Report on EIA/EMP and modelling studies for the sand mining clusters in the rivers of Goa

Report on Mandovi Estuary

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EXECUTIVE SUMMARY

Mandovi River is one of the nine major rivers flowing from the east (Western Ghats) to the west (Arabian Sea) in the state of Goa. It is located between the latitudes ($15^0$09' and $15^0$33'N) and longitudes ($73^0$45' and $74^0$14'E). The river originates in central western ghats and flows in Goa, where it is known as Mahadayi River in the up-streams, and enters into Goa where it is popularly known as Mandovi. The present study was undertaken to study the following aspects of the Mandovi estuary: Hydrodynamic modelling of flow dynamics; Numerical modelling of replenishment and recharge related aspects / issues of clusters - including dynamics of accretion and erosion; hydrological study of the area under consideration; the diversity and abundance of phytoplankton, zooplankton and benthos in the study area; fish diversity; to evaluate the impact of sand extraction on the estuarine ecology and biodiversity and to calculate the biodiversity index of the estuary.

The results of all the above aspects have been incorporated in the chapters of this report as baseline study. The overall biological results suggest moderate to poor conditions, possibly several parts of the estuary impacted due to cumulative activities in the region. The lower reaches of the estuary show good growth of mangroves and the mangrove cover has doubled in couple of decades. Many riparian zones in the lower half of the Mandovi have shown change in land use wherein paddy fields have been converted into saline marshlands and subsequently this area has proliferation of mangroves. The major reason for this is saline water intrusion due to tidal surges, flooding, and other anthropogenic activities such as sand extraction close to the banks as well as deterioration of embankment. The upper stretches of the estuary show bank erosion and breaching of bunds, due to non-maintenance. Hence, the banks are vulnerable and may experience erosion in the future.

Spatial variations observed in the backscatter sonar intensity and ripple patterns. The Side Scan Sonar images of Mandovi river shows varying smooth to rippled to heavily rugged riverbed morphology between off Miramar to Khandepar. Point and mid-channel bars are more frequent in upstream region of the river.

Sparker system achieved a subsurface penetration of ~3-25 m in the survey area. Due to the shallow depth of riverbed, multiples (up to second-order) are observed in the study area. Sand volume are estimated using side scan sonar image zonation of sand features, sediment thickness from seismic data. Sand dominates the sediments followed by silt.

Considering the physical baseline parameters, modelling studies have been carried out. The Hydrodynamic simulations is carried out using MIKE21 Flow Model FM. The MIKE 21 Flow Model FM is a modelling system based on a flexible mesh approach providing the hydrodynamic basis for the Sediment transport Module. The modelling system is based on the numerical solution of the two-dimensional shallow water equations i.e., depth-integrated incompressible Reynolds Averaged Navier-Stokes equations. The Sediment transport module calculates the resulting transport of non-cohesive materials based on the flow conditions found in the hydrodynamic calculations. The model output consists of bed level changes, amongst other parameters. The comparisons of the current speed between Case 1 (present scenario) and Case 2 (scenario after mining) at each section A to I are also included. The comparisons of the bed level changes between Case 1 and Case 2 are presented in the morphology model results.

Following the results, all the anticipated impacts have been delineated along with the mitigation measures. A comprehensive Environmental Conservation & Management plan has been prepared covering all the aspects of sand extraction and its impacts. A monitoring plan also has been formulated to ensure that all the activities fall within the legal framework and the best practices in the industry. Following are the recommendations from the study:

- Considering the results of the baseline, the Mandovi estuary has been impacted by cumulative anthropogenic activities and natural riverine and costal processes.
- Based on the studies eight feasible sand mining regions are identified.
- In the Mandovi estuary the bed level changes for the post-mining scenario are mostly around -0.15 m to 0.25 m during both simulated monsoon (August-November, 2020) and non-monsoon period (November, 2020 - May, 2021). The changes in bed morphology in the post-mining scenario at different sections of the river are highly dynamic and patchy in nature.

- A higher salinity regime influences the lower stretches of the estuary; thus, the adjacent banks have been protected by traditional embankments. These embankments allow the locals to carry out agriculture- predominantly paddy.
- These traditional embankments consistently face the problem of saline water intrusion and require continuous repair and maintenance, which has not been carried.
- Salinity intrusion has changed the land use, converting many paddy fields, riparian zones and mudflats into mangrove areas.
- Based on the SSMG (2016) & Hon'ble NGT recommendations, certain areas in the estuary stretches have been demarcated where sand extraction from the estuary bed cannot be carried out. These sites identified as "sensitive" include islands, bridges-piers, embankments, eroded and erosion prone banks, ecologically sensitive areas viz; mangroves.
- No sand is available in the upper stretches of the Mandovi estuary, which is non saline region of the estuary. In contrast, the majority of sand deposits are in the salinity influenced areas.
- The stretches with low sensitivities, can be considered for sand extraction while following the national statutory and legal guidelines.
- While recommending the lease areas, the authority shall conduct a reconnaissance site survey and a consultative discussion with the stakeholders and accordingly work out areas that do not have a conflict of interest.
- Once the lease areas are issued, then the delineated "Environmental Conservation and Management Plan" needs implementation. The plan also describes the team/committee, which should be capable of addressing, executing, and monitoring all aspects of the plan. Furthermore, the team/committee should appoint sub-teams, SHG's, Village committees on requirement basis as per the plan.

CHAPTER 1- INTRODUCTION

1.1 Sand Mining Scenario in the State of Goa

Sand is available in three forms in the State of Goa. They are ordinary sand, silica sand and beach sand. The ordinary sand is brought by the river originating from the Western Ghats and flowing west to join the Arabian Sea. The process of weathering helps the deposition of sand. Sand is extracted mainly from the river Mandovi, Zuari, Terekhol, Chapora and its tributaries. Where the water column is deep, sand is extracted with the help of canoes and buckets attached to bamboos. Sand is mostly used in construction activities.

The extraction of sand is a traditional activity being carried out in Goa before the Portuguese regime. The extraction was manually carried out and some communities who are dependent on sand extraction for livelihood. Post-Portuguese regime Goa, Daman and Diu Minor Minerals Extraction and Removal Rules, 1974 were in force and after that, the Goa Minor Mineral Concession Rules, 1985 were notified. In 1979 various references are available in the form of application from traditional extractors, letters from cart owners, village panchayats etc.

The extraction of sand from the rivers beds in Goa is governed by the Goa Minor Mineral Concession Rules, 1985 and permission was granted yearly. However, after the CRZ Notification dated 6th January 2011, no permission for sand extraction was granted after 2011-2012 onwards as it was declared a non-permissible activity in CRZ. Subsequently some States including Karnataka requested the Ministry of Environment, Forests & Climate Change, Government of India for permission to remove sand bars naturally formed in rivers by manual methods by traditional communities and an Office Memorandum dated 08/11/2011 of the Dy. Director, Ministry of Environment, Forests & Climate Change was issued which carved out an exception to the CRZ notification. To facilitate the grant of sand permits in Goa, the State Government has constituted two District Committees under the Chairmanship of the respective District Collectors to deal with the grant of licence for extraction of sand. The said committees are notified in the Official Gazette Series II no. 37 dated 13th December, 2012. Based on studies conducted by the committees certain zones/stretches were identified in

Terekhol, Chapora, Mandovi, in North Goa and Dudhsagar, Ragada, Kushavati, Ugvem, Zuari and Sal River in South Goa wherein manual extraction by traditional communities could be permitted. Prior Environment Clearance was obtained by the respective District Collectors vide 3-181-2010/STA-DIR/159 dated 01/10/2015, 3-181-2010/STA-DIR/158 dated 01/10/2015 and 3-181-2010/STA-DIR/184 dated 14/12/2015 from the Goa State Environment Impact Assessment Authority. As per letter no. 39/8/13-MAG/DC-Sand-Ext-NG/9486 dated 04/12/2015 received from District Magistrate, North Goa it was informed that in its meeting held on 02/12/2015 it was unanimously decided that Directorate of Mines & Geology can issue the permission/permits for extraction of sand by local communities by traditional method. Similar decision was recorded in the meeting held on 11/12/2015 by District Magistrate, South Goa. 458 Sand permits were issued by the Directorate starting 2015 onwards for the year 2017-18, 333 permits were renewed for the period 1 October 2017 to 31st May 2018. As per one of the conditions in the EC, sand extraction is banned from 1st June to 30th September due to monsoon. The sand permit holders for the year 2017-18 are being assessed for payment of royalty and non-filling of monthly returns which is a violation of Goa MMCR. Recovery is being carried and penalties imposed as per rules. On 3rd May 2018 a PIL Writ petition (14 of 2018) was filed in Hon'ble High Court of Bombay at Goa by Federation of Rainbow Warriors regarding Sand Extraction in Goa. Subsequently as per High Court Order dated 3rd October 2018 the learned Advocate General submitted that the State is in the process of examining various conditions and permits will be renewed/ granted after consideration of the same. However as per para 9 of the High Court Order dated 23rd October 2018 the Hon'ble Court has not passed any restraint order against issuance of permits. Further affidavit was filed by the State Environment Impact Assessment Authority (SEIAA) on 31/10/2018, wherein at para no. 4 of the Hon'ble High Court's order various lacunae's are pointed out and has made further observation. Subsequently, a note was forwarded by the office of the Learned Advocate General for seeking extension of the time cited in the order of Hon'ble High Court dated 31 October 2018 for the State Government to take a decision on renewal of sand permits as well as seeking modification of the order as approved by the State Government. MCA application was filed before the Hon'ble High Court seeking a time frame of 8 weeks as the Directorate of Environment was in the process of finalizing the studies to be conducted as required under Sustainable Sand Mining Management Guidelines 2016 and

MOEFF notification no So. 141(E) and Directorate of Mines and Geology are working out modalities such as stacking point of sand, installation of weigh bridges, etc. Subsequently, in the order dated 4th April 2019, eight weeks were granted to the State Government to decide on renewal of sand permits. The directorate of Environment has agrred to incorporate Environment Management Plan for an individual cluster to capture all possible externalities before the renewal of the licences. A proposal for the Environmental Management plan is sent for cabinet approval. Hon'ble High Court gave its Judgment in PIL WP No. 14 of 2018 on 18th December 2019. The studies as far as sustainable sand mining as per guidelines of 2016 and MOEF Notification, the Environment Department accorded the work to NIO, Dona Paula. This report presents the EIA/EMP and modelling studies for the sand mining in the Mandovi Estuary.

1.2 Mandovi Estuary

Mandovi river is one of the nine major rivers flowing from the east (Western Ghats) to the west (Arabian Sea) in the state of Goa. It is located between the latitudes ($15^0$09' and $15^0$33'N) and longitudes ($73^0$45' and $74^0$14'E). The river originates in central western ghats and flows in Goa, where it is known as Mahadayi River in the up-streams, and in downstreams is popularly known as Mandovi (Figure 1.1). Mandovi is one of the most important rivers of the state of Goa and is the largest among all the rivers. The Mandovi and Zuari (two major rivers of the state) are joined / interlinked by a canal, called Cumbarjua canal. The river Mandovi and Zuari meets at a common point at Cabo Rajniwas opposite to Mormugao Harbour. The total flowing distance of the river is 70 km in the State of Goa. The total basin area of the Mandovi river is 1530 km^2 and it runs amidst a typical tropical setting along the Midwest coast of India. Mandovi is remarkably influenced by monsoon maritime climate with its three distinct seasons, namely pre-monsoon (February-May), monsoon (June-September), and post-monsoon (October-January).

The annual freshwater runoff of the Mandovi River is approximated to be 16 km^3 with a small pre-monsoon runoff of approximately 0.06 km^3. The river carries drainage from 435km^2 of forestland. The Goa State Pollution Control Board (GSPCB) monitors the water quality of River Mandovi at 5 locations (i.e., Tonca, Hotel Marriott, IFFI Jetty, Mandovi Bridge, Amona Bridge & Marcel) under the National Water Monitoring Program (NWMP) of CPCB. The polluted stretch identified for the Mandovi River is 9.00 kms i.e., from Marcel to Volvoi, whereas the stretch from Panjim to Marcel is 20 kms (action plan as per Hon. NGT order in original application No. 486 / 2018 in Feb. 2019). This stretch of the River Mandovi between Volvoi to Marcel is classified as SW-II (for bathing, contact water sports and commercial fishing). On the basis of GSPCB reports, Central Pollution Control Board (CPCB) has classified Mandovi River (Volvoi to Marcel) under Priority IV, as it has the BOD level range between 3.3 to 6.2 mg/l.

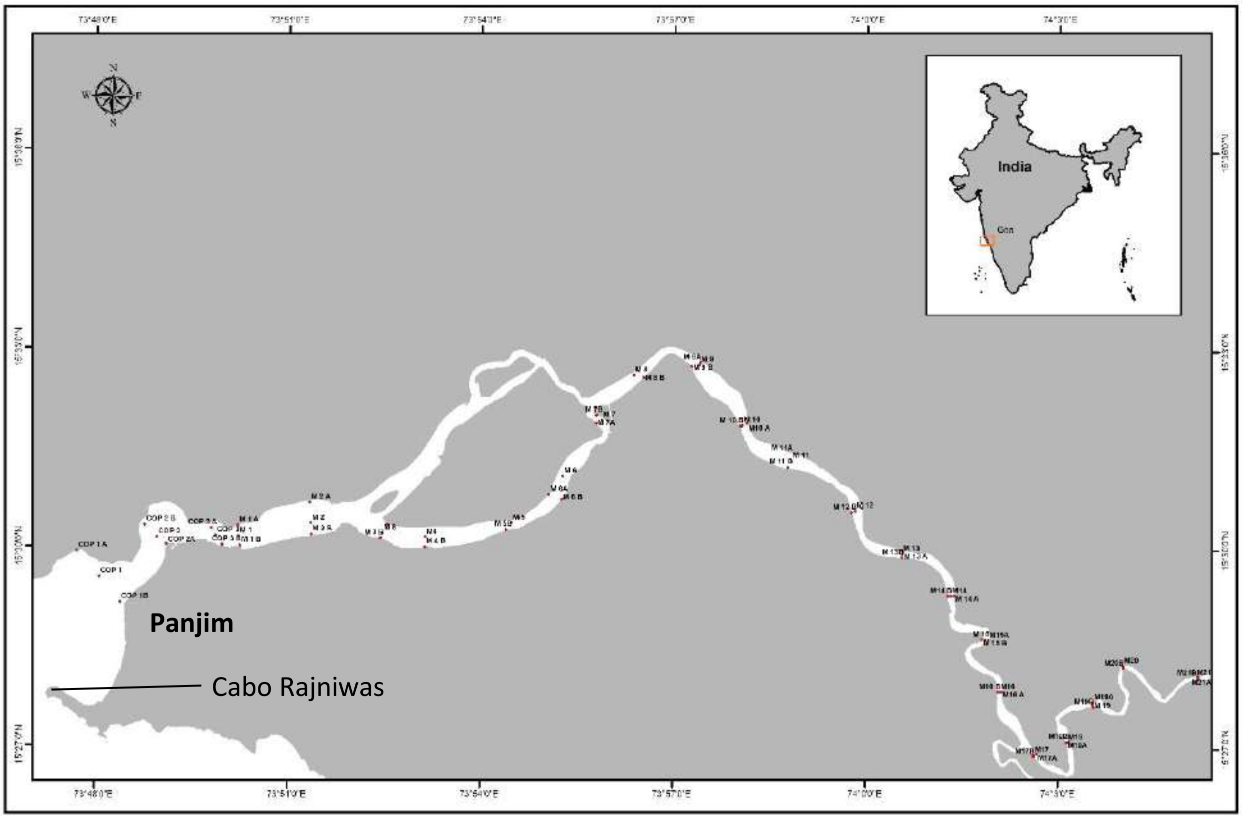


Figure 1.1: Map showing sampling stations in the Mandovi Estuary

1.3 Constraints in adopting SSMMG (2016) for the state of Goa

Goa is a small state located on India's central west coast, part of the rich and biodiverse 'Western Ghats'. There are numerous west flowing rivers in the state of Goa which originate mostly in the hilly regions of the Western Ghats and meet the Arabian sea, forming a major estuarine expanse. The upper stretches of the rivers in Goa are mostly small rivulets, numerous streams that collectively join to form tributaries which further join to form the major rivers. Heavily influenced by south-west monsoon, the rivers bring sedimentary material by regular processes such as denudation and erosion of top soil and rocky material of the Western Ghat formations (Barcem, Sanvordem, Bicholim, Vagheri Formation) shown in Figure 1.2. The average distance of the rivers in the state of Goa from the origin to the Sea is about 25 km or less. With this short distance and the amount of geogenic material brought to its lower reaches by typical process of sediment erosion and denudation the overall process of sand and gravel formation is deficient and truncated. Considering the topography, river velocity and the quantum of riverine flow from each watershed, the magnitude and scale of the rivers in Goa are smaller by an order, as compared to the other Indian rivers such as Ganga, Yamuna, Bramhaputra, Krishna, Cauveri, Mahanadi and Pennar. Additionally, the estuarine complexes in the state of Goa cover a major area of the state. A significant influence of coastal hydrodynamics and salinity intrusion upto several kilometers upstream is a typical characteristic of all the rivers in the state of Goa. Therefore, a majority of riverine expanse is under the influence of salinity.

The second important aspect critical in deciding the sand budget for the rivers in Goa is the dams, barrages and bandaras built on the rivers as the source of important freshwater supply for the state. The lower stretches of these rivers are the major sites of sand extraction but the restricted supply of eroded/denuded material coming downstream makes the riverbeds impoverished due to manmade structures. Indeed, the preliminary studies for replenishment of sand material have revealed very low rate (a few centimeters) of sand deposition after each monsoon season. Furthermore, this replenishment is mostly 'local adjustment' that is redistribution of already existing sand from nearby areas, which is shifted mainly due to flow velocity and tidally influenced hydrodynamics.

These unique traits of rivers in Goa make it difficult to apply the SSMMG which is generically designed considering the diverse nature of rivers in the entire country. Understandably, the SSMMG fits well for important and large river basin that are major sand producing sites contributing a significant percentile of the national requirement. Therefore, at times it becomes difficult to follow all the guidelines delineated in the SSMMG, although this report tries to adopt all relevant plans and implement them for the greater interests of the state of Goa.

It is recommended to consider few additional aspects in the SSMMG (2016) so as to accommodate the small estuarine rivers which exist in the States like Goa. The norm of 3 meters may be explicitly reviewed as it may not fit few of the estuarine regions on the west coast. The guidelines may also mention a mechanism to include capital dredging and maintainance dredging activities which are sectors (or part of coastal projects) requiring MoEFCC clearance. These acticvites demand proper disposal of dredged material at designated offshore locations, with large volumes, if feasible, dredged material can be well utilized as 'commercial sand' instead of dumping in the offshore locations resulting in additional impacts. Coastal hydro-dynamics and bathymetry studies are vital to understand the fate of sedimentary material and its repleninshment in the saline influenced riverine stretches. Inclusion of such baselines can be used to evaluate the vulnerability of banks as well as salinity intrusion pertaining to sand extraction activity.

The present scope also includes a study on the 'river biodiversity index' delineated along with methodology (CPCB, 2002). This index categorically uses freshwater benthic species as indicators for calculating the diversity indices. The values derived from application of these index denotes the status of the river/stretch in terms of pollution/degradation. As mentioned earlier, the rivers in the state are influenced by salinity. A significant span of these rivers can be categorized as estuarine zone and the majority of sand available areas overlap this zone. Estuaries predominantly represent marine biodiversity adopted to low saline conditions and most of the freshwater species tend to perish with any small spike in salinity. Therefore, freshwater indices are not applicable to estuarine communities (benthic or pelagic) and because of this inapplicability the present report uses other standard diversity indices that are used by the scientific community globally.

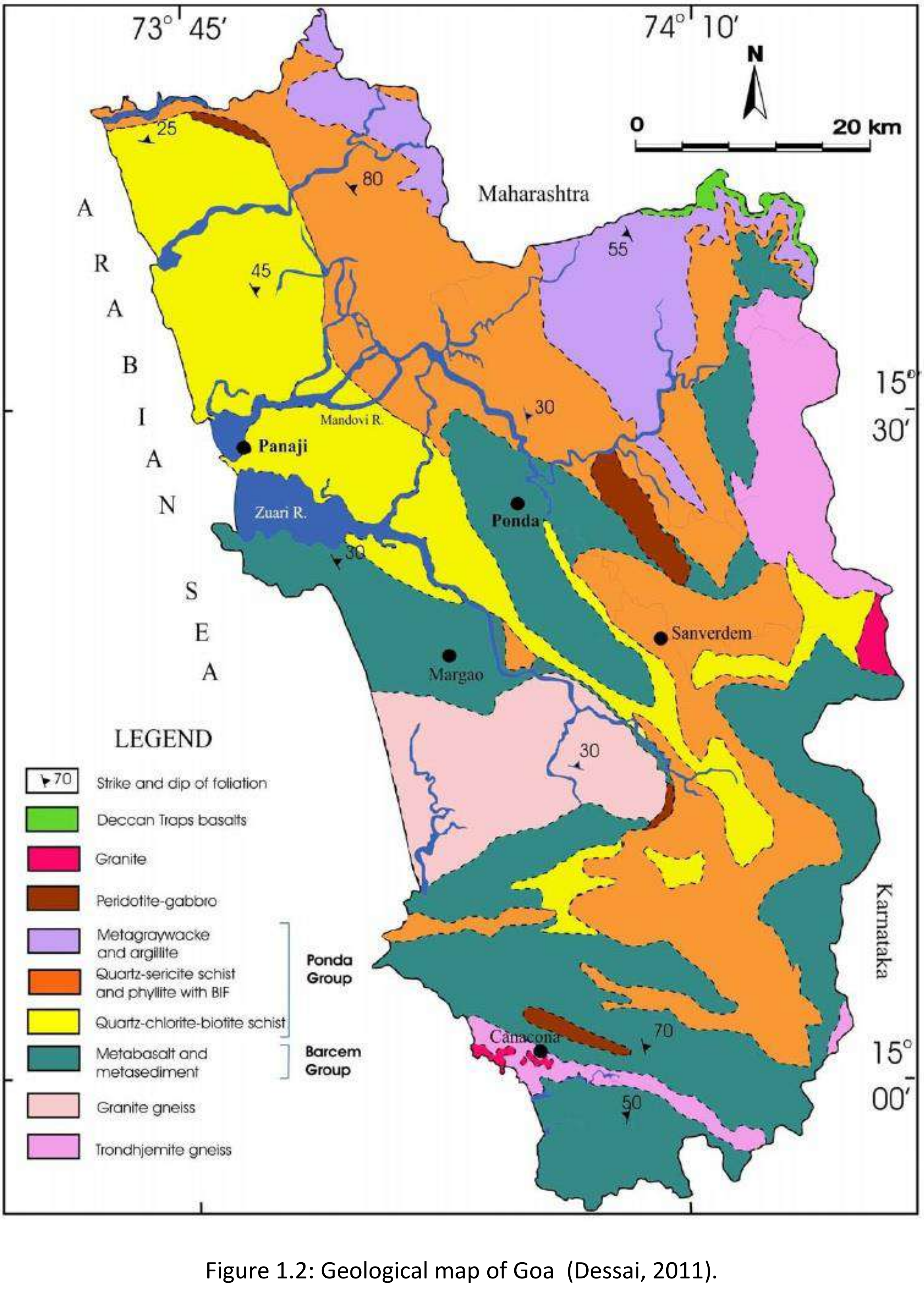


Figure 1.2: Geological map of Goa (Dessai, 2011).

CHAPTER 2-METHODOLOGY:

Following table represents the work plan and the steps involved in Assessing and executing the EIA studies. Which involves surveys, water and sediment parameters and collection and identification of fauna which represents the ecosystem in which the base line study is conducted. All the biotic and abiotic studies those includes Biological, Physical, chemical and geological studies are taken into consideration and a base line report is prepared which includes impacts on the environment, mitigation measures and recommendations for monitoring and conservation and management aspects.

Steps involved in EIA	Particulars
Baseline data collection	• Surveys for all the parameters and measurements as per the requirement • Baseline data collection as per the scope of work. All the baseline data collection has to be as per the plan. • The baseline data collection / monitoring is from primary and secondary sources and field monitoring studies.
Laboratory analysis	• Sample preparation, processing and analysis using various concerned instruments. Calibration and standardisation of all the parameters/ instruments is carried out prior to sample analysis.
Data analysis	• All data generated via direct measurements and laboratory analysis is pooled, outliers are eliminated and data analysis and processing is carried out using standard software to generate Graphical Representations, maps, trends and indices etc.
Preparation of report	• Input of all the experts are given for each of parameters analysed reports in the EIA study • Final compilation of the report (following standard methodology) with the basic requirements for each aspect. Standard report is designed with the following format with analysis and synthesis for decision making. ○ EXECUTIVE SUMMARY ○ INTRODUCTION: Sand Mining Scenario in the State of Goa, About specific study area. ○ METHODOLOGY: Study Area and sampling locations, Water sample collection and processing, Sediment Sample Collection, Meiofaun, Macrobenthos, Diversity indices,

	Biotic indices, AMBI index, M-AMBI index, BENTIX index, AMBI and M-AMBI index, BENTIX Index. ○ Methodology for Modelling- Climatology & Meterology and Methodology for Numerical Modelling Studies ○ RESULTS: Physico- Chemical And Biological Parameters, Temperature and Salinity, pH and Turbidity. Phytoplankton biomass, Chlorophyll a (Chl a), Phytoplankton, species composition and abundance of phytoplankton, Phytoplankton Diversity, ○ Zooplankton, Biomass of Mesozooplankton, Total abundance of Mesozooplankton, Distribution of taxonomic groups of Mesozooplankton, Species Diversity, Sediment Characteristics, Total suspended matter (TSM). ○ Meio-benthos , Foraminifera, Macro benthos, Land Use Land Cover (LULC), Fishery, Reptiles & Mammals, Avifauna, Riparian Vegetation, Seaweeds & Grass (Halotolerant), Mangrove. ○ MODELLING- CLIMATOLOGY & METEOROLOGY ○ NUMERICAL MODELLING STUDIES ○ ANTICIPATED IMPACT: Quantification of impacts wherever possible, Clear difference between prediction modelling, identification of pollution and narration of impacts (Impacts are always on common or sensitive receptors) ○ Prediction & Assessment of impacts, Impact on all the paramters, Positive anticipated impacts, Mining Sensitive Areas. ○ MITIGATION MEASURE Protection of river embankment, Annual replenishment of sand, Maintenance of flood capacity, Seasonal ban on sand mining activity, Limiting sediment impact, Prevention and mitigation of pollution, Protection and management of groundwater, Soil management, Alternative resource generation. ○ ENVIRONMENTAL CONSERVATION AND MANAGEMENT PLAN: Strategy for the management plan, Development of green belts and Nursery, Mangrove management and conservation, Embankment protection and restoration, Biodiversity conservation & management plan, Conservation plan for fauna, Conservation & natural resource utilization, Community participation, Floodplain management (saline marshlands), Development of sustainable integrated aquaculture, Development of eco-tourism, Development of team and funds for the plan,

	Funds for the plan, Role and responsibility of the team, Corrective action/contingency plan, Documentation and record keeping, Complaint handling procedures, Incident and non-conformance reporting. o ENVIRONMENTAL MONITORING PLAN o RECOMMONDATIONS

2.1 Study Area and sampling locations

Table 2.1: Coordinates, depth and sediment texture of Mandovi Estuary

Sampling stations	Location		Depth (m)	Sediment Texture
	Latitude (^{o}N)	Longitude (^{o}E)		
COP1	15^{o}29'21.0"	73^{o}48'24.3"	7	Sandy
COP2	15^{o}30'08.6"	73^{o}48'57.9"	5	Sandy
COP3	15^{o}30'10.4"	73^{o}49'52.9"	2	Silty clay
M1	15^{o}30' 9.84"	73^{o}50' 14.16"	8	Clayey silt
M2	15^{o}30'21.66"	73^{o}51'21.6"	4	Sandy
M3	15^{o}30' 13.02"	73^{o}52' 28.5"	3	Silty sand
M4	15^{o}30'11.3"	73^{o}53'25.2"	2.5	Sandy
M5	15^{o}30'22.7"	73^{o}54'28.8"	5.5	Sandy
M6	15^{o}31'05.1"	73^{o}55'16.9"	3.5	Sandy
M7	15^{o}31'56.1"	73^{o}55'52.9"	8.5	Silty sand
M8	15^{o}32'37.0"	73^{o}56'22.9"	10	Rocky
M9	15^{o}32'46.6"	73^{o}57'24.5"	5.5	Sandy
M10	15^{o}31'51.8"	73^{o}58'04.3"	9.5	Sandy
M11	15^{o}31'26.6"	73^{o}58'53.0"	5	Sandy+gravel
M12	15^{o}30' 34.9"	73^{o}59' 50.4"	6	No data
M13	15^{o}29' 56.28"	74^{o}0' 34.14"	10	Silty sand
M14	15^{o}29'17.94"	73^{o}01'19.92"	2.5	No data
M15	15^{o}28' 38.22"	74^{o}1' 52.08"	8.5	Sandy gravel
M16	15^{o}27'51.3"	74^{o}02'5.52"	7.5	No data
M17	15^{o}26'54.12"	74^{o}02'37.56"	5	Pebbles
M18	15° 45'3.3"	74^{o}05'17.7"	4	Clayey silt
M19	15^{o}27'39.9"	74^{o}3' 32.82"	8.5	Pebbles and sand
M20	15^{o}28'15.3"	73^{o}04'0.72"	7	Sandy
M21	15^{o}28'4.98"	73^{o}05'10.8"	1.5	Pebbles

Plate 2.1: Study area– the Mandovi Estuary

2.2 Water sample collection and processing

Mandovi Estuary was sampled (at eqi-distant locations from mouth to upstream) during November 2020 with the objective to understand the hydrography and productivity pattern on a spatial scale based on biological parameters such as chlorophyll *a* concentration and analyses of phytoplankton and zooplankton composition (see below). The phytoplankton and zooplankton form the bases of the aquatic food web. Since phytoplankton production depends on the availability of nutrients, nutrients such as nitrate, phosphate, and silicate acid were also simultaneously measured.

Sample collection, preservation, and processing were done following the standard protocol mentioned in the project proposal. The samples were collected from 21 stations (surface and near the bottom) starting from near mouth to upstream (M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17, M18, M19, M20, and M21; Table 2.1, Plate 2.1).

2.3.1 Sediment Sample Collection:

The sediments from the margins of the estuary were manually collected from 1 m deep waters, by scrapping the top 2 cm of the sediments with a spatula. The surface sediments from the middle of the estuary were collected by using a grab sampler. The top 2cm of the grab sediment was scrapped with a sterile spatula and transferred to zip-lock bags. A part of the sediment was transferred to plastic containers and immediately stained with ethanol Rose-Bengal solution (2g Rose-Bengal in 1L of 70% ethanol) to identify the living benthic foraminifera. The samples were stored in cool-dry storage boxes. The surface water samples were collected in clean sterile plastic containers for the total suspended matter measurements.

2.3.2 Sediment Sample Processing:

For grain-size analysis, sediments were freeze-dried, weighed and washed by using 63 µm sieve. The material retained on the sieve (sand, coarse fraction) was dried and stored in plastic vials. The water passing through the sieve containing the clay and silt fraction was collected. The fine fraction solution volume was made to 1000 ml in a glass measuring cylinder, stirred vigorously and left undisturbed for a pre-determined duration, as per the ambient temperature. After the passage of pre-determined time, 25 ml of the solution was siphoned and transferred to pre-weighed glass beakers and dried. The beaker with dried clay was weighed again to get the clay weight. The silt weight was estimated by subtracting the weight of the sand plus clay from the weight of the dry sediment. A part of the freeze-dried sediment was powdered and used for total carbon, nitrogen and inorganic carbon analysis. The total carbon and nitrogen were analysed by using a CN analyser and the inorganic carbon was measured by coulometer. The organic carbon was estimated by subtracting the inorganic carbon from the total carbon.

The stained sediments were stored for a couple of weeks for proper staining. The sediments were then directly washed by using a 63 µm sieve. The material retained on the sieve was stored in plastic vials.

2.3 Meiofauna methodology

The sediment samples were collected from 72 stations across the Mandovi Estuary. Sampling was carried out from a mechanized boat during 4th, 5th and 6th November 2020 using an acrylic core of 4.5 cm in diameter. The sampling stations were represented as MA and MB indicating the peripheral regions of Mandovi estuary upstream of the Mandovi bridge. Similarly, COPA and COPB was used to indicate peripheral stations downstream of the Mandovi bridge. Stations at the center of the estuary were labelled M and COP upstream and downstream of the Mandovi bridge respectively. The sand is mainly extracted from the center of the estuary while the peripheral regions generally contain sensitive areas like mangroves and embankments. The samples were collected in duplicates at the stations. Samples were not collected at stations M21, M20, M18, M17, M16 and M14 due to hard substratum All samples were preserved in 10% buffered formalin mixed with Rose-Bengal solution and stored in polythene bags.

2.3.1 Laboratory analysis

The meiobenthos samples were sieved by using a 0.3 mm mesh to remove larger macrofauna and then through a 0.04 mm sieve for smaller fauna. The fauna retained on the 0.4 mm mesh was considered as meiofaunal which was collected in a 100 ml sample container and preserved in 5% buffered formalin. The fauna was identified and enumerated up to the group level under the stereo-zoom microscope (Nikon SMZ18 and Nikon Eclipse Ci) using the guide "Introduction to study of meiofaunal" (Robert P. Higgins et al., 1988).

2.4 Macrobenthos methodology

Total 72 stations were sampled for benthic study in the Mandovi Estuary. The stations at the center were represented as M where there is extraction of sand and peripheral area by MA and MB, where there are mangroves and other sensitive areas. Central stations of the estuary showed sandy texture and peripheral stations showed silty clayey texture. Sediment samples could not be retrieved from stations M17, M18, M19, M20 and M21 due to hard/rocky bottom. Sampling was carried out on a mechanised boat in November 2020 using Van veen grab (0.0410 m^2) for the central stations and Metal Quadrat (0.0625 m^2) at the periphery of the estuary. All the sediment samples were washed separately through 300µm nylon mesh in the field and then transferred to polythene bags and preserved in 10% formaldehyde containing Rose-Bengal stain.

2.4.1 Laboratory analysis

In the laboratory, all the sediment samples were again washed on a 300 µm sieve. All the fauna were sorted and preserved in plastic vials containing 5% formaldehyde. The fauna was enumerated and identified up to the family/genus level under the stereo microscope (Nikon SMZ 18) and compound microscope (Nikon Eclipse Ci). Faunal abundance was calculated as number/m^2. Polychaete was identified to the highest taxonomic level using available identification keys (Day, 1967; Fauvel, 1953; Fauchald, 1977). Abundance of other fauna such as Oligochaeta, Crustacea, Bivalvia, Gastropoda, Platyhelminthes, Nemertea, Nematoda, Bryozoans, Chyronomidae larvae, Fish juveniles were recorded group-wise. Station wise biomass (wet weight) was done and expressed as g/m^2.

2.4.2 Diversity indices

All the raw data was initially processed using Microsoft Excel. Further processing of the ecological data was done using the PRIMER (Plymouth Routine in Multivariate Ecological Research) software package (Clarke and Warwick, 1994) after square root transformation. The univariate measures such as number of individuals or specimens (N), number of species (S), total abundance (A), Shannon- Wiener diversity index (H'), Margalef species richness (d), Pielou's evenness (J') and Simpson index (1-lambda') were calculated using $\log_2$ scale at each station (Clarke & Gorley, 2001).

Shannon-Wiener index of diversity:

Shannon-Wiener index of diversity (information index), a measure derived from information theories developed by Shannon & Wiener (1949), is used by ecologists when a system contains too many individuals for each to be identified and examined. A small sample is used; the index is the ratio of the number of species to their importance values (e.g. biomass or productivity) within a trophic level or community. This normalizes the Shannon diversity index to a value between 0 and 1. The lower values indicate more diversity while higher values indicate less diversity. Specifically, an index value of 1 means all groups has the same frequency.

$$D = -\Sigma^{s}_{i} p_i \log p_i$$

Where (D) is the number of species within a tropic level or community
(S) is the total number of species in the sample,
(i) Is the total number of individuals in one species,

(P_i) is the number of individuals of one species in relation to the number of individuals in the population.

Simpson's Diversity Index:

Simpson's Diversity Index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so diversity increases. The value of Simpson's Diversity Index (D) ranges between 0 and 1, the greater the sample diversity.

$$D = 1 - \Sigma p_i^2$$

Where D is the diversity index,
P_i is the proportion of individuals in the i^{th} Species, and ∑ is the 'sum of'.

Margalef Species Richness: The Margalef index is a species diversity index divided into two types of species richness (how many types are there) and assessment of species evenness or dominance (how individual species are distributed among the community.

$$D = (S - 1) / \ln N$$

Where S is the number of species,

N is the total number of individuals in the sample

Pielou's Eveness index: Species evenness refers to how close in numbers each species in an environment is. Mathematically it is defined as a diversity index, a measure of biodiversity which quantifies how equal the community is numerically.

$$J' = \frac{H'}{H'max}$$

Where H' is the number derived from the shanon diversity index,

H' max is the maximum possible value of H'

$$H'_{max} = -\sum H'_{max} = -\sum_{i=1}^{S} \frac{1}{S} \ In \ \frac{1}{S} = In \ S.$$

J' is constrained between 0 and 1. The less evenness in communities between the species (and the presence of a dominant species), the lower J' is. And vice versa.

2.4.3 Biotic indices

Biotic indices are developed based on indicator species, used as a guide to the level of a particular abiotic factor. For example, the presence of certain invertebrate groups in aquatic ecosystem can be awarded a score that indicates the quality of the water. Such indices like the AZTI Marine Biotic Index (AMBI), Multivariate AMBI (M-AMBI), Bentix index are specialized case of a diversity index generally considered an important means for assessment of water-pollution, and ecosystem stability.

2.4.4 AMBI index

The AZTI Marine Biotic Index (AMBI) is software developed by AZTI-Tecnalia for assessing the quality of benthic macro-invertebrate assemblages by calculating the homonymous index. It was developed in order to establish the ecological quality of European coasts and estuaries.

This index explores the response of soft-bottom communities to natural and man-induced changes in water quality, integrating long-term environmental conditions. AZTI Marine Biotic Index (AMBI) relies on the calculation of the biotic coefficient (BC), which is based in turn on the proportion of disturbance-sensitive taxa and is expressed on a continuous scale ranging from 0 (best status) to 6 (worst status). The AMBI approach follows a model (Glémarec & Hily, 1981; Grall & Glémarec, 1997) which categorises benthic invertebrates into five ecological groups (EGs), depending on their dominance along a gradient of organic enrichment and oxygen depletion. The software includes near 8.000 taxa from all seas, representative of the most important soft-bottom communities presents at estuarine and coastal systems, from the North Sea to the Mediterranean, North and South America, Asia, etc.

2.4.5 M-AMBI index

M-AMBI ('Multivariate AMBI', Bald et al., 2005; Muxika et al., 2007) is a multimetric index for assessing the ecological quality status of marine and transitional waters. It is based on benthic macro invertebrates and integrates AMBI, a biotic index based on species sensitivity/tolerance, with diversity and richness, making it compliant with the European Water Framework Directive. It adopts a multivariate (trivariate) approach, integrating the response of three selected metrics, i.e., species richness, the Shannon diversity index (Shannon & Weaver, 1949) and the biotic index AMBI (Borja et al., 2000). The success of AMBI paved the way for the introduction of M-AMBI, which was subsequently incorporated into the regulations of several European countries. The M-AMBI algorithm integrates the metrics by means of factor analysis (FA).

2.4.6 BENTIX index

The Bentix index (Simboura and Zenetos, 2002) is a marine biotic index based on the concept of indicator species and was developed for the purpose of the ecological status classification of the marine environment using the macro invertebrate's quality element. The index is designed for the assessment of the impact caused by general stress factors and does not discriminate among natural and anthropogenic disturbance. It has been tested successfully in a variety of Hellenic benthic ecosystems (Simboura and Zenetos, 2002) and in case areas subject to organic pollution such as the Athens or Saronikos gulf (Simboura et al., 2005), to oil spills accidents (Zenetos et al., 2004) and is currently tested in other Mediterranean areas within the framework of the EU Water Framework Directive intercalibration exercise (EC, 2003).

2.4.7 AMBI and M-AMBI index

AMBI relies on the abundance-weighted average disturbance sensitivity of the macrobenthic species in a sample (Borja et al., 2000). Each species were distributed in five ecological groups (EG) as per their sensitivity to an increasing stress gradient as summarized by AZTI's classification (Grall and Glémarec 1997).

EG I: species sensitive to organic enrichment and present only under unpolluted conditions.

EG II: species indifferent to enrichment, present in low densities with non-significant variations.

EG III: species tolerant to high organic matter enrichment.

EG IV: second-order opportunistic species.

EG V: first-order opportunistic species, able to withstand high disturbance.

The index was calculated by AZTI's software, following the guidelines of Borja and Muxika (2005). The index generates a final score on a continuous scale from 1 to 6 (7 in azoic sediments) and the thresholds used to define benthic community health were <1.2 (undisturbed), 1.2–3.3 (slightly disturbed), 3.3–5.0 (moderately disturbed), 5–6 (heavily disturbed) and >6 (extremely disturbed) (Borja et al., 2000) which were then condensed to a high, good, moderate, poor and bad status respectively. The multivariate AMBI (M-AMBI) combines with AMBI values in a factor analysis multivariate approach (Table 2.2).

2.4.8 BENTIX Index

BENTIX considers sensitive (GS) and tolerant (GT) taxa based on the reduction of five EG's (as per AMBI) to two EG's, i.e.. EG-I, II as EG-I and EG-III, -IV, -V as EG-II for BENTIX. For BENTIX computation, a newly developed add-in BENTIX v.09 (beta version) software package was used.

Table 2.2: Threshold limits used for ecological status of AMBI and M-AMBI index

Status	AMBI	M-AMBI
High	0.0-1.2	>0.77
Good	1.2-3.3	0.53-0.77
Moderate	3.3-5.0	0.35-0.53
Poor	5.0-6.0	0.20-0.38
Bad	6.0-7.0	<0.2

2.5 Methodology for physical parameters measurement

This section comprises of the physical measurements carried out at Mandovi Estuary for the validation of numerical model. The deployment locations (Figure 2.1), duration and various instruments used for measuring different parameters, are given in Table 2.3. Current measurements (MC1 and MC2) and water level measurements (ML1) were done in the Mandovi Estuary. During pre and post-monsoon, current measurements were carried out at MC2 while during monsoon, current measurements were carried out at MC1. Current measurements at mid-depth were carried out using self-recording current meters (RCM). Watch-keeping boats were engaged for guarding the same. The current meter was hanged from the watch keeping boat. Water level measurement was carried out at ML1. CEESCOPE portable echosounder was used to measure the water depths along the cross sections of Mandovi estuary during January, 2021. The water depth measurement track is shown below (Figure 2.2).

Table 2.3: Table showing instruments used and deployed locations

Location ID	INSTRUMENT	POSITION (Latitude and longitude)	Measurement Period	Water depth at measuring point (m)
MC1	RCM9	15°29'50.10"N 74° 1'5.43"E	Aug-Sep, 2020	8

MC2	RCM9	15°30’08.7” N 73°50’24.6’’E	Nov-Dec, 2020	6
		15°30'9.00"N 73°50'24.40"E	March-April, 2021	5.8
ML1	SeaGuard	15°30'1.54"N 73°50'15.77"E	Jan-Feb, 2021	3.2

Figure 2.1: Locations of current and water level measurements in the Mandovi Estuary

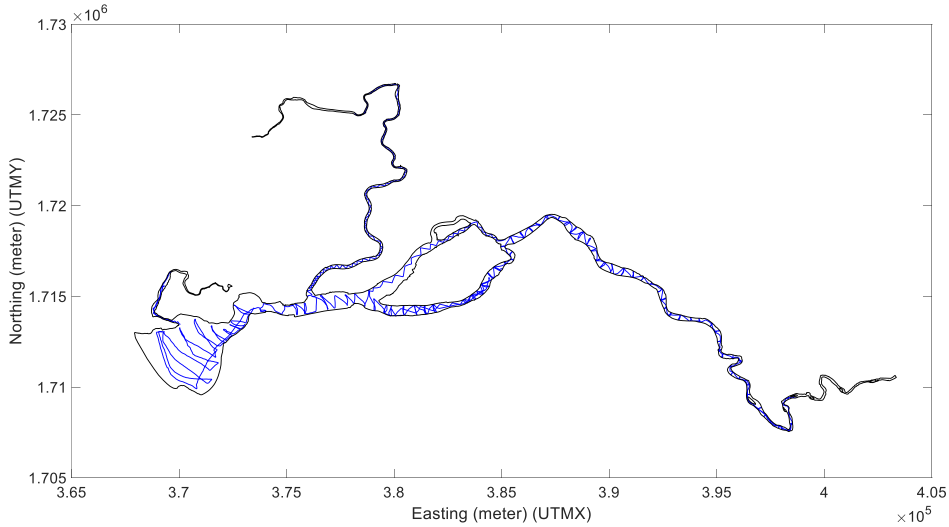


Figure 2.2: Water depth measurement track

2.6. Methodology for Numerical Modelling Studies

The main inputs considered to the numerical model are river topography and water level. The water depth information of Mandovi Estuary was collected during January-February, 2021 using an echosounder. Then the collected water depth information is processed and used for numerical modelling. The base case scenario (Case-1) is with measured water depth information. The second scenario (Case-2) is the modified bathymetry by deepening 3m uniformly at 9 locations (A-I), as in Figure 2.3, of Mandovi Estuary.

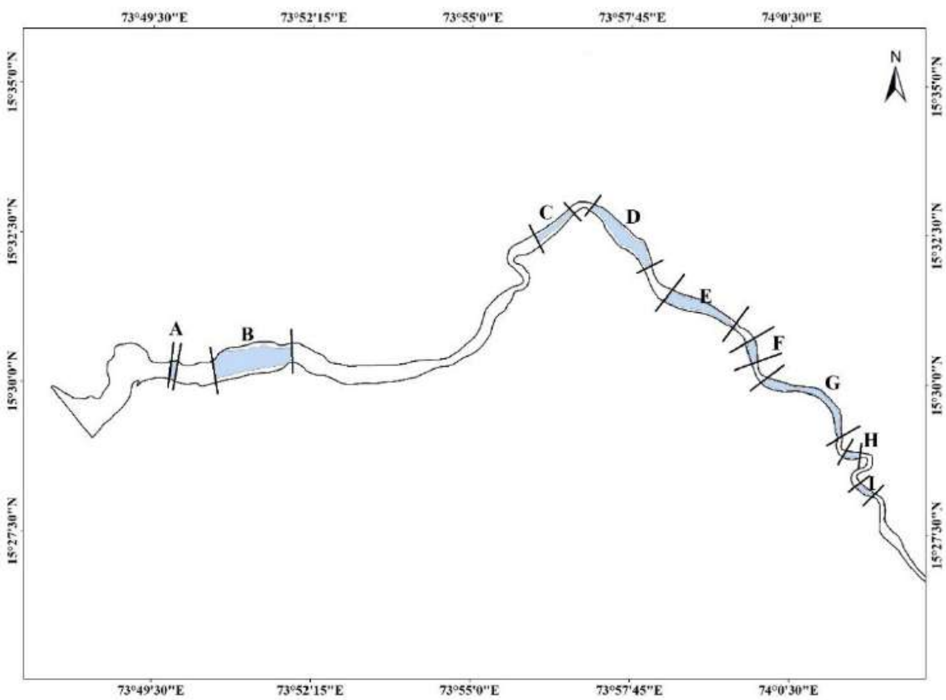


Figure 2.3: Figure showing nine different sections (A-I).

The numerical model described in the previous sections is setup for various scenarios initially to ascertain the validity of the model for the study region. In order to test the validity of the model, purely tidal forcing is given to the model during non-monsoon. However, during monsoon, measured water level data at the upstream model boundary of Mandovi estuary, is given to the model and the hydrodynamic results are compared.

In this study, the effects of the deepening of the river at A-I sections on the hydrodynamics and morphology are studied by comparing with the base case scenario. The Case-1 (base case) scenario model therefore provides a basis for comparison with the modified bathymetry model simulations. However, it is important to simulate the model for the both monsoon and non-monsoon period to understand the dynamics of the sediment transport. In this study, after testing the validity of the model, the numerical model is simulated for August-November, 2020 (during monsoon period) and November, 20 - May, 21 (during non-monsoon period) of Mandovi estuary.

Assessment of mining

Based on the modelling of the hydrodynamics or flow conditions of the region, possible impacts due to the Case-2 scenario of this work are reported in terms of (i) changes in flow or hydrodynamics impact, and (ii) bed level change or morphological impact. The difference between the base case (Case-1) and modified bathymetry case (Case-2) are studied to ascertain the changes in flow patterns and bed morphology changes. The variations of current speed and bed level changes for each of the scenarios are also compared for each section A-I, in the study region.

Hydrodynamic impact

Any change in existing bathymetry, results in changes in the local hydrodynamics till such time equilibrium is attained. Till then the local hydrodynamics would be in dynamic mode adjusting to the new and changing conditions. The extent of change in the hydrodynamics can be ascertained through comparison of flow conditions between the base case (Case-1) and modified bathymetry case (Case-2). In this study, the hydrodynamic impact assessment is carried out through numerical modelling of flow conditions. This is ascertained by studying the differences between the validated model results for the base case and the modified bathymetry case.

Morphological impact

The activity of sand mining would modify the local bottom topography which in turn changes the local hydrodynamics. The impact of the change in bottom topography is studied through numerical modelling of the bed level changes. Modelling the morphology changes using the sediment transport model provides the bed level changes. The changes in the bed morphology for the base case, as well as the modified bathymetry scenario, are carried out.

CHAPTER 3- PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS

3.1 Introduction

Estuaries are specialized ecosystems with contrasting biogeochemical regimes linking two ecosystems, riverine and marine, with distinct biological communities and the structuring processes. It is well known that estuaries receive a substantial contribution of carbon and nitrogen, more so from the terrestrial region that can at times lead to the uncontrolled growth of some organisms, such as harmful algal blooms.

The Mandovi –Zuari, the two primary rivers in the state of Goa described as the lifeline of Goa, are no exception to this. These tropical monsoonal estuaries of India undergo an extreme change in salinity regime seasonally. Owing to its geographical set up the estuarine systems receive enormous precipitation during the wet season and run-off from a large catchment area. In contrast, negligible riverine discharge leads to seawater domination and a prominent salinity gradient formation during the dry season. Thus, the estuarine sediments have a vital role to play in ecosystem functioning/health, such as preventing an estuarine system from being nutrient-limited by giving out nutrients and, on the other side, can avoid being eutrophic by acting act as a nutrient trap. Thus, any disturbance to the benthic ecosystem, including sand mining, is likely to disturb the benthic life and its effect expect to percolate into the food chain bringing imbalance in the whole ecosystem, which is addressed through this project to facilitate appropriate ecosystem management.

3.2 Physico-chemical parameters

3.2.1 Temperature and Salinity

During the sampling period, the Mandovi station depths varied between 1.5 and 10m (avg. 6m), with a deeper zone between station 7 and station 16 (Figure 3.1). As seen in the other estuaries of Goa, the Mandovi Estuary is also being influenced by the tidal currents. Hydrographic variations are thus known to vary accordingly, controlling the temperature and salinity variation.

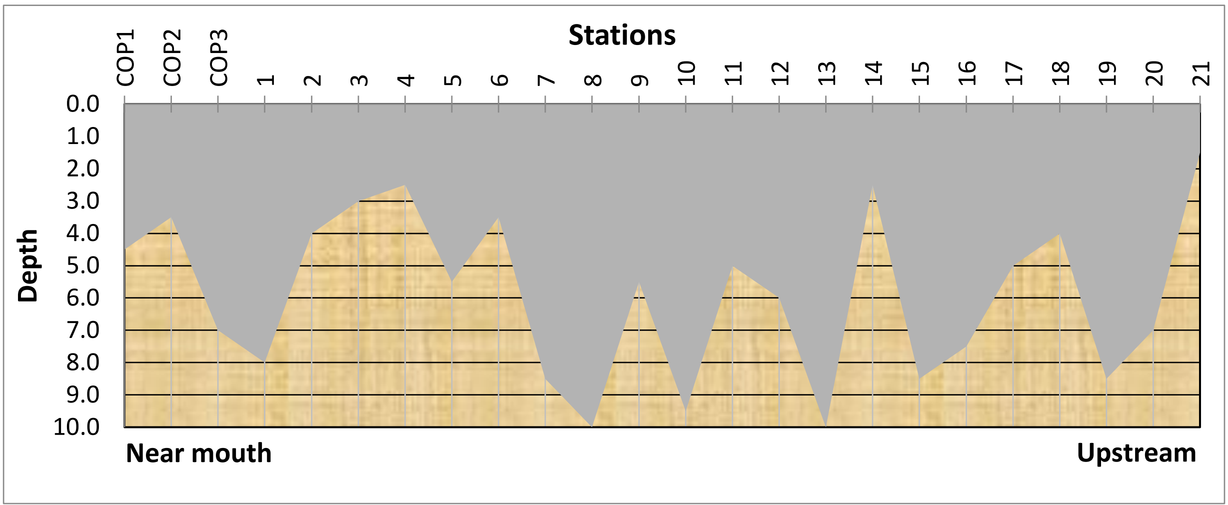
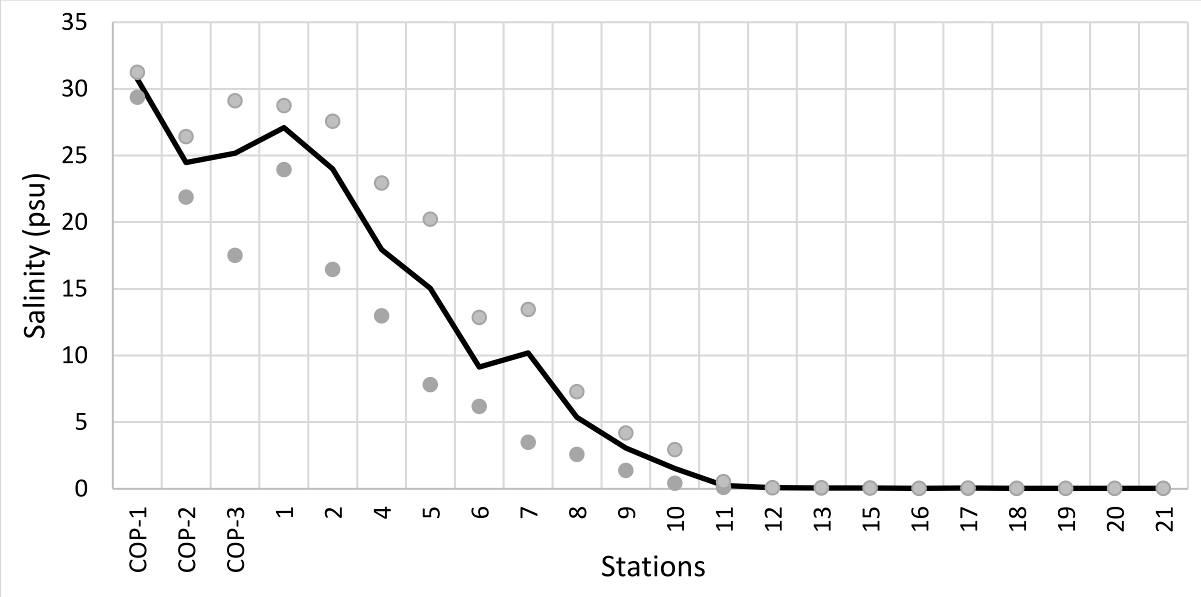


Figure 3.1: Depths of the stations in the Mandovi estuary.

In general, salinity profiles in the water column depicted significant variations (0.0-28.7 PSU) than that of temperature (see below) (27.0° C- 29.5°C) (Figure 3.2a). Freshwater dominated the estuary beyond station 11. Thus, hydrographic features characteristically divided the estuary into two zones; region under the influence of seawater (Zone 1; stn M1-M10) and region influenced by the freshwater (Zone 2; M11-M20) (Figure 3.2a).

On the other hand, the water temperature varied narrowly between 27.9 and 29.9°C (avg. 28.9°C). The relatively higher water temperature (>29°C) was restricted to the middle part of the estuary (Stn 4 and Stn 10) while lower temperature waters (<28.5°C) prevailed in the upstream region (beyond Stn 19; Figure 3.2b). The temperature fluctuation could be a function of time of day during the sampling period.



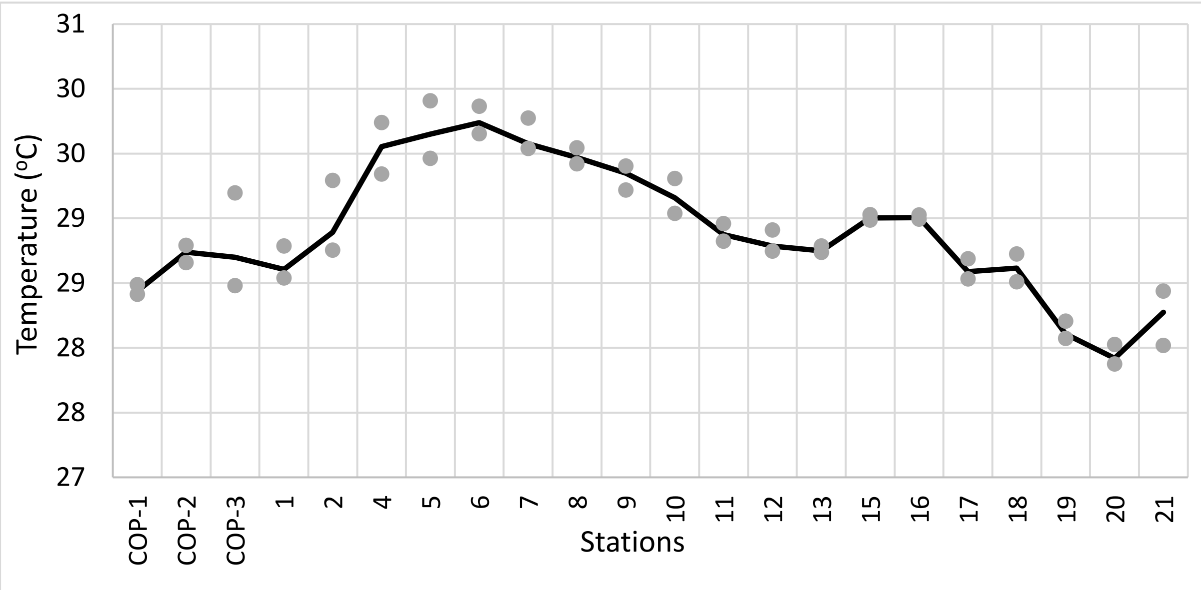


Figure 3.2: Spatial variations in (a) Salinity and Temperature (b) in the Mandovi Estuary. (1-estuary mouth station and 21-upstream station; solid line indicate average values and circles represents low & high values).

3.3.2 Dissolved oxygen and nutrients

Sampling carried out in the Mandovi Estuary starting from downstream region to upstream region found waters to be saturated with oxygen varying from 3.2 to 5.3 ml L^{-1} (avg. 4.2 ml L^{-1}) with an increasing trend from downstream to upstream. Mainly, the bottom water oxygen was found to be above the hypoxic threshold (O2 >1.4 ml L^{-1}), which indicated a healthy environment for aquatic organisms (Figure 3.3).

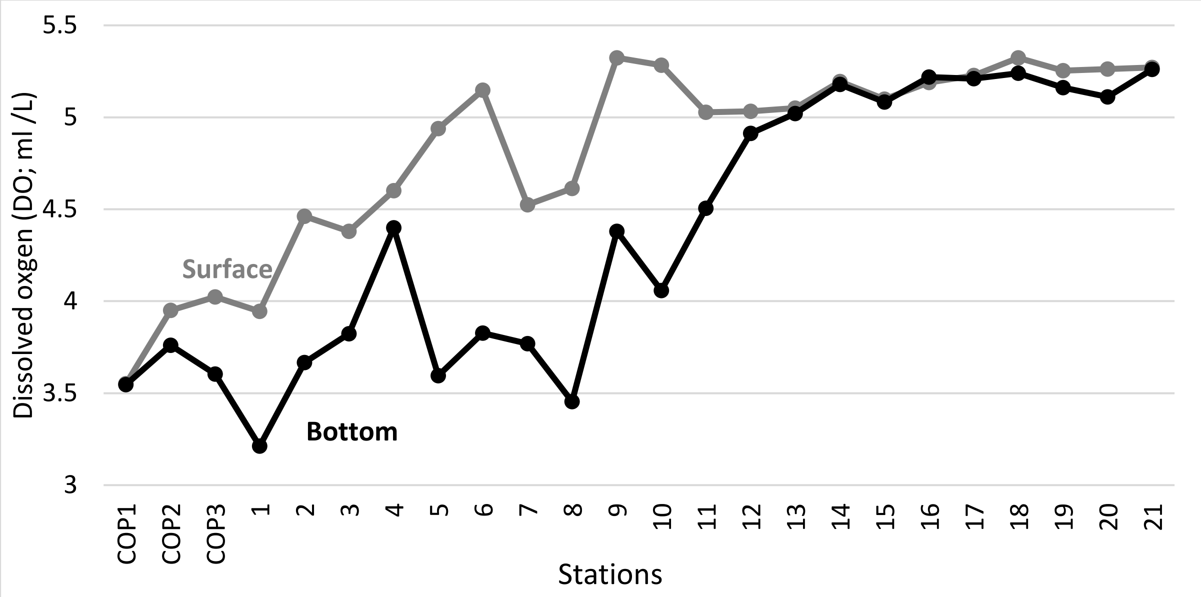
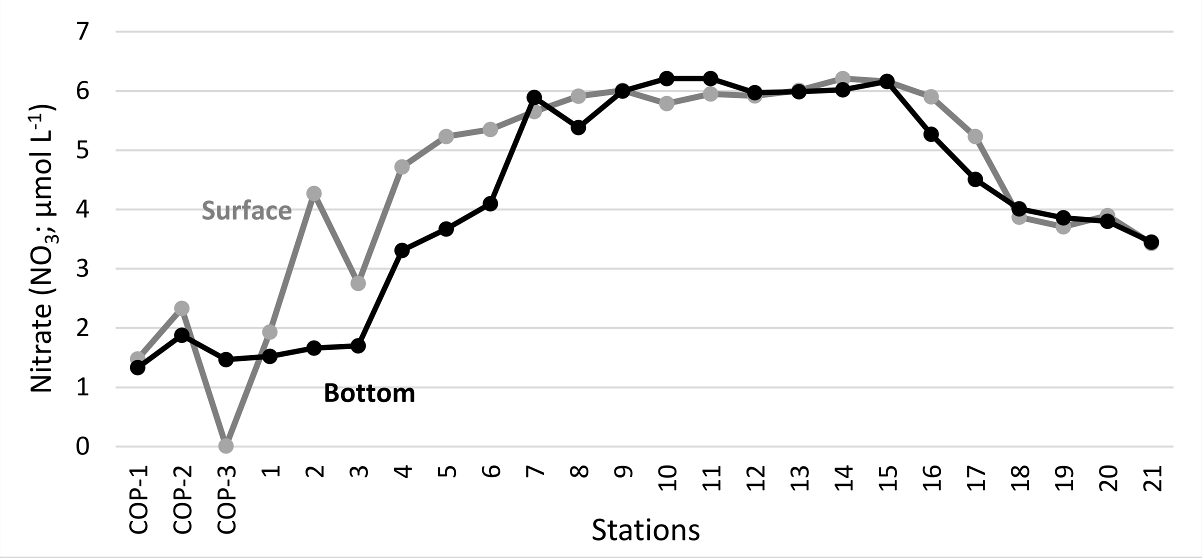
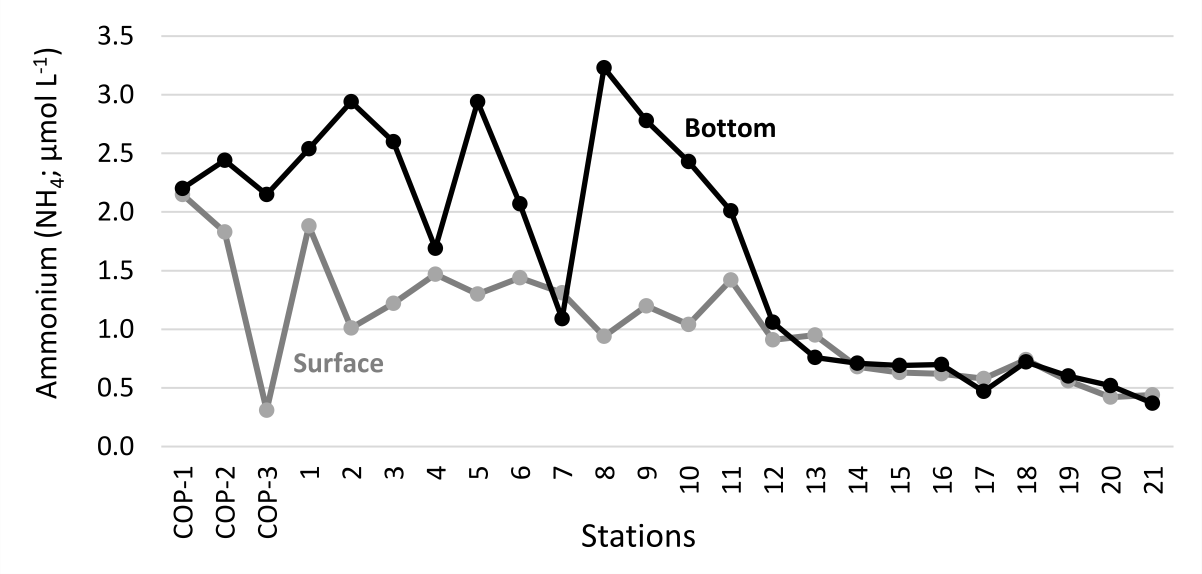


Figure 3.3: Spatial variations (surface and bottom) in dissolved oxygen in the Mandovi Estuary.

Phytoplankton needs nutrients to grow. They are like the fertilizers we add to land plants that are used to make proteins, nucleic acids, and other cell parts by the phytoplankton to survive and reproduce. The two most critical nutrients are nitrogen and phosphorous. In most cases, nitrogen runs out first, and the growth of phytoplankton stops.

The nitrate level varied from 1.5 to 6.2µM with an increasing trend from near mouth to the middle part of the estuary and decreased further upstream to 3.4 µM, showing a mid-estuary maximum (Figure 3.4a). Similar trend was also seen in Ammonium level that varied from 2.9µM (near mouth) to 0.3µM (upstream; Figure 3.4b) and in phosphate concentration; varied from 0.67µM (near mouth) to 0.03µM (upstream; Figure 3.c). On the contrary, silicate levels that varied from 32µM (near the mouth) to 193µM (upstream) showed a clear increasing trend from downstream to upstream (Figure 3.4d). It is remarkable to see the impact of seawater penetration in the bottom water up to Amona as observed from salinity data. This is well reflected in the difference in surface and bottom concentrations of oxygen and nutrients, which gradually decreases from Panjim to Amona and becomes insignificant further upstream. The concentrations of O_2 and nutrients (especially in bottom water) and their trends are typical of the Mandovi Estuary, as expected during the dry season.


