gulf of Khambhat and regional domains.

4.3 Wave modelling

MIKE21 SW model has been run with three domains (i) Indian Ocean domain, (ii) Gulf of Khambhat, and (iii) regional domain. The 'modified ETOPO2' (https://www.nio.org) bathymetry data representing the best available bathymetry values for open ocean spaced at every two-minute latitude/longitude, has been extracted for the required region and updated this again in the coastal region with the National Hydrographic Office (NHO) digitized data. The model domain covers region 60°S to 30°N and 25°E to 100°E.For running the Gulf of Khambhat domain model, bathymetry values for the area of interest (Lat 19°N to 22.33°N and Long 70.92°E to 72.91°E) have been digitized from NHO charts.For running the regional domain model, bathymetry values for the area of interest (Lat 20°39'N to 24°48'N and Long 86°57'E to 88°45'E) have been digitized from NHO Charts and updated with the measured bathymetry data.

4.3.1 Model details

MIKE21-SW developed by the Danish Hydraulic Institute, Denmark (User guide for MIKE 21-SW Wave modelling, 2014),is used to simulate wave conditions in the Indian Ocean. MIKE21-SW models can be run with constant, time series, and gridded winds. Here we have used CFSv2 winds and WRF winds for the Indian Ocean domain and regional domain, respectively.

MIKE 21 SW includes a new generation spectral wind-wave model based on unstructured mesh. The model simulates growth, decay, and transformation of wind-generated waves and swells in the offshore and coastal areas.MIKE 21 SW with a fully spectral formulation is used in this study. The fully spectral formulation is based on the wave action conservation equation, as described in, e.g., Komen *et al*. (1994) and Young (1999), where the directional-frequency wave action spectrum is the dependent variable. The basic conservation equations are formulated in Cartesian co-ordinates for small-scale applications and polar spherical coordinates for large-scale applications. MIKE 21 SW includes the following physical phenomena:

- Wave growth by the action of wind
- Non-linear wave-wave interaction
- Dissipation due to white-capping
- Dissipation due to bottom friction
- Dissipation due to depth-induced wave breaking
- Refraction and shoaling due to depth variations
- Wave-current interaction
- Effect of time-varying water depth and flooding and drying

The discretization of the governing equation in geographical and spectral space is performed using a cell-centered finite volume method. In the geographical domain, an unstructured mesh technique is used. The time integration is performed using a fractional step approach, where a multi-sequence explicit method is applied for the propagation of wave action. MIKE 21 SW is used for the assessment of wave climates in offshore and coastal areas - in hindcast and forecast mode.

The basic output of the model is significant wave height, wave period, and wave direction. The output of the Indian Ocean model has been used as input to the Gulf of Khambhat model and later its output used for the regional model. The model was run for the period from 1 - 31 January 2019. The wave parameters are simulated at 1h interval.

4.3.2 Model Validation

Comparison between measured and modelled significant wave heights (SWHs) is shown in Figure 4.5, and it shows very good agreement.

4.4. Hydrodynamic Modelling

4.4.1Model details

MIKE21 FM HD numerical modelling of coastal hydrodynamics (HD) is a proven tool that can be used to provide solutions to industrial projects, where coastal and nearshore waterfronts are utilized for developments. Numerical modelling techniques are capable of recreating scenarios that can provide solutions much before the actual implementation of the project. In order to simulate the hydrodynamics of GoK, MIKE21 HD FM model has been applied. MIKE 21 HD FM is a hydrodynamic modeling system for 2D free surface flows based on a flexible mesh approach. The specific modules used in the present study are hydrodynamic (HD) and sediment transport (ST). Basically, HD results are required to run all the other modules as the hydrodynamic properties of the system control all the processes in the marine environment. MIKE21-HD FM can accommodate a high-resolution grid for simulation of water level variations, currents, and all other related parameters. The modelling system is based on the numerical solution of the two-dimensional shallow water equations: the depth-integrated, incompressible Reynolds averaged Navier-Stokes equations. The model consists of continuity, momentum, temperature, salinity, and density equations. In the horizontal domain, both Cartesian and spherical coordinates can be used. MIKE21-HD FM follows a triangular grid concept. It can take up any irregular coastline and easily distribute grids over a narrow region.

4.4.2 Model setup

Bathymetry and open boundary tides are the two major input parameters required for modeling coastal hydrodynamics. With the help of tidal constituents, open boundary tides were predicted at the nearest coastal tidal station. The model results depend mainly on the accuracy of the tides prescribed along the open boundary and the bathymetry data used to generate the model domain depth mesh.

Tidal constituents of Kotra and Bandra were used for predicting the tides at these locations. MIKE 21 toolbox utilities have been used for predicting tides by using 35 tidal constituents for each of these locations. The maximum tidal ranges at these locations are 3.05 m and 4.06 m, respectively. Time series of these predicted tides were interpolated and prescribed to force the model from the southern open boundary. Maximum and minimum of predicted water level variations at Kotra and Bandra are given in Table 4.2, and the variation of the tide during January 2019 at Kotra and Bandra are given in Figure 4.6.

Table 4.2. Maximum and minimum of the predicted water level variations at Kotra and Bandra during 1 – 31 January 2019

Station	Water level (m)		Tidal range (m)
	Min	Max	
Kotra	-1.61	1.44	3.05
Bandra	-2.10	1.96	4.06

4.4.3 Model validation

Water level and current velocity components are extracted from the model at the locations of measured Tide gauge and current meter. The maximum and minimum values of surface elevations obtained from model simulations and tide gauge measurements are given in Table 4.3. Measured and modeled tidal ranges are 4.74 m and 4.82 m, respectively. A comparison between measured and modeled sea surface elevation is given in Figure 4.7.

The maximum and minimum values of U&V current velocity components and current speed obtained from model simulations and measurement are given in Table 4.4. The maximum measured current speed is to be 1.68, and the model is 1.61. Model results of U&V velocity components are also showed good agreement with the measured values. Comparison between measured and modeled U&V current velocity components and speed are given in Figure 4.8.

Table 4.3. Comparison between measured and model simulated water levels

	Water level (m)		Tidal range (m)
	Min	Max	
Measured	-2.28	2.46	4.74
Modelled	-2.31	2.51	4.82

Table 4.4. Comparison between measured and model simulated u & v current velocity components

Station	u-component (m/s)		v-component (m/s)	
	Ebb current	***Flood current***	***Ebb current***	***Flood current***
Measured	-1.41	1.36	-0.91	0.99
modelled	-1.25	1.32	-0.85	0.94

Typical current patterns obtained from the model run during the flood, and ebb phases of the tide are given in Figs. 4.9 and 4.10.

4.5 Modelling of hydrodynamics and sediment transport

For running the regional domain model, bathymetry values for the area of interest (Lat 20°39'N to 24°48'N and Long 86°57'E to 88°45'E) have been digitized from NHO Charts and updated with the measured bathymetry data.Numerical modelling for the NWE regional domain is carried out to understand the impact of the monopiles of the windfarms on surface elevation, current speed, and bed level change.

A numerical model simulation is carried out for three different scenarios mentioned below.

Scenario 1: the existing condition

Scenario 2: with 162 monopiles (wind farm layout 1)

Scenario 3: with 125 monopiles (wind farm layout 2)

4.5.1 Scenario 1: the existing condition

The model domain selected for simulation of Coupled Wave, HD & ST is given in Fig. 4.3. The western boundary of the model taken from the Vadhera and extended to 55 km offshore. Naip to 48 km offshore has been taken as the eastern boundary. The southern boundary is 61 km long. Boundary forcing for the regional domain with all the scenarios are extracted from the GoK model domain. The model simulation runs were carried out for a period of 31 days (1 to 31 January 2019).

Typical surface elevation & current pattern during spring flood and ebb tide for Scenario-1 are given in Figures 4.11 & 4.12, respectively. The monthly averaged bed level change is given in Figure 4.13.

4.5.2 Scenario 2: with 162 monopiles

MIKE21HD FM and MIKE21SW are having features to impose structures in the model. The horizontal dimension of the monopile structure is much smaller than the resolution used in the computational grid. Therefore, the presence of these structures is modeled by a subgrid scaling technique.

In the present scenario, we have imposed 162 monopiles with 7 m diameter. The locations of the monopiles are shown in Fig. 2.1. In MIKE21HD FM, the effect of piers is modelled as sub-grid structures using a simple drag-law to capture the increasing resistance imposed by the piers as the flow speed increases. In MIKE21SW, the source term approach takes the effects of the structures into account by introducing a decay term to reduce the wave energy behind the structure. This formulation is only accurate when the energy decay is limited, and the reflection of the wave energy is not taken into account. The convective flux approach is based on a correction of the convective flux term in geographical space.

Surface elevation and current speed are extracted 1 km away from the four sides of the outermost monopiles in the wind farm. Comparison between the surface elevation and current speed of the Scenarios 1 and 2 for all four sides are given in Figures 4.14 and 4.15, respectively. The monthly averaged bed level change for the scenario-2 is given in Figure 4.16. The difference between monthly averaged bed level change of Scenarios 1 & 2 are given in Figure 4.17.

4.5.3 Scenario 3: with 125 monopiles

Surface elevation and current speed are extracted 1 km away from the four sides of the outermost monopiles of the wind farm. Comparison between the surface elevation and current speed of the Scenarios 1 and 3 for all four sides are given in Figure 4.14 and 4.15, respectively. The monthly averaged bed level change for the scenario-3 is given in Figure 4.18. The difference between monthly averaged Bed Level Change of the Scenarios 1 & 3 is given in Figure. 4.19.

4.5.4 Change in current patterns and sediment distribution

In both the scenarios 2 and 3, the model results indicate almost similar sediment movement with respect to the base scenario 1. Statistical mean of the bed level change over the model simulation period indicate a marginal increase in bed level of 0.08 m around the monopiles of northern half and decrease in the southern half by the same magnitude. This would suggest marginal accretion around the northern monopiles and erosion (scouring) around the southern ones. However, the impact of these changes around the monopiles are insignificant as the sediment transport is predominantly controlled by the reversing tidal currents which flow upstream and downstream during flood and ebb tides respectively and thereby evenly distribute of the sediment in the installation area.