Nitrate (NO3; µmol L-1)
7
6
5
4
3
2
1
0
Surface
Bottom
COP-1
COP-2
COP-3
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Stations


Ammonium (NH4; µmol L-1)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Bottom
Surface
COP-1
COP-2
COP-3
1
2
3
4
5
6
7
8
9
10
11
12
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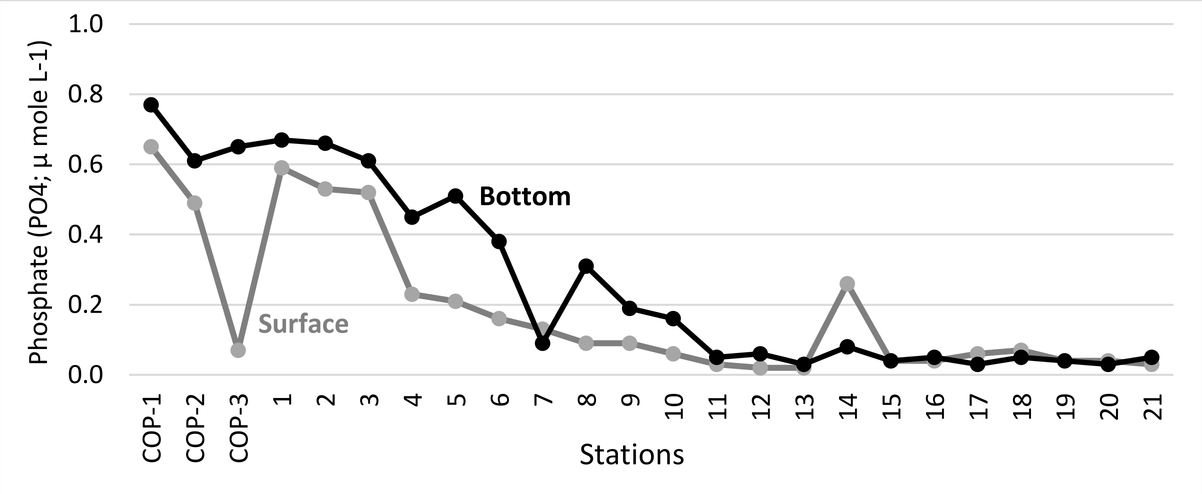
18
19
20
21
Stations


Phosphate (PO4; µ mole L-1)
1.0
0.8
0.6
0.4
0.2
0.0
Bottom
Surface
COP-1
COP-2
COP-3
1
2
3
4
5
6
7
8
9
10
11
12
13
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18
19
20
21
Stations

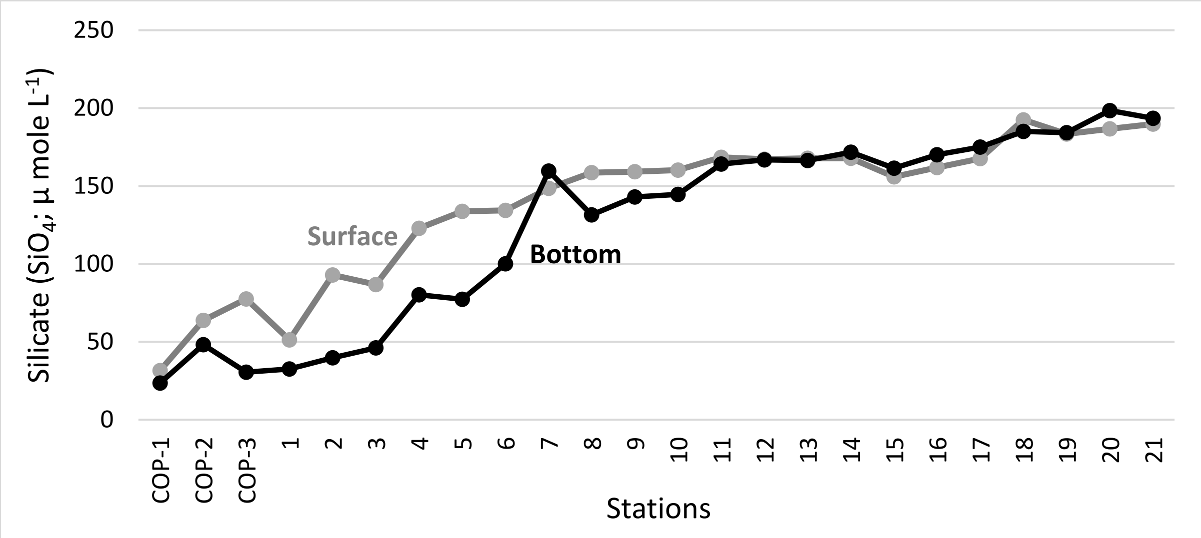


Figure 3.4: Spatial variations in (a) nitrate (NO_3); (b) Ammonium (NH_4,); (c) phosphate (PO_4) and (d) silicate (SiO_4) in the Mandovi Estuary.

3.3.3 pH

The increasing amount of carbon dioxide in the atmosphere alters the Earth's climate and shifts ocean chemistry as carbon dioxide gas can dissolve into the water bodies. This extra carbon dioxide imparts acidity to the liquid represented as pH. The lower the pH value, the higher the acidity, while solutions with high pH are basic (= alkaline). Before the industrial revolution, the average ocean pH was about 8.2.

In the Mandovi Estuary, pH was generally well below 8.0 (avg. 7.38; 6.82-8.39) except at central part estuarine stations (stn M11-M14). Vertically in the water column, higher values were recorded in the near-surface compared to the near-bottom measurements. Spatially, less alkaline condition (<7.5) prevailed in the freshwater-influenced region (Figure 3.5).

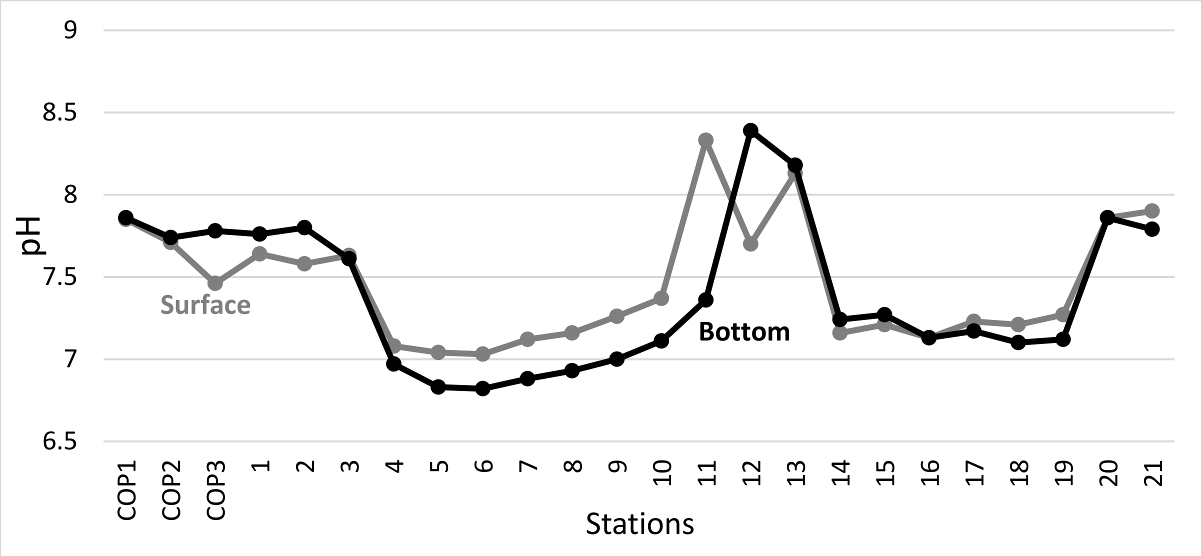


Figure 3.5: Spatial variations (surface and bottom) in pH in the Mandovi Estuary. (1-estuary mouth station and 21-upstream station)

3.3.4 Turbidity layer

This layer in the water column contains significant amounts of suspended sediment (called turbidity/napheloid layer), which generally forms due to resuspension of bottom sediments caused by tidal currents/ anthropogenic activities, including mining. The turbidity layer can scavenge organic particles from the water column, such as phytoplankton, which act as tracers of productivity.

In the Mandovi estuary, turbidity varied between 4.9 and 95.0 NTU, with higher values at the near bottom (>20NTU) (Figure 3.6). Noted peak values (>50 NTUs) at stations M5, M10, M11, M15, and M19 indicate sites of anthropogenic disturbance.

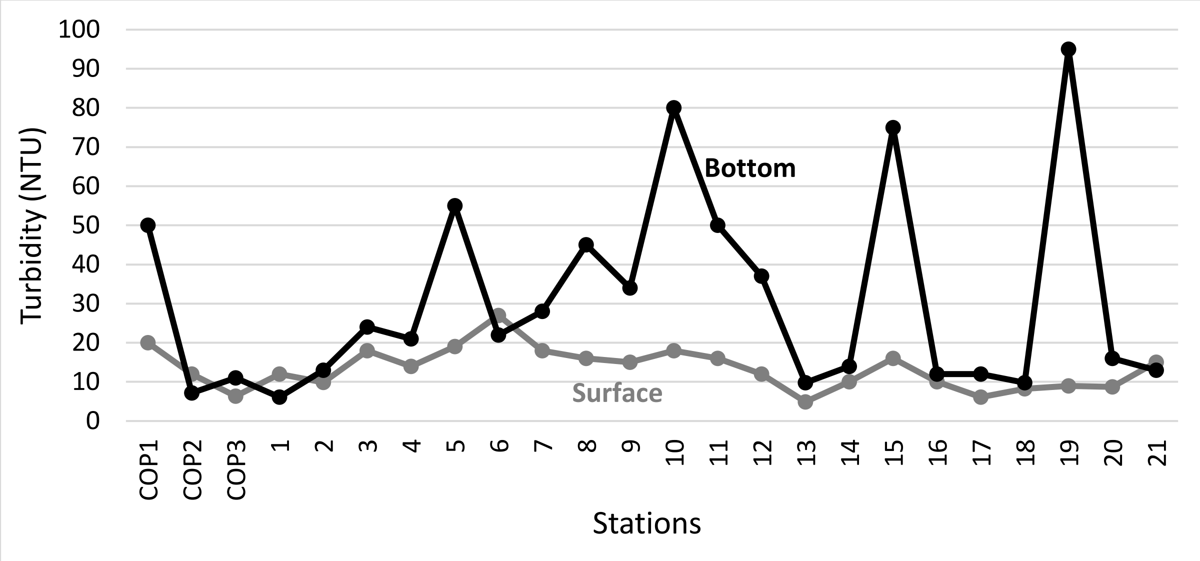


Figure 3.6: Spatial variations (surface and bottom) in turbidity (NTU) in the Mandovi Estuary.

3.3 Phytoplankton biomass

3.3.1 Chlorophyll a (Chl a)

One of the most widely used proxies of phytoplankton biomass is the total chlorophyll-a concentration measured fluorometrically. Chl *a* (µg/L) showed spatial variation generally decreasing trend towards the upstream region. Biomass that varied between 0.1 and 5.3 (avg. 0.87) with the highest concentration in the mid-stream region, particularly at stn M10, also showed variations in the water column vertically. The near-surface waters were found to be more productive, especially near the mouth region (stns: M1-M12), while the upstream (Stns: M13-M21) area remained well mixed (Figure 3.7).

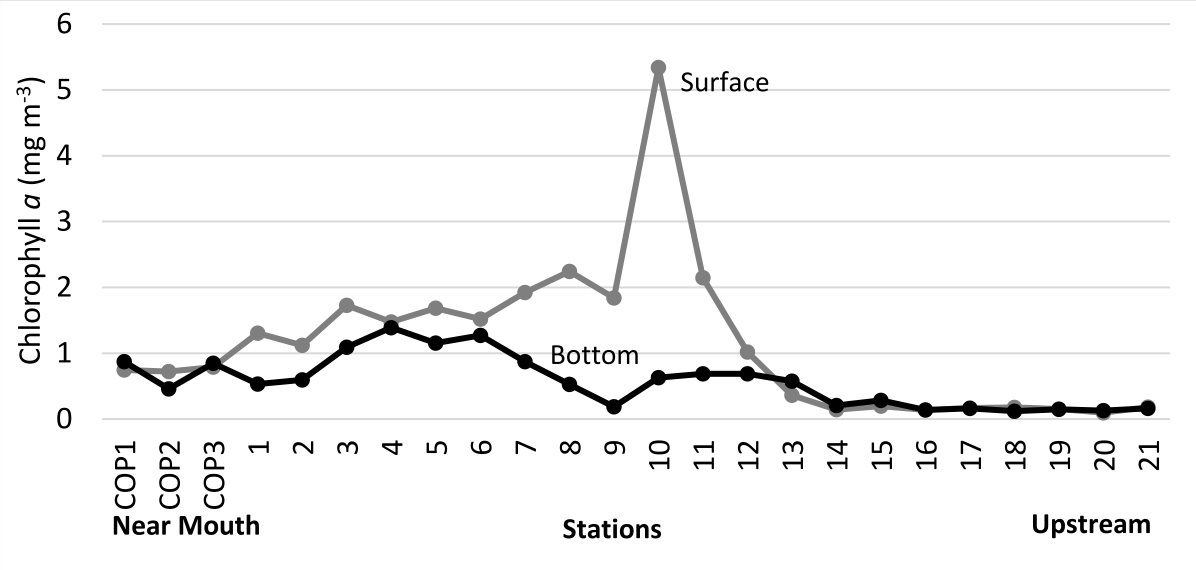


Figure 3.7: Spatial variations (surface and bottom) in Chlorophyll *a* (mg m^{-3}) in the Mandovi Estuary. (1-estuary mouth station and 21-upstream stations)

Likewise, sedimentary chlorophyll *a* biomass also showed a variability (0.01 and 0.6 mg Chl a g^{-1}; avg 0.14) with higher concentration, particularly in the midstream region consistently lower values ($\leq$ 0.06 mg g^{-1}) were recorded in the upstream region (beyond stn M10; Figure 3.8).

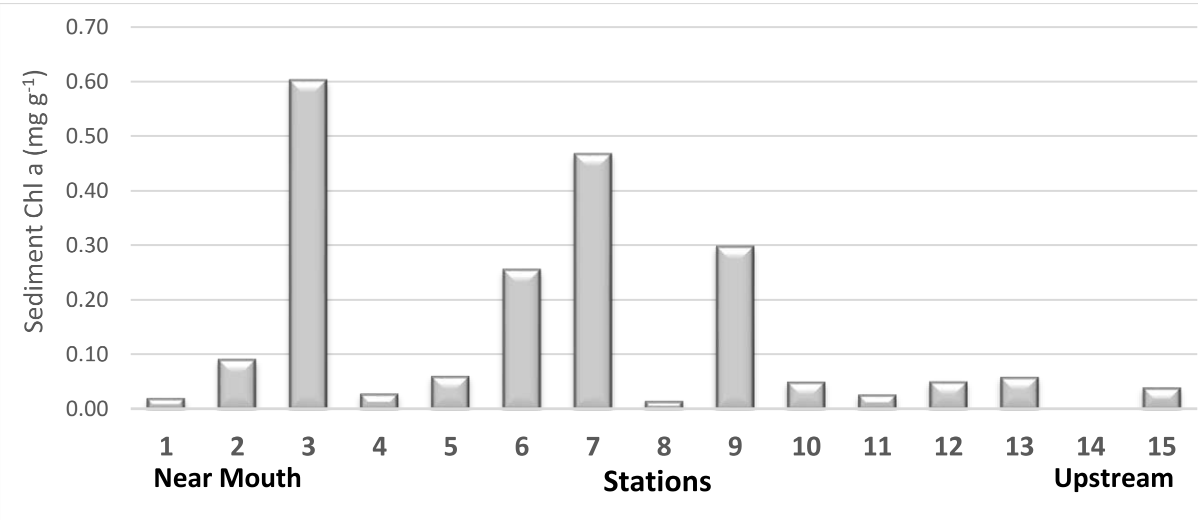


Figure 3.8: Spatial variations in sedimentary Chlorophyll *a* (mg g^{-1}) in the Mandovi Estuary.

3.4 Phytoplankton

3.4.1 Species composition and abundance of phytoplankton

Phytoplankton composition and its numerical abundance studied from the Mandovi estuary following microscopic technique (>10µm in size) showed diverse forms (Genera: 104; Table 3.1). These forms representing the phytoplankton community are grouped broadly into five Phyllum: (i) Bacillariophyta (ii) Dinoflagellata (iii) Cyanobacteria (iv) Charophyta, and (v) Chlorophyta. The Bacillariophyta comprising diatoms were predominantly pennate forms (centric: 20 genera and pennate: 30 genera). While Dinoflagellata, the second-most diverse form, was comprised of 23 genera. The forms belonging to other phylum were less diverse: Charophyta represented by 17 Genera, Cyanobacteria (by 6 genera), and Chlorophyta (5 genera).

Amongst species belong to Genera *Surirella, Cyclotella, Dictyosphaerium, Stephanodiscus, Aulacoseira, Coscinodiscus, Melosera, Thalassiosira*, and *Chaetoceros* (of centric diatoms); *Navicula, Synedra, Nitzschia, Pinnularia, Pleurosigma, Gomphonema, Cymbella, Gyrosigma, Thalassionema, Amphora, Cocconeis, Diatoma, Diploneis, Pseudo-nitzschia* (of pennate diatoms); *Gymnodinium, Peredinium, Cryptomonas, Euglena, Gonyaulax, Oxytoxum, Chlamydomonas, Prorocentrum, Protoperidinium, Rhodomonas, Scrippsiella, Alexandrium* (of dinoflagellates); *Oscillatoria, Anabaena* (of cyanobacteria); *Staurastrum, Scenedesmus, Coelastrum, Micrasterias, Chlorella, Elakatothrix* (of Charophyta) and *Monoraphidium, Ankistrodesmus* (of Chlorophyta) dominated the community.

Table 3.1: Station wise and spatial variation of phytoplankton composition and abundance in the Mandovi estuary.

						<-- Near mouth			Stations							--> Upstream					
Phytoplanton compostion & abundance(average abundances of surface and near bottom samples)	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**M19**	**M20**	**M21**
Phyllum: Bacillariophyta																					
DIATOM (Centric)																					
Actinoptychus spp.					190																
Amphanizomenon spp.										553											
Aulacoseira spp.							640	373		211	195		300						273	68	
Aulacodiscus spp.						147		50													
Bacteriastrum spp.	28				71			25													
Chaetoceros spp.	254	1098	400	43																	
Coscinodiscus spp.	84			29				132	27	109			22		33						
Cosmerium spp.																					309
Cyclotella spp.	997	364		270	626	1101	318		82				97								
Dictyosphaerium spp.		207				132					142	75	99	624	214	51					
Guinardia spp.		414																			
Leptocylindrus spp.		10278	3400		3141																
Melosera spp.	38				728	1896	674	1159		448											
Rhizosolania spp.	113																				
Skeletonema spp.	1408			3354																	
Stephanodiscus spp.							900	1182	1708	4581	1161	132			164					102	
Surirella spp.	38						64	44	82	237	73	38	172		33	94	32		109	136	69
Telmemorus spp										316	2911								328		
Thalassiosira spp.	898	2352	2600	279	190																
DIATOM (Pennate)																					
Actinastrum spp.								2038	546				264								
Actinotaenium spp.										158											
Amphiprora spp.										1610	799										
Amphora spp.	336			93		196	96						375								
Asterionella spp.				93					164												
Asterionellapsess spp.	226			172																	
Bacillaria spp.													450								
Cocconeis spp.	42									79	73	36					139				
Cymatopleura spp.							90														
Cymbella spp.			200		95		372	131	94	346			357		436		291		82	204	
Cylindrotheca spp.			400																		
Diatoma spp.	28					98				53			19					64			
Diploneis spp.				179	190					158	142							166			
Fragillaria spp.	339		800															261			
Gloeotrichi spp.					252																
Gomphonema Spp.							96		176	1047	361	144	1848		2707	450	1851		8585	9273	17450
Gyrosigma spp.			200					66		277			38		164	45			123		51
Licmophora spp.	113																				
Meridion spp.																		249			
Navicula spp.	126	137		571	22		91	74	116	556	146	61	517	246	333	303	329	53	831	1225	205
Neidium sp.										158			75								204
Nitzschia spp.	327	600		1080	365	775	1074	151	321	927	146		173	134	87			84	115	664	411
Peronia spp.				93				1054													
pinnularia spp.				47			96	50	211	608	321	18	563	651	255	45	354		854	1061	1489
Pleurosigma spp.	38			29			96	186	348	1113	266	48	344		327	157	67		476	268	34
Pseudo-nitzschia spp.	197	1734	400		84																
Rhoicosphenia spp.						196															
Synedra spp.	75	108		153	95	33	534		86	184	242	60	1213	224	1544	67	561	343	2057	1234	1639
Tabellaria spp.														236				513			
Thalassionema spp.	3549	7674	4000	1523	3528	3893												87			
Ulothrix spp.																101					
Phyllum:Dinoflagellata																					
Alexandrium spp.	281		400	258	95																
Amphidinium spp.		138			190																
Carteria spp.				186				262	94			36									
Ceratium spp.	168																				
Chlamydomonas spp.				516					2632					288	109			261			
Chromulina spp.												156		96							
Cryptomonas spp.				233			672	131	22372	127270	12461							216		408	
Dinophysis spp.	113	108	400																		
Dissodinium spp.					285																
Euglena spp.							90	99	182					201			52		58	153	257
Gonyaulax spp.	57	3485		22	42	74	360	99											29		
Gymnodinium spp.	875	138	200	1032	1392	3967	750	297	2632	8455	1994	1188	225	192	1063	595	603		115	507	103
Heterocapsa spp.		414																			
Oxytoxum spp.	23	138		854	1430	1600	4862	4012	188												
Phacus spp.				358	285	490								192							
Prorocentrum spp.	141	35		22	24	49															
Protoperidinium spp.	478	1308	200		274								264								
Peredinium spp.	140			124	32	807	224	406	376	59	24	12				30	32				
Pyramimonas spp.											73										
Pyrophacus spp.				93																	
Rhodomonas spp.				558			288		1880			36	792								
Rhoicosphenia spp.							90	131						588							
Scrippsiella spp.	1056	2604		172	221															153	
Trachelomonas spp.				279			864											166		408	
Phylum- Cyanobacteria																					
Chroococcus spp.											730			96							
Anabaena spp.				93						356					327		388				
Arthrospira spp.							90		82												
Gloeocapsa spp											142										
Homoeothrix spp.																		83			
Oscillatoria spp.	126		1400		258	49		197	205	79	110					101	208			99	257
Rivularia spp.																	388				
Phylum: Charophyta																					
Arthrodesmus spp.								198						384							
Closterium spp								131												300	103
Chlorella spp.				387	238		192											208			
Coelastrum spp.							2115	2228	705	1516	36						65		633		
Cosmarium spp.							180													297	719
Crucigonia spp.							630		376											495	
Closterium spp.																90					
Elakatothrix spp.						1078	810	393		79											
Euastrum spp.													66				97				
Micrasterias spp.												4938	2115	3276	4470	909	873				
Oedogonium spp.						98						72									
Spondylosium spp.																		688			
Staurastrum spp.								156	323	33	80	38	17	26	258	121	54	96	49	87	38
Scenedesmus spp.				22	155			322	352	287		36	33		55	101	119		115		
Xanthidium spp.																270					
Spirogyra spp.																			312		
Sphaerozosma spp										267											
Desmidium spp.											284										
Phylum: Chlorophyta																					
Chladophora spp.																				396	
Ankistrodesmus spp.							6792	3560			1798	624			1100		971				
Monoraphidium spp.				527	1099	2310	480		3722	2072	218	102	47		133	30	340	29	191	170	274
Mougeotia Sp.																			574		
Tribonema spp.												1404			327						
Total phytoplankton Abundance (Cells/L)	**12711**	**33333**	**15000**	**13739**	**15596**	**18988**	**24630**	**19332**	**40082**	**154199**	**24925**	**9254**	**10483**	**7454**	**14138**	**3560**	**7813**	**3566**	**15907**	**17707**	**23613**

Numerically, phytoplankton abundance (x 10^3/L) that varied within the water column (3.56-154.19; avg. 23.14+ 31.37) showed spatial variation along the estuary length (Figure 3.9). The higher population, chiefly at the near mouth region (station M1-M6 and at stations. M9 & M10), was primarily due to the contribution of diatoms and dinoflagellates (Figure 3.10a). A sudden spike in the abudance was noted at M11 which also coincided with high chl-a conc. probably due to high nutrients. While a few upstream locations (stns: M19-M21) showed an increasing trend of numerical abundance due to the presence of freshwater species of phytoplankton belonging to Phylum Cyanobacteria and Charophyta (Figure 3.10b). Interestingly, Chlorophyta was found to proliferating in the middle part of the estuary (Stns M5- M12; Figure 3.10b).

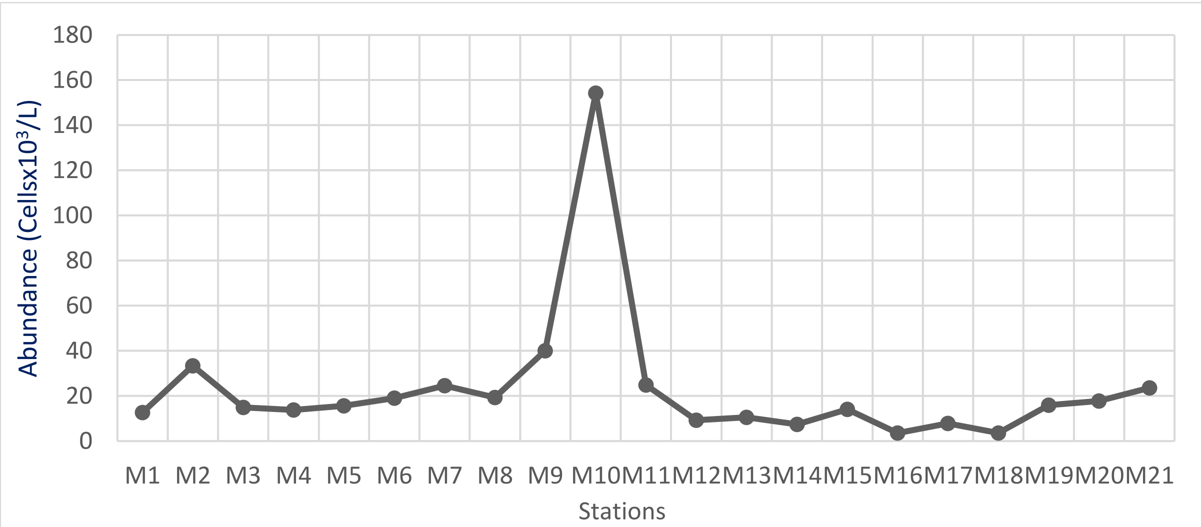


Figure 3.9: Spatial variations in phytoplankton abundance (average) in the Mandovi Estuary.

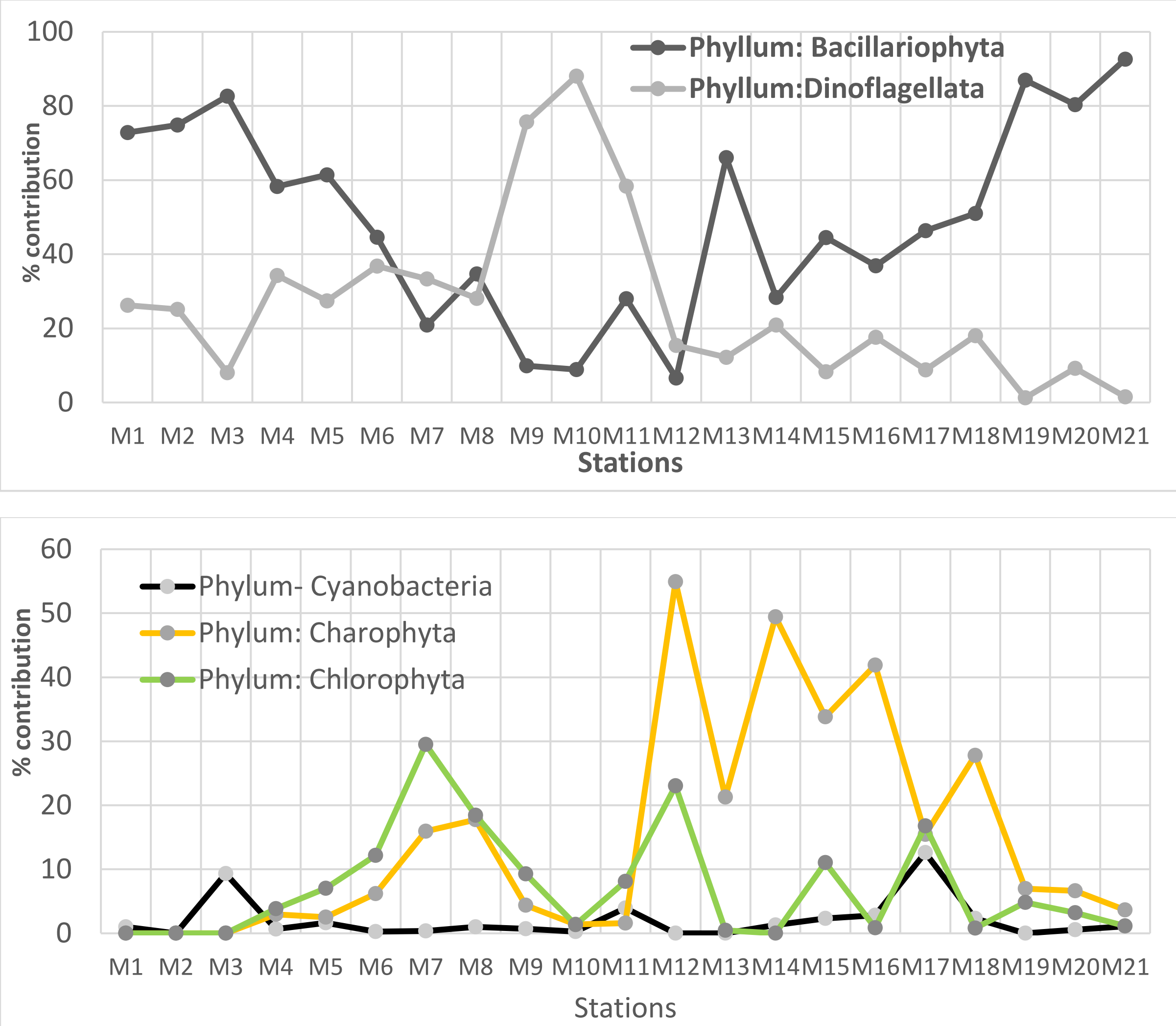


Figure 3.10: Percent contribution of (a) Bacillariophyta & Dinoflagellata and (b) Cyanophyta, Charophyta and Chlorophyta to the phytoplankton abundance (average) in the Mandovi Estuary.

3.4.2 Phytoplankton Diversity

Statistical analysis of phytoplankton diversity in the Mandovi Estuary is shown in Table 3.2. Overall, the total number of species (s) decreased towards the upstream region and vertically in the water column; they were higher at the near bottom (data not shown here). Analyses depicted species richness (d) to vary from 1.11-2.53 (avg:1.72 +0.36). Similarly, evenness (J) ranged from 0.48-0.94 (avg. 0.77+0.10), and Diversity index (H) from 1.62-2.63 (avg. 2.21+0.27). The low value of 'd' and J' at stn.M10 was due to the dominance of dinoflagellate Cryptomonas spp. that accounted ca. 82% numerical abundance of phytoplankton.

Table 3.2: Distribution of number of species (S), total abundance (N), species richness (d), evenness (J') and diversity (H') of phytoplankton in Mandovi Estuary.

Stations	**S**	**N**	***d***	***J'***	***H'(loge)***
M1	27	24504	2.53	0.80	2.63
M2	19	61062	1.60	0.74	2.12
M3	22	18800	2.13	0.82	2.53
M4	25	30679	2.34	0.80	2.57
M5	23	33558	2.11	0.73	2.27
M6	16	45568	1.35	0.84	2.19
M7	21	67008	1.78	0.71	2.12
M8	23	53125	2.05	0.73	2.28
M9	21	81784	1.83	0.67	2.01
M10	25	306266	2.01	0.48	1.62
M11	19	45223	1.71	0.65	1.91
M12	15	11460	1.53	0.72	1.92
M13	19	20415	1.83	0.82	2.41
M14	12	12288	1.11	0.87	2.04
M15	17	24822	1.58	0.85	2.40
M16	13	8099	1.34	0.87	2.24
M17	17	13835	1.63	0.90	2.51
M18	15	7417	1.52	0.94	2.52
M19	15	30837	1.36	0.78	2.10
M20	17	35271	1.48	0.80	2.22
M21	15	33048	1.35	0.64	1.73

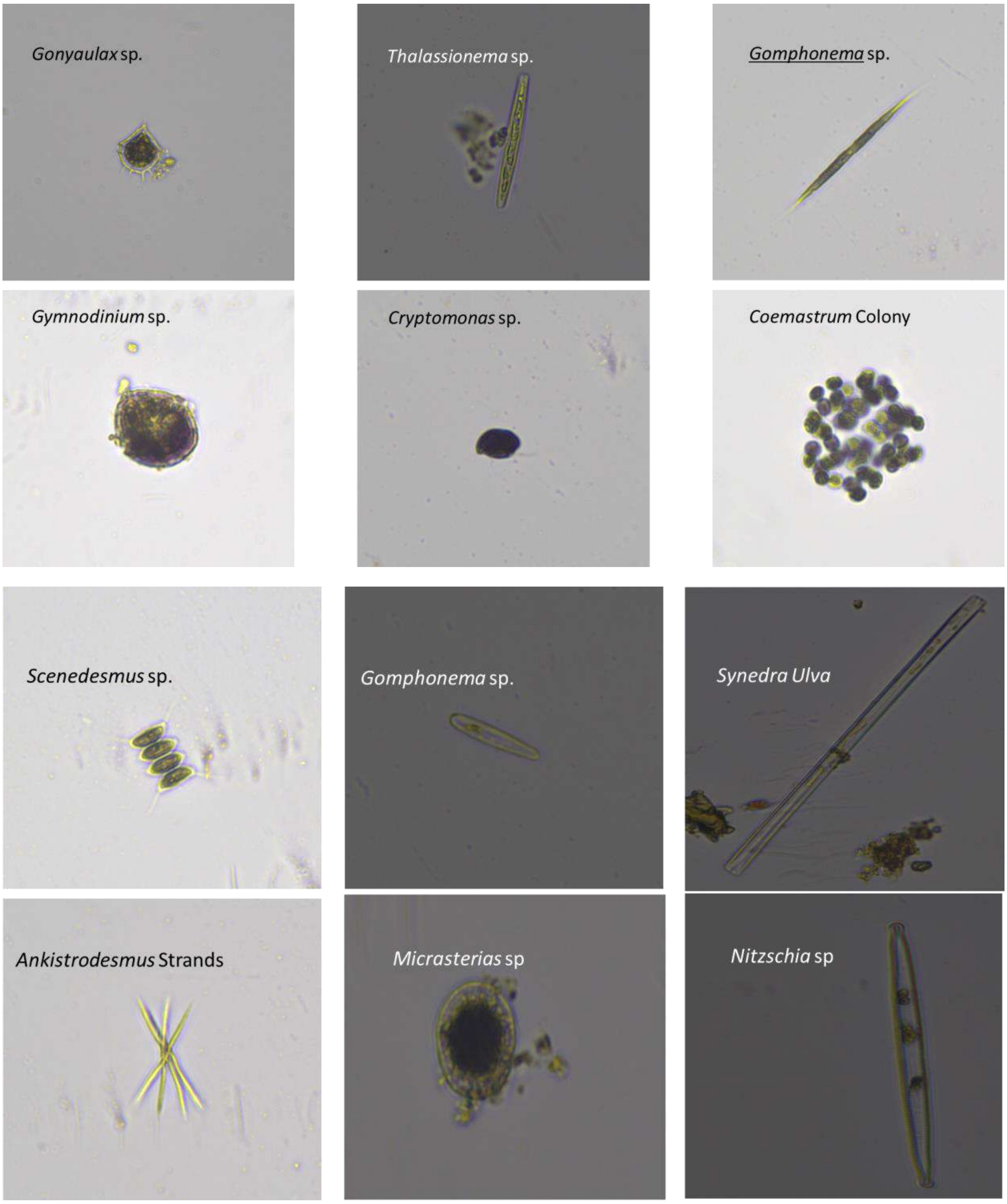


Plate 3.1: Represantative species of Phytoplankton

3.5 Zooplankton

Mesozooplankton are the key link between phytoplankton (primary producers) and fishes (secondary or tertiary consumers) in marine, estuarine and freshwater systems. These organisms play a significant role in regulating algal and microbial productivity through grazing. Hence, they are critical intermediaries in the flow of both energy and matter in the aquatic food web. Also, they are essential contributors and modifiers of the biogeochemical cycles.

Prominent zooplankton includes radiolarians, foraminiferans, cnidarians, crustaceans, mollusks, and chordates. The conspicuous members of the tropical plankton are the crustaceans, dominated by copepods. Others ecologically important zooplankton include crustaceans (such as ostracods, cladocerans, isopods, amphipods, mysids, and krill); chaetognaths, mollusks (bivalves, gastropods, pteropods), and chordates (salps and fish larvae, fish egg).

Different species have different tolerance/adaptive levels to environmental variables, hydrographical conditions (pollutants), and responses to changes in their diversity and abundance. Hence, they act as indicators to monitor aquatic ecosystems. Hence for understanding the ecology of any water body, study on zooplankton communities is essential.

3.5.1 Samples analysed

A total of 24 stations were selected from estuary mouth to upstream region. The zooplankton samples were collected using Heron Trancter net (200um mesh size; horizontal tow). Samples from stations COP1, COP3, M2, M4, M6, M8, M10, M11, M12, M13, M14, M15, M16, M18, and M20 (from estuary mouth to upstream) are processed for biomass estimation, taxonomic identification, and enumeration of mesozooplankton. Stations labeled as 'COP' are additional sampling sites at the near mouth region of the estuary close to station 1.

3.5.2 Biomass of Mesozooplankton

The current study results reveal the spatial variation of mesozooplankton along the Mandovi Estuary. Measured biomass was highest at the mouth region (COP1 with 70.65ml/100m^3) and observed a decreasing trend towards midstream, further decreasing towards the upstream regions to an undetectable level (UDL) (Table 3.3).

Table 3.3: The spatial variation of mesozooplankton biomass in the Mandovi estuary. For the stations M8-20, the displacement volume-based biomass is negligible; hence their biomass is marked as UDL; COP –near mouth and M20 - upstream).

Station	Lat N	Long E	Biomass (ml/100m³)
COP1	15° 29.339'	73° 48.388'	70.65
COP3	15° 30.219'	73° 49.792'	14.75
M2	15° 30.361'	73° 51.360'	10.57
M4	15° 30.180'	73° 53.505'	14.88
M6	15° 31.093'	73° 55.251'	4.27
M7	15° 31.965'	73° 55.762'	0.36
M8	15° 32.653'	73° 56.436'	0
M10	15° 31.918'	73° 58.076'	0
M12	15° 30.607'	73° 59.844'	0
M14	15° 29.299'	74° 1.332'	0
M16	15° 27.855'	74° 2.092'	0
M18	15° 45.0550'	74° 05.2959'	0
M20	15° 28.255'	74° 4.012'	0

3.5.3 Total abundance of Mesozooplankton

The abundance of mesozooplankton showed a downtrend from the estuary mouth to upstream. However, this trend was not uniform in the upstream region. This may be due to community shift and dominance of any particular group of organisms (like a higher abundance of decapod larva and mosquito larva in certain upstream regions). Near mouth station COP1 observed the highest (1875159 ind./100m^3) abundance, while the lowest was at M13 (108.49 ind./100m^3) (Figure 3.11).

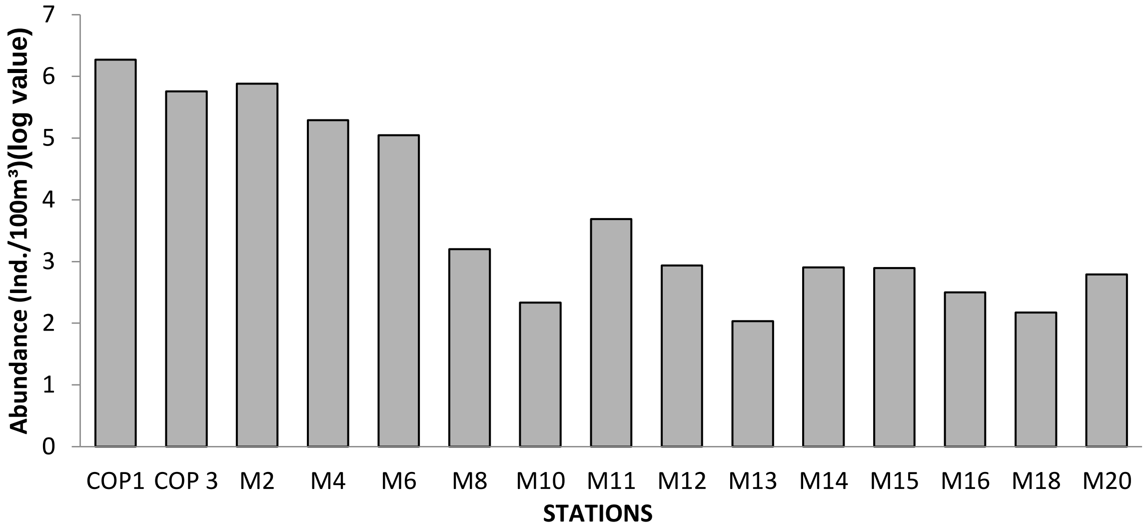


Figure 3.11: Spatial variations in mesozooplankton abundance (Ind./100m3, log values) in the Mandovi Estuary.

3.5.4 Distribution of taxonomic groups of Mesozooplankton

Mesozooplankton community composition was grouped into two major categories such as copepods and non-copepods. The percentage composition of copepod varied from 3.76% (M14) to 92.27% (COP1). In estuary mouth (COP1–COP3), copepod dominated over non-copepod groups. In contrast, non-copepod groups were major contributors (96.27-65%) in midstream and upstream (except stns M8, M10, and M11) (Figure 3.12).

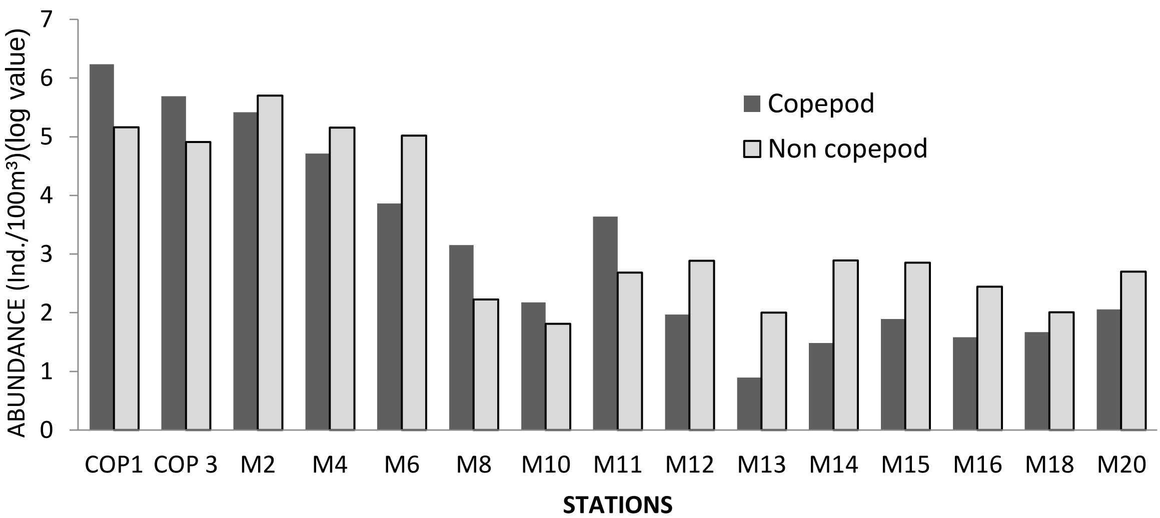


Figure 3.12: Distribution of copepods and non-copepods along the Mandovi estuary.

Among non-copepod groups, cladoceran, decapod larva, fish larva, and gastropods have more or less even distribution throughout the estuary. However, certain groups such as Siphonophora, hydrozoa, polychaete, and bryozoans larva were observed only in the estuary mouth region. Also, barnacle nauplius, bivalve, lucifer, and isopod juvenile were absent in the upstream areas. Whereas, Ostracoda, a sizable number of mosquito larva and other insect larvae were found only in upstream waters.

3.5.5 Distribution of copepods

The taxonomic composition and abundance of copepods varied from the estuary mouth to upstream regions. The copepod in the estuary comprised form belong to orders calanoida, cyclopoida, harpacticoida, poicelostomatoida. However, order calanoid was found to have a more consistent distribution throughout the estuary. Again, calanoids dominated copepods along the estuary, with a few exception upstream stations (stns: M12, M14, M16, M20). The presence of cyclopoid and poecilostomatoid copepods were noted in the estuary mouth, midstream, and upstream regions. In comparison, harpacticoid copepods were rarely present in the upstream areas. Even though copepods were present all along the estuary, species composition was different upstream than midstream and mouth regions (Figure 3.13).

The species such as *centropages furcatus, Temora discaudata, Tortanus* sp., **Subeucalanus** sp., *Nanocalanus minor, Labidocera kroyeri, Labidocera detruncate, Centropages orsinii, Acartia bispinosa,* and *Acartia ambionensis* are mostly confined to estuary mouth region. *Acrocalanus gibber*, *Acrocalanus gracilis*, *Paracalanus* sp., *Acartia* sp., *Oithona* spp, and *Euterpina acutifrons* were present both in the mouth region and midstream. But species like *Oithona plumifera* and *Tortanus* sp. are observed only in midstream stations. Nevertheless, *Sinodiaptomus indicus* and a parasitic copepod, *Ergasilus* sp. were observed in midstream and upstream areas. Also, species belong to *Diacyclops bicuspidatus*, *Megacyclops* and *Acanthocyclops* were confined to upstream regions. Moreover, specific genus like *Pseudodiaptomus*, *Oncea*, and *Corycaeus* were distributed all along the estuary.

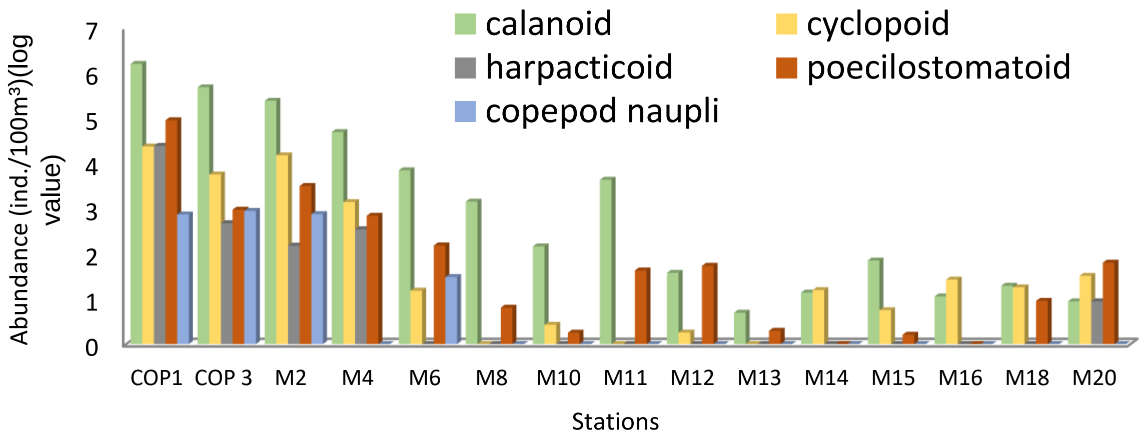


Figure 3.13: The abundance and spatial distribution of copepod orders in the Mandovi Estuary.

3.5.6 Species Diversity

Diversity indices are significant aids to characterize the diversity, richness, and evenness of the species in the community. Shannon diversity indices are commonly used to describe a community. The number of species (S) and the range of diversity indices (based on Shannon index) in the Mandovi estuary is given in Table 3.4 showing the number of species is highest at the estuary mouth, followed by midstream. In comparison, a comparatively a smaller number of species inhabits upstream regions. Diversity index (H') also shows a similar pattern with the highest diversity at the near mouth (stn: COP1; 4.054) and lowest at upstream (stn: M11; 1.98).

Table 3.4: Number of species (S), species richness (d), evenness (J') and species diversity(H') in the Mandovi estuary. COP1 (near mouth) and M14 (Upstream).

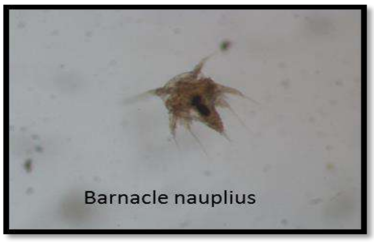
STATION	**S**	***d***	***J'***	***H'***
COP1	26	2.963	0.8625	4.054
COP 3	24	3.049	0.7164	3.285
M2	25	3.093	0.7665	3.56
M4	21	2.833	0.7983	3.506
M6	14	2.028	0.6464	2.461
M8	8	1.626	0.7373	2.212
M10	12	3.035	0.8531	3.058
M11	12	2.333	0.5532	1.983
M12	13	2.846	0.7941	2.938

M13	9	2.661	0.7963	2.524
M14	9	2.075	0.6763	2.144
M15	11	2.564	0.6789	2.349
M16	6	1.44	0.8194	2.118
M18	9	2.368	0.8875	2.813
M20	11	2.516	0.8036	2.78


Fish larva


Decapod postlarva


Gastropod


Barnacle nauplius


Cladocera


Paracalanus aculeatus


Zoea


Chaetognatha


Acrocalanus gibber

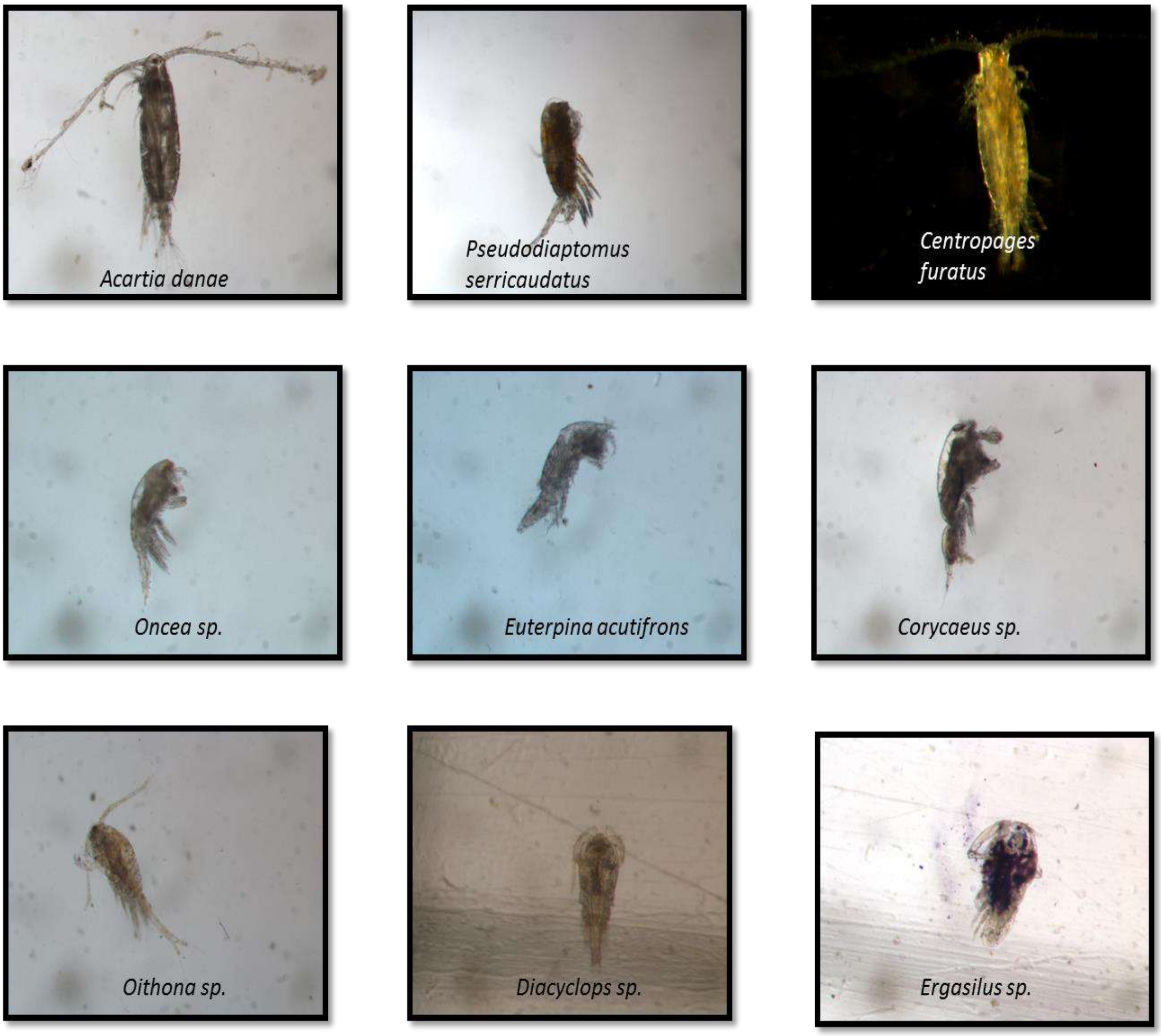


Plate 3.2: Representative species of Zooplankton

3.6 Sediment Characteristics:

The sand fraction increases towards the mouth of Mondovi. Also, at a majority of the stations, the central part of the Mandovi (channel) has a higher percentage of sand compared to either estuary margins (Figure 3.14). The organic carbon was less near the mouth of Mandovi and increased away from the mouth (Figure 3.15). The stations with higher sand fraction had corresponding lesser organic carbon. As the margins has relatively finer sediments, the organic carbon was also higher for the either side of the estuary and comparatively lesser in the central part. The calcium carbonate ($CaCO_3$) was estimated from the inorganic carbon. The stations towards the mouth had higher $CaCO_3$ and it was insignificant (<2%) at a majority of the inner estuarine stations (Figure 3.15). Since it is estuary sample the Nitrogen values were coming in negligible level. C/N ratios didn't show any significant trend.

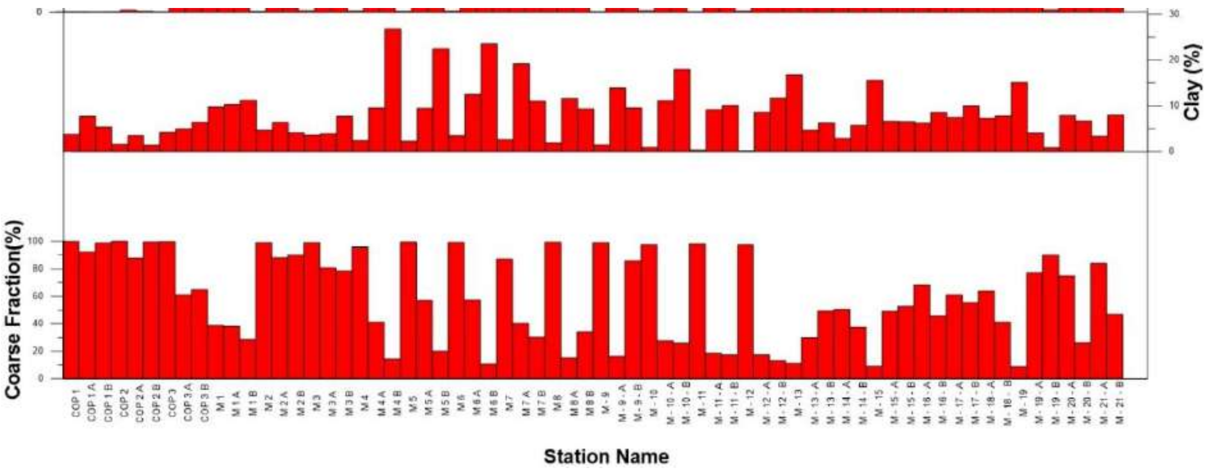


Figure 3.14: The relative abundance of coarse fraction and clay in the surface sediments of the Mandovi.

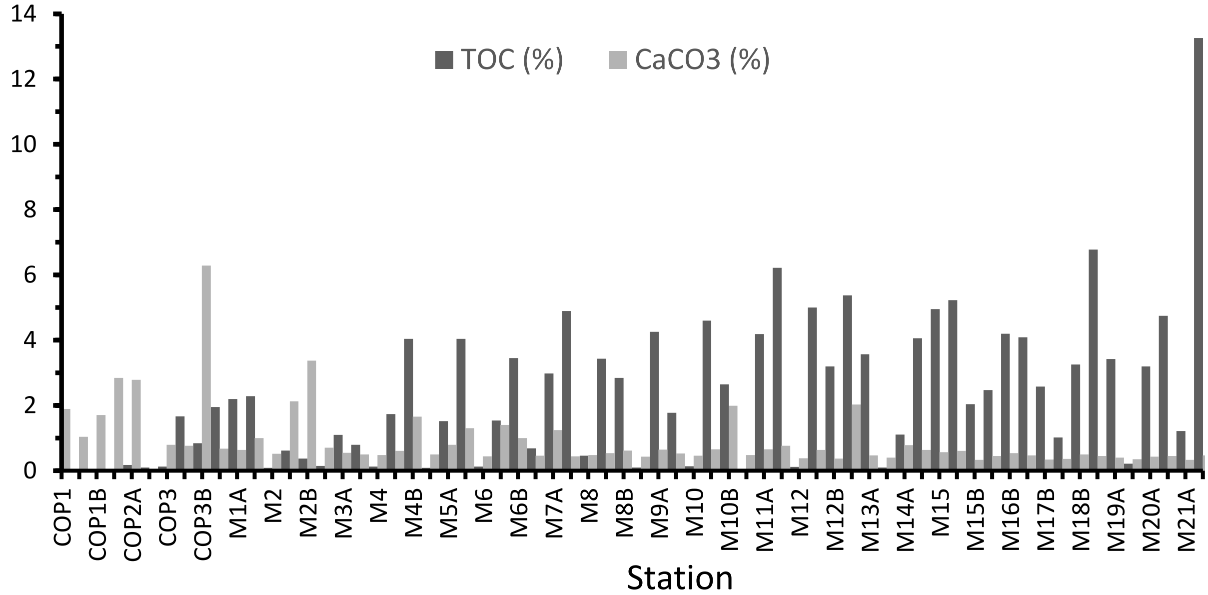


Figure 3.15: The organic carbon and $CaCO_3$ at different stations in the Mandovi.

3.6.1 Total suspended matter (TSM)

The total suspended matter (TSM) is much higher at the estuary mouth, and decreases in the inner estuary (Figure 3.16). TSM varies from as high as 11 mg/l to as low as 1 mg/l. The higher TSM at the mouth is attributed to strong tidal influence leading to re-suspension of the material.

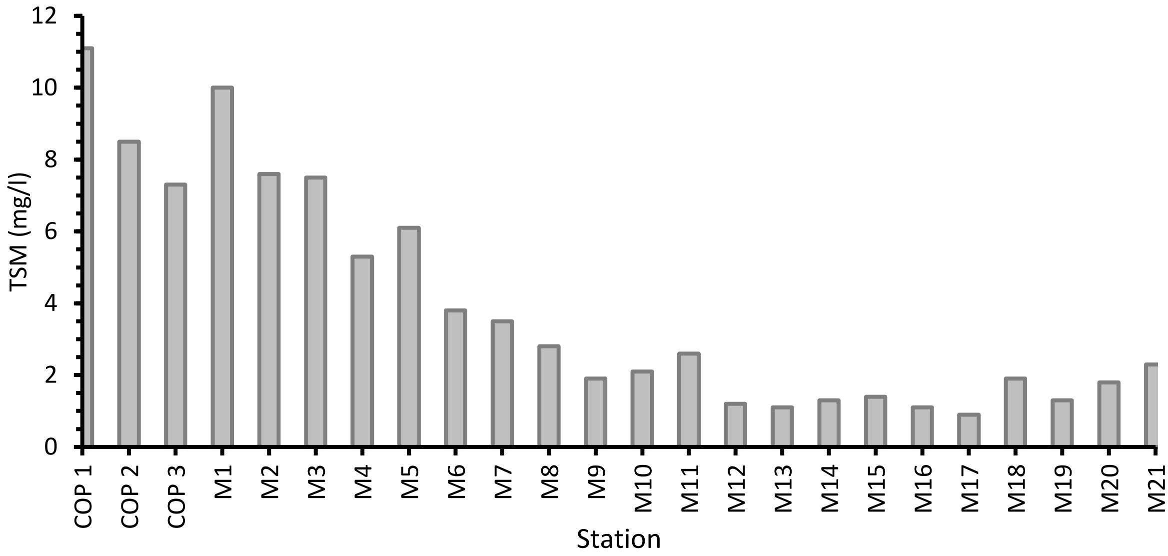


Figure 3.16: Total suspended matter at different stations of the Mandovi.

3.7 Meio-benthos:

Central transect:

The meiofaunal abundance was recorded from 24 stations (Table 3.5). Total 14 meiofaunal taxa were identified in the central region of the estuary (Figure 3.17). Among them, Nematoda was the most abundant group followed by Harpacticoida, Turbellaria, Polychaeta, Naupli larva, Isopoda, Gastropoda larva, Oligochaeta, Nemertea, Bivalvia and Kinorhyncha. (Figure 3.19; Table 3.5). The highest meiofaunal abundance (696 ind/10 cm^2) was recorded at station COP1 and lowest (5 ind/10 cm2) at station M 19 (Table 3.5). The percent composition of meiofaunal community showed that Nematoda (73.1 %) was the most dominant meiofaunal groups followed by Harpacticoida (15.1%), Turbellaria (5.4%), Polychaeta (2.2%), Naupli larva (1.4%), Isopoda (0.5%), Gastropoda larva (0.5%), Oligochaeta (0.5%), Nemertea (0.2%), Bivalvia (0.2%) and Kinorhyncha (0.1%) (Table 3.5, Figure 3.19).

Peripheral transects

In the peripheral region of Mandovi estuary 13 meiofaunal taxa were identified from the 24 sampled stations. The highest meiofaunal abundance (3070 ind/10 cm2) was recorded at station M1A and lowest (0 ind/10 cm2) at station M14A, M14B and M19A (Table 3.6, Figure 3.18). Nematoda was found to be the most abundant group followed by Harpacticoida, Turbellaria, Polychaeta, Naupli larva, Oligochaeta, Gastropoda larva, Isopoda, Nemertea, Bivalvia and Kinoryncha. The percent composition of meiofaunal community showed that Nematoda (73.1%), Harpacticoida (15.9%), Turbellaria (5.4%), Polychaeta (2.2%), Naupli larva (1.4%), Oligochaeta (0.5%), Gastropoda larva (0.5%), Isopoda (0.5%), Nemertea (0.2%), Bivalvia (0.2%) and Kinoryncha (0.1%) (Figure 3.20)

Nematoda: Copepoda ratio

A ratio of Nematoda: Copepoda <100 indicates degrading quality of water (Raffaelli and Mason, 1981). In the central transect the nematode copepod ratio showed an increasing trend towards the lower part of the Mandovi Estuary with the Nematoda: Copepoda ratio being 96 at station M4 and 175 at station COP1(Table 3.7; Figure 3.21). This indicates polluted water at these stations. In the peripheral transect the Nematoda Copepoda ratio shows a similar increasing trend towards the lower estuary (Table 3.8; Figure 3.22). The Nematoda Copepoda ratio is 137 at station COP1B indicating polluted water quality at this station. The next highest ratio of 52 was observed at station M1B.

Conclusion

The distribution and abundance of meiobenthic community was analysed and revealed variations in the distribution of meiofaunal community. Our observations showed that meiofaunal abundance was found to be increasing towards the periphery in the lower estuary i.e., COP1- M6, increasing towards the centre between M7-M15 with the exception of M12 and again increasing towards periphery in the upper estuary. The Nematoda: Copepoda ratio suggested by Raffaelli and Mason (1981) used to assess water quality where values greater than 100 is used to indicate polluted water quality indicated polluted water at stations COP1 (175), COP1B (137). The value for station M4 was also close to the threshold value at 96.

Table 3.5: Total meiofaunal abundance (ind/10 cm^2) of Mandovi Estuary (Central transect).

Taxa	COP1	COP2	COP3	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Nematoda	661	183	128	14	42	59	362	56	7	49	111	145	47
Polychaeta	3	1	5	3	0	5	1	11	0	13	1	1	3
Harpacticoida	4	3	29	6	14	5	4	31	0	3	20	227	67
Naupli Larva	1	0	9	1	5	9	0	3	0	0	0	0	6
Isopoda	0	0	0	0	4	0	0	1	0	1	0	3	0
Kinoryncha	0	0	1	1	0	0	0	0	0	0	0	0	0
Bivalvia	0	0	0	0	0	0	0	1	0	3	0	0	1
Gastropoda Larva	0	0	1	1	0	0	0	0	0	5	5	0	0
Oligochaeta	9	1	0	0	0	1	0	1	0	1	0	1	1
Nemertea	5	1	0	0	1	0	0	0	0	0	0	0	0
Turbellaria	14	1	14	0	28	5	24	13	1	18	4	1	6
Total	**696**	**189**	**188**	**26**	**93**	**84**	**391**	**117**	**8**	**92**	**141**	**378**	**130**

Table 3.5: Total meiofaunal abundance (ind/10 cm²) of Mandovi Estuary (Central transect). Cont..													
Taxa	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**M19**	**M20**	**M21**	**Total**	**%**
Nematoda	35	78	49	0	15	0	0	0	4	0	0	**2045**	73.1
Polychaeta	11	3	0	0	1	0	0	0	0	0	0	**60**	2.2
Harpacticoida	15	8	1	0	9	0	0	0	0	0	0	**444**	15.9
Naupli Larva	1	1	1	0	0	0	0	0	0	0	0	**38**	1.4
Isopoda	0	1	0	0	3	0	0	0	0	0	0	**13**	0.5
Kinoryncha	0	0	0	0	0	0	0	0	0	0	0	**3**	0.1
Bivalvia	1	1	0	0	0	0	0	0	0	0	0	**7**	0.2
Gastropoda Larva	0	1	0	0	0	0	0	0	0	0	0	**14**	0.5
Oligochaeta	0	0	0	0	0	0	0	0	0	0	0	**15**	0.5
Nemertea	0	0	0	0	0	0	0	0	0	0	0	**7**	0.2
Turbellaria	11	0	0	0	11	0	0	0	1	0	0	**152**	5.4
Total	**76**	**93**	**52**	**0**	**39**	**0**	**0**	**0**	**5**	**0**	**0**	**2797**	100.0

Table 3.6: Total meiofaunal abundance (Ind/10 cm^2) of Mandovi Estuary (Peripheral transect).