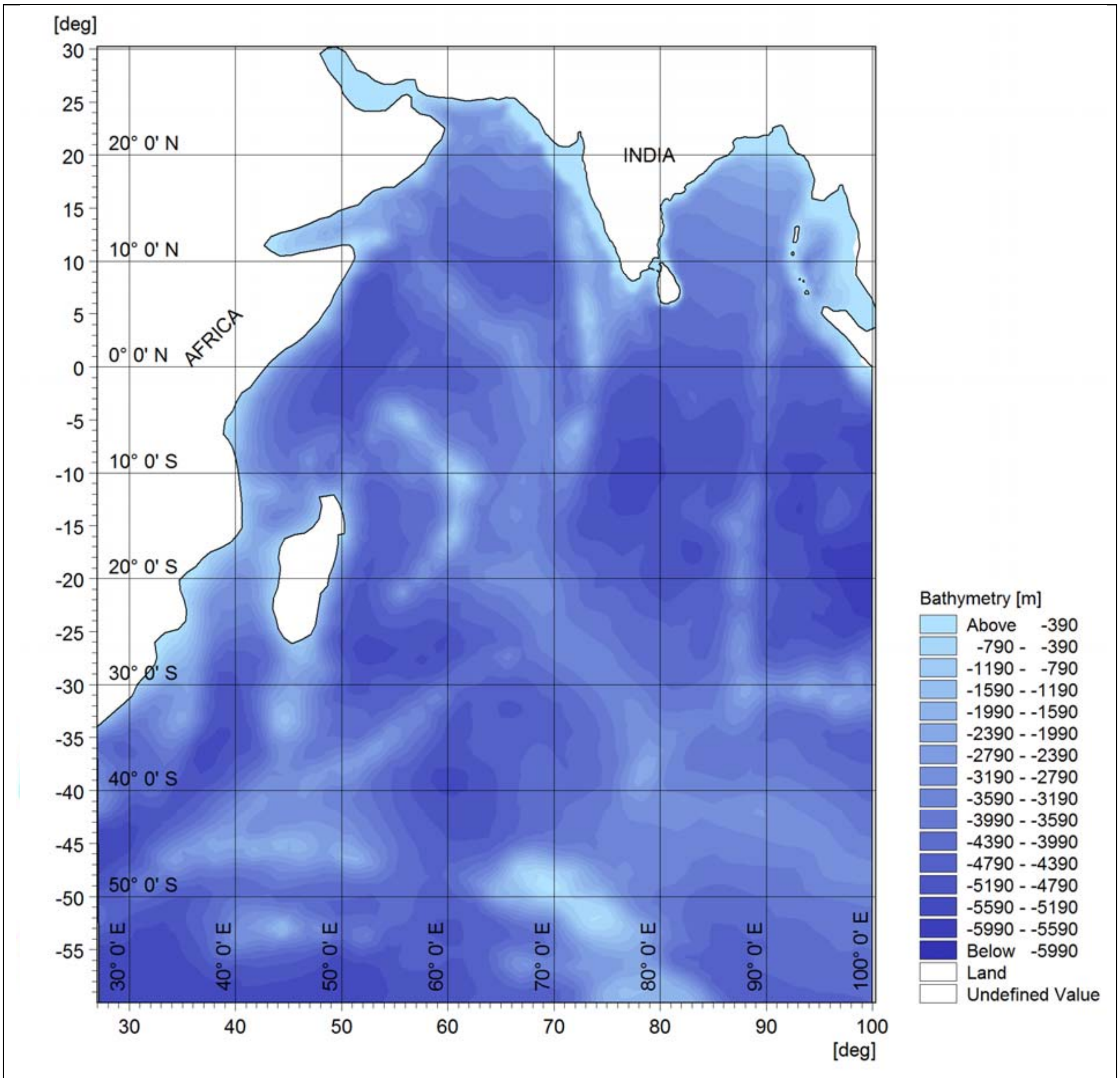


Figure. 4.1 Model domain – Indian Ocean

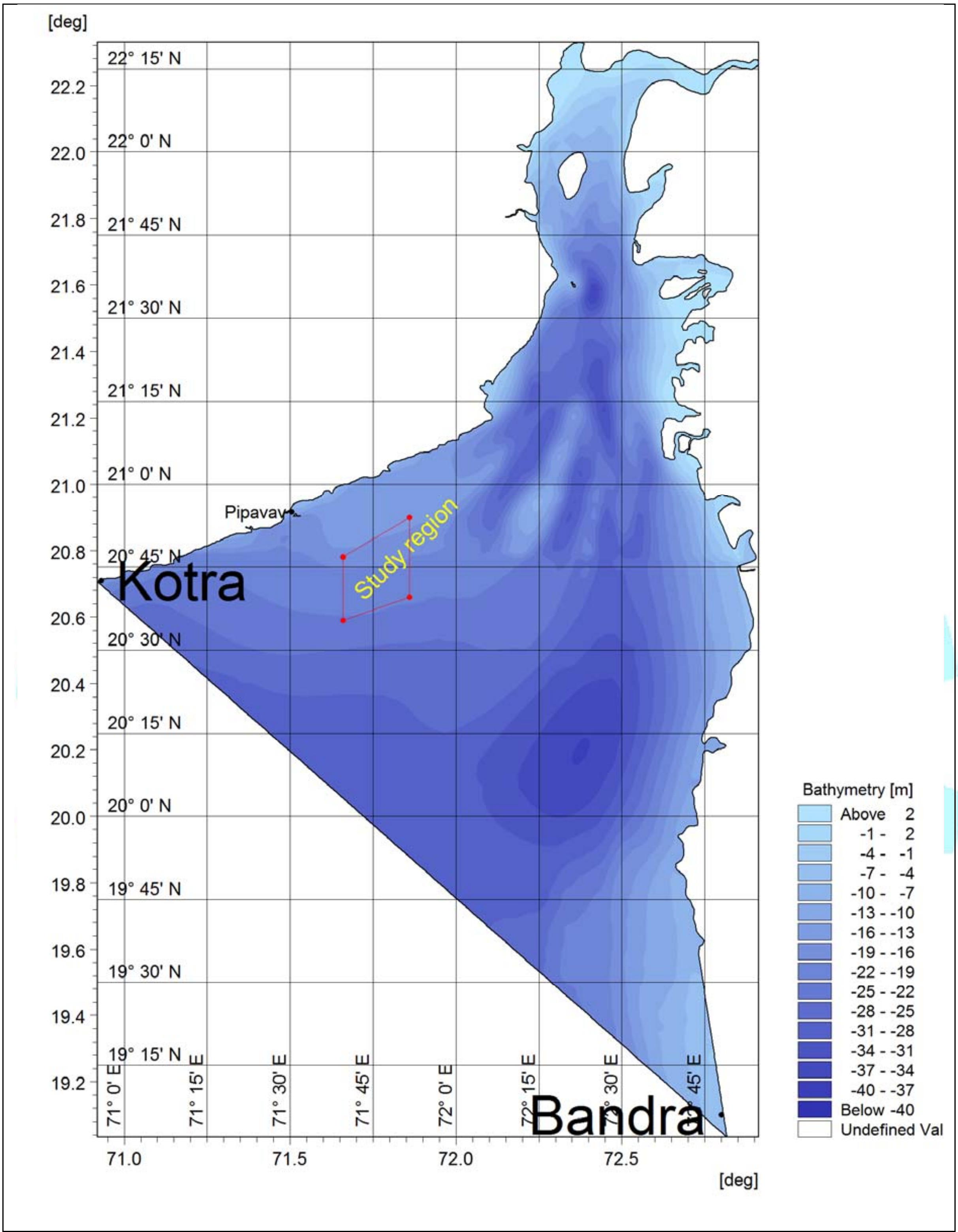


Figure.4.2 Model domain – Gulf of Khambhat

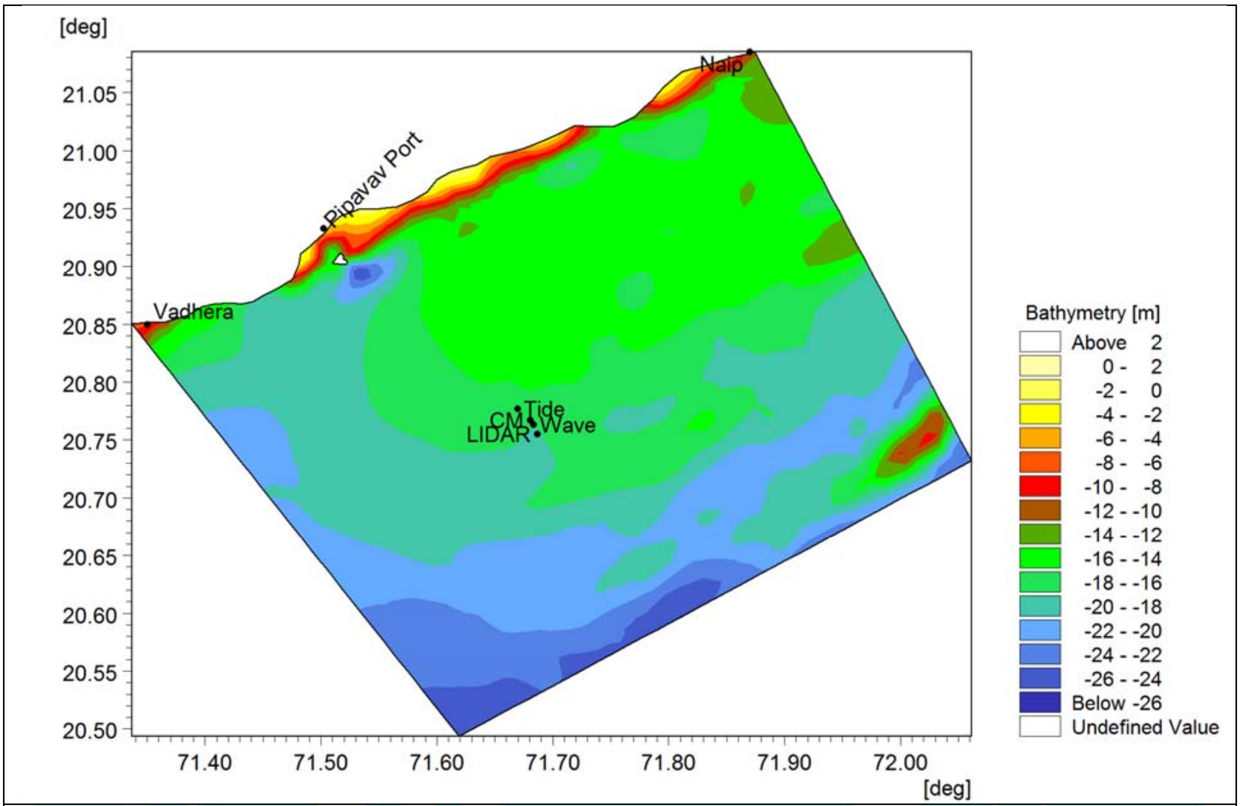


Figure. 4.3 Regional model domain

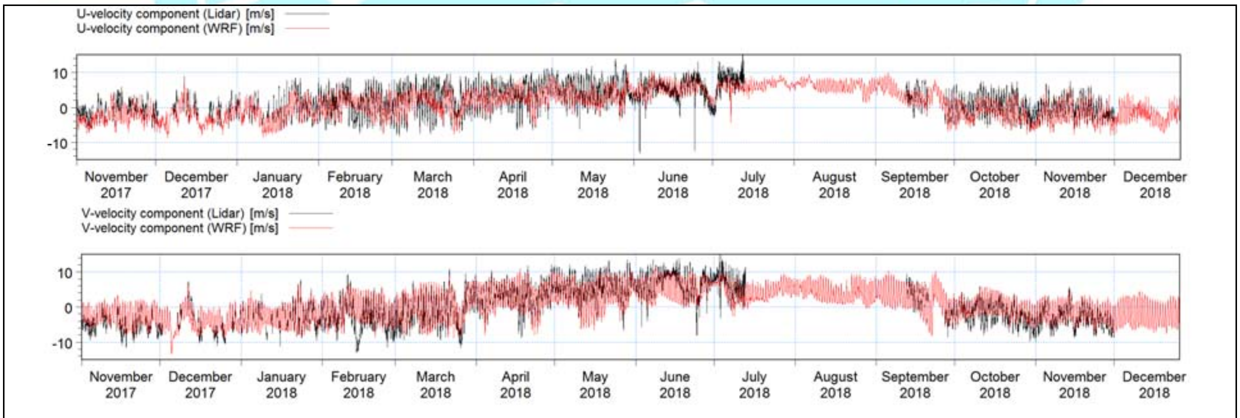


Figure.4.4 Comparison between measured and modelled wind U&V velocity components

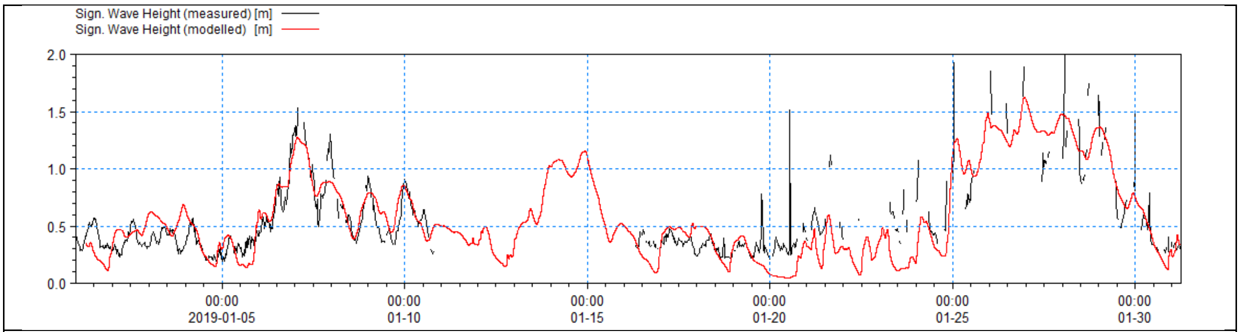


Figure.4.5 Comparison between measured and model Significant Wave Height

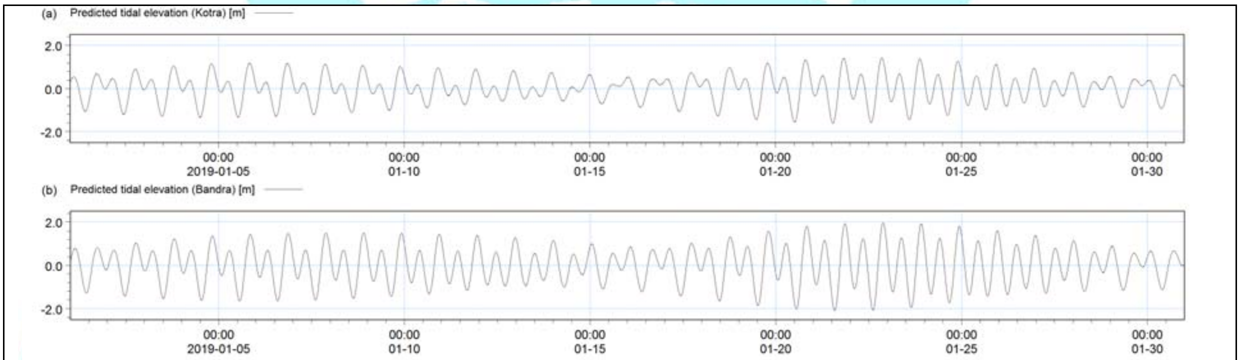


Figure. 4.6 Predicted Tides at (a) Kotra and (b) Bandra

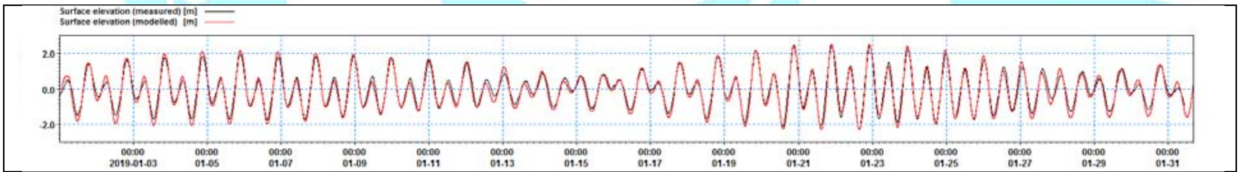


Figure.4.7 Comparison between measured and modelled sea surface elevation

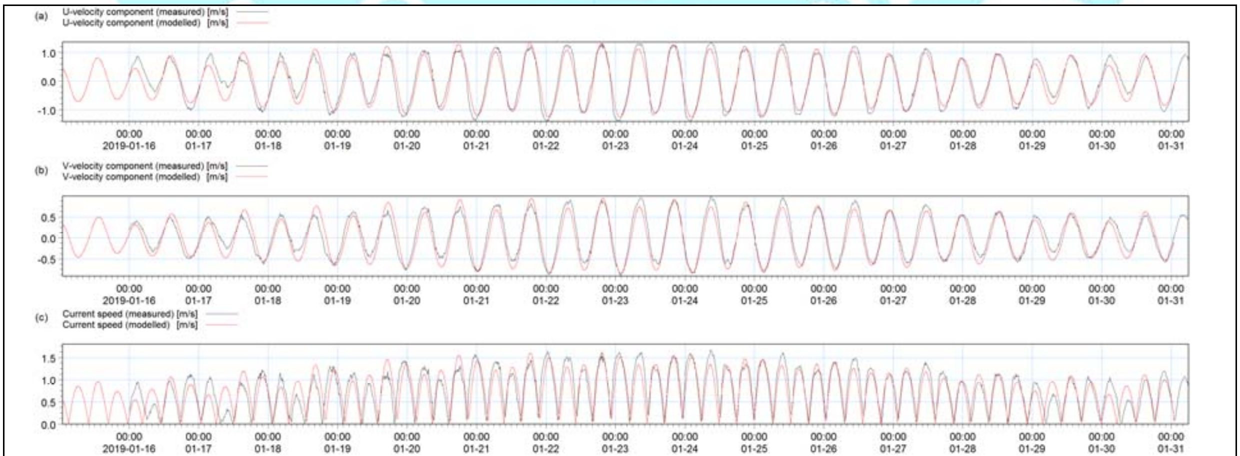


Figure.4.8 Comparison between measured and modelled current (a) U & (b) V velocity components and (c) speed

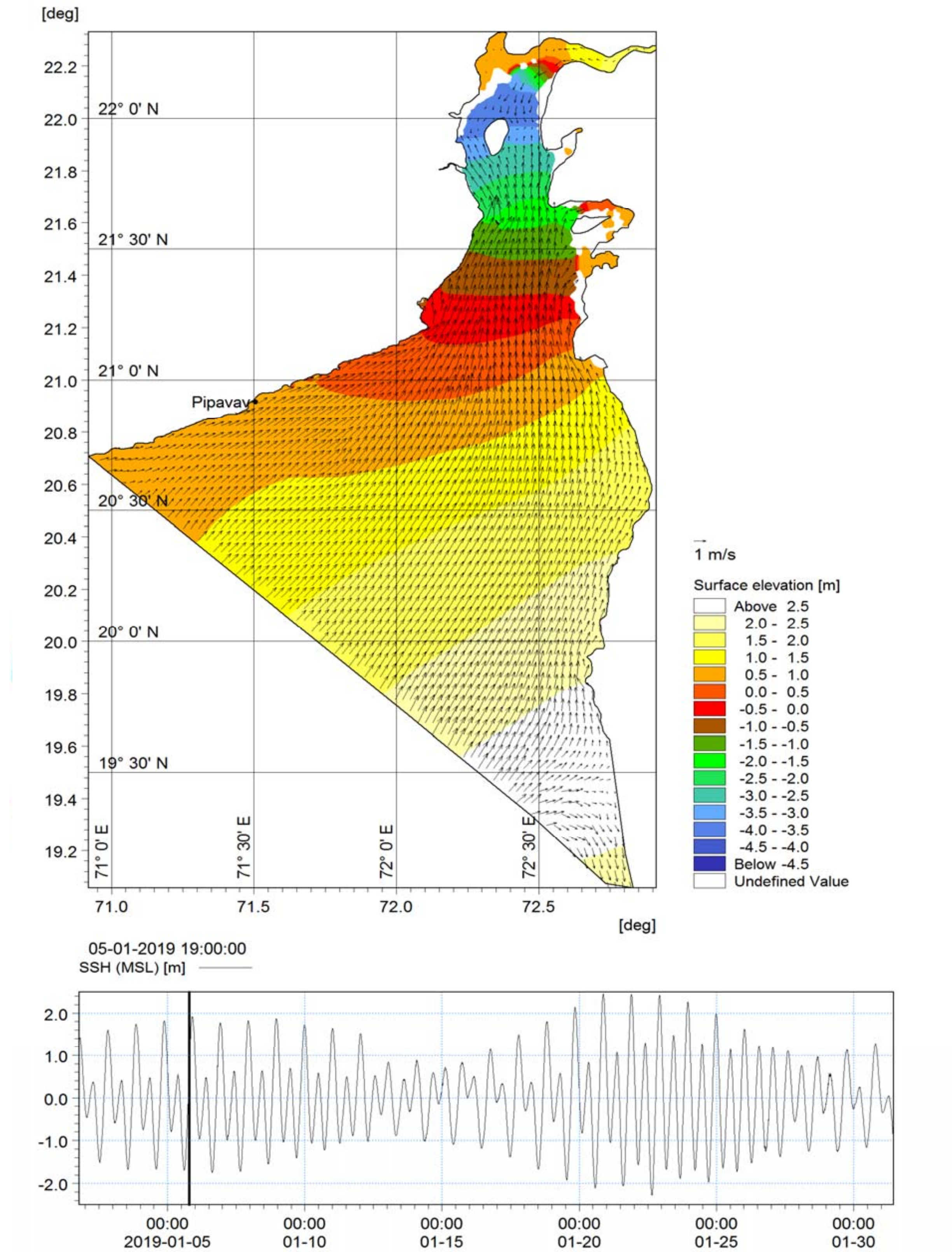


Figure. 4.9 Surface elevation & current pattern during spring flood tide for GoK

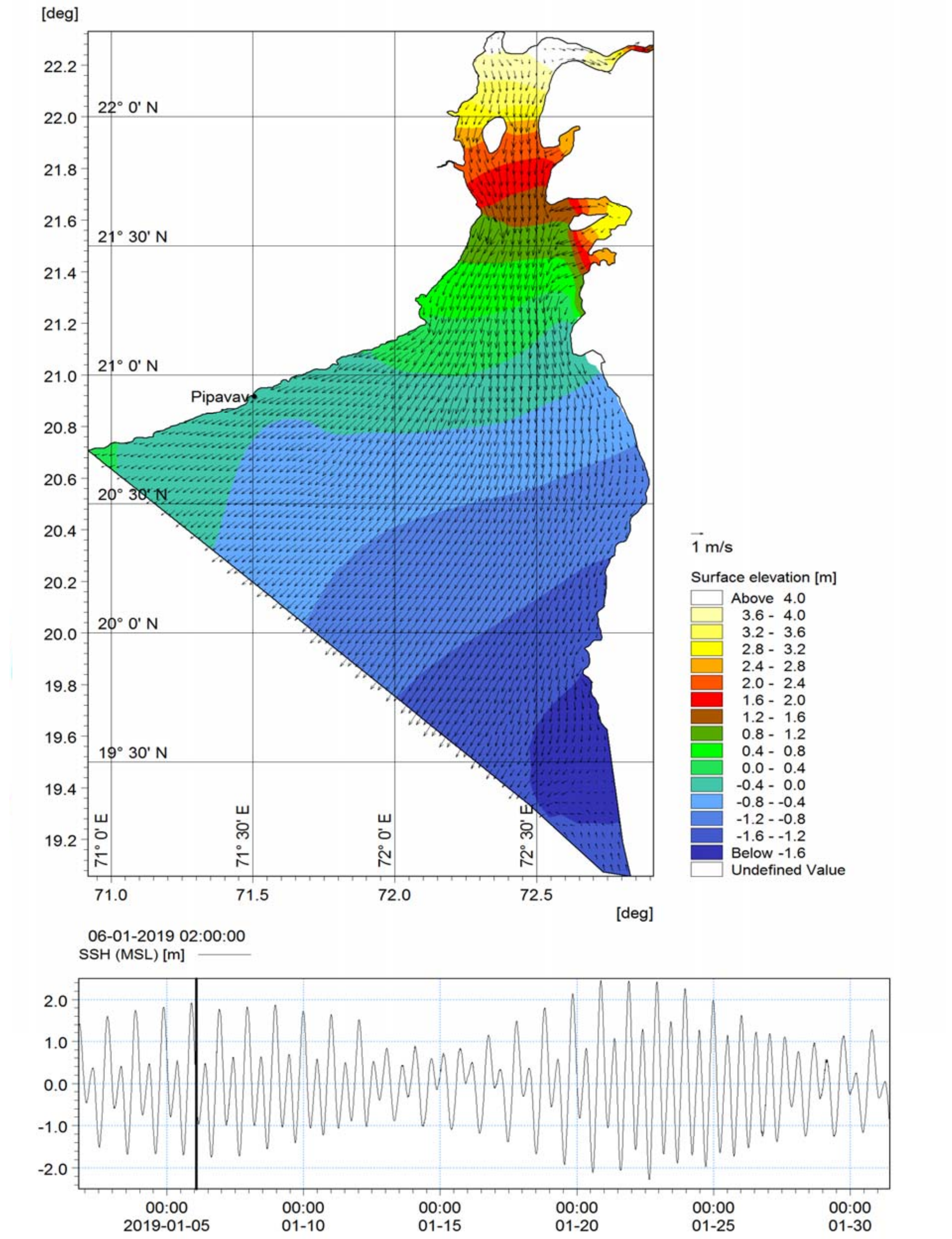


Figure. 4.10. Surface elevation & current pattern during spring ebb tide for GoK

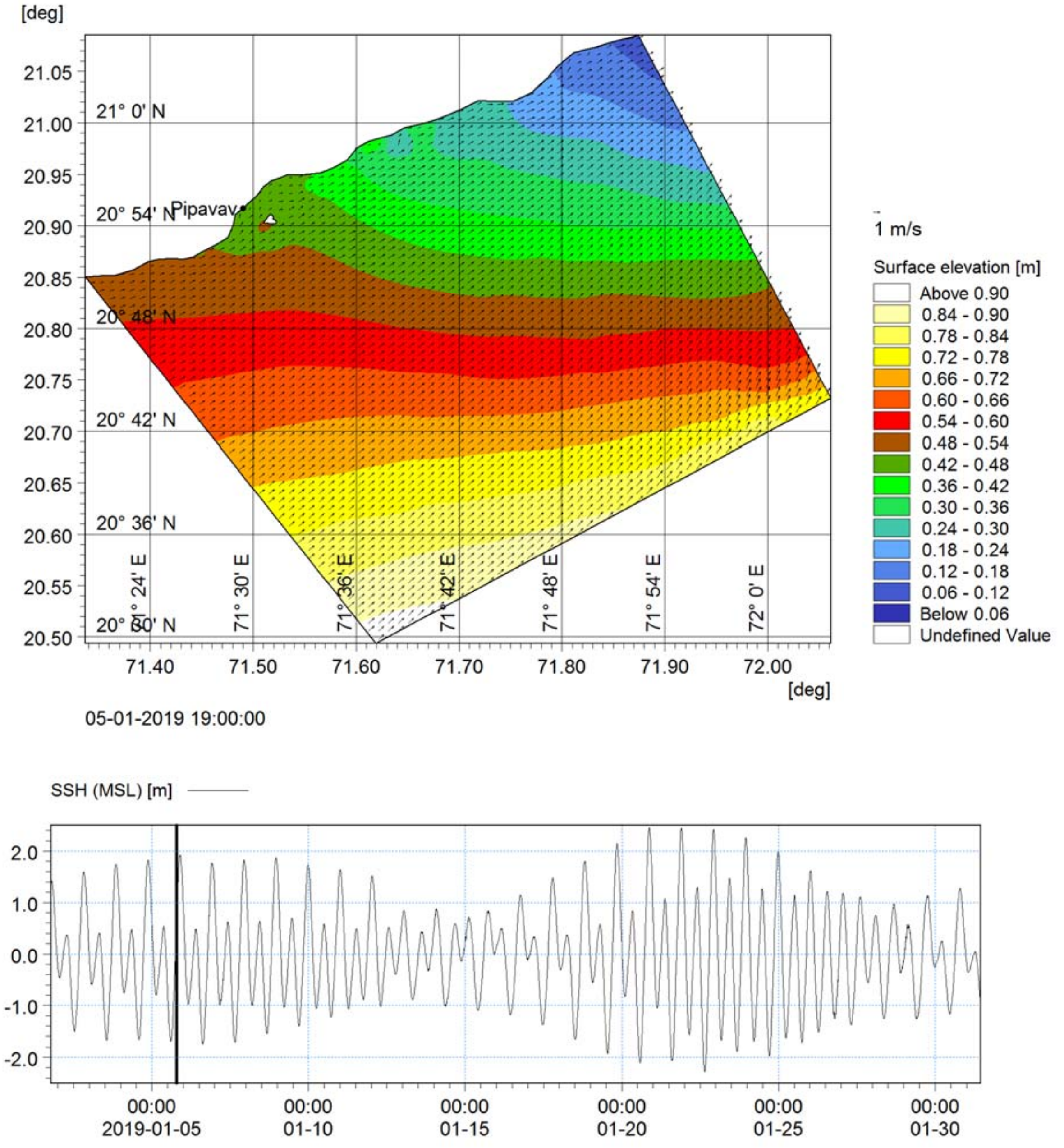


Figure. 4.11. Surface elevation & current pattern during spring flood tide for Scenario-1

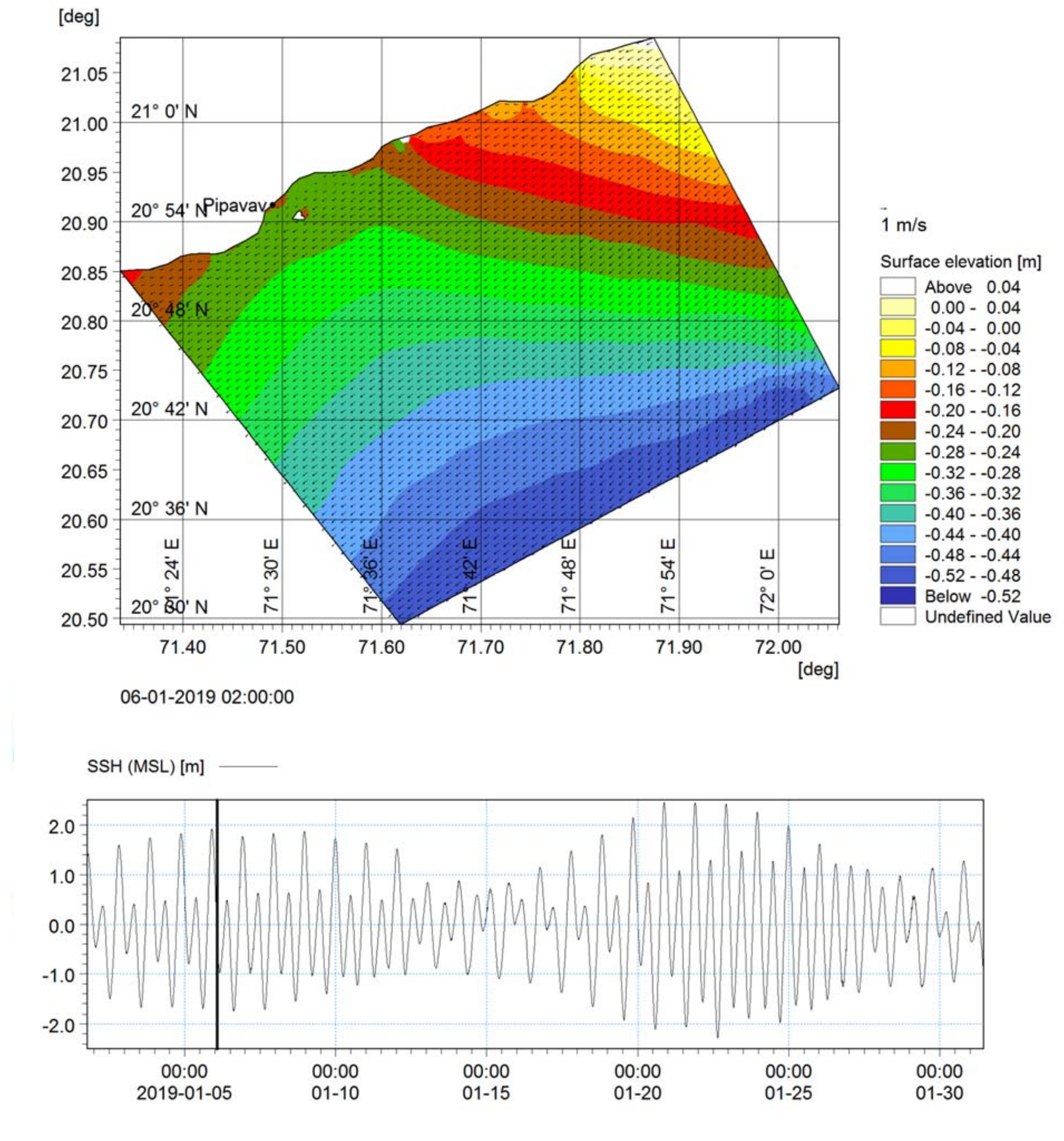


Figure. 4.12. Surface elevation & current pattern during spring ebb tide for Scenario-1

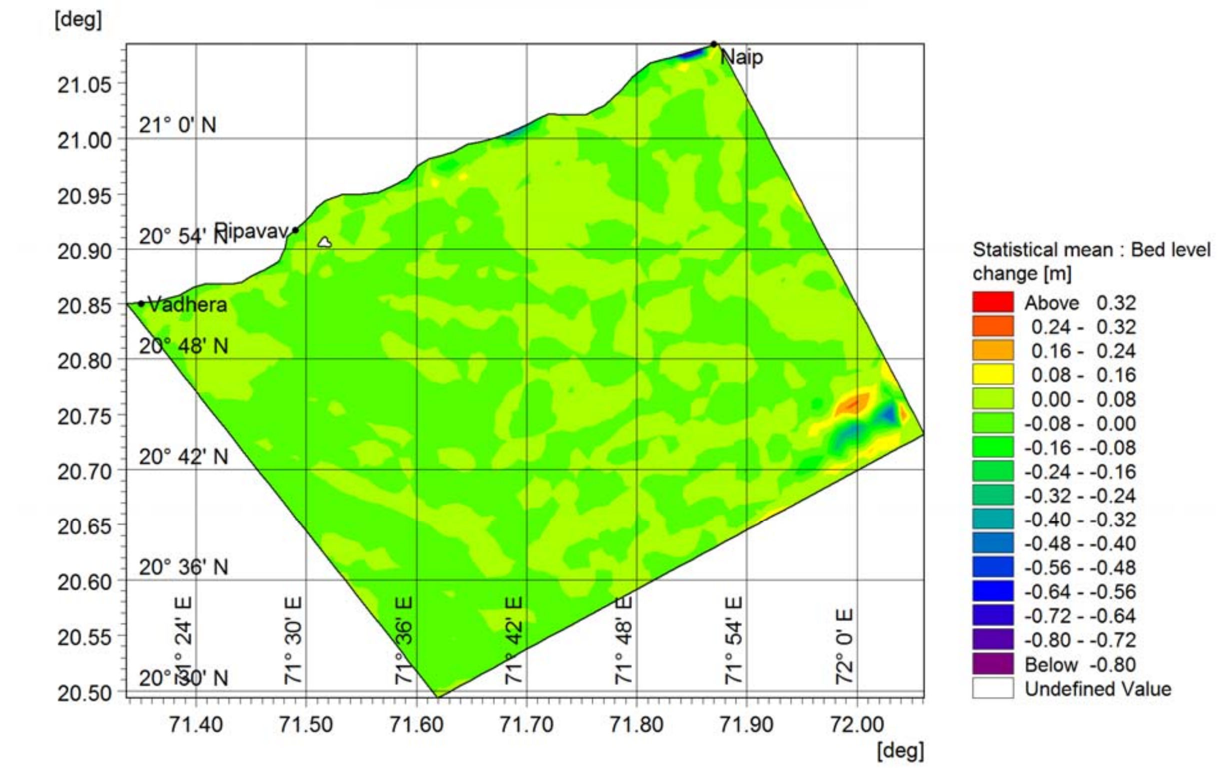


Figure. 4.13 Monthly averaged Bed Level Change for the Scenario-1 (Existing)