Taxa	COP1A	COP1B	COP2A	COP2B	COP3A	COP3B	M1A	M1B	M2A	M2B	M3A	M3B	M4A
Nematoda	63	863	1007	15	30	25	2593	131	249	98	99	55	60
Polychaeta	1	47	3	64	1	1	42	4	0	0	1	5	1
Harpacticoida	8	6	25	10	0	52	258	3	20	3	11	166	10
Naupli larvae	18	0	26	1	0	16	65	0	18	0	0	3	1
Amphipoda	0	0	4	0	0	0	0	0	0	0	0	0	0
Isopoda	34	0	0	0	0	0	0	0	0	0	0	0	0
Kinoryncha	0	0	4	0	0	0	23	0	9	0	1	0	0
Bivalvia	0	0	3	0	0	0	0	0	0	0	0	0	0
Gastropoda Larva	0	1	0	0	0	0	0	1	4	0	0	0	0
Oligochaeta	13	0	3	0	6	0	59	1	4	0	5	1	1
Nemertea	0	1	5	0	1	0	20	0	0	0	3	0	0
Turbellaria	15	26	47	8	1	3	10	0	55	0	20	4	1
Total	**151**	**945**	**1125**	**98**	**40**	**97**	**3070**	**140**	**359**	**101**	**141**	**234**	**76**

Table 3.6: Total meiofaunal abundance (ind/10 cm^2) of Mandovi Estuary (Peripheral transect).Cont.

Taxa	M4B	M5A	M5B	M6A	M6B	M7A	M7B	M8A	M8B	M9A	M9B	M10A	M10B
Nematoda	67	50	122	18	5	26	0	3	47	8	15	68	10
Polychaeta	0	1	1	1	0	0	0	1	0	1	0	0	0
Harpacticoida	6	4	19	16	0	0	0	0	4	0	1	82	0
Naupli larvae	0	0	0	0	1	0	0	0	0	0	0	4	0
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	4	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	1	0
Kinoryncha	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalvia	0	0	0	1	0	0	0	0	0	0	0	0	0
Gastropoda Larva	0	0	0	23	0	0	0	0	0	0	0	0	0
Oligochaeta	3	19	8	1	5	0	0	0	4	0	0	5	8
Nemertea	0	3	5	1	0	0	0	0	0	0	0	0	4
Turbellaria	1	1	1	9	1	0	0	0	0	0	0	1	0
Total	**77**	**78**	**156**	**70**	**13**	**26**	**0**	**4**	**54**	**9**	**16**	**165**	**21**

Table 3.6: Total meiofaunal abundance (ind/10 cm^2) of Mandovi Estuary (Peripheral transect).Contd..

Taxa	M11A	M11B	M12A	M12B	M13A	M13B	M14A	M14B	M15A	M15B	M16A	M16B
Nematoda	3	35	10	517	16	4	0	0	1	18	0	24
Polychaeta	0	0	5	1	0	0	0	0	0	0	0	0
Harpacticoida	0	1	10	164	0	4	0	0	0	1	0	0
Naupli larvae	0	0	1	45	0	0	0	0	0	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Kinoryncha	0	0	0	1	0	0	0	0	0	0	0	0
Bivalvia	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda Larva	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	0	0	3	30	5	1	0	0	0	4	1	8
Nemertea	0	0	3	0	0	0	0	0	0	0	0	0
Turbellaria	1	0	1	0	1	0	0	0	0	0	0	0
Total	**4**	**37**	**32**	**759**	**23**	**9**	**0**	**0**	**1**	**23**	**1**	**31**

Table 3.6: Total meiofaunal abundance (ind/10 cm^2) of Mandovi Estuary (Peripheral transect). Contd..												
Taxa	**M17A**	**M17B**	**M18A**	**M18B**	**M19A**	**M19B**	**M20A**	**M20B**	**M21A**	**M21B**	**Total**	**%**
Nematoda	0	9	9	15	0	4	13	28	0	1	6435	77.2
Polychaeta	0	0	1	0	0	0	1	0	0	0	184	2.2
Harpacticoida	0	0	0	0	0	0	0	0	1	0	885	10.6
Naupli larvae	0	0	0	0	0	0	0	0	0	0	200	2.4
Amphipoda	0	0	0	0	0	0	0	0	0	0	8	0.1
Isopoda	0	0	0	0	0	0	0	0	0	0	35	0.4
Kinoryncha	0	0	0	0	0	0	0	0	0	0	38	0.5
Bivalvia	0	0	0	0	0	0	0	0	0	0	4	0.0
Gastropoda Larva	0	0	0	0	0	0	0	0	0	0	29	0.3
Oligochaeta	5	5	0	16	0	23	0	8	0	0	253	3.0
Nemertea	0	0	0	0	0	0	0	4	0	0	48	0.6
Turbellaria	0	0	1	1	0	5	0	0	0	0	216	2.6
Total	**5**	**14**	**11**	**33**	**0**	**31**	**13**	**39**	**1**	**1**	**8334**	**100.0**

Table 3.7: Nematoda:Copepoda ratio of Mandovi Estuary (Central transect)

Station	COP1	COP2	COP3	M1	M2	M3	M4	M5	M6	M7	M8	M9	M 10
Nematoda	1050	290	204	22	66	94	576	89	11	78	176	231	74
Harpacticoida	6	4	46	10	22	8	6	50	0	4	32	360	106
Nematoda: Copepoda Ratio	**175**	**73**	**4**	**2**	**3**	**12**	**96**	**2**	**0**	**20**	**6**	**1**	**1**

Table 3.7: Nematoda:Copepoda ratio of Mandovi Estuary (Central transect) Cont

Station	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21
Nematoda	56	124	78	0	24	0	0	0	6	0	0
Harpacticoida	24	12	2	0	14	0	0	0	0	0	0
Nematoda: Copepoda Ratio	**2**	**10**	**39**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**

Table 3.8: Nematoda:Copepoda ratio of Mandovi Estuary (Peripheral transect)

Taxa	COP1A	COP1B	COP2A	COP2B	COP3A	COP3 B	M1A	M1B	M2A	M2B	M3A	M3B
Nematoda	100	1372	1600	24	48	40	4121	208	396	156	158	88
Harpacticoida	12	10	40	16	0	82	410	4	32	4	18	264
Nematoda: Copepoda Ratio	**8**	**137**	**40**	**2**	**0**	**0**	**10**	**52**	**12**	**39**	**9**	**0**

Table 3.8: Nematoda:Copepoda ratio of Mandovi Estuary (Peripheral transect) Cont

Taxa	M4A	M4B	M5A	M5B	M6A	M6B	M7A	M7B	M8A	M8B	M9A	M9B

Nematoda	96	106	80	194	28	8	42	0	4	74	12	24
Harpacticoida	16	10	6	30	26	0	0	0	0	6	0	2
Nematoda: Copepoda Ratio	**6**	**11**	**13**	**6**	**1**	**0**	**0**	**0**	**0**	**12**	**0**	**12**

Table 3.8: Nematoda:Copepoda ratio of Mandovi Estuary (Peripheral transect) Contd..

Taxa	M10A	M10B	M11A	M11B	M12A	M12B	M13A	M13B	M14A	M14B	M15A	M15B
Nematoda	108	16	4	56	16	822	26	6	0	0	2	28
Harpacticoida	130	0	0	2	16	260	0	6	0	0	0	2
Nematoda: Copepoda Ratio	**1**	**0**	**0**	**28**	**1**	**3**	**0**	**1**	**0**	**0**	**0**	**14**

Table 3.8: Nematoda:Copepoda ratio of Mandovi Estuary (Peripheral transect) Contd..

Taxa	M16A	M16B	M17A	M17B	M18A	M18B	M19A	M19B	M20A	M20b	M21A	M21B
Nematoda	0	38	0	14	14	24	0	6	20	44	0	2
Harpacticoida	0	0	0	0	0	0	0	0	0	0	2	0
Nematoda: Copepoda Ratio	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

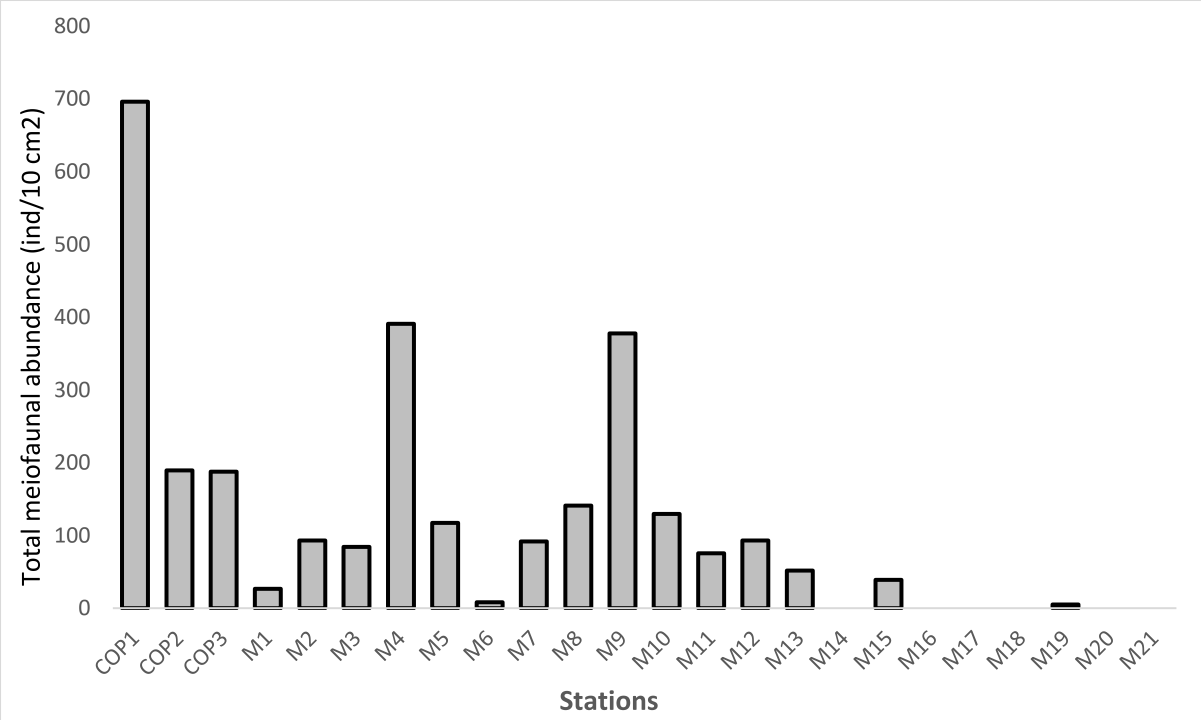


Figure 3.17: Station-wise meiofaunal abundance (ind/10 cm^2) from Mandovi Estuary (Central transect).

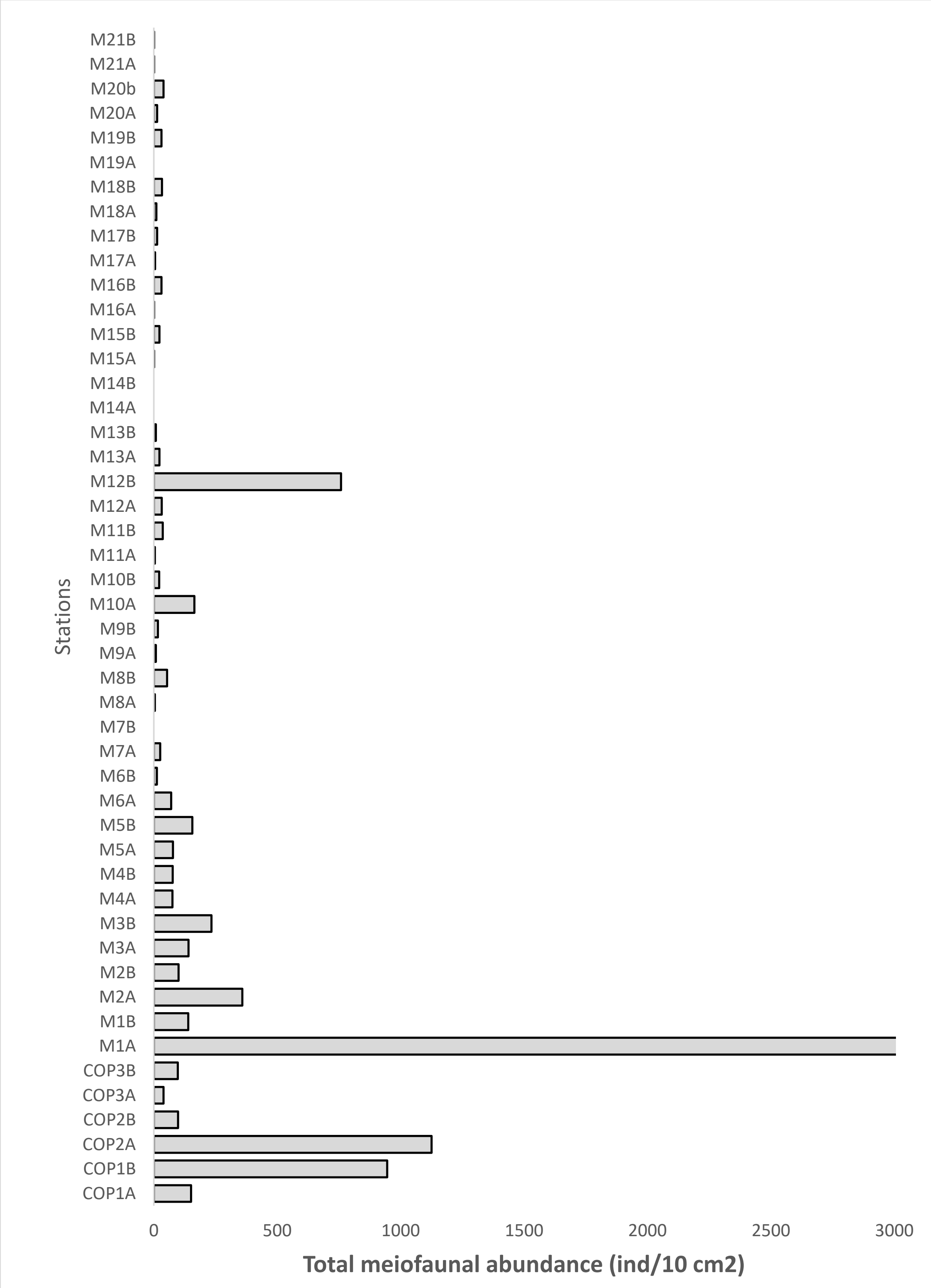


Figure 3.18: Station-wise meiofaunal abundance (ind/10 cm^2) from Mandovi Estuary (Peripheral transect).

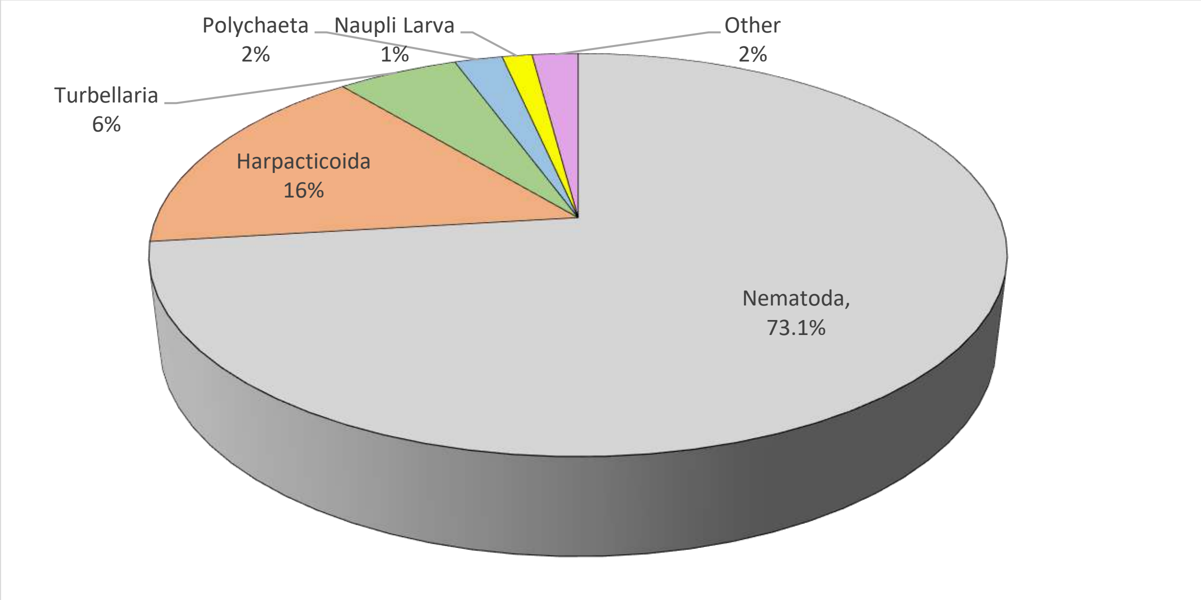


Figure 3.19: Percent composition of meiofaunal taxa from the Mandovi Estuary (Central transect).

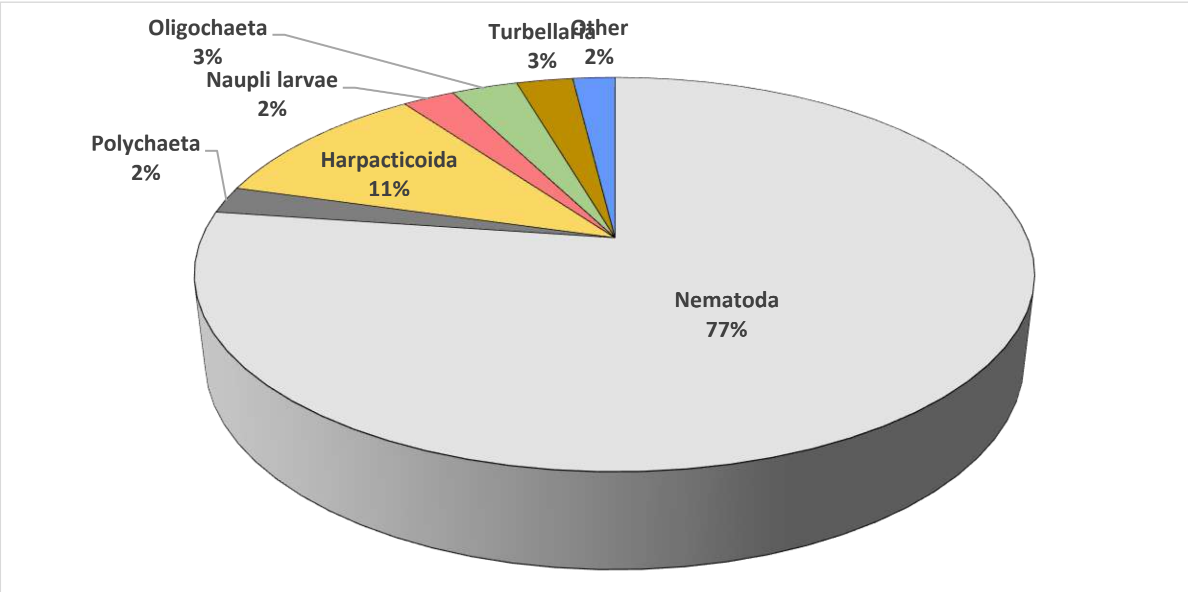


Figure 3.20: Percent composition of meiofaunal taxa from the Mandovi estuary (Peripheral transect).

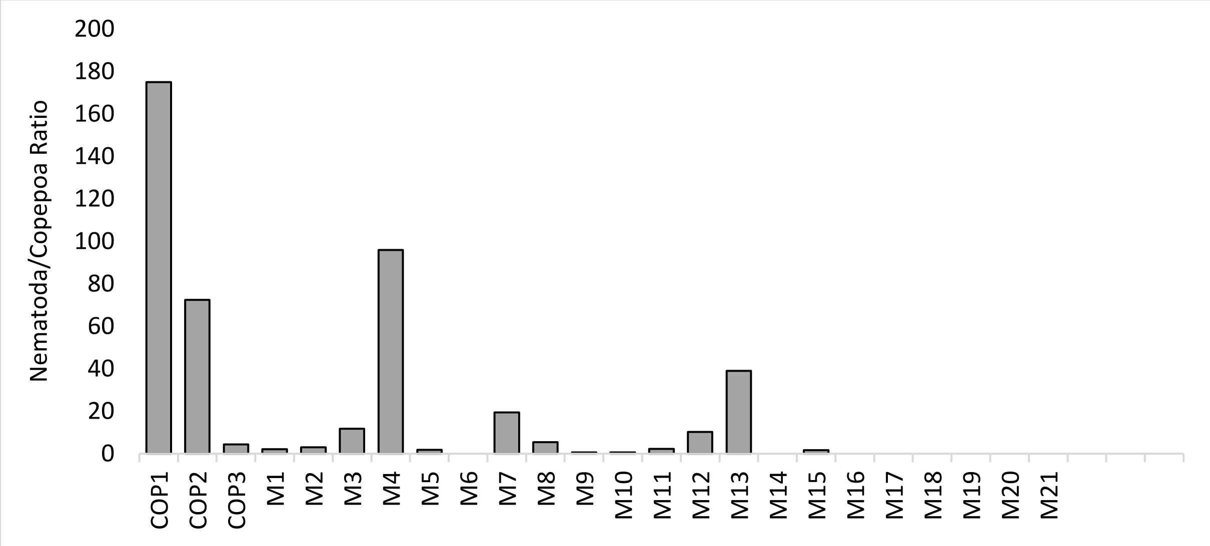


Figure 3.21: Station-wise Nematoda:Copepoda ratio from the Mandovi estuary (Central transect).

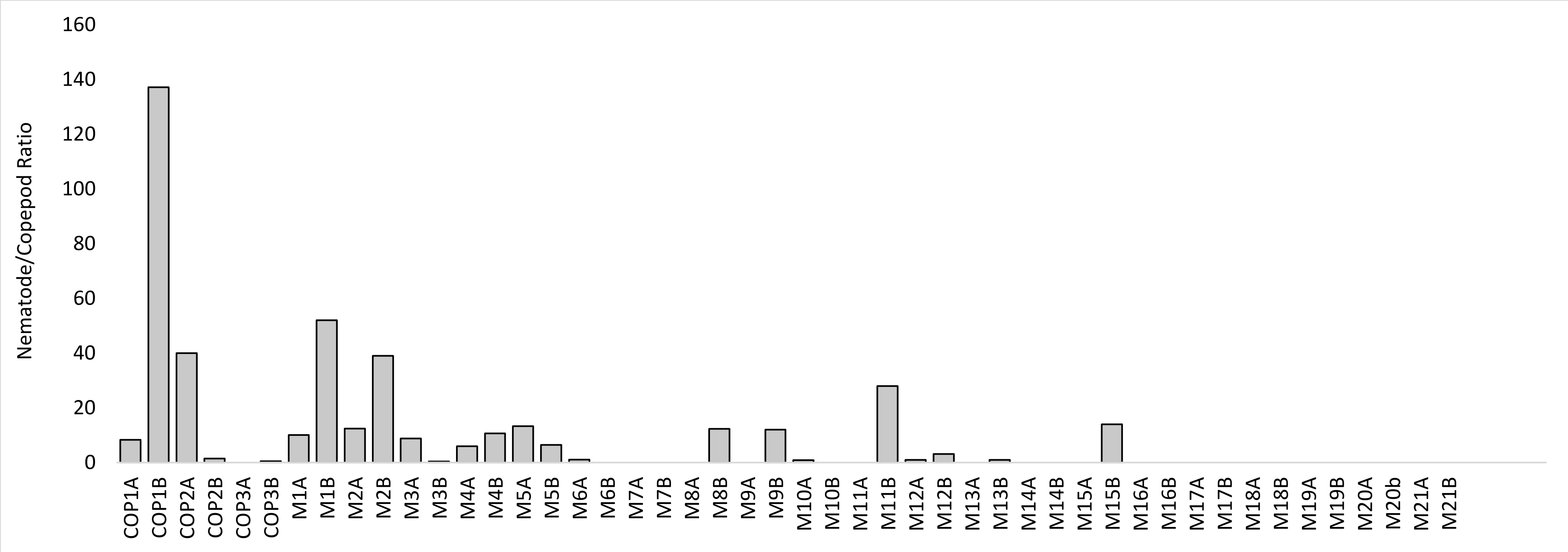


Figure 3.22: Station-wise Nematoda:Copepoda ratio from the Mandovi estuary (Peripheral transect).

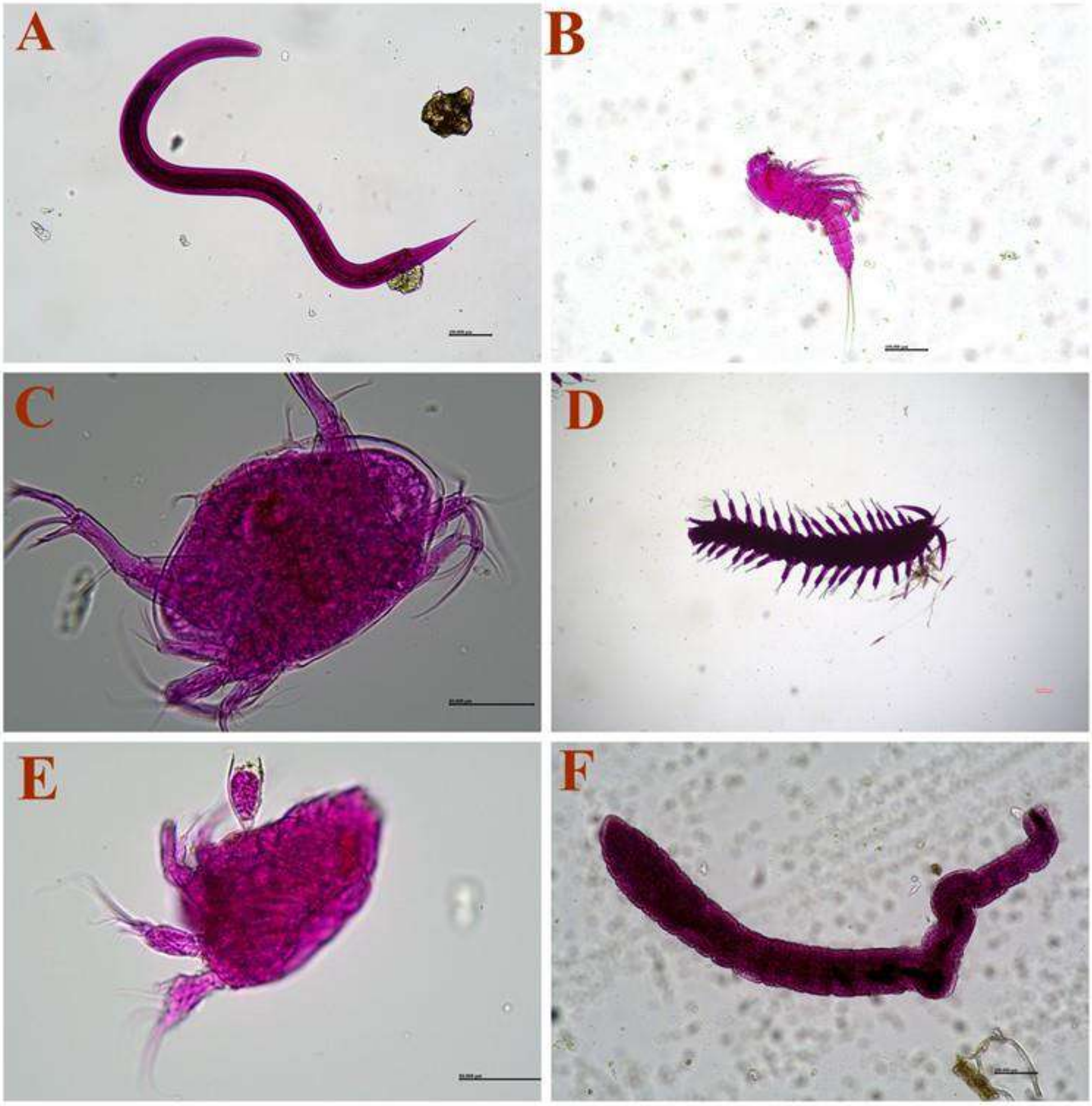


Plate 3.3: A. Nematoda; B. Harpacticoida; C. Ostracoda; D. Polycheta; E. Naupli Larva; F. Oligocheta.

3.8 Foraminifera

The foraminifera abundance increased towards the mouth of the Mandovi. The foraminifera were rare in the inner part of the Mandovi. The trochospiral and rounded forms were dominant in the foraminiferal assemblage (Plate 3.4). A large number of relict and reworked tests were also observed. The foraminiferal abundance was comparatively high in fine grained organic matter rich sediments, falling within the large tidal influence region.

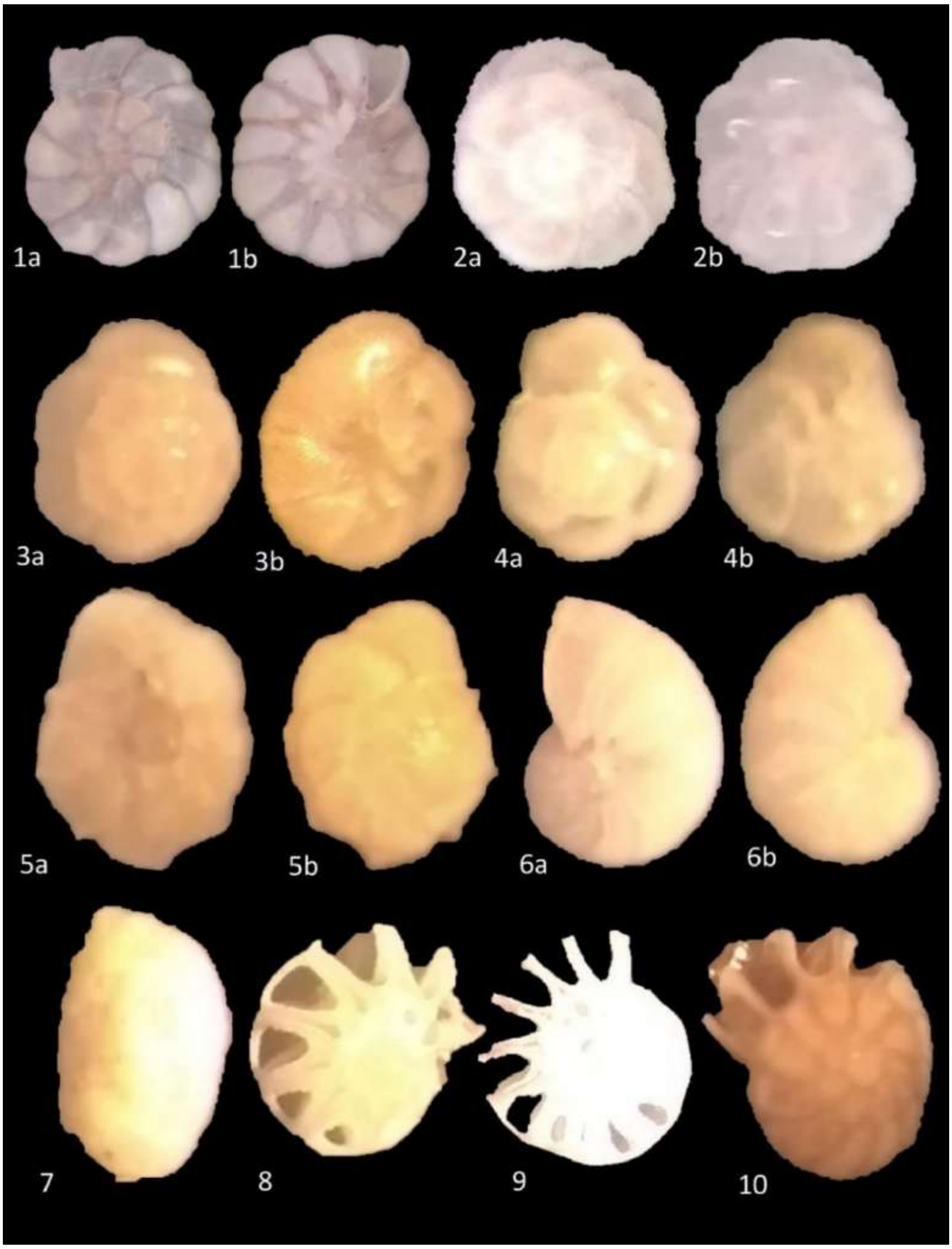


Plate 3.4: Dominant benthic foraminifera in the Mandovi. 1. *Rotalidium*, 2-4. *Ammonia*, 5. *Asterorotalia*, 6. *Nonion*, 7. Miliolid, 8-10 reworked tests.

3.9 Macro benthos

Central transect

Total 37 invertebrate taxa belonging to 10 phyla were identified from the Centre stations of Mandovi Estuary. Highest abundance of macrofauna was recorded at station M11 (12998 no/m^2) followed by station M10 (2994no/m^2) and M9 (2969 no/m^2) whereas, lowest abundance was recorded at station M4 (24no/m^2) (Table 3.9, Figure 3.23). Among all the macrofauna, polychaetes were the most abundant taxa (Figure 3.24). High abundance of polychaetes was found at station M11 (5501 no/m^2) followed by station M10 (2604 no/m^2), however lowest abundance was found at station M3 (24 no/m^2). In Polychaeta, *Mediomastus capensis* was highly abundant species at station M11 (4089 no/m^2) and showed less in abundance in all the stations. *Prionospio cirrifera* was the second dominant species at station M10 (2410 no/m^2) followed by station M9 (2166 no/m^2) and *Pisione* sp. was also found only at COP 1 (949 no/m^2) and COP2 (1144 no/m^2) station. Crustacea was the second dominant taxa which showed high abundance of Amphipoda (5623 no/m^2) and Cumacea (633 no/m^2) from all the stations. Other taxa like Oligochaeta, Nematoda, Chyronomous larvae, Nemertea, Platyhelminthes, and Bryozoan were found less in abundance among all the stations (Table 3.9). Macrofauna was absent at Stations M14, M16, M18A, M18B, M19A, M20A, M20B, M21A and M21B.

The macrofaunal composition (%) showed polychaetes was highly abundant (60%) followed by Crustacea (20%), Chyronomidae larvae (7%), Nematoda (5%) and the remaining 8% of the fauna was comprised by Bryozoan, Nemertea, Platyhelminthes, Bivalvia and Oligocheata (Figure 3.24). Among polychaeta, *Prionospio cirrifera* (44%) showed highest composition followed by *Mediomastus capensis* (23%), *Pisione* sp. (11%) and remaining (22%) polychaete species include *Glycera alba, Nepthys inermis, Sigambra* sp. etc. were found less in abundance at the central station of the estuary (Figure 3.25)

Peripheral transects

Total 34 invertebrate belonging to 10 phyla were recorded from peripheral stations of Mandovi Estuary. Highest abundance of macrofauna was recorded at station M11B (14969 no/m^2) followed by station M5A (13728 no/m^2) and M6A (8495 no/m^2) whereas the lowest abundance was recorded at M14B (32 no/m^2) (Table 3.10; Figure 3.26). Among all these macrofauna, polychaeta was the most dominant group in all the stations. High abundance of *Mediomastus capensis* was recorded at station M11B (10637no/m^2) and M5A (10637no/m^2) followed by station M1B (7862 no/m^2) and the lowest abundance was recorded from 3 different stations (M 15A, M 16A, M16B (16no/m^2) respectively. *Prionospio cirrifera* was the second dominant species with (7010 no/m^2) at station 1B followed by station 5B (4844 no/m^2), station 4B (4625 no/m^2) and station 6A (4381 no/m^2) and the remaining stations showed less in abundance. *Dendronereis* sp. (5225 no/m^2) was also found in some stations. Other taxa include Nematoda, Nemertea, Oligochaeta, Chyronomous larvae, Gastropod larvae, Platyhelminthes etc were also found in less abundance (Table 3.10).

The macrofaunal composition showed polychaeta (82%), Crustacea (9%), Chyronomous larvae (4%), Oligochaeta (3%) and others (2%) from all the stations. The remaining fauna includes Nemertea, Bryozoan, Nematoda etc (Figure 3.27) Among polychaeta, *Prionospio cirrifera* showed high composition (47%) followed by *Mediomastis capensis* as the second dominant composition (36%) followed by *Dendroneries* sp (5%), *Orbinia* sp (5%) and others (7%). The remaining polychaete species include *Cossura* sp., *Lumbrineries* sp.etc (Figure 3.28).

Biomass

Macrofaunal biomass (wet weight) from central station of Mandovi Estuary varies from 0.02 to 5.35g/m^2. Highest diversity of macrofauna was recorded at station COP3 (5.35g/m^2) which was contributed by polychaetes and oligochaetes and lowest diversity was recorded at station M 4 and M 19 (0.02g/m^2) respectively due to low abundance (Figure 3.29). Peripheral stations of macrofaunal biomass of Mandovi Estuary vary from 0.03 to 33.69g/m^2. Highest diversity in the peripheral region was recorded at station M10A (33.69g/m^2) due to high abundance of polychaetes and the lowest diversity was recorded at station M 17B and M 19B (0.03g/m^2) due to low abundance of polychaetes (Figure. 3.30).

Conclusion

Based on the present data set, macrofaunal abundance was found to be higher at mid region of the Mandovi Estuary as compared to upper stream area. The present analysis also found that the peripheral region of upstream was rich in macrofaunal diversity, while the abundance found decreased gradually towards the up-stream area. The centre stations of the estuary found less diversity may be because of the continuous dredging in the estuary.

Table 3.9: Abundance (no/m^2) of macrofauna from Mandovi Estuary (Centre transect)

Taxa	COP 1	COP 2	COP 3	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13	M 15	M 19	Total	%
Bryozoan	0	24	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.14
Nematoda	0	1631	97	0	0	0	0	24	0	0	0	24	0	0	0	0	0	0	1777	5.04
Mediomastus capensis	0	0	268	0	0	0	0	0	0	97	49	195	122	4089	0	24	0	0	4844	13.73
Heteromastus sp.	0	0	706	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	730	2.07
Capitella capitata	0	0	0	49	0	0	0	0	0	146	0	0	0	0	0	0	0	0	195	0.55
Prionospio pinnata	0	0	0	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0.28
Prionospio cirrifera	0	0	0	49	146	24	0	560	24	1533	1217	2166	2410	755	219	122	97	0	9322	26.43
Scolelepis sp.	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	24	0.07
Glycera alba	49	0	243	73	24	0	0	24	24	73	0	0	0	0	0	0	0	0	511	1.45
Diopatra sp.	0	0	243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	243	0.69
Onuphis sp.	0	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.14
Pisione sp.	949	1144	0	0	0	0	0	97	24	0	0	49	0	0	24	0	0	0	2288	6.49
Nephtys inermis	0	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0.21
Orbinia sp.	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.14
Saccocirrus sp.	0	122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	122	0.35
Sigambra sp.	0	0	438	195	0	0	0	0	0	0	0	0	0	0	0	0	0	0	633	1.79
Namalycastis sp.	0	0	195	0	0	0	0	0	0	73	0	0	24	535	0	0	0	0	828	2.35
Dendroneries sp.	0	0	0	462	0	0	0	0	0	73	24	97	49	122	24	73	24	97	1047	2.97
Phyllodocea sp.	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.07
Amphipoda	0	97	49	24	24	0	0	0	24	24	268	0	268	4746	0	97	0	0	5623	15.94
Isopoda	0	0	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	49	0.14
Harpacticoida	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.07
Mysis	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	24	0.07
Cumacea	0	0	0	0	0	0	0	268	170	24	24	97	49	0	0	0	0	0	633	1.79
Tanaidacea	0	0	0	0	0	0	0	0	0	122	0	0	0	0	0	0	0	0	122	0.35

Decapoda	0	0	0	24	0	0	24	0	0	0	0	0	0	0	0	0	0	0	49	0.14
Shrimp	0	0	24	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	49	0.14
Zoae larvae	0	0	0	0	0	0	0	24	341	0	0	0	0	0	0	0	0	0	365	1.04
Bivalvia	0	0	0	0	24	0	0	122	0	0	49	0	73	0	0	0	0	0	268	0.76
Gastropod larvae	0	0	0	0	0	0	0	535	170	0	0	0	0	0	0	0	0	0	706	2.00
Cirrithidia	0	0	0	0	0	73	0	0	0	0	0	0	0	0	0	0	0	0	73	0.21
Platyheminthes	0	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0.21
NeMrtea	0	49	0	0	0	0	0	487	146	0	0	341	0	0	0	0	24	0	1047	2.97
Chironomidae larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	2702	0	0	0	0	2702	7.66
Oligochaeta	0	49	462	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	535	1.52
Total abundance(no/m²)	**1047**	**3116**	**2921**	**1047**	**243**	**97**	**24**	**2166**	**974**	**2166**	**1679**	**2969**	**2994**	**12998**	**268**	**316**	**146**	**97**	**35269**	**100.00**

Table 3.10: Abundance (no/m²) of macrofauna from Mandovi Estuary (Peripheral transect)

Taxa	COP 1 A	COP 1B	COP 2A	COP 2 B	COP 3 A	COP 3 B	M 1 A	M 1 B	M 2 A	M 2 B	M 3 A	M 3 B	M 4 A	M 4 B	M 5 A	M 5B	M 6A	M 6 B	M 7A	M 7B
Bryozoan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0
Nematoda	0	0	1047	24	0	0	0	0	0	0	24	195	24	0	0	0	0	0	0	0
Mediomastus capensis	0	0	0	122	24	146	1801	122	24	0	487	462	24	316	1436	316	779	268	609	122
Prionospio cirrifera	243	49	0	24	2385	146	2069	7010	0	195	341	1728	268	4625	10637	4844	4381	1947	24	24
Scolelepis sp.	0	0	0	682	49	49	24	0	438	0	0	0	122	0	0	0	0	0	24	0
Glycera alba	73	49	0	73	49	0	0	122	24	24	49	170	0	24	146	0	0	122	0	0
Lumbrineris sp.	0	0	0	0	0	0	146	73	0	0	0	0	0	0	0	0	0	0	0	0
Pisione sp.	0	0	1193	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cossura sp.	0	0	0	0	0	24	0	146	0	0	0	0	0	0	0	0	0	0	0	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0
Levinsenia oculata	0	0	0	0	0	24	0	0	0	24	0	0	0	0	0	0	0	0	0	0

Nephtys inermis	24	0	0	24	535	97	0	24	0	0	0	0	0	24	0	0	0	0	0	0
Onuphis sp.	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	0	0	0
Sigambra sp.	0	0	0	170	97	49	0	219	0	49	0	0	0	0	0	0	0	0	0	0
Namalycastis sp.	0	0	0	0	0	170	414	49	0	0	0	0	0	170	122	0	535	122	0	0
Dendroneries sp.	0	0	0	73	292	24	195	97	24	24	122	341	0	0	195	219	0	122	122	0
Orbinia sp.	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saccocirrus sp.	0	0	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maldinella sp.	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	24	73	24	341	0	0	0	73	0	49	73	97	49	0	0	146	2653	195	0	195
Isopoda	0	24	0	0	0	0	0	73	0	0	49	97	0	73	24	122	0	316	0	0
Harpacticoida	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0
Mysis	0	0	0	24	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0
Lucifera	0	24	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	0	0	0	0	0	0	0	0	0	73	122	0	0	24	0	0	0	0
Tanaidacea	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	268	0	0
Shrimp	0	0	0	0	0	0	0	0	0	0	24	24	49	0	49	49	24	0	0	0
Bivalvia	49	24	0	24	0	0	0	49	195	0	170	73	414	24	0	24	73	0	0	0
Gastropoda (Juvenile)	0	0	0	0	0	24	0	0	0	0	0	0	24	0	0	0	0	0	0	0
Platyheminthes	0	0	0	0	0	0	0	24	0	0	0	0	0	0	73	0	0	0	0	0
Nemrtea	0	49	535	24	49	24	0	0	0	0	0	0	0	0	97	0	0	0	0	0
Chironomidae larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	24
Oligochaeta	0	24	0	0	438	0	49	462	24	24	24	49	0	73	949	0	0	560	0	0
Total abundance (No/m^2)	559	365	2969	1655	3919	779	4698	8543	730	389	1387	3408	1120	5330	13728	5744	8495	3919	828	365

Taxa	M 8 A	M 8 B	M 9A	M 9 B	M10 A	M 10 B	M 11 A	M 11 B	M 12 A	M 12 B	M 13 A	M 13B	M 14 A	M14 B	M15A	M 15 B	M16 A	M16 B	M17A	M17B	M19B	Total	%
Bryozoan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0
Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	1346	1
Mediomastus capensis	609	1606	5257	195	122	1558	4040	10637	2832	288	0	272	1776	32	0	0	0	0	0	0	0	36282	30
Prionospio cirrifera	0	1606	316	657	2020	97	146	389	0	0	0	0	128	0	0	0	0	0	0	0	0	46301	38
Scolelepis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1388	1
Glycera alba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	925	1
Lumbrineris sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	219	0
Pisione sp.	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1217	1
Cossura sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	56	0
Levinsenia oculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0
Nephtys inermis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	729	1
Onuphis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0
Sigambra sp.	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	609	0
Namalycastis sp.	0	24	828	0	0	0	0	1290	352	0	0	0	480	0	0	0	0	0	0	0	0	4556	4
Dendroneries sp.	414	195	243	97	49	170	0	1071	0	608	48	128	96	0	16	208	16	16	0	0	0	5225	4
Orbinia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	194	0
Saccocirrus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	146	0
Maldinella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0
Amphipoda	0	73	219	828	341	1850	0	1022	0	0	0	0	80	0	0	0	0	0	16	0	0	8420	7
Isopoda	0	0	0	560	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	1355	1
Harpacticoida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0
Mysis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0
Cumacea	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	243	0
Tanaidacea	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	341	0
Shrimp	0	0	24	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	268	0
Bivalvia	0	0	0	49	73	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	1266	1
Gastropoda (Juvenile)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0
Platyhelminthes	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	113	0
Nemertea	0	0	0	0	0	24	24	0	0	0	0	0	0	0	0	0	0	0	0	48	0	876	1

Chironomidae larvae	122	122	633	0	0	0	243	487	768	1456	272	432	512	0	0	0	0	0	0	0	0	5119	4
Oligochaeta	0	24	0	0	0	24	0	49	0	0	32	0	16	0	112	80	288	96	16	256	272	3943	3
Total abundance (No/m2)	**1144**	**3700**	**7521**	**2410**	**2653**	**3797**	4454	14969	3968	2352	368	864	3088	32	128	288	304	112	80	304	304	121770	100

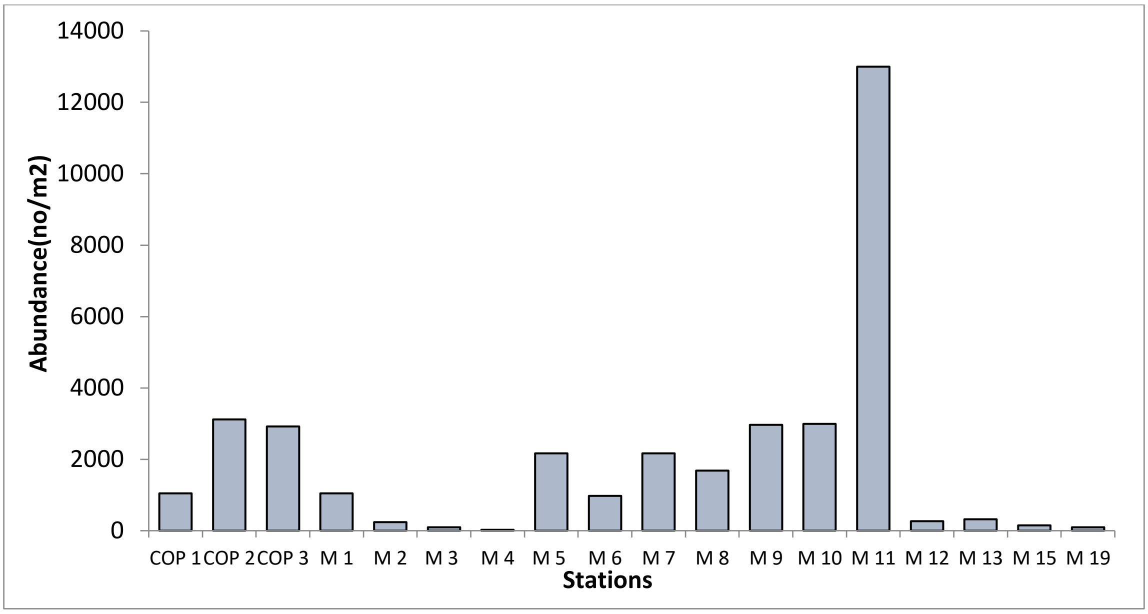


Figure 3.23: Station- wise macrofaunal abundance (no/m^2) of the Mandovi Estuary (Central transect).

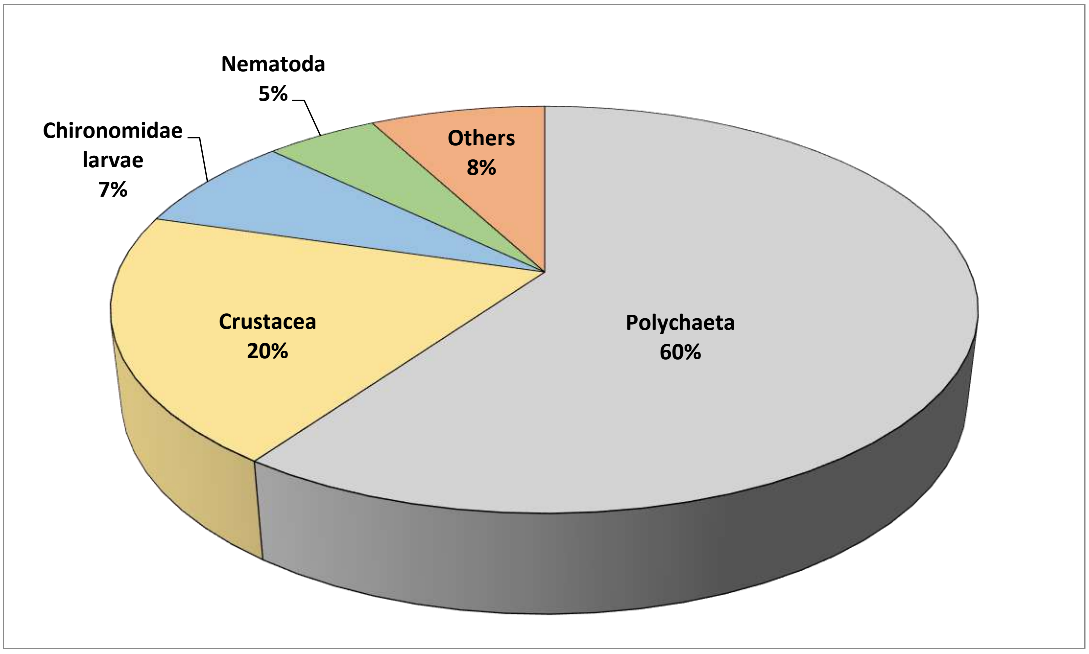


Figure 3.24.: Percent (%) composition of macrofaunal abandance of the Mandovi Estuary (Central transect)

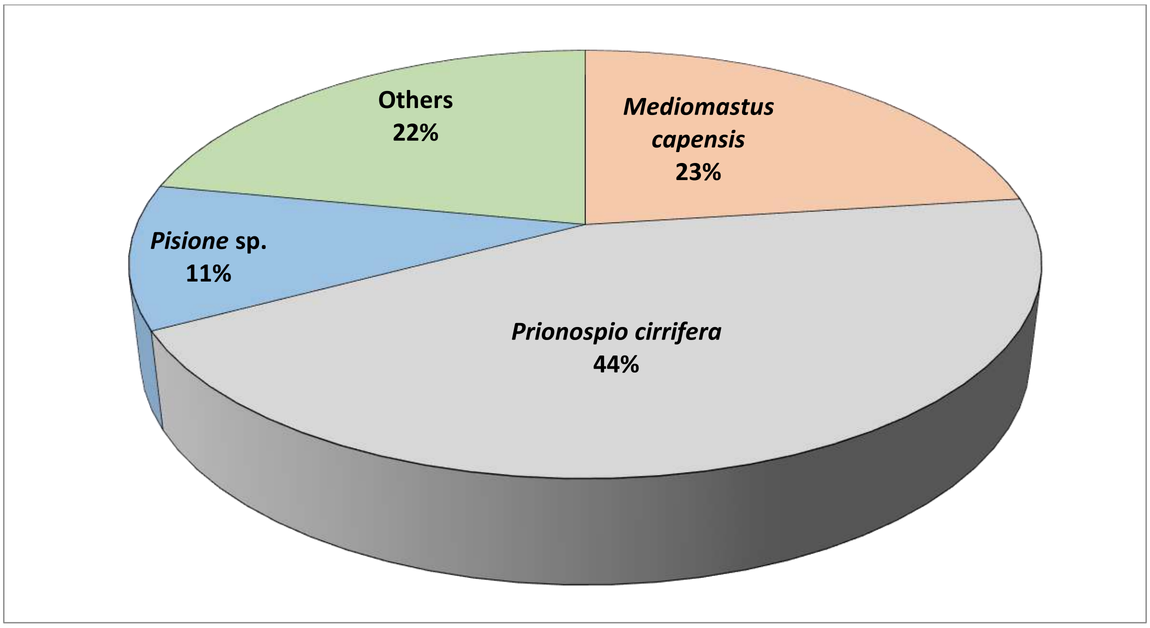


Figure 3.25: Percent (%) composition of polychaetes of the Mandovi Estuary (Central transect)

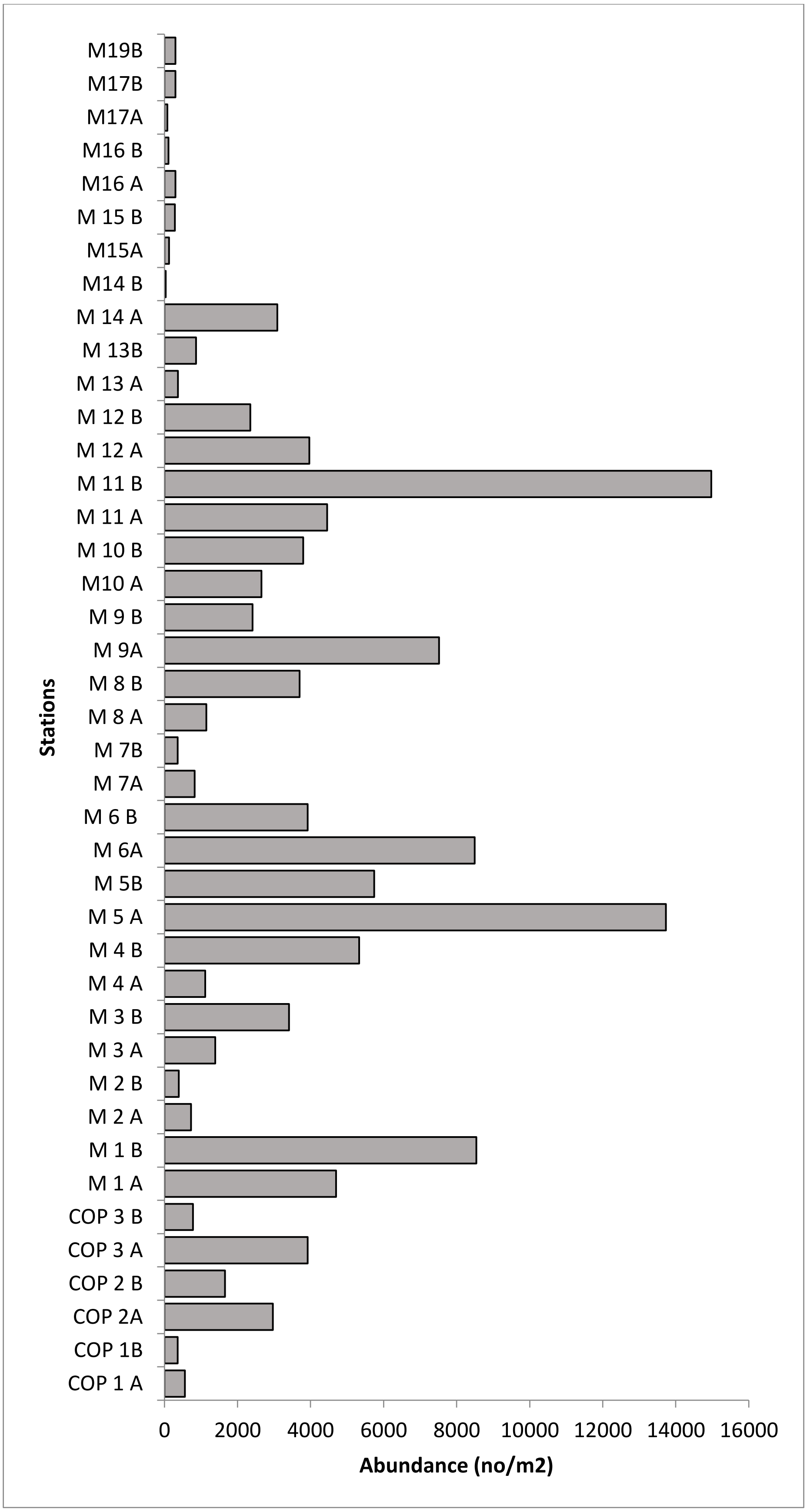


Figure 3.26: Station-wise macrofaunal abundance (no/m^2) of the Mandovi Estuary (Peripheral transect)

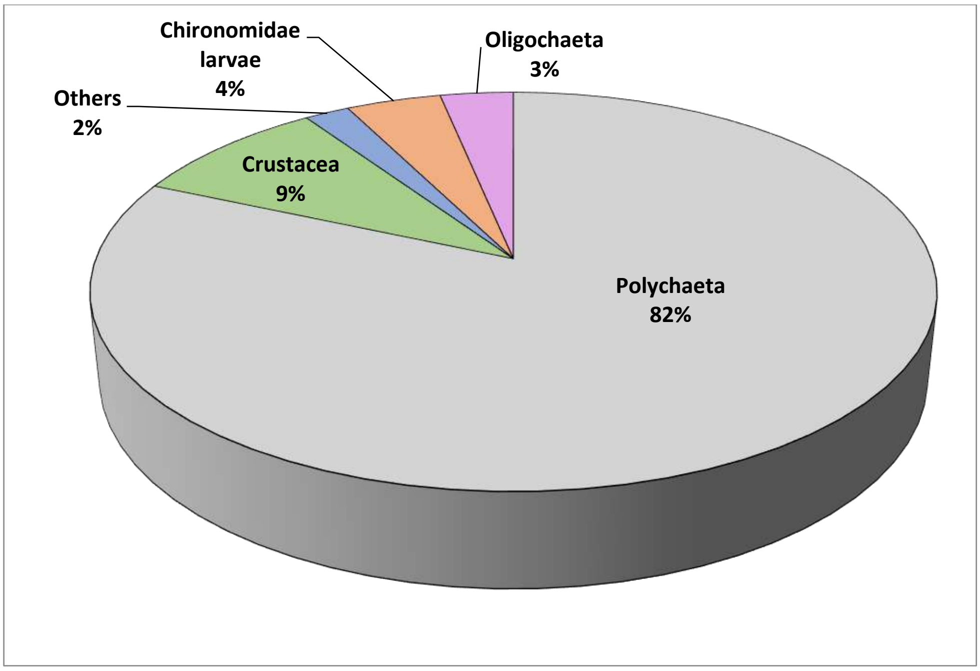


Figure 3.27: Percent (%) composition of macrofaunal abandance of the Mandovi Estuary (Peripheral transect)

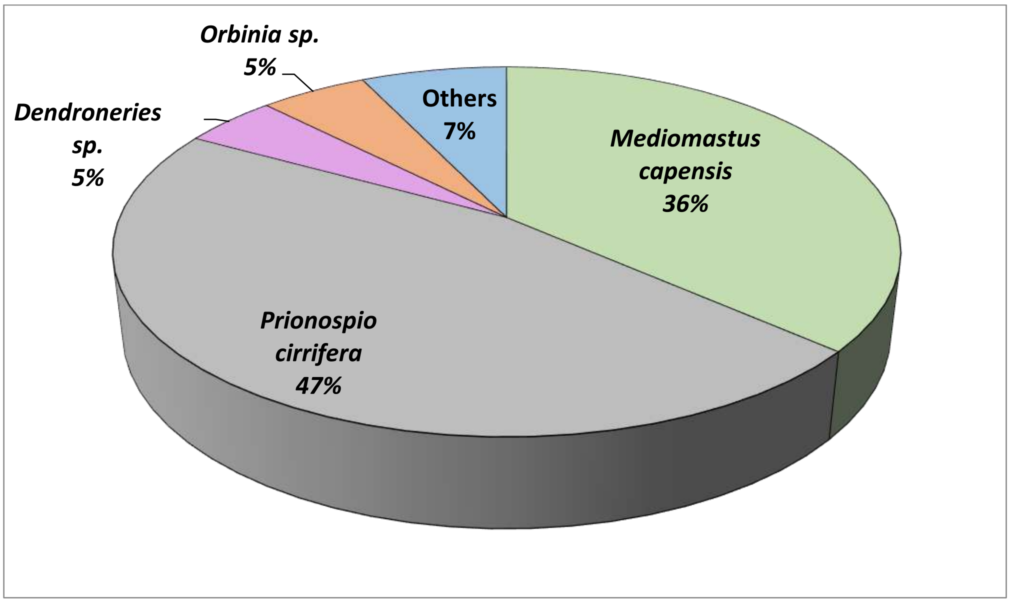


Figure 3.28: Percent (%) composition of polychaetes of the Mandovi Estuary (Peripheral transect)

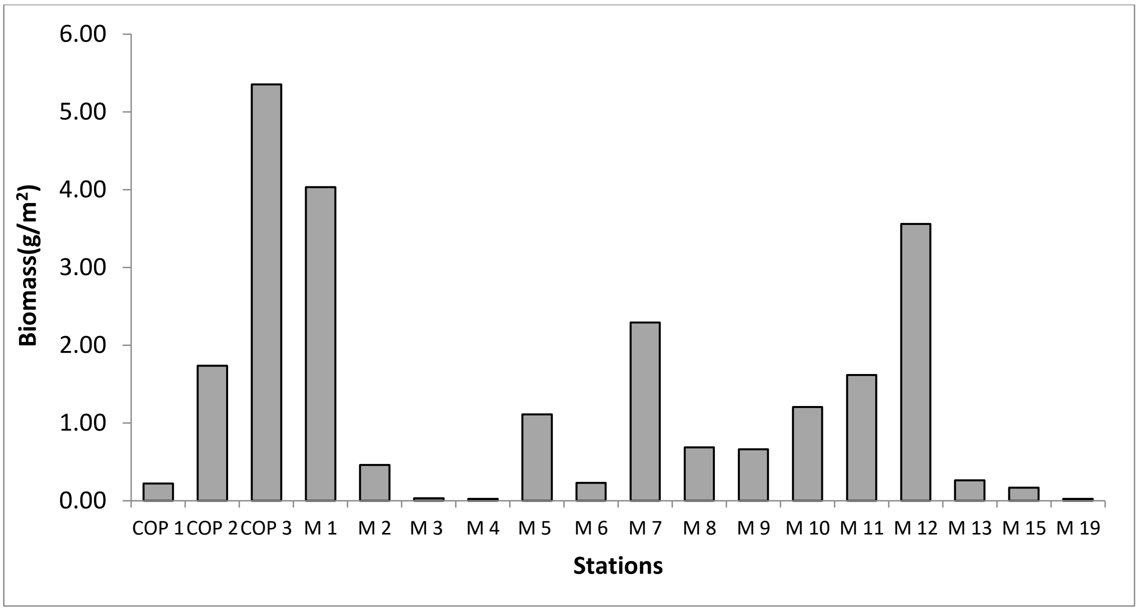


Figure 3.29: Station-wise Biomass (g/m^2) of macrofauna in the Mandovi Estuary (Central transect)

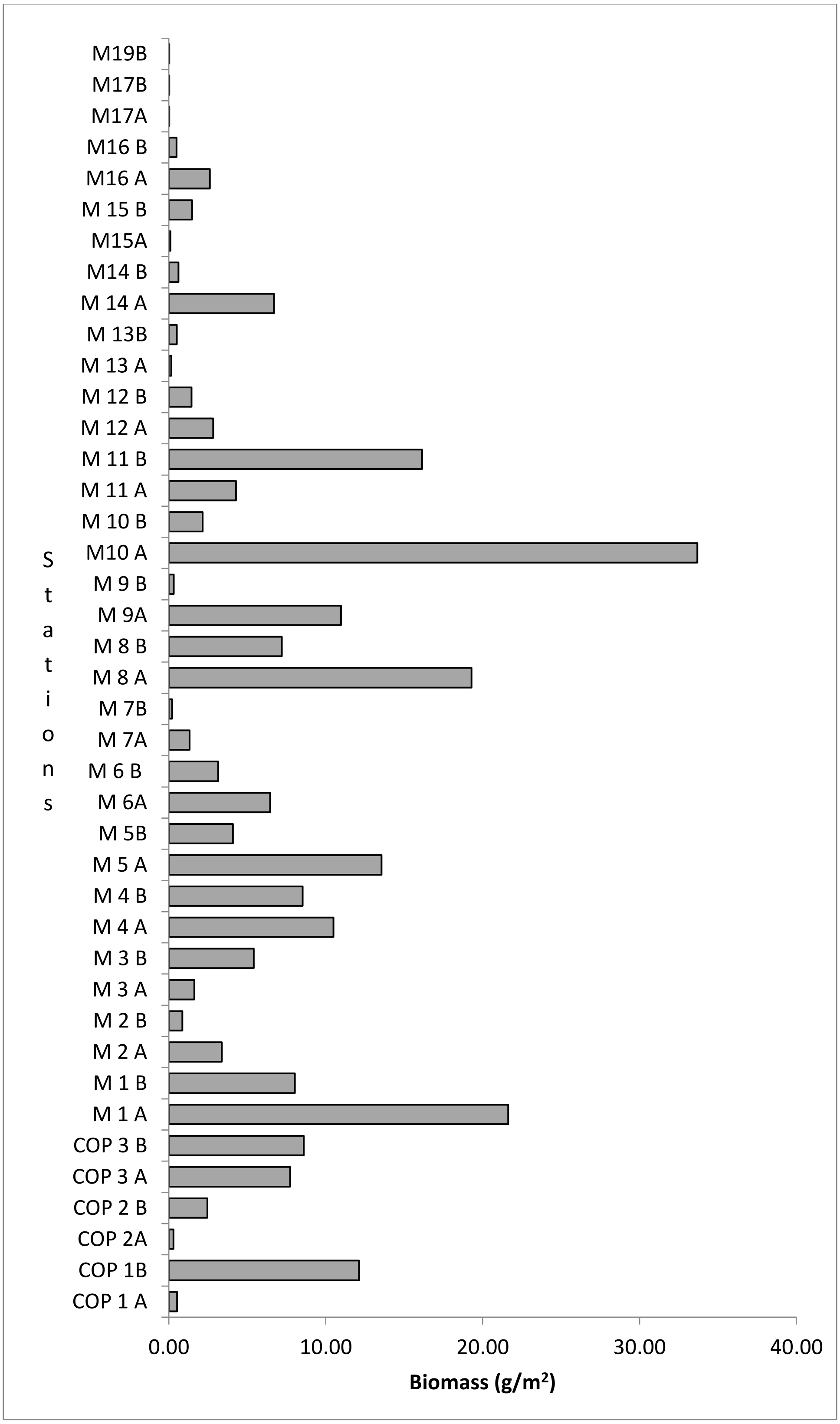


Figure 3.30: Station-wise Biomass (g/m^2) of macrofauna in the Mandovi Estuary (Peripheral transect)

Benthic Polychaeta: Amphipoda (BPA) Ratio:

To study the pollution status of the marine environment and to access the ecological quality status of the area, biotic indices like Benthic Polychaetes Amphipods Index (BPA) was carried out. This index is mainly based on the ratio of sensitive amphipods to other fauna like annelids (polychaetes). The Benthic Polychaetes Amphipods Index (BPA) was determined by the lack of sensitive species among polychaetes from the study area. Amphipods are the second abundant fauna of the estuarine area and marine soft-bottoms and they are sensitive to polluted sediments. They mainly disappear from benthic communities which is impacted by pollution and will reappear when the environmental condition recover (Ré *et al*., 2009; de-la-Ossa-Carretero *et al*., 2012).