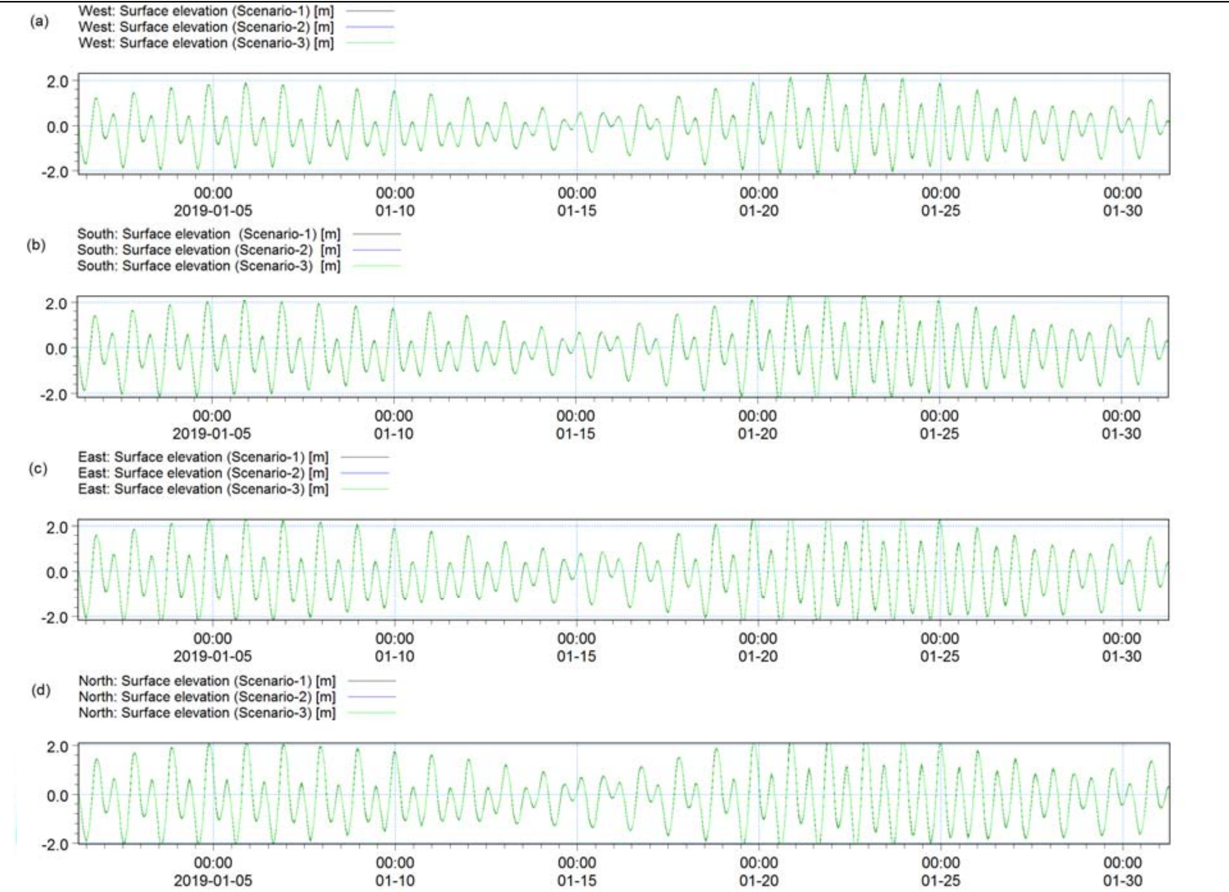


Figure. 4.14 Comparison between the surface elevation of Scenarios 1,2 and 3 for the (a) West, (b) South, (c) East and (d) North

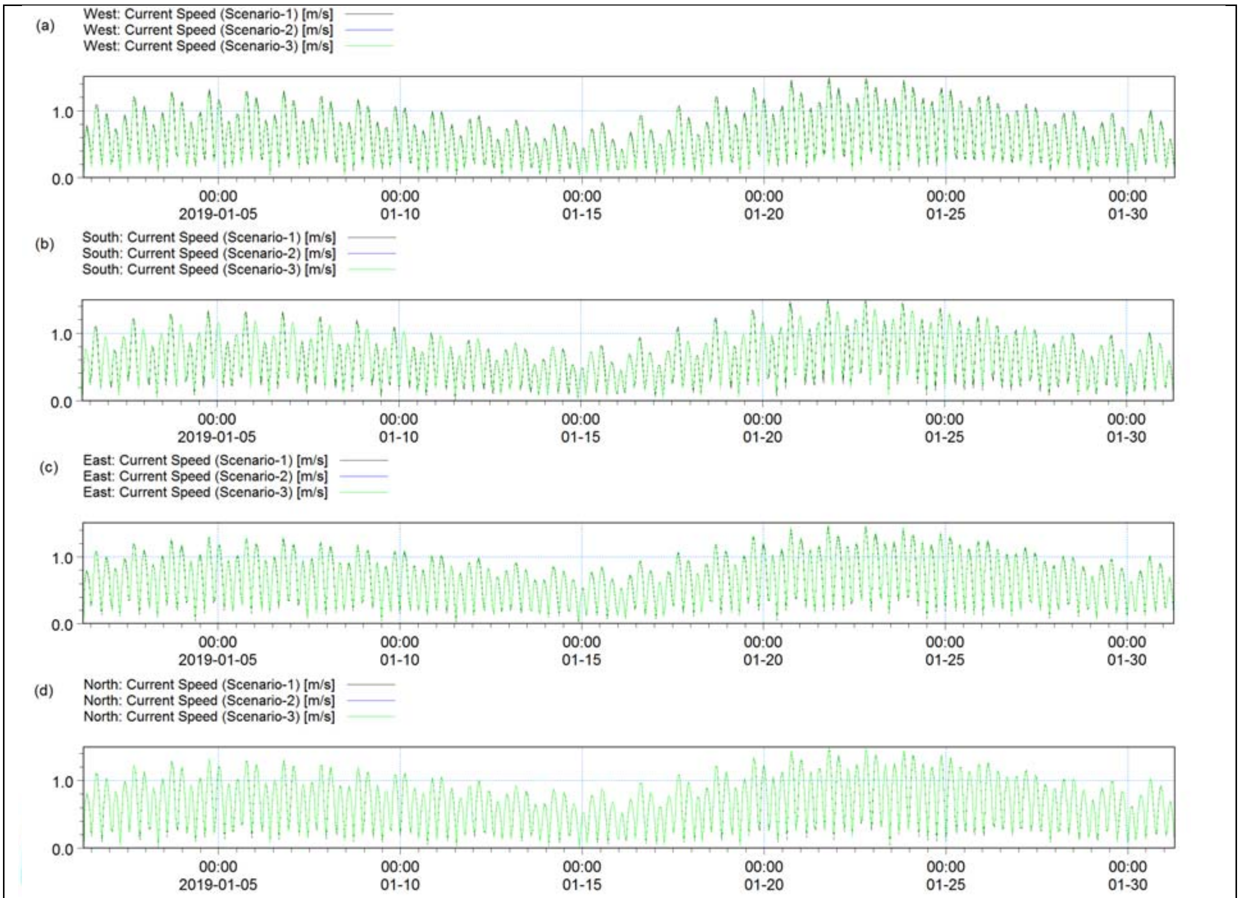


Figure. 4.15 Comparison between the current speed of Scenarios 1,2 and 3 for the (a) West, (b) South, (c) East and (d) North

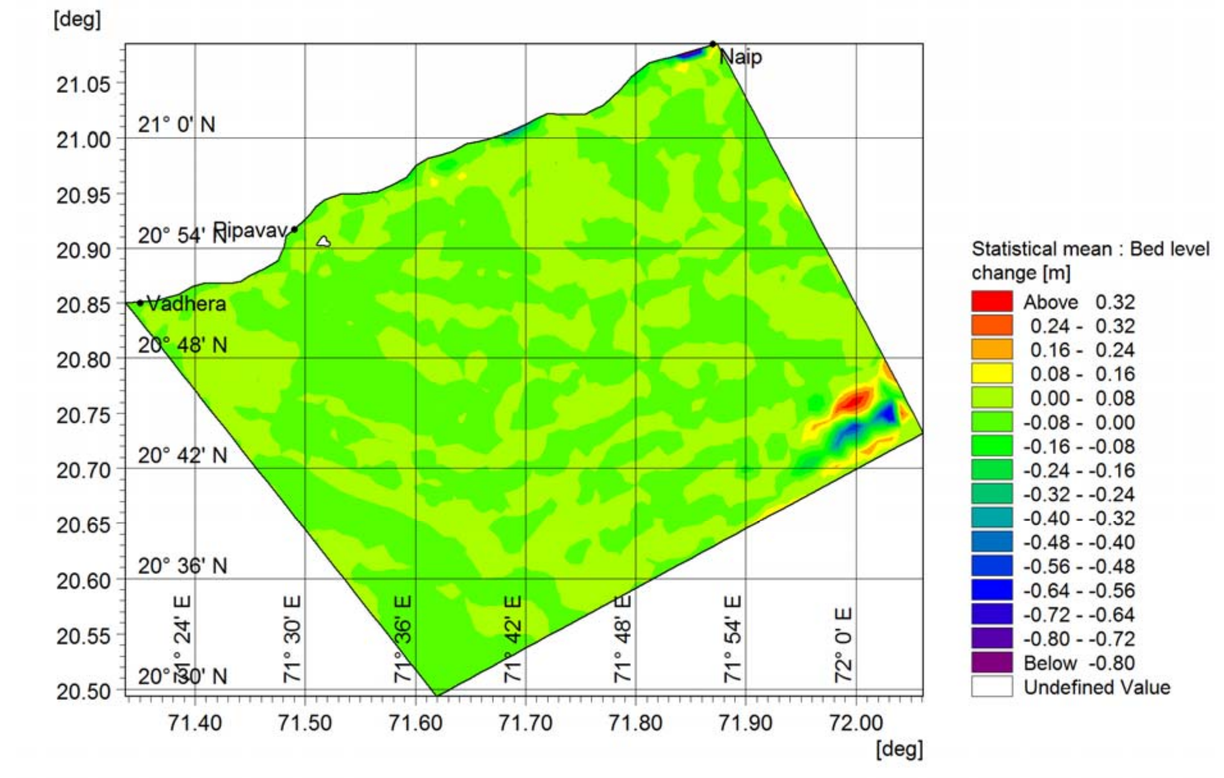


Figure. 4.16 Monthly averaged Bed Level Change for the Scenario-2

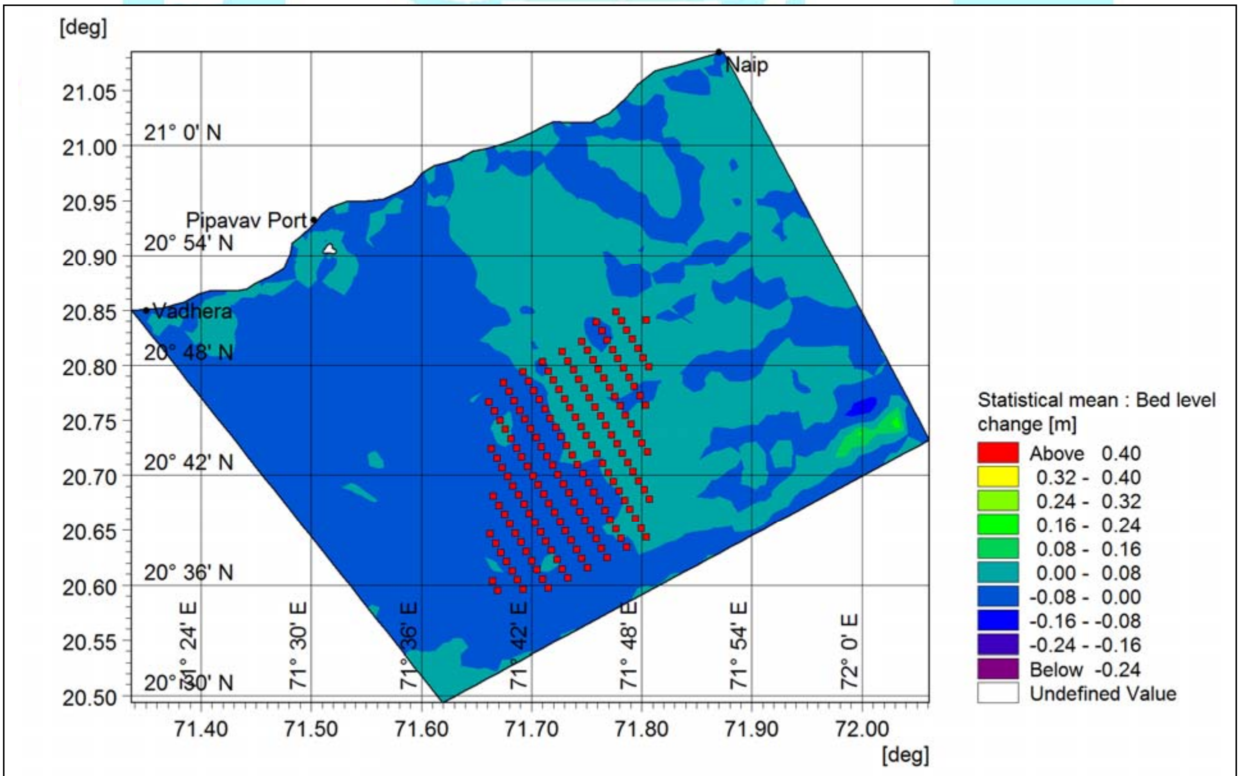


Figure. 4.17 Difference between monthly averaged Bed Level Change between Scenarios 1 & 2

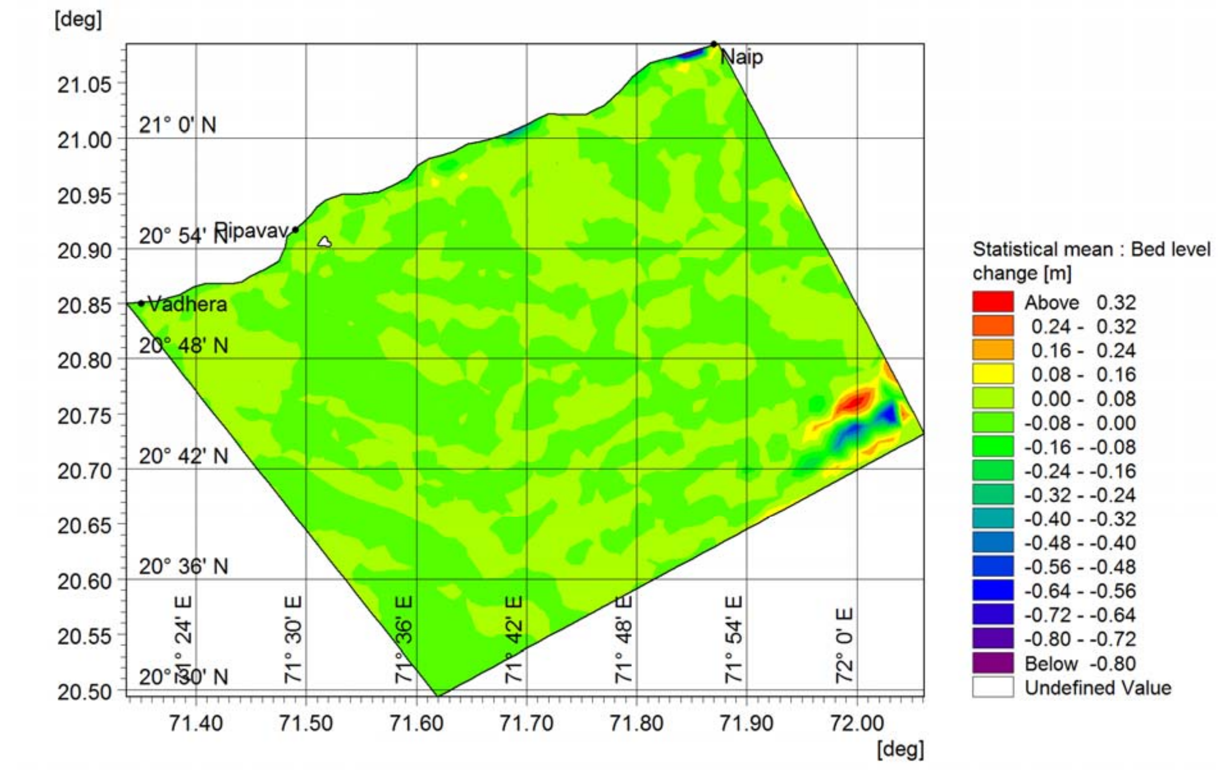


Figure. 4.18 Monthly averaged Bed Level Change for the Scenario-3

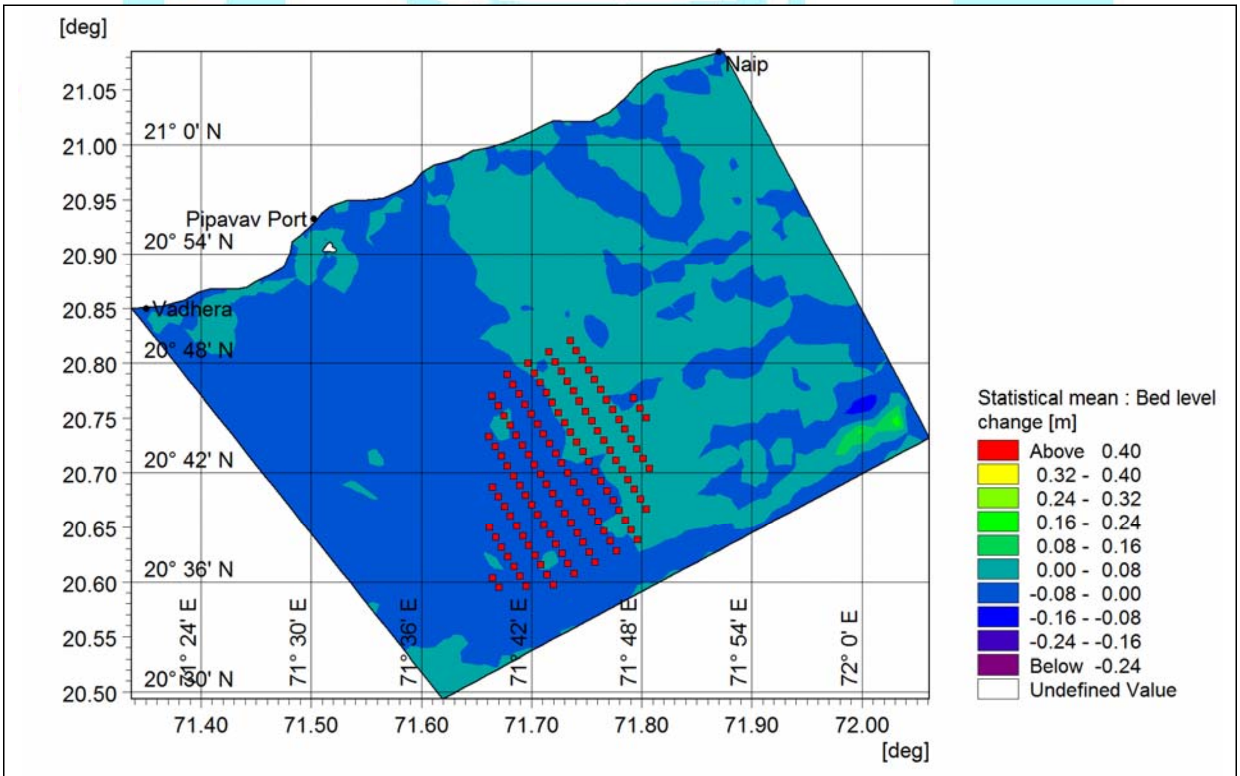


Figure. 4.19 Difference between monthly averaged Bed Level Change between Scenarios 1 and 3

Chapter 5: Bird Migration and Distribution

5 DISTRIBUTION OF MIGRATORY BIRDS

Introduction:

Wind-generated electricity is renewable and generally considered environmentally clean, and recent technological advances and tax subsidies have allowed commercial wind generation to compete with energy produced from fossil fuels and nuclear power (Gipe, 1995; Redlinger *et al*., 2002). Harnessing wind energy is an affordable form of power generation that is pollution-free with relatively less environmental impacts. These advantages have lead to a dramatic increase in its popularity in recent years and have resulted in the proliferation of wind farms around the world (Osborn *et al*., 2000). Bird fatalities caused by human-made infrastructures (power lines, communication towers, wind turbines) are widely reported from around the world (Erickson *et al*., 2005; Manville, 2009). Wind farms affect birds mainly through collision with turbine blades (Drewitt and Langston 2006; Lekuona & Ursua 2007) or disturbance displacement (Drewitt and Langston, 2006). Observed impacts vary geographically due to varying topography, habitat, weather conditions, flyways, species diversity and species abundance (GAO, 2005).

Collision Risk:

The collision risk at offshore wind farms is generally considered to be low, except for facilities erected at migratory “bottle-necks” and at sites with large, less maneuvrable species, such as those that habitually soar in thermals. The impact of such losses can be particularly severe in large, long-lived species with low natural mortality rates and low productivity. For such, even a small increase in mortality may have a devastating effect on population levels. Most seabirds and waterfowl and many waders are long-lived species.

Longer rotor blades results in significantly higher tip-speeds and higher turbulence. In the offshore, the birds’ acoustic perception will be hampered by background noise from waves and wind. Additionally, nearly all seabirds and water-fowl fly low above the water surface; mostly <100 m, often<50 m, especially during foraging trips or when moving between roosting or breeding sites and feeding areas, i.e. during short sea crossings (e.g. Dirksen *et al*. 1996, 1998a, van der Winden *et al*. 1999, Krüger & Garthe 2001). Many terrestrial species also tend to cross the sea at low altitudes. There are considerable differences in characteristic flight altitude between different taxonomic groups.

However, as high-flying waders are difficult to spot and low-flying waders are mainly seen in headwinds, when many sea and coastal birds fly in lower altitudes than in tailwinds, the real percentages of high-flying birds is probably much higher. In general, most migrating waders tend to fly at greater heights. But, when moving between high-tide roosts and low-tide feeding areas waders generally fly at altitudes below 100 m. The greatest collision risk occurs at night, especially on moonless nights or in unfavourable weather conditions such as fog, rain, and strong wind. These conditions also tend to reduce the flight altitudes of migrating birds. Radar studies of behavioural responses to turbines on Lake Ijsselmeer, The Netherlands, indicate that some ducks will fly between turbines in moonlight, but around the outside of turbine clusters in conditions of poor visibility. This suggests that some, probably local, birds can adjust their behaviour to the presence of turbines (Spaans *et al*. 1998). Nevertheless behavioural observations have shown that most birds fly closer to rotor blades at night than during the day and that birds collide with them at night than by day (Winkelman 1990).

Long-term habitat loss: disturbance and barrier effects

Disturbance by operating wind turbines can exclude birds from suitable breeding, roosting, and feeding habitats. Whereas direct loss of habitat due to the foundations of the turbines seems to be of no major concern for birds, numerous studies have shown that wind farms may indirectly affect a much larger area. In general, migrants, especially the larger species, seem to be more affected than residents. Moreover, there are indications that wind farms may act as barriers: either between ecologically linked areas, such as roosting and feeding sites of migrants.

Black-headed Gull:

The Black-headed Gull breeds in southern Greenland and Iceland, through most of Europe and Central Asia to Kamchatka, extreme southeast Russia, and northeast China, and marginally in Northeast America. The northern population of this species is migratory. Birds from Central Asia migrate south to India, Malaysia, and the Philippines (Fig 5.1).

Black Tern:

The Black Tern which occurs in the Indian subcontinent is distributed from Southern Scandinavia to southern Spain, east through Europe and Western Asia to central

Mongolia. It is a vagrant to the Indian subcontinent, with scattered reports from Delhi, Punjab, Gujarat, Andhra (Fig 5.2). The preferred summer habitats of the black tern are inland marshes and sloughs with fairly dense cattail or other marsh vegetation and pockets of open water. These wetlands are often shallow in nature.

Bridled Tern:

The race *antarcticus* of the pelagic Bridled Tern that occurs in the Indian subcontinent is distributed in the Red Sea, the Persian Gulf, and the southern Indian subcontinent, south to Seychelles, Aldabra, Madagascar, and Mascarenes, and perhaps Maldives (del Hoyo*et al*. 2017). In the Indian subcontinent, it breeds on the island off the Maharashtra coast (Vengurla rock), Kerala. Post breeding, it disperses to the coasts of Pakistan, west and east India, Andamans, and Sri Lanka (Fig 5.3). This bird is migratory and dispersive, wintering more widely through the tropical oceans. It has markedly marine habits compared to most terns.

Caspian Tern:

The Caspian tern frequents shallow waters of lagoons, coral reefs, and estuaries along with all types of shoreline and also far out in the open sea. It is locally common across North America, northern Europe, Africa, Madagascar, Central, and South Asia, Australia, and New Zealand disperse widely during winter (del Hayo*et al*., 2017). In the Indian subcontinent, it occurs in winter along the sea coast, on large lakes, and reservoirs of saltworks. It breeds in Baluchistan, Western Gujarat, and Sri Lanka (Ali and Ripley 1987). The migration pathway of Caspian Tern fall in close proximity to the windfarm area (Fig 5.4).

Common Tern:

Common Tern breeds from North America, northern South America, Atlantic islands, Europe, North Africa, West Africa, Middle East, Black and Caspian Seas to Yenseley Valley, and winters south of Tropic of Cancer (Fig 5.5).

Gull Billed Tern:

Breeds in Southern Europe and Western & Northern Africa (South to Mauritania, East to Tunisia) East through the Middle East, Kazakhstan, and North Indian subcontinent to Transbaikalia and Northeast China (Northeast inner Mongolia); winters from tropical Africa through the Persian Gulf to India. In the Indian subcontinent, it occurs in jheels, rivers, and coastal mudflats (Fig 5.6).

Lesser Crested Tern:

The Lesser Crested Tern keeps to offshore waters and is seldom seen on the coast. It breeds along the red sea, Pakistan, Lakshwadeep, and Maldives, and winters south to Sri Lanka and South Africa. The range extends along with southern Asia, from the Persian Gulf of the Straits Malacca, Sumatra, and Java (del Hoyo*et al*., 2017). In the Indian subcontinent, it occurs in offshore waters of the eastern and western coast, Lakshadweep, Andaman, and Nicobar Island, Maldives, and Sri Lanka. It breeds on islets off the entire coast (Fig 5.7).

Sandwich Tern:

The Sandwich Tern, essentially a maritime species, breeds from Europe to the Caspian Sea and winters from the Caspian, Black, and Mediterranean Seas to the coasts of the west and south Africa and from the southern Red Sea to northwest India and Sri Lanka (del Hoyo*et al*., 2017) In the Indian subcontinent, it occurs along the coasts of Pakistan, Gujarat, Maharashtra, Goa, Tamil Nadu, Orissa and Sri Lanka (Ali and Ripley1987) (Fig 5.8).Sandwich terns inhabit a variety of habitats, including sandy or rocky oceanic beaches, oceanic cliff sides, estuaries, and large inland lakes.

Sooty Tern:

Sooty Tern that occurs in the waters of the Indian subcontinent is distributed in the southern Red Sea, the Gulf of Aden, and the Indian Ocean east to west Pacific Ocean (del Hoyo*et al*., 2017).In the Indian subcontinent, it occurs in Lakshadweep (breeding), Vengurla Rocks (off south Maharashtra coast), and probably Maldives, Andamans, and west and south Sri Lanka (Fig 5.9).

Pallas's Gull:

Pallas's Gull breeds in a few scattered localities from the black Sea east to Balkhash Lake and i some locations in northwest Mongolia, possibly also in China and Tibet. It winters along the coast of Mediterranean, Red Sea, the south Caspian Sea, south-central Ethiopia, northern Indian Ocean, east to Myanmar (del Hayo*et al*., 2017) In the Indian subcontinent, it occurs along the sea coasts of the mainland, Sri Lanka, and the Maldives; occasionally inland on large rivers and lakes from the Indus to the Gangetic Plains, northeast India, Bangladesh, and rarely central India (Ali and Ripley 1987) (Fig 5.10).

Masked Booby:

Two races of Masked Booby occur in the waters of the Indian subcontinent (del Hoyo*et al*. 2017). Melanops breeds in Islands of southern red Sea and the western Indian Ocean. In the Indian subcontinent, it occurs off Pakistan, and occasionally western Indian seaboard and Sri Lanka (Ali and Ripley 1987) (Fig 5.11).

Little Stint:

The little stint breeds in north Scandinavia through south Novaya Zemlya, northwest, and central Siberia to the New Siberian Islands and Yana river. It winters from the Mediterranean and Africa through the Arabian Peninsula and the Persian Gulf east to the Indian subcontinent and Myanmar, with small numbers in southeast Britain and Madagascar (del Hoyo*et al*. 2017). It is a winter migrant to the Indian subcontinent, frequenting shores, mudflats, and marshes in the mainland (Fig 5.12).

Marsh Sandpiper:

The Marsh Sandpiper breeds in eastern Romania, eastern Ukraine, and western Russia through North Kazakhstan and southern Siberia to Transbaikalia, northeast China, and Ussriland, with isolated populations in the Baltic States west to Poland. It winters from the Mediterranean and sub –Saharan Africa through the Persian Gulf and South Asia to Indonesia and Australia (del Hoyo *et al*. 2017). In the Indian subcontinent, it frequents marshes, margins of ponds, inundated fields, and mudflats in the mainland, Sri Lanka, Andaman Islands, and Maldives (Ali and Ripley 1987) (Fig 5.13).

Sanderling:

The race *alba* of the Sanderling that occurs in the Indian subcontinent breeds in extreme north Canada, Greenland, and Svalbard to Severnaya Zemlya Island and Taymyr peninsula. It winters on the coasts of the west and south Europe, Africa east across the southern parts of Asia to Australasia, and some tropical Pacific Islands (del Hoyo*et al*. 2017). In the Indian subcontinent, it occurs along sandy shores of the mainland, Nicobars, Lakshadweep, and Maldives. Occasionally, it is seen on inland lakes in Nepal, Kashmir, Punjab, and Bihar (Ali and Ripley, 1987) (Fig 5.14).

Ruff:

The Ruff breeds in the northwest and northern Europe, east through Siberia to Chukotskiy peninsula, Russia, and Sea of Okhotsk in the western Pacific. It winters from Western Europe, Mediterranean, and sub-Saharan Africa through the Middle

East to the Indian subcontinent and Southeast Asia, and also Greater Sundas and Philippines (del Hoyo*et al*. 2017). It is one of the most frequent winter visitors to the Indian subcontinent, occurring in mudflats, marshes, and wet paddy stubble in the mainland, Sri Lanka, and the Maldives, wintering mainly in the Gangetic plains, coastal southern India, and Sri Lanka (Ali and Ripley, 1987) (Fig 5.15).

Eurasian Spoonbill:

The race *leucorodia* of the Eurasian Spoonbill that occurs in the Indian subcontinent breeds n south Spain, Holland, and southeast Europe to Central and East Asia, extending southward to the Persian Gulf, India, and Sri Lanka. It winters in the west and east Africa, and southeast China (del Hoyo *et al*. 2017). In the Indian subcontinent, it is partly resident and nomadic, and partly a winter migrant. It frequents marshes, rivers, and jheels inn the plains and plateaus in the mainland, Sri Lanka (Ali and Ripley, 1987) (Fig 5.16).

Demoiselle Crane:

The Demoiselle Crane occurs in central Eurasia, from the Black Sea to Mongolia and northeast China. It winters in the Indian subcontinent and sub-Saharan Africa from Lake Chad to Ethiopia (del Hoyo*et al*. 2017). In the Indian subcontinent, it is a winter visitor to northwest India, and the northern plains with records eastward to Assam and Bangladesh, and south to Andhra Pradesh and Karnataka. Passage through northwest and the north-central Indian subcontinent has been reported (Ali and Ripley, 1987) (Fig 5.17).

Glossy Ibis:

The Glossy Ibis has a wide discontinuous breeding distribution from southern Europe, Africa, and Madagascar, to central and South Asia, Philippines, Sulawesi, and Java; southern New Guinea and Australia; also the Atlantic coast of North America and West Indies to north-central Venezuela. It occurs more widely as a vagrant (del Hoyo*et al*. 2017). It is a resident or winter migrant in the Indian subcontinent, frequenting marshes and river banks in Pakistan, India, Bangladesh, Sri Lanka, and the Maldives. Recent breeding records obtained from Vedathangal and other sites in south India (Fig 5.18).

Great White Pelican:

The Great White Pelican breeds from Eastern Europe to western Mongolia, and winters in western Africa and Iraq to northern India. It is also resident in Africa, south of Sahara, and in single sites in northwest India and South Vietnam (del Hoyo*et al*.

2017). It is a winter migrant to the subcontinent, mainly Pakistan, northern and central India, Gangetic Plains, Assam valley, and Bangladesh. A solitary breeding record was made from Kachchh (Fig 5.19).

Greater Flamingo:

The Greater flamingo occurs in southern Spain and southern France, east to Kazakhstan; south through north, west, and East Africa, and through the Middle East to India and Sri Lanka (del Hoyo*et al*. 2107). The Indian subcontinent supports both resident and migratory populations of the species. It breeds in the Great Rann of Kachchh, and breeding has also been reported from Sambhar Lake, Rajasthan, and Thol Lake, Ahmedabad, in Gujarat. It frequents brackish lakes and lagoons, sea coasts, estuaries, and mudflats of the mainland and Sri Lanka (Ali and Ripley, 1987) (Fig 5.20).

Garganey:

The Garganey breeds in northern Eurasia, and winters in Africa, South Asia, and Southeast Asia (del Hoyo*et al.* .2017). The Garganey is of the commonest and most widespread migratory ducks in India, frequenting marshes, reservoirs, and lakes in the mainland, and in Lakshadweep, the Maldives and Sri Lanka (Fig 5.21) (Ali and Ripley, 1987).

Conclusion:

The studies to date do not give a comprehensive picture of avian migration in the study area. Thus, only sporadic records are available, and the concern records pertaining to the study area are described above.

As per the Balchandran *et al.*; (2018), the altitude of the migratory path has not been mentioned. Mostly the migratory avifauna take-off and attains high altitude for long-distance migration. Local migratory species may fly short distances on lower altitudes, which may have wind farms as potential hazards and can cause the collision. However,many times, avifauna tends to fly, avoiding the visible obstacle and avert the accident. Overall it may be concluded that this area will have very few species maneuvering through the region (considering the height of the windmills). However, mitigations are suggested to avoid any residual impacts.