The Benthic Polychaetes Amphipods ratio (BPA) index is given as:

$$BPA = \log 10\, [fp/(fa+ 1)+ 1]$$

Where *f*p was the polychaete frequency and *f*a is the amphipod frequency and +1 used to prevent a total absence of amphipods and the other +1 used to prevent a total absence of opportunistic polychaetes. This index corresponded to the total number of polychaetes (annelida) and total number of amphipods divided by the overall abundance accounted in a station sample. Thresholds for establishing the Ecological Quality status by each index, the valves ranged as 0.025-0.130 (Good status), 0.130-0.199 (moderate status), 0.199-0.255 (poor status).

At the centre region of Mandovi Estuary, the BPA ratio ranged from 0.040 to 0.301 (Table 3.11). At station M3, M5, M6, and M11, the BPA ratio showed good status and in stations COP3 and M13, the BPA ratio showed moderate status whereas the remaining stations (COP1, COP3, M1, M2, M8, M9, M10, M12, M15 and M19, the BPA ratio showed poor status (Table 3.11) where there was absence or low abundance of amphipods and high abundance of polychaetes. At the periphery region, the BPA ratio ranged from 0.05 to 0.30 at Station M13A and M1A (Table 3.12). *Mediomastus capensis* of the family Capitellidae and *Prionospio cirrifera* of family Spionidae dominated in the Mandovi estuary, which are the opportunistic polychaete species.

Table 3.11: Benthic Polychaete Amphipode (BPA) ratio of Mandovi Estuary (Central transect)	
Stations	Benthic Polychaete Amphipod ratio (BPA)
COP 1	0.301
COP 2	0.144
COP 3	0.240
M 1	0.281
M 2	0.214
M 3	0.097
M 5	0.122
M 6	0.040
M 7	0.281
M 8	0.221
M 9	0.266
M 10	0.255
M 11	0.117
M 12	0.301
M 13	0.185
M 15	0.263
M 19	0.301

Table 3.12: Benthic Polychaete Amphipode (BPA) ratio of Mandovi Estuary (Peripheral transect)	
Stations	Benthic Polychaete Amphipod ratio (BPA)
COP 1 A	0.26
COP 1B	0.09
COP 2A	0.16
COP 2 B	0.20
COP 3 A	0.27
COP 3 B	0.29
M 1 A	0.30
M 1 B	0.28
M 2 A	0.23
M 2 B	0.24
M 3 A	0.23
M 3 B	0.25
M 4 A	0.13
M 4 B	0.29
M 5 A	0.28
M 5B	0.28
M 6A	0.18
M 6 B	0.21
M 7A	0.29

M 7B	0.10
M 8 A	0.28
M 8 B	0.28
M 9A	0.27
M 9 B	0.11
M10 A	0.24
M 10 B	0.12
M 11 A	0.29
M 11 B	0.26
M 12 A	0.26
M 12 B	0.14
M 13 A	0.05
M 13B	0.18
M 14 A	0.25
M14 B	0.30
M15A	0.05
M 15 B	0.24
M16 A	0.02
M16 B	0.06
M17A	0.18
M17B	0.00
M19B	0.00

Simpson's Diversity Index:

Simpson's Diversity Index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so diversity increases. The value of Simpson's Diversity Index (D) ranges between 0 and 1, the greater the sample diversity.

The macrofaunal diversity was explained in terms of number of individuals or specimens (N), number of species (S), Margalef's species richness (d), Pielou's evenness (J') and Shannon index (H') and Simpson index (1-lambda') using square root scale at each station (Clarke & Gorley, 2001). In central region of Mandovi estuary, the number of species was maximum at station COP3 (14) and minimum at station M3 (2) (Figure 3.31). The species richness (d) was highest at COP3 (d= 1.62) and lowest at M3 & COP2 (d= 0.2) (Figure 3.31). Evenness was recorded highest at M13 (J'=0.9) and lowest at COP1 (J'=0.3) (Figure 3.31). The Shannon index was highest at COP3 (H'=2.2) and lowest at M3 (H'=0.5) (Figure 3.31). Simpson index was high at COP3(Figure 3.31). COP stations were located at the estuary mouth and the M stations were located where sand mining is carried out which might be the main reason in low macrofaunal diversity. In peripheral region, the number of species was maximum at station COP2B (14) and M1B (14) and minimum at station M3 (2) (Figure 3.32). The species richness (d) was highest at COP2B (d= 1.75) and lowest at M17 and M19 (d= 0.17) (Figure 3.32). Evenness was recorded highest at COP1B (J'=0.96) and lowest at M4B (J'=0.2) (Figure 3.32). The Shannon index was highest at COP1B & COP3B (H'=2.1) and lowest at M16A (H'=0.) (Figure 3.32). Because of mangroves adjacent to the estuary, the diversity was high in the peripheral area. Simpson index was high at COP1B (Figure 3.32)

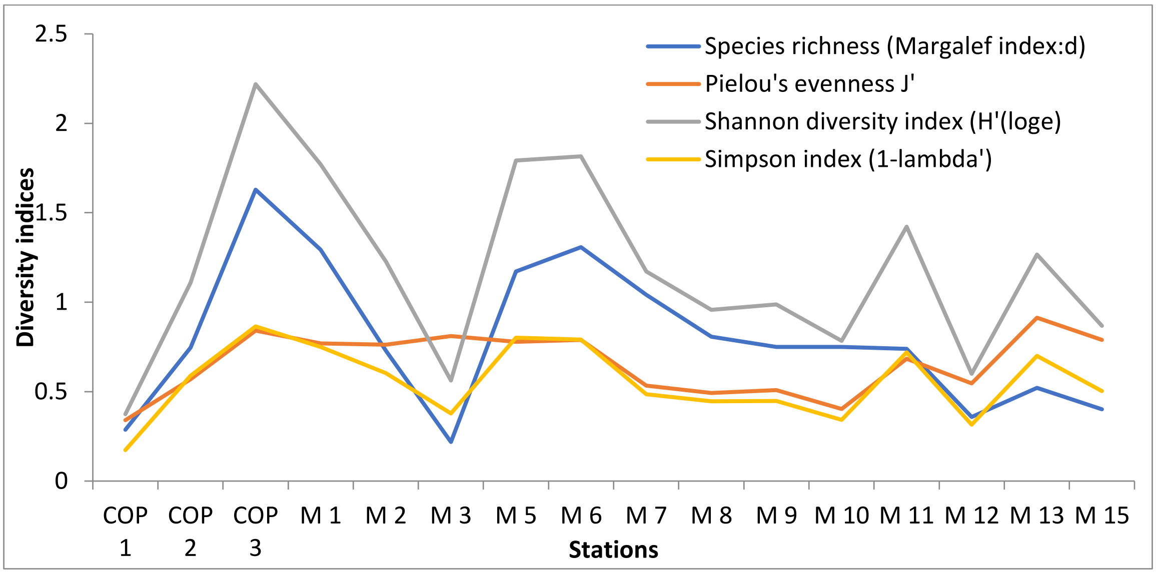


Figure 3.31: Station-wise diversity indices of the Mandovi Estuary (Central transect).

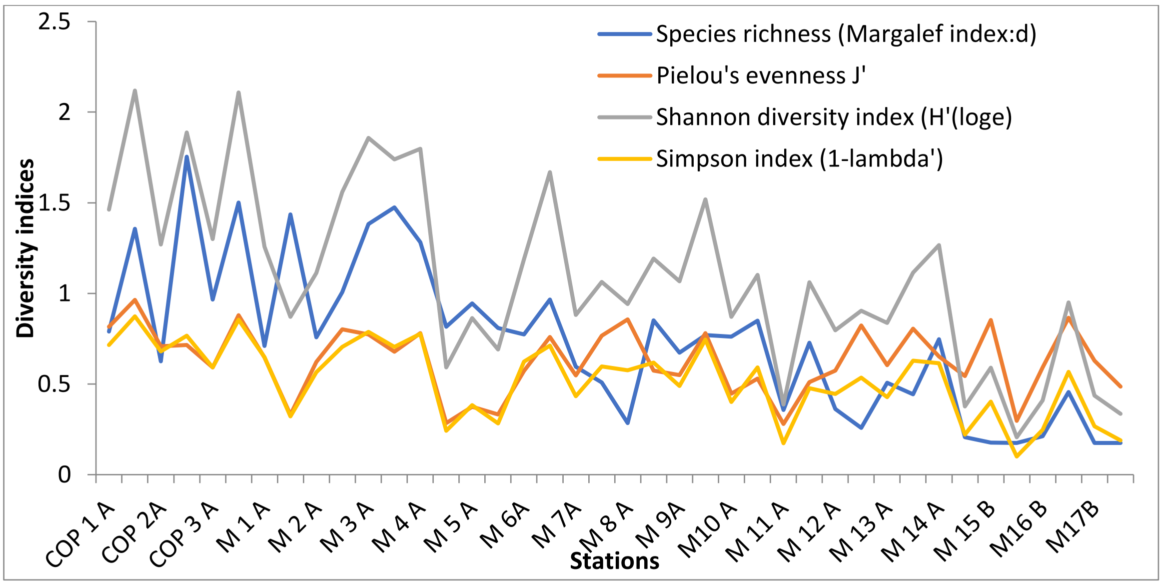


Figure 3.32: Station-wise diversity indices of the Mandovi Estuary (Peripheral transect).

Biotic indices

Ecological quality status assessment carried out by AMBI analysis based on the benthic polychaete diversity and abundance. This index assigned most of the sampling sites as moderately disturbed to slightly disturbed. Upper stream stations (M16, M18, M19, M20) of Mandovi estuary were extremely disturbed. Only sites COP1, COP2, COP3 and M17 were found to be undisturbed based on the AMBI results (Figure 3.33). According to M-AMBI, most of the sampled sites were assigned to poor ecological quality status. Stations COP3 and M1 were in good status, COP1, COP2, M2A, M3A, M6 and M8 showed moderate status. Station M11, M11A, M14B showed bad status. Stations towards the mouth of the estuary showed good to moderate status whereas the stations towards the upper stream areas, it showed poor status (Figure 3.34).

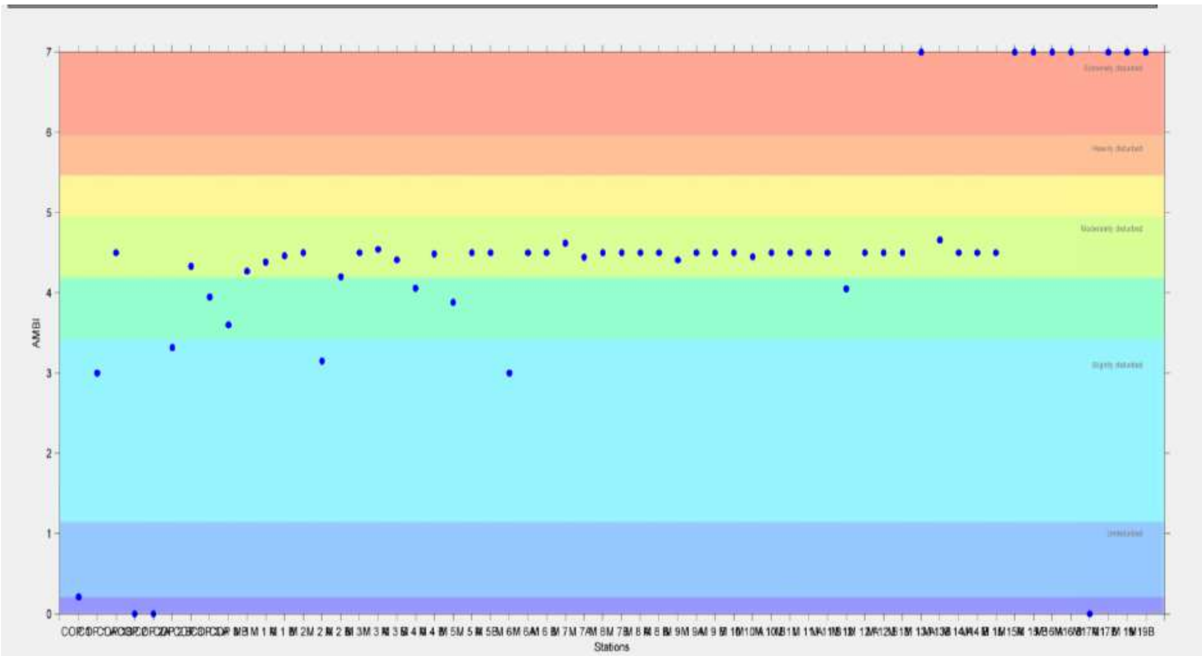


Figure 3.33: Ecological quality status assessment through AMBI index from the Mandovi Estuary

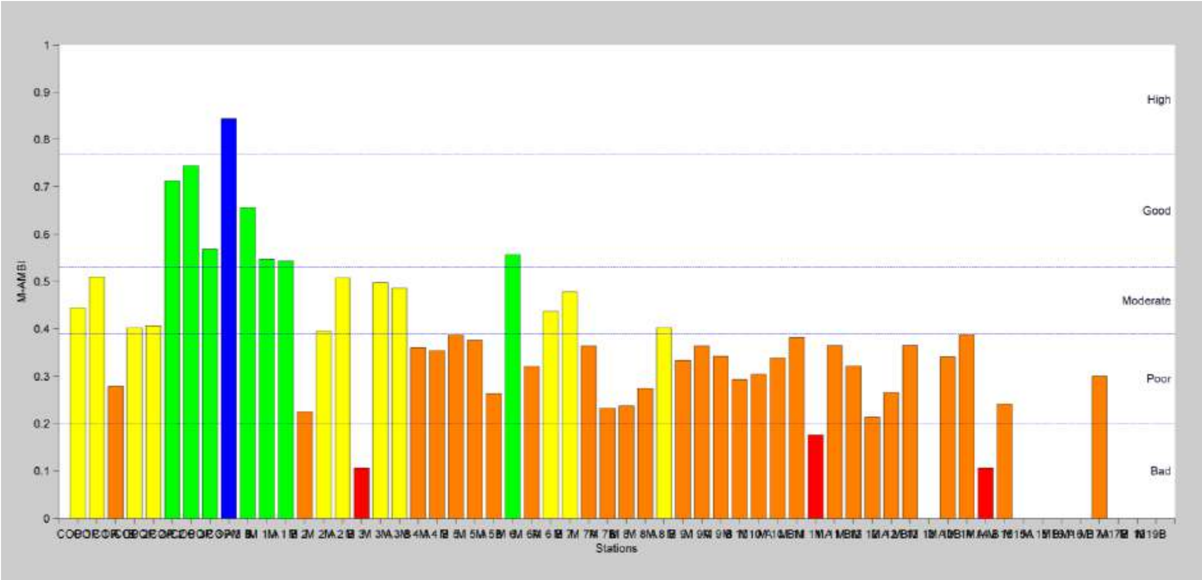


Figure 3.34: Ecological quality status assessment through M-AMBI index from the Mandovi Estuary

BENTIX produced a poor status in most of the stations mainly in the upper stream of the Mandovi Estuary, except the station COP1A, COP3, COP3A and COP3B, which displayed moderate ecological quality status (Figure 3.35). Stations of upper stream areas showed poor ecological quality status due to the diversity and abundance in benthic fauna present in all the stations. Tolerant species were more dominant in all the sampling stations (Figure 3.36).

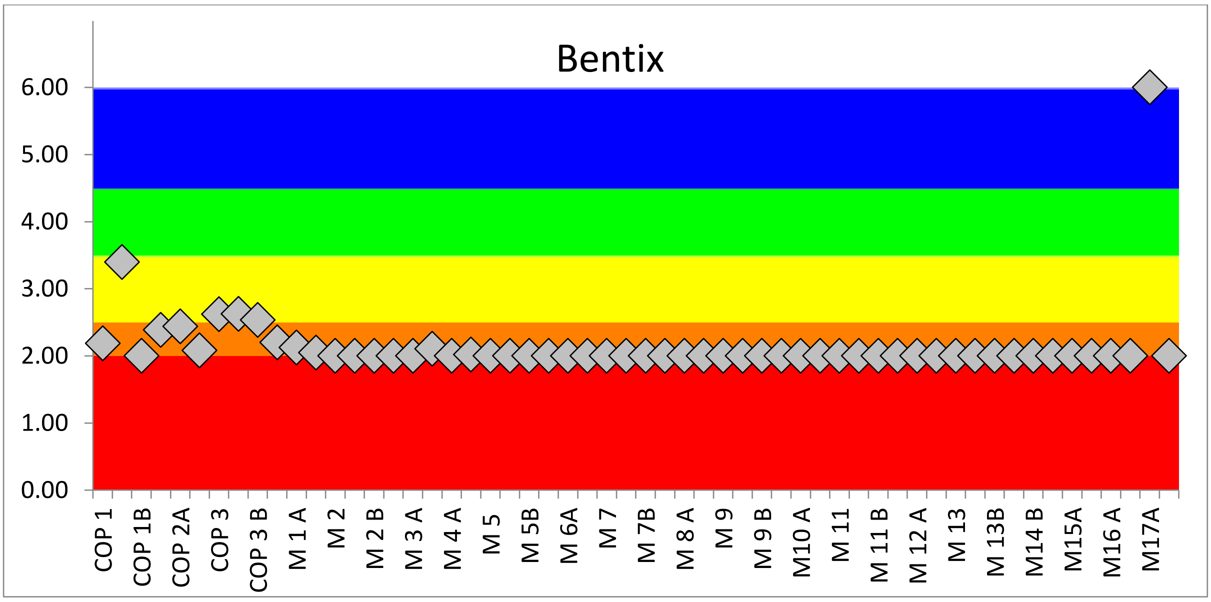


Figure 3.35: Ecological quality status assessment through BENTIX index from the Mandovi Estuary

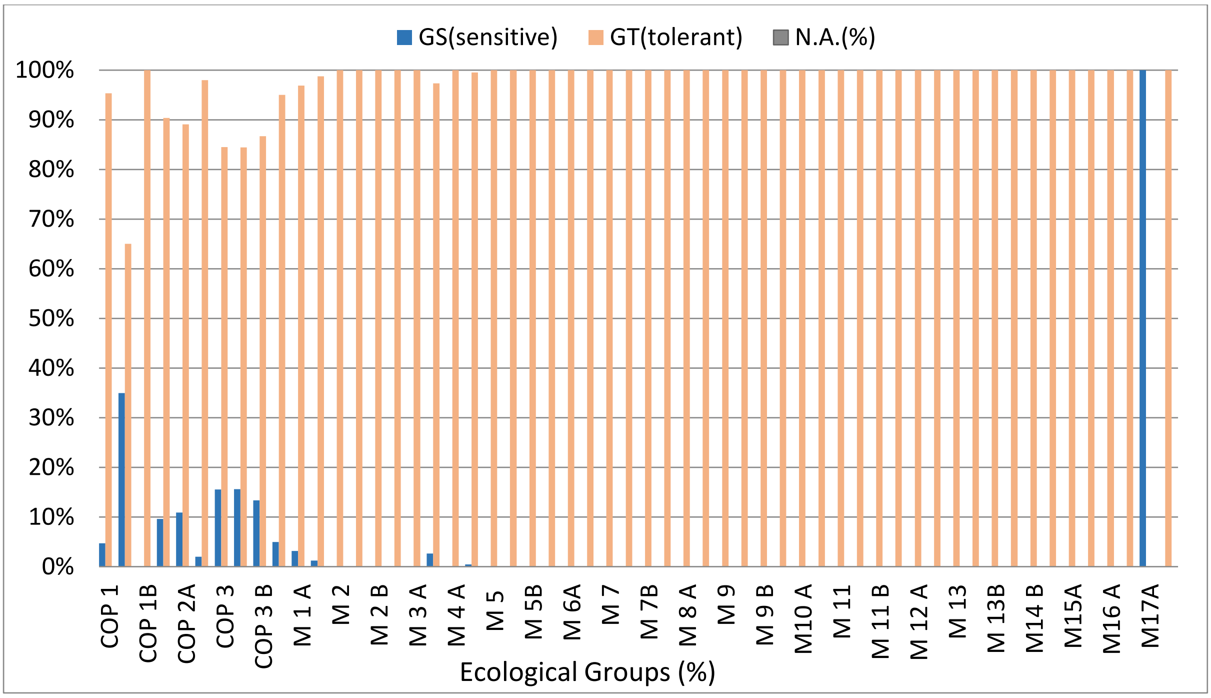


Figure 3.36: Distribution of macrobenthic- Polychaeta based on the ecological sensitivity group assessed through BENTIX index from the Mandovi Estuary.

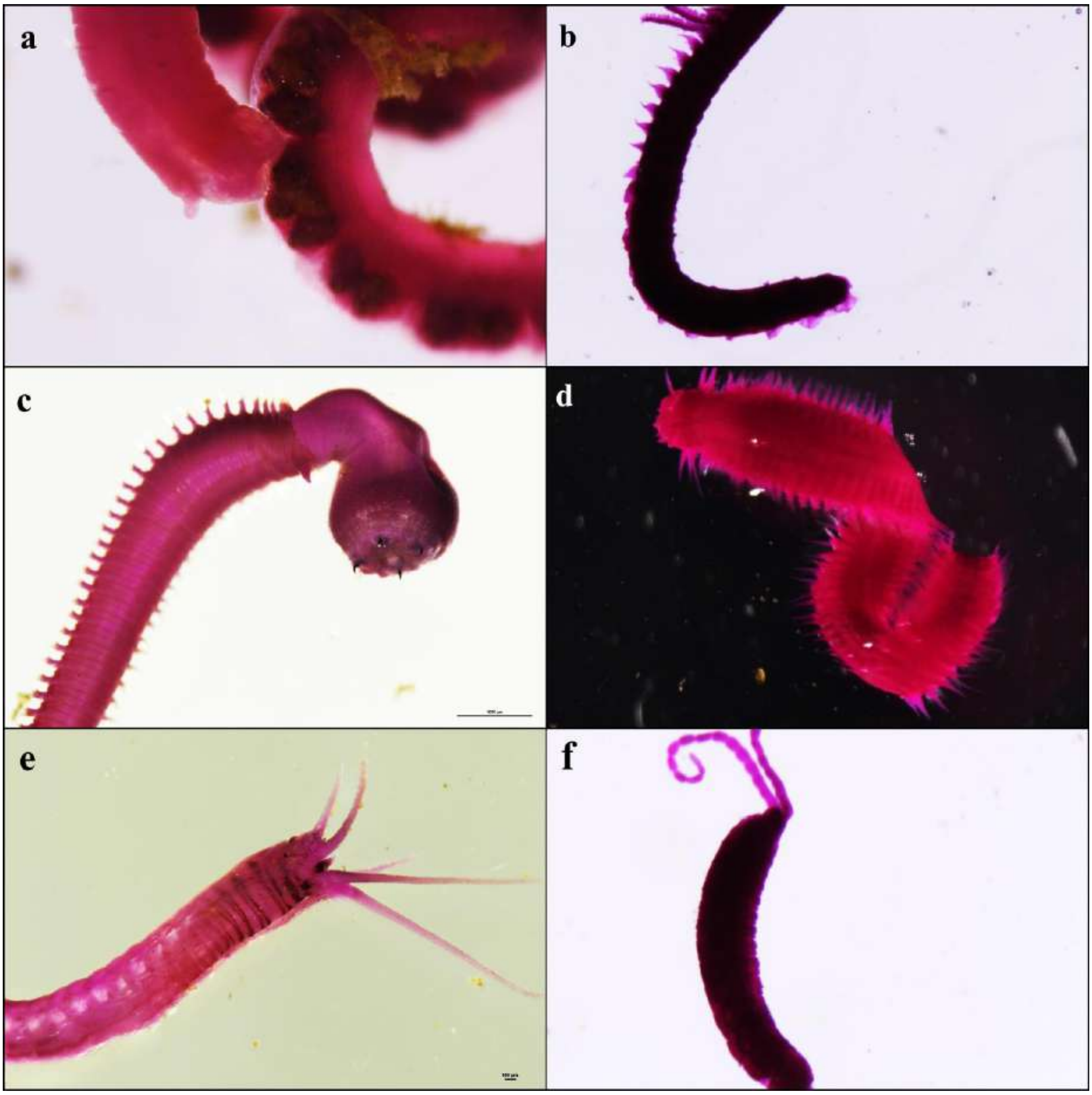


Plate 3.5: a. *Mediomastu scapensis*; b. *Prionospo pinnata*; c. *Glycera alba*; d. *Sigambra* sp.; e. *Onuphis* sp.; f. *Saccocirrus* sp.

Plate 3.6: a. Amphopida; b. Isopoda; c. Bivalvia; d. Shrimp

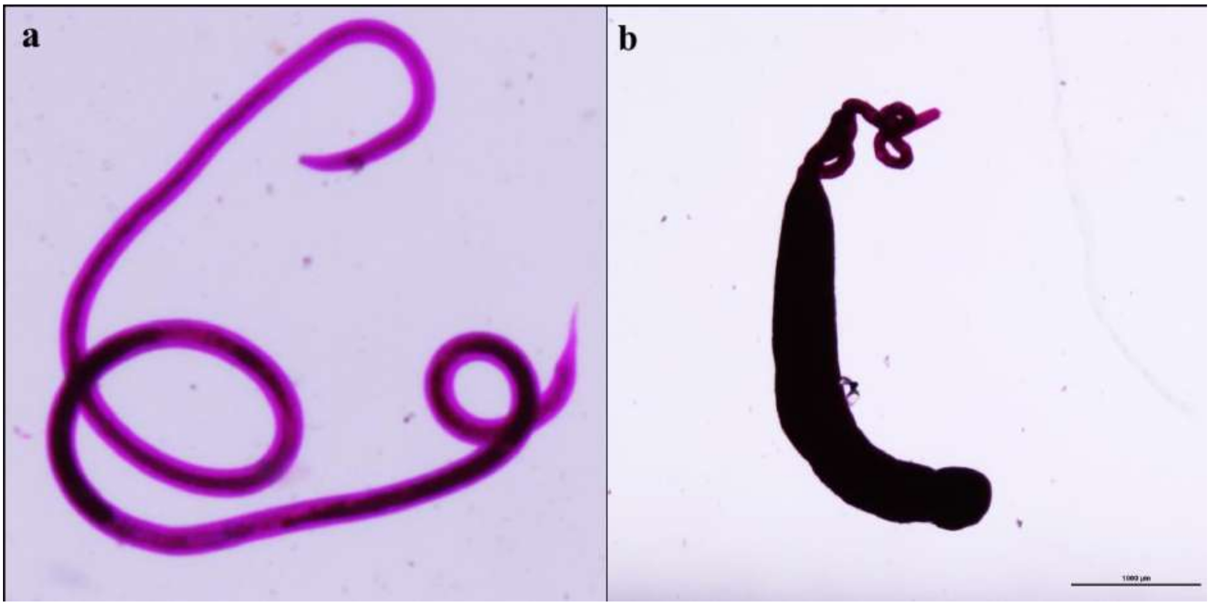


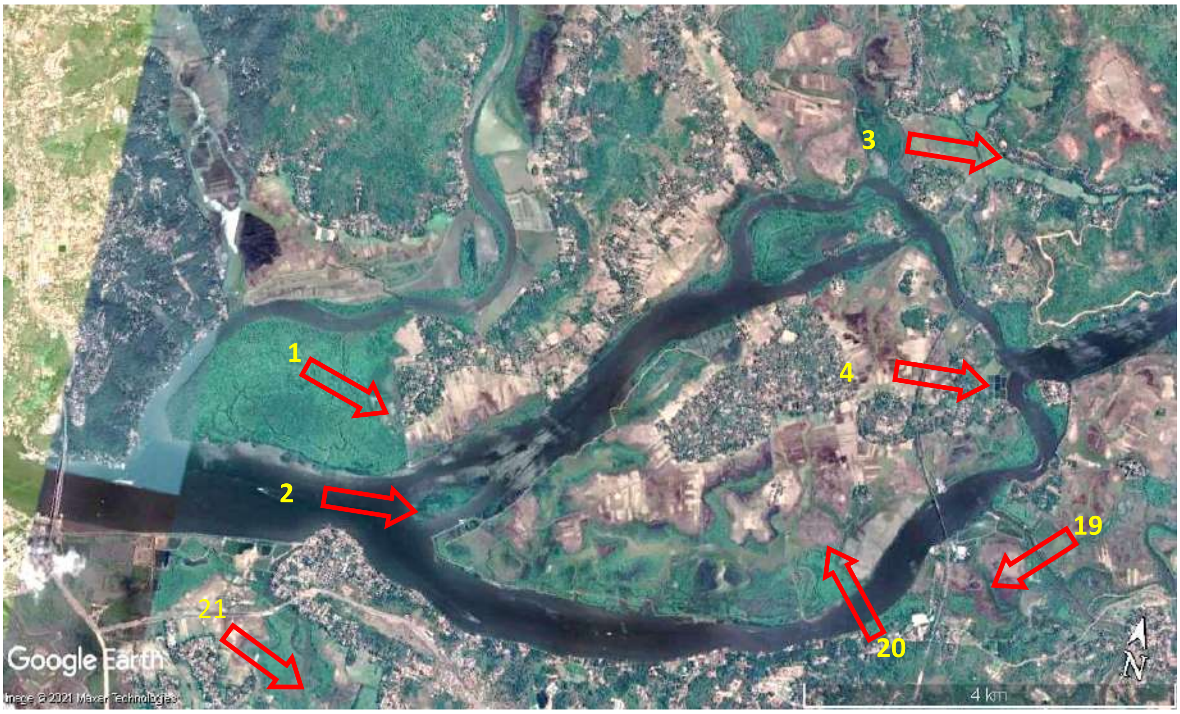
Plate 3.7: a.- Nematode and b.- Nemertea.

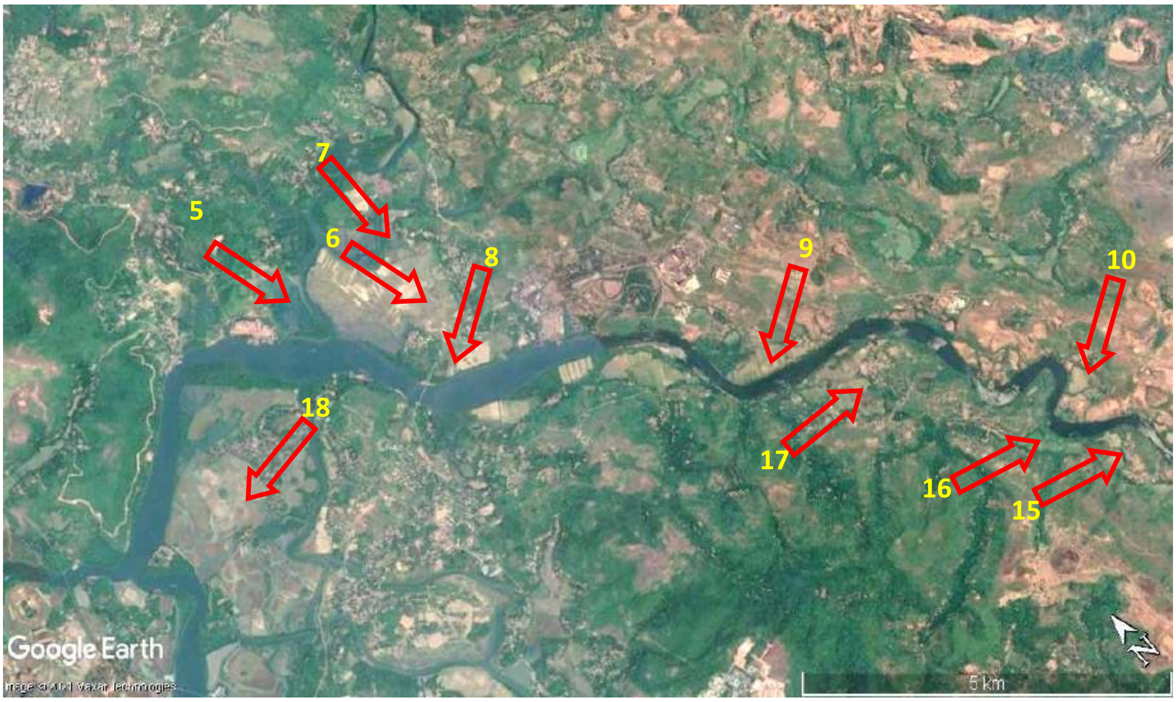
3.10 Land Use Land Cover (LULC)

LISS 4 data was used for the purpose of classification of Land Use Land Cover for the study area. The LISS-4 (Linear Imaging Self-Scanning Sensor-4) multispectral high-resolution camera is the prime instrument of Resourcesat satellite series, with a spatial resolution of 5.8 m and a swath of 70 km.

The study area comprised of the sub scene (A) of path and row 96 and 62 respectively of the LISS 4 data. The Red (Band 2, 0.62- 0.68), Green (Band 3,0.52- 0.59) and Infrared Red (Band 4, 0.77-0.86) bands were used to prepare the false colour composite for the area.

The land use and land cover for an area of 500 meters around the Mandovi Estuary was extracted from the imagery with the help of object-oriented classification of the data where a group of pixels were identified as features with the help of factors such as shape, texture, tone, and spatial relation between the surrounding pixels. All the LULC maps of Mandovi river were prepared by using Google earth.


3
1
4
2
19
21
20
Google Earth
4 km


7
5
6
8
9
10
18
17
16
15
Google Earth
5 km

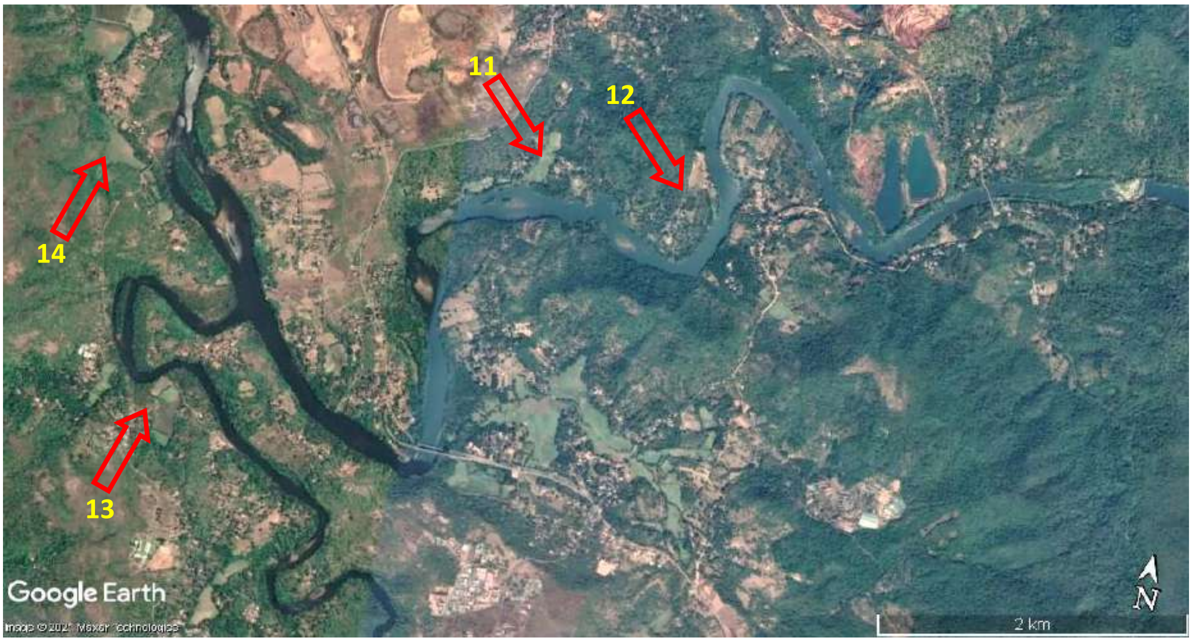
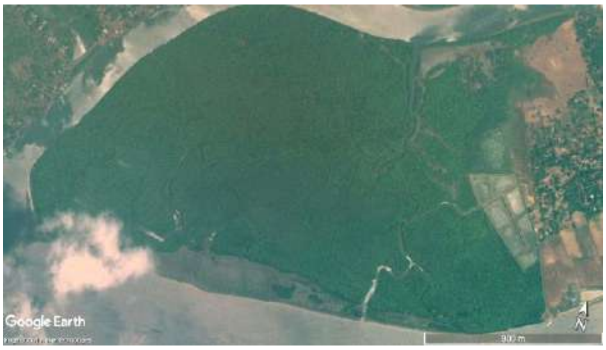


Figure 3.37: Sections of the rivers depicting areas highlighted in the subsequent Figure 3.38 for land use changes.

2010	2021
 1a	 1b
 2a	 2b
 3a	 3b
 4a	 4b

 5a	 5b
 6a	 6b
 7a	 7b
 8a	 8b
	

9a	9b
	
10a	10b
	
11a	11b
	
12a	12b
	
13a	13b

14a

14b

15a

15b

16a

16b

17a

17b

18a

18b

19a

19b

20a

20b

21a

21b

Figure 3.38: Areas depicting Land Use Land Cover along the Mandovi Estuary in 2010 and 2021.

In the present study of Land Use Land Change (LULC) cover was observed and obtained by mapping the project area by comparing present scenario with year 2010. Several areas were noted and maps were prepared accordingly along the entire stretch of Mandovi Estuary. A total of 21 regions were identified and depicted based on land use change. For all the regions two maps were created, representing current scenario and the other depicting 2010 scenario. These maps have been numbered 1-21.

First region lies near the mouth area of the estuary, from the year 2010 to present time it's shown very minimal change, present mangrove cover seems almost similar compared to the images from the year 2010 although the aquaculture ponds seem to abandoned which were observed functional during 2010. Similarly, in the next region there is an increase in mangroves on the island and also on the banks, signs of siltation can also be seen. Image 3 depicts loss of agriculture land which could be due to salt water intrusion. Image 4 denotes use of land for saltpans or aquaculture purpose. Images from (6,7,8,9,10,11,13,14,15,16,17,18 and 19) show that the land used for agriculture earlier is now not in use. This could be the result of salt intrusion and simultaneous increase in the mangrove cover which has grown into a thicket. The areas once utilised for paddy field cultivation, has now turned barren/ fallow probably due to a single saline water surge or recurrent high tide water brining in salinity. This intrusion of saline water could be due to lack of maintenance of already existing bunds/embankments, breach in embankments, eroding mudflats or shift in mangrove area to landward side as well as excavation of sand. While images from (5, 12, 20 and 21) denotes the land is used for agricultural purpose, which also indicates the reduction in mangrove cover in these areas and are replaced by paddy fields. This change of land use is noted mostly in the mid-region of the estuary. Furthermore, most of the regions clearly depicts that there is an increase habitation in and around the mangrove region, the structures can be houses, buildings or any sort of manmade structure.

From the comparison of historic land use, it is clearly visible that land once used for paddy cultivation has been converted into waste/marshy land due to saline intrusion (Figure 3.38). Apart from the major areas depicted in the Figure 3.38 1A-B to 21A-B there are several small land parcels that have been either intruded by saline water or are eroded due to strong monsoon currents.

3.11 Fishery

Fisheries is one of the important economic activities in Goa. Goa has continental shelf of about ten million ha and an actively fished area of 20,000 sq. km. EEZ of Goa has estimated annual potential pelagic yield of 77,660 ton and demersal yield of 1,12,600 tons. A lot of communities in Goa are dependent upon fishing as a source of livelihood in the coastal as well as inland areas. The fish caught is used for both domestic consumption as well as export. Coastal marine waters off Mandovi and Mandovi estuary is endowed with rich fishery resources and famous for fishing activities which are carried out through fibre reinforced plastic (FRP) outboard engines boats, trawlers and small size traditional dugout canoes. Fishery data was collected from observations during sampling as well as secondary data was collected from the locals and fishermen community living around Mandovi estuary. Malim jetty is a major fish landing centre on the banks of Mandovi estuary. Commercially important fish varieties such as mackerels, sardines, mullet, catfish, sharks, seerfish, pomfrets, cuttlefish as well as various prawns, crabs and shellfishes are also found in Mandovi estuary and surrounding coastal waters (Table 3.13). The fishery data represents marine, estuarine and freshwater species. The methods of fishing in Mandovi estuary are cast-nets, gill nets, stake nets, hook and line, shore seine (Rapon), purse seine, trawling and free diving for the collection of clams oysters and green mussels. The shell fishery is common fishing practice used by the local people. Bivalve clams, *Meritrix casta* and *Paphia malbarica* were commonly found in the estuary. These bivalves support the livelihood of locals' dependent on them. They are harvested by hand picking and hand operated scoop net or with the help of a small hand held digging sick. Locals use canoe to collect these clams from deeper waters.

Plate 3.8 Fish species observed at the mouth of Mandovi estuary [A. *Penaeus monodaon*; B. *Stolephorus indicus*; C. *Sphyraena jello* D. *Portunus pelagicus*]

Table 3.13: Fish diversity from Mandovi Estuary				
Families	**Species**	**Common name**	**Vernacular name**	**Habitat class**
Upper Estuary				
Cyprinidae	*Dawkinsia filamentosa*	Blackspot barb		Demersal
Cyprinidae	*Devario malabaricus*	Malabar danio		Demersal
Cyprinidae	*Pethia setnai*	Pethia		Demersal
Cyprinidae	*Rasbora daniconius*	Slender rasbora		Demersal
Cyprinidae	*Garra mullya*	Sucker fish		Demersal
Cyprinidae	*Systomus sarana*	Olive barb		Demersal
Cyprinidae	*Puntius mahecola*	Mahecola barb		Demersal
Cyprinidae	*Cabdio morar*	Morari		Demersal
Tetraodontidae	*Chelonodonpatoca*	milkspotted puffer	Bebo	Pelagic

Cobitidae	*Lepidocephalichthys thermalis*	Common spiny loach		Demersal
Middle Estuary				
Gobiidae	*Glossogobius giuris*	Tank goby	Khorsani	Demersal
Aplocheilidae	*Aplocheilus lineatus*	Striped panchax		Demersal
Mugilidae	*Mugil cephalus*	Flathead grey mullet	Shevtto	Demersal
Tetraodontidae	*Dichotomyctere nigroviridis*	Spotted green pufferfish	Bebo	Demersal
Lower Estuary				
Oxudercidae	*Boleophthalmus sp.*	Mudskipper	Kheldho	Demersal
Mugilidae	*Mugil cephalus*	Flathead grey mullet	Shevtto	Demersal
Gobiidae	*Glossogobius giuris*	Tank goby	Khorsani	Demersal
Gobiidae	*Acentrogobius nebulosus*	Shadow goby		Demersal
Sciaenidae	*Johnieops belangerii*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius borneensis*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius carouna*	Caroun croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius dussumieri*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius macrorhynus*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Otolithes ruber*	Tiger toothed croaker	Dhodiyare	Demersal
Sciaenidae	*Otolithes argenteus*	Croaker	Dhodiyare	Demersal
Lactariidae	*Lactarius lactarius*	False trevally	Saundallo	Pelagic
Clupeidae	*Sardinella longiceps*	Indian oil sardine	Tarle	Pelagic
Clupeidae	*Sardinella fimbriata*	Fringscale sardine	Pedi	Pelagic
Leiognathidae	*Secutor insidiator*	Pugnose pony fish	Kapi	Demersal
Leiognathidae	*Secutor ruconius*	Deep pugnose pony fish	Kapi	Demersal
Leiognathidae	*Leiognathus brevirostris*	Silver bellies	Kapi	Demersal
Leiognathidae	*Leiognathus blochii*	Silver bellies	Kapi	Demersal
Leiognathidae	*Leiognathus bindus*	Silver bellies	Kapi	Demersal
Leiognathidae	*Leiognathus splendens*	Silver bellies	Kapi	Demersal

Leiognathidae	*Leiognathus daura*	Silver bellies	Kapi	Demersal
Carangidae	*Alepes kleinii*	Razorbellyscad	-	Pelagic
Carangidae	*Parastromateus niger*	Black pomfret	Paplet	Pelagic
Carangidae	*Carangoides ferdau*	Blue trevally	Konkor	Pelagic
Chanidae	*Chanos chanos*	Milkfish	Gholsi	Pelagic
Carcharhinidae	*Carchachrinus sp.*		Vattu	Pelagic
Stromatidae	*Pampus chinensis*	Chinese pomfret	Paplet	Pelagic
Stromatidae	*Pampus argenteus*	Silver pomfret	Paplet	Pelagic
Stromatidae	*Rastrelliger karagurata*	Indian mackerel	Bangdo	Pelagic
Polynemidae	*Leptomelanosoma indicum*	Indian threadfin	Rawas	Demersal
Engraulidae	*Stolophorus indicus*	Indian anchovy	Dindvus	Pelagic
Engraulidae	*Thryssa malabarica*	Malabar thryssa	Khavali	Pelagic
Congridae	*Bathy congrusnasicus*	Eel	Vam	Demersal
Chirocentridae	*Chirocentrus dorab*	Wolf herring	Karli	Pelagic
Pristigasteridae	*Opisthopterus tardoore*	Tardoore	Kateri	Pelagic
Platycephalidae	*Eurycephalus carbunculus*	Papilose flathead	-	Demersal
Ambassidae	*Ambassis gymnocephalus*	Bald glassy	Burantte	Pelagic
Ambassidae	*Ambassis urotaenia*	Banded-tail glassy perchlet	Burantte	Pelagic
Nemipteridae	*Nemipterus japonicas*	Japanese threadfin bream	Rano	Demersal
Lutjanidae	*Lutjanus campechanus*	Red snapper	Tamoshi	Pelagic
Serranidae		Grouper	Palu	Pelagic
Cichlidae	*Etroplus suratensis*	Pearl spot	Kalunder	Benthopelagic
Terapontidae	*Terapon jarbua*	Crescent grunter	Korkoro	Pelagic
Terapontidae	*Terapon puta*	spiny-checked grunter	Korkoro	Pelagic
Gerridae	*Gerres filamentosus*	Silver biddy	Shetuk	Demersal

Gerridae	*Gerres limbatus*	Silver biddy	Shetuk	Demersal
Gerridae	*Gerres oyena*	Silver biddy	Shetuk	Demersal
Latidae	*Lates calcarifer*	Giant sea perch	Chonak	Demersal
Megalopidae	*Megalops cyprinoides*	Indo-Pacific tarpon	Ker	Pelagic
Muraenesocidae	*Muraenesox bagio*	Common pike conger	Toem-Baiem	Demersal
Muraenesocidae	*Congresox talabonoides*	Indian pike conger	Divodd Baiem	Demersal
Sillaginidae	*Sillago sihama*	Silver whiting	Mudoshi	Demersal
Polynemidae	*Polydactylusplebeius*	Stripped threadfin	Ravas	Pelagic
Scombridae	*Scomberomorus commerson*	seerfish	Visvonn	Pelagic
Scombridae	*Scomberomorus guttatus*	seerfish	Visvonn	Pelagic
Sparidae	*Chyrsophrys datnia*		Palu	
Sphyraenidae	*Sphyraena jello*	Pickhandle barracuda	Tonki	Pelagic
Triacanthidae	*Tricanthus biaculeatus*	Short-nosed tripodfish	Chamat	Demersal
Scatophagidae	*Scatophagus argus*	Spotted scat	Bannsire	Pelagic
Ariidae	*Arius jella*	Blackfin sea catfish	Sangot	Demersal
Ariidae	*Arius arius*	threadfin sea catfish	Sangot	Demersal
Ariidae	*Arius caelatus*	Spotted catfish	Sangot	Demersal
Ariidae	*Arius platystomus*	Flatmouth sea catfish	Sangot	Demersal
Ariidae	*Arius tenuispinis*	Thinspine sea catfish	Sangot	Demersal
Ariidae	*Arius thalassinus*	Giant catfish	Sangot	Demersal
Ariidae	*Arius venosus*	Veined catfish	Sangot	Demersal
Dasyatidae	*Himantura uarnak*	Reticulate whipray	Vagollim	Demersal
Dasyatidae	*Himantura imbricata*	Scaly whipray	Xevnne Vagollim	Demersal
Trichiuridae	*Lepturacanthus savala*	Ribbon fish	Baye	Pelagic
Trichiuridae	*Trichiurus lepturus*	Ribbon fish	Baye	Pelagic
Solidae	*Synapturaalbo maculata*	Kaup's sole fish	Lepo	Demersal
Pleuronectidae		Flounder	Lepo	Demersal
Cynoglossidae	*Cynoglossus arel*	Sole fish	Lepo	Demersal

Cynoglossidae	*C. macrostomus*	Malabar tongue sole	Lepo	Demersal
Penaeidae	*Penaeus monodon*	Tiger shrimp	Vaghi	Demersal
Penaeidae	*Fenneropenaeus merguensis*	Banana prawn	Safed sungata	Demersal
Penaeidae	*Metapenaeus affinis*	Jinga shrimp	Sungat	Demersal
Penaeidae	*Metapenaeus dobsonii*	Kadal shrimp	Sungat	Demersal
Penaeidae	*Meapeaneus monoceros*	Speckled shrimp	Sungat	Demersal
Penaeidae	*Parapenaeopsis hardwickii*	Spear shrimp	Kandianim	Demersal
Palaemonidae	*Palaemon stylifera*		Poting	Demersal
Sergestidae	*Acetes spp*		Galmo	Demersal
Portunidae	*Scylla serrata*	Mud crab	Kulli	Demersal
Portunidae	*Scylla olivacea*	Mud crab	Kulli	Demersal
Portunidae	*Charybdis lucifera*		Kulli	Demersal
Portunidae	*Charybdis (Charybdis) natator*		Kulli	Demersal
Portunidae	*Portunuss anguinolentus*	Three spot swimming crab	Tin doyanchi kurli	Demersal
Portunidae	*Portunus pelagicus*	Blue swimming crab	Padyachi kurli	Demersal
Portunidae	*Charybdis feriatus*	Crucifix crab	Khrusachi kurli	Demersal
Calappidae	*Matuta lunaris*	Moon crab	Bhamburte	Demersal
Dotillidae	*Dotilla myctiroides*	Sand bubbler crab		Demersal
Ocypodidae	*Uca sp.*	Fiddler crab		Demersal
Ocypodidae	*Gelasimus vocans*	Fiddler crab		Demersal
Oziidae	*Epixanthus frontalis*			Demersal
Pilumnidae	*Heteropanope glabra*			Demersal
Grapsidae	*Sesarma sp.*	Marsh crab		Demersal
Grapsidae	*Metopograpsus frontalis*			Demersal
Lithodidae	*Calappalophos*	Box crab	-	Demersal

Squillidae	*Oratosquilla aquinquedentata*	Mantis shrimp	Luchi	Demersal
Diogenidae	*Pagurus sp*	Hermit crab	-	Demersal
Xanthidae	*Leptodius exaratus*		-	Demersal
Loliginidae	*Uroteuthis duvauceli*	Indian squid	Manki	Demersal
Sepiidae	*Sepia* sp.	Cuttle fish	Bebo	Demersal
Cyrenidae	*Villoritacyprinoides*	Black clams	Khube	Benthic
Cyrenidae	*Polymesoda erosa*	Mud clam	Khube	Benthic
Mactridae	*Mactra sp.*			Benthic
Veneridae	*Meretrix meretrix*	Asiatic hard clam	Tissryo	Benthic
Veneridae	*Meretrix casta*	Backwater hard clam	Tissryo	Benthic
Veneridae	*Timoclea scabra*			Benthic
Veneridae	*Gafrarium pectinatum*			Benthic
Ostreidae	*Paphia malabarica*	Venus clams	Khube	Benthic
Ostreidae	*Paphia textilis*	Venus clams	Khube	Benthic
Ostreidae	*Crassostrea madrasensis*	Oyster	Kalva	Benthic
Ostreidae	*Crassostrea gigas*	Oyster	Kalva	Benthic
Ostreidae	*Crassostrea gryphoides*	Oyster	Kalva	Benthic
Ostreidae	*Saccostrea cuccullata*	Oyster	Kalva	Benthic
Mytilidae	*Perna viridis*	Asian green mussel	Shenanyo	Benthic
Mytilidae	*Modiolus sp.*		Shenanyo	Benthic
Tellinidae	*Tellina sp.*			Benthic
Littorinidae	*Littorina scabra*			Benthic
Littorinidae	*Littorina intermedia*			Benthic
Melongenidae	*Hemifususpugilinus*	Sea snail	-	Benthic
Turritellidae	*Turritella acutangula*	Screw shell	Congali	Benthic
Rostellariidae	*Tibia curta*	Indian tibia	Congali	Benthic
Cerithiidae	*Cerithium echinatum*			Benthic
Burside	*Bufonaria rana*	Frog shell	-	Benthic
Muricidae	*Murex aduncospinosus*	Spine murex	-	Benthic
Naticidae	*Natica picta*	Moon snail		Benthic
Naticidae	*Notocochlis tigrina*	Moon snail		Benthic
Babyloniidae	*Babylonia spirata*	Whelks	-	Benthic

Conidae	*Conus* sp.	Cone shell	-	Benthic
Potamididae	*Pirenella cingulata*	Horn snail		Benthic
Potamididae	*Telescopium telescopium*	Horn snail		Benthic
Trochidae	*Umbonium vestiarium*	Button tops		Benthic
Astropectinidae	*Astropectenindicus*	Star fish	-	Benthic
Rhzostomatidae	*Rhopilema* spp.	Jelly fish	Zar	Pelagic

3.12 Reptiles & Mammals

Mandovi Estuary supports a variety of reptiles and mammals such crocodiles, snakes, turtles, otters and dolphins. The estuarine crocodile *Crocodylus palustris* is found along the banks of Mandovi estuary. The Indian Ocean humpback dolphin and the Finless porpoise are found in the coastal waters off Mandovi and are a major tourist attraction. The smooth coated otter is also spotted on the banks of Mandovi especially around Chorao Island. Sea snake such as *Enhydrina schistosa and Hydrophis curtus* are also found commonly in the Mandovi estuary. Mammals are mainly represented by Otters, jackals and Indian flying fox.These mammals visit mangroves for shelter, breeding or feeding on molluscs, crabs, fishes and other crustaceans (Table 3.14). The animals that belong to the Schedule I species are the highly protected species and falls in the priority list. Hunting of scheduled species is strictly prohibited and animal trading, trophies and buying and possession of wild animals is illegal (Wildlife Protection Act, 1972).

Table 3.14: List of Reptiles and Mammals around Mandovi Estuary

Sr. no.	Common name	Scientific name	IUCN status	Wildlife Protection Act (1972)
1	Indian flapshell turtle	*Lissemyspunctate punctata*	Least concern	Schedule I
2	Mugger crocodile	*Crocodylus palustris*	Vulnerable	Schedule I
3	Indian rock python	*Python molurus*	Near threatened	Schedule I
4	Beaked sea snake	*Enhydrina schistosa*	Least concern	Schedule IV
5	Short sea snake	*Hydrophis curtus*	Least concern	Schedule IV
6	Finless porpoise	*Neophocaena phocaenoides*	Vulnerable	Schedule I
7	Indian ocean humpback dolphin	*Sousa plumbea*	Endangered	Schedule I

8	Smooth-coated otter	*Lutrogale perspicillata*	Vulnerable	Schedule II
9	Asian small-clawed otter	*Aonyx cinereus*	Vulnerable	Schedule I
10	Indian flying fox	*Pteropus medius*	Least concern	Schedule IV
12	Dog faced water snake	*Cerberus rynchops*	Endangered	Schedule II
13	Bengal monitor lizard	*Varanus bengalensis*	Least concern	Schedule I (Part II)
14	Checkered keelback	*Xenochrophis piscato*	Least concern	Schedule II (Part II)
15	Indian jackal	*Canis aureus indicus*	Least concern	Schedule II (Part I)

3.13 Avifauna

Birds are the prominent part of the mangrove ecosystem and they are often present in large numbers. Many bird species make extensive use of mangroves for roosting, feeding and breeding. The mud flats, marshes provide abundant food to these birds in the form of small molluscs, crustaceans, worms, insects etc. Bird species such as kingfishers, Plovers, large Herons, Storks, and Egrets etc. were found feeding in the mangrove mudflats. Mandovi estuary is a common site for birds perched on mangroves for roosting or some waiting for an opportunity to catch a fish when they surface in the water. Besides mangroves shore birds like Gulls were observed off the coast. Mandovi Estuary also hosts a variety of migratory birds such as Painted stork, Heuglins gull, Caspian gull during the winter months. Large numbers of birds were seen during low tides and river islands in the upper estuary. Eroded vertical banks of the upper stretches of the banks have burrow nests mostly by kingfishers and bee-eaters. List of birds found in and around Mandovi estuary (Table 3.15). Hunting of birds which falls under Schedule-I species is strictly prohibited (Act No.09 of wildlife Protection Act, 1972) Eurasian spoonbill falls under schedule I species in the list. All birds of prey in India are categorized has Schedule-I Species which includes, White bellied sea Eagle, Brahminy kite, Black kite and Osprey.

Table 3.15: List of Bird species around Mandovi Estuary

Sr.No.	Common name	Scientific name	IUCN status	Wildlife Protection Act 1972
1	Collared Kingfisher	*Todiramphus chloris*	Least Concern	Schedule IV

2	Pied kingfisher	*Ceryle rudis*	Least Concern	Schedule IV
3	Brahminy Kite	*Haliastur indus*	Least Concern	Schedule I
4	Black kite	*Milvus migrans*	Least Concern	Schedule I
5	White wagtail	*Motacilla alba*	Least Concern	Schedule IV
6	Indian Cormorant	*Phalacrocorax fuscicollis*	Least Concern	Schedule IV
7	Little Cormorant	*Microcarbo niger*	Least Concern	Schedule IV
8	Chestnut-headed bee-eater	*Merops leschenaulti*	Least Concern	Schedule IV
9	Blue-bearded Bee-eater	*Nyctyornis athertoni*	Least Concern	Schedule IV
10	Small green bee eater	*Merops orientalis*	Least Concern	Schedule IV
11	White-throated Kingfisher	*Halcyon smyrnensis*	Least Concern	Schedule IV
12	Stork billed kingfisher	*Pelargopsis capensis*	Least Concern	Schedule IV
13	White breasted waterhen	*Amaurornis phoenicurus*	Least Concern	Schedule IV
14	Striated Heron	*Butorides striata*	Least Concern	Schedule IV
15	Indian Pond-Heron	*Ardeola grayii*	Least Concern	Schedule IV
16	Purple Heron	*Ardea purpurea*	Least Concern	Schedule IV
17	Grey Heron	*Ardea cinerea*	Least Concern	Schedule IV
18	Black crowned night heron	*Nycticorax nycticorax*	Least Concern	Schedule IV
19	Lesser whistling duck	Dendrocygna javanica	Least Concern	Schedule IV
20	Black-tailed Godwit	*Limosa limosa*	Near threatened	Schedule IV
21	Eurasian curlew	*Numenius arquata*	Near threatened	Schedule IV
22	Yellow-wattled Lapwing	*Vanellus malabaricus*	Least Concern	Schedule IV
23	Red-wattled Lapwing	*Vanellus indicus*	Least Concern	Schedule IV
24	Common Redshank	*Tringa totanus*	Least Concern	Schedule IV
25	Intermediate Egret	*Ardea intermedia*	Least Concern	Schedule IV

26	Greater Racket-tailed Drongo	*Dicrurus paradiseus*	Least Concern	Schedule IV
27	Little Egret	*Egretta garzetta*	Least Concern	Schedule IV
28	White ibis	*Threskiornis melanocephalus*	Near Threatened	Schedule IV
29	Little grebe	*Tachybaptus ruficollis*	Least Concern	Schedule IV
30	Cinnamon bittern	*Ixobrychus cinnamomeus*	Least Concern	Schedule IV
31	Glossy ibis	*Plegadis falcinellus*	Least Concern	Schedule IV
32	Eurasian spoonbill	*Platalea leucorodia*	Least Concern	Schedule I
33	Ruddy Turnstone	*Arenaria interpres*	Least Concern	Schedule IV
34	Common Sandpipers	*Actitis hypoleucos*	Least Concern	Schedule IV
35	Caspian Gull	*Larus cachinnas*	Least Concern	Schedule IV
36	Heuglin's Gull	*Larus heuglini*	Least Concern	Schedule IV
37	Steppe Gull	*Larus (heuglini) barabensis*	Least Concern	Schedule IV
38	Pallas's Gull	*Ichthyaetus ichthyaetus*	Least Concern	Schedule IV
39	Brown headed Gull	*Chroicocephalus brunnicephalus*	Least Concern	Schedule IV
40	Black headed Gull	*Chroicocephalus ridibundus*	Least Concern	Schedule IV
41	Gull-billed tern	*Gelochelidon nilotica*	Least Concern	Schedule IV
42	Greater Crested Tern	*Thalasseus bergii*	Least Concern	Schedule IV
43	Greater spotted eagle	*Clanga clanga*	Vulnerable	Schedule IV
44	White bellied Sea Eagle	*Haliaeetus leucogaster*	Least Concern	Schedule I
45	Osprey	*Pandion haliaetus*	Least Concern	Schedule I
46	Common snipe	*Gallinago gallinago*	Least Concern	Schedule IV
47	Greater Painted snipe	*Rostratula benghalensis*	Least Concern	Schedule IV
48	Western Reef-egret	*Egretta gularis*	Least Concern	Schedule IV
49	Great Egret	*Ardea alba*	Least Concern	Schedule IV

50	Cattle Egret	*Bubulcus coromandus*	Least Concern	Schedule IV
51	Common Kestrel	*Falco tinnunculus*	Least Concern	Schedule IV
52	Kentish plover	*Charadrius alexandrinus*	Least Concern	Schedule IV
53	Lesser Sand Plover	*Charadrius mongolus*	Least Concern	Schedule IV
54	Greater Sand Plover	*Charadrius leschenaultii*	Least Concern	Schedule IV
55	Caspian Sand Plover	*Charadrius asiaticus*	Least Concern	Schedule IV
56	Common Redshank	*Tringa totanus*	Least Concern	Schedule IV
57	Common Greenshank	*Tringa nebularia*	Least Concern	Schedule IV
58	Common Sandpiper	*Actitis hypoleucos*	Least Concern	Schedule IV
59	Ruddy Turnstone	*Arenaria interpres*	Least Concern	Schedule IV
60	Terek sandpiper	*Xenus cinereus*	Least Concern	Schedule IV
61	Woolly-necked Stork.	*Ciconia episcopus*	Vulnerable	Schedule IV
62	Asian Openbill	*Anastomus oscitans*	Least Concern	Schedule IV
63	White stork	*Ciconia ciconia*	Least Concern	Schedule IV
64	Painted stork	*Mycteria leucocephala*	Near Threatened	Schedule IV
65	Lesser Adjutant	*Leptoptilos javanicus*	Vulnerable	Schedule IV
66	Brown fish owl	*Ketupa zeylonensis*	Least Concern	Schedule IV
67	Great cormorant	*Phalacrocorax carbo*	Least Concern	Schedule IV
68	Oriental darter	*Anhinga melanogaster*	Near Threatened	Schedule IV
69	Blue Tailed bee-eater	*Merops Philippnus*	Least Concern	Schedule IV
70	Indian spot-billed duck	*Anas poecilorhyncha*	Least Concern	Schedule IV
71	Brahminy duck	*Tadorna ferruginea*	Least Concern	Schedule IV
72	Common teal	*Anas crecca*	Least Concern	Schedule IV
73	Northern pintail	*Anas acuta*	Least Concern	Schedule IV
74	Northern Shoveler	*Spatula clypeata*	Least Concern	Schedule IV

75	Garganey	*Spatula querquedula*	Least Concern	Schedule IV
76	Eusrasian Wigeon	*Mareca penelope*	Least Concern	Schedule IV
77	Cotton Pygmy-goose	*Nettapus coromandelianus*	Least Concern	Schedule IV
78	Gadwall	*Marcea strepera*	Least Concern	Schedule IV
79	Spotted Owlet	*Athene brama*	Least Concern	Schedule IV
80	Ashy Prinia	*Prinia socialis*	Least Concern	Schedule IV
81	Plain Prinia	*Prinia inornata*	Least Concern	Schedule IV
82	Common Tailor bird	*Orthotomus sutoris*	Least Concern	Schedule IV
83	White rumped munia	*Lonchura striata*	Least Concern	Schedule IV
84	Tricoloured munia	*Lonchura malacca*	Least Concern	Schedule IV
85	Scaly breasted munia	*Lonchura punctulata*	Least Concern	Schedule IV
86	Wire tailed swallow	*Hirundo smithii*	Least Concern	Schedule IV
87	Red rumped swallow	*Cecropis daurica*	Least Concern	Schedule IV
88	Black winged Stilt	*Himantopus himantopus*	Least Concern	Schedule IV
89	Pied Avocet	*Recurvirostra avosetta*	Least Concern	Schedule IV
90	Wood sandpiper	*Tringa glareola*	Least Concern	Schedule IV
91	Marsh sandpiper	*Tringa stagnatilis*	Least Concern	Schedule IV
92	Red avadavat	*Amandava amandava*	Least Concern	Schedule IV
93	White browed wagtail	*Motacilla maderaspatensis*	Least Concern	Schedule IV
94	Western yellow wagtail	*Motacilla flava*	Least Concern	Schedule IV
95	Ruddy breasted crake	*Zapornia fusca*	Least Concern	Schedule IV
96	Common moorhen	*Gallinula chloropus*	Least Concern	Schedule IV
97	Watercock	*Gallicrex cinerea*	Least Concern	Schedule IV
98	Temminck's stint	*Calidris temminckii*	Least Concern	Schedule IV
99	Ruff	*Calidris pugnax*	Least Concern	Schedule IV

100	Whimrel	*Numenius phaeopus*	Least Concern	Schedule IV
101	Black-capped Kingfisher	*Halcyon pileata*	Least Concern	Schedule IV

3.14 Riparian Vegetation

A riparian zone is the interface between land and water bodies, including streams, rivers, lakes and estuarine marine shores. Riparian zones can therefore be considered as a transitional belt between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes and biota (National Research Council, U.S, 2002).

A riparian zone is often a habitat for rare species and it is also a breeding ground for aquatic fauna such as fish and invertebrates (Naiman *et al*., 2005). Loss of riparian vegetation can decrease the amount of suitable habitat for riparian and aquatic fauna such as fish and invertebrates, thereby reducing stream productivity and fish carrying capacity (Karen, M. & Karen, S., 1998). Riparian vegetation has many critical functions; it provides resistance to flowing water as well as to runoff during floods. The vegetation provides protective cover which helps to absorb the forces exerted by flowing water (Watson & Basher, 2006). Riparian plant canopies intercept, store and evaporate a portion of precipitation and have an important role in influencing stream temperature and the health of aquatic species (National Research Council, U.S., 2002).

A considerable change in riparian zone of the estuary is evident. Increased urbanisation, especially in the coastal areas and river fronts is visible as well as many areas having increased accessibility by roads. Apart from expansion of villages and increase in urban areas, forest area has reduced and vegetation cover changes are evident as many natural habitats are converted to orchards and plantation. In the upstream half of the estuary, the vegetation and plantations are unsuccessful in protecting the banks from erosion. In the stretches of the estuary wherever there are soft muddy and silty banks, erosion has taken away a part of land while taking with it the riparian vegetation as well and leaving behind vertical banks. These vertical banks remain vulnerable to erosion and it is extremely important to protection these banks urgently.

Downstream part of the estuary has more saline influenced waters with higher salinity compared to upper stretches. Thus, most of the areas have been protected by embankments traditionally. These embankments require constant repair and maintenance, as the terrestrial part of it is used for paddy cultivation and building houses. In the downstream areas, many parts of the riparian zone have been intruded by salinity and now converted to saline marsh lands, mudflats or mangroves. This is one of the most significant land use changes noted for this estuary. The present land use of the riparian zone of the estuary in shown in Figure 3.20.

The riparian vegetation along the banks of the estuary in the upstream stretches consist of typical tropical deciduous species typical to this region and the department of forest categorises this region under open forest (https://fsi.nic.in/isfr19/vol2/isfr-2019-vol-ii-goa.pdf). The area is predominantly planted with *Cocos nucifera* and mostly represented by species of *Terminalia* spp., *Ficus* spp., *Careya arborea, Mangifera indica, Anacardium occidentale, Xylia xylocarpa, Caesalpinia* spp. and *Bombax ceiba* along with several species of bamboos, shrubs, herbs and grasses.

The estuary bank in the upstream areas (with mostly narrow mudflats) has grasses which have ability to resist some salinity. Although grasses are known to offer protection from erosion, these grasses may not be able to resist strong current which is visible from the eroded bank stretches in the upstream regions which have also uprooted larger trees (mostly coconut palms).

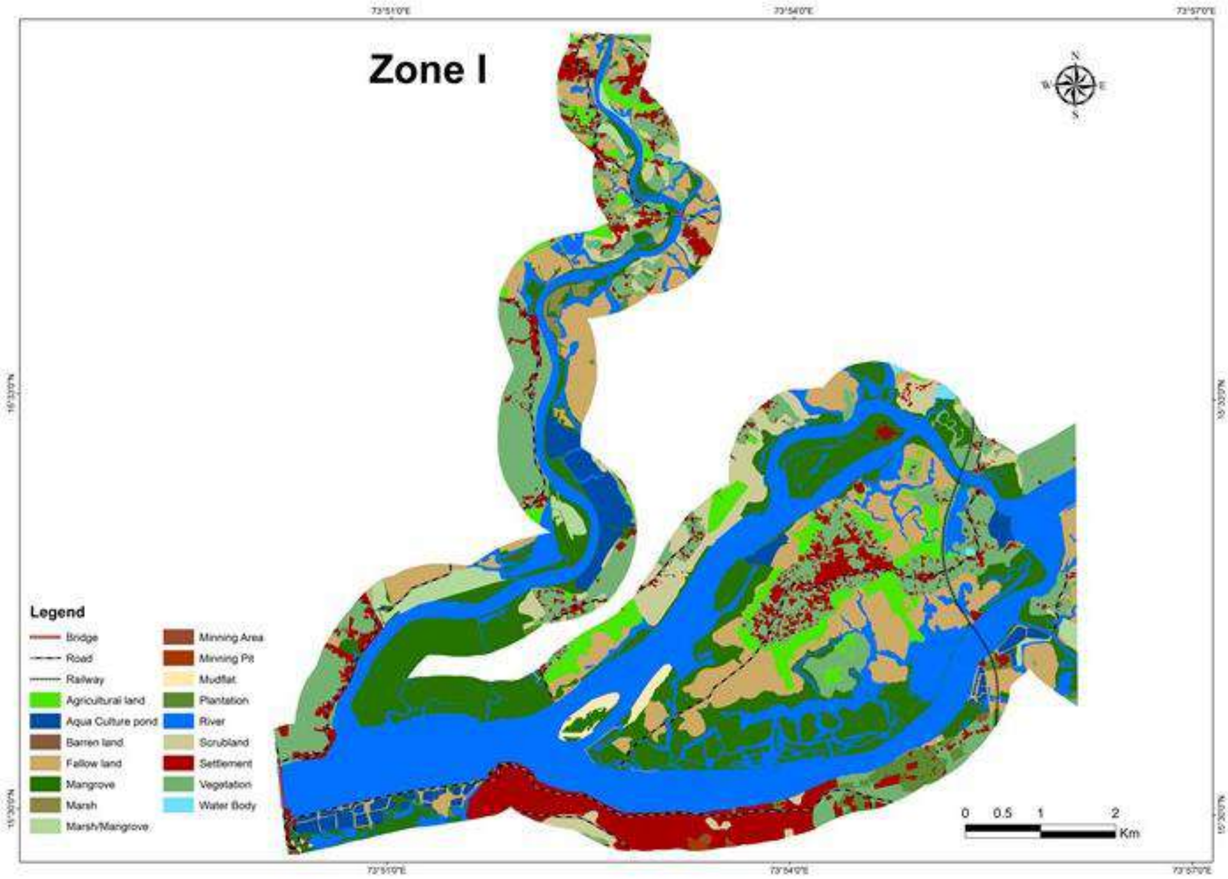
There are few notable species which have invaded this region and may pose threat to the native vegetation in the long run. Some of the plants were *Chromolaena odorata, Cassia tora, Ageratina adenophora, Triumfetta rhomboidea* and *Acacia farnesiana* (https://fsi.nic.in/isfr19/vol2/isfr-2019-vol-ii-goa.pdf).

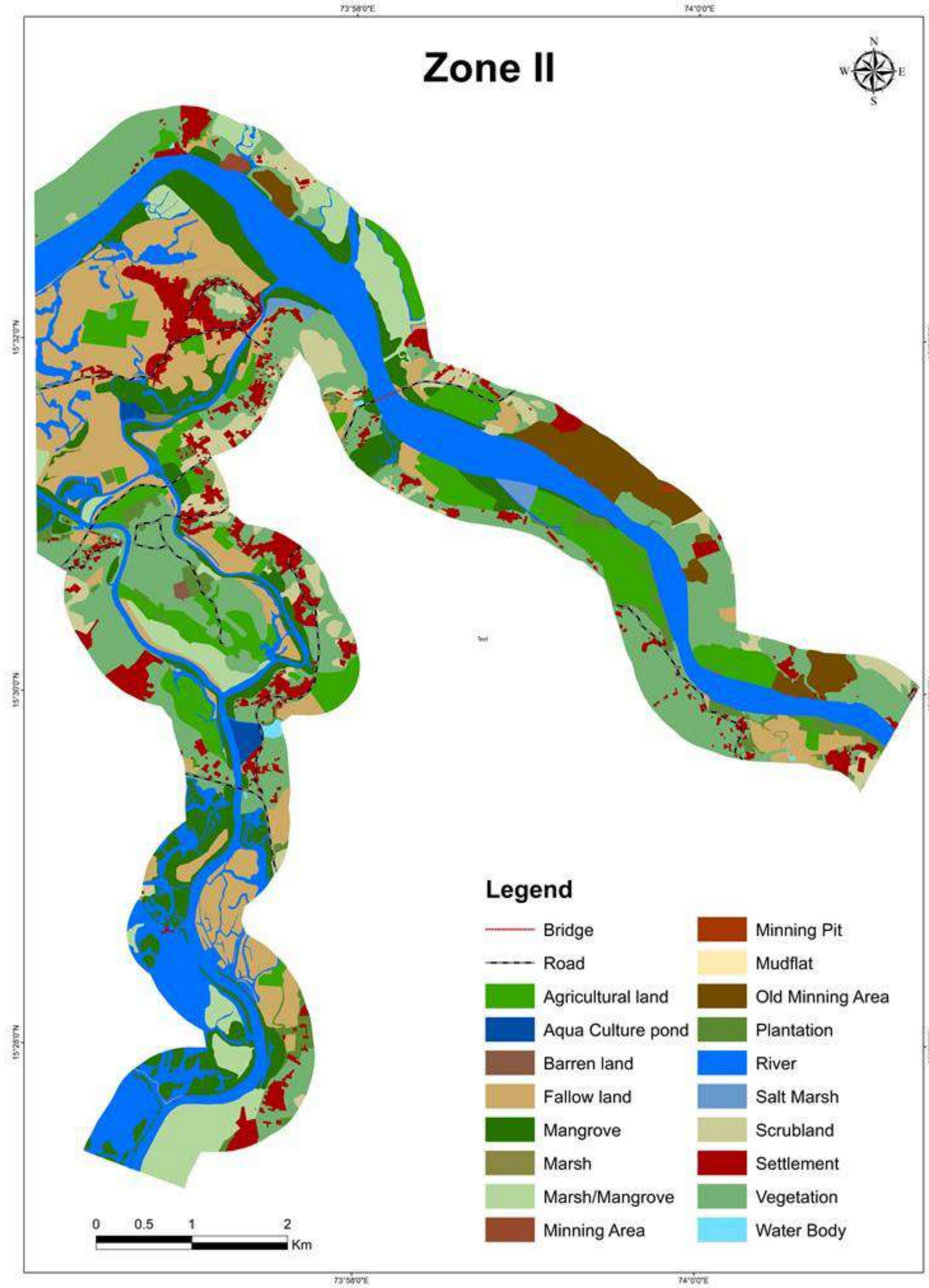
Khazan Land

Khazans are low lying agricultural lands that have been reclaimed by using salinity control structures from mangrove fringed estuaries. These saline low-lying, flat lands were originally mangrove swamps or mudflats lying along both the banks of the rivers of Goa. The presence of peat deposits at depths of 1.5- 2.5 m in these fields suggests they were covered with a thick growth of mangrove forests some 6000 years ago (Mascarenhas and Chauhan 1998). The early settlers who came to this place reclaimed these fertile lands by constructing bundhs all along the estuary and cultivating it. Similar coastal lands like khaznam with paddy cultivation and fish farming are found in other parts of India such as Khar in Maharashtra, gazzani in Karnataka and Pokkali in Kerala.

Khazan lands are carefully designed topo-hydro-engineered agricultural ecosystem. The important aspects of the structure of the land are based on the principle of salinity regulation and knowledge of tidal clock as well as distance from nearest watershed and tidal estuary. It is dependent upon the availability and flow of fresh water and saline water. Excess freshwater can cause growth of weeds and unwanted vegetation leading to eutrophication while surplus saline water flow makes the land useless for agriculture. The balance of these factors promotes a system that allows for agriculture, fishing as well as a balanced flow to the land (Kamat, 2004).

The Mandovi Estuary supports a number of Khazan lands along its banks in various places such as Chorao, Divar and St. Estevam and Vanxim (Kamat and Bhonsle, 2007). These promote the economic upliftment of the local community through various economic activities such as agriculture, horticulture, fisheries, and food production such as dried fish, salt production recreation and tourism. These activities promote self-sufficiency to the local people who are dependent on them.


Zone I
N
S
E
W
Legend
Bridge
Road
Railway
Agricultural land
Aqua Culture pond
Barren land
Fallow land
Mangrove
Marsh
Marsh/Mangrove
Minning Area
Minning Pit
Mudflat
Plantation
River
Scrubland
Settlement
Vegetation
Water Body
0 0.5 1 2
Km


Zone II
N
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73°58'0"E
74°0'0"E
15°32'0"N
15°30'0"N
15°28'0"N
Legend
Bridge
Road
Agricultural land
Aqua Culture pond
Barren land
Fallow land
Mangrove
Marsh
Marsh/Mangrove
Minning Area
Minning Pit
Mudflat
Old Minning Area
Plantation
River
Salt Marsh
Scrubland
Settlement
Vegetation
Water Body
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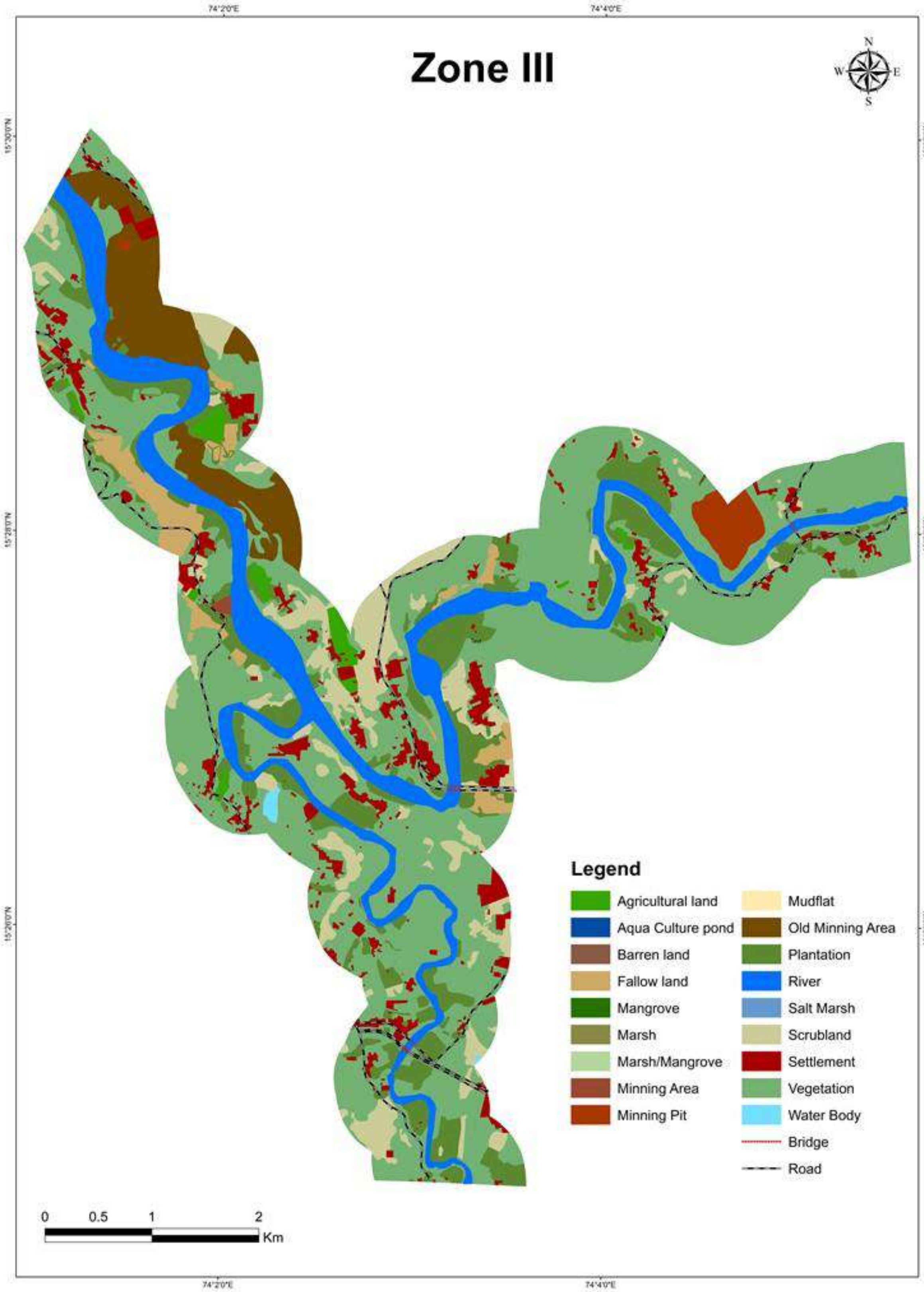


Figure 3.39: LULC Map of Mandovi Estuary (Divided in 3 zones, image used LISS-IV, December 2019)

Table 3.16. LULC Mandovi estuary			
Sr. no.	**LULC Class**	**Area (Km^2)**	**Percentage Area**
1	Agricultural land	5.35	4.7
2	Aqua Culture Pond	1.68	1.5
3	Barren land	0.04	0.0
4	Fallow land	12.32	10.9
5	Mangrove	12.98	11.5
6	Marsh	0.17	0.2
7	Marsh/Mangrove	2.76	2.4
8	Mining Area	0.09	0.1
9	Mining Pit	0.37	0.3
10	Mudflat	0.26	0.2
11	Old Mining Area	2.68	2.4
12	Plantation	4.42	3.9
13	River (Mandovi)	27.2	24.1
14	Salt Marsh	0.12	0.1
15	Scrubland	5.63	5.0
16	Settlement	8.44	7.5
17	Vegetation	28.38	25.1
18	Water Body	0.15	0.1
Total		113.04	100.0

3.15 Seaweeds & Grass (Halotolerant)

Coastal regions are among the most vulnerable to future climate change. Current climate change scenario could restructure the coastal foundation communities mainly the inter-tidal habitants i.e., seaweed (macrophytes). Macrophytes including seaweeds, seagrass and mangroves act as blue-carbon sink as they capture atmospheric CO_2, sequester and store it in live tissue or sediment for longer durations. Macrophytic blue-carbon system is considered more efficient than terrestrial systems. The 2009 UNEP blue-carbon report states that coastal macrophytes account for less than 0.5% of the seabed community structure and sequester between 114 and 328 teragrams of carbon per year, or 1.6 to 4.6% of total anthropogenic emissions (7,200T g/year). Therefore, protecting and restoring the ocean's fringing vegetation should be a high priority. Seaweeds are the primary producers of marine ecosystem and have wider utility in agrichemicals, cosmetics, biomaterials, energy molecules in addition to their conventional utilization as edible food, feed ingredients and hydrocolloids. Macroalgae are the primary producers for marine ecosystem. The carbon they produce in photosynthesis enters the different trophic levels in food chain via microbial assimilation. Many of the vertebrates and invertebrates such as herbivorous fish, crabs and sea urchins are directly dependent on macroalgae mainly for shelter. The small seagrass Halophila beccarii Aschers. is distributed along the coasts of south and south-eastern Asia. *Halophila beccarii* is monoecious and the flowers are strongly protogynous.

Halophila beccarii is most abundant in shallow, sheltered localities in estuarine and marine environments inhabiting sandy and muddy substrates. Plants exhibiting the monoecious condition, with either male and female flowers occurring in successive lateral shoots or even distantly, have a mature female flower or a fruit and a male flower in bud condition. In the estuarine environments of Cuddalore, Pichavaram and Portonovo the plants mostly occur in shallow open areas from near shore to a depth of 1.2 m. In the marine environment of Tuticorin they were found down to a depth of 1.7 m. In the Mandovi Estuary, Goa, Jagtap and Untawale (1981) reported that the biomass of *H. beccarii* varied from 2.5 to 26 g wet weight m^{-2}.

Table 3.17: List of Grass found in Mandovi Estuary

Sl. No.	**Species**
1	*Padina* sp.
2	*Cyperus* sp
3	*Halophila beccarii*

Table 3.18: List of Seaweeds found in Mandovi Estuary

Sl. No.	**Seaweeds**
	Rhodophyta
1	*Acanthophora muscoides*
2	*Amphiroa fragilissima*
3	*Catenella repens*
4	*Centroceras clavulatum*
5	*Ceramium cimbricum*
6	*Caloglossa leprieurii*
7	*Ceramium fastigiatum*
8	*Chondracanthus acicularis*
9	*Gelidium pusillum*
10	*Gracilaria corticata*

11	*Hypnea musciformi*
12	*Hypnea spinella*
13	*Hypnea valentiae*
14	*Pterocladia capillacea*
	Chlorophyta
15	*Boodlea composita*
16	*Bryopsis plumosa*
17	*Caulerpa verticillata*
18	*Chaetomorpha spiralis*
19	*Chlorodesmis hildebrandtii*
20	*Cladophora socialis*
21	*Cladophoropsis sundanensis*
22	*Rhizoclonium riparium*
23	*Ulva clathrata*
24	*Ulva compressa*
25	*Ulva fasciata*
26	*Ulva flexuosa*
27	*Ulva lactuca*
	Phaeophyta
28	*Canistrocarpus cervicornis*
29	*Chnoospora minima*
30	*Dictyota dichotoma*
31	*Dictyota pinnatifida*
32	*Padina gymnospora*
33	*Padina apavonica*
34	*Padina tetrastromatica*
35	*Sargassum cinctum*
36	*Sargassum glaucescens*
37	*Sargassum ilicifolium*
38	*Sargassum tenerrimum*
39	*Spatoglossum asperum*
40	*Sphacelaria rigidula*
41	*Vaucheria longicaulis*

Plate 3.9: Representative grasses on the upper banks of Mandovi Estuary

3.16 Sand Dune Vegetation

Sand dunes are a mount, hilly or ridge of sand formed mainly by Aeolian action that lies behind the beach affected by tides. They are formed over many years when windblown sand is trapped by beach grass or other stationary objects. Dune grasses anchor the dunes with their roots, holding them temporarily in place, while their leaves trap sand promoting dune expansion. Without vegetation, wind and waves regularly change the form and location of dunes. Sand dunes provide sand storage and supply for adjacent beaches. They also protect inland areas from storm surges, hurricanes, floodwater, and wind and wave action that can damage property.

Sand dunes arrest blowing sand, deflect wind upwards, assist in the retention of fresh water and protect the hinterland from attack by waves and storm surges and thus obstruct the ingress of saline marine water into the hinterland, and thus protecting the inland low-lying areas and terrestrial ecosystem from strong wave actions and tide surges. Dune vegetation helps in dune stability however, is vulnerable to even slightest interference due to its fragility.

Moreover, sandy stretches including dune vegetation contain many species of specific flora (and fauna).

Sand dunes, especially if covered by dune vegetation which acts as sand binders, preclude loose sand from advancing inland on the coastal zone, thus menacing coastal populations and structures.

Sand dunes support an array of organisms by providing nesting habitat for coastal bird species including migratory birds. Sand dunes are also habitat for coastal halophilic vegetation. Increased tourism foot traffic, and removal of plant species can cause destruction of dunes and erosion. Sand dunes are of various sizes, shapes and the size depend on two factors, namely, physical and biotic factor. The physical factors are the speed of wind, the prevailing wind directions, wave regime, the amount of sand available, the size of the sand, the sand supply from the beach and offshore bars whereas the biotic factor are plant succession and grazing pressure.

In the Mandovi estuary sand dunes are observed below Mandovi bridge. The dominant species of dune vegetation was *Ipomoea pes-caprae* as well as large trees like *Cocos nucifera* and *Casuarina equisitifolia* (Table 3.19).

Table 3.19: Sand dune vegetation along Mandovi estuary

Sr. No.	**Scientific name**
1	*Ipomoea Pes-caprae*
2	*Spinifex littoreus*
3	*Cyperus arenarius*
4	*Saccharum spontaneum*
5	*Sporobolus virginicus*
6	*Dactyloctenium aegyptium*
7	*Eragrostis unioloides*
8	*Clerodendrum-inerme*
9	*Pedalium murex*
10	*Physalis minima*
11	*Triumfetta rhomboidea*
12	*Vitex trifolia*

13	*Calotropis gigantea*
14	*Casuarina equisetifolia*
15	*Anacarduium oxydentrum*
16	*Cocos nucifera*

3.17 Mangrove

India has 4827 km of mangrove cover out of which only 23% is present on West Coast of India. Altogether, 69 species of mangroves belonging to 25 families and 43 genera have been reported from Indian Coast. On the West Coast, rich mangrove habitat can be observed along Gujarat Coast in Gulf of Kutch and Gulf of Khambat which is approximately 80% of total mangrove cover of West Coast and 23% that of India. Reported 370 km of mangrove cover in Gujarat which is now increased in last two decades due to declaration of Marine National Park in Gulf of Kutch in 1983. Though mangrove cover is more in Gujarat state (1058 km), species diversity is limited to nine species; on the other hand, species diversity is more in Maharashtra, Goa, Karnataka and Kerala states. Mangroves show various specialized root structures for support, oxygen supply and sediment accumulation. Some of the mangroves like *Kandelia candel* adapt buttresses root system which not only helps in balancing but also cover wide area for long distance transport of water, nutrients and metabolites. A total of ten mangrove species and eight mangrove associates have been recorded from the Mandovi estuary (Table 3.20).

From the historic images (Courtsey: Google Earth) it can be noted that mangrove vegetation has increased over the years. The mudflats and paddy fields have been established by new grown mangrove forest and many areas are in progression of converting into mangrove habitat. It can be noted that the dominance of mangroves has been a major change in land use in Mandovi estuaries' downstream stretch. There can be several reasons for this change of land use viz; non-maintenance of embankments, extreme weather events, tidal surges, flooding, sand mining and dredging activity.

Table 3.20: Mangroves and associated species found in Mandovi estuary.

Sr. No.	True mangrove species	Mangrove associate species
1	*Sonneartia alba*	*Acrostichum aureum*
2	*Acanthus ilicifolius*	*Derris heterophylla*
3	*Brugiera cylindrica*	*Derris trifoliata*
4	*Rhizophora mucronata*	*Cleredendron inerme*
5	*Avicennia marina*	*Doliochandrone spathacea*
6	*Avicennia officinalis*	*Ipomoea grandiflora*
7	*Aegicerus corniculatum*	*Operculina turpethum*
8	*Caesalpinia crista*	*Cyperus malaccensis*
9	*Volkameria inermis*	
10	*Exoecaria agallocha*	

Plate 3.10: Mangroves from Mandovi Estuary

CHAPTER- 4 MODELLING- CLIMATOLOGY & METEOROLOGY

The meteorological data is important to understand the meteorological and climatic conditions of the study area for the evaluation of impacts of the proposed project. Historical data on meteorological parameters also plays an important role in identifying the synoptic meteorological regime of the region.

Mandovi originates in the Western Ghats and flows down the entire width of the State of Goa to discharge into the Arabian Sea (Figure 4.1). The Mandovi watershed receives abundant rainfall from the southwest monsoon during the months of June to September.

Climate:

Goa has warm tropical climate with average annual temperature of 26.4 °C. December to February are coolest months. The difference between mean annual winter temperature and mean annual summer temperature is 0.4 °C. The temperature is extreme in months of April and May and lowest month of January. Due to closeness of the State to the Arabian Sea, the humidity is excessive from beginning to end of the year. The relative humidity varies from 60% to 90%.

Winds:

Winds are strong and blow from west or south-west during the monsoon season. During October-December, the winds are generally moderate and blow from directions between north-east and south-west. In the three months from January to March the winds continue to be moderate and are predominantly from directions between south-west and north-west. Sometimes associated with cyclonic storms in the Arabian Sea in the post-monsoon months and to a lesser extent in May, the region experiences strong winds, occasionally reaching gale force with widespread heavy rain.

Soil:

Soil is one of the predominant non – renewable basic natural resources of the earth. The total geographical area of the state has been digitized (NBSS soil map), and reclassified. Goa has about 25 soil classifications and it is divided two major classes based on landform viz. Konkan coast soil and Central Sahydris soils groups. Konkan consists beaches, Mudflats, swamps and marshes, salt pans, fluvio – littoral plains and islands, conical hills, flat topped hills, hillside slope, undulating lands, narrow valleys. Central Sahydris comprises high hills, low hills, interhilly basins, and narrow valleys.

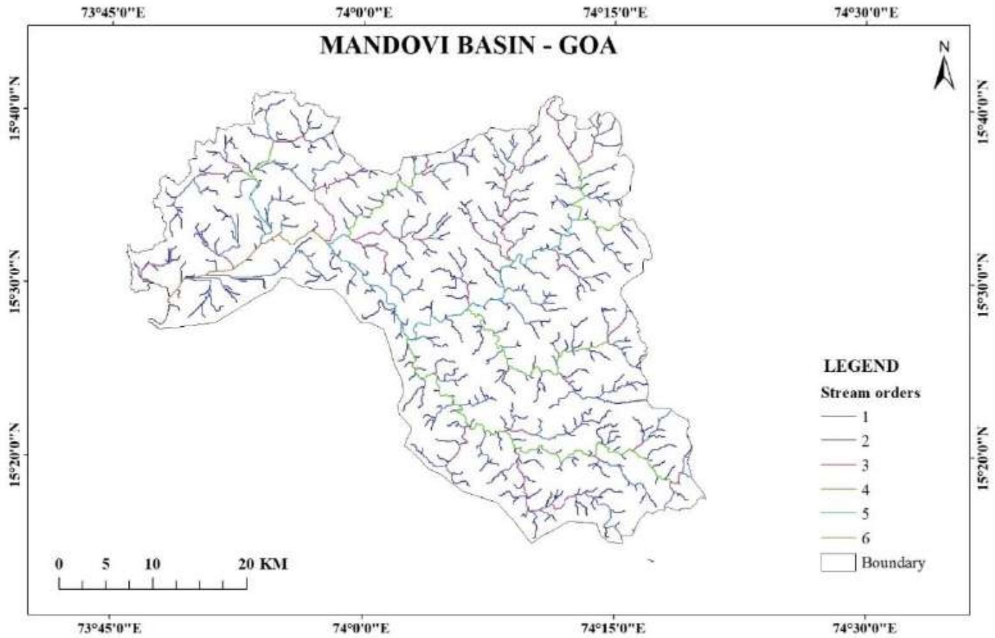


Figure 4.1: Stream orders in Mandovi basin, Goa

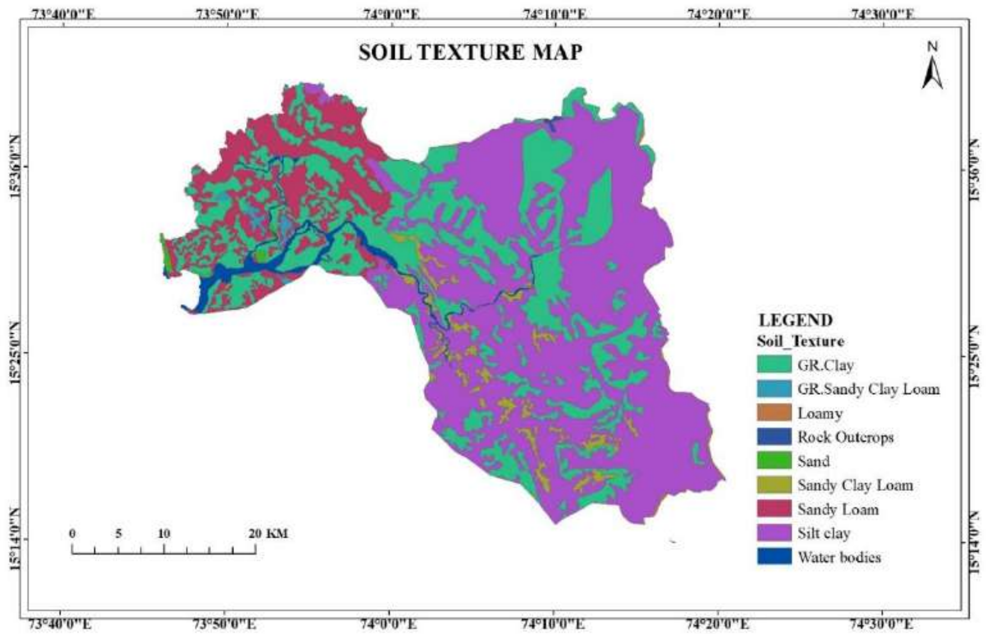


Figure 4.2: Soil texture map of Mandovi basin, Goa

Figure 4.2 shows reclassified soil texture distribution of the Mandovi basin. loamy, sand, sandy clay, sandy loam, silt clay, gravelly clay, and gravelly sandy clay distributed over the study area. The western Ghats regions occupied loamy and silt clay soils formations. Around 85% of the area is covered with silt clay and gravelly clay soils, these textures are dominant along the eastern part of the Mandovi basin. Loamy, sand, and silt clay soil types are excessively drained and very less in drainage capacity. Sandy loam soil is widely distributed in the Mapusa region, along with gravelly clay also partially distributed.

Rainfall:

Eleven rainfall Stations were chosen for the Study. Daily Rainfall data for 10 consecutive years have been collected for the years from 2010 to 2019. IMD Rainfall data has been analysed and accordingly seasonal and annual mean calculated (Figure 4.3).

The Sahydris hills plays significant role in the rainfall distribution in Goa. The State receives high rainfall during south-west monsoon period. The long term mean annual rainfall of the state is 3295.91mm, which may vary from 4195.3mm (Valpoi) to 2984mm (Panaji). Topography of the study area under direct influence of Western Ghats and about 90% of the annual rainfall receives during south–west monsoon period.

Winter Season

Winter Season starts after the north-east monsoon season i.e., in the last week of December or first week of January and continues up to the end of February. This season, study area receives very less amount of rainfall distribution. The maximum rainfall during this season had recorded at Sanguem (19.52mm) and the minimum rainfall were recorded at Panaji (0.34mm). The average rainfall of winter season is 4.03mm. South, south-east and eastern part of study area receive comparatively good amount of rainfall during winter season.

Summer season

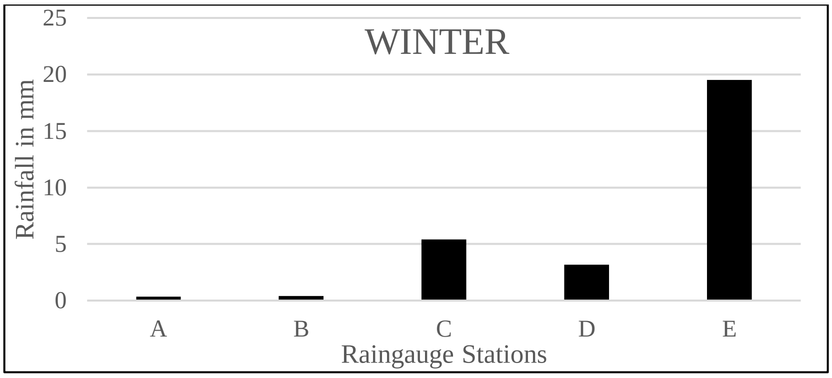
Summer Season begins March and it's continues till May, during this season study area experiences hot weather condition. The average rainfall of this season is 56.32mm. The highest rainfall recorded at Valpoi with 62.1mm and lowest rainfall recorded at Mapusa with 44.16mm.

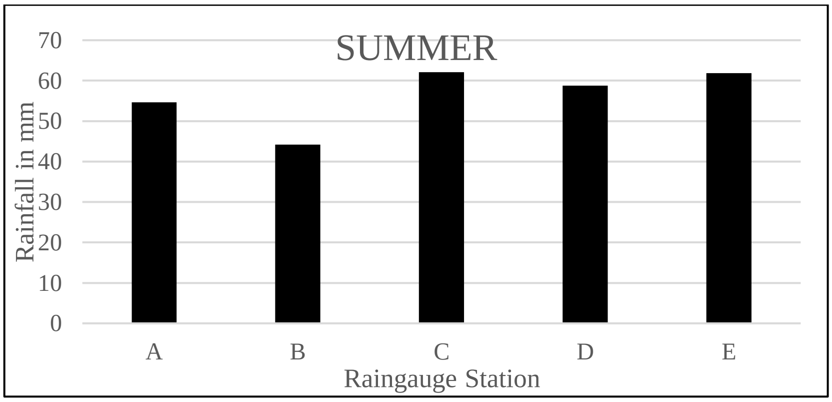
South – West Monsoon (SWM)

The State receives rainfall mainly from the June to September. Valpoi and Sanguem stations record maximum rainfall. Highest rainfall is received during the month of July followed by a gradual decrease in subsequent monsoon months. Western, central and south western portions receive very high amount of rainfall.

North – East Monsoon (NEM)

During post-monsoon the study area experiences adequate rainfall as compared to winter season and summer season. Eastern part of the study area rainfall intensity gradually increases and coastal region receives less amount of rainfall distribution. Maximum rainfall has been recorded in Valpoi which is located in the North eastern part of the study area and very low rainfall has been recorded at Panaji and Mapusa station which lies in the Eastern part of study area.





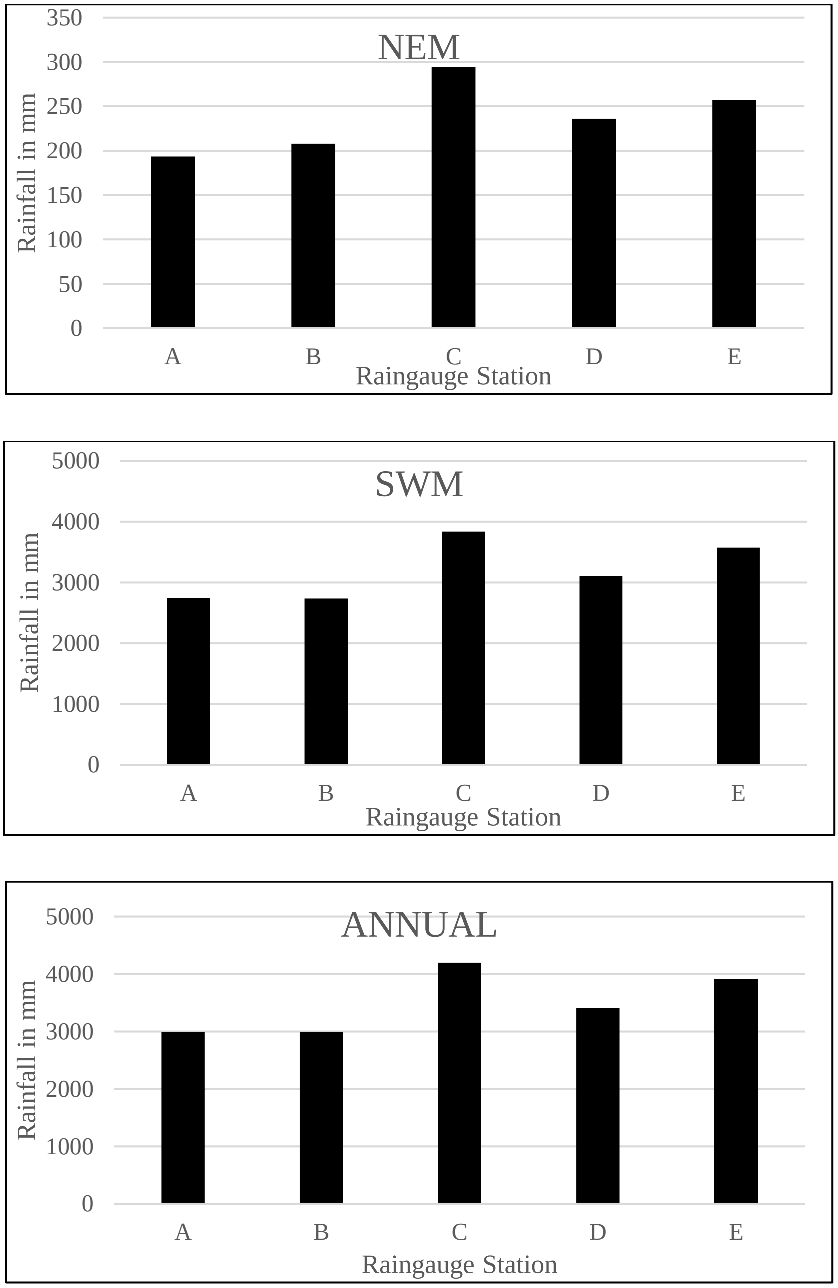


Figure 4.3: Mean rainfall distribution at Panaji (A), Mapusa (B), Valpoi (C), Ponda (D) and Sanguem (E).

Physical parameters

This chapter comprises of the physical measurements carried out at Mandovi Estuary for the validation of numerical model.

Results

The results of the current measurements carried out in the study region are presented in this section. Water level measurement results are presented and validated in the next chapter.

Currents

Current measurement was carried out at locations MC1 and MC2 in Mandovi Estuary during August-September 2020, November-December, 2020 and March-April 2021. The current meter was placed at mid-water depth. The measured current speed and direction during monsoon are shown in Figure 4.4. The current is mainly towards north-west (NW) with maximum current speed 1.41 m/s and average current speed 0.54 m/s during measuring period at MC1. In Figures 4.5 and 4.6, the measured current speed and direction are presented for MC2 during post and pre-monsoon respectively. From the Figures, it is observed that the maximum current speeds were 0.77 m/s and 0.87 m/s and the average current speeds were 0.33 m/s and 0.35 m/s at MC2 during post and pre-monsoon measuring period respectively. The current is mainly towards south-west (SW) and north-east (NE) at MC2.

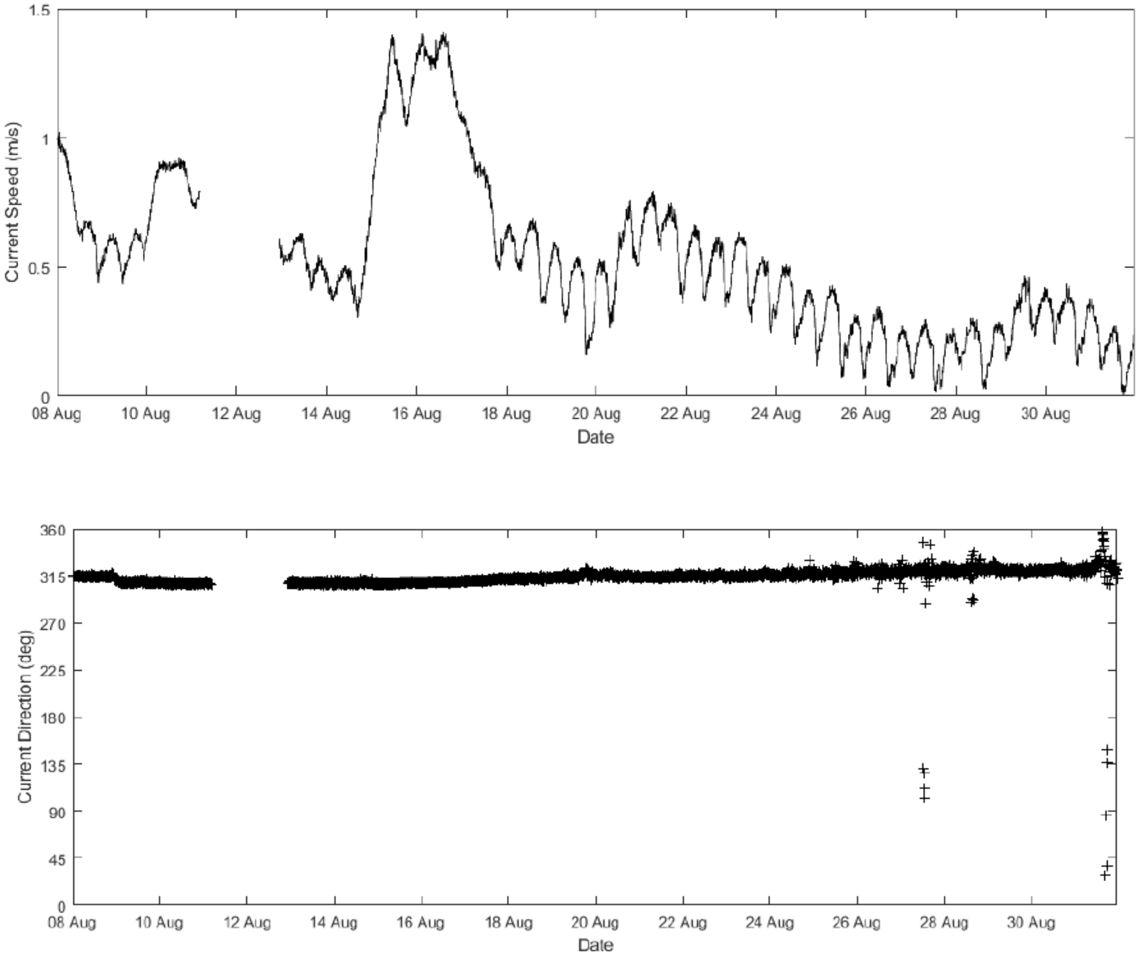
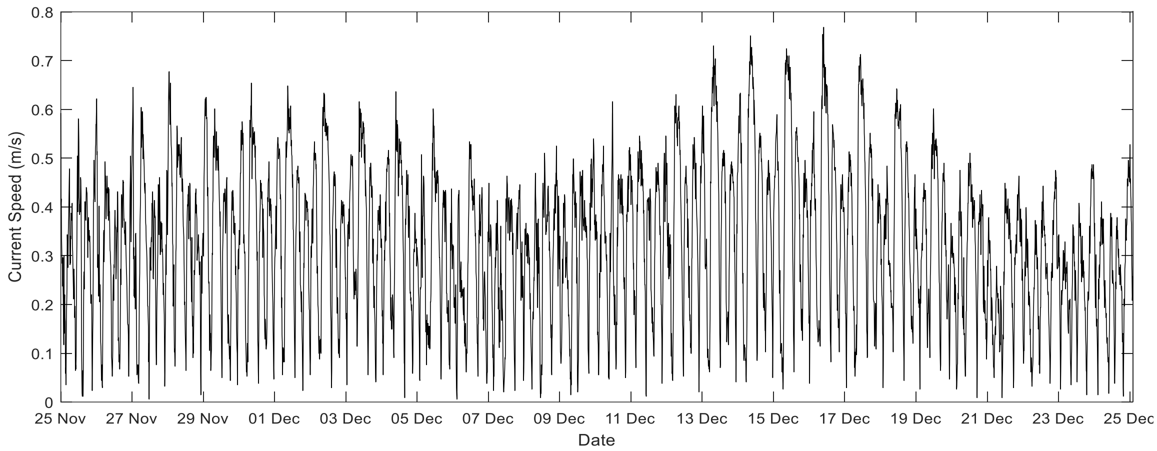


Figure 4.4: Variation of measured current speed and directions at MC1 in monsoon, 2020.

Table 4.1: Maximum and average value of Current speed (m/s) in Mandovi

Current Parameter	Location	Maximum Speed (m/s)	Average speed (m/s)
Current Speed (m/s) (monsoon)	MC1	1.41	0.54
Current Speed (m/s) (post-monsoon)	MC2	0.77	0.33
Current Speed (m/s) (pre-monsoon)	MC2	0.87	0.35



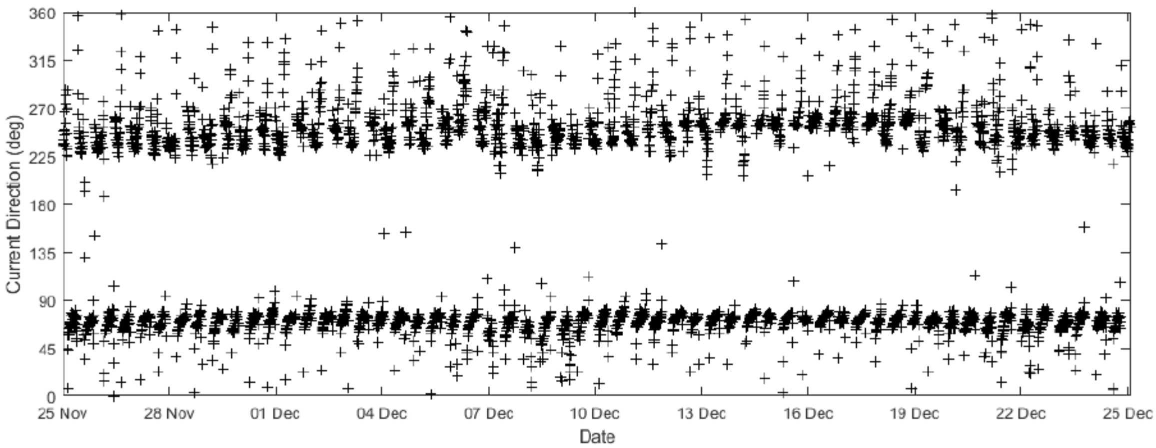


Figure 4.5: Variation of measured current speed and directions at MC2 in post-monsoon 2020.

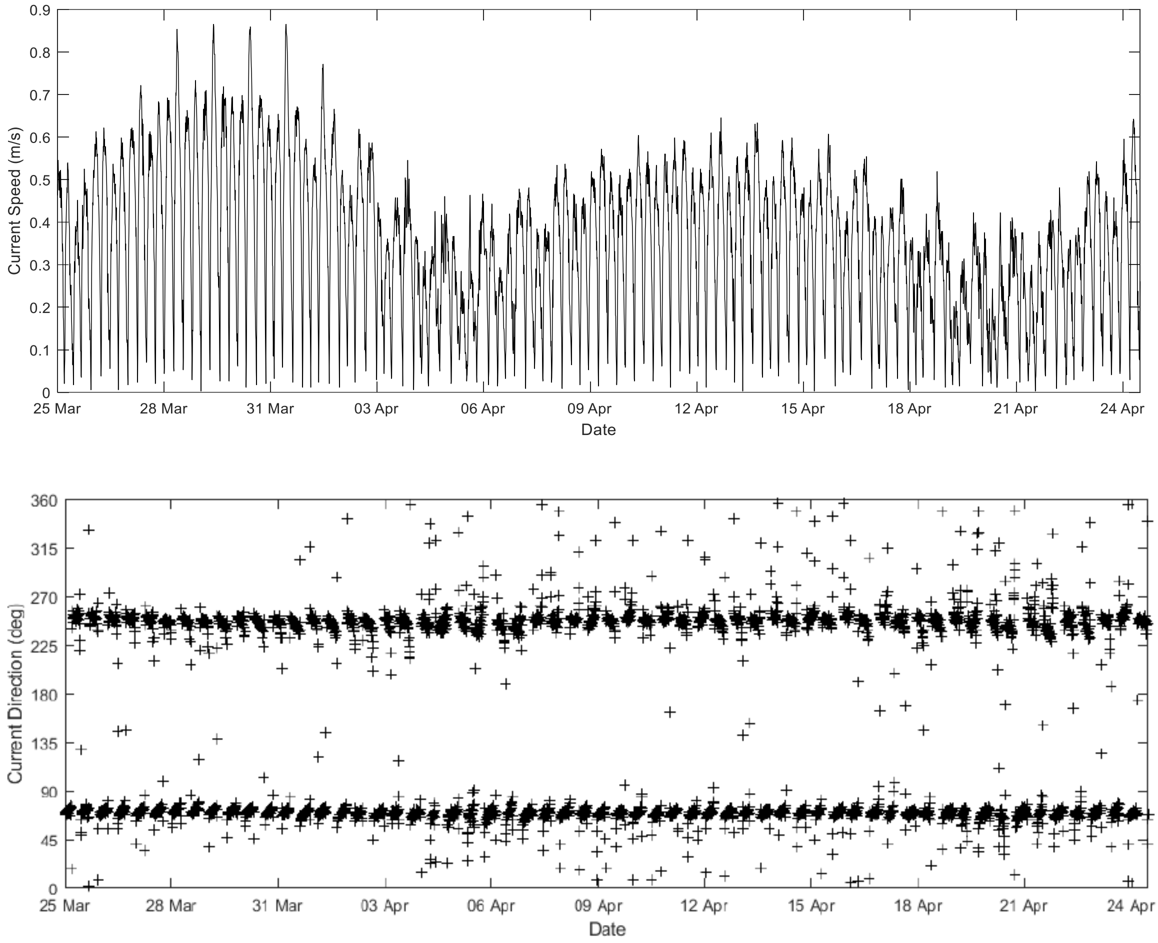


Figure 4.6: Variation of measured current speed and directions at MC22 in pre-monsoon 2021.

CHAPTER 5: NUMERICAL MODELLING STUDIES

Introduction

In order to simulate the coupled hydrodynamics and morphology in the study region, a state-of-the-art numerical modelling software suite (MIKE by DHI) is used. The flow model FM comprising of flow model, and sediment transport model is used to study the hydrodynamics and morphology impact in the region due to different mining pit scenario. All these models take feedback from each other as well as provide inputs to each other. The sediment transport models also utilise the flow parameters from the hydrodynamics model. In this manner, the coupled model provides output of modified flow, and changes in the bed morphology in the study region.

Coupled model

The MIKE 21 flow model FM is used in this study which dynamically couples the flow and sediment transport calculations. Full feedback of bed level changes on flow calculations is included in this formulation. The flow model FM is mostly used for investigating the morphological evolution of the near shore bathymetry due to the impact of engineering works (coastal structures, mining, dredging works etc.) and also to study the morphological evolution of tidal inlets and rivers. It is most suitable for medium-term morphological investigations (several weeks to months) over a limited study area. The computational effort can become quite large for long-term simulations, or for larger areas. The different models used in the flow model FM are briefly described below.

Hydrodynamic model

The Hydrodynamic Module is the basic computational component of the entire MIKE21 Flow Model FM modelling system. The MIKE 21 Flow Model FM is a modelling system based on a flexible mesh approach providing the hydrodynamic basis for the Sediment transport Module.

The modelling system is based on the numerical solution of the two-dimensional shallow water equations i.e., depth-integrated incompressible Reynolds Averaged Navier-Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity and density equations. In the horizontal domain both Cartesian and spherical coordinates can be used. The spatial discretization of the basic equations is performed using a cell-centred finite volume method wherein the spatial domain is discretized by subdivision of the continuum into non-overlapping element/cells. An unstructured grid comprising of triangles or quadrilateral element is used in the horizontal plane. An approximate Riemann solver is used for computation of the convective fluxes, which makes it possible for MIKE21 FM model to handle discontinuous solutions. For the time integration an explicit scheme is used. Coriolis term, eddy viscosity using Smagoransky formulation and bed friction are included in the model. For more details of the MIKE 21 FM module and its validation, the scientific manual can be referred.

The model domain used in this study is shown in Figure 5.1. This model domain was further used for all simulations. In this study, a sand mining case scenario is studied by modifying existing bathymetry at different sections (A-I) (see Figure 5.2) along Mandovi estuary. The model domain for post sand mining case is shown in Figure 5.3.

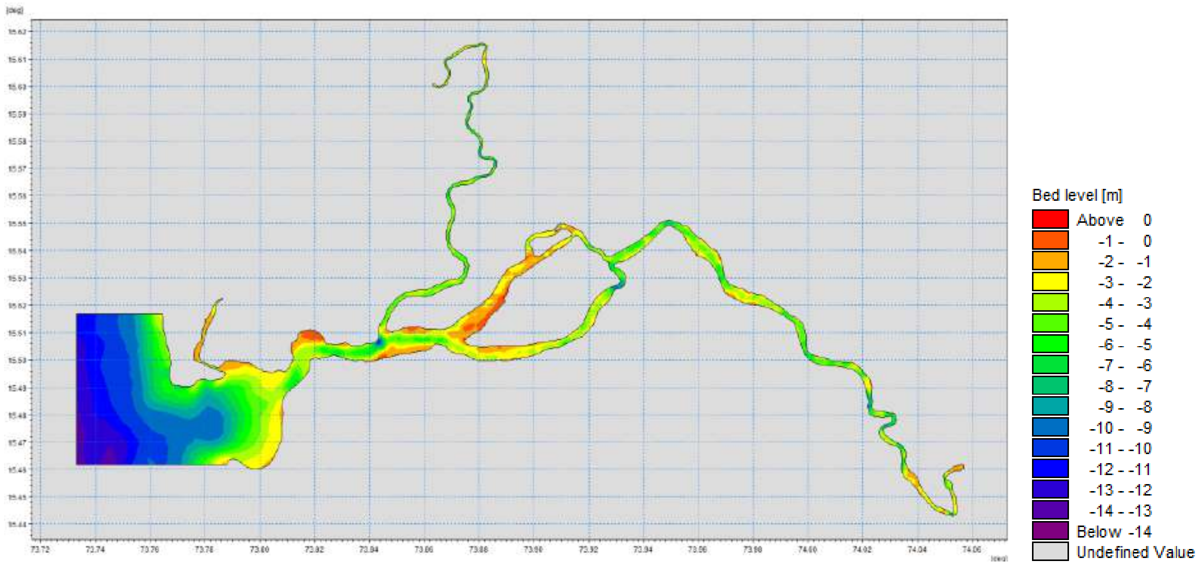


Figure 5.1: Model domain for original bathymetry of the Mandovi estuary

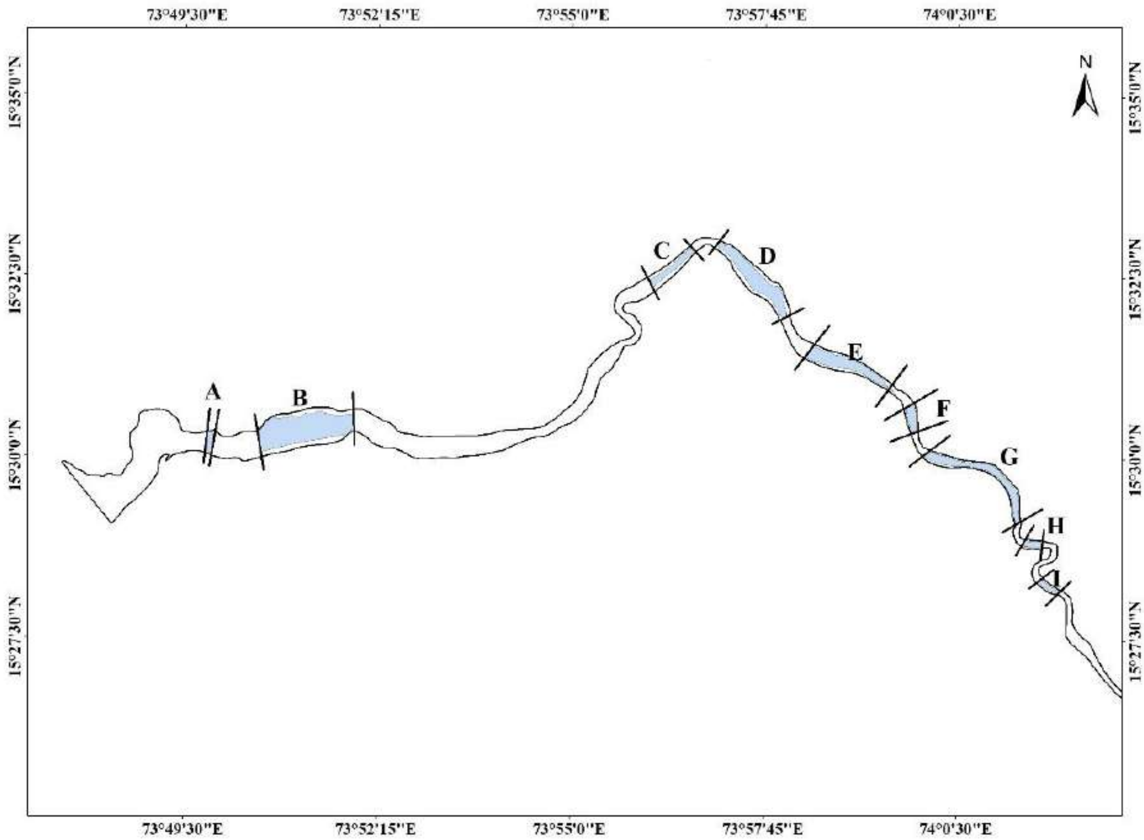


Figure 5.2: Figure showing nine different sections (A-I) in the model domain.

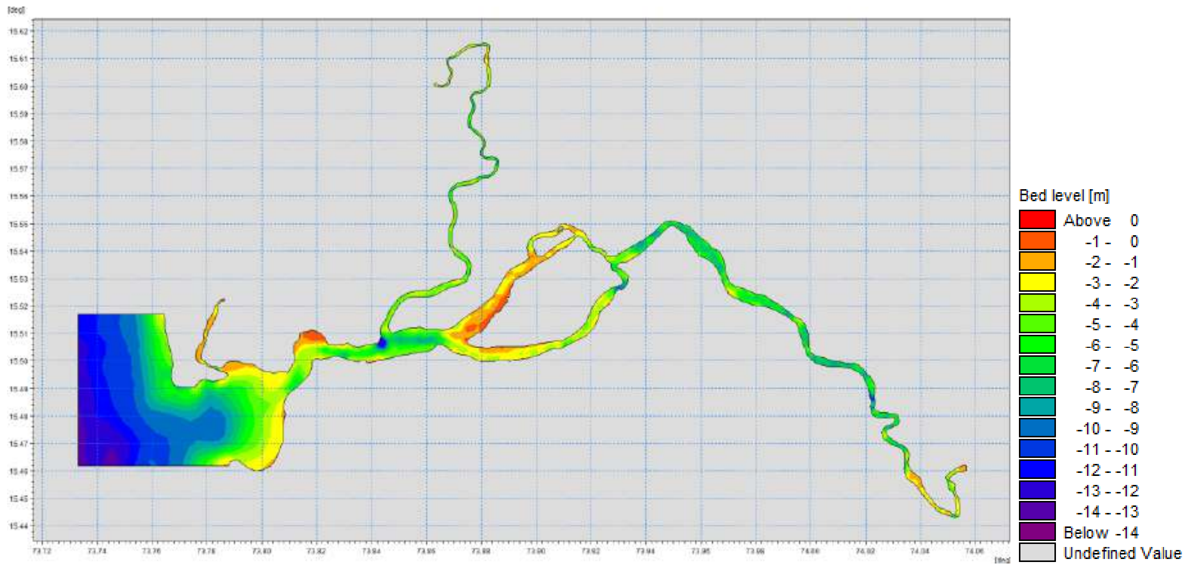
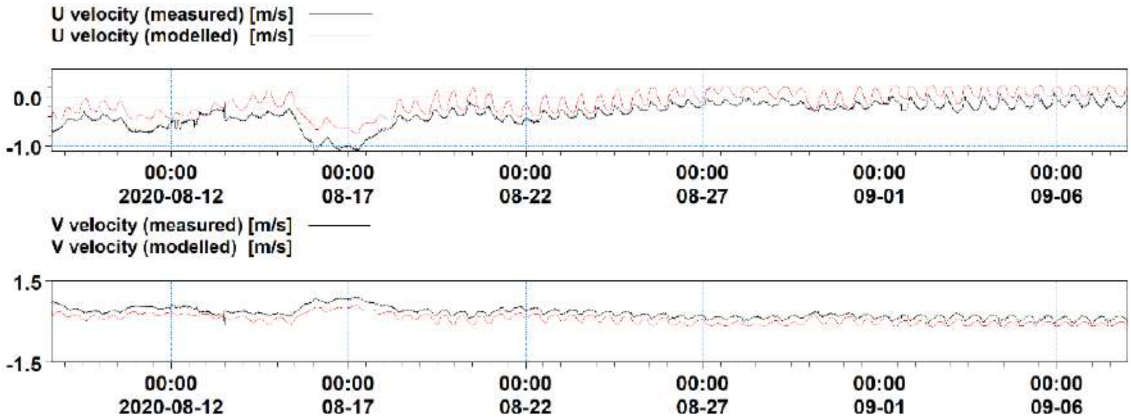
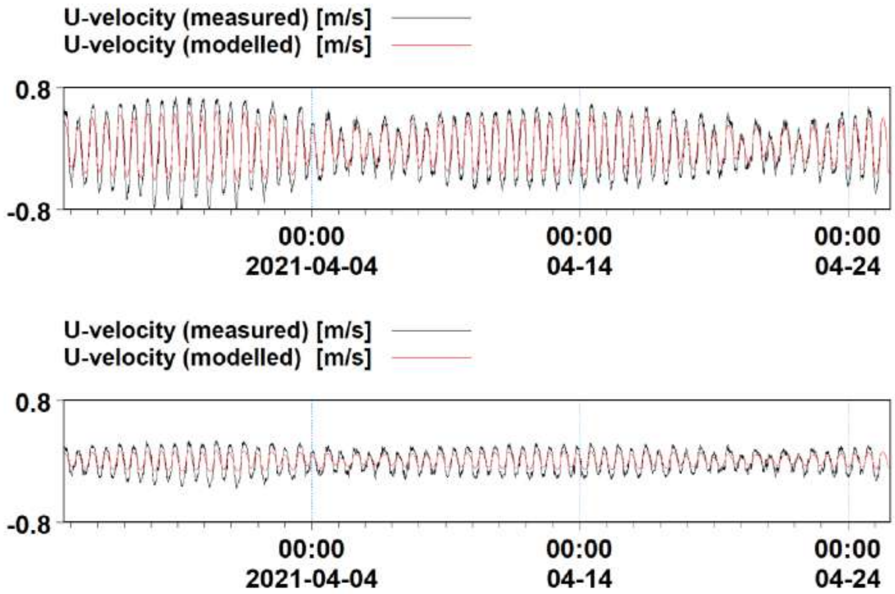


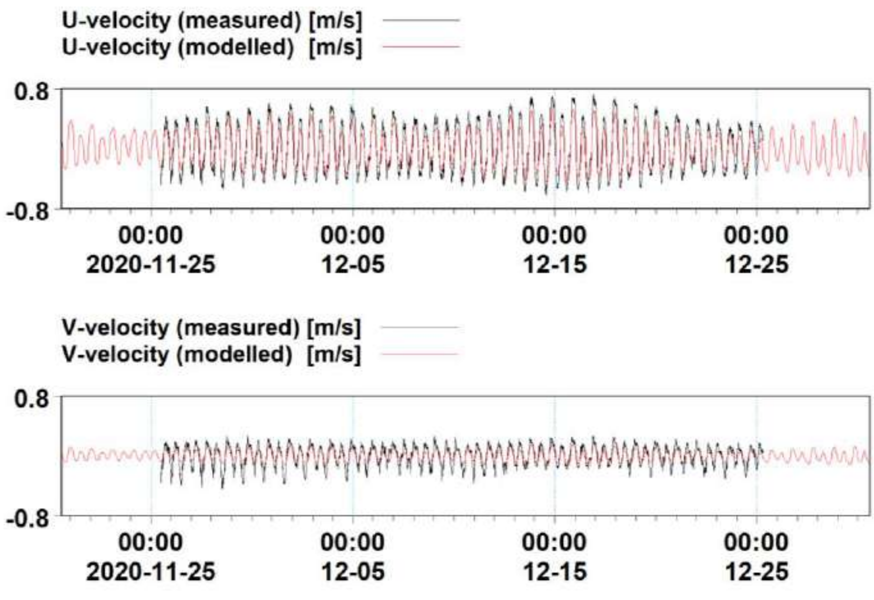
Figure 5.3: Model domain for modified bathymetry increasing depth by 3 m at different sections (A-I)


U velocity (measured) [m/s]
U velocity (modelled) [m/s]
0.0
-1.0
00:00
2020-08-12
00:00
08-17
00:00
08-22
00:00
08-27
00:00
09-01
00:00
09-06
V velocity (measured) [m/s]
V velocity (modelled) [m/s]
1.5
-1.5
00:00
2020-08-12
00:00
08-17
00:00
08-22
00:00
08-27
00:00
09-01
00:00
09-06

(a)


U-velocity (measured) [m/s]
U-velocity (modelled) [m/s]
0.8
-0.8
00:00
2021-04-04
00:00
04-14
00:00
04-24
U-velocity (measured) [m/s]
U-velocity (modelled) [m/s]
0.8
-0.8
00:00
2021-04-04
00:00
04-14
00:00
04-24

(b)


U-velocity (measured) [m/s]
U-velocity (modelled) [m/s]
0.8
-0.8
00:00
2020-11-25
00:00
12-05
00:00
12-15
00:00
12-25
V-velocity (measured) [m/s]
V-velocity (modelled) [m/s]
0.8
-0.8
00:00
2020-11-25
00:00
12-05
00:00
12-15
00:00
12-25

(c)

Figure 5.4. Comparison between measured and modelled U&V component of current during (a) monsoon at MC1, (b) Pre-monsoon at MC2 and (c) Post-monsoon at MC2.