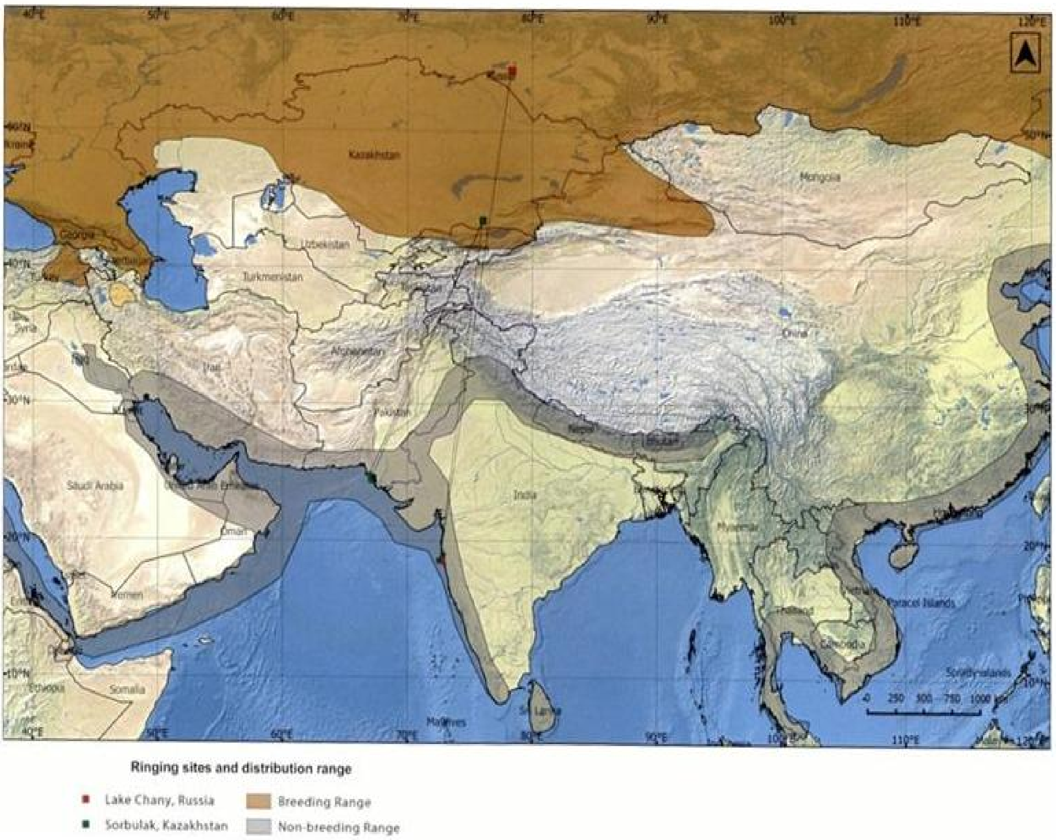


Figure 5.1: Black-headed Gull distribution and migration pathway

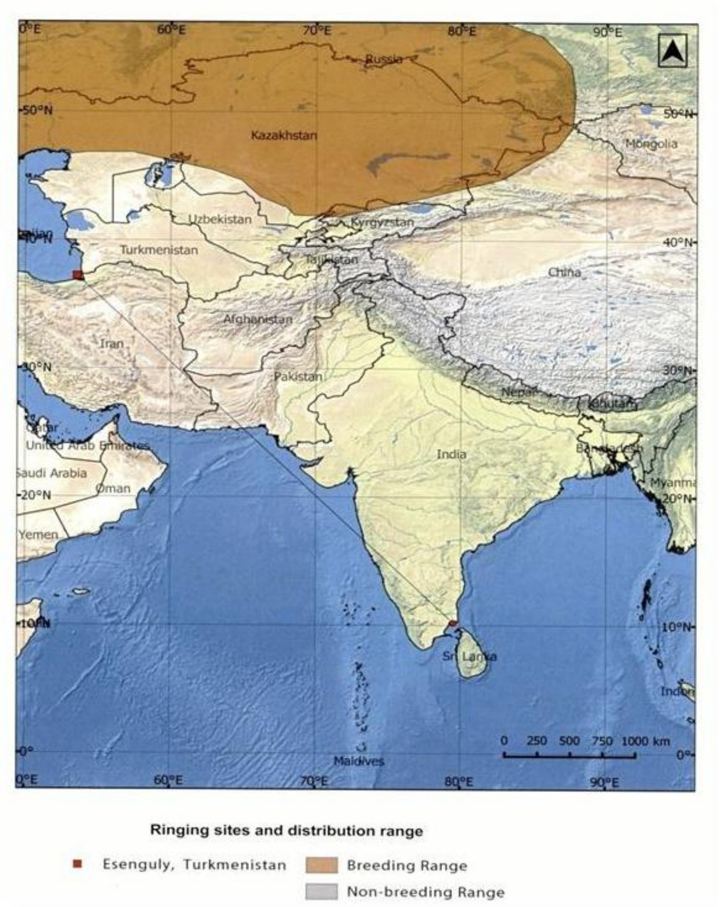


Figure 5.2: Black Tern distribution and migration pathway

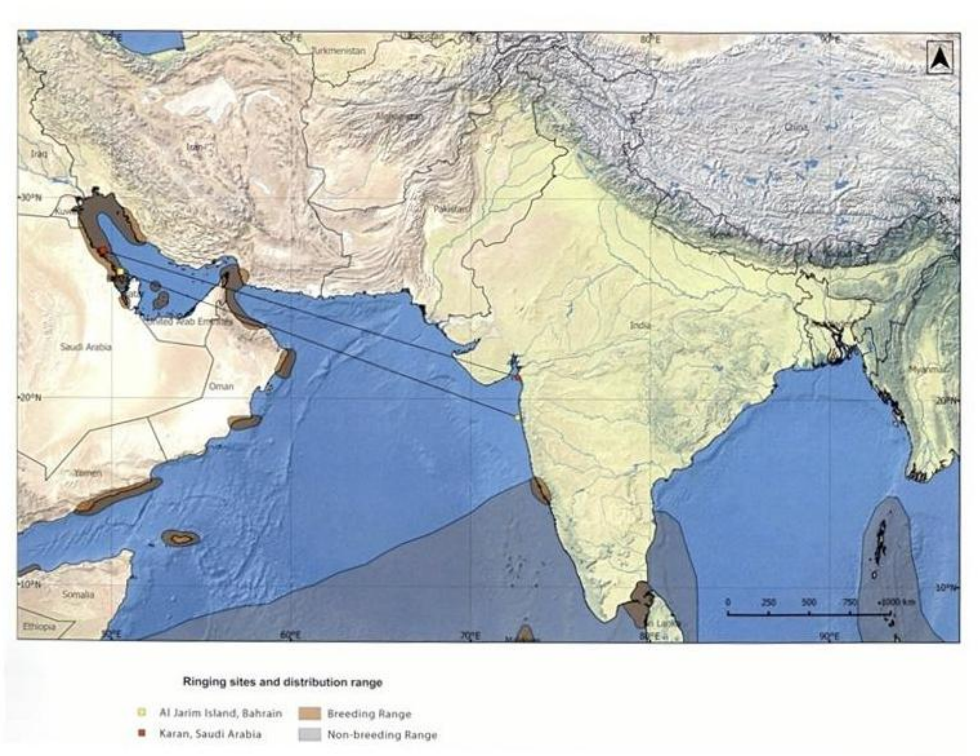


Figure 5.3: Bridled Tern distribution and migration pathway

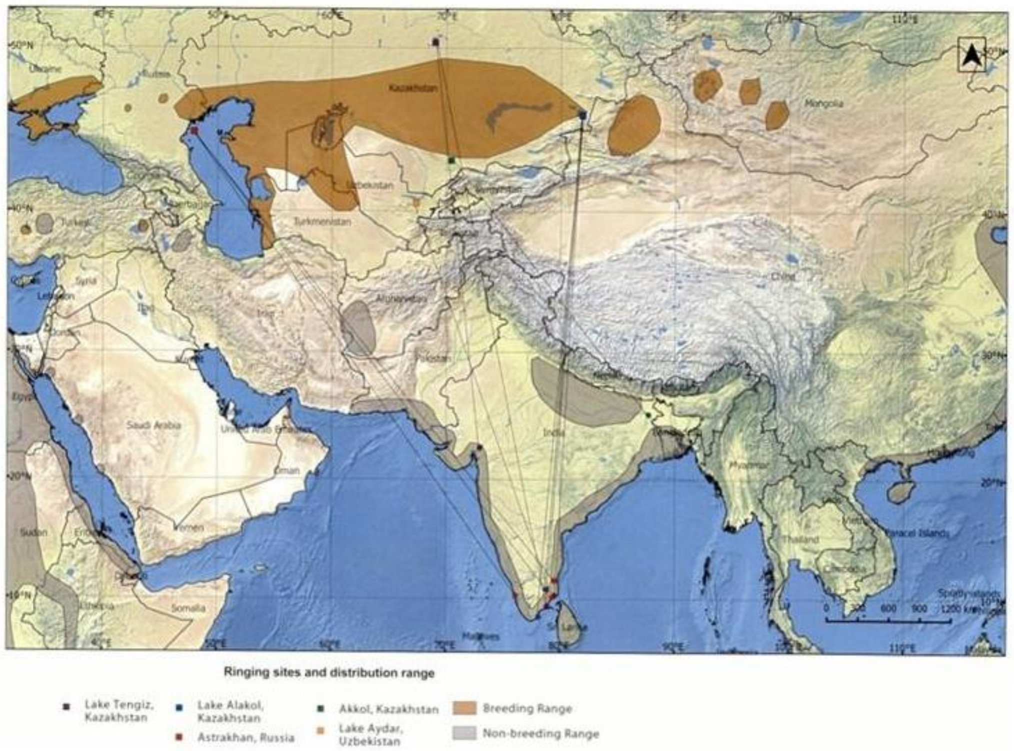


Figure 5.4: Caspian Tern distribution and migration pathway

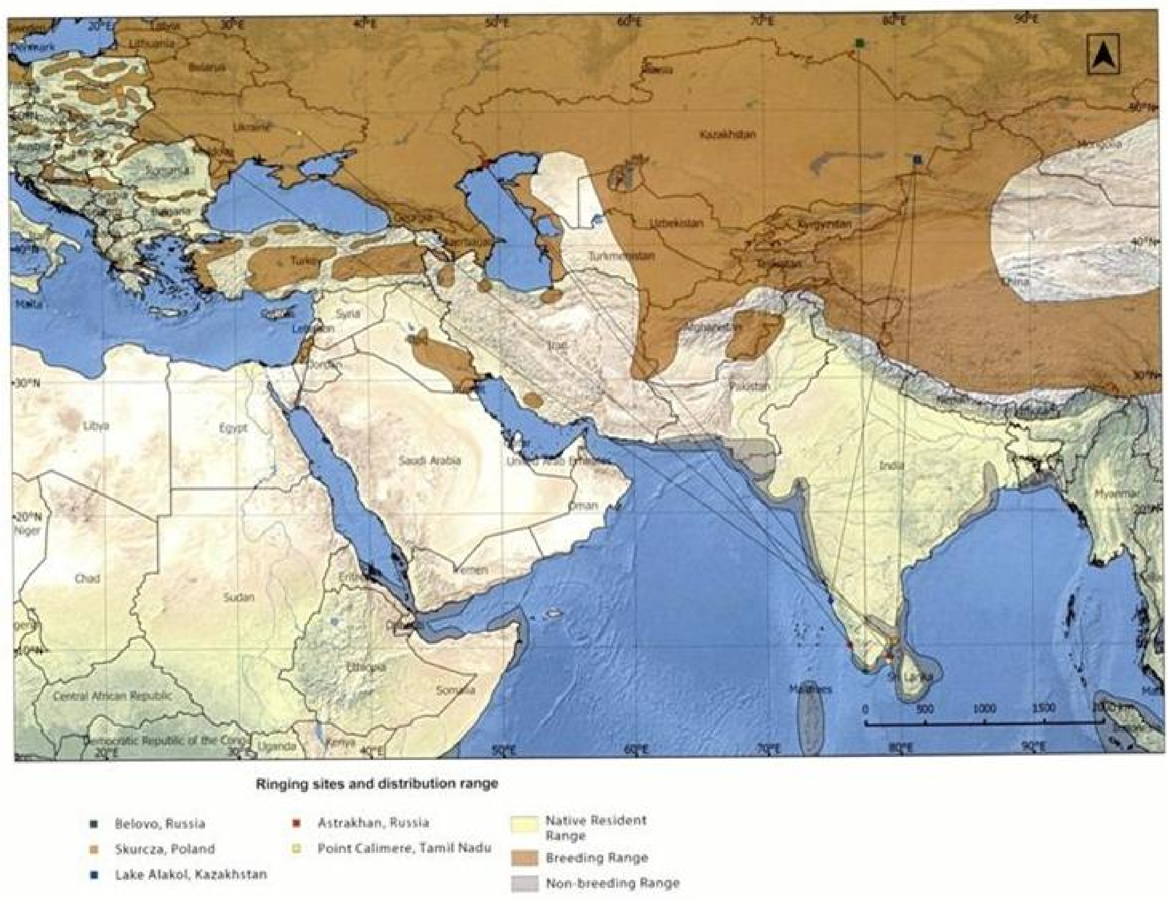


Figure 5.5: Common Tern distribution and migration pathway

Figure 5.6: Gull Billed Tern distribution and migration pathway

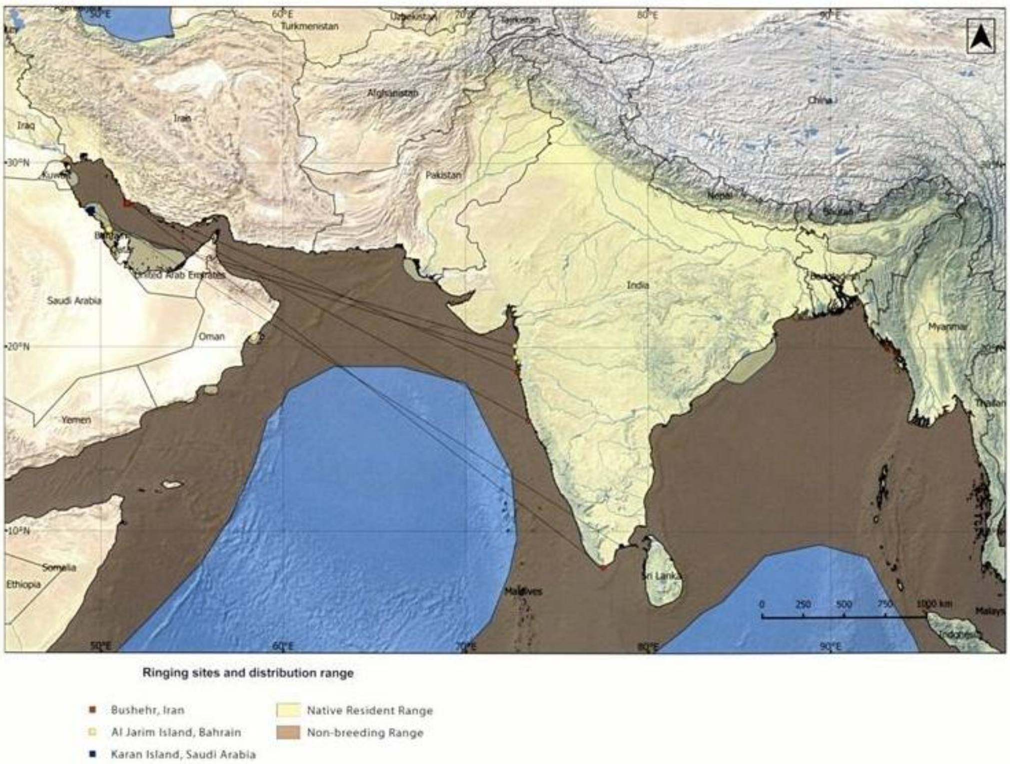


Figure 5.7: Lesser Crested Tern distribution and migration pathway

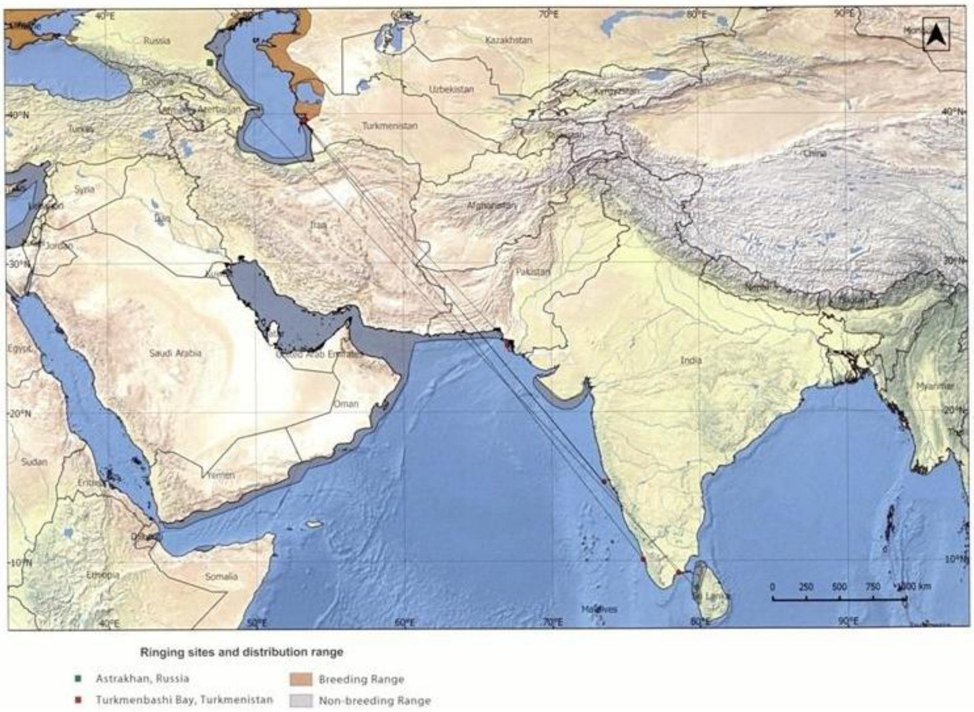


Figure 5.8: Sandwich Tern distribution and migration pathway

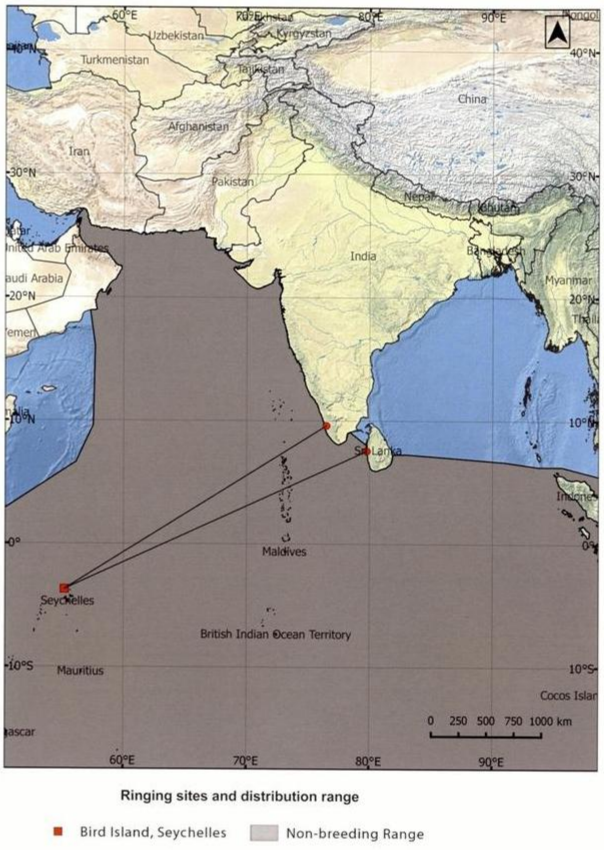


Figure 5.9: Sooty Tern distribution and migration pathway

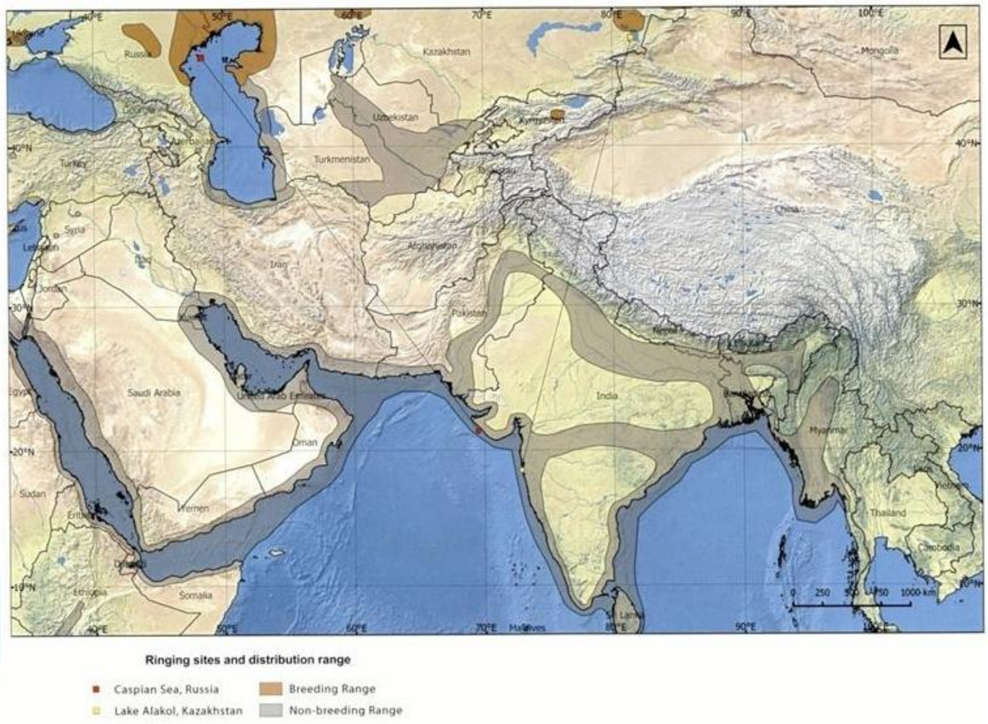


Figure 5.10: Pallas's Gull distribution and migration pathway

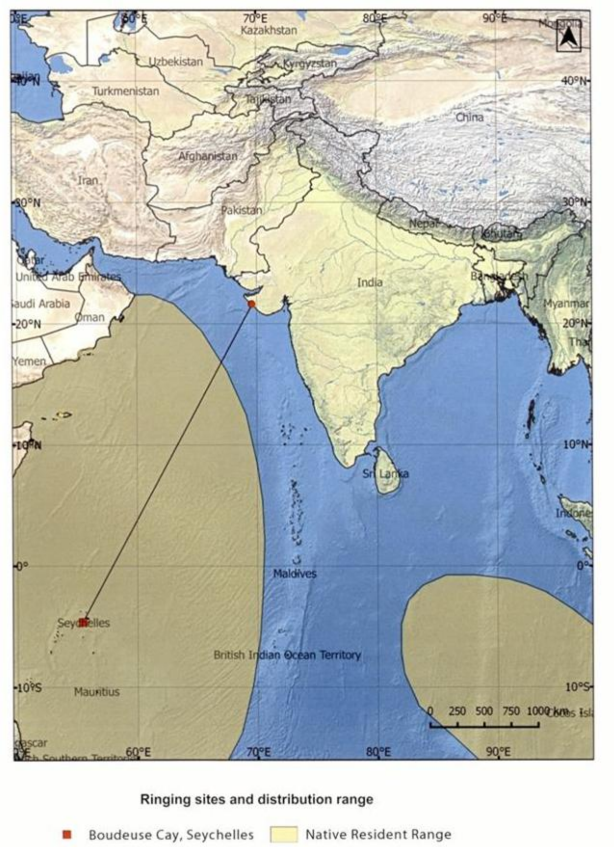


Figure 5.11: Masked Booby distribution and migration pathway

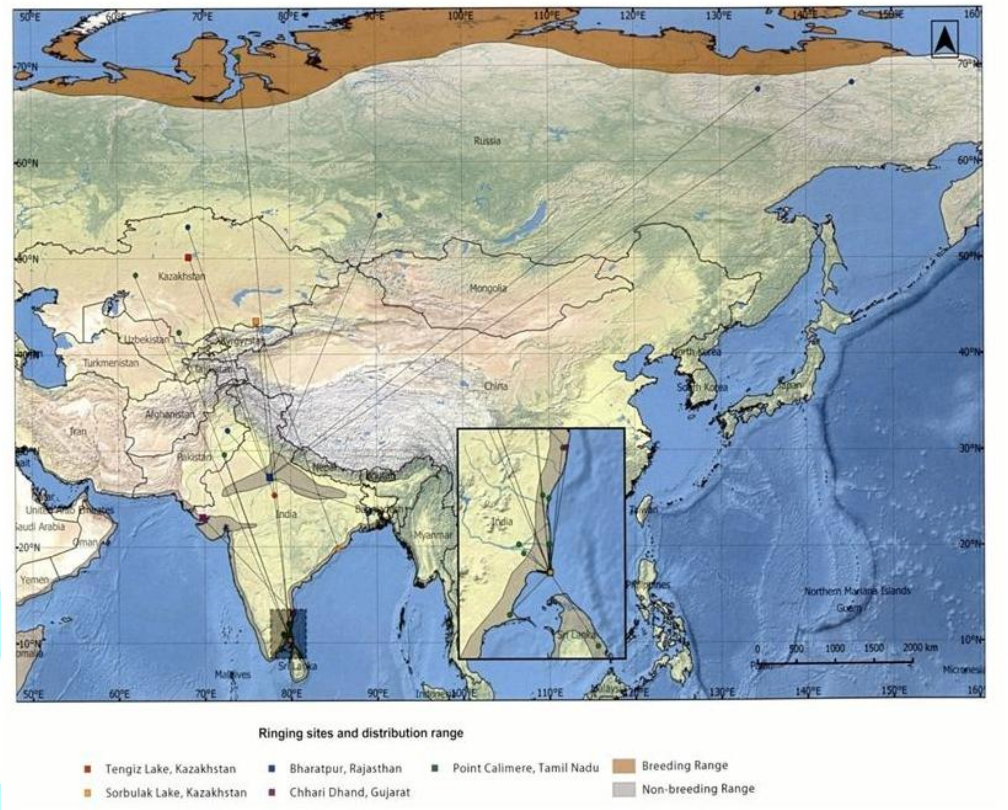


Figure 5.12: Little Stint distribution and migration pathway

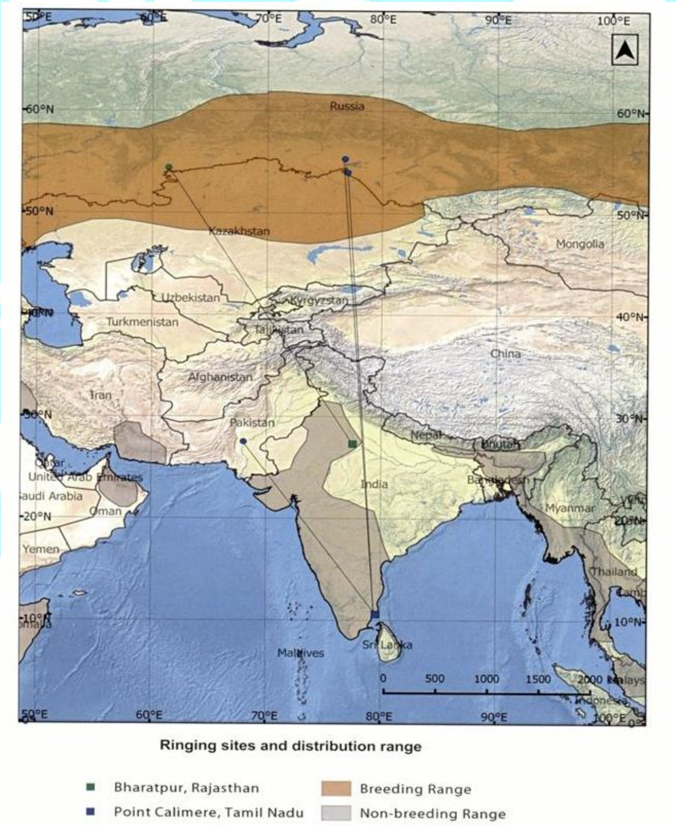


Figure 5.13: Marsh Sandpiper distribution and migration pathway

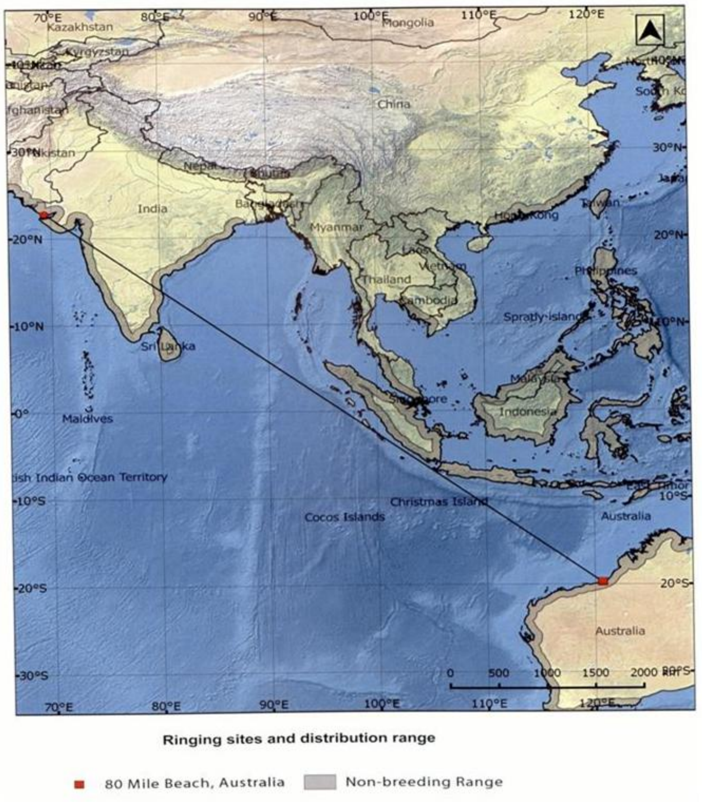


Figure 5.14: Sanderling distribution and migration pathway

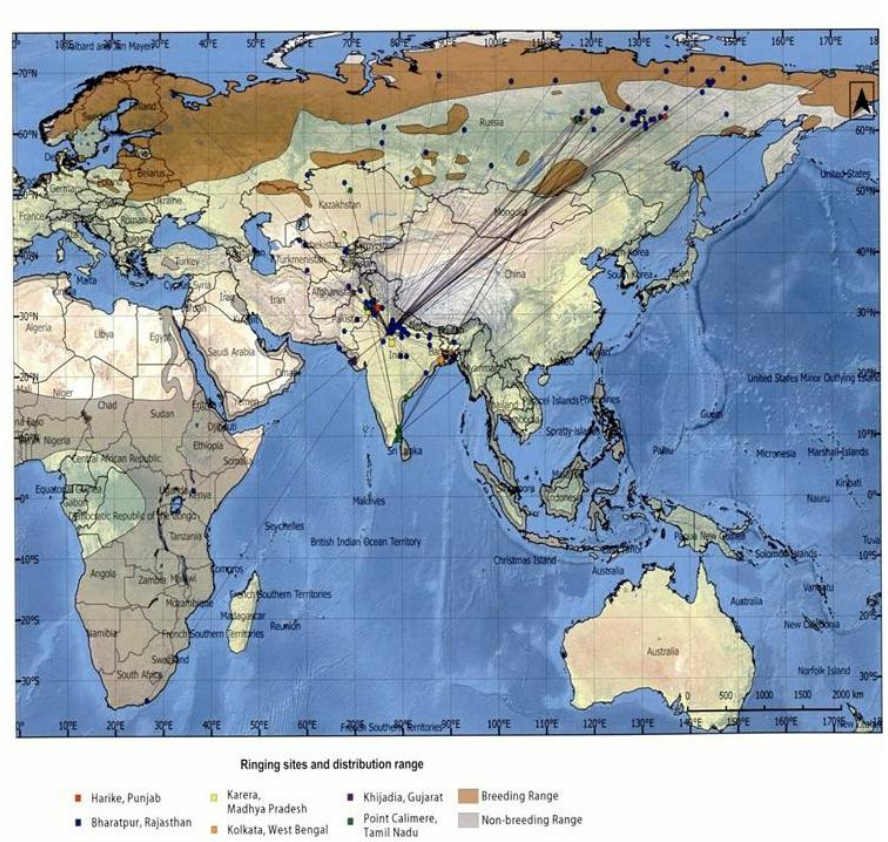


Figure 5.15: Ruff distribution and migration pathway

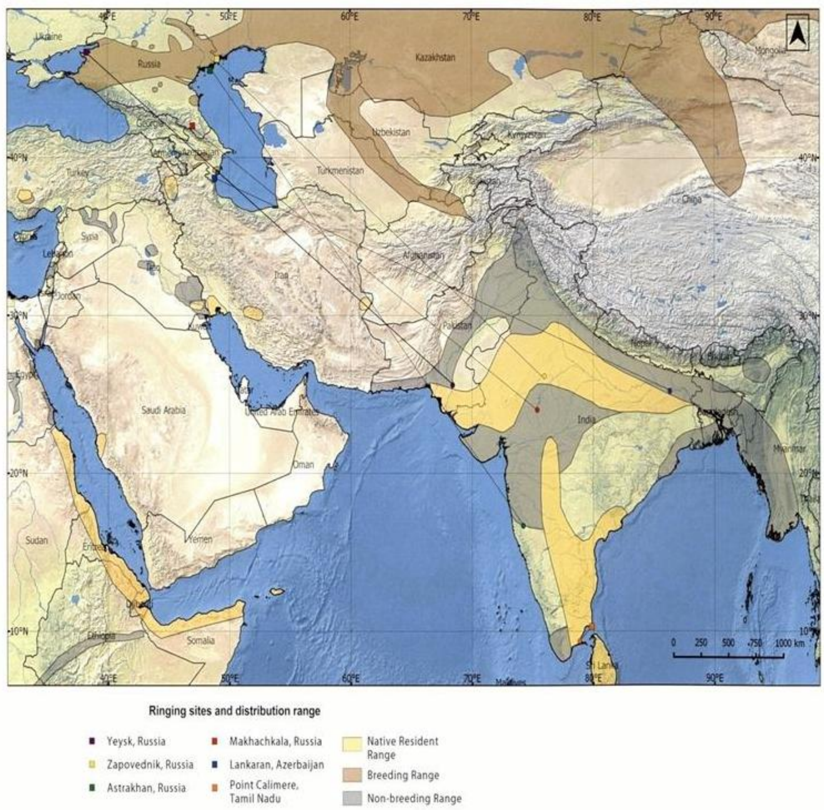


Figure 5.16: Eurasian Spoonbill distribution and migration pathway

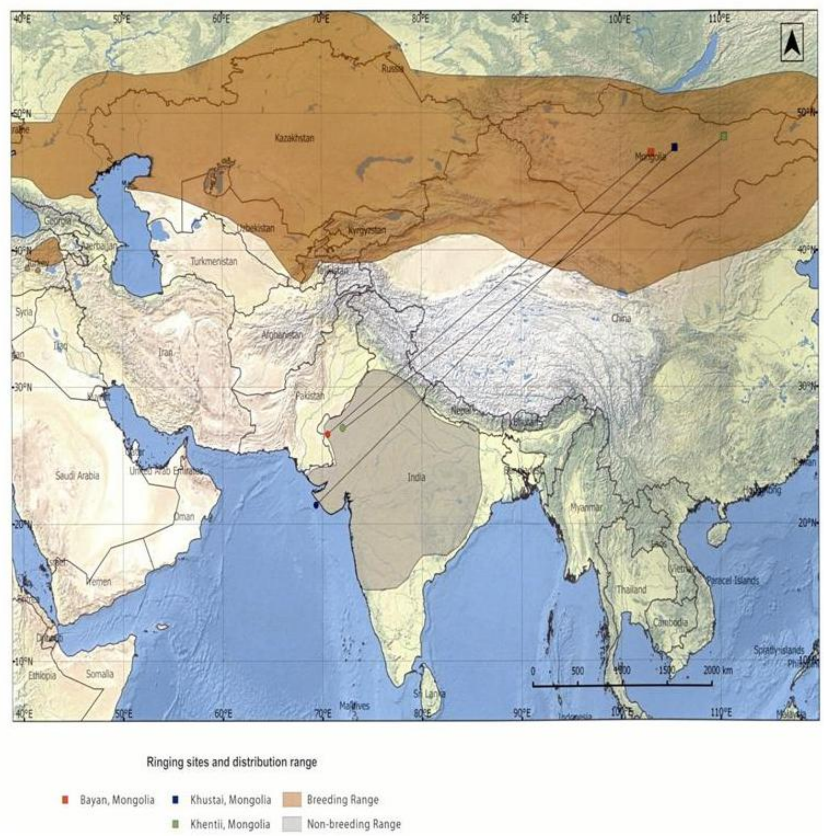


Figure 5.17: Demoiselle Crane distribution and migration pathway

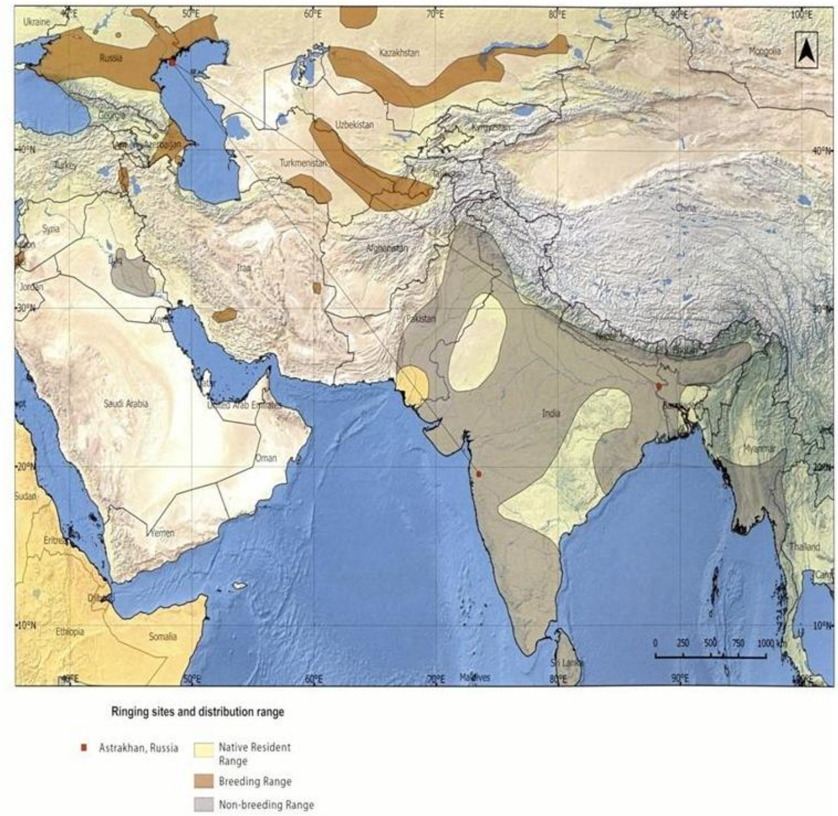


Figure 5.18: Glossy Ibis distribution and migration pathway

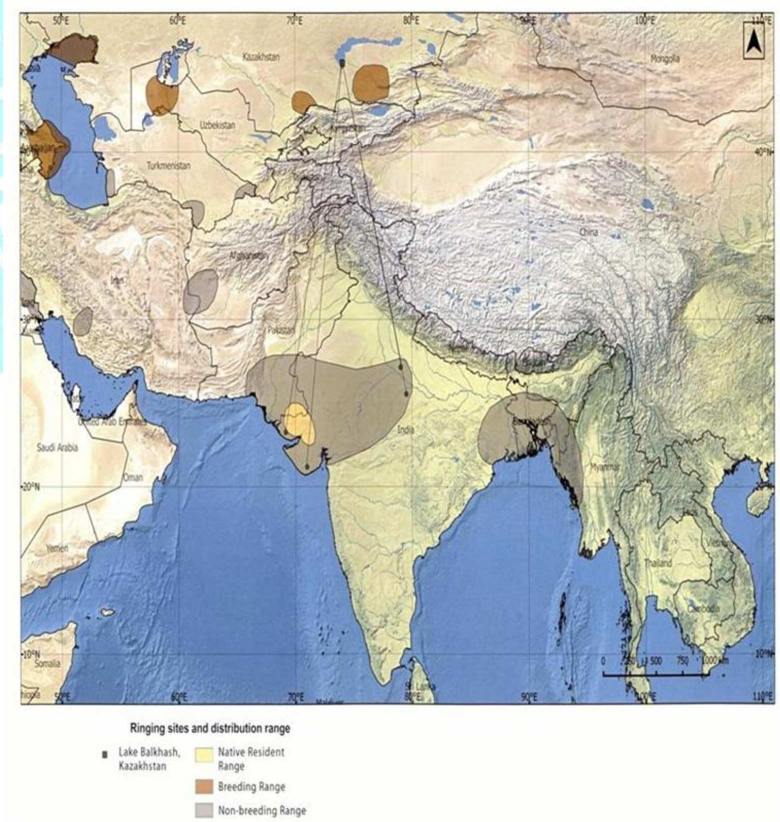


Figure 5.19: Great White Pelican distribution and migration pathway

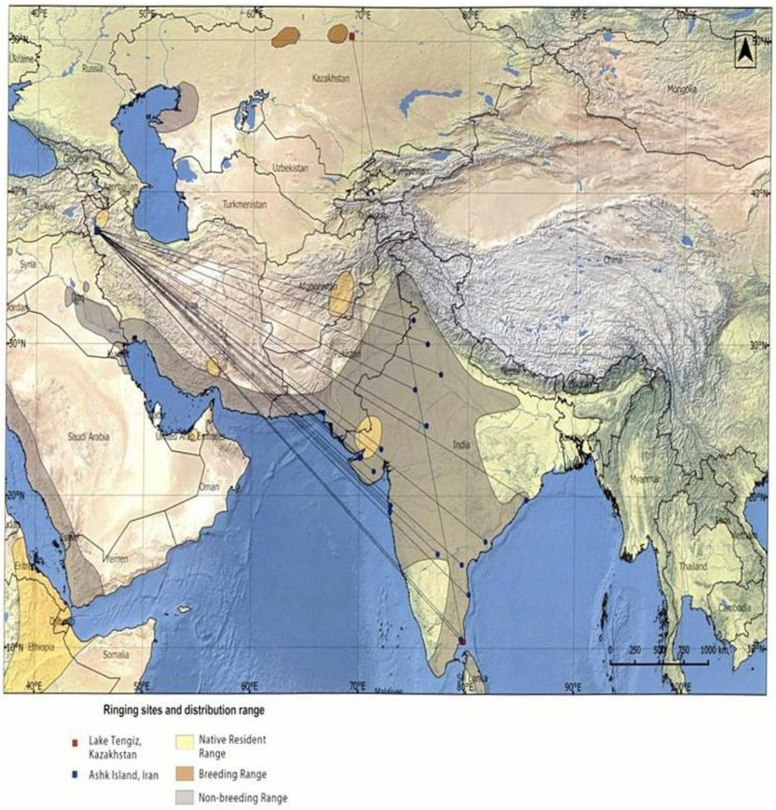


Figure 5.20: Greater Flamingo Pelican distribution and migration pathway

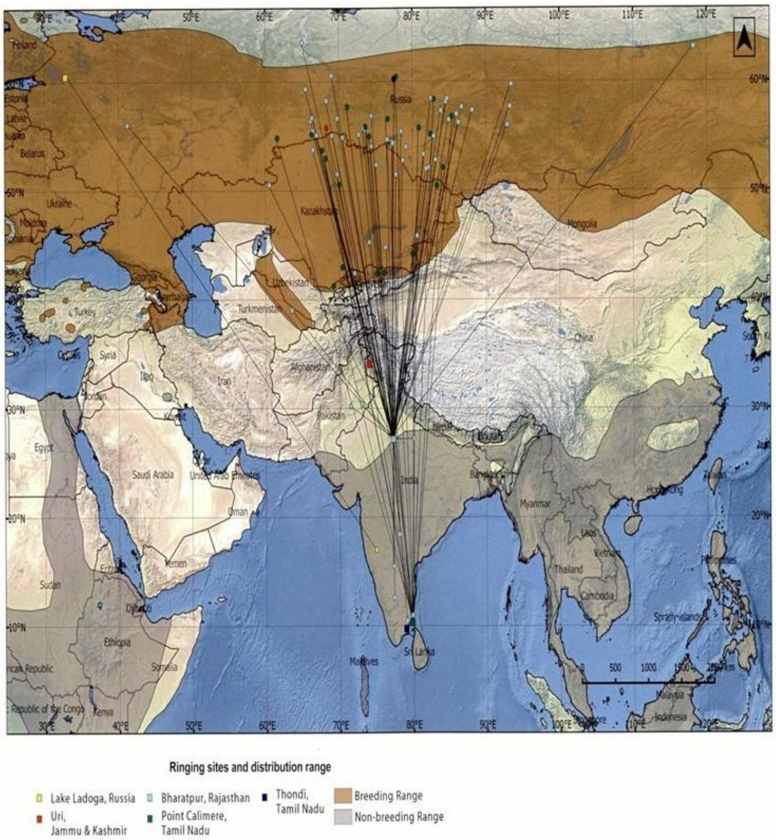


Figure 5.21: Graganey distribution and migration pathway

Chapter 6: Anticipated Impacts

6 ANTICIPATED IMPACTS ON THE MARINE ENVIRONMENT

The impacts of the project on the marine environment will be during construction, operation, and decommissioning.

6.1. Construction phase

The primaryimpact sources during construction will be:

- Sound and light emissions by barges/vessels and machinery during construction
- Noise in connection with pile driving for monopile foundations
- Temporary/permanent loss of habitats due toconstruction activities and an increase in sediment load
- Pollutant emissions

During the construction phase, impacts in the wind farm area and the immediate surroundings are expected to be more intense but of a shorter duration. The significant impact of pile driving mostly results in the disturbance of benthic habitat because of the dislodging of the sediment. Resettlement or sedimentation is another inevitable impact in the vicinity of piledriving. In addition, the construction works will entail an impact on seabed caused by trenching forpower cables andother impacts such as increased navigation of constructionvessels, limitations to the commercial fishing, etc.

As the top seabed layer in the entire windfarm area consists of predominantly medium-coarse grained sand with a high settling velocity, no significant environmental impacts from suspended sediment are expected. Besides, the project area has a high concentration of suspended sedimentsduring most of the time due to the interaction of high currents and the active seabed contours in the very dynamic marine environment.The absence of fine-grained and organic material in the sediment is also reflected in the total absence of bottom vegetationin the area.

6.1.1Impacts on Benthos

During pile driving operations, the removal of material from the seabed also removes the animals living on and in the sediments, which are collectively called as ‘Benthos’. The initial reduction in abundance, species diversity, benthic biomass as well as recovery of the lost biota varies with scale and duration of disturbance, local hydrodynamics, and associated transport processes. It lacks similarity to the habitat that existed prior to the project.

- Pile driving will initially result in complete removal of the surface sediment-associated biota in an area of 4808 m^2. As the abundance and diversity of benthic organisms in the baseline revealed very low faunal occurrence; thus, the impacts will be of low nature.
- Construction activities may lead to a patchy distribution of organisms, reflecting the differences between and the adjacent disturbed surfaces. Recolonization occurs within the area most likely by the migration of adults through transport on tidal currents.
- Increased sedimentation during the construction may pose significant harm to all other organisms, including macroalgae. Generally, the destruction of seaweed is irreparable. It may cause ecological losses, but their seasonal occurrence gives a chance for survival.
- The vertebrates and invertebrates are directly dependent on the macroalgae mainly for shelter and support other life forms of the ocean, such as herbivorous fish, crabs, sea urchins, etc. Thus any impact over seaweed diversity may influence drastically other trophic levels disturbing the community structure.
- Disturbance of the upper layers of the seabed causing short-term re-suspension of sediments, re-mineralization of nutrients and contaminants, and re-sorting of sediment particles. A short-term attraction of carrion consumersare expected during the construction phase.
- Increased suspended sediments can affect filter-feeding organisms, such as shellfish, through clogging and damaging feeding and respiratory organs.
- Construction activities maytemporarily increase the population of undesirable species, such as viruses and parasites.

6.1.2Impacts on Pelagic Environment

- Resuspension of sediments is one of the potential sources of nutrients that are of greater concern resulting in temporary eutrophication of surface waters.
- Project activity may result in increased turbidity leading to a decrease in the dissolved oxygen (DO) in the water column during the operation in progress.
- Increase in suspended sediment not only limit the light penetration, but sediment loads and turbidity levels create adverse effects on pelagic marine producers and consumers by reducing the euphotic zone of the water column.Increased suspendedsediments in water also affect the filter-feeding organisms, such as zooplankton.The area already has high turbidity load, and low diversity and construction activities are mostly temporary and would last for a short-term only; thus, the impacts will be of low nature.
- Potential threatsmay include an increase in events such as algal blooms, harmful algal blooms, jellyfish blooms due to construction activity.
- There is a potential threat of the introduction of alien/ invasive and undesired species due to long-distance vessel movement and ballast water exchange.
- Adult fish are likely to move away from or avoid areas of high suspendedsolids, such as project sites unless food supplies are increased as a result of increases in organic material.
- Physiological stress to marine fish and commercially important species by the creation of short-term higher sediment loads in the water column is expected. However, as the abundance of fish in the region seems to be low, the impacts will be of low nature.
- Increased bioaccumulation of contaminants in commercially important species might occur as some of the contaminants (such as metals) at the baseline level show significant high values.

Most of the impacts of the construction phase on the pelagic, as well as the benthic environment, are envisaged to be of low nature, and also, the effects are presumed to be temporary. However, there might be some impacts that might be a long term, such as stress on fishes as well as any change in their breeding phenology. Secondary effects of bio-accumulation of contaminants might also remain for a long duration.