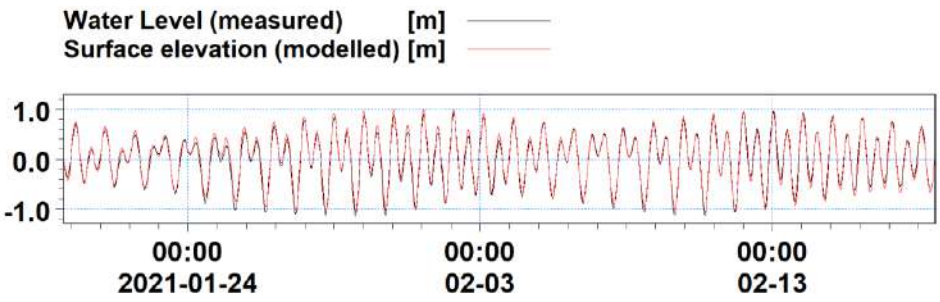
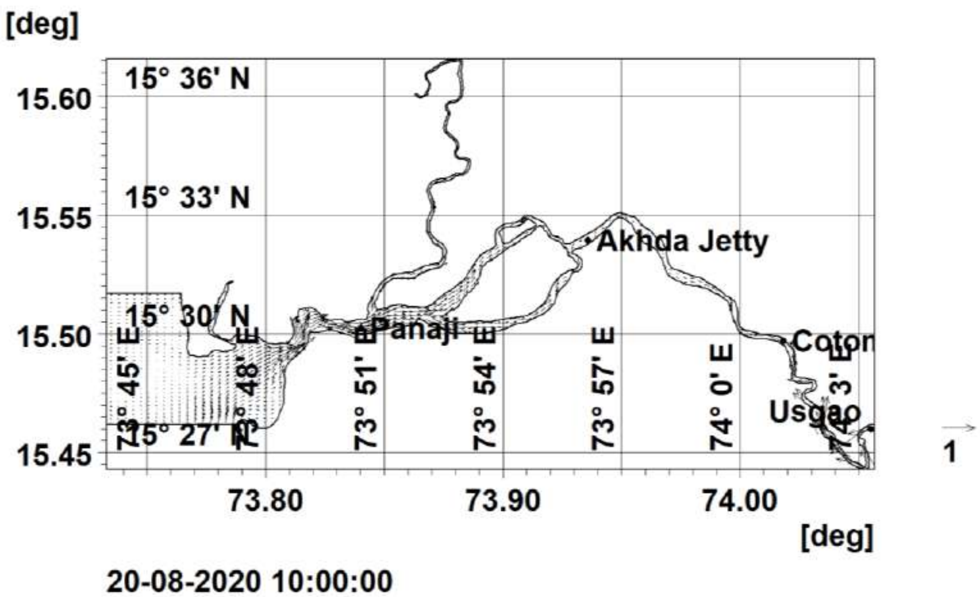


Figure 5.5. Comparison between measured and modelled surface elevation at ML1.

A comparison between the model derived and measured surface elevations (at ML1), currents (at MC1 & MC2) have been carried out in Figure 5.4 and 5.5. In Figure 5.5, 0 line is considered as Mean Sea Level (MSL). It is observed that the surface elevations and currents are well predicted by the model.

Sediment transport model

The sediment transport module calculates the resulting transport of non-cohesive materials based on the flow conditions found in the hydrodynamic calculations. The model output consists of bed level changes, amongst other parameters. In this study, the current formulation of sediment transport is considered with the flow model providing the currents.



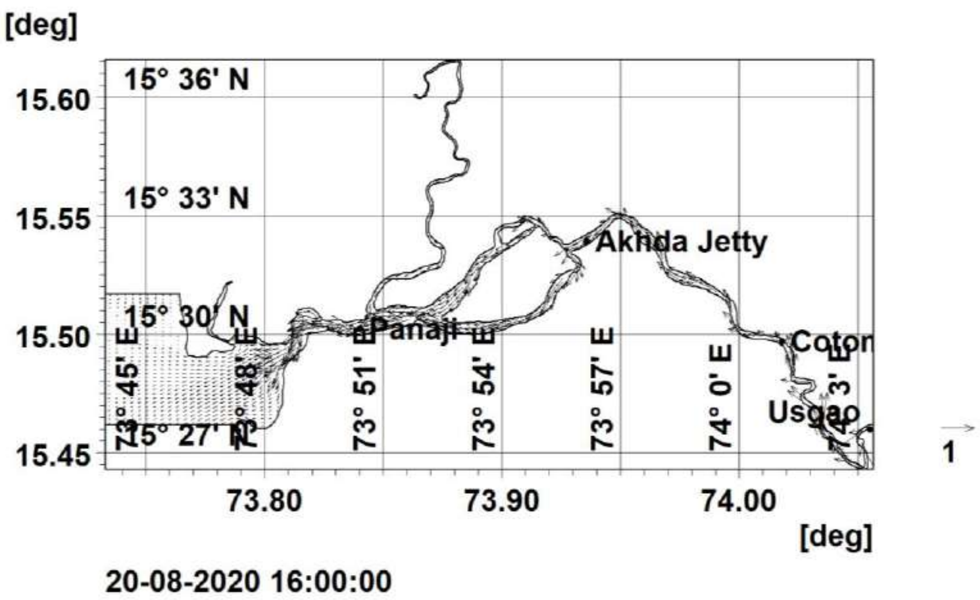


Figure 5.6: Typical flood and ebb current.

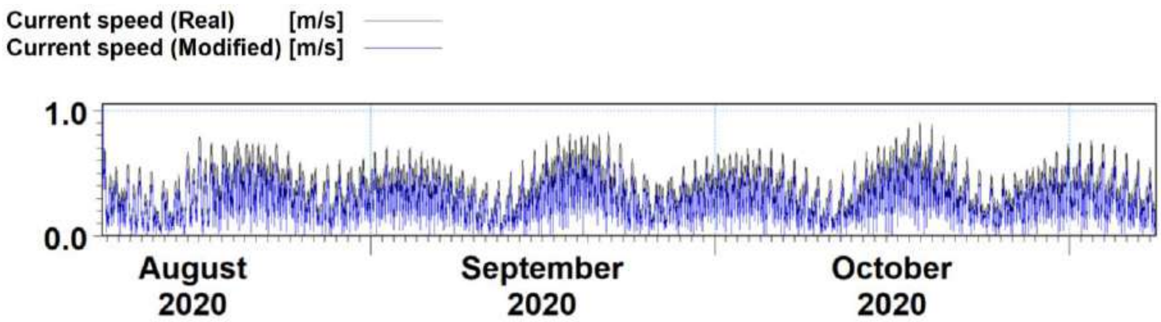
Results

The numerical model study results are presented in the following sections. The flow patterns in the study region for the Case 1 and Case 2 are presented in the hydrodynamic model results. The comparisons of the current speed during both monsoon and non-monsoon period, 2020-21 between Case 1 and Case 2 at each section A-I are presented. The comparisons of the bed level changes between Case 1 and Case 2, are also presented in the morphology model results.

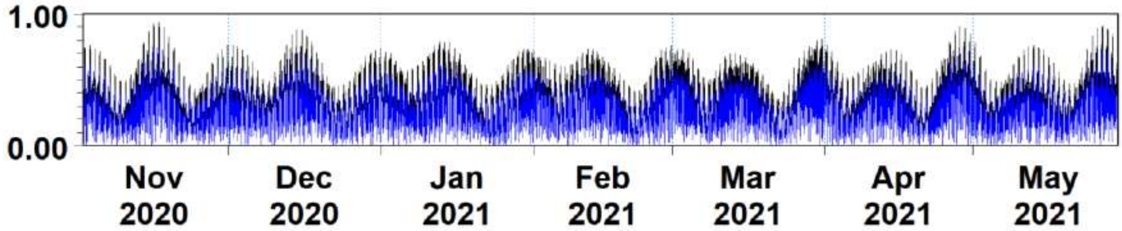
Hydrodynamics modelling

Hydrodynamic model validation is carried out with the measured currents and water levels in the study region. The comparison of water levels, u-component and v-component of currents are presented in Figure 5.4-5.5. The model simulated water levels, and the current flow components well for both the east-west and north-south components. The typical flood and ebb currents are shown in Figure 5.6.

A comparison of current speeds between the Case-1 and Case-2 is carried out. A total of 9 points covering the nine sections A to I as in Figure 5.2 are considered for comparing the currents. The comparison figures are presented in Figure 5.7-5.15. Higher current speeds are observed for Case-1, than the Case-2 at the different sections A-I. The reduction in current speeds at these sections is mainly due to the change in the water depths.

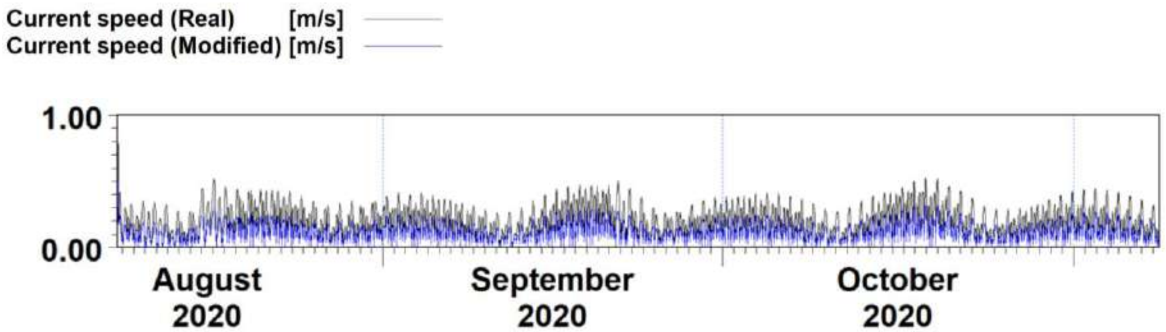


(a)

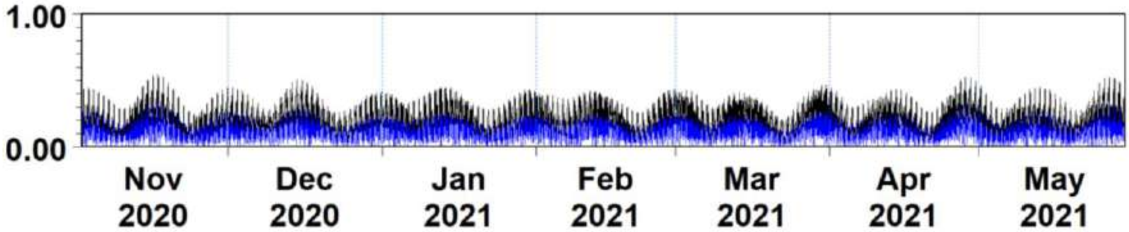


(b)

Figure 5.7: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section A for case 1 (real) and case 2 (modified)

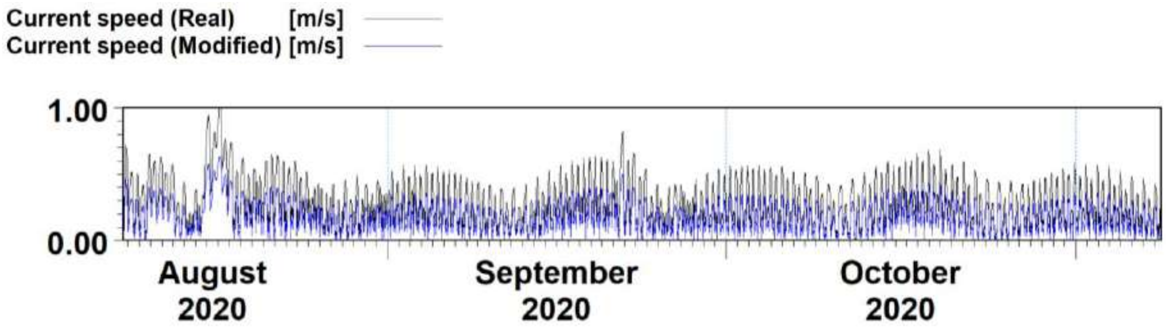


(a)

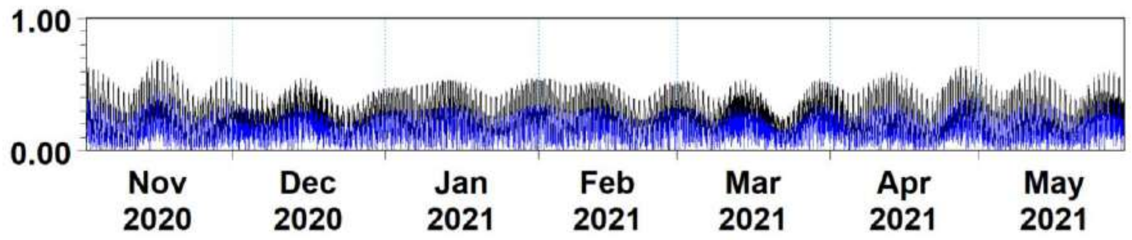


(b)

Figure 5.8: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section B for case 1 (real) and case 2 (modified)

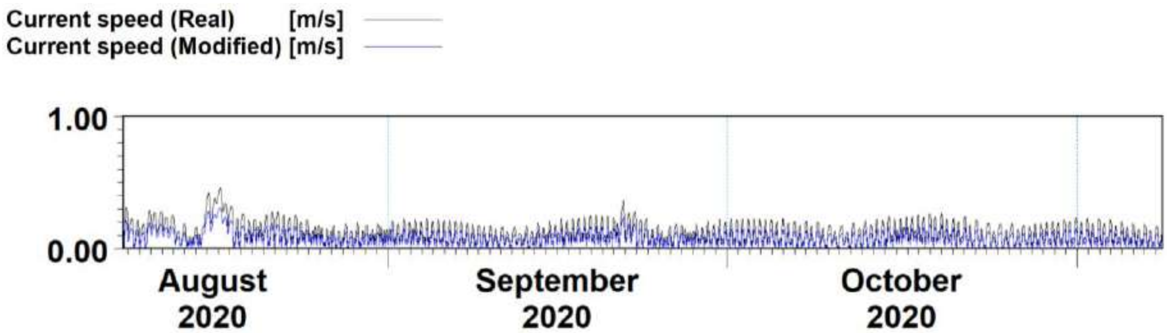


(a)

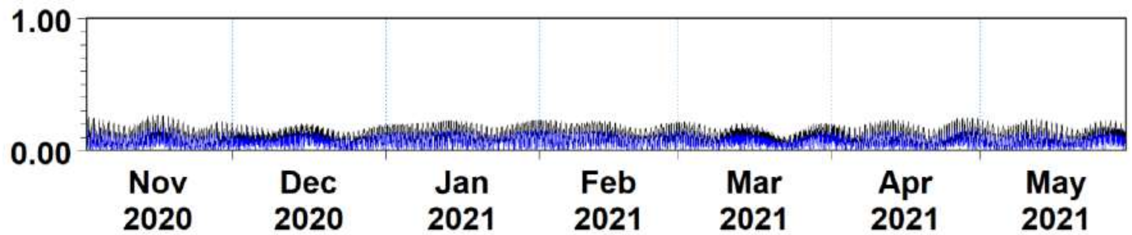


(b)

Figure 5.9: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section C for case 1 (real) and case 2 (modified)

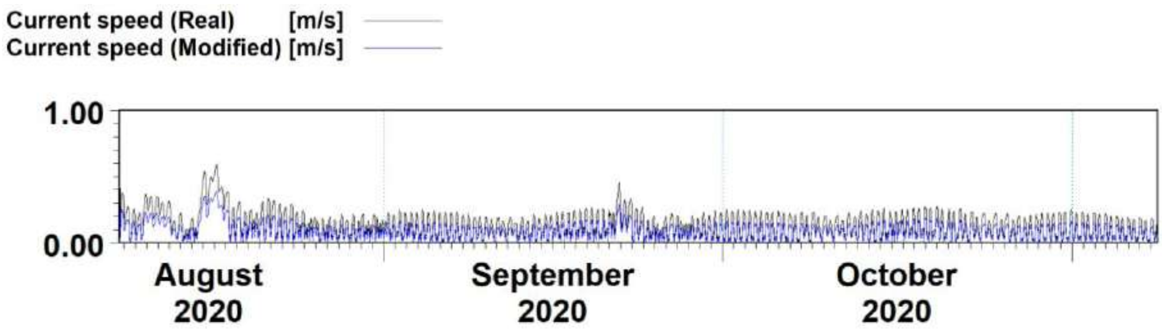


(a)

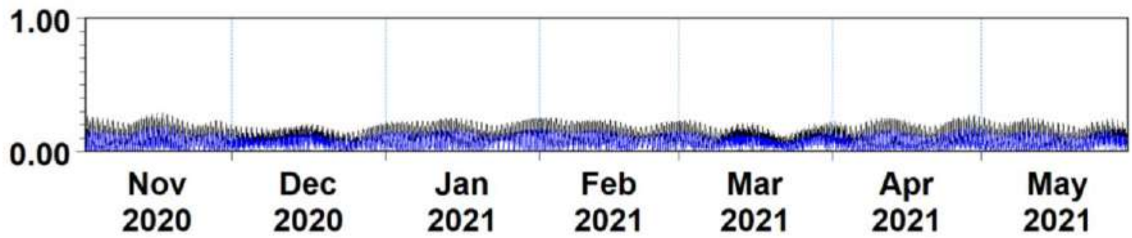


(b)

Figure 5.10: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section D for case 1 (real) and case 2 (modified)

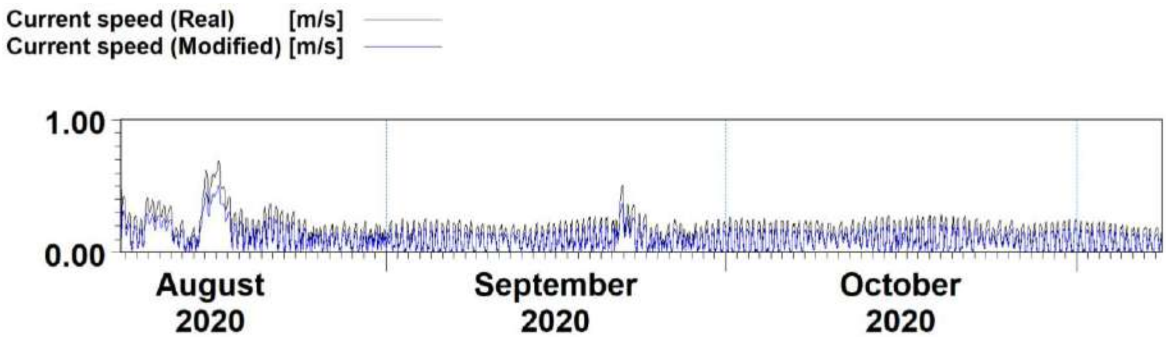


(a)

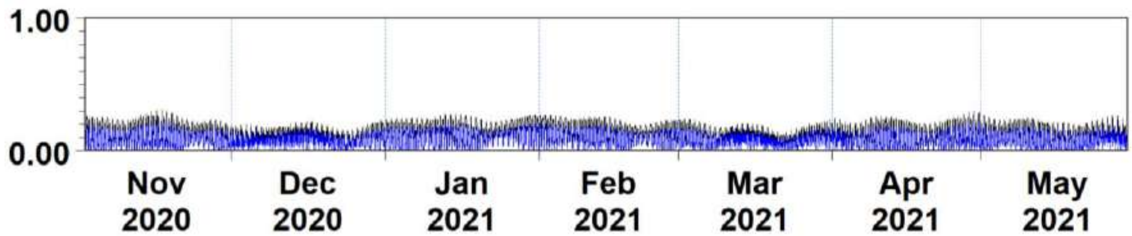


(b)

Figure 5.11: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section E for case 1 (real) and case 2 (modified)

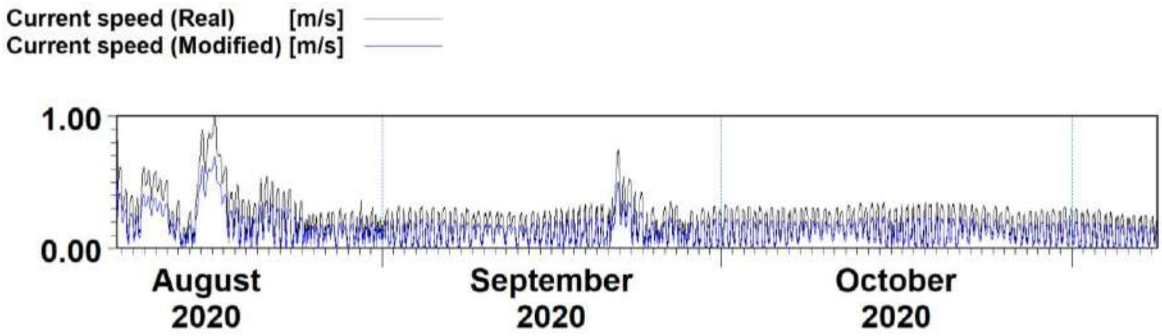


(a)

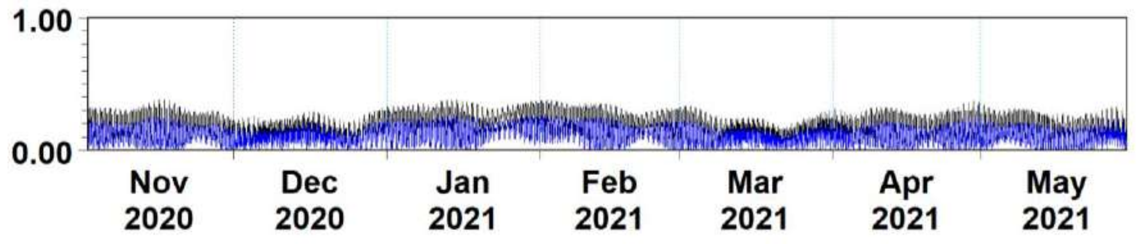


(b)

Figure 5.12: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section F for case 1 (real) and case 2 (modified)

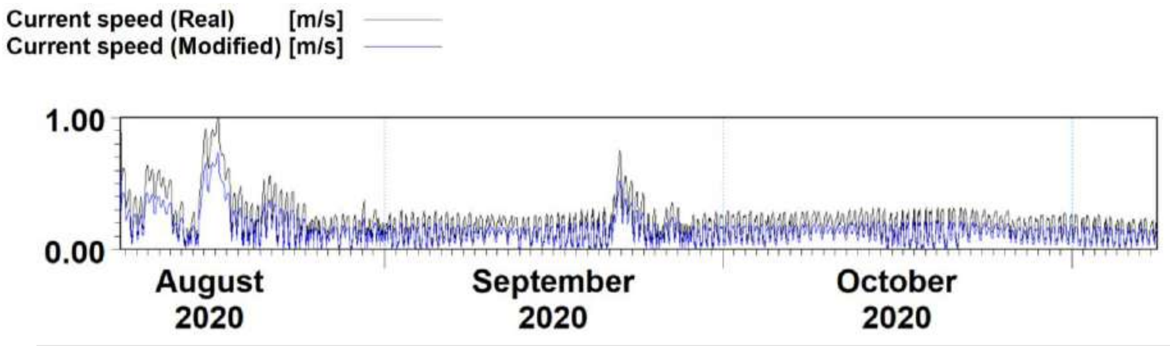


(a)

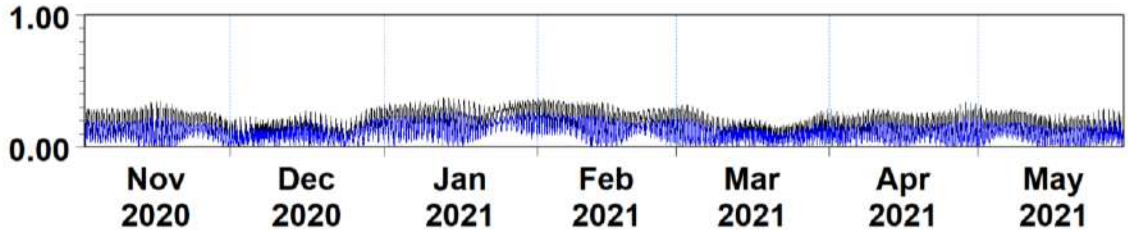


(b)

Figure 5.13: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section G for case 1 (real) and case 2 (modified)

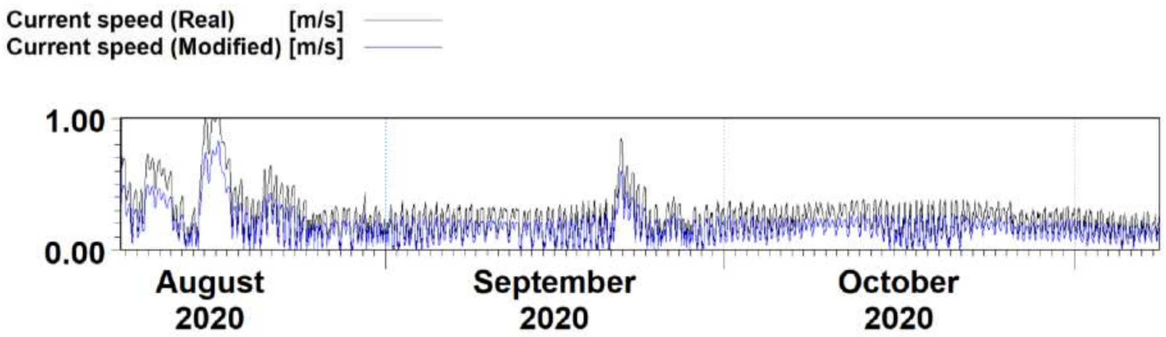


(a)

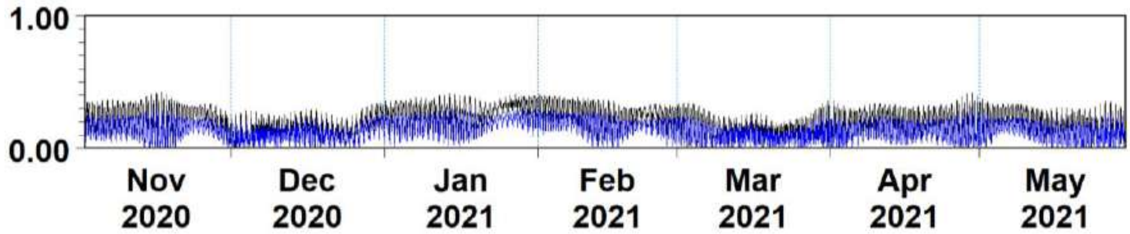


(b)

Figure 5.14: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section H for case 1 (real) and case 2 (modified)



(a)



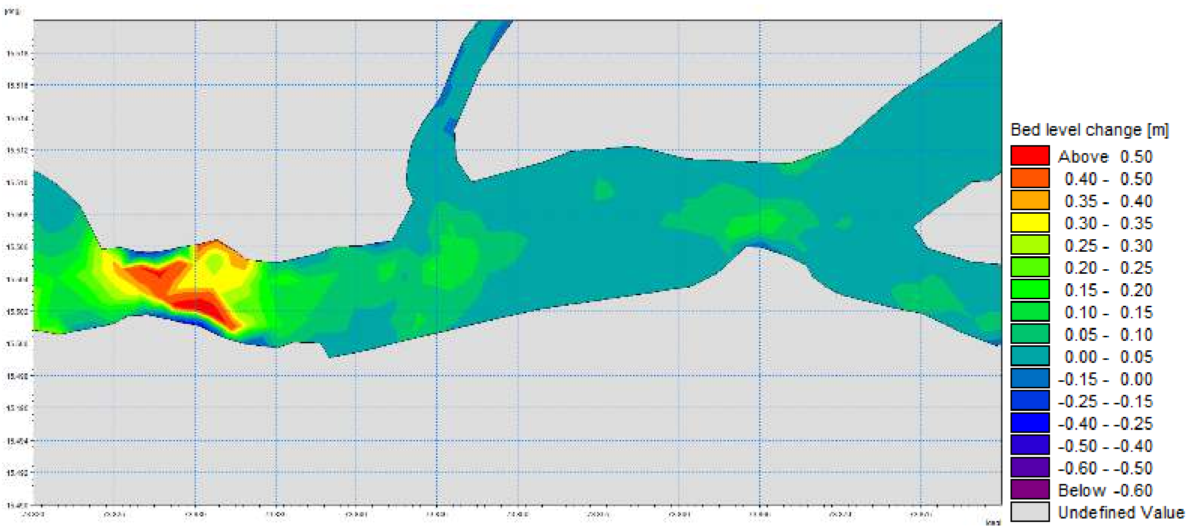
(b)

Figure 5.15: Comparison of U, V and current speed during (a) monsoon and (b) non-monsoon at section I for case 1 (real) and case 2 (modified)

Bed level changes

The change in the bed level from the sediment transport model simulations provides accretion/erosion in the study region for the simulation period. This study is carried out assuming that the mined channel is stable and the flow dynamics are stabilized. For the sake of clarity, the sections A-B and C-I are divided and the comparisons of bed level changes between the between the Case-1 and Case-2 models are shown. The changes in bed morphology at different sections of the river are highly dynamic and patchy in nature. In

Figure 5.16, It is observed that high sediment deposition occurs at around section A of Mandovi estuary. During non-monsoon period, the sediment deposition around section A is more than the monsoon period. In Figure 5.17, it is observed that for Case-2, erosion occurs at section B. In Figures 5.18-5.19, the upstream of Mandovi receives higher sediment deposition at monsoon than non-monsoon. During monsoon, at and around sections G, H and I, more sediment deposition is observed in Case 1 than Case 2 while intense erosion is observed at sections D and E for Case 2. During non-monsoon period, there is not much difference between Case 1 and Case 2 at sections D and E. It is important to note that localized bed level changes may happen due to abrupt change in the bed morphology.



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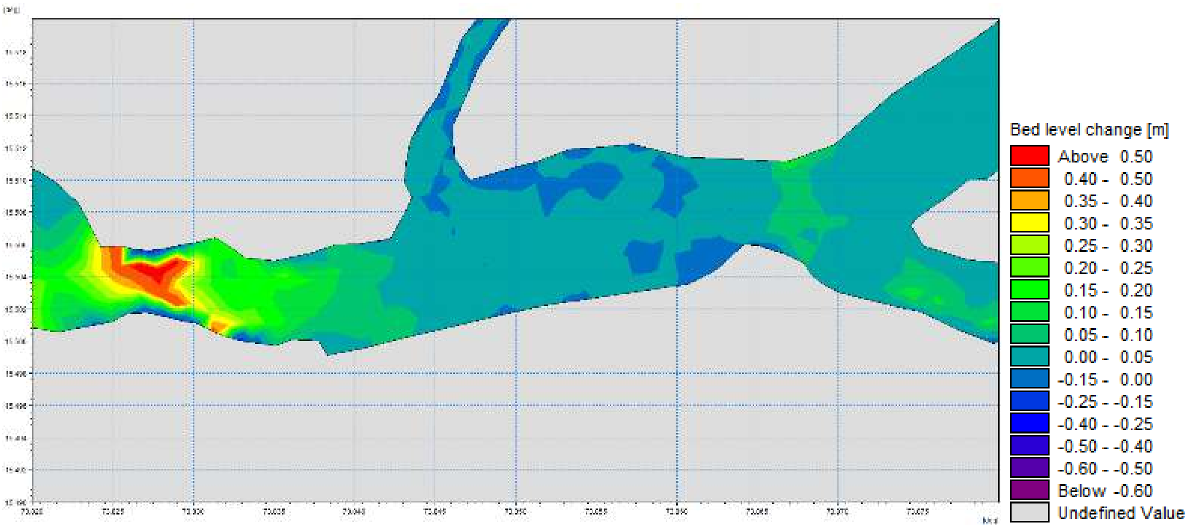
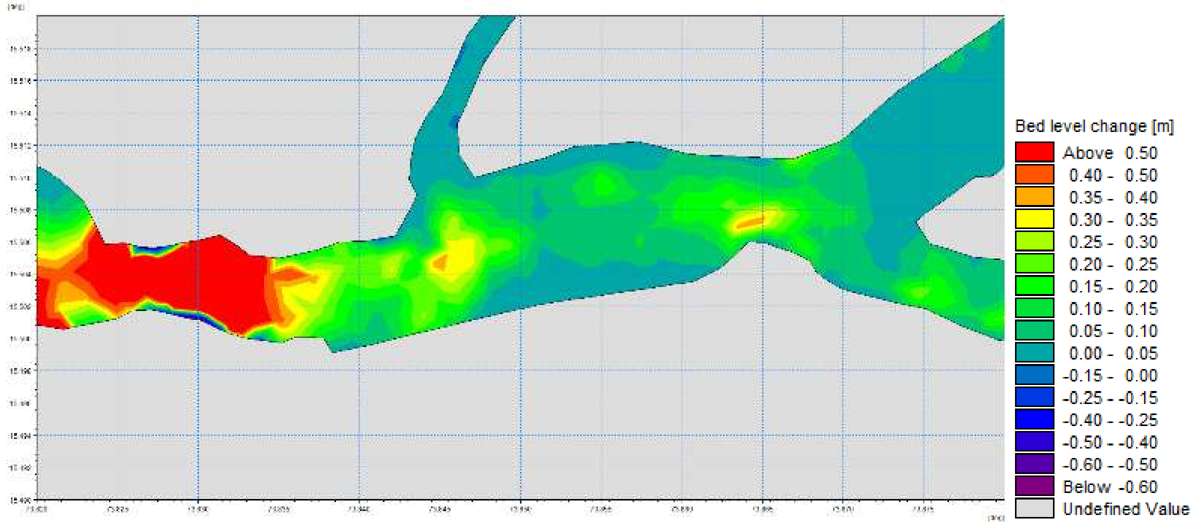


(b)

Figure 5.16: Bed level change at sections A and B with (a) Case 1, (b) Case 2 during Monsoon.



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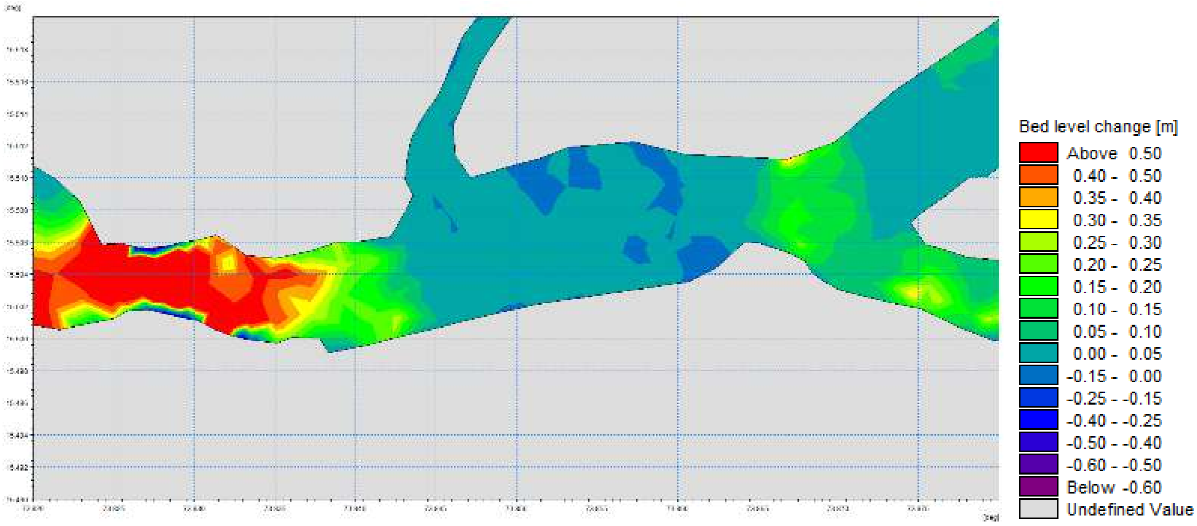

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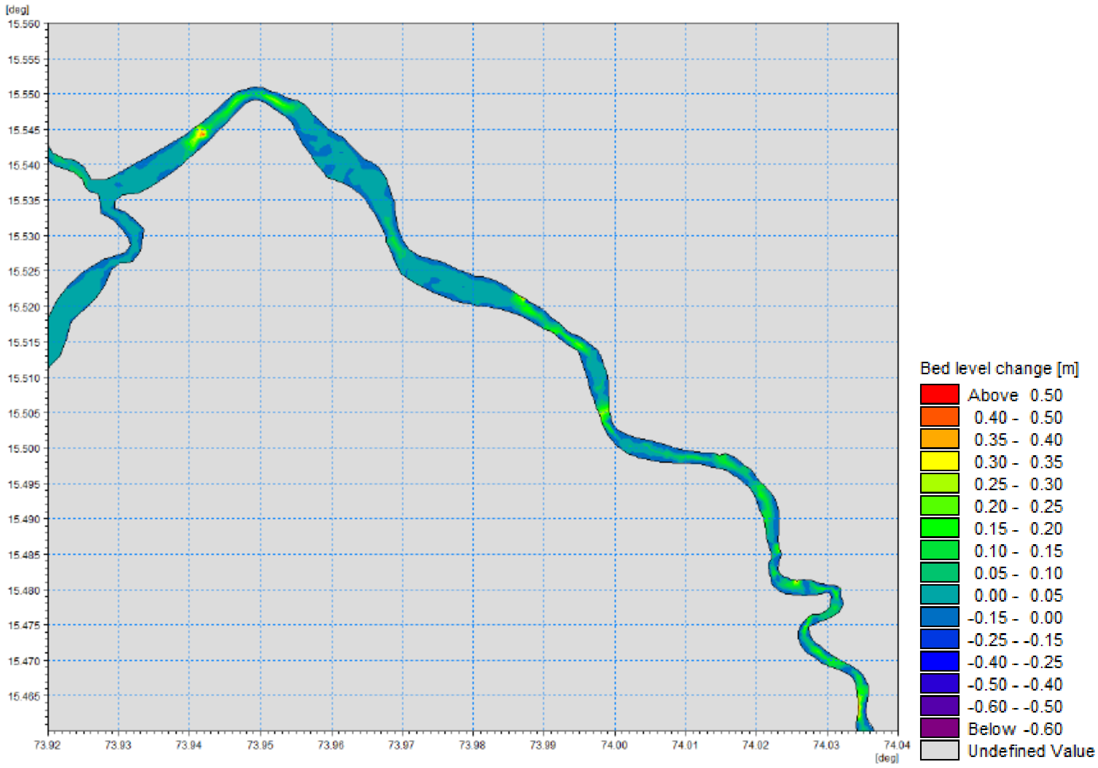
Figure 5.17: Bed level change at sections A and B with (a) Case 1, (b) Case 2 during Non-Monsoon.



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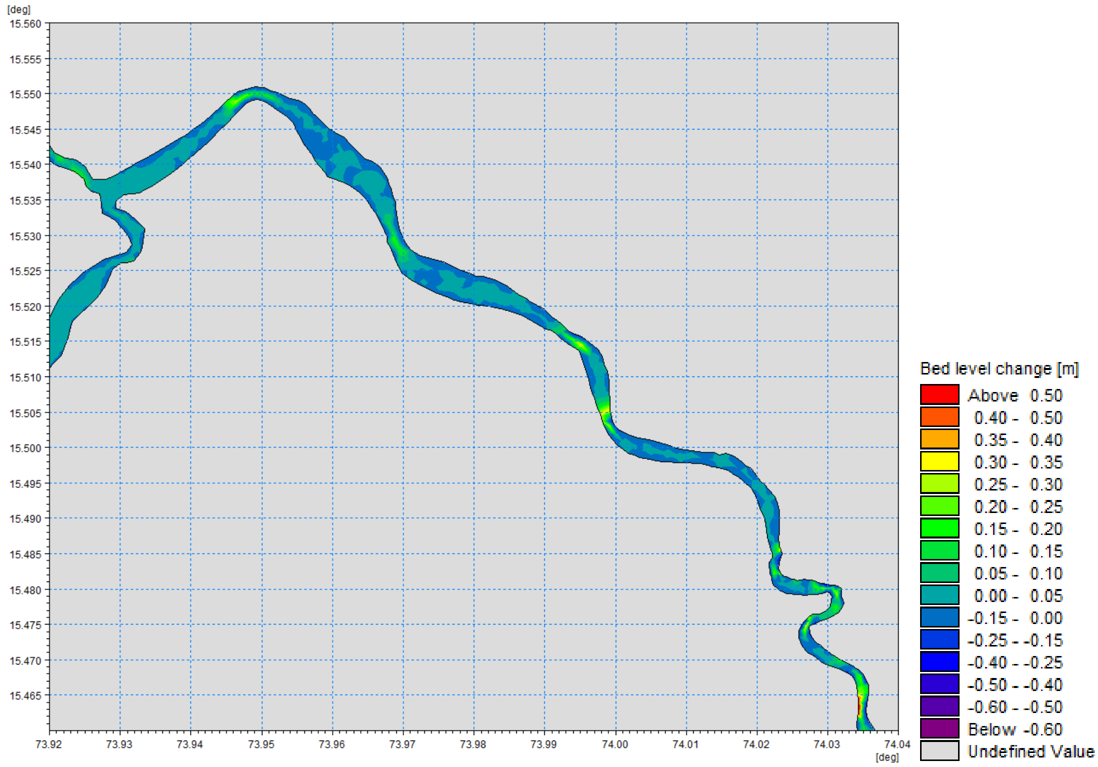

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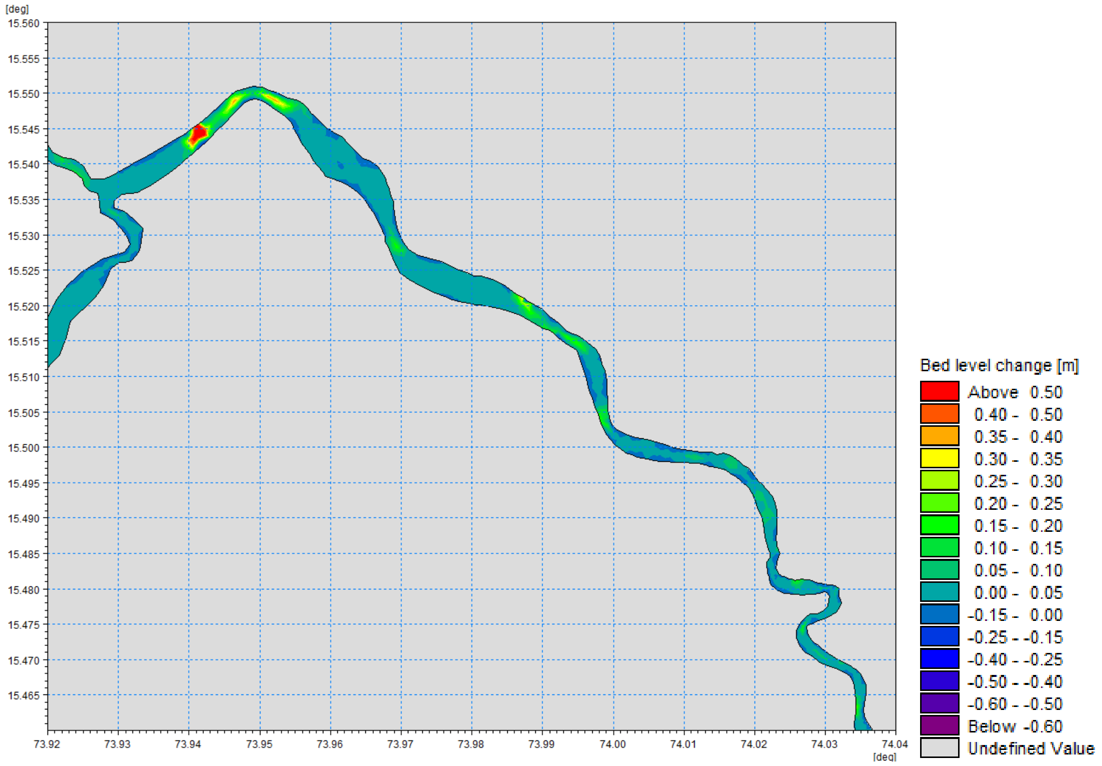
Figure 5.18: Bed level change at sections C, D, E, F, G, H and I with (a) Case 1, (b) Case 2 during Monsoon.



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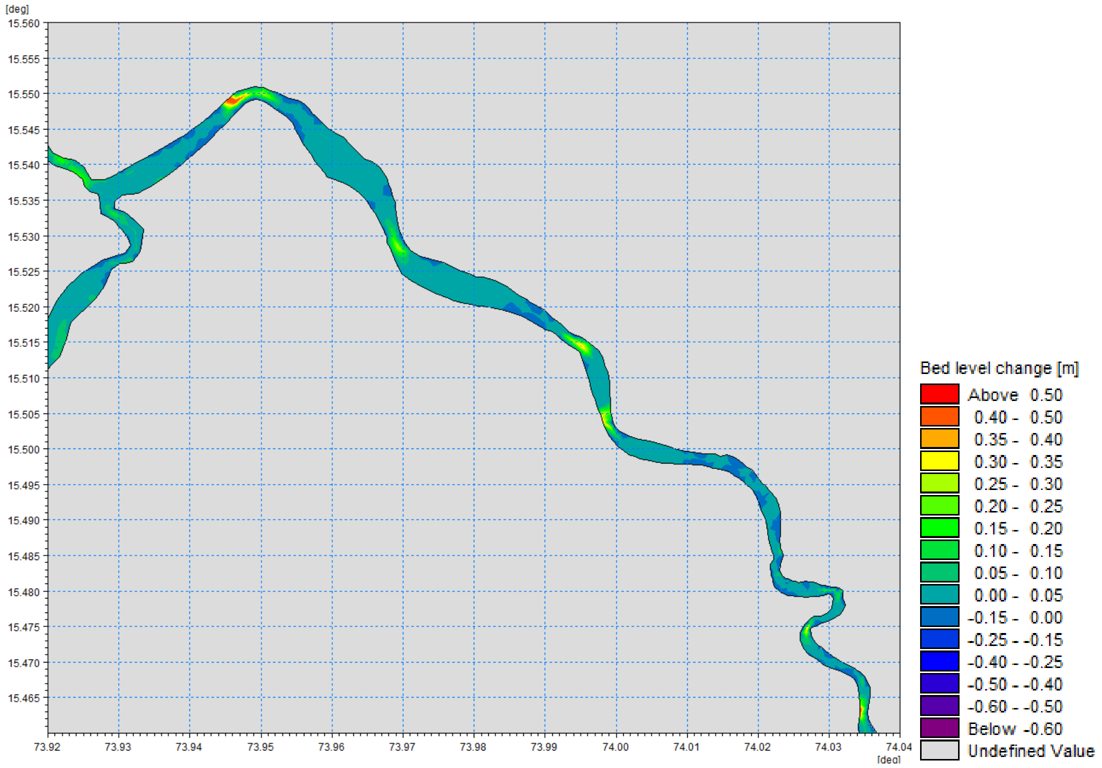

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Figure 5.19: Bed level change at sections C, D, E, F, G, H and I with (a) Case 1, (b) Case 2 during Non-Monsoon.

CHAPTER 6: ANTICIPATED IMPACTS

The primary function of an environmental impact assessment study is to predict and quantify potential impacts, and assess & evaluate the magnitude. Environmental impacts could be positive or negative, direct or indirect, local or regional and also reversible or irreversible. For each identified environmental impact, the associated risk is assessed based on its likelihood and significance.

Sand has become a very important mineral for our society due to its many uses. It is used for making concrete, filling roads, construction of buildings, brick-making, making glass, sandpapers, reclamations etc. The role of sand is very vital with regards to the protection of the coastal environment. It acts as a buffer against strong tidal waves and storm surges by reducing their impacts as they reach the shoreline. Sand is also a habitat for crustacean species and other related marine organisms. Individuals and private companies are increasingly demanding sand for construction purposes and this has placed immense pressure on sand resources. It is a practice that is becoming an environmental issue as the demand for sand increases in industry and construction.

Environmental Management Plan is a guiding document for environmental impacts associated with the proposed projects. It is a guiding document for management of good environmental condition on the site & surrounding of the proposed sand mining areas.

A scientific assessment of these impacts those are likely to influence the existing environmental scenario is needed. This could also facilitate in formulating a suitable environmental management plan depicting all mitigation measures. It can help in implementing the project in an eco-friendly manner. The project activities influencing the following environmental attributes have been studied and their impacts on the following attributes have been assessed.

The proposed project is to study impact of sand mining on the health of the Mandovi Estuary. The projects seek to understand the geomorphology, bathymetry, sand budget and flow dynamic of the estuary and the impact of sand mining on environment and biodiversity of the estuary. The EIA seeks to ensure that the potential negatives impacts arising from sand mining are mitigated or minimised whilst at the same time maximising on the positive impacts. The potential impacts of the project have been identified through literature review and site-specific baseline. A variety of technical studies and investigations were also conducted. These include geo-morphological, modelling, physico-chemical and ecological studies.

6.1 Prediction & Assessment of impacts

Development projects such as sand mining have an impact on their surrounding environment. These impacts beneficial or harmful, depending on the effect it brings about in the status of air, land, water, natural systems, ecology, socio-cultural, lifestyles and economics.

Depending on the improvement or the deterioration it brings about in the status of air, water, land, ecology, natural systems, socio-cultural life styles and economics of the local population. The impacts are assessed for their importance based on the nature of activities and environmental screening.

Marine organisms are known for their adaptive nature to the environmental changes though they possess certain tolerance capacity. Crossing these tolerance limits could give rise to serious impact on their existence which will ultimately result in ecological damage to the environment. The extent to which the baseline conditions can be altered by sand mining needs to be thoroughly analysed, and adequate mitigation measures need to be adopted so as to minimise the damage, if any to environment. Impacts to biological resources from physical and chemical environmental alterations are associated with sand mining activities. Major classes of alteration include suspended sediments, sedimentation, chemical release, flow patterns, topography. The biological impacts of marine sediments extraction are the disturbance and removal of benthic epifauna and infauna and alteration of the substance upon which the colonization depends. This in turn affect its stability as a fish or shellfish food habitat where the remnant substrate is identical to the surficial sediment, disturbance is unlikely to be permanent and the extraction area will be re-colonized, although the time scale will vary depending on the nature and location of the deposit.

Sand mining is the physical activity in the proposed project and it is known and increased sand mining has an adverse impact on the biodiversity by disturbing the biological community structure. Furthermore, sand mining activities potentially affect not only the site itself but also the surrounding areas. The major impact of sand mining will be habitat destruction due to dislodging of sediment. The important parameters that influence the impacts are the scale of sand mining, its extent and duration.

Based on the present study and using available information, following major threats to the environment in the study area of the estuarine system have been identified.

6.1.1 Impact on physical environment

- Large-scale extraction of streambed materials, mining below the existing stream bed and the alteration of channel-bed form and shape may lead to several impacts such as erosion of channel bed and banks, increase in channel slope, and change in channel morphology.
- Undercutting and collapse of river banks.
- Loss of adjacent land and/or structures.
- Upstream erosion as a result of an increase in channel slope and changes in flow velocity.
- Formation of deep pits in the channel bed produce slower flow velocities and lower flow energies, causing sediment transported from upstream to deposit at mine site.
- Alteration of the bed can have a high erosive effect on the river banks.
- It can result bank erosion and damages to existing structures in the downstream.

6.1.2 Impact on traffic

- Mining contractor uses the same main roads to transport product out of the zone and through road networks. This may result in an increase in the number of trucks utilising the road.
- Traffic congestion may occur due to narrow width of road and damage to roads due to plying of heavy vehicles further disturbing local well-being and increasing the maintenance cost.

6.1.3 Impact on Air Environment

- Dust generation may occur due to loading, screening and transportation operations. This dust becomes air borne and gets carried away to surrounding areas.

- The impact on air will be localized in nature as large sized dust particles settle down after travelling short distance.

- Combined impact of air borne dust from the mining lease areas may give a relatively larger picture of fugitive dust emission in the area.

- Collection and lifting of material are to be done manually without any blasting. Therefore, the dust generated is insignificant as compared to mining process of other hard minerals like the process of drilling, blasting, mechanized loading etc.

6.1.4 Impact on Water environment

- Sand mining activities may have impact on the river's water quality. Impacts include increased short-term turbidity at the mining site due to re-suspension of sediment, and dumping of excess mining materials, oil spills or leakage from transportation vehicles and washing of vehicles in the river.

- Suspended solids may adversely affect water towards downstream and aquatic ecosystems. The impact is particularly significant if water toward downstream of the site are abstracting water for domestic and irrigation purposes etc.

- Excessive mining may reduce the thickness of the natural filter materials (sediments) through which the groundwater is recharged. The pollutants due to mining, such as washing of mining materials, wastes disposal, diesel and vehicular oil lubricants and other human activities may pollute the groundwater.

6.1.5 Plume generation

- At the proposed sites of river/estuary, a turbid plume would eventuate as material is released to the water column during sand mining operations.

- Increased turbidity results in decreased primary productivity in the water column.

- Sand mining activity changes the nutrient regime of the water column and results in increased pollutant such as particulate associated pollutants, Polyhydrocarbons (PHC), oil and grease (O&G), heavy metals, organic matter and other contaminants and toxins from the sediment.

- The turbidity plume generated may have localized dispersal due to tidal action and riverine flux, thus the overall impacts may be localized and not of chronic nature.
- The size and duration of plume depends on the scale and periodicity of the mining.

6.1.6 Impact on Pelagic environment

- The increased turbidity leads to decrease in dissolved oxygen (DO) in the water column during sand mining operations. These sediments contain highly variable levels of nutrients, typically an order of magnitude several hundred to several thousand.
- Increase in suspended sediment loads and turbidity level due to sand mining could have adverse impacts on marine producers and consumers by reducing euphotic zone of water column.
- This increased load not only limits light penetration in water but also affects filter feeding organisms such zooplankton and bivalves.
- Reduced DO can cause the loss of micro-eukaryotic biomass, decrease aerobic bacteria and increase sulphate-reducing bacteria.
- Loss or reduction of bacteria means the remineralisation of matter will be significantly slower affecting the invertebrate grazers, predators and fish community.
- Nutrients such as phosphate released from the bottom churning of the sediments during sand mining will increase surface phytoplankton bloom that may clog membranes of filter feeding zooplankton and larval fish.

6.1.7 Impact on planktons

- Sand mining causes resuspension of sediments in the water column during extraction. The increase in turbidity would decrease light penetration and reduce photosynthesis, thereby causing changes in phytoplankton community structure and the food web. Many bottom dwelling pinnate phytoplankton and zooplankton groups such as bivalves could be impacted or translocated. The suspended solids would also release excessive material such as nitrates during mining. This could lead to blooms of dinoflagellates. Since the activity does not involve long distance vessel movement, the chances of exotic/weed/invasive species to be introduced would be negligible.

- One of the main concerns of sand mining is the suspension of fine sediments into water column, causing short term increase in turbidity. This increased turbidity has short-lived effect on phytoplankton, which are light dependant, these are generally of low significance and temporary. However, the release of contaminants such as heavy metals associated with suspended sediments can lead to increased accumulation of contaminants in the food chain.

6.1.8 Impact on Fishery

- Common fish found in Mandovi Estuary are *Etroplus suratensis*, *Mugil cephalus, Sillago sihama, Lates calcarifer* and the overall fishery yield from the river is high. Thus the mining may have negative effects on fish population.
- Sand mining affects the area by limiting the ability of mined areas to function as a nursery area, and/or feeding ground for the fauna.
- Physiological stress to marine fish and commercially important species by creation of higher sediment loads in the water column.
- Increased bioaccumulation of contaminants in commercially important species.
- Reduction in habitat due to loss of benthic primary producer habitat.
- Change in fish catch may occur due to proposed activity.
- Increased turbidity and organic matter may change the microbial water quality at nearby sites and thus may affect the fish fauna. Increase in the population of undesirable species such as viruses and parasites.

6.1.9 Impact on Benthic environment

- During sand mining operations, the removal of material from the seabed also removes organisms living on and in sediments which are collectively termed as ‘Benthos’.
- 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 and lacks similarity to the habitat that existed prior to sand mining.
- Sand mining may result in complete removal of benthic surface biota at mining sites.

- Excessive and unplanned riverbed sand mining results in the destruction habitat through large changes in the channel morphology.
- Disturbance of the upper layers of the seabed causes short term re-suspension of sediments, re-mineralization of nutrients and contaminants and re-sorting of sediment particles. Direct removal damages, displaces or kills a portion of benthic flora and fauna. It also causes a short-term attraction of carrion consumers. It leads to alteration of habitat structure (e.g., removal of sand, flattening of wave forms, and removal of structures required by some organisms).
- Increased suspended sediment due to sand mining can affect the filter feeding organisms such as shellfishes by clogging and damaging their feeding and breathing physiology.
- Sand mining may lead to patchy distribution of organisms between mined and adjacent non-mined areas.
- Adult fish are likely to move away or avoid areas of sand mining sites, unless food supplies are increased in mining sites as result of increase in organic matter.
- Fauna was comprised of polychaetes & crustacean which constitute a major food source for benthic feeding fishes, these showed low population in the central regions of the river and thus lowered secondary benthic productivity.

6.1.10 Impact on channel

- Sand-and-gravel mining in stream channels can damage public and private property. Channel incision caused by sand/gravel mining can undermine bridge piers and expose buried pipelines and other infrastructure.
- Excavation of a mining pit in the active channel lowers the stream bed, creating a nick point that locally steepens channel slope and increases flow energy.
- Impacts include bed degradation, bed coarsening, and channel instability. This in turn can cause erosion of banks, embankments along fields leading to salt water intrusion and loss of land.

6.1.11 Impact on mangrove

- Mangroves are crucial habitats as they act as feeding and breeding grounds for many organisms. These are also an important site for crab fisheries. Mangroves could be affected by sustained inundation of pneumatophores and declining water quality which may lead to their death.

- In downstream areas, sand mining can lead to damage to embankments which cause saline water intrusion into fields which leads to abandonment of fields that are further colonized by mangroves.

- Damage to mangroves can also affect species (eg: *Meretrix* spp*, Polymesoda* spp*.,* other oysters and clams) that depend on mangroves for resources.

- However, the overall impacts to mangrove in the study area are of low concern as mangrove cover has shown steady increase in-turn showing indications of increasing its expanse.

6.1.12 Impact on mudflats

- Sand mining can cause increased scour, erosion and increase steepening of slopes thereby removing the mudflat habitat.

- Create a disturbed benthic community and possibly reduce the number and diversity of benthic species and affects larval recruitment negatively on mudflats.

6.1.13 Impact on sandflats

- In-stream mining lowers the stream bottom, which may lead to bank erosion. Depletion of sand in the streambed and along coastal areas causing deepening of rivers and estuaries, and the enlargement of river mouths and coastal inlets.

- Epifaunal and large in-faunal organisms will be most affected by sand mining. Crustacean spawning areas occur where sand banks meet rocky areas. It can cause extinction of commercially important species dependent on sand flats for eg: *Paphia* spp.

- Cumulative impacts may include undercutting and collapse of river banks, loss of adjacent land and/or structures, upstream erosion and uprooting of flora as a result of an increase in channel slope and changes in flow velocity. In the downstream region there is channel widening and deepening, undermining of engineering structures, dwindling of riverine habitats, damage to protective structure such as bandhs leading to salt water intrusions into paddy field.

6.1.14 Others

- The most likely adverse impact might be of cumulative nature and it will be hard to discern from any singular impact of new or old activity in the given location and period.
- There are crocodile and smooth coated otters found in the river which are protected under schedule I and II respectively by the Indian Wildlife Protection Act, 1972. Other mammals such as Otters, jackals, flying fox, wild cats, wild boar etc. visit mangroves for shelter, breeding or feeding. These species can face increased threats and can be harmed due to disturbance.
- Mandovi Estuary has a good diversity and abundance of avifauna. Birds gather on the mud flats of River Mandovi for feeding. Several migratory birds visit these rivers during winter and use it as an important feeding ground. These are most sensitive to any sort of disturbance such as noise, use of mechanized vessels, change in turbidity, productivity or change in water quality. The disturbance by sand mining may affect foraging behavior of birds, mainly aquatic birds. These birds are likely to move away from such areas.
- Occurrence of unintended events such as vehicle collision, accidents, fire, fuel leaks and other inadvertent events may occur mainly due to lack of coordination, casual approach, un-managed activity and associated activities (e.g.: fishing) and no timely communication within and between stakeholders involved in nearby areas. These events may also result in environmental disaster if there are no precautions taken.
- Oil spills due to any unplanned eventuality is one of the major long-term threats to the marine biota and can have a major long term irreversible loss depending on the extent, quantity and expanse of spillage. The likeliness of this occurrence will be very low if proper precautions and contingency plans are in place.

6.1.15 Positive anticipated impacts

- Sand mining can help the economy directly by generating jobs for extraction of sand and income from sale of sand.

6.2 Mining Sensitive Areas:

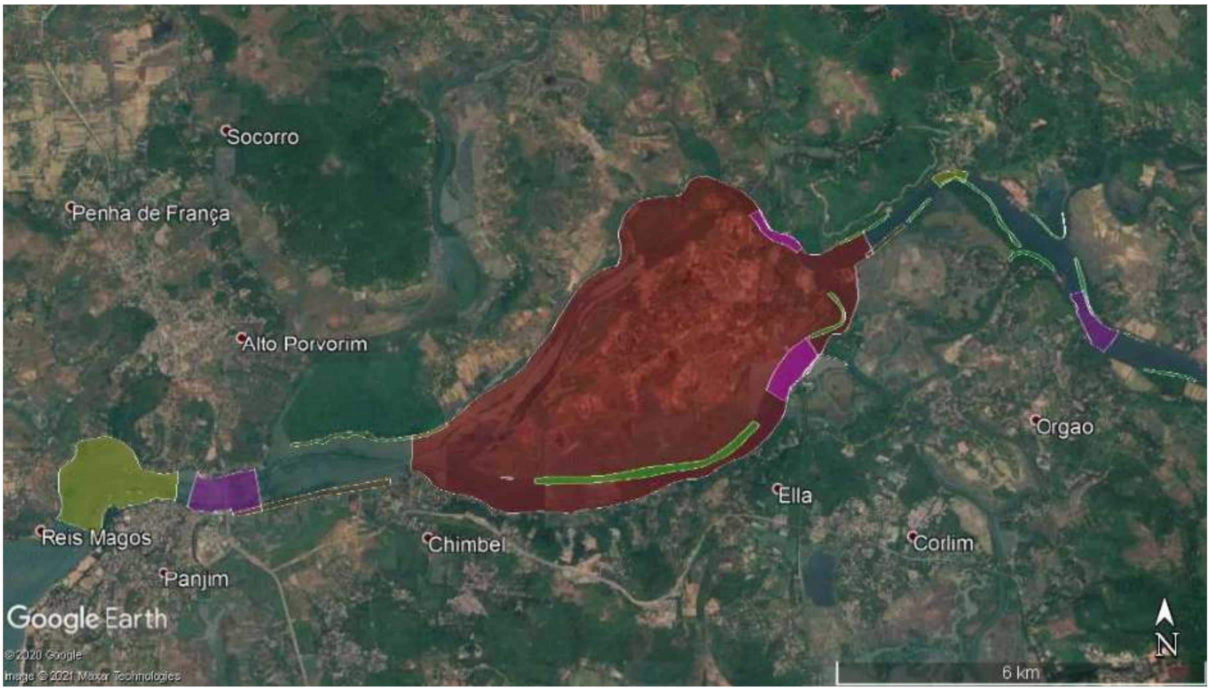
Estuaries are most dynamic and complex ecosystems known around the globe. They are made up of a wide range of different habitats, which exist in an ever-changing mosaic structure. Typical habitats that make up an estuary include sand banks, mudflats, mangroves, salt marshes, sand flats, and at their coastal edge sand dunes, small islands sandy beaches etc. They are prime importance for wildlife especially migrating and breeding birds and major values in terms of their rich natural resources (nursery grounds and commercially important fish). In addition, they also offer a wide range of ecosystem services such as shoreline stabilization, nutrient regulation, carbon sequestration, detoxification of polluted water and supply of food and energy resources.

To preserve and protect these habitats areas have been demarcated based on importance and in accordance with Sustainable Sand Mining and Management Guideline (2016). The entire region is divided into three different zones. Zone –I (Fig 6.1) (and Legends as per Table 6.1) is located at the mouth region, it ends at Candola village jurisdiction. The area consists of sensitive regions *viz.* embankment to protect paddy fields, sand flat, Mangroves, riverside urban areas and bridge. Shallow sand and mud flats provide feeding habitat to a lot of migrating and local birds, if sand is excavated from zone-I (Fig 6.1) it is predicted to impact shoreline, change in geo-morphology, beach profile and grain size of sandy beach, which will potentially have adverse impact on birds feeding grounds. Further a bridge is present connecting Panjim and Porvorim, mining might damage this structure, stability or strength of the bridge. As per SSMMG, 2016, to avoid structural damage to any bridge, an area of 500 meters on both the sides of bridge is restricted for mining. North to the bridge an Island (East of Ribander village) vegetated with mangroves, and considering the Hon'ble NGT order (28/2015 (WZ) an area of 1000m (upstream and downstream) has to be restricted for mining. An embankment exists to protect salt water intrusion as well as to secure paddy field on Ribander side. Beside this embankment lies mangrove forest, and as per SSMMG (2016), a

50m wide area from ecologically sensitive areas (such as mangroves) and 25m from the embankments are to be avoided for mining.

Next zone is considered from Gaundalim to Khandepar which consists of two adjacent islands towards east end, bridge and meandering towards west. The order of Hon'able NGT order (28/2015 (WZ) has been followed for excluding an area of 1000m upstreams and down-streams of Chorao Island is applied to all the islands of this river. Thus, 1000m upstream and downstream area from these islands to be restricted for sand mining. Meandering bends are to be avoided as these may have major geo-morphological changes such as accretion which may lead to deposition and erosion at the upper/lower reaches pertaining to sand extraction. Mudflats and mangroves are also to be avoided as these serve as habitat, breeding ground and nursery for myriad of marine organisms. A flyover bridge is also present at the meandering point where an area of 500 m on both the sides is restricted for mining. Zone III (Fig 6.1) falls between Khandepar to Ganjem, it consists of an Island and meander towards Ganjem. On the westward side there is an Island and bridge which are restricted as well 1000m and 500m on either side respectively. Last zone has three main features *viz* Bridge, Meander and islands and thus as per SSMMG (2016), these zones are restricted as well from mining activities.

ZONE-I



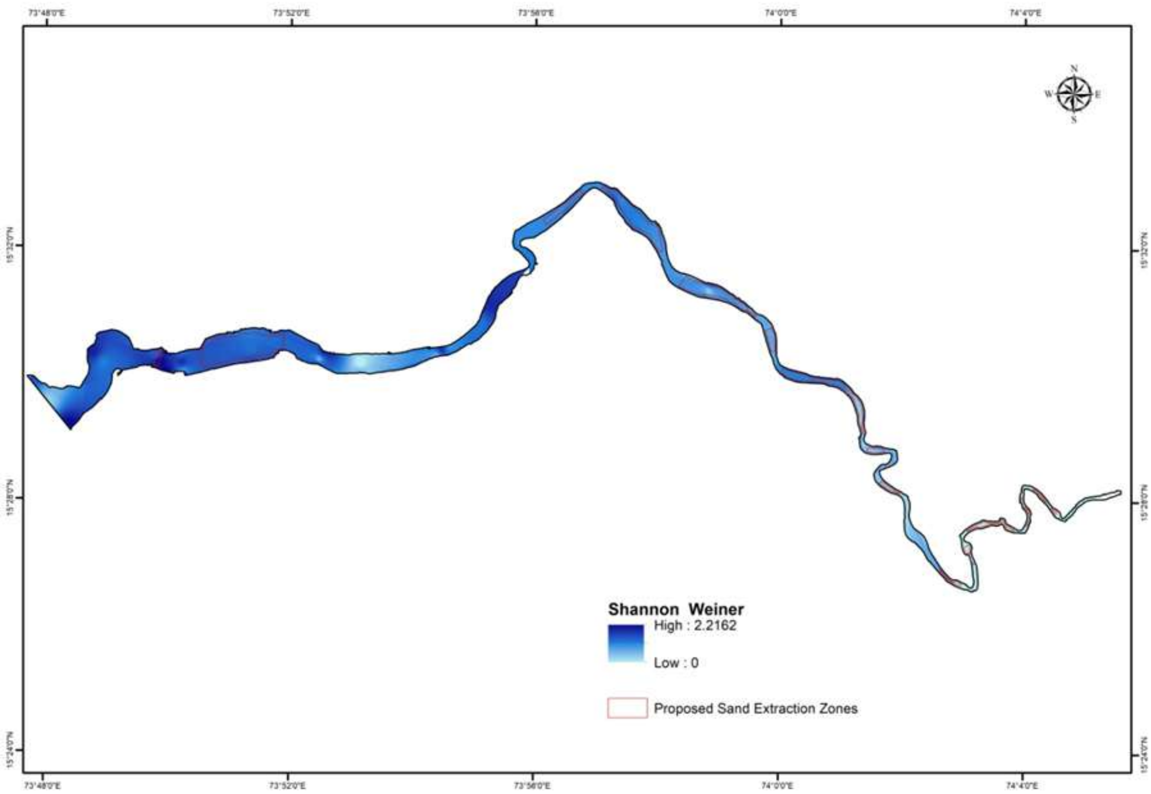
ZONE-II

ZONE-III

Figure 6.1: Depicting Mining Sensitive Zones for the Mandovi Estuary (Zone I to III)

Table 6.1: Depicting type of sensitivity, colour code, width and guidelines referred.

Colour	Sensitive Areas	Width	Guideline
Green	Mudflats and Mangrove	50 m	Sustainable Sand Mining Management Guideline 2016
Pink	Bridges	500 m	Sustainable Sand Mining Management Guideline 2016
Red	Islands	1000 m	Sustainable Sand Mining Management Guideline 2016/ National Green Tribunal.
Yellow	Meandering	200 m	Sustainable Sand Mining Management Guideline 2016
Brown	Embankment	25 m	Sustainable Sand Mining Management Guideline 2016



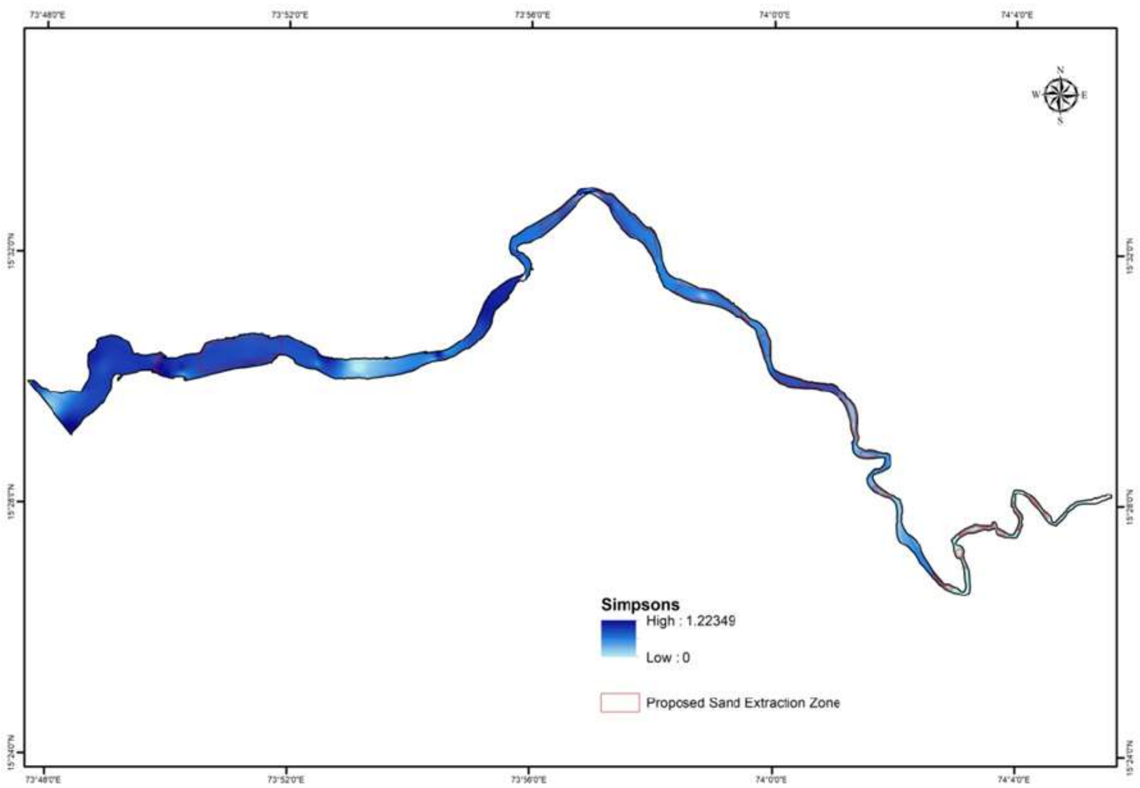
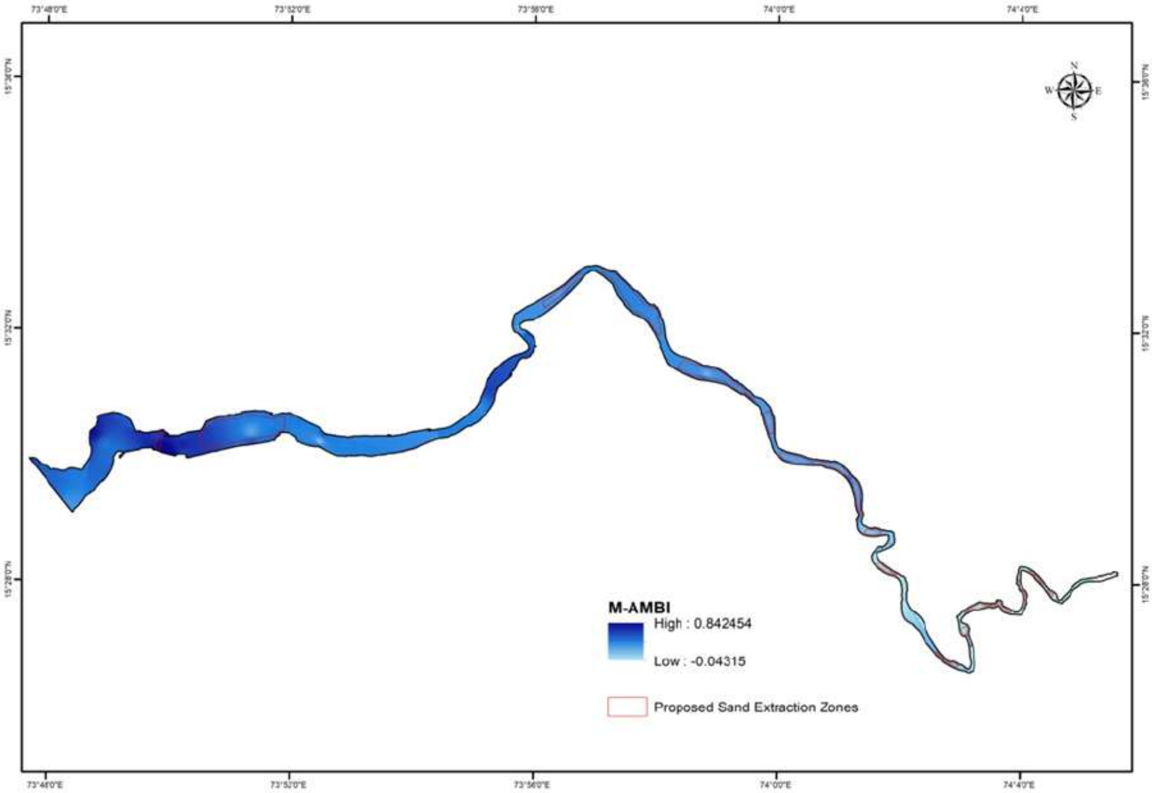


Figure 6.2: Shannon-Wieners and Simpsons Index depicted on the river stretches with encircled proposed sand extraction zones.



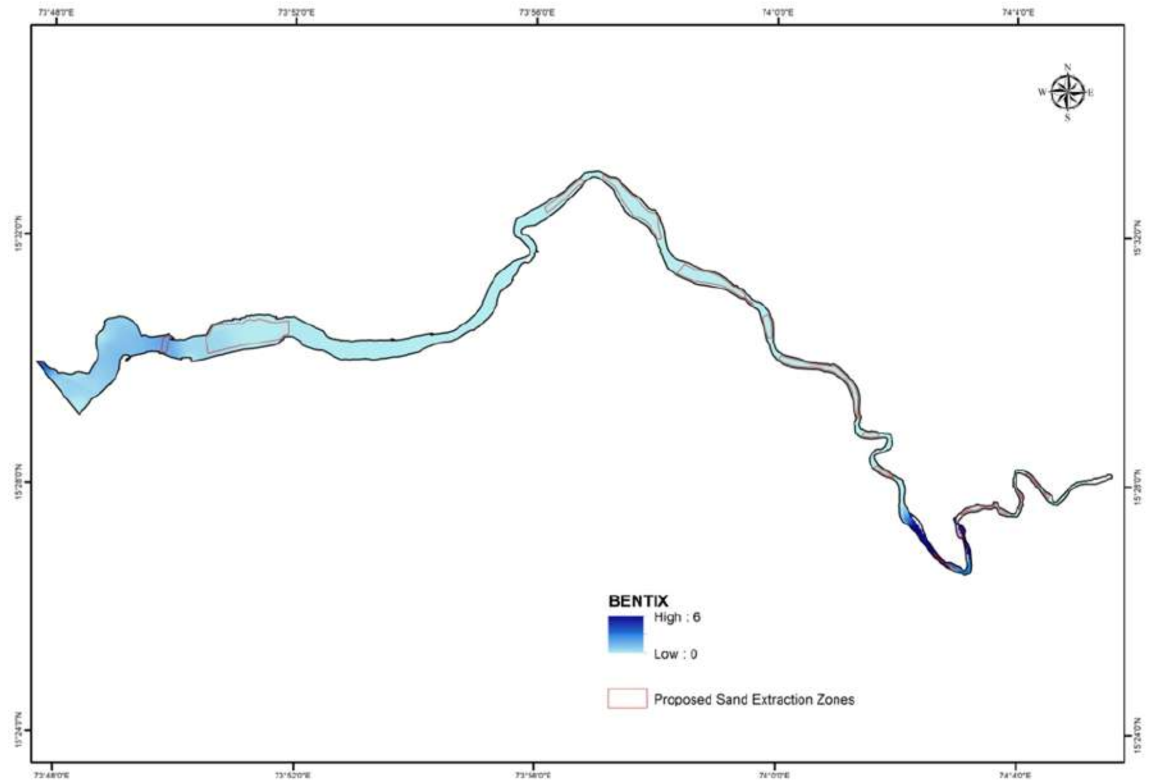


Figure 6.3: M-AMBI and BENTIXindices depicted on the river stretches with encircled proposed sand extraction zones.

CHAPTER 7: MITIGATION MEASURE

The aim of the mitigation guidelines to ensure that the sand mining is carried out in an environmentally sustainable and socially responsible way, improve the effectiveness of monitoring of mining and transportation of mined out material, conservation of river equilibrium and it's ecosystem health, no obstruction of the river flow, water transport and restoring the riparian rights and in-stream habitats, to prevent river pollution and water quality deterioration. The extraction of sand and gravel from the river bodies has to be regulated and done with the adoption of required environmental safeguards. Mapping of the sand resources at the district level, identification of appropriate sites for extraction, appraisal of the extraction process, putting in place the required environmental safeguards and rigorous monitoring of the volume of extracted material is required to ensure the sustainability of the entire process. In broader sense, the impacts of sand mining can be reduced or avoided and mitigating it may only imply replenishment (which may happen over a course of time during which the magnitude and expanse of impacts might change thus making it difficult to comprehend).

7.1 Protection of river embankment

Site-specific evaluation is needed to evaluate each proposed operation to minimize disturbance and maximize the stability of the channel. In downstream areas, sand mining can lead to damage of bunds, which causes saline water intrusion into fields, leads to abandonment of fields. Mining lease should be preferably granted for those locations which have the least possibility of an impact on the environment and nearby habitation. Demarcation of the mining area with pillars and geo-referencing should be done before the start of mining to ensure that sand extraction is going on only within the permitted area. The permanent boundary pillars need to be erected after the identification of an area for deposition of mined sand outside the river bank at a safe location. The distance between boundary pillars on each side of the bank shall not be more than 100 m.

Sand and gravel shall not be allowed to be extracted where erosion may occur, such as at the concave bank. Sand and gravel shall not be extracted up to a distance of 1 kilometer (1 km) from major bridges and highways on both sides, or five times (5x) of the span (x) of a bridge/public civil structure (including water intake points) on up-stream side and ten times (10x) the span of such bridge on the down-stream side, subjected to a minimum of 250 meters on the upstream side and 500 meters on the downstream side as per the guidelines issued by Hon'able National Green Tribunal. The borrow area should preferably be located on the riverside of the proposed embankment because they get silted over time. For low embankment, less than 6 m in height, the borrow area should not be selected within 25 m from the toe/heel of the embankment. In the case of the higher embankment, the distance should not be less than 50 m. In order to obviate the development of flow parallels to the embankment, crossbars of width eight times the depth of borrow pits spaced 50 to 60-meter center-to-center should be left in the borrow pits.

River bed sand mining shall be restricted within the central 3/4th width of the river/rivulet or 7.5 meters (inward) from river banks but up to 10% of the width of the river. The mining area must be demarcated at a minimum distance of at least 50 m away from the river embankment on either side. The boundaries of the quarries may be fixed concerning the existing survey marks from the survey fields adjacent to the river. Sand quarrying lease area shall be demarcated on the ground with pucca stone or concrete pillars to show the present natural bed level, and the depth of mining allowed. The zone of river bed mining shall ensure that the objective to minimize the effects of riverbank erosion and consequential channel migration are achieved to the extent possible. In general, the area for removal of minerals shall not exceed 60% of the mine lease area.

7.2 Annual replenishment of sand

It is necessary to ascertain the rate of sand replenishment in the river bed. A regular replenishment study needs to be carried out to keep a balance between deposition and extraction. Replenishment would need to occur before subsequent extraction could take place. The concept of annual replenishment accounts for the episodic nature of sediment transport. For example, during monsoon, high stream flows result in a high contribution of sediment from hill slopes and tributaries, and during the dry periods, low stream flow led in little sediment supply. The use of monitoring data is essential in measuring when actual replenishment occurs.

The use of the concept of annual replenishment protects long-term channel stability as well as aquatic and riparian habitat by extracting a sustainable volume of sand. Sand mining must not be done on one site, but in alternating sites, to reduce over-extraction, which damages the environment beyond rehabilitation.

According to best practices, the distance between any two sand mining clusters should not be less than 2.5 km to reduce the cluster formation. Mining lease should be defined in such a way that the total area of the mining leases in a cluster should not be more than 25 Ha. After every year, a mandatory audit of the quantity extracted and quantity permitted along with the replenishment rate.

7.3 Maintenance of flood capacity

Flood capacity in the river should be maintained in areas where there are significant flood hazards to existing structures or infrastructure. Sand and gravel could be extracted from the downstream of the sand bar. Retaining the upstream one to two-thirds of the bar and riparian vegetation is accepted as a method to promote channel stability. Mining depth should be restricted to 3 meters, and distance from the bank should be ¼th or river width and should not be less than 7.5 meters.

7.4 Seasonal ban on sand mining activity

There shall be no river bed mining operation allowed in the monsoon period. The period as defined by IMD Nagpur for each state shall be adhered to. The cumulative riverine impact of all mining activity should be reviewed on an annual basis to minimize long-term impacts and inequities in permits between adjacent mining operations.

7.5 Limiting sediment impact

Minimize activities that release fine sediment to the river. No washing, crushing, screening, stockpiling, or plant operations should occur at or below the streams "average high-water elevation," or the dominant discharge. These and similar activities have the potential to release fine sediments into the stream, providing habitat conditions harmful to local fish.

7.6 Prevention and mitigation of pollution

Proper entry and exit points for the movement of loading vehicles in and out of the sand mining sites shall be carefully located, taking into consideration the habitations/settlements in the area. Construction of separate gravel roads for tipper trucks to reduce traffic congestion, accidents, as well as noise and air pollution, maybe consider. All the vehicles should be serviced regularly according to the existing Govt. guidelines to minimize noise and air pollution. The transportation route so selected should be verified by the Goa Government for its carrying capacity. Movement of heavy vehicles from public roads to pit sand, gravel, and river sand collection points need access roads. To prevent air pollution due to the dust during sand mining operations and safeguard the workforce in the sand mining and depot site, constant water sprinkling on the pathways and dust prone areas may be conducted. The sand loaded vehicles are to be covered with a tarpaulin before moving out of the quarries/depots. Plantation needs to be done with the consultation of the state forest department beside the sand transportation road to curtail the dust pollution.

The air and water quality should to be checked periodically to ensure that no pollution is caused due to sand transport operations. Safety gadgets such as earplugs, goggles, respiratory devices, luminescent vests may be provided to the workers at the sand mining site. First aid kit with all essentials shall be kept ready at all quarry/depot sites, in case of any emergency. Independent environmental auditsneed to be carried out at least once in a year for each mining site by reputed third party entity and report of such audit be placed in the public domain.

7.7 Protection and management of groundwater

To monitor the groundwater level during sand extraction operations, a network of existing wells may be established around the sand mining area, and new piezometers must be installed at all sand mining sites. The monitoring of groundwater quality in the vicinity (one Km radius from the sand mining site) shall be carried out once in two months. If, at any stage, it is observed that the groundwater table is getting depleted due to the mining activity, necessary corrective measures shall be carried out, which may include immediate stopping of the mining operation.

GSPCB has been monitoring water quality for Mandovi river and has not found significant change in water quality (Action Plan Report on River mandovi river, 2019) wherein sand extraction was an on-going activity thus representing cumulative results. The report delineates several activities for the rejuvenation of Mandovi River and considering these proposed actions, the management aspects in this report have been proposed.

7.8 Soil management

Sand mining can cause weakening of soil in adjacent areas, which can lead to erosion of river banks. Sand mining destabilizes soil structure, river banks and often leaves isolated islands of trees; the subsequent flow will erode the banks and islands. Construction of soil conservation structures like river embankments/bundhs, extensive plantation drive, and mitigation of afforestation are some of the prerequisites to reduce soil erosion. Mangroves around the Mandovi river are crucial habitats that serve as feeding and breeding ground to many ecologically and economically organisms like oysters and clams, crab, fishes. Mangroves also protect the river embankment and an excellent source of carbon sequestration. Hence, ultimate care needs to be taken to protect the mangrove habitat.

Soil salinity is a major global issue owing to its adverse impact on agricultural productivity and sustainability. It should be noted that no single approach can deliver a complete solution to fix/reclaim the soil salinity problem. Soil salinity undermines the resource by decreasing soil quality and can jeopardize the integrity of soil’s self-regulatory capacity. Therefore, regular salinity mapping of the river bank may assist in taking necessary and timely actions to tackle the increased soil salinity and to avoid a further spread of soil salinity to a new area. Different methods, such as physical (levelling, salt scraping, tillage, subsoiling, and sanding); chemical (use of soil amendments such as elements, acids, gypsum to rectify soil sodicity problems and to improve soil health); hydrological (irrigation systems: Surface, flood, basin, drip, sprinkler, subsurface irrigation, leaching, and drainage), and biological (biosaline agriculture: Salt tolerant crops, and a serial biological concentration approach), may be employed to manage and prevent soil salinization.

7.9 Alternative resource generation

Promotion of manufactured sand, artificial sand, and alternative technologies in construction materials and processes are also required for reducing the dependence and demand on naturally occurring sand and gravel. Reusing and recycling of building material to reduce demand for river sand, pit sand, and gravel.

CHAPTER 8 ENVIRONMENTAL CONSERVATION AND MANAGEMENT PLAN

8.1 Background

Under the Environmental Impact Assessment notification of 2006 issued by the Ministry of Environment, Forests and Climate Change (MoEFCC), Govt. of India, which forms the legal basis for environmental impact assessment of development projects in India, mining of minerals with a lease area of less than 5 hectares did not require prior environmental impact assessment (EIA), until 2012 when the Supreme Court of India ruled that EIAs were mandatory for minor minerals, irrespective of the lease area. Pursuant to this, the MoEFCC, in response the increase in the EIA applications requiring scrutiny devolved the process of environmental clearance to the district level. This included amending the EIA Notification of 2006 to create District-level authorities for screening and evaluating EIAs for mining of minor minerals, including sand. Since this directive was enacted, the National Green Tribunal and other courts have issued repeated directives to halt illegal sand mining, based on the environmental impacts arising from the activity. These have included a 2015 National Green Tribunal directive to ban sand mining in Madhya Pradesh during the monsoon, but the ban was lifted within a month (SANDRP, 2016). In 2016, the Union Ministry of Mines (Ministry of Mines, India, 2016) released a press release addressing the administrative responsibilities associated with legal and illegal sand mining in rivers, stating that:

- Sand mining is regulated at the state level under powers granted by the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act).
- States can grant mineral concessions for minor minerals and enact regulations to control these activities.
- The same Act empowers state governments to frame rules to prevent illegal mining, transportation and storage of mineral sands, and therefore the control of illegal activities is under the legislative and administrative jurisdiction of the state governments.

8.2 Legal requirements

As per the provisions of the EIA Notification issued on 14th September 2006 and subsequent amendments till date

All projects and activities are broadly categorized in to two categories – Category A and Category B. Category 'A' in the Schedule requires prior environmental clearance from the MoEFCC and Category 'B' in the Schedule, from the State/Union Territory Environment Impact Assessment Authority (SEIAA). An application seeking prior environmental clearance in all cases shall be made in the prescribed Form –I along with the pre-feasibility project report. "Scoping" refers to the process by which the Expert Appraisal Committee in the case of Category 'A' projects or activities, and State Level Expert Appraisal Committee in the case of Category 'B1' projects or activities, determine detailed and comprehensive Terms of Reference (TOR) for the preparation of an Environment Impact Assessment (EIA) Report in respect of the project or activity for which prior environmental clearance is sought. However, after the introduction of standard TOR for each sector amendment of EIA notification the issued on 10th April, 2016 it was stated that "Standard TOR developed by the Ministry in consultation with the sector specific Expert Appraisal Committees shall be the deemed approved TOR for the projects or activities. These standards TOR shall enable the Project Proponent to commence preparation of an Environment Impact Assessment Report after successful online submission and registration of the application. All Category 'A' and Category B1 projects or activities shall undertake Public Consultation. But now as per Gazette notification amendment S.O. 3977(E) dated on 14.08.2018 issued by the MoEFCC of India, the Public consultation are not required for B2 Sub-category under B category project.

Acts and legislations applicable for proposed activites

- The Mines Act 1952
- The Mines and Mineral (development and Regulation) Act 1957
- Mines Rules 1955
- Mineral Concession Rules 1960
- Mineral Conservation and Development Rules 1988

- The Environment (Protection) Act, 1986
- EIA Notification (and amendments) 2006
- Wildlife Protection Act, 1972
- The Forest (Conservation) Act, 1980
- Water (Prevention and Control of Pollution) Act (and subsequent amendments) 1974
- The Water (Prevention & Control of Pollution) Rules 1975, Cess Act 1977 & Cess Rules 1978.
- Air (Prevention and Control of Pollution) Act (and subsequent amendments) 1981
- Solid Waste Management Rules, 2016
- CRZ notification 2019

8.3 Mining plan

A mining plan has to be prepared by each lease owner and accordingly the state/district level committee may issue the permits. The basic information required in the mining plan is given below which has to be prepared as per the guidelines of EIA Notification (2006).

- Location & Basic Information of the Mining Lease Area (quantities Haulage and Surface Transport Plan.
- Brief layout of mine working & layout mine faces.
- Demarcation of Mining Lease Area.
- Mining methodology (Should include tools and machinery used, energy requirement, water, manpower, waste [solid, liquid & air emissions].
- Yearly schedule of sand mining.
- Facilities and amenities for workers (Porta-cabins, toilets, fuel, health check-up as per Mines Rule 1955).
- Compensatory plantation and CSR activities.

Sustainable Sand Mining Management Guidelines, (2016) and Enforcement & Monitoring Guidelines for Sand Mining (2020) by MoEFCC are being followed for formulating this management and subsequent monitoring plan. Sustainable sand mining guidelines in India have been developed by the Ministry of Environment Forest and Climate Change (MoEFCC, 2016). The guidelines are based on the premise that sand extraction from rivers is required for construction, but it is also required for maintaining river health. The Guidelines recommend the following process be followed and included:

a) Identification of areas of deposition where mining can be allowed; and identification of areas of erosion and proximity to infrastructural structures and installations where mining should be prohibited. Use of satellite imagery for identifying areas of sand deposit and quantity be done.
b) Calculation of annual rate of replenishment and allowing time for replenishment after mining in area.
c) Identifying ways of scientific and systematic mining.
d) Identifying measures for protection of environment and ecology.
e) Determining measures for protection of bank erosion.
f) A bench mark (BM) with respect to mean sea level (MSL) should be made essential to in mining channel reaches (MCR). Below which no mining shall be allowed.
g) Identifying steps for conservation of mineral.
h) Permanent gauging facilities (for discharge and sediment both) should be made compulsory for the sites having excessive mining in consultation with Central Water Commission or any competent State Agency.
i) Implementing safeguards for checking illegal and indiscrete mining.

Sand extraction from riverbanks and river channels areas causes local disruptions which can be anticipated and prevented through appropriate studies. After various environmental problems of river sand mining in various physiographic zones, an EIA was carried out to suggest appropriate Environmental Management Plan (EMP) for regulating the mining activities on a sustainable basis. The river environments in all the three physiographic zones such as highlands, midlands and lowlands are deteriorated drastically due to illicit scooping of sand even from prohibited areas close to bridges and water intake structures. Hence, an attempt has been made to analyse the environmental impacts caused by river sand mining to identify and address the key environmental issues that results in from the activity. The main intention of the effort is to mitigate the negative impacts and enhance the positive ones.

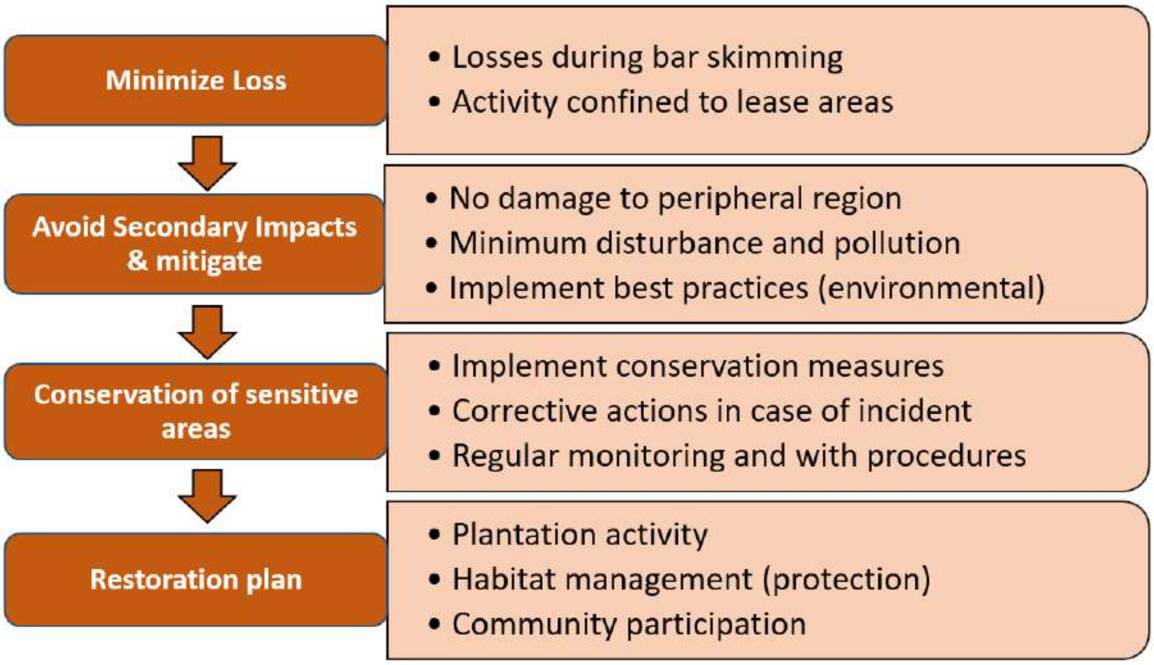


Figure 8.1: Schematic diagram of management of sand mining

8.4 Strategy for the management plan

Following requirements are suggested for defining a mechanism for monitoring of mining activities which will help in identification of mining which is operating either illegally or are violating the regulatory provisions. All precaution shall be taken to ensure that the water stream flows unhindered and process of natural river meandering doesn't get affected due to mining activity. Stretches shall be identified for species of significant importance in the river ecosystem. Such stretch with adequate buffer should be declared as no-mining zone and no mining shall be permitted. The regulatory authority as defined for granting Environmental Clearance, while considering the application of issuance of ToR and/or EC for the adjacent block (to non-mining zone) of mining shall take due precaution and impose requisite conditions to safeguard the interest of such species of importance.

District administration shall provide detailed information on its website about the sand mines in its district for public information, with an objective to extend all information in public domain so that the citizens are aware of the mining activities and can also report to the district administration on any deviation observed. Appropriate feedback and its redressal mechanism shall also be made operational. The details shall include, but not limited to, lease area, geocoordinates of lease area and mineable area, transport routes, permitted capacity, regulatory conditions for operation including mining, environmental and social commitments etc. (Fig.8.1).

8.5 Management plans

a) River bed mining recommendations

Permit mining volume based on measured annual replenishment in the first year following adoption of the management plan, a volume equal to the estimated annual replenishment could be extracted from the reach of channel. Replenishment (up to the elevation of the selected channel configuration) would need to occur before subsequent extraction could take place. The concept of annual replenishment accounts for the episodic nature of sediment transport. For example, during wet periods with high stream flows, and a high contribution of sediment from hill slopes and tributaries, monitoring data would show that sand and gravel bars are replenished quickly. During drought periods with low stream flow, and little sediment supply or transport, monitoring data would likely show that bars were replenished at a slower rate.

The use of monitoring data is essential in measuring when actual replenishment occurs. The use of the concept of annual replenishment protects long-term channel stability as well as aquatic and riparian habitat by extracting a volume sustainable by watershed processes.

B) Establish an absolute elevation below which no extraction may occur (minimum enveloped level or redline)

The absolute elevation below which no mining could occur or “redline” would be surveyed on a site-specific basis in order to avoid impacts to structures such as bridges and to avoid vegetation impacts associated with down-cutting due to excessive removal of sediment. An extraction site can be determined after setting the deposition level at 1 m above natural channel thalweg elevation, as determined by the survey approved by mine plan approving authority.

c) Limit river bed extraction methods to bar skimming

If mining is limited to the downstream end of the bar with a riparian buffer on both the channel and hill slope (or floodplain) side, bar skimming would minimise impacts. Other methods such as excavation of trenches or pools in the low flow channel lower the local base level, and maximizes upstream (head cutting and incision) and downstream (widening and braiding) impacts.

d) Extraction of sand/ gravel from the downstream portion of the bar

Retaining the upstream one to two thirds of the bar and riparian vegetation while excavating from the downstream one to two third of the bar is accepted as a method to promote channel stability and protect the narrow width of the low flow channel necessary for aquatic life. Sand and gravel would be re-deposited in the excavated downstream one to two thirds of the bar (or downstream of the widest point of the bar) where an eddy would form during sediment transporting flows. In contrast, if excavation occurs on the entire bar after removing existing riparian vegetation, there is a greater potential for widening and braiding of the low flow channel.

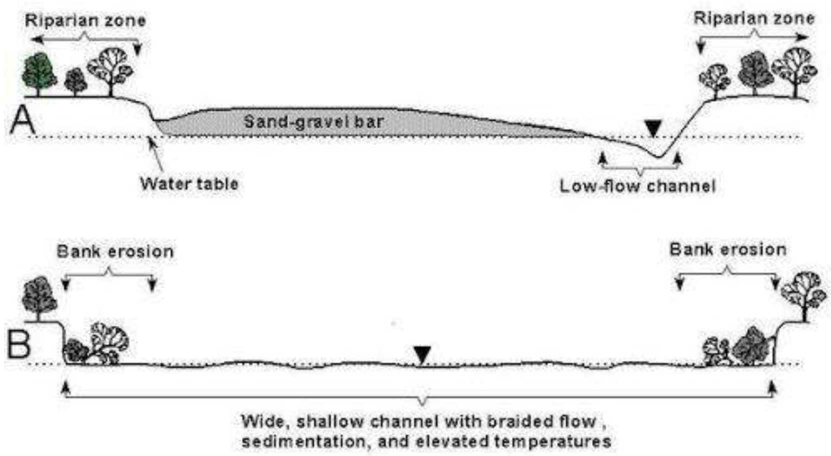


Figure 8.2: A typical sand-gravel bar in relation to the low-flow channel, riparian zone and water table, and (B) the wide shallow channel that results from unrestricted mining and that is characterized by bank erosion, braided flow, sedimentation, and increased water temperatures. (Source:http://threeissues.sdsu.edu/three_issues_sandminingfacts01.html).

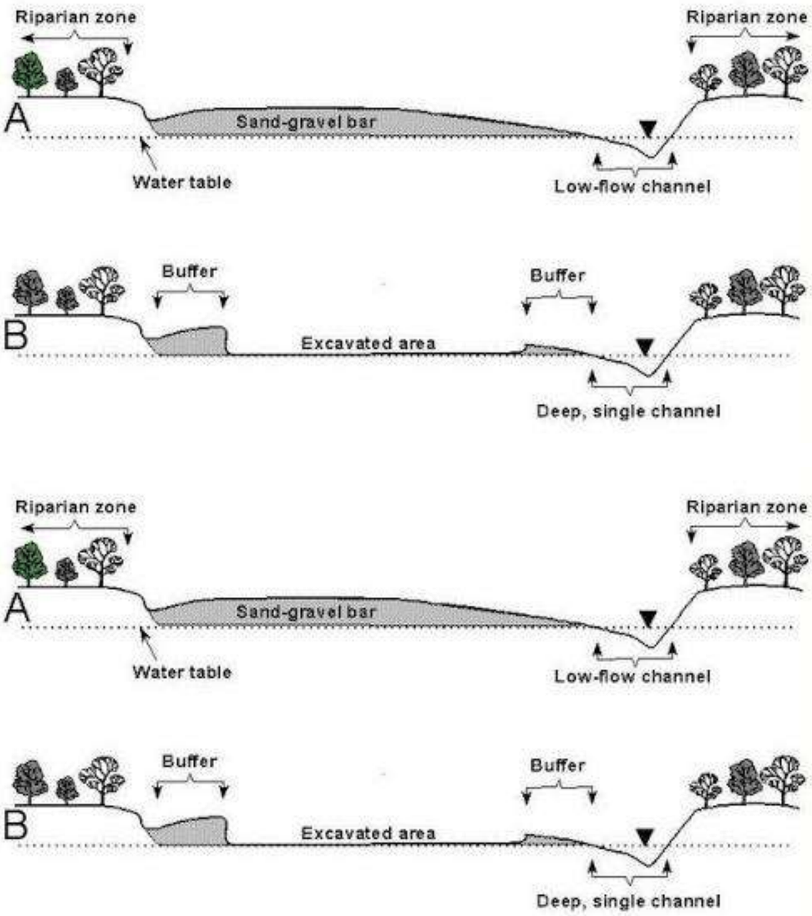


Figure 8.3: Diagram of channel cross sections showing
8.3 (A)- A typical sand-gravel bar in relation to the low-flow channel, riparian zone and water table, and (B) the protected deep, single channel and channel banks when mining is restricted within a buffer of designated width and above the water table. (Source: http://threeissues.sdsu.edu/three_issues_sandminingfacts01.html).

e) Concentrate activities to minimise disturbance

River bed extraction activities should be concentrated or localised to a few bars rather than spread out over many bars. This localisation of extraction will minimise the area of disturbance of upstream and downstream effects. Skimming decreases habitat and species diversity – these effects should not be expanded over a large portion of the area.

f) Review cumulative effects of sand and gravel extraction

The cumulative impact of all mining proposals should be reviewed on an annual basis to determine if cumulative riverine effects or effects to the estuary are likely.

g) Maintain flood capacity

Flood capacity in the river should be maintained in areas where there are significant flood hazards to existing structures or infrastructure.

h) Establish a long-term monitoring program

Monitoring of changes in bed elevation and channel morphology, and aquatic and riparian habitat upstream and downstream of the extraction would identify any impacts of sand and gravel extraction to biological resources. Long-term data collected over a period of decades as sand and gravel extraction will provide data to be used in determining trends.

i) Minimise activities that release fine sediment to the river

No washing, crushing, screening, stockpiling, or plant operations should occur at or below the stream's average high-water elevation, or the dominant discharge. These and similar activities have the potential to release fine sediments into the stream, providing habitat conditions harmful to local fish.

j) Retain vegetation buffer at edge of water and against river bank

Riparian vegetation performs several functions essential to the proper maintenance of geomorphic and biological processes in rivers. It shields river banks and bars from erosion. Additionally, riparian vegetation, including roots and downed trees, serves as cover for fish, provides food source, works as a filter against sediment inputs, and aids in nutrient cycling. More broadly, the riparian zone is necessary to the integrity of the ecosystem providing habitat for invertebrates, birds and other wildlife.

k) Seasonal ban in sand mining

The River bed mining should only be allowed during the dry season. No River bed mining should be permitted during rainy season.

l) An annual status and trends report

This report should review permitted extraction quantities in light of results of the monitoring program, or as improved estimates of replenishment become available. The report should document changes in bed elevation, channel morphology, and aquatic and riparian habitat.

The report should also include a record of extraction volumes permitted, and excavation location. Finally, recommendations for reclamation, if needed should be documented.

m) Prevention and management of illegal mining

Prevention and mitigation to illegal mining can be achieved through close monitoring, cancellation of mining license of violators, imposing heavy penalties including long-term jail for mining on sensitive areas, and confiscation of mining machinery and vehicles. Department of Mines, law and order authorities need to restrict some areas for example, riverbanks, near schools, clinics, or residential areas. Only miners with licenses should be allowed into mining areas and stop illegal miners through tight security; additionally, 24x7 security to be employed to apprehend illegal miners daily. Night surveillance by night-vision drones may be employed to control illegal mining incidents. The committees formed to guard and monitor mining should control and restrict the number of truckloads per day. The districts/state sharing the boundary shall constitute the combined task force for monitoring of mined materials, mining activity.

n) Management of infrastructure

Temporary access roads or Katcha roads shall be formed between the banks of the river and the mining area with locally available bio-degradable materials such as sugarcane waste, hay, etc. The preliminary works such as the construction of temporary sheds, bio-toilets, drilling of bore wells, waste management facilities need to be developed before mining operations. CCTV cameras need to be installed at the entry and exit points. Cameras may be installed at all quarries/depots to monitor illegality if any is taking place. All such points should have 24X7 CCTV coverage of the footage of which should be made available to the district administration. The entry/exit points should have boom barriers which will record the vehicles entering and exiting the plot to reduce unrecorded dispatch.

o) Management of pollution

Proper entry and exit points for the movement of loading vehicles in and out of the sand mining sites shall be carefully located, taking into consideration the habitations/settlements in the area. Construction of separate gravel roads for tipper trucks to reduce traffic congestion, accidents, as well as noise and air pollution, maybe consider. All the vehicles should be serviced regularly to fulfil the existing legal framework to minimize noise and air pollution. The transportation route so selected should be verified by the Goa Government for its carrying capacity. Movement of heavy vehicles from public roads to pit sand, gravel, and river sand collection points need access roads. To prevent air pollution due to the dust during sand mining operations and safeguard the workforce in the sand mining and depot site, constant water sprinkling on the pathways and dust prone areas may be conducted. The sand loaded vehicles are to be covered with a tarpaulin before moving out of the quarries/depots. Plantation needs to be done with the consultation of the state forest department beside the sand transportation road to curtail the dust pollution.

The air and water quality may be checked periodically to ensure that no pollution is caused due to sand quarrying operations. Safety gadgets such as earplugs, goggles, respiratory devices, luminescent vests may be provided to the workers at the sand quarry site. First aid kit with all essentials shall be kept ready at all quarry/depot site, in case of any emergency. Independent labour camp and environmental and its need to be carried out at least once in a year for each mining site by reputed third party entity and report of such audit be placed in the public domain.

8.6 Development of green belts and Nursery

This helps in prevention of dust and screening noise, maintaining ecological balance, increasing aesthetic value, plantation to be carried out on both sides of the roads/river, saplings will be planted with recommended interval. Channel erosion often occurs on riverbanks with no or minimum vegetation cover, hence, plantation is prerequisite to improvement of river banks.

- Development of nursery can help in providing sapling for the region. It is recommended to cultivate nursery (for grasses, palms and other native tree including mangrove species) that are helpful in river bank protection and erosion control.
- A plantation plan developed by a plant ecologist familiar with the flora of the river for areas (in consultation with the Forest Dept.).

- River bank should be stabilized by means of compaction and then planting with vegetation.
- Any access routes without vegetation, especially if they are not beneficial to the local community should be ploughed and replanted with native species.
- Plantation along the riverbanks with no or minimal vegetation need to be conducted, irrespective of signs of erosion or not (ensure that species selected are indigenous).

8.7 Mangrove management and conservation

In Mandovi, the mangroves are well represented in the middle and lower stretches of the river. Most of the mangroves are well grown and there has been a steady growth in the mangrove cover along this river.

There is no requirement of mangrove plantation in the study area but management of the existing mangrove vegetation is essential. The areas which are intruded by saline water need protection and the mudflats need to be maintained. Areas with newly recruited mangrove saplings can be blocked by restricting the tidal influx so that land use change can be avoided (from paddy fields to mangrove).

8.8 Embankment protection and restoration

This river is traditionally managed by construction of embankments so that floodplain can be used for paddy cultivation. The region is also represented by coconut plantation. Embankments have been constructed mostly by mud, silt and soil with protection of laterite bricks/boulders as lining between the estuarine river and land. Regular maintenance of embankments is an essential activity and failure to maintain results in saline water intrusion towards the landward side and turns the paddy fields into saline marshy areas rendering them uncultivable fallow lands.

- One saline surge can destroy the paddy fields and render them fallow lands as well as it can damage the houses; thus, it is imperative to protect the riverbank sensitivities constantly. In recent times there are few stretches of the river where construction of concrete embankments is completed.

- The areas adjacent to the river with paddy field and villages/ houses will require safeguarding from saline intrusion and flooding. Bunds have to be made with traditional means and should ensure maintenance. The authorities may also consider new methods that are innovative and sustainable for protection of bunds, restrict erosion and arrest saline intrusion.
- The vulnerable (soft sediment bank walls of the river) areas should be protected and no sand extraction shall be permissible in these regions.
- Provision of funds for maintaining embankments is essential

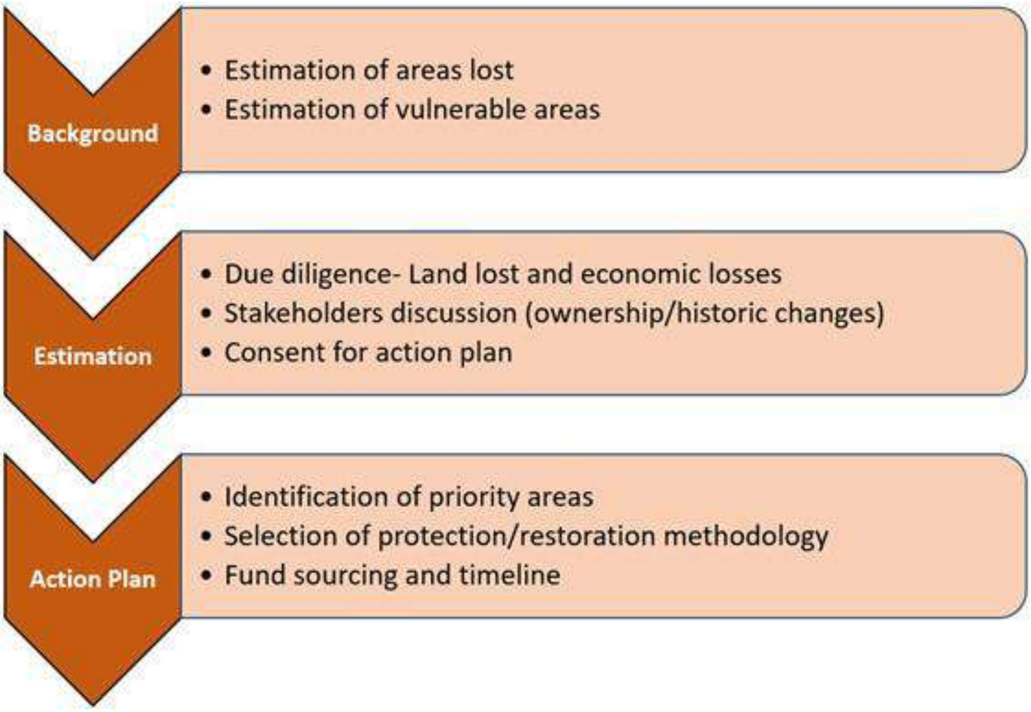


Figure 8.4: Schematic diagram of river bank protection and restoration plan

8.9 Biodiversity conservation & management plan

Several habitats in the study area are important habitats for several species of conservation importance. It is important to protect not only the species but the resources and habitats on which they are dependent. No doubt the proposed activities are deleterious to the ecosystem, no matter how sustainable we make it. Thus, to compensate the negative impacts, proactive conservation efforts have to be undertaken to minimize the impacts and to further enhance biodiversity, improve conservation and add ecosystem services.

Being an area of edible natural resources, necessary protection should be provided to promote the traditional fishing by public consultations and if necessary, through environmental protections.

Objectives

- To minimize direct and indirect disturbance to marine flora and fauna other than within the immediate works areas.
- To ensure turbid plumes from the works and re-suspension of material from the disposal site do not impact the long-term ecological values and integrity of the adjacent benthic assemblages and important faunal groups.
- To reduce the impacts to the intertidal sensitive habitats to the maximum extent possible.

8.9.1 Conservation plan for fauna

The estuarine region is a known habitat (based on secondary information) for Otters, Crocodiles, and Dolphins. Crocodiles are found near the mangrove forests and inland marshy areas. The otters inhabit the mangrove areas and frequent the river banks and sub-tidal estuarine waters for foraging. These species require minimal human disturbance therefore they thrive well if given protection and their habitat is well conserved. Several birds visit the river and adjoining habitats for foraging as well as nesting. There are few species that are long distant migrants (especially waders) as well as local migrants. Mangroves and banks of the rivers are used as nesting sites by several species.

Following measures have to be followed to ensure the conservation of marine fauna and their habitat:

- An on-site expert (observer) to be deployed for periodic monitoring of the important species in the entire stretch of the river which is being carried out in the region and the same activity can be extended to the proposed areas
- Vessel movement has to be regulated. Vessel movement has to be immediately halted at the sighting of any marine mammals/reptile in the active working zone. The excavation of sand as well has to halt until the animal leaves the area.

- Management of marine litter, garbage and plastic is one of the important aspects with respect to each active mining zone.
- Noise levels, air pollution and sewage discharge have to be kept at minimum and have to be within limits as prescribed by laws.
- Capture, trade or killing of any scheduled species has to be reported and accordingly non-conformance action has to be initiated by the team/committee.

8.9.2 Conservation & natural resource utilization

The estuarine region and river bed harbour important benthic faunal and floral diversity. In order to conserve these habitats, they are needed to be monitored regularly as they are dynamic habitat and are constantly exposed to anthropogenic pressures. Hence proper management plan for solid waste and oil pollution is needed to be followed and precautionary measures for any incident should be in place. The hard substratum within the study area is good for the growth of green mussel (*P. viridis*) and oyster (*Crassostrea madrasensis* and *C. gigas*). Shellfish in the study area are exploited due to its high price as a food source. Due to frequent localized extraction, and no scope of growth, shellfish size has decreased over the years and at many places, there population has been replaced by other species. Restoration and sustainable use of such species helps in good ecological and economic gains. Several species of clams of commercial importance occur in the study area. These clams mostly inhabit the mudflats/sandflats and preferably collected during the low tide. Species of *Paphia malabarica, Paphia textile, Meretrix meretrix, Meretrix casta, Villorita ceprenoides, Anadra* sp. and *Polymesoda erosa* are found in the mudflats, sand flats and mangrove sediments in the study area. These species have shown a drastic reduction in the population and their revival is very important. The team/committee appointed for this plan can further carry out these activities and should make village level teams for monitoring and implementation of all the activities. Following practices have to be followed for sustainable utilization of these resources:

- Harvest of the natural population requires regulation and regular restoration. It is necessary to block certain areas as no harvest zone, so as to ensure their population to replenish. Integrated sustainable aquaculture as given below (sub-sections of this plan) is to be implemented to harvest and rejuvenate these ecologically and economically important species.

- Quota system should be implemented by each village so that depletion of natural stock can be avoided.
- Cleaning programs, by participatory approach for sustainable resource utilization from mudflats, rocky shore is essential.
- There should be size restriction for each species wherein, care should be taken to harvest natural populations so that they attained reproductive size.
- The empty shells after extraction of edible flesh should be placed back in the same habitat as they serve as recruitment substratum for new spat. The cues from the dead shells attract larvae for settlement that aids in avoiding succession for establishment of another species as well.
- Conservation of habitat for the above mentioned commercially important species will also aid in conserving other species that are not commercially important but are ecologically very vital for sustenance of healthy and functional ecosystem.

8.9.3 Community participation

The existing mangrove management strategy is a combination of conservation through statutory compliance, community awareness and sustainable utilisation of natural resources through cooperative management. In 1952, Government of India (GoI) formulated National Forest Policy, which classified Indian forests into four classes, viz. i) Protected forests, ii) National forests, iii) Village forests and iv) Tree lands. Forest Conservation Act of 1980 encourages reasonable use of natural forest resources while National Forest Policy of 1988 invites community participation for the regeneration and management of forest through Joint Forest Management (JFM) program. This gives rights to local inhabitants to exploit forest resources to some extent like collection of fuel wood, fodder, fish, shrimp, honey and wax and thus provided mutual benefit to community and forest department. Presently, almost all mangrove habitats of India enjoy legal protection under Wildlife Protection Act of 1972 and Forest Conservation Act of 1980. Gadgil (2002) lists the following 6 factors as important considerations in a participatory assessment program;

- Motivating local people to revive and build on their traditional conservation practices;
- Establishing a positive relationship between local communities and government agencies;
- Identifying and establishing a system of positive incentives for local communities to adopt conservation management;
- Enhancing elements of good governance such as efficiency, participation and transparency;
- Incorporating local information into the formal system of scientific knowledge so as to make it richer and more immediately relevant; and
- Ensuring that folk knowledge of conservation management and sustainable resource use is preserved and at the same time giving recognition to the validity of such knowledge.

Based on the above concepts it is imperative to carry out the conservation, restoration and monitoring with community participation. Local village committee/ Biodiversity Management Committees (BMC are already formed by GSBB) to carry out the responsibilities of the restoration and conservation plan. These committees adhere to the people's biodiversity register (PBRs) and can form self-help groups (SHGs). A technical team of experts is usually attached for the smooth working and guidance from subject experts. These procedures will help to develop responsibility and equitable sharing of resources as well as conservation of the area (Goa State Biodiversity Board [GSBB] carries out these responsibilities regularly for the entire state).

Below mentioned techniques and methods are can be mostly financed by several existing governmental schemes. There are several schemes which provide training, start- up grant and technical guidance to carry out sustainable integrated fishery and cultivation. The schemes are fully or partially funded, wherein the role of technical team and experts is important to bridge the gap between the involved stakeholders. The financial support in case of a prerequisite can be taken up by the respective project proponent as part of their CSR.

8.10 Floodplain management (saline marshlands)

The areas with saline intrusion have been converted to saline marshlands followed by mangroves and many areas are at different stages of progression towards these habitats. If these areas are unattended, not maintained or taken care off, will be ultimately succeeded by mangroves. Once mangroves are established, the spread to adjoining areas is usual as they tend to accumulate more sediment and concurrently the embankments are penetrated by salinity due to natural deterioration of embankments. There are various reasons for the deterioration of embankments such as sea level rise, high tide surges, other extreme events and floods. Overall, over the time to come, if protection by embankments is penetrated by saline water more floodplain areas will be dominated by salinity.

Considering the present status of this river and the adjoining land use in the floodplain areas there is already intrusion of salinity, and it is important to manage these areas. Restoration of bunds should be undertaken on priority basis along with management and maintenance of sluice gates. Following activities are proposed for sustainable use of existing lands;

- There are developed varieties of saline resistant rice species. Such species can be recommended for cultivation in areas of saline intrusion.
- Various state level schemes and subsidies are available for carrying out the paddy cultivation which can be tapped via the committee members of this plan.
- Traditionally, paddy cultivation has been a community activity and the same can be extended to manage the saline marshland and its cultivation.
- Village level SHGs, BMCs, Farmer's group can be formed/ a sub-committee including members of concern state government officials and technical expertise as well for the smooth running of the schemes.

These areas which do not have mangroves can be utilized for sustainable aquaculture practices.

8.11 Development of sustainable integrated aquaculture

Several options are suitable for the rivers in Goa which have estuarine region with mangroves and mudflats, thus the suggestions given below are added after consultation with State Fisheries Dept., Goa and ICAR, Old Goa.

Integrated aquaculture is a technique of sustainable aquaculture which includes raising fish with combination of rice, pigs, and ducks as well as poultry which helps in rising family income. Since animal waste make good fertilizer it can save upto approximately 60 percent of the cost of fish farming which goes for feed. This technique includes different types of farming: paddy cum fish farming, composite culture and polyculture. Several species are available that give good economic gains and if a compatible mix species culture can be carried it reduces the risk of losses. The team for the plan can suggest the combination of species and the methods accordingly considering the site, locations, area, tidal regime, physico-chemical parameters and economics.

The important estuarine fish species caught are *Mugil cephalus, Johnieops* sp., *Sardinella* sp., *Secutor* sp., *Leiognathus sp., Parastromateus niger, Pampus chinensis, Pampus argenteus, Rastrelliger karagurata, Stolophorus indicus, Chirocentrus dorab, Opisthopterus tardoore, Lutjanus campechanus, Etroplus suratensis, Lates calcarifer, Polydactylus plebeius, Scomberomorus commerson, Scomberomorus guttatus, Arius sp., Cynoglossus arel, Penaeus monodon, Fenneropenaeus merguensi, Metapenaeus affinis, Metapenaeus dobsonii, Scylla serrata, Portunus pelagicus, Charybdis feriatus, Loligoduvauceli, Villorita cyprinoides, Polymesoda erosa, Meretrix meretrix, Meretrix casta, Paphia malabarica, Paphia textilis, Crassostrea madrasensis, Crassostrea gigas*

From the available statistics, the approximate fish production from the east coast and west coast estuaries are 30,000 and 20,000 tonnes respectively. However, there is always a scope revising, reclassifying, and adding the estuarine systems in order to formulate an estuarine monitoring network along the Indian coast. Therefore, we would be able to understand the major gaps in the fisheries data of estuaries, which would enable us to focus on these ecosystems to explore its diversity, fish biomass, and landing patterns.

Development of shrimp farming from a traditional activity to a highly commercial farming enterprise in a span of about one decade has been one of the most spectacular achievements of aquaculture in India. The government of India enacted the Coastal Aquaculture Authority Act, 2005, enabling the establishment of the Coastal Aquaculture Authority for enforcing proper regulatory measures for sustainable eco-friendly aquaculture. The Act encompasses all forms of aquaculture to be practiced in saline or brackish water in the coastal areas.

The brackish water aquaculture can also further go ahead with the means of diversification of species used in the farming practices. Seabass, *Lates calcarifer* is a fast growing, high valued carnivorous fish ideal for Indian conditions. The technologies are available for seed production and grow out culture. However, the demand for seed needs to be met through the development of more hatcheries along the coastal states. The total area under seabass farming is 2500 ha with a total production of 5000 tonnes. At present 30, 000 farmers are employed in this farming practice and project a huge potential for the future. The other candidate species for the brackishwater aquaculture are Milkfish (*Chanos chanos*), Pearlspot (*Etroplussuratensis*), Mud crab (*Scylla serrata*), and Grey mullet (*Mugil cephalus*), Red snapper (*Lutjanus argentimaculatus*), and Silver pompano (*Trachinotus blochii*) etc.

Apart from the species diversification, the diversification of aquaculture systems is essential to provide access to a large number of farmers to support their livelihood through brackishwater aquaculture. Cage culture of finfish in brackish waters provides a great opportunity for farmers with access to open waters to adopt aquaculture as a livelihood option. However, the availability of the quality seed and feed are the major hurdles that need to be addressed through indigenous seed production systems to address the demand.

Goa state encompasses huge potential for fishery activities with a coastline of 105 km, continental shelf area of 10 million ha, estuarine area of 13,157 ha (covering 8 estuaries), brackishwater area of 3500 ha, Khazan land of 18,000 ha, 555 km length of rivers, 100 ha freshwater ponds, 3250 ha of reservoirs and mine reject pits of 200 ha. The fish production of state currently stands as 1.05 lakh tonnes of which 1 lakh comes from marine and 5000 comes from inland fisheries (95% from estuarine and brackishwater resources). On the other hand, inland fish production is gradually decreasing and there is ample scope for coastal aquaculture for further improvement in production on account of greater demand. The estuarine area of Goa is not utilised for development of coastal aquaculture. There are several culture systems that can be practiced in the estuaries of Goa, which has higher productivity and abundant natural seed resources. The government of Goa has introduced various schemes to encourage development of aquaculture in the state (Table 8.1).

Table 8.1: Schemes for aquaculture in Goa (Source: Fishery department)

1.	Financial Assistance to Brackish Water Aquaculture Pond	A. Financial Assistance for Construction and Renovation of Farms 25% subsidy limited to Rs.2.00 lakh per ha of which Rs.45, 000/- per ha will be the Central Share. Up to 2 ha after 5 years. B. Financial Assistance for purchase of farming equipments: 50% subsidy limited to Rs.1.00 lakh per ha. Up to 2 ha after 5 years. C. Financial Assistance for purchase of feed: 25% subsidy of the cost of feed limited to Rs. 30000/- per crop per ha for 2 crops in a yr. Eligible every year.
2.	Financial Assistance for setting up of Crab farming Unit in Goa	A. Financial Assistance for setting up of the crab culture unit: 25% of the actually cost limited to Rs.1,50,000/- per ha. Farmer will be eligible to 2 ha. B. Financial Assistance for purchase of seed and feed: 50% of the actual cost limited to Rs.75, 000/- ha. Limited to 2ha per yr.
3.	Financial Assistance to Freshwater Aquaculture farm	A. Financial Assistance for Construction and Renovation of Farm: 25% subsidy limited to Rs. 2.00Lakh per ha. Eligible every after 5 yr.

		B. Financial Assistance for purchase of seed and feed: 25% subsidy limited to Rs.50,000/- per ha. Limited to 2 ha. Eligible on seed and feed once in every year. C. Financial Assistance for purchase of Farm Equipments: 50% limited to Rs. 60,000/- per ha. Eligible after every 5 years.
4.	Financial Assistance to Mussel Culture and Oyster Farming in Goa	A. Setting up of unit in estuarine waters: 50% subsidy limited to Rs. 25,000 per unit, maximum for 2 units. Each unit in the estuarine water will be of size 4 mtrs X 4 mtrs. B. Setting up of unit in open sea 50% limited to Rs. 40,000 per unit, max for 2 units. Each unit in the open sea will be of size 6 mtrs X 6 mtrs.
5.	Financial Assistance for setting up of Ornamental Fish Unit in Goa	A. For setting up of Breeding unit-50% of the actual cost limited to Rs.1, 50,000/-. B. For setting up of Rearing unit-50% of the actual cost limited to Rs.1, 50,000/-. C. For setting up of Rearing unit and Breeding unit- 50% of the actual cost limited to Rs.2,50,000/-.

Following are some of the known aquaculture species that are well suitable for considering as small-scale business model.

8.11.1. Paddy cum fish farming (freshwater)

This system explained here produces mix species of fishes with paddy. Process of culture starts from growing two crops of paddy; the one which is tall variety and the other is high yielding variety in wet season and dry season respectively with single crop of fish. In freshwater, Rohu (*Labeorohita*), Catla (*Catla catla*), Mrigal (*Cirrhinus cirrhosis*), and fast-growing species like Silver carp (*Hypophthalmichthys molitrix*), Grass carp (*Ctenopharyngodon idella*) and Common carp (*Cyprinu scarpio*) were used as pelagic, mid pelagic and benthic fishes. Prawns also grow well on paddy fish culture plots. Optimum stocking density that is usually practiced in case of carps is 6,000- 20,000 number of seeds per hectare.

Selection of site: Water holding capacity of selected plot should be good enough. Clay-loamy soils are suitable for paddy- fish culture. Low laying area with high rainfall is suitable for culture. Either side of the central line dug deep to act as main supply or drain canal. Each plot is bordered with bundhs with 0.3m height and 0.3m width. Dike or bundh is provided by inlet and outlet made up of bamboo shoots. These are placed in the middle and fitted with screens to avoid entry of predators as well as escape of cultured fishes.

Culture of paddy-fish together: Generally, this technique is practiced in moderate or low paddy fields where water source exists for 4-5 months naturally. Carps or other fishes like Tilapia are cultivated along with the rice.

Fish culture after harvesting rice: In this technique, fishes ate stoked after the harvesting of rice crops. This will provide 6-7 months of rearing fishes.

9.11.2. Oyster culture

Some Oysters are edible and its culture is widely practicing in India. Four species are commercially cultivated in India. They are: *Crassostrea madrasensis*, *Crassostrea gryphoides*, *Crassostrea rivularis*, *Saccostrea cuculata.*

Site selection: Site must have good water quality, open sea from strong wave action and salinity range should be 25-31ppt.Avoid sites prone to toxic algal bloom.

Seed production: Seed requirement for culture is met either from wild or from hatcheries.

Spat fall prediction: Gonadal maturity stage helps in spat fall prediction. When 70% of female are with ripe gonad spat collectors used to collect the spat. If they are placed much earlier or after the spat, fall they get silted or fouled and make them unsuitable for spat settlement.

Intensive culture: Containerized production of oysters is referred in intensive culture. Containerized production includes floats, bags, rafts, long line system, racks etc. for predator protection. This system has to face impacts from storms, fouling organisms etc. Therefore, selection of site should be based on water quality, wave action and predation level. This type of culture is more expensive as it requires more labour for gear and product maintenance.

Extensive culture: This culture refers to spat on shell or clutched production. Oyster larvae from hatchery are set on clean oyster shell and planted directly on the bottom and grow out in clusters. This method is not expensive as the other one but in this methods mortality, rates are higher as there is very less maintenance.

Feeding: Oysters feed on algae especially *Isochrysisgalbana* and *Chaetocero s*sp.

Farming methods: Seed oysters could be grown either on bottom or off bottom culture methods. Rate of production depends on culture methods. Bottom should be firm and free from predators and silting. There are different types of culture methods: Rack and Tray Method, Stake Method and Rack and String Method.

Rack and tray method: The young oysters are scrapped from the tiles and transferred to box type cages and covered with synthetic twine. After two months of rearing by suspending cages from racks, the grown oysters are transferred to rectangular trays. 20 trays each of 200 oysters are reared on rack and at the end of the year oysters attain length from 78mm-105mm. The approximate production rate in this method of culture is 120t/ha/year.

Stake method: Stake is a support used to keep spat on spat collector above bottom. It may be Casuarina or eucalyptus pole of 1.50m. To protect spat from predation pole can be covered with piece of fabric. Production rate may be 20t/ha/year.

Rack and string method: A string can hold six shells valves holding 80-100 spats and the strings are enclosed in a bag. These suspended from racks should keep in calm and good water movement site. After 2 months of rearing the bags are removed and the oysters are transferred to oyster farm. In this method the production rate is 80t/ha/year.

Threats: Pest and predators can cause considerable damage. Common predators are barnacles, serpulids, anemones, sponges and gastropods.

Harvesting: Harvesting season depends on spawning season which is March-April and August-September. Harvested oysters go through depuration which is cleaning and reducing the bacterial load on shellfish and shucking which is the process of removing meat from depurated oysters. Meats of the oysters are edible and shells are used in spar settling and manufacturing of calcium, lime etc.

8.11.3. Mussel culture

India has a long history of mussel farming that dates back to the 13^{th} century. They are considered as popularly eaten and delicious food by the people of West Cost. The main producers are India, China, Korea, Spain, France, New Zealand and Netherlands. Three different types of mussels are cultivated in India. They are: *Perna viridis* (Blue green mussel), *Mytilus edulis* (Blue mussel), *Modiolusmetacalfie* (Brown mussel).

Site selection: Estuarine areas which are free from strong wave actions may be selected. Clear water with high plankton production is ideal for mussels. Depth of culture should be 2m and salinity should be 30-35 ppt. and should be free from industrial pollution.

Seed collection: Healthy seeds from natural habitat are collected. Seeds are healthier if they are from submerged tidal area. Size of the seed should be 20-25mm. Nylon rope or coir rope is used for seeding. Cotton cloth or cheap net is used to cover seeds on the rope. After placing the rope over the seed, the net is tightly stitched in such a way that seeds spread uniformly around the rope.

Culture methods: There are 3 main types of culture methods in mussels.

A. Deep Water Culture

- Raft Culture
- Long Line Culture

B. Intertidal and Shallow Water Culture

- Rack Culture
  - Hanging Method
  - Stake Method
  - Tray Method
  - Buochot Method
  - Wigwarm Method

C. Bottom Culture

Raft culture: The depth of the site may vary from 5-10m and rafts measured 5×5m or 8×8m. Teakwood, Casuarina and bamboo shoots are used to make poles in raft construction. Empty oil drums are used as floats. Seeds of 2.6-2.8mm length are seeded on coir or rope. Depending on the depth length of the rope varies. Ropes are spaced 0.6-1m apart. Average growth rate is 9-11mm/month and can be harvest in 5-6 months. Production rate in this type of culture is high.