During the operation phase, most of the impacts should be of low significance as there are no emissions or discharges expected from the project activity. However, any unforeseen events such as accidents or oil spills or vessel collisions might result in significant impacts on the marine biodiversity of the region. These impacts can be considered of low significance since all the rules, regulations, and international best practices are followed along with the delineated management plans.

6.1.3 Noise

Provided that the monopile foundation type is selected, the most significant noise impact during the construction phasewill be from pile driving. Moreover, trenching of cables, possible excavation works, navigation, etc. will provide minor contributions to the noise impact. The noise is particularly expected to affect dolphins, whales,turtles, fish, and birds in the area. In connection with pile driving, sonic equipment will be used to actively scare away the mammals from the area. Furthermore, pile driving will start with small impacts and gradually be intensified to give the fish and mammals time to leave the area. Noise impacts during construction are expected to be temporary in nature.

6.1.4 Other impacts during construction

Installation of underwater power cables could cause electromagnetic fields and heat emissions, which influence marine organisms, especially fish. It may influence the behaviour and migration of the fish fauna because they use the Earth's magnetic fields for navigation. The cable could act as a barrier to the migration of fish and also have a scaring effect. Heat emission can change physicochemical conditions of sedimentary substrates leading to a positive impact on the reproduction of certain species, especially those adapted to warmer water.

- For safety reasons, the construction area will be closed off to prevent unauthorised traffic. This will entail the restriction of commercial fishing in the area.
- Due to the distance to the coast and the rough wave and current conditions, the area is not used for recreational activities. It will not have an impact on such activities.

- Dolphins have been regularly sited off the Gulf of Khambhat area, and whales are also known to occur, the increased turbidity and noise levels may drive away these highly sensitive species.
- Oil spills from construction vessels due to any unplanned eventuality is one of the major threat to the marine biota and can have a significant long-term irreversible loss depending on the extent, quantity, and expanse of spillage. However, the likeliness of this occurrence will be very low if proper management, precaution, and contingency plans are in place.
- Likely occurrence of unintended events such as vessel collision, accidents, fire, and other inadvertent events. These occur mainly due to lack of coordination, casual approach, un-managed activity, and associated activities (e.g.,vessel movement, fishing, etc.) and no timely communication within and between the stakeholders involved in nearby areas. These events may result in human casualties if there are no precautions taken.
- In the construction period, there will be increased traffic of vessels in the wind farm area and the navigation routes to and from the port of disembarkation. It is not possible to determine the extent of this traffic until the construction methodology is finalized. However, it is estimated that the number of vessels in the construction phase will vary between three and 15 on a daily basis.

6.1.5 Landfall site and Intertidal Area

There are no sensitive sites or essential species in the route of the proposed cable landing site. There are no corals or seagrass beds on the route, and there are no mangroves along the path. A small mangrove plantation patch that exists adjacent to the port but will not be affected by the activity.

The intertidal area where the cable landfall site is proposed has mostly mixed sandy and muddy shore. Some areas are rocky, and overall faunal diversity from the baseline is shows very low diversity and abundance. The impacts will be of low nature, and no significant loss is expected due to trenching and burial of cable route connecting to the main grid.The power cable route crosses the navigationalroute to the Pipavav port. While designing the burial depth of the power cable, the future developments of Pipavav port and the approach route deepening are to be considered.

6.2 Operation phase

Compared to the construction phase, the impacts during the operation phase will be permanent impacts in the entire lifetime of the wind farm. The impacts in the operation phase will primarily be caused by:

- The physical presence of the offshore wind farm
- Noise and vibration from the wind turbines

6.2.1 Physical presence of the offshore wind farm

The wind turbine foundations potentially affect the water movements,locally as well as in the area around the wind farm. Waves close to the shore will virtually be unaffected by the presence of the wind farm since the wind farm is more than 23 km from the coast. Similarly, the reduction of the current velocity by the wind farm is also assessed to be insignificant, and it will thus not impact sediment transportation or coastal morphology of the area. Locally around the foundations, increased turbulence with the risk of consequential erosion is expected. Putting down large rocks as scour protection around the foundations will limit the sand transportation close to the monopiles to a minimum. Physically speaking, foundations and scour protection, regardless of the choice of foundation type, cover minimum percent of the seabed in the wind farm area. This will cause a direct, though minimal, loss of habitat for seabed fauna. No bottom vegetation has been observed in the area. In the long term, the wind farm foundations will be colonised by more animals and plants than the surrounding soft seabed. This may potentially attract fish, which may find shelter between the rocks and food on the firm structures. As the changes in the physical conditions compared to the wind farm area are limited, no significant direct impacts on marine fauna in the area are expected.

However, in relation to birds, there is a risk of collision between rotating turbine blades and migrating birds. Also, there is the possibility that birds might avoid using the wind farm as a resting and foraging area due to the presence of the wind turbines.

Since the wind farm is more than 23 km away from the coast, the facility will not have an impact on viewscape, since it is not visible from residential areas or tourism sites.

Wind turbine blade tips, at their highest point, will reach up to 202 m. There are four airports near to the project site; i) Diu (~77 km towards west), ii) Daman (~111 km towards southeast), iii) Surat (~96 km towards east) and iv) Bhavnagar (~103 km towards northeast). Pipavav Shipyard Limited (PSL) at a distance of ~ 23 km has a designated helipad.

The sub-sea structures (mono-pile and scourprotection) are expected to be colonised by a range of species leading to a localised increase in biodiversity. The presence of the structures would also provide habitat for mobile species and, for example, serving as a refuge for fish. Although potentially viewed as a positive effect, this represents a change from the baseline ecology and may also increase the potential for colonisation by non-native species. Overall, the area available for colonisation would be low.

One of the most significant impacts on the marine environment originating from offshorewind parks documented till now is the so-called “reef effect” primarily caused by solid man-made structures founded on the seafloor. Offshore wind park turbines are functioningas artificial reefs, affecting the local surrounding ecosystem. Artificial structures may favour the settlement, reproduction, growth, andchange in biomass of native and fouling benthic species, which could influence the small and large scale processes in coastal and offshore systems.

Occurrence of reef effect in connection with the installation of the new hard substrate has high importance for the soft-bottom communities. Construction of a wind park adds a hard substrate on soft bottoms, and it completely changes existing seabed habitats. Native benthic communities are partly or completely replaced by fouling benthic communities associated with hard bottom structures. Considering the baseline conditions, it can be presumed that exceptionally few organisms will be able to colonies these structures because of high turbidity, sedimentary load in the water column, and strong hydrodynamic region in the area.

6.2.2 Noise and vibration from the wind turbines

During operation, the wind turbines will emit noise and vibrations to the surroundings. Underwater noise from the wind turbines will be audible to dolphins and whales at a distance of 100-200 m. At a distance of 1,000 m, the noise will be too low for Dolphins to hear it, but Whales, however, may be able to hear the wind turbines at this distance. The impact zone is thus limited, and the noise level is furthermore too low to cause behavioural reactions, to affect animal communication, or to cause temporary physical harm to the hearing of marine mammals. It is uncertain whether a possible choice of a larger wind turbine will entail more noise. However, it seems reasonable to expect that a possible increase in the noise level will primarily be in the lower frequency range below 100 Hz. As neither mammal species is assumed to be particularly sensitive in this frequency range, it is doubtful if the choice of a larger turbine will have a different effect.

Baseline noise and vibration studies show that impact is restricted to 1 kilometer at the most and will only affect passing marine traffic when in the vicinity of the wind turbines while entering and exiting the ports. No impact is seen on any habitation on the coastline onshore, as the distance is more than 25 times the maximum extent of the wind turbine's low-frequency noise vibrations. The wind turbines are safe for human habitats in the nearest villages to the project as the Low-frequency noise vibration will not be perceptible by the human habitats.

6.2.3. Shadow flicker from rotor blades

Shadow flicker is not to be a significant issue since the wind farm is away from the potential receptors is located on shore.

6.2.4 Collisions of birds with wind turbines and barrier effect on bird migration

Wind farms do have some negative impact on the avifauna due to the creation of a zone that is no fly barrier, which tends to kill the birds by its physical presence. The rotor blades rotating at high speeds may act like thrasher for any flying organisms.

- Resident birds will be impacted due to the installation of windmills in the offshore coastal habitat. Nevertheless,as this region off the coast of Gujarat is not very productive in terms of coastal marine subtidal region, there are few birds resident to this region.
- Secondary impacts of noise, vibration, electromagnetic waves may have disturbance to sensitive bird species, and they might leave the area. But the overall abundance of birds in the proposed area is very low thus will have less impact.

- Most of the species occurring in the region are local migratory and do not reside permanently in the core zone of the project; therefore, negligible negative impacts on avifauna are expected.
- The core zone of the project is sparsely visited by very few species of gulls and terns, thus remain unimportant for the avifaunal group.
- The impact on the migratory species will be of low nature considering the species occurring in the region, which mostly visits the coastal intertidal habitat that is much productive for avifaunal foraging compared to the subtidal region.
- Considering the location and the dimensions of the entire wind farm,it does not fall on any recognized migratory routes of avifauna. Thus the threat of collision will remain of low significance. Furthermore, there are no protected areas within the 10km radius buffer zone from the proposed site.However, there might be impacts outside the buffer zone (10km radius) as there are migratory birding areas and ecologically sensitive habitats. A thorough study is recommended for migratory species during the over-wintering season.
- Flamingos are known to breed in the Gulf of Kutch and migrate locally in different parts of central and southern India as foraging grounds. Few flocks are known to visit mudflats of coastal Mumbai, and this migration route (exact path not known) might come close to the present proposed site. As the altitude of flight is quite high and the height of the rotor blades is maximum, only up to 202 m, thus will not overlap the altitude that is attained by the birds.
- Bats are known to be negatively impacted by wind farms;the blades of the windmill tend to create high and low-pressure areas due to its rotating action. This pressure difference directly results in the mortality of flying mammals. The impacts on bats are of low significance as this region is not anecosystem inhabited by bats, wherein offshore regions are less preferred sites by bats.

6.2.5. Potential discharge of pollutants (oils & grease) and impact on water quality

The release of oil and grease may occur due to the pile driving activity as well as installation of windmills as there is several specialized machinery required for this kind of work. The heavy machinery may require regular maintenance and excessive use of oil, and grease results in it to get washed off in the ambient marine environment.

- The released oil and grease forms a layer on the water surface blocking the exchange of gases.
- Large scale spillage may result in mass mortality of pelagic birds, mammals, fishes, and invertebrates.
- Over the course of time, these form aggregates and form into tarballs which may settle on the seabed or floating ones reach the coast and significantly impact the coastal fauna on beaches, mudflats, mangroves, and rocky shore.
- The chronic effects of PAH and PH released from these discharges or spillages have significant negative impacts on the organisms affecting its eco-physiology, reproduction, genetics, and behaviour.

Considering the present scale of the project and the activities involved, it can be anticipated that oil and grease may spill out if no proper management measures are followed. The baseline study suggests very high values of metals in the water column. Thus any release of metals will add to the already contaminated water column considerably increasing the toxicity.

6.2.6. Additional electric and magnetic fields from power cables

The electric cable heat emission can cause changes in the physico-chemical conditions of sedimentary substrates, such as alteration of redox, O_2, sulphide profiles, changes of nutrient profiles, and increase in bacterial activity. This, in turn, may cause changes in the distribution of species. However, most studies predict the sediment temperature rise not to exceed 2 K at 20 cm sediment depth if the cable burial depth is 1 m. As most of the benthic organisms supposedly reside in the upper 35 cm of the sediment, the heat generated will not affect them. Hence, there will not be any impact on the marine environment.

The occurrence of electromagnetic fields is inevitable. The occurrence of electric and magnetic fields depends on the transmission system. If perfect shielding is provided, a cable does not directly generate an electric field outside the cable. Only cables with non-perfect shielding allow the generation of electric fields outside the cable. However, the directly generated electric fields are supposed to be smaller than the electric field induced by the presence of the magnetic field in the surroundings of the cable.

Electromagneticemissions from the sites may affect the navigation of bats, and the noise and vibrations from the mills may interfere with locomotion and eco-locations.

6.2.7. Anticipated impacts on the socio-economy

Assessing socio-economic effects in the study includes the assessment of the development proposal's impact on the local community and the environment they live in. The impacts can be positive or negative, and the major areas concerned are like demographic impacts, economic impacts including employment, income, etc., impacts on social values and attitudes. The significant impacts identified for the construction of the project are detailed below.

- The loss of land envisaged from the project or the requirement of rehabilitation and resettlement is being studied.
- Loss of income due to restricted fishing activity
- During the construction phase, many vehicles will be using the road facility and will generate much traffic, and in turn, affect the movement of the local population.
- Local people not capable of working in the industries/project will be adversely affected, and the local people migrating to another place for getting work will be checked. Because of the revenue contract system, the local population may face some issues for employment.
- Increase in employment for skill and semi-skilled population due to the project construction phase.
- Increase in the economy of the region due to project and its associated commercial activities, leading to an increase in small and large businesses.

The major impacts identified for the operational phase of the project are detailed below:

- The loss of land is not envisaged due to the project, and the requirement of rehabilitation and resettlement is not applicable, and if there is any in future will be dealt with as per R&R rules and regulations as prescribed by the Government of India.

- Changes in fishing-related activities are expected. It will be highly unpredictable, which might be positive or negative depending on the yield of fish in the area. Furthermore, the catch and the type of species or stocks will remain dynamic spatiotemporally.
- Employment in the project and related activities is expected due to the requirement of the workforce and staff to maintain and operate the project.
- Enhancement in the socio-economic status of the local communities due to the addition of infrastructure, amenities, and facilities associated with the project.
- With the implementation of best practices in the industry and adhering to the CSR policies, an increase in employment, infrastructure development, and facilities are expected due to the project.

Chapter 7: Mitigation Measures

7 MITIGATION MEASURES

7.1 Mitigation Measures

Mitigation is the process of providing solutions to avoid the severity of impacts or reduce them to acceptable levels.

The key objectives of mitigation are:

- To enhance the environmental and social benefits of a proposal.
- To avoid, minimise, or remediate the adverse impacts.
- To ensure that the residual adverse impacts remain within acceptable levels.

The project should incorporate environmental and social alternatives at the initial stages of project development. However, there are some impacts that can be managed only after being identified and predicted.Mitigation measures can be classified into structural and non-structural measures.

Structural measures include site alternatives, changes in the design, engineering modifications, substitution, and change in construction, automation, and mechanisation.

Non-structural measures include incentives, legal, institutional and policy instruments, corporate social responsibility (CSR), benefit-sharing, training,and capacity building. For long-term sustainability and to avoid long-term conflicts between local people and the project proponent, non-structural measures are very vital and are gradually being adopted.

The recovery of biodiversity from any impact is dependent on various ecological and physical factors and also on the magnitude of the impact. The competition among various species for resilience and recovery potential of sensitive species pose a hurdle in mitigation. Thus it is empirical to validate the diversity before and after the impact to ensure the damage caused and to understand the recovery. However, it is hard to avoid all ecological damage by any means of mitigation; nevertheless, the impact can be minimized as far as possible. Following are a few major mitigation measures:

A well-defined management and monitoring plan needs to be in place for each of the aspects related to the proposed project activity.

An expert should be assigned and should be onsite during the entire phase of the project so that the activities are in check, and the impacts are minimized.

- The project proponent should consider and adhere to all the international treaties and agreements to which India is a signatory and party.
- All the international, national, and state-level legislations have to be followed, and necessary approvals from the statutory bodies have to be taken before commencement of the proposed activities.
- Adhere to the best industrial practices in the industry so as to minimize the environmental impacts due to the project activities.
- Regular maintenance of all the activities and deployment of trained personnel will reduce many impacts, and unplanned events will not occur.
- Quality and standards have to be the priority for usage of resources, raw material, equipment, and manpower with regular calibration and checking with proper record keeping.
- Emissions from the construction vessels, vehicles, and the instruments should be within the permissible limits described by CPCB.
- Noise levels of the machinery and equipment should be within the permissible limits described by MoEFCC and CPCB and machinery should be with noise suppression enclosures.
- Power transmission lines should be deployed with bird diverters on conductors and paint the vane tips of wind turbines with orange colour to avoid bird hits.
- A big Bubble Curtain, which is a ring of pipes positioned on the seafloor around the foundation to be piled, releases freely rising bubbles forming a large curtain around the entire structure, thus shielding the environment from the noise source should be utilised during the construction phase (depicted in the Fig. 7.1).
- Organic solid and liquid waste on the vessels involved in the project should not be disposed in the ambient waters. It should be appropriately processed and or disposed of as per the guidelines.
- Inorganic waste, hazardous waste, including oil and grease, should be stored appropriately. It should be delivered to authorized vendors for proper disposal.

- Project construction activities should be avoided during the notified fish breeding season (June-July), which is considered as egg-laying and larval recruitment season.
- During the construction phase, the proposed activities will be notified to mariners and the area, and the route through which the construction material will be transported will be demarcated by marker buoys. Prior to the commencement of construction activity, local residents and fishermen would be advised about the construction, period of construction, and associated activities.
- During the construction phase, temporary colonies of the workforce will be established sufficiently away from the High Tide Line, and proper sanitation, including toilets and bathrooms, will be provided to the inhabitants to prevent abuse of the intertidal area. Sewage and other wastes generated in these settlements will not be released to the marine environment.
- The barges engaged in laying the pipeline and foundation should implement a hazardous materials management plan that includes the specification for proper storage and handling of fuels, oil, wastes, and other potentially hazardous materials as well as a plan for containment and cleanup of accidental spills into the marine environment.
- To prevent damage to the cables, all submarine cables will be trenched/jetted/ploughed at least 1 m into the seabed. The cable route falling in the intertidal zone has to be restored to its original morphology without disturbing the nearby areas.
- Temporary marine navigation marking in connection with the construction phase will consist of yellow special-purpose marking. The marking will indicate the entire area, including a safety zone. The safety zone is expected to be approximately 500 m.
- After the construction phase, permanent marine navigation markings of the wind turbines will be installed. The marking will, as a minimum, consist of a number of yellow lanterns. Wind farm area to be notified in the National Hydrographic Office (NHO) Charts.
- It is proposed to establish air navigation marking of the corner wind turbines with medium intensity white lights. White flashing light on top of the nacelle for air traffic safety.

- In the operation period, ship navigation will be prohibited in the wind farm area.
- Buffer zone of upto 3 km to be set up around the periphery of the proposed wind farm. This should also extend below the sea surface to ensure that marine wildlife is not adversely affected by the low-frequency vibrations of the wind turbines. Reflectors to be made to obstruct the noise vibrations away from the areas of impact.
- Analysis of the marine species that are affected by low-frequency vibrations and identification of possible alternate habitats for these species should be conducted.
- Analysis of radar and radio waves to ensure no impact on communications of air and marine traffic is affected.

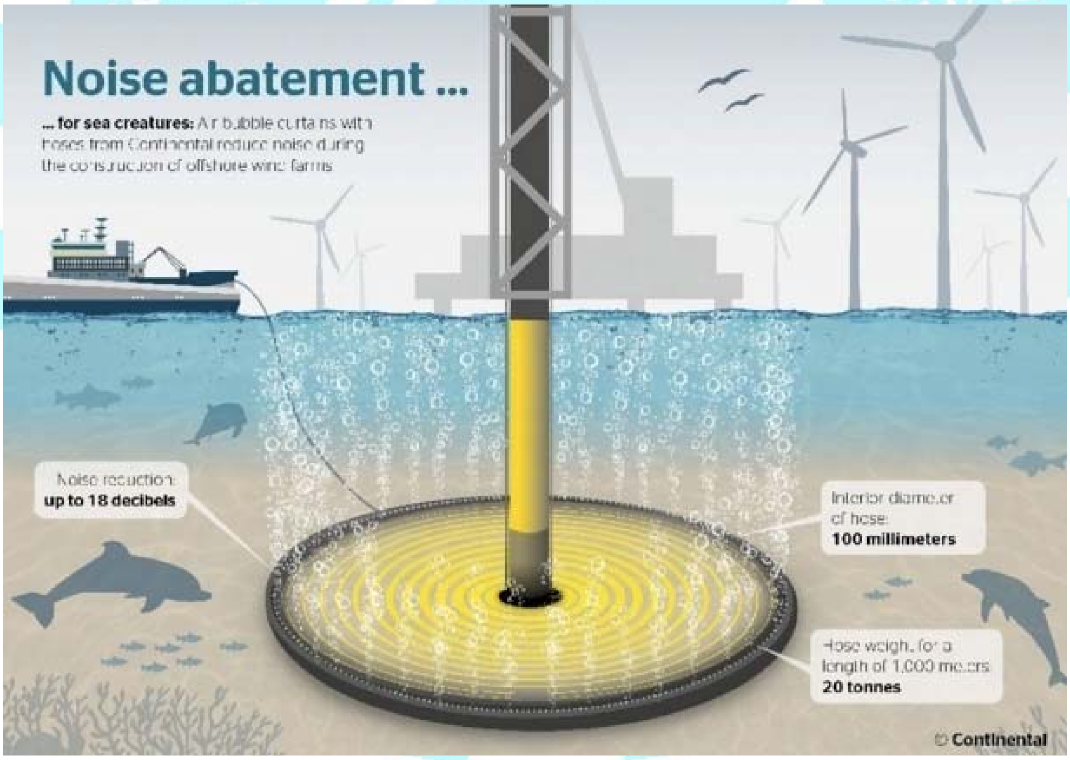


Fig 7.1: Depicting noise abatement via use of bubble curtain.

(Ref: https://www.engineerlive.com/content/novel-air-bubble-curtain-large-marine-projects)

- Local people capable of working in the project should be recruited to decrease the transport and in-migration of the workforce.

- The semi-skilled people or with lesser skills should be given skill development training to promote employment.
- The stakeholders who will be restricted in their income-earning sources shall be compensated accordingly and given alternative training for earning a livelihood as other sources of income.
- Township to be made at a safe distance away from society to make sure the stakeholders is not adversely affected.
- Green Belt to be made near the township to ensure a less polluted atmosphere.
- Regular Occupational health check-up.
- Roads should be constructed for local people to travel comfortably.
- Training of workers on appropriate waste control and transfer techniques, upkeep guidance, and better work conditions. Awareness programs should be carried out as per local people's knowledge for better waste management.
- With the implementation of best practices in the industry and adhering to the CSR policies, an increase in education, employment, infrastructure development, amenities, and facilities are expected due to the project.

Table 7.1: Depicting summarized impacts and mitigations.

Sr.no.	Impacts	Mitigation	Actions to be Taken	Responsibility
Construction Phase				
1	Noise in connection with pile driving for monopile foundations.	Noise levels of the machinery and equipment should be within the permissible limits described by MoEFCC and CPCB.	Machinery should be with noise suppression enclosures.	NIWE/ Contractor
2	Impact of Noise and Vibration during pile driving on Marine Mammals.	Sonic equipment should be used to actively keep away the mammals from the area.	A big Bubble Curtain, which is a ring of pipes positioned on the sea floor around the foundation to be piled, releases freely rising bubbles forming a	NIWE/ Contractor

			large curtain around the entire structure, thus shielding the environment from the noise source should be utilised during construction phase.	
3	Oil spills from construction vessels.	Proper management, precaution and contingency plans for construction vessels.	Emissions from the construction vessels, vehicles and the instruments should be within the permissible limits described by CPCB.	NIWE/ Contractor
4	Pile driving will initially result in complete removal of the surface sediment-associated biota in an area of 4808 m^2.	As the abundance and diversity of benthic organism in the baseline revealed very low faunal occurrence thus the impacts will be of low nature.	Re-colonization occurs within the area most likely by migration of adults through transport on tidal currents.	
5	Increased bioaccumulation of contaminants in commercially important species might occur as some of the contaminants (such as metals) at the baseline level show significant high values.	Abatement of disposing metal waste into the seawater directly.	Should be stored appropriately and to be delivered to authorized vendors for proper disposal. Follow a solid and hazardous waste management plan and adhere to the norms of CPCB.	NIWE/ Contractor
6	Any Residual Impacts and conservation measures	Marine Environmental Management Plan (MEMP)	Carryout activities as delineated in the MEMP	NIWE/ Contractor
Operational Phase				

1	Collision of birds with wind turbines.	Considering the location and the dimensions of the entire wind farm; it does not fall on any recognized migratory routes of avifauna.	Paint the vane tips of wind turbines with orange colour to avoid bird hits. A thorough study is recommended for migratory species during the operation.	NIWE/ Contractor
2	Impact of electric and magnetic field from power cables.	The occurrence of electric and magnetic fields depends on the transmission system.	If perfect shielding is provided, a cable does not directly generate an electric field outside the cable.	NIWE/ Contractor
3	Shadow flicker from the rotor blades.	No significant issue since the wind farm is away from the potential receptors are located onshore.	No necessary action is required.	NIWE/ Contractor
4	Loss of income due to restricted fishing activity in the wind farm area	Wind farm area is not a very productive area	Consultation with fishing communities to avoid areas close to the wind farm	NIWE/ Contractor
5	Any Residual Impacts and conservation measures	Marine Environmental Management Plan (MEMP)	Carryout activities as delineated in the MEMP	NIWE/ Contractor

Chapter 8:
Marine Environmental Management Plan

8 MARINE ENVIRONMENTAL MANAGEMENT PLAN

An MEMP is a framework for the implementation and execution of mitigation measures and alternatives.

The objectives of an EMP are:

- To ensure that mitigation measures are properly implemented.
- To establish a scheme and procedures for this purpose.
- To monitor how effective are the mitigation measures.
- To ensure that proposed mitigation measures comply with environmental laws and regulations.
- An adequate action when unexpected impacts occur.

The MEMP outlines:

- A plan for operation or execution of the recommended mitigation plan, including assigning responsibility and schedules.
- The detailed estimated costs to execute the mitigation plan.

Legal Framework

A number of rules and laws regulate activities on the Indian coast. India has regulatory agencies such as the Central Pollution Control Board (CPCB) at the central level and State Pollution Control Boards (SPCB) at the state levels, constituted under Water (Prevention and Control of Pollution) Act, 1974. The Aquaculture Authority of India has been constituted and guidelines on sustainable aquaculture development for regulating coastal aquaculture have also been developed.

A National Contingency Plan has been formulated to combat oil spills in the EEZ of India with the Coastal Guard as the nodal agency. The disposal of ship-based wastes is regulated by the Merchant Shipping Act, 1958 and by the adoption of MARPOL 73/78. Standards for discharging effluents are listed in the Environmental Protection Act, 1986. This serves as an umbrella act providing for the protection and improvement of the environment including coastal and marine areas. The effluents/discharges from various resources have to meet these standards before being discharged into marine waters.

The Coastal Zone Regulation Notification was issued in 1991 in India, under the EPA, 1986. The Notification aims at protecting and improving the quality of the coastal environment. The Notification declares the limits of the Coastal Zone and classifies it into four categories for the purpose of regulation. A state-wise Mangrove Committee has been formed for effective management of the mangrove ecosystem. Mining of corals and coral sands has been banned. The CRZ notification also offers protection to coastal communities, such as traditional fishermen.

The Recycled Plastics Manufacture and Usage Rules, 1999; Municipal Solid Wastes (Management and Handling) Rules, 2000; Ozone Depleting Substances (Regulation) Rules, 2000; The Prevention and Control of Pollution (Uniform Consent Procedure) Rules, 1999, are some of the rules framed under EPA, 1986, with an aim to providing environmental protection and are relevant to the coastal environment. Since 1982, the CPCB has been carrying out a rapid inventory annually to assess the pollution status of coastal waters of India. This program known as the Coastal Pollution Control Series (COPOCS), comprises among other things, a) Identification of the uses of coastal water at different stretches and the best use among them; class designation of the sector or a portion thereof, and b) Identification of land-based pollutants and polluting activities and those that require immediate control.

Efforts have been made to set up sewage treatment plants in all coastal states. Treated effluents are being discharged into deeper waters through pipelines. The Government is also preparing an action plan for the treatment of domestic wastes. Legislation has helped in the treatment of industrial wastes. In India, the Water (Prevention and Control of Pollution) Act includes tidal waters, unlike some other countries. The Act is applicable upto five km into the sea. Though the discharge of effluents from small-scale industries is still a problem, efforts are being made to set up common treatment plants. This will help in minimizing the load that is discharged to the sea.

The Indian Coast Guard is empowered to prevent the capture of endangered marine species under the Wild Life (Protection) Act, 1972. A number of threatened marine species have been placed in Schedules I and III of the Wildlife (Protection) Act, 1972. Some of these are the whale shark, sea horse, sea cucumber, seashells, and different types of corals. The most important of these is the whale shark, which is placed in Schedule I.

To prevent overexploitation of fish stocks and protect the interests of coastal communities, the following legislation/rules/acts are in force in the country:
The Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Act, 1981, provides regulations for foreign fishing vessels operating in Indian waters. The Coast Guard and the State/UT Police has been authorized under the Act to apprehend and prosecute unauthorized foreign fishing vessels/crew for fishing/poaching in Indian waters.

The Marine Fishing Regulation Act (MFRA), 1978. Consistent with the guidelines contained in the MFRA, 1978, which is a model act, providing guidelines to the maritime states, legislations have been enacted and enforced for regulating fishing and conservative measures in territorial waters. Such state enactments provide for the regulation of mesh size to avoid catching juvenile fish, regulation of gear to avoid over-exploitation of certain species, reservation of zones for various fishing sectors to provide exclusive rights to traditional fishermen to fish unhindered in near-shore areas and also for declaration of closed seasons during the fish-breeding period to avoid catching of young juvenile fish.

India also is actively involved in the Intergovernmental Oceanographic Commission, UN Convention on the Law of the Sea, Antarctic Treaty System, and the UNEP Regional Seas Programme. Scientific and technical bilateral cooperation with other nations, e.g., Russia, Germany, the Republic of Korea, Argentina, Peru, Italy, and others, has been established. India has also ratified the International Convention for the Prevention of Pollution from Ships (MARPOL Convention 73/78). Some of the other international conventions on environment ratified by India are the International Convention for the Regulation of Whaling, International Plant Protection Convention, 1951, Convention on Facilitation of International Traffic, 1965, International Convention on Load Lines, International Convention on Tonnage Measurement of Ships, International Convention on Civil Liability for Oil Pollution Damage, 1969, Special Trade Passenger Ships Agreement, 1971, International Convention on Establishment of an International Fund for Compensation for Oil Pollution Damage, 1971, Convention on the International Regulations for Preventing Collisions at Sea, 1971, as amended (COLREG 1972), International Convention of Safe Containers, 1972, Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1973, International Convention for the Safety of Life at Sea, 1974, Framework

Convention on Climate Change, 1992, Convention on Biodiversity, 1992. India is also a signatory to the Convention of Wetlands of International Importance, the protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, Vienna Convention for the Protection of the Ozone Layer, Convention on Migratory Species, Basel Convention on Trans-boundary Movement of Hazardous Substances, Montreal Protocol on Substances that Deplete the Ozone Layer.

All the acts with existing acts/rules with their salient features are given in Table 8.1, and Table 8.2 shows the conventions and international treaties to which India is a signatory.

Table 8.1:Table showing the existing act/rules and their salient features.

Existing Act/Rules	**Salient Features**
Environment Protection Act (EPA), 1986 Coastal Regulation Zone Notification, 1991 Coastal Zone Management Plans (CZMPs) Hazardous Waste Management Act, 1989 Environmental Impact Assessment Notification, 1994 & 2006.	*An umbrella Act* Regularizes the various activities in the coastal zone.Supreme Court Intervention that all the Coastal States prepare their CZMPs by 1996.This Act provides guidelines for hazardous waste management and also for the import and export of hazardous waste in the Country.The objective of this Act is to conserve and protect the environment.
Water (Prevention and Control of Pollution) Act, 1974, Amended in 1988	Control of pollution from land-based sources Pollution Control Board was constituted under this Act.
Indian Ports Act,1908	Enactment relating to ports and port charges. Provides for rules for the safety of shipping and conservation of ports
Major Port Trust Act, 1963	The Act makes provision for the constitution of port authorities for certain major ports in India and to vest the administration, control, and management of such ports in such authorities and for matters connected therewith.
Merchant Shipping Act,1958	Control of pollution from ships and off-shore platforms.

Existing Act/Rules	Salient Features
Coast Guard Act, 1950	Provides levying of heavy penalties for the pollution of port waters. In 1993, the Coast Guard under the Ministry of Defence made directly responsible for combating marine pollution.
Maritime Zones Act, 1976	Describes various zones such as territorial waters, EEZ, Continental shelf, etc.
Forest Conservation Act, 1980, Amended in 1988	Protection to (Marine) Biodiversity
Wildlife Protection Act, 1972 (Amended in 1983, 1986, 1991, 1997, 2001)	Offers protection to marine biota. Creates conditions favourable for in-site conservation of fauna and flora. Amended in 2001 to include several species of fish, corals, sea cucumbers and seashells in Schedule I and III Whale shark placed in schedule I
Indian Fisheries Act, 1897	Offers protection to fisheries against explosives or dynamites.
Marine Fishing Regulation Act, 1978	A model act, which provides guidelines to the maritime States to enact laws for protection to marine fisheries by regulating fishing in the territorial waters. The measures include regulation of mesh size and gear, reservation of zones for various fishing sectors, and also a declaration of closed seasons. Laws framed and amended from time to time by different maritime States.
National Environmental Tribunal Act, 1995	This has been created to award compensation for damages to persons, property, and the environment arising from any activity involving hazardous substances.
The National Environment Appellate Authority Act, 1997	Addresses appeals with respect to restrictions of areas in which classes of industries etc. are carried out or prescribed subject to certain safeguards under the EPA. The objective is to bring in transparency and accountability and to ensure the smooth and expeditious implementation of developmental schemes and projects.
Biodiversity Act, 2002	The Act that has been passed, with an aim to protect and conserve biodiversity and sustainable use of its components.

Table 8.2: Convention to which India is a signatory.

UNCLOS	Disposal of ship-based wastes.
Basel Convention,1992	The Basel Convention contains specific provisions for the monitoring of hazardous waste. A number of Articles in the Convention oblige Parties (national governments which have acceded to the Convention) to take appropriate measures to implement and enforce its provisions, including measures to prevent and punish conduct in contravention of the Convention.
Ocean Policy Statement	Sets out basic principles through which the development of the ocean is to be carried out.
Convention on Migratory species	Convention gives protection to many species of crocodiles, sharks, turtles, etc.
MARPOL 73/78	Disposal of ship-based wastes.
IUCN	For influence, encourage and assist the global societies to preserve and conserve nature. They also ensure that thenatural resources are used sustainably.
Ramsar	Provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

8.1 Development of Plan

Improvement of baseline information

Methods and systems for the effective and efficient collection and utilization of information will be considered for the systematic accumulation of information and knowledge regarding marine biodiversity. Marine areas of particular importance for conserving biodiversity will be identified based on scientific knowledge.

Identification of factors and implementation of measures

To promote conservation of marine biodiversity and its sustainable use appropriately, causes of the problems, and those responsible for actions to reduce their impacts. Measures will be conducted with methods and procedures suitable to solve these problems, under cooperation among relevant parties.

Implementation of measures

Measures for conservation and sustainability of marine biodiversity will be implemented in accordance with characteristics of individual marine areas, such as differences in the ecosystems and major influencing factors between estuarine water and the nearshore waters.

Enhancement of pristine Areas

Designation of conservation zones will be promoted appropriately using the existing systems to improve and enhance marine biodiversity. For conservation and sustainable use of marine biodiversity, a concept of effective networking will be considered, and if required, a new system will be considered as well.

It is difficult and, in many cases, impossible to determine the status of most species in the marine environment. So little is known of marine species distribution or range that it cannot be determined whether they are plentiful or naturally rare or whether their populations are stable or changing. Marine species that are relatively easily monitored are those restricted to nearshore habitats, especially if they are sedentary or attached and those that spend time at the sea surface or on land. Hence the ‘precautionary principle’ is considered as best practice in the industry so that there is no unabated and commitment-less development. Thus developmental activities have to be mitigated, and further enhancement strategies have to be adopted to keep up sustained biodiversity. Policy level provisions at the national and regional level for management and conservation of marine biodiversity include:

i) Integrated Coastal Zone Management (ICZM), which deals with the management of the land side of the coastal ecosystem.
ii) Marine Spatial Planning, whereby different marine areas are planned for different activities in accordance with the environmental conditions.
iii) Watershed Management, which involves the management of drainage basins and activities that affect water flow and water quality.
iv) Fisheries Management.
v) Marine Protected Areas.

Apparently, marine biodiversity management is a complex issue that depends on the holistic mitigation actions to be carried out by all establishments. As such, no single agency can achieve this task, which is influenced by many activities carried out by different stakeholders in and around the marine area in question.

8.2Marine Biodiversity Management Plan

The Indian subcontinent is bordered by the tropical seas, which include an extensive coastal zone and deep seas. Within the coastal zone, there are a 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 varies both spatially and temporally. These habitats have been exploited for food and aesthetic purposes with no apparent ill effects till large scale mechanization began to be introduced. Increasing human population coupled with the greater need for development has led to intensive exploitation of coastal areas and various fisheries resources and has caused considerable stress to many habitats.

Managing a complex ecosystem to balance the delivery of all of its services is at the heart of ecosystem-based management. 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 “ecoservice 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.

- The physico-chemical parameters need to be in check so that the biodiversity isnot affected indirectly. A water quality monitoring plan is to be followed with management actions at the onset of any anomalous results.
- Management actions of the MEMP team are required to halt the project activity and take corrective actions if there is any occurrence of algal blooms or jellyfish blooms pertaining to the project activity.

- Management actions of the MEMP team are required to halt the project activity and take corrective actions if there is any occurrence of fish kill or mass deaths.
- Introduction of any invasive and alien species is to be avoided by proper inspections of long-distance vessel movement pertaining to the project. Ballast water exchange has to be carried out as per the national and international regulations set for ships involved in the project.

Stakeholder's involvement

Although this project does not involve the local community as receptors of direct impacts, there will be indirect impacts that may be positive or negative. Involvement of stakeholders is one of the key strategies to have inclusive development and avoid unnecessary conditions. Fishermen communities may be impacted directly if their fishing grounds and project core zone overlaps. This may create conflicting situations as the construction phase will involve cordoning the area to avoid accidents.

- The stakeholders have to be informed about the project well in advance and their suggestions and requirements to be considered through a formalised process.
- The state administration shall co-ordinate the mediation between the project proponent and the stakeholders.
- All the legal norms and regulations have to consider while dealing with the stakeholders
- As best practices in the industry, the stakeholders have to be considered as the most important entities, and compensatory activities have to be undertaken
- If the livelihood of the locals is being affected, appropriate alternative means of livelihood has to be given for the betterment and enhancement of their status.
- Depending on the educational qualifications and skills of the local communities, appropriate personnel have to be hired for the project activity to the maximum extent possible.
- The Corporate Social Responsibility (CSR) cell of the project proponent shall undertake all the activities related to the locals and other stakeholders.

- The cell can also undertake activities that can enhance the livelihood of all the social categories equally. This may consider, for e.g, education for children, skill development programs for youth, self-help groups for women, incentivizing organic farming, sustainable aquaculture, or animal husbandry.

8.3 Vessel Management Plan

This Vessel Management Plan is based on the design team's best professional judgment regarding the types of equipment typically needed to complete this work, the sizes of marine construction equipment typically available, rates that have been achieved for similar projects, and a prospective construction sequence that could be used to conduct the activities. The actual type, size, and quantity of equipment, production rates, work schedules, and project sequence will be determined collaboratively with the contractor to complete the work. Thus, some of the details provided in this Vessel Management Plan may be superseded following contractor procurement and initial project planning activities. Further, marine projects are subject to factors such as weather, tides, and other encumbering issues that are beyond the control of the contractor and which may necessitate some changes to planned contractor vessel movements even after initial project planning has been completed.

8.4Pile Driving Management Plan

Management practices for the environment are a diverse collection of measures used to conduct a project in a way that avoids, reduces, or mitigates environmental impacts. Management practices require a thorough understanding of the technical, environmental, and economic characteristics of pile driving plans and the potential seriousness of environmental impacts. In some cases, these management practices may require rather minor changes, such as slowing down the removal of sediment. In other cases the project may call for major innovative technologies requiring substantial investments. Operational procedures, aspects involved, and action plan for any contingencies have to be prepared by the offshore contractor.

8.5Water Quality Management Plan

The waters in the site are subject to a variety of potential pollutant sources including boat and ship antifoulants, boat hull cleaning, and other releases and discharges from boats, wastewater discharges from municipalities and industrial facilities, storm-

water runoff from municipal, industrial (including shipyards) and agricultural activities, groundwater and the atmosphere. These sources of potential pollutants can degrade the water quality-beneficial uses of the waters bycausing aquatic life toxicity and excessive food web bioaccumulation, as well as causing other impairments of the water body's beneficial uses. There are considerable confusion and unreliability in regulating storm-water runoff water quality impacts. There is under the regulation of potential pollutants for which there are no proper criteria/standards. The regulation of potential pollutants that accumulate in sediments is even more unreliable since there is no relationship between the total concentration of a constituent in sediments and water quality impacts. The monitoring plan has been delineated following which the appointed environmental consultant shall monitor the permissible limits as per norms and regulations and guide the proponent for corrective actions.
Monitoring of water quality needs to be carried out as given the plan for monitoring with the frequency in the table below.

- The parameters mentioned in the plan should be regularly sampled and their values to be compared with the baseline condition.
- Any significant spike in the values should consider immediate actions invoking management intervention that involves project activity.
- Higher values of contaminants should not go beyond the prescribed norms and limits by the statutory authority.
- Other plans relating to the construction and operational phase of the project activity have to be followed meticulously so that no water quality anomalies are accrued.

8.6Fishery Management Plan

This plan aims to create an enabling integrated coastal and marine biodiversity management and protection, and to mainstream marine and coastal biodiversity into national plans and coastal zone management plans, with particular focus on conserving biodiversity. As such, it provides an opportunity to coordinate with past and new initiatives in the region to address gaps in assessments, and seek sustainable and economically viable solutions, technological options for the protection of coastal biodiversity and improve fishery potential of the region.The fishery management plan also has to be aligned with the plans of CSR and stakeholder’s involvement.

- , The fishery management plan, can be executed with the policies and scope of the local fishery department.
- This plan can involve aquaculture and improvement of fish yield in the offshore and on-shore region.
- Sustainable mariculture can be promoted wherein culturing of crayfish and shellfish can be carried in the offshore region and intertidal areas.

8.7 Conservation Plan for (Marine) Mammals& Turtles

Under the Marine Mammal Protection Act (MMPA, 1972), conservation plans are required for species that have been designated as"depleted."Endangered and threatened marine mammals are also protected under the Endangered Species Act (ESA). Stocks of marine mammals may also be considered "strategic" under the MMPA.

In India, 27 species placed under Wildlife Protection Act, 1972. Under the Act, three species, namely Gangetic dolphin, Irrawaddy dolphin, and dugong is under Schedule I, and others are under Schedule II. Capture, use, and trade of marine mammals’ are punishable under the Act (Marine mammal research and conservation in India, 2010). Following measures have to follow to ensure the conservation of marine mammals in the study area:

- On-site visual observation for marine mammal observer has to be done regularly during the construction activity.
- Vessel movement has to be regulated with speed limitations.
- Vessel movement has to be immediately halted at the sighting of any marine mammals in the active working zone.
- Management of marine litter, garbage, and plastic is one of the critical aspects with respect to the project.

Given below in Table 8.3 explains the applicable state government rules and regulations to be followedas per the type of project. For restricting the impacts of pollutants and effecting monitoring and reporting procedures, these rules are being monitored by the respective state governments based on the type of wind farm.

Table 8.3: Applicable approval required for wind power project from SPCB

What type of wind power projects are required to apply for CTE?	If it involves activities such as quarry operation and/or crusher or both, hot mix plant for the construction of access road or any other project-related activities or discharge of sewage on land and waterbodies.
Whether the CTE is required under the provisions of Water Act & Air Act?	Required to obtain CTE under section 21(1) of the Air (prevention and control of pollution) Act, 1981. Also, CTE under section 25/26 of the Water Act is required in case of discharge of sewage or trade effluent in a stream or a well or a sewer or a lake.
Whether wind power development activity is required to apply for CTO?	Yes, prior to commercial generation, it is obligatory to apply for CTO under section 21 of the Air (P & CP) Act 1981, with respect to ambient air quality related to noise.
Whether a wind power project is required to apply for Hazardous Waste Authorisation?	Yes, wind power projects use different types of fluids for the smooth operation of the WTG. Primarily, three main types of fluid are used: (a) Generator cooling fluid is used as coolant (a mixture of glycol and water, similar to what is used in automobile radiators) (b) Lubricating oil is used in the gearbox (synthetic oil) (c) Hydraulic oil for operating the blade pitch system, yaw mechanism, and rakes. To protect the transformer from heating, mineral oil (transformer oil) is used as a coolant. According to Section 3 (ze) of the Hazardous Wastes (Management, Handling, and Transboundary Movement) Rules, 2008: **“Used oil”** *means any oil derived from crude oil or mixture containing synthetic oil, including used engine oil, gear oil, hydraulic oil, turbine oil, compressor oil,*

	industrial gear oil, heat transfer oil, transformer oil, spent oil and their tank bottom sludge. It clearly indicates that the used lubricating oil, hydraulic oil, and transformer oil falls in the hazardous waste category as per Section 3 (ze), Therefore, as per the said Rule, each and every wind power project operator has to take authorisation from the concerned SPCB under Section 5 (1) of the said Rule. The irony is that many SPCBs do not regulate wind power projects or grant authorisation.
Whether wind power projects are required to file Cess returns?	Yes, if they use more than 10 KLD of water, including domestic water supplies. In such a case, the wind power project required to file Water Cess returns.
Inspection and monitoring	Under Section 24 of the Air (P & CP) Act 1981, the right to enter for the purpose of determining whether provisions of this Act or the rules made there under or any notice, order, direction or authorisation served, made, given or granted under this Act are being or have been complied with. Empowered to check the record, register, document or any other material or for conducting a search of any place in which the SPCB official has reason to believe that there has been an offence under the said Act or the rules.

Monitoring and reporting

All sightings of any turtles and dolphins, which could possibly have been impacted by the works, will be recorded and reported to the site in-charge/ superintendent, who will forward details to the concerned statutory authority.

Pre and post hydrographic surveys to be undertaken to confirm the construction area and extent of changes at the reclaimed site and surrounding areas.

This report shall be provided to concerned statutory authority on request and submitted following the completion of the monitoring program.

Corrective action/contingency plan

All incidents involving flora or fauna are to be reported to the Superintendent and the ESS. Construction activity outside of approved areas is a breach of approval conditions and shall be reported to the Superintendent, and the ESS and remediation works shall be undertaken to the satisfaction of approval agencies.

The team for the plan is given below in Fig 8.1, and the budget is provided in Table 8.4. The monitoring plan for both the construction and operation phase is delineated in Table 8.5.

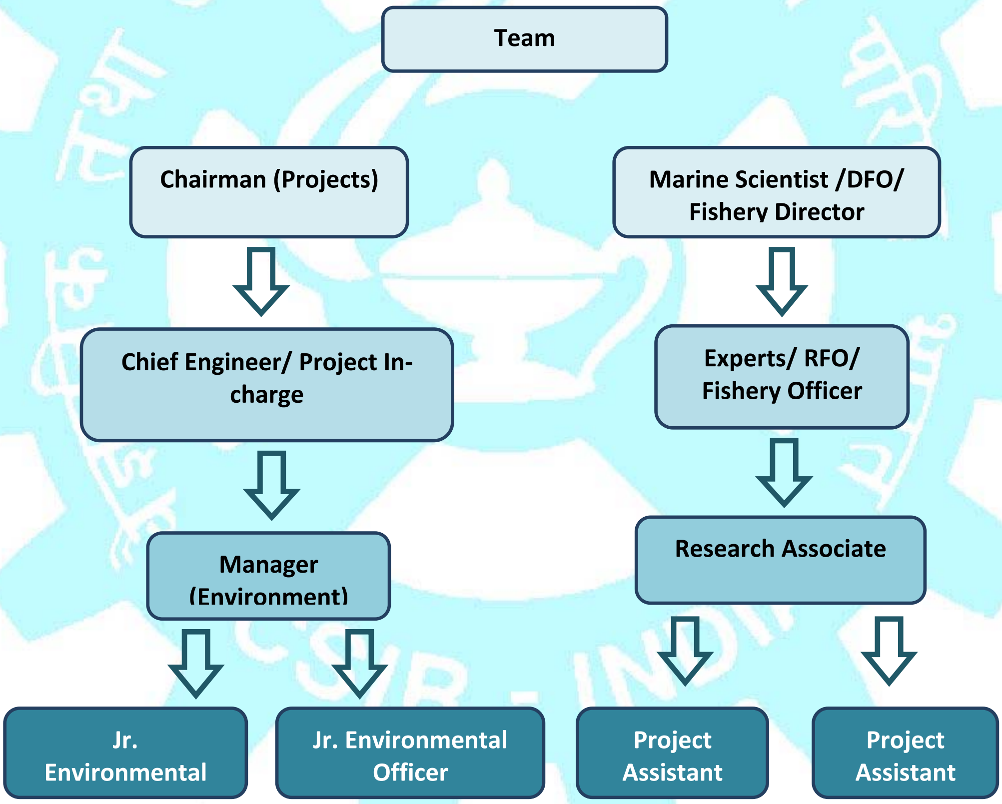


Figure 8.1: Team for the Plan

8.8 Budget for the MEMP

Budgetary planning is the process of constructing a budget and then utilizing it to control the operations of a business. In this present study there are few management plans are described below with their estimated budget cost:

Table 8.4: Budgetary provision for the Plan

Sr. No.	Description of Item	Cost (INR Lakhs)
1	Pile Driving Management Plan	80*
2	Water Quality Management Plan	80
3	Fishery Managment Plan	70
4	Vessel Management Plan	120
5	Biodiversity Management Plan	140
Total		490

**Construction & related management will be carried out by the project contractor.*

Table 8.5: Marine Environmental Monitoring Plan

Sr. No	Cluster	Parameters	Sample	Frequency	
				Construction Phase	Operation Phase
1	Sea Water	Temp. Salinity, DO, BOD, TOC, Nutrients, Heavy, Metals.	10 locations	Monthly Once	Annually once
2	Sediment	Texture, Grain Size, OC	10 locations	Monthly Once	Annually once
3	Plankton & Benthos	Phytoplankton, Zooplankton, Meio-, Macro-fauna	10 locations	Monthly Once	Annually once
4	Megafauna	Marine mammals, reptiles & avifauna	All known habitats as per the baseline	Monthly Once	Annually once

9. 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. EIA experts and their specialization as well as the nature of work carried out are are listed below:

Name	Specialization	Nature of consultancy rendered
Dr. Mandar Nanajkar	Biological Oceanography; Benthic Biodiversity & Ecology	Project co-ordinator, Coordinated the work components related to eco-biological, EIA and management plan
Dr. Sanil Kumar V	Coastal Processes, Marine Structures, Ocean Engineering	Coordinated work related to physical parameters and Environmental impact assessment
Dr Durbar Ray Dr Damodar Shenoy Dr Siby Kurian Dr Hema Naik	Chemical Oceanography, Marine Pollution	Coordinated the work components related to water and sediment quality, Metals in environment
Dr Samir Damare	Marine Microbiology	Coordinated the work components related to Microbial Ecology, Analysis for sediment and water microbiology
Dr Manguesh Gauns	Phytoplankton & Zooplankton Ecology	Coordinated the work components related to Phytoplankton biomass, phytoplankton abundance and diversity
Mr. Vasudev Mahale	Survey and Bathymetry	Bathymetry and geology
Mr. K.Sudheesh	Numerical modelling	Numerical modelling of waves, currents and sediment transport
Mrs.K. K. Dubhashi	Data Management and computer applications	Analysis of wind data, compilation of secondary data
Mr. Amey Gawde	Modelling Project Management	Model interpretation, Project Management and interpretation and writing of reports
Mr Subimal Pattadar Ms Anita Gedam	Socio-economy	Analysis of data for socio-econmy and project related activties
Dr. Milind Sawant	Fisheries and Social Studies	Project Management and interpretation and writing of reports
Mr. Udeet Methala	Wind, Noise and Vibration Studies	Wind, Noise and Vibration Modelling Simulations, data analysis and interpretation

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