Long line culture: Long lines are long ropes anchored at each end supported by plastic barrels. Depth may be 10-15m. It can withstand severe climatic conditions. The rope is 60 m long with 20-24m thickness anchored at both the ends with 150kg concrete and barrels are fixed at 3m intervals. A long line unit of 60×60m rope can accommodate 12 horizontal ropes and 900-1000 seeded ropes. The production rate was 15.32kg/net bag/5 months.

Rack culture: Fixed structures are constructed ain the waters at the depth of 3 m. Bamboo or *Casurina* pole are driven at the bottom at 1-2m interval. Wooden frame built on ropes used to suspend seeded bags. Once the mussel seeds are placed the netting is wrapped and both the ends are stitched with cotton twines. In about six months mussels reach around 65-77m length. The production rate is approximately 33.5kg/net bag/5 months.

Hanging method: Nylon ropes are threaded with coco fibres supported by empty oyster shells to collect spat. Piece of stone is attached at the end of the rope to prevent surface floating.

Stake method: Bamboo pole of 4-6 m length are staked at the bottom at the depth of 3 m. collected spats are allowed to grow for 6 months until they reach marketable size. Around 2000-3000 seeds are attached to 1 m stake below low water level.

Tray culture: Tray culture is limited to detached clusters of mussels. Bamboo or metal trays are used. They are either hang between pole of hanging or stake methods.

Bouchotculture: They are also called Pole Culture. Poles which are used are big branches of oak tree around 4-6 m which are staked 0.7m apart on soft, muddy bottom of intertidal zones. Mussel seeds are collected on coco fibers and are attached to oak branches in spiral fashion until they grow marketable size. Production was 14kg/pole of 15.7mm average length mussels.

Bottom culture: This method is widely practiced all over the world. Mussels are grown directly on the bottom. Firm bottom is required with adequate tidal flow with silt deposition and provide sufficient oxygen. If the natural ground is unsatisfactory then those seeds can be transferred to private farming ground. Natural conditions control quality and quantity of food as well as water flow. This type of culture requires minimum investment however it is prone to heavy predation such as oyster drills, crabs, starfish etc.

Harvesting: Harvesting takes place after 6 months and meats as well as shells are used in various fields.

8.11.4. Clam culture

Clams, as a general term, can be used to describe any bivalve mollusc species which buries itself in the sediment. There are numerous commercially important clam species which are cultivated in India. Some of the species are given below: ***Villorita cyprinoides, Paphia malabarica, Meritrix casta, Anadara granosa*****.**

Site selection: Intertidal and sub-littoral locations are best. They are buried in the substrate. Their survival is better in sand or gravel substrates but it is possible to grow them in muddy areas too. Salinity should generally be above 25 ‰.

Cultural techniques: Their stocking density should be approximately 400 to 500 seed at 8mm shell length. Manual methods can be used for small-scale cultivation but mechanisation is needed for laying mesh and harvesting as scale of production is increased. Seed are available from commercial hatcheries at a range of sizes from 4 to 30 mm shell length. Clams are usually grown in plots under lengths of netting to protect them from predators. The edges of the netting should be buried in the substrate down to 10 cm and kept in place with rope stapled round the edges with metal hooks every 0.5 m pushed through the mesh into the substrate. It will be necessary to change the netting at least once during culture period increasing the mesh size since the clams will take around 3 years to grow to a harvest size. Clams can also be grown in oyster bags sunk into the sand in rectangular plots and staked into place leaving about 2.5 cm protruding above the sand.

Harvesting: Harvesting takes place when they reach marketable size.

8.11.5. Seabass culture

Pond culture of Asian Seabass (*Latescal carifer*) is one of the commercially important finfish. This variety is much-in-demand with huge export potential. Small and marginal farmers can adopt this method of culture as it is cost-effective manner. This is a euryhaline fish, growing rapidly up to 3-5 kg within a growing period of 2-3 years in both freshwater and brackish water environments. It is a voracious carnivorous fish; juveniles are omnivorous, feeding mainly on crustaceans and other small fishes. It attains maturity at the age of 3-4 years at a length and weight range of 60 to 70 cm and 2.5 to 4.0 kg respectively.

Nursery: The main purpose of the nursery is to culture the fry from hatchery to juvenile size. During nursing period, the juveniles can be graded into different size groups and stocked in separate grow-out ponds. Nursing the fry in concrete tanks is not recommended as accumulation of excess feed on the bottom of the tank cannot be avoided. Such accumulation can cause bacterial disease.

Nursery pond: Nursery Pond size ranges from 500 to 2000 m^2 and water depth should be 50–80 cm. The pond has separate inlet and outlet gates which facilitate water exchange. Pond bottom should be flat and sloping towards the drainage gate.

Stocking: Stocking of 1 kg fish biomass/m3 is recommended for a 100 tonne of water.

Culture methods:

- Cage Culture
- Traditional Culture

Cage Culture: Seabass culture can be done in more organized manner as a large-scale activity in cages. The size of the cage may be 50 m (5 x 5 x 2 m) with mesh size depending upon the size of the fish to be stocked. In cage culture, both floating and stationary net cages are used.

Traditional culture: In ponds, juveniles of various sizes collected from estuarine areas are introduced and fed with the trash fishes like tilapia, shrimps and prawns. These ponds receive water from adjoining brackish water or freshwater canals or from monsoon flood. Harvesting is done after 6-8 months of culture. Production can go up to 2 ton/ha/7-8 months.

Pond culture: The two-week nursery reared fingerlings are ideal for pond culture. Pond can have concrete walls and a soft bottom with water depth of up to 2 m and salinity of 5-10 ppt. Seabass culture in ponds can be carried out either by monoculture or by polyculture method. Monoculture is that type of culture where a single species of animal is produced and Polyculture is method which involves incorporation of a species of forage fish with the main species in the pond. The choice of forage fish will depend on its ability to reproduce continuously in quantity sufficient to sustain the growth of seabass throughout the culture period. The forage fish must be such a species that could make use of natural food produced in the pond and does not compete with the main species in terms of feeding habit such as *Oreochromis mossambicus, Oreochromis niloticus*, etc.

Pond preparation: The pond is at first dried, tilled, levelled and manured with raw cow dung @ 1000 kg/ha. If required, lime is added @ 50-200 kg/ha to maintain soil pH above 7. Sea water/fresh water is then filled to a depth of 60-70cm in the pond. When the pond water becomes light green in colour indicating sufficient development of algae in the pond, forage fishes are introduced.

Feeding: The fish feed methods have to be carried out as per the following. In the first method, the fish are fed exclusively with chopped trash fish and in the other; the food is made available in the pond in the form of forage fish like Tilapia **(***Oreochromis mossambi*cus**).** Pelletized feed can also be given.

Harvesting: Harvesting is done with the help of seine-netting the pond or by draining. After harvesting they are usually transported live in tanks by truck.

8.11.6. Shrimp culture

Shrimp is one of the most traded seafood commodities, and aquaculture of shrimp is considered to be one of the success stories of modern aquaculture. Shrimp farming generated millions of employments, and provides foreign exchange to developing countries. Modern practices with growth on scientific basis using hatchery produced seeds, formulated feeds water management methods have been initiated over the last 20 years. Although growth of shrimp aquaculture is remarkable, the sector has been facing several issues such as viral diseases, issues in marketing, and poor farm level performances. For optimum utilization of the resources and increased production, productivity and returns to the farmer, improvement in the existing technology is necessary. Such improvements should aim at the following:

a) Improved farm design – for operational ease

b) Optimum soil and water condition

c) Removal of pests and predators

d) Qualitative and quantitative aspects for stocking shrimp larvae

e) Supplementary feeding

f) Soil and water quality management

g) Monitoring of growth and health

h) Improved methods of harvesting post-harvest management

According to Brackish Water Fish Farmers Development Agencies (BFDA), the topography of Goa is ideally suited for prawn farming, as the seawater is regulated only on the basis of high and low tides and the flooding of water is almost negligible. The BFDA also claims that Goa has good tidal amplitude as well as spring-tides which facilitate natural flushing. Moreover, there are no turbulences or fast currents. Costal Aquaculture Authority (CAA) guidelines were formed to ensure orderly and sustainable development of shrimp aquaculture in the country. The guidelines are intended to lead to environmentally responsible and socially acceptable coastal aquaculture and also enhance the positive contributions that shrimp farming and other forms of aquaculture can make to socio-economic benefits, livelihood security and poverty alleviation in the coastal areas.

Stocking: The most suitable species for culture in India are the Indian white prawn *Penaeusindicus,* White leg shrimp *P. vannamei* and tiger prawn *P. monodon*. Apart from these candidate species other commercially important species such as *Metapenaeusensis*, *M. monoceros*, *M. brevicornis*, *P. semisulcatus* and *P. merguiensis* are also potential species that can be grown in India.

Site selection

Selection for a suitable site is a critical activity and must be carefully determined before establishing of a shrimp farm. Site evaluation is not only undertaken to determine if a site is suitable for shrimp farming. It is also valuable in determining what modifications are needed concerning layout, engineering, and management practices to make shrimp farming possible at a given site. Factors involved during site selection are topography and climatic condition, infrastructure, accessibility, electricity, security, availability of labor and other factors, water supply, soilconditions. Besides these, the environmental and socio-economic aspects covering social, economic and legal issues are important parameters to be considered while finalizing the site for setting up a shrimp farm.

Pond design and construction: Shrimp Pond should be designed according to the characteristics of the selected site and the culture system. There is no unique design, but optimum and functional farm layout plan and design should be based on the physical and economic conditions prevailing in the locality.

Culture systems: There are three types of shrimp culture being practiced in most countries.

Traditional/extensive cultures: Extensive Freshwater Prawn Culture extensive culture means rearing in ponds (but also in other impoundments such as reservoirs, irrigation ponds and rice fields), which produce less than 500 kg/ha/yr of freshwater prawns. They are stocked, often from wild sources, with PL or juveniles at 1-4/m^2. There is no control of water quality; the growth or mortality of the prawns is not normally monitored; supplemental feeding is not normally supplied; and organic fertilisation is rarely applied.

Semi-intensive culture: Semi-intensive systems involve stocking PL or juvenile freshwater prawns (usually from hatcheries) at 4-20/m2 in ponds, and result in a range of productivity of more than 500 kg/ha/year and less than that defined as intensive in this box. Fertilisation is used and a balanced feed ration is supplied. Predators and competitors are controlled and water quality, prawn health and growth rate are monitored. This form of culture is the most common.

Intensive culture: The ponds are usually of 0.5-1 ha in size and are designed to keep the water at 1.5-2.0 m deep. A reservoir of at least 30 % of the pond area is usually required. High stocking density of 25-60 PL/m2 with feeding rate of 4-6 times daily and strong aeration is maintained.

Open system: This system requires a high supply of good quality water because it needs water, exchange of more than 20% of the total pond volume at one time, in order to reduce pond wastes and the density of the plankton. Seed can be stocked up to 60 PL/m2 and will grow to 25-35 grams within 120 days.

Re-circulation system: In order to avoid deterioration of the environmental conditions, several advanced and company run farms have adopted the re-circulation system to minimize contact with poor quality water from outside the farm. Farms must devote 40-50 % of the area for the construction of water storage/reservoir, sedimentation pond, and treatment pond and drainage canals. Stocking density for this system generally varies between 30-50 PL/m2 and the culture period is between 110-130 days.

Minimal water exchange system: To reduce contact with the water from outside the farm, the minimal water exchange system or closed pond system is practiced in some countries, particularly in Thailand. The system involves filling up the pond with cleaned seawater, treating it with chemicals to eradicate predators and competitors. Then the shrimps are stocked up to 30 PL/m2 and cultured for a period of less than 100 days to attain the average weight of 10-20 gm.

Ponds: Pond preparation is an essential part of culture practices during which the metabolite load and contaminants (chemical and biological) in the soil from the previous culture cycle is removed through tilling, ploughing and drying. During pond preparation, the pests and predators are removed and pH and nutrient levels in the water and soil are brought to optimal concentrations through application of lime, organic manures and inorganic fertilisers.

Water quality and its management: The quality of the water available in the site has a strong influence on the success of the shrimp farm. Water quality parameters like pH, salinity, dissolved oxygen (DO) and the presence of toxicants/ pollutants should be ascertained. The water source should be free from any industrial/ agricultural pollution. The presence of contaminants and their levels should be considered in the light of the tolerance and also sub-lethal effects on the species to be cultured.

Seed selection and stocking: Seed quality has a direct relationship with the survival and growth of the cultured shrimps and the stocking density has a strong bearing on the level of waste generated in the pond. Only healthy and pathogen-free seed from registered hatcheries should be used for stocking. Before stocking the seeds should be acclimatized to prevailing temperature, salinity and pH conditions in the pond by gradual mixing. In areas with very low salinity, salinity adjustments are to be made over a period of 4 –5 days and hence should be done at the hatchery itself.

Feed and feed management: Using good quality feed in reasonable quantities, water and soil quality in ponds remains in optimum conditions. This reduces stress on shrimp, there is less likelihood of disease, and they convert feed more efficiently to improve the feed conversion ratio and minimize feed costs.

Health management of shrimps: The health management approach includes reduced stocking of disease-free seed, better handling, maintenance of good pond environment, and optimal feed management to reduce the stress and prevent most infectious and non-infectious diseases. Disease should be diagnosed immediately with the help of trained pathologists/ microbiologists. Treatment should be undertaken only when a specific disease has been diagnosed and it is known that this disease is treatable.

Harvest and post-harvest: Successful harvesting can be achieved if the shrimp can be harvested in good condition within a short period of time. The harvesting technique should not damage or excessively contaminate the shrimp with waste. Rapid harvesting will reduce the risk of bacterial contamination and the shrimp will still be fresh when reaching the processor.

Methods of harvesting: Harvesting can be done by completely draining the pond either by gravity or through pumping and hand picking or trapping.

The water drained out for harvesting should be pumped into the waste stabilization ponds and kept for a few days for settlement before releasing into the open water. Icing should be done immediately after harvest.

8.11.7. Mud crab culture

Among the marine edible crustaceans, crabs are one of the most important shellfish by virtue of its delicacy, demand and price. Since 1987, live mud crabs (Scylla spp.) are exported to an extent of 1500 tons annually, valued at Rs. 30 crores. Most of the commercially important crabs belonged to the family Portunidae and they can be recognized by the presence of flattened last pair of legs, which help them in swimming in the columnar waters. Species belonging to genera *Scylla, Portunus* and *Charybdis* which grow to 0.2 to 2.3 kg are considered as commercially important portunid crabs as they are utilized for both local consumption and export trade.

Mud crabs stand first in the context of both capture and culture fisheries due to their larger size, great demand and higher price. Mud crab is one of the components in the traditional fish/shrimp farming system of Indian and Southeast Asian countries. Due to their great demand, monoculture of mud crabs is being practiced in most of the Southeast Asian countries. These mud crabs have a remarkable habit of remaining alive after capture for considerable time, say 5 to 8 days. There are only two species of mud crabs *Scylla serrata* and *Scylla tranquebarica* occurring in most of the Indian brackish water areas and inshore seas. They usually grow to a maximum size of 0.7 kg in case of *Scylla serrata.*

Though both the species co-exist in the same habitat, they differ in habits. The larger species remains buried under sand or mud. While the smaller species makes a deep burrow either at the bottom of estuary or in earthen bunds of canals/ponds. s. These differential habits make them more abundance in specified habitats. For example, the larger species is more abundant in the open inshore seas backwaters and coastal lakes, while the smaller species is more in number in mangrove areas.

The size-frequency studies indicated that male and female of mud crabs grew at rate of 9 and 10 mm in CW per month respectively. *Scylla serrata* attains a size of 0.7kg. In an experimental field culture the early juvenile mud crabs (15 to 60 mm in CW (Carapace width)/3 to 20 g in total weight-TW) grew at a rate of 7 to 12 mm/3 to 13 g per month, while juvenile crabs (61 to 80 mm/25 to 70 g) exhibited a monthly growth of 1 to 12 mm/145 to 97 g. In the sub-adult and adult stages, the monthly growth worked out to 8 to 10 mm/100 to 130 g.

Mud-crab farming involves the following steps nursery rearing, soft-shell crab rearing, grow-out culture and fattening. Nursery rearing involves the rearing of megalopa (0.003 g)/crablets (0.03 g) to juveniles in two phases, namely, up to 3 g (in hapas) and 3 g to 25 g (in nursery ponds). Soft shell crab rearing includes the stocking of juvenile crabs (50 to 100 g of *S. serrata*) individually in small plastic cage till they moult. Grow-out culture refers to farming of nursery grown juveniles of about 25 g (seed crabs of *S. serrata*) for a period of 3-6 months to produce marketable size crabs. During this growth period, the crabs undergo several moults (shedding of old skeleton).

Fattening refers to the holding of marketable sized crabs for about 3 to 4 weeks time, during which period, the stocked crabs gain weight. The live mud crab export from India has started in 1987-88 and exported mostly to south east Asian countries. The live crabs are packed in perforated carton boxes lined with thermocole sheets and air-lifted. In order to conserve and protect the natural stock from overexploitation and to meet the ever-increasing demand for local consumption and export trade, mud crab farming with hatchery produced seed will be the best option and as such collection of wild juvenile crab for farming/fattening needs to be discouraged.

In Goa due to low yields from salt-tolerant local varieties of paddy seeds like Korgutt and Azgo, Khazan fields in Goa are generally neglected by farmers. In order to provide farmers with alternative source of income, crab aquaculture can be taken up by these farmers. Goa has about 18,000 hectare of Khazan fields and there is huge opportunity for farmers to harness this to their benefit.

Site Selection: The mandatory guidelines enlisted for shrimp culture for the selection of sites for coastal farms should be strictly adhered to in the site selection for mud crab pond construction. In addition to the guide lines, there are other parameters should be addressed such as physiochemical condition, water quality, flow rate and temperature should be, appropriate for the species concerned. Other factors that must be considered for site selection are weather, shelter, depth and substrate.

Criteria for pen culture in mangrove areas: Mangrove areas should have sufficient supply of marine or brackish water throughout the year. Water depth at high tide should range between 0.3 to 1.0 m. Salinity should be ranging from 10 to 35 ppt and temperature between 25 and 30'C. The site must be free from big waves and pollution, protected from environmental hazards such as big waves and floods and secure from vandals and poachers.

Pond preparation: Pond preparation strategies generally employed in shrimp aquaculture can also be adopted in mud crab aquaculture. However, it is generally believed that meticulous and stringent pond preparation is not required. The installations like net fencing, earthen mounts should be considered. Pond should be drained and kept dry for 1 week to kill pests.

Nursery rearing: Nursery rearing in mud crabs is carried out in two stages as nursery phase - 1 and nursery phase - 2. During first phase, hatchery produced megalopa, which are very small in size are reared with maximum care to attain a size of about 3 g. These 3g sized crablets are further reared in second phase to attain a size of about 25 g

Transport and stocking: Crab juveniles are relatively easy to transport by using cane basket, carton lined with moist sea weeds or mangrove leaves. Chelae are tied to prevent fighting among crabs. Stocking should be done with individuals having intact appendages, and without injury, further seeds should of uniform size. Different sizes leads to cannibalism. Stocking density has a major effect on crab growth, survival and production, and it is generally ranged between 0.5 and 3 crabs per square meter.

Nutrition and feeding: In grow out culture management, locally available cheap protein sources (trash fish, molluscs) at the rate of 8-10%W of biomass can be given. The crabs can be fed a mixed diet of 25% fish by catch (trash fish) and 75% fresh flesh of mollusc or crustacean.

Harvest and post-harvest: Culture period is generally 3 to 6 months and is dominated mainly by the size at stocking and the preference and demand, existing in the market. For *Scylla serrata*, culture duration will be 120 days with an initial size of 25 g and harvestable size of 200-300 g if the stocking density will be 1 crab per square meter. To obtain larger sizes (400-500 g), culture period can be extended to further 3 months. Partial harvest can be made with baited lift nets and bamboo cages. To have a total and complete harvest, crabs are to be handpicked after completely draining the culture pond. Crabs should be tied immediately after their capture in order to curb their movement and to avoid the fighting among them. The tied-up crabs are to be initially washed with fresh sea water and subsequently sent for local marketing after packing them in bamboo baskets.

8.11.8. Milkfish (*Chanos chanos*) culture

Semi-intensive pond farming of Milkfish fingerlings of 7-15 cm size can be stocked @ 8000-10,000/ha and formulated grow-out feed can be applied. Periodical manuring can be done to facilitate the growth of phytoplankton, as food item for the cultured fish. In 5 to 8 months, this fish can attain 0.5 to 0.6 kg body weight and a production of 3 to 4 t ha-1 can be obtained. Milk fish can also be raised in cages and however, this method is not commonly adopted.

8.11.9. Pearlspot fish culture

Pearlspot, *Etroplus suratensis* (locally known as “Kalundhar”) is another important candidate species for culture in ponds, cages and tanks. Polyculture of pearlspot with other brackishwater fish species like milkfish, grey mullet or liza species is commonly practiced. Monoculture of pearl spot is commonly practiced in low volume cages. More recently, cage culture (2 to 4 m3 for 7 to 9 months) is commonly practiced by small scale farmers in estuarine waters and feeding can be carried out using locally prepared feed, agro waste and kitchen discards.

8.11.10. Grey Mullet (*Mugil cephalus*) culture

Grey mullet, *M. cephalus* (locally known as "shevto") can be culture in monoculture or polyculture with other brackish water species (Pearlspot and milk fish and other mullets such as like *Liza tade, L. parsia*) for about 8 months. Size of species stocked is more than 50 to 60 g, with a stocking density of 6000 to 8000 no. ha^{-1}. A total production of 2 to 3 t ha^{-1} can be expected from the system. Feeding is carried out by supplementary feeding and fertilisation of the pond.

8.11.11. Red snapperculture

Mangrove Red snapper (locally knows as "Tamso") can be cultured both in the pond and cages. Cage culture of *L. argentimaculatus* is being practiced in Karnataka and Maharashtra by stocking the wild collected seed in the cages/ponds either by monoculture or polyculture methods.

8.11.12. Ornamental fish culture

There are also some important ornamental fishes from the estuarine areas which can be promoted for domestic and international markets. Major species are silver-moony, *Monodactylus argenteus*, and orange chromide, *Etroplus maculatus*. At present, scarcity of seeds in adequate quantity is creating burden on the wild stock and increasing the price in the ornamental industry. Seed production technology is being standardised by various research institutes such ICAR-CIBA, that offer scope for development of the culture fisheries for these ornamental fish.

8.11.13. Seaweed farming

Seaweed is marine algal species that functions as renewable source of food, energy, bio-chemicals and medicines. It provides a valuable source of raw material for industries like health food, medicines, pharmaceuticals, textiles, fertilizers and animal feed. One of the most important uses of seaweed is for the production of agar, alginates & carrageenan. In India, currently sea weed farming is practiced in Mandapam, especially for the extraction of carrageenan and also to use as a bio-fertiliser. The cultivation of *Kappaphycus alvarezii* and other commercial seaweed are grown by the fishing community in Tamil Nadu specifically in Ramanathapuram, Thoothukudi, Pudukottai and Thanjavur region. Seaweed is grown in three different ways. One of the most popular in India is using the Single Rope Floating Raft (SRFR) method (Coir Rope & Nylon Rope). This involves building of tethered rafts and spreading them out in the sea. After around 45 days, the seaweed is harvested, dried and carrageenan is extracted from it. The second method is using a Fixed Bottom Long Line method (Coir Rope & Nylon Rope). And the third is the less practiced, and however, offer wide scope as a component of the Integrated Multi Trophic Aquaculture (IMTA) method. The input costs for sea weed farming are almost nil and from a single raft, the dried seaweed earns up to Rs. 86,000 annually.

8.11.14. Integrated Multi-Trophic Aquaculture (IMTA)

Coastal brackishwater systems face challenges of waste water management, which can be addressed through culture of species in multi-trophic levels a model Integrated Multi-Trophic Aquaculture can include combination of fish, seaweed and shellfish culture systems. Successful culture trials of Milkfish culture with other species like Shrimp (*P. monodon*), Tilapia (*Oreochromis niloticus*) and red seaweed (*Gracilaria* spp.) has been investigated and offer scope for the future prospects in this sector.

8.12. Development of eco-tourism

Ecotourism is now defined as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education. Ecotourism is catering for holiday makers in the natural environment without damaging it or disturbing habitats. It is a form of tourism involving visiting fragile, pristine, and relatively undisturbed natural areas, intended as a low-impact and often small-scale alternative to standard commercial mass tourism. It means responsible travel to natural areas, conserving the environment, and improving the well-being of the local people. The origins of the term 'ecotourism' are not entirely clear, one of the first to use it appears to have been Hetzer (1965), who identified four pillars or principles of responsible tourism: minimizing environmental impacts, respecting host cultures, maximizing the benefits to local people, and maximizing tourist satisfaction. The major objectives of eco-tourism are as follows:

- Build environmental and cultural awareness and respect.
- Provide positive experiences for both visitors and hosts.
- Provide direct financial benefits for conservation.
- Generate financial benefits for both local people and private industry.
- Design, construct and operate low-impact facilities.
- Recognize the rights and spiritual beliefs of the native community and work in partnership with them to create empowerment.

Ecotourism in Goa: Goa is gifted with abundant natural beauty as it a part of the Western Ghats. Goa is rich with over 1512 documented species of plants, over 48 genera of animals, over 275 genera of birds, over 48 genera of animals and over 60 genera of reptiles along with very rich marine biodiversity.

The river Mandovi has a good potential for development of ecotourism activities. These activities can not only help in employment generation it helps in the development of villages along the river. Historic sites along river include Reis Magos fort, Aguada fort, well-known tourist places such as Old Goa, Miramar, Chorao, Divar as well as the capital of Goa (Panaji). Mandovi Estuary also has a good diversity of birds hence bird watching tours, mangrove walks could be conducted. Water sports such as kayaking, river cruises in smaller boats. Nature trails can also be promoted. Recreational fishing could be encouraged. Spice garden plantations and picnic spots can be developed. Cycling tourism, photography tourism, meditation and rejuvenation tourism, cultural tourism can also be developed.

The above tourism activities should employ people from the local communities, as it helps in the regions development. These activities should be sustainable and waste generation should be minimised by reuse, reduce and recycling materials. The government on its part to incentivize ecotourism should provide schemes and funding to interested people as well as training courses in various fields such as culture, language, management, identification of flora and fauna etc.

Guidelines to be adopted for sustainable ecotourism suggested by some experts specifically for Goa are as follows:

1. The management plan areas proposed for eco-tourism should be prepared through professional ecotourism experts and in consultation with the local community as well as other stakeholders.
2. To avoid conflicts, inclusive and integrated planning should be adopted.
3. The architectural programme for eco-tourism centers should include controlled access points and cabins, roads, self-guided nature trails. Transportation options, interpretive signs, observation towers, adequate but unpretentious lodging and dining facilities, water docks, garbage disposal facility etc.
4. Structures creating visual pollution, unaesthetic values and non-compatible architecture should be controlled.
5. Exclude development in geologically unstable zones and define development and buffer zones after proper environmental impact assessment. For example, on beaches Coastal Regulation Zone (CRZ) regulations must be followed.
6. Establish standards, building codes and other regulations.
7. Specify environmental, physical and social carrying capacities to limit development activities.
8. Ensure continuous monitoring of adverse effect of tourism activities and initiate suitable corrective measures.
9. Recognize and award quality labels to eco-tourism operators.
10. Provide visitor information and interpretation services covering particularly i) what to see ii) how to see iii) how to behave.
11. Prepare and widely distribute codes of conduct to all visitors.
12. Launch training programmes on eco-tourism to tourism administration planner's operators and general public.

8.13. Development of team and funds for the plan

For management, monitoring and smooth running of the entire plan which will be spread across the river-scape, a well-coordinated team is essential. As there are several activities involved pertaining to sand mining and environmental conservation it is imperative to have a multi-disciplinary team to undertaken activities as well as co-ordination between various stakeholders.

Stakes of all the interest groups is essential thus the team should have the representation of each group, community and related agencies, which also ensures discussion to reach consensus and transparency. This a generic structure that allows freedom to each of the bodies to discuss within themselves as well as with other bodies and decide the responsible team member. Given below is the structure of the team to be appointed after a consultative meeting (Fig. 8.5).

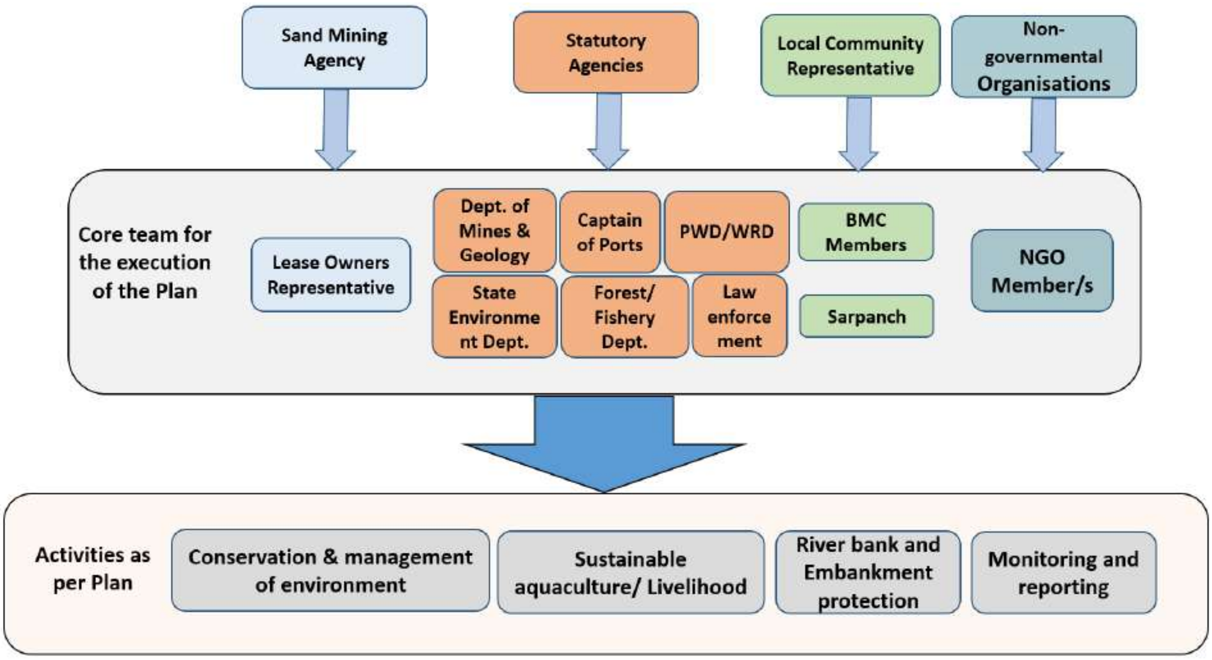


Figure 8.5. Schematic diagram depicts execution of management plan

8.13.1. Funds for the plan

A mechanism has to be formulated to impose minimum burden on the government for mitigating the impacts. Considering this perspective, as per the guideline provided by MoEFCC, the funds to carry out the activities to mitigate the impacts of sand mining, environmental safeguard and restoration need to be acquired from the lease holding agencies. A share of proportionate amount has to be assigned to carry out the aforementioned activities of the plan as part of CSR/CER.

Funds also have to be deviated towards sustainable aquaculture practices and eco-tourism, for which initial seed money can be provided from a corpus fund to bind with government schemes and subsidies. At the initial stage the interest group can also contribute for the small-scale businesses in which they would like to participate.

8.13.2 Role and responsibility of the team

The plan gives freedom to discuss and decide the roles and responsibilities of each of the member as well as the rights to the team to appoint additional team members as felt necessary. Following are the responsibilities of the team:

- Monitor all the sand mining lease holder's activities and compliances.
- Carry out conservation activities and promote eco-tourism.
- As the expanse of the river spans across many villages with changing land use and activities, the team may appoint sub-teams to properly execute each activity. The sub-teams can be made or committees can be formed or SHGs can be formulated depending on the interests of the stakeholders and interest groups.
- Implement, supervise, monitor and take corrective actions for sustainable livelihood schemes as deemed fit considering the environmental conditions, available land, local expertise and willingness.
- The team has to monitor the activities of the sub-teams or the groups formed and weigh the achievement of work undertaken, suggest corrective measures and way forward for undertaken activity or projects.
- The team members (representatives of statutory agencies) shall help the activities by extending the available schemes and subsidies to the required stakeholders so as to support environmental conservation, sustainability and livelihood.
- Instruct actions to stop any environmental degradation (eg: tree cutting, garbage dumping, species decline/loss, embankment damage, saline intrusion etc).

- Carry out training for capacity building and to promote sustainable livelihood practices.
- The team is required to maintain all the records, handle complaints, incident and con-conformance and keep its record.

8.13.3 Corrective action/contingency plan

Any unlawful activity or failure to meet the performance criteria shall be recorded as a non-conformance incident and be reported. In the event of any incident, the team has to take immediate actions, document the incident, and report it to statutory authorities. This has to be followed by remedial actions as directed by the Dept. of Mine and Geology and Environment Department (eg: GSPCB/GSBB).

8.13.4 Documentation and record keeping

Efficient and accurate record-keeping is essential for the application of a plan. Following necessary aspects are to be considered for record keeping and documentation-the DPR & Management plan, list of important areas (in terms mine lease, ecological sensitivities etc.) and details of priority areas for action. According to the size of the lease and areas/expanse of each lease area, the team needs to formulate and document a manual for their own working which shall include: critical limit determination, analysis, procedures -e.g. standard operating procedures, corrective action procedure, work instructions, monitoring activities, deviations and associated corrective actions, verification procedures performed, modification to the plan, training undertaken, periodic records, visual inspection reports, team meeting records, processing records.

8.13.5 Complaint handling procedures

Every complaint is different but the steps for dealing with them should be the same. As well as having a complaint policy, comes under best practices which will have a procedure handling protocol prepared by the team. A complaint handling procedure ensures complaints are dealt with the same way every time (Fig 8.8).

8.13.6 Incident and non-conformance reporting

Non-Conformance report which is work done without approval of any concerned documents/not related to the standards (Construction Standards/Contract specification).

Especially some works are not followed by the standards and specifications. Non-conformance report shows the exact possible error due to not following or deviate the procedure, while corrective action shows that, how the process or method will follow the right procedure. There is a formalized way of reporting environmental incidents i.e. uncontrolled events that have or could have had an impact on the environment, such as chemical/ oil spills; contamination of land, flora or fauna; damage to listed structures/building/embankments etc.

The objectives of the procedure are to:

- Ensure all relevant contractors are made aware of environmental incidents/ violation of lease granted and its handling procedure. Complaints can be forwarded to the appointed committee or to the office of Mamlatdar/ Dy. Collector/ Police.The complaint can be given manually or by electronic means to be devised by the committee.
- Ensure site workers and stakeholders understand the immediate environmental incident reporting requirements.
- Ensure all concerned stakeholders understand reporting timeframes, including statutory requirements.
- Ensure incidents are reported to enable monitoring, sharing of lessons learnt and response to emerging environmental incident trends.
- Comply with statutory obligations to report certain environmental incidents to regulators and other relevant government agencies for further action.

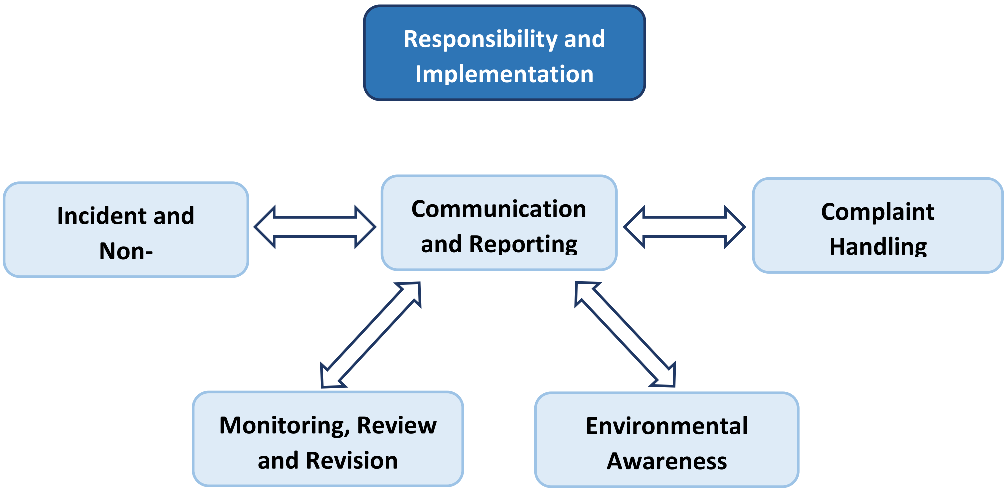


Figure 8.6. Schematic diagram of development and functioning of team

9.13.7 Attempts to deal with the illegal trade (WWF, 2018)

The Directorate of Mines & Geology, the Costal Police, the Captain of Ports and the District Magistrate, North Goa, shall ensure maintenance of regular vigil in the area. As suggested by Honourable NGT, CCTV camera installation is essential at important location that have been leased as well as other critical areas vulnerable for mining need to be monitored. Wherever the monitoring shows that the guidelines and legality is not followed or violated, actions shall be taken as directed by the Honourable NGT order date 12/12/2019 (No: 28/2015 (WZ)).

Numerous approaches have been adopted by District, State and the Central Government to attempt to curb the illegal mining and the associated environmental, ecological and social impacts, including:

- Development of sustainable sand mining guidelines. The guidelines provide detailed information and recommendations on how to extract sand sustainably, but they are non-binding.
- Completion of sediment audits to identify sustainable sediment extraction limits. This approach was applied to Kerala in 2015 and resulted in the banning of sand mining from six rivers with severe restrictions placed on others.

The establishment of a complaint cell to receive and investigate complaints regarding sand mining. Legal authorities have been instructed to conduct raids, seize vehicles that engage in the illegal activity and take custody of illegally mined sand for subsequent sale at government rates, and to provide armed police to provide protection for revenue squads (Jha, 2013).9.13.8 Alternatives to river sand mining (WWF, 2018)

Alternatives sources to river sand have been identified and adopted by most western countries, and similar shifts in developing countries could reduce pressure on the resource. However, without improved governance changing the primary sources of construction materials is difficult as alternatives are likely to cost more due to additional handling, processing and transport costs. Any increase in the cost of 'legal' sand as compared to illegally derived river sand drive an increase in illegal activities. Alternative sources and substitutes for sand in concrete is an area of active research. A literature review found the following examples.

8.13.8 Recycling of concrete for use as road bases (Smith, 2018)

Development of bacteria and fungi that can produce calcium carbonate can be used to repair existing concrete structures, increasing their lifespan. This may be particularly useful when applied to the huge highway systems of the world that are requiring repair or replacement (Smith, 2018). Replacement of sand with other materials should focus on the recycling of waste materials. It is notable that a web search of this topic returned many recent articles by Indian researchers, all of which highlight the need to identify replacement materials to diminish sand mining and its related environmental impacts. Examples (not all from India) include:

- Backfilling of mining voids using fly ash composites in place of river sand in India due to a decrease in the availability of river sand. Finding an alternative use for fly ash is also desirable as it would reduce landfill (Mishra &Karanamk, 2006).
- Use of walnut shell and PET-fibres as a replacement for aggregate in lightweight shotcrete suitable for roadway or mine supports (Cheng, et al., 2017).
- Use of fly ash and polypropylene or steel fibers to produce high quality concrete (Raut&Deo, 2017).
- Use of rubber tyres and copper slag as aggregate in concrete (Blessen, et al., 2012).

- Replacing aggregate with recycled concrete sand in masonry and mortar design for indoor use (Fernandex-Ledesma et al., 2016).
- The use of residual materials such as kaolinitic waste, sewage sludge, schist fines and wasted glass to create light weight granules suitable for light concretes, road engineering and waste water treatment (Kanari et al., 2016).
- The use of crushed oil palm shell as a replacement for aggregated in concrete. Investigations have found that replacement rates of between 50% and 75% can be used to produce a lightweight concrete for use in non-load bearing structures, and structural concrete can be created at replacement rates of about 25% (Muthusamy et al., 2013).
- The replacement of river sand with manufactured (crushed) sand. Manufactured sand is a by-product of the production of coarse aggregate and has historically been used for road bases and land fill. Replacement of river sand with manufactured sand at a rate of 75% was found to produce concrete with properties suitable for use as high-performance concrete (Prasanna et al., 2017).
- Replacement of river sand with crushed waste stone, dust and polish slurry generated by the production of dimension stone (stone quarried and cut to specific sizes or shapes, e.g., ornamental stone). Replacement of 100% of river sand in concrete by 85% stone waste and 15% slurry waste resulted in a very high-quality concrete product (Rana et al., 2017).
- Use of iron-ore tailings to replace sand in concrete. The inclusion of the tailings reduced the workability of concrete, but all other strength modulus of elasticity data was consistently higher than conventional replacement at all levels of replacement (25% to 100%). The use of tailings is recommended to minimise environmental problems, cost and natural resource depletion (Shettima et al., 2016). Note, this approach would not be suitable for tailings containing sulfides.

CHAPTER 9 ENVIRONMENTAL MONITORING PLAN

Environmental monitoring program includes periodic analysis of air, soil, noise and water, flora and fauna. Environmental monitoring should be conducted on regular basis to assess the pollution level in the mining lease area as well in the surrounding areas. Therefore, regular monitoring program of the environmental parameters is essential to take into account the changes in the environment.

Mining of sand and all the activities listed out in the conservation and management plan require periodic monitoring. Considering the activities and the monitoring results the team may decide to suggest additional management strategies to be implemented as appropriate. Competent outsourced certified organization/laboratory (eg: GSPCB) should be appointed to conduct the monitoring parameters wherever there are samples involved.

9.1 Mining activity monitoring

1. Daily quantity of sand to be extracted from each lease should be based on the quantity given in the permit/ EC conditions.
2. De-casting from river beds should be monitored on a regular basis to keep a track of excavated quantity.
3. Every year, a mandatory audit of the quantity extracted and quantity permitted along with the replenishment rate should be carried out.
4. Depth should be up to 3.0m from the existing riverbed level and not less than one meter from the water level of the river channel.
5. Peizometer and eco-sounder (for depth measurement) should be used by each lease holder and daily records of these measurements should be made available to the monitoring team.
6. Monitoring team should ensure that sand mining activity in Monsoon season and during night time is not carried out.

9.2. Sand Transport Monitoring

1. Mandatory e-pass/ e-permit should be made available at each lease area for transportation of any sand by an GPS enabled vehicle with the provision of entering

the vehicle number of the vehicle carrying sand and expected delivery address and customer name/ mobile number.

2. Documents should be made available for stockyards/ stockiest of sand. In the case of nomination based (controlled pricing) business model, the margin of private stockiest should be capped over a fixed percentage of notified prices.
3. At the stockyard, the stock supervisor should verify the authenticity of payment receipt before issuing the transit pass. The loading of sand should be monitored electronically and all transporting vehicles should pass through an electronically monitored weighbridge.
4. To make transportation monitoring effective and useful, all the sand carrying vehicles (tractors/ trucks) should be registered with the department and GPS equipment should be installed in all the sand carrying vehicles.
5. There shall be one entry and exit point provided for trucks/vehicles. The said entry point should have facilities as mentioned above. In case, it is necessary to have more than one entry/exit points, all such points shall have checkpoints with facilities as mentioned above. All other possible ways of entry/exit should be closed using barriers like compound, trench, etc. All provisions shall be made to not make it possible for any vehicle to enter or exit without entry into the computerized system.
6. The Project proponent has to enter the destination, distance between plot and destination, vehicle number etc in the system. After scanning, unique bar code number, invoice date time and validity date-time are generated by the software which gets printed individually on each TP Validity of TP is calculated based on the distance between plot and destination. After validity time is over the TP stands invalid.
7. Weighbridges with CCTV should be installed at all the stockyards, active reaches to ascertain the exact quantity of sand being transported in the vehicle. Check posts with CCTV cameras should be established near all major consumption centers to check if all the transporting vehicles are carrying a valid transport permit.
8. The transport permit generated should contain advanced security features so that one permit cannot be re-used by generating photocopies of the permit.

9. It is necessary to prevent any truck/vehicle from transporting sand out of the identified plot bypassing the strong IT enabled system. Therefore, at each of the sand plot, the following additional measures should be taken.

10. All such points should have 24X7 CCTV coverage, the footage should be made available online to the district administration. In cases, where sufficient internet bandwidth is not available, it may be deposited with the district administration on a weekly basis. If possible, the entry/exit points should have boom barriers which will record the vehicles entering and exiting the plot.

9.3 Surveillance & monitoring

11. Constantly monitor mining with drones and if possible, night surveillance of mining activity through night- vision drones.

12. Project Proponent must ensure that CCTV camera, Personal Computer (PC) or laptop, Internet Connection, Power Back up, access control of mine lease site; and arrangement for weight or approximation of weight of mined out material on basis of volume of the trailer of vehicle used at mine lease site are made available for monitoring.

13. Even after all the regulatory procedure and policy being in place, there are instances where illegal mining is taking place. The monitoring agencies can monitor the sites remotely by using Unmanned Artificial Vehicles (UAVs)/Drone which are now a viable option. The drone can also be used for reserves estimation, quantity estimation, land use monitoring. Other options for the monitoring team may also be made available for possible use of IT/Satellite/Drone technology for effective monitoring of sand mining.

14. The officials involved in monitoring should be provided with mobile application and/or bar code scanners using which the TP can be checked anywhere on road. As soon as the bar or QR code on TP gets scanned through using the mobile application and/or scanner or vehicle number is entered into the application or sent by SMS to a predefined number, all details of TP such as plot details, vehicle details, validity time, etc. should be fetched from the server. This means if anything is re-written on TP and attempt is made to reuse the same, it can be traced immediately. Various reports can

be generated using the system showing daily lifting reports and user performance report. This way the vehicles carrying sand can be tracked from source to destination.

15. The facility to fetch details using mobile app, website and SMS may be made available to the general public as well. If the citizen finds that the vehicle doesn't have such a permit, as ascertained from mobile app or website or SMS, he should alert local authorities, who shall then take further action as per the law.

16. Land contamination (by diesel, oil etc.) due to movement of site vehicles: Vendors of state pollution control board will be contracted for collection of hazardous waste (used oil) & oil spill kit will be provided with each vehicle used for transport. Monitoring team will ensure the log books are updated and accordingly check any signs of violation, accidents, spillage etc.

17. Monitoring wells should be established adjacent to each excavation area to record changes in ground water levels. Measurements should be taken monthly. This should help analyse surface water and ground water interaction around the lease area as well as for monitor the salinity intrusion into freshwater bodies.

18. River mining from outside shall not affect rivers; no mining shall be permitted in an area up to a width of 25m from the active edge of embankments.

19. A monitoring report should review permitted extraction quantities in light of results of the monitoring program, or as improved estimates of replenishment becomes available. The report should document changes in bed elevation, channel morphology, and aquatic and riparian habitat. The report should also include a record of extraction volumes permitted, and excavation location. Finally, recommendations for reclamation, if needed should be documented.

20. Sand mining has to be monitored as per The Mines Act 1952 and The Mines and Mineral (development and Regulation) Act 1957, Mines Act 1952, Mines rules 1955, Mineral Concession Rule 1960, Mineral Conservation and Development Rules 1988.

9.4. Air quality Monitoring

As per the EIA Notification (2006) and subsequent amendments, Air Environment is one of the pollution sources from mining sector which needs to be categorically addressed. Measuring and understanding air pollution provides a sound scientific basis for its management and control. If concentration of pollutant is higher than threshold limit values are observed, the source of fugitive emissions will be identified and necessary measures will be taken. If the levels are high, suitable measures as detailed in Environment Management Plan will be taken. The criteria for pollutants measured are Particulate Matter 10 (PM_{10}), Particulate Matter 2.5 ($PM_{2.5}$), Sulphur dioxide (SO_2), Oxides of Nitrogen (NOx), and Carbon Monoxide (CO) concentration in downwind direction considering predominant wind direction, at the source and a distance of 500 meters from the following dust generating sources shall be measured. Air pollution has to be monitored as per Air (Prevention and Control of Pollution) Act (and subsequent amendments) 1981. The air pollution impacts from the present baseline activities are of low nature as the sand extraction is from water therefore minimum dust emission. Hence emission from transportation and fugitive emission are to be taken care off using best practices in the industry.

9.5. Water Quality monitoring plan

Enforcing environmental monitoring. Plan is the responsibility of the assigned team and the major objective is to follow the best practices and legislative provisions for the prevention of environmental degradation. Thus, the main actions would be:

- Pooling and communicate the results of the environmental monitoring.
- Proposing mitigation measures based on the results of the monitoring.
- Introducing environmental education programme among the workers and the villagers.

Mines can affect surface runoff and groundwater quality through contamination with dissolved and suspended materials. Mines can de-water groundwater aquifers some distance from shafts or open pits, which can make nearby wells or groundwater bores run dry or saline. Monitoring should inspect the water against the release of chemically or radiologically contaminated water. The sample collection, procedures for sample preservation and methods of analysis are followed as per Standard Methods. Monitoring of water samples will be done at a frequency of once in each season as per CPCB Guidelines for waste water: and Ground water (BIS-10500:2012). Water quality has to be monitored as per the law of Water (Prevention and Control of Pollution) Act (and subsequent amendments) 1974 and the water (Prevention and Control of Pollution) Rules 1975, Cess Act 1977 & Cess Rules 1978.GSPCB carries out regular monitoring of river water quality, same can be extended to the proposed stretches of the river with added parameters to fulfil the legality.

9.6. Solid waste management

Solid waste management is one of the most acute environment issues. Site clearance and tidiness is very much needed to have less visual impact of mining. Dumping of waste shall be done in earmarked places as approved in Mining Plan. Thus, team/operator can monitor the bin and waste receptacles at the site, storage, segregation and its lawful disposal to a registered vendor. Monitoring has to be carried for each lease area and area of operation follows the Solid Waste Management Rules 2016. Monitoring team should ensure a record/log will be maintained for general and regulated waste disposal. The log shall record the type of waste, and the point and date of disposal.

9.7. Marine Environmental Monitoring

Water quality monitoring is an important aspect which needs to be monitored. A water quality monitoring system is required to signal, control or predict changes or trends of changes in the quality of a particular water body, so that curative or preventive measures can be taken to restore and maintain ecological balance in the water body. Project team should collect water parameters to check the physico-chemical parameters. Along with the parameters, the project team has to collect sediment sample to check the benthic faunal diversity. The monitoring has to be done as per The Environment (Protection) Act, 1986 and EIA Notification (and amendments) 2006.

Water quality is the main cause for the damage to marine environment and can be monitored by conducting training / awareness programs once a year for all the relevant staff/stakeholders.

The project teams also have to identify floral diversity like native and invasive species along the estuarine and riparian region of the estuary. The station locations identified in the baseline are to be monitored every six months (covering pre- and post- monsoon season) as given in table 9.1.

Table 9.1: Water quality monitoring parameters and schedule.

Sr. No	Cluster	Parameters measured	Locations	Operation Phase
1	Sea Water	Temperature, Salinity, DO, BOD, OC, Nutrients	15 locations	Once every six months
2	Sediment	Texture, Grain Size, OC	15 locations	Once every six months
3	Plankton & Benthos	Phytoplankton, Zooplankton, Meio & Macro- fauna	15 locations	Once every six months
4	Flora & Mega fauna	Seaweeds, Marine mammals, reptiles & avifauna	Identified habitats in the study area	Once every six months
5	Sensitive habitats	Mudflats, Mangroves, Sand flats and Rocky shores	Identified habitats in the study area	Once every six months
6	Fisheries	Benthic & Demersal fish species & intertidal shellfish.	One bottom trawl & intertidal survey	Once every Six months

9.8 Embankment management and protection:

Embankments are the oldest known forms of flood protection works and have been used extensively for this purpose. They serve to prevent inundation, when the stream spills over its natural section, and safeguard lands, villages and other properties against damages. The embankment needs to be monitored as per the Environment (Protection) Act, 1986, CRZ notification, 2019.

- These embankments should be monitored on monthly basis and care must be taken to ensure the proper condition of the embankments. Damaged during the mining activity may leave many riparian zones vulnerable as they are known to protect from floods and soil erosion.
- Other areas should be monitored where there is no protection and it requires embankment construction.
- Saline intrusion in the adjoining areas should be monitored.
- Any repair work and construction of embankments should be monitored are recorded in site visit reports.

9.9 Monitoring of conservation plans:

Conservation of ecosystem is the most neglected aspect of any developmental project or mining activity as such. The present area is rich in biodiversity and requires serious conservation efforts. Otters, crocodiles, turtles play an important role in maintaining riverine ecosystem. As this ecosystem provide promising habitat for these species but it might be a difficult task for their survival because of sand mining, iron ore mining, dynamite fishing etc. Construction along the banks of river like embankments, check dams cause negative impact on their habitat. Cutting and loping of trees along the banks, should be also be monitored. Mass public awareness campaign should be undertaken to educate people, especially fishermen inhabiting closer to estuarine habitats about the ecological role of the important species and their habitats which ultimately provides goods and services to the human society. All the aspects given in the conservation have to monitor to note the status of species, their habitat and actions to be taken for their improvement and enhancement. Conservation of the ecosystem has to be monitored as per Wild Life Protection Act, 1972, Forest (Conservation) Act 1980

9.10 Monitoring of Plantation Plan:

Mining activities will not cause any harm to riparian vegetation cover as the working will not extend beyond the offset left against the banks. Plantation should be followed along the bank of river and along road sides of approach roads. While selecting plant species preference will be given for planting native species of the area and shall have soil binding capacity. The state forest department will supply saplings to surrounding villagers for green belt development in their villages and encourage the plantation by means of social forestry. Green belt development as per the scheduled plan will be reviewed every year plantation records will be maintained for period of plantation, area under plantation, length of avenue plantation, type of species density of planted area and survival rate. Monitoring of Plantation needs to be monitored as per Environment (Protection) Act, 1986

- The implementation for development of green belt will be of paramount importance as it will not only add up as an aesthetic feature, but also act as a pollution sink.
- The species to be grown in the area should be dust tolerant and fast-growing species so that permanent green belt is created.
- To stabilize the river bank erosion, the plants having good growth will be planted along the river bank.
- Apart from the green belt and aesthetic plantation for elimination fugitive of emission and noise control, all other plantation efforts shall be decided and executed with the assistance and co-operation of the local community.

9.11 Integrated Aquaculture and eco-tourism

The discharge of nutrients, sediment, BOD, bacteria, and pathogens into estuarine waters is one of the problems which impacts the aquaculture and to be covered by existing programs. Land based facilities can be regulated under the existing waste discharge laws and regulations. The impacts are site specific and controllable with any other source of water to estuaries.

- The site of the aquaculture should give more important to the conservation; such importance can be maintained by monitoring the norms to be followed as per national guidelines and best practices in aquaculture.
- Aquaculture farms should not pose a significant threat to the surrounding environment. The potential impact of the aquaculture must be understood and an accurate assessment made to monitor the water quality changes.
- The feed is a primary cause of direct and indirect pollution of water resources used for aquaculture. Therefore, the assessment of feeds should be considered as important practices and monitored frequently.
- Land based facilities can be regulated under the existing waste discharge laws and regulations. The impacts are site specific and controllable with any other source of water to estuaries. Potential problems exist where water quality standards either do not exist for some pollutants (eg: Nitrate or phosphate in estuarine waters).
- The eco-tourism activities planned and carried out should be monitored, for their impacts (negative and positive).
- It should be monitored that the native community gets maximum benefit from the eco-tourism schemes.
- It is to be monitored that the eco-tourism activities should be non-polluting and should be carried out using indigenous material.
- The number of tourist/foot fall should have a cap every season and the activities also should have upper limit considering the carrying capacity of the region/habitat/area.

RECOMMONDATIONS

Sand mining is one of the most sensitive subjects in India as well as other parts of the world. It has been the issue of social conflict, environmental sustainability and administrative issues. 'Sand Mining' has been one of the most revenue generating business as direct extraction of natural resources does not require much investment or skillset or purchases of raw material for production. It has to be considered as limited natural resource with a limited ability to be replenished over long-term duration. But the impacts of sand mining have been deleterious and sustainability of sand mining is always difficult. Being the most important commodity, sand is required for construction and thus the holistic development and urbanization.

The present status of the river has been detailed out in this report. Considering the on-going activities including sand mining, site sensitivities, national guidelines, international best practices and concerns raised by local community as well as directions by Hon'ble NGT, following are the recommendations:

- Considering the results of the baseline, Mandovi estuary has been influenced by cumulative anthropogenic activities and natural riverine and costal processes.
- These effects have changed the geo-morphology and bathymetry at many stretches of the river/estuary. Over the years sand extraction has caused many pits and deep gorges in the lease areas as well as outside the lease areas.
- The lower stretches of the estuary are influenced by higher salinity regime thus the adjacent banks have been protected by traditional embankments. These embankments allow the locals to carry out agriculture- predominantly paddy. These traditional embankments consistently face the problem of saline water intrusion and require continuous repair and maintenance. There are several reason for the damage of embankments viz; high tidal surges, subsidence of land, removal of sand/sediment from the river bed, non-maintenance of embankments and flooding due to rainfall and upstream water flow.
- The salinity intrusion has also changed the land use, converting many paddy fields and riparian zones and mudflats into un productive areas or mangrove areas.

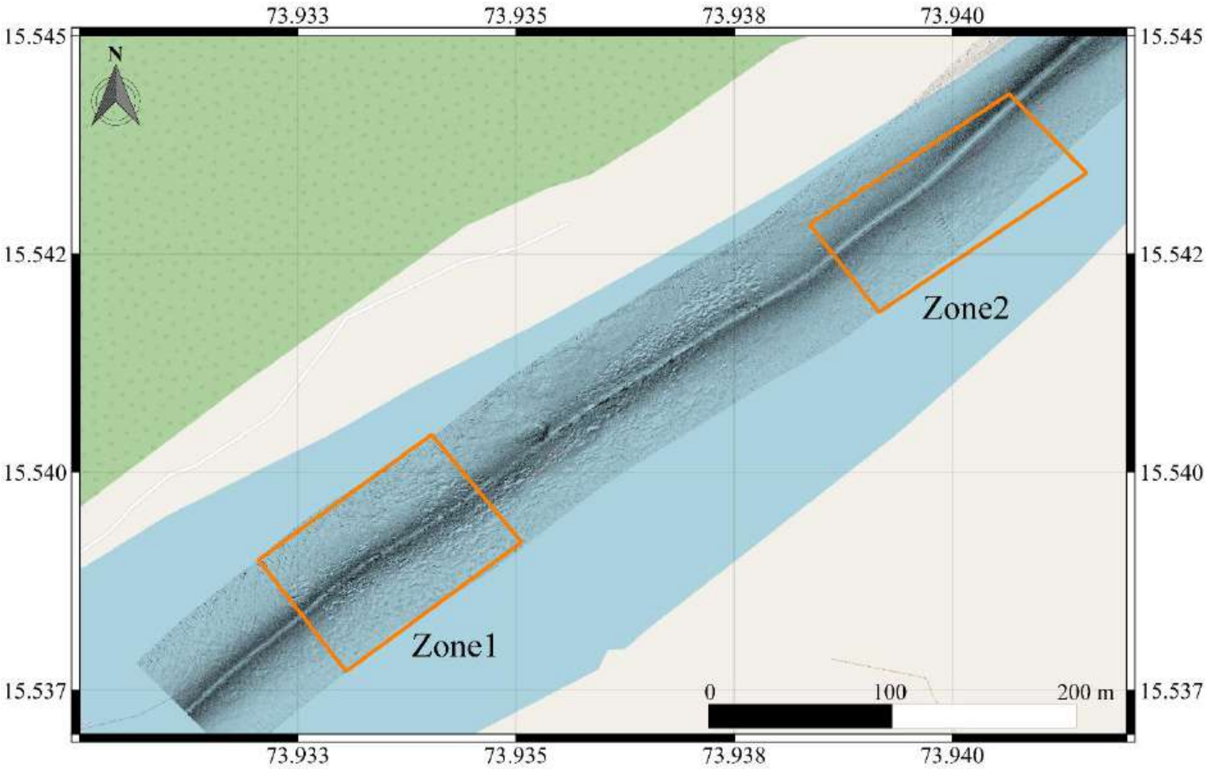
- Based on the baseline data and the prevailing site conditions (cumulative impacts herein) sand extraction at unregulated rates or in the sensitive area will have negative impacts on the environment. Therefore, minimum areas recommended by SSMG (2016) & Hon’able NGT are to be followed. Accordingly, certain areas in the stretches of the river have been demarcated where sand extraction from the river bed requires restrictions.
- Based on the side scan sonar imaging, single beam echosounder bathymetry and high resolution seismic (HRS), morphological features of river bed have been interpreted across a stretch of 38 km of Mandovi river. The side scan sonar image shows various geomorphological features like ripple marks (associated with sand), rock outcrops, river banks, erosion features, mud zones and shadow zones of the road and railway bridges across the Mandovi river. Apart from this, active sand mining zones in different regions of Mandovi river have also been identified. The single beam echo sounding data is used for estimating the depth of the river bed and the high-resolution seismic data is utilized for the estimating the sediment thickness.
- The microscopic grain size analysis shows a decrease in grain size when moving from Khandepar to the river mouth. The bulk sediment grain size in most of the samples is dominated by sand fraction. Most of the stations contain a considerable amount of quartzite, iron oxide, and fewer lithic fragments. Based on the analysis, the region is divided into three zones. Zone1: Khandepar to Navelim (sampling point 86-100), characterised by poorly sorted, semi rounded pebbles and large size sediment along with silt clay pockets; Zone2: Piligao to Navelim (sampling points 81-85), characterised by poor to moderately sorted, admixture of pebbles and fine to medium grain sand and Zone3: River mouth to Piligao (sampling point 67-81), characterised by well-sorted and highly angular grain distribution (Fig.33).
- The comparative analysis reveals that Khandepar, Cotombi, Volvoi, Navelim, and Betqi, are the locations where mid-channel/point bars erosion and deposition of non-cohesive sediment in the nearby downstream region is prominent. Whereas, Navelim-Betqui, Amona, Piligaon, Narve are the regions where the morphological changes are not prominent, except sand mining signatures and mining patterns. Integrated analysis of SSS and HRS data at respective locations revealed that a local redistribution

of the sediment in most of the region. It also suggests that the erosion and depositional processes are simultaneously working at very local scale in the river.

- In the Mandovi estuary the bed level changes for the post-mining scenario are mostly around -0.15 m to 0.25 m during both simulated monsoon (August-November, 2020) and non-monsoon period (November, 2020 - May, 2021) of Mandovi estuary. The changes in bed morphology in the post-mining scenario at different sections of the river are highly dynamic and patchy in nature.
- Considering the stretches which have low sensitivities, can be considered for sand extraction while following the national statutory and legal guidelines. While recommending the lease areas the authority shall conduct a reconnaissance site survey and a consultative discussion with the stakeholders and accordingly work out areas that do not have conflict of interest.
- The sand extraction has to be conducted by traditional (manual) method only. No mechanized boats or machinery to be operated. The activity shall be restricted to the available areas given below and the depth of extraction should not exceed 3m from the existing baseline profiles.
- Once the lease areas are issued, the delineated "Environmental Conservation and Management Plan" needs implementation. The plan also describes the team/committee which should be capable to address, execute and monitor all the aspects of the plan. Furthermore, the team/committee should appoint sub-teams, SHG's, Village committees on requirement basis as per the plan.

Mandovi - Possible Mining Zones

Zones 1 – 2



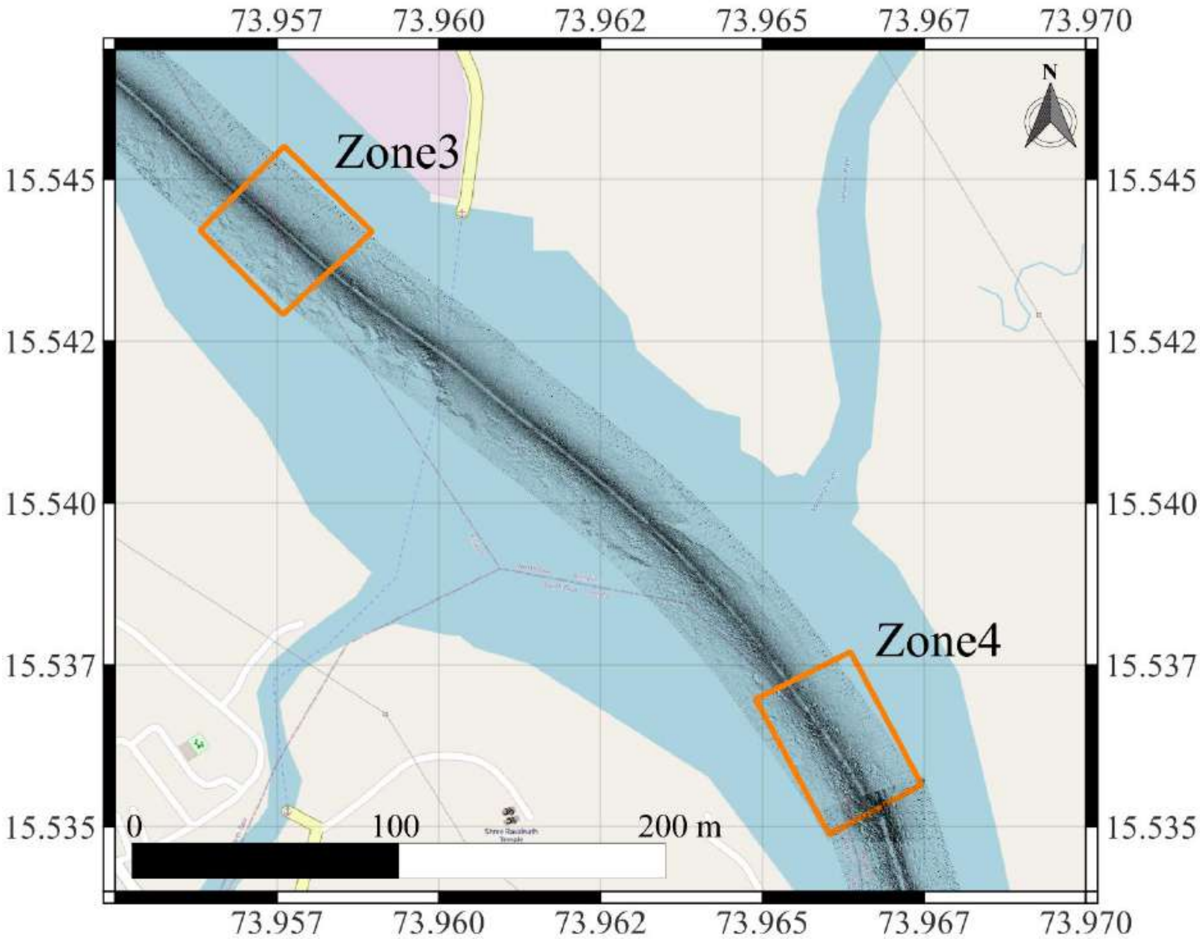
Zone-1 Block Coordinates

S.No.	Longitude	Latitude
1	73.93506	15.53919
2	73.933053	15.53771
3	73.93204	15.53899
4	73.93403	15.54042

Zone-2 Block Coordinates

S.No.	Longitude	Latitude
1	73.94154	15.54343
2	73.93916	15.54183
3	73.93836	15.54284
4	73.94065	15.54434

Zones 3 – 4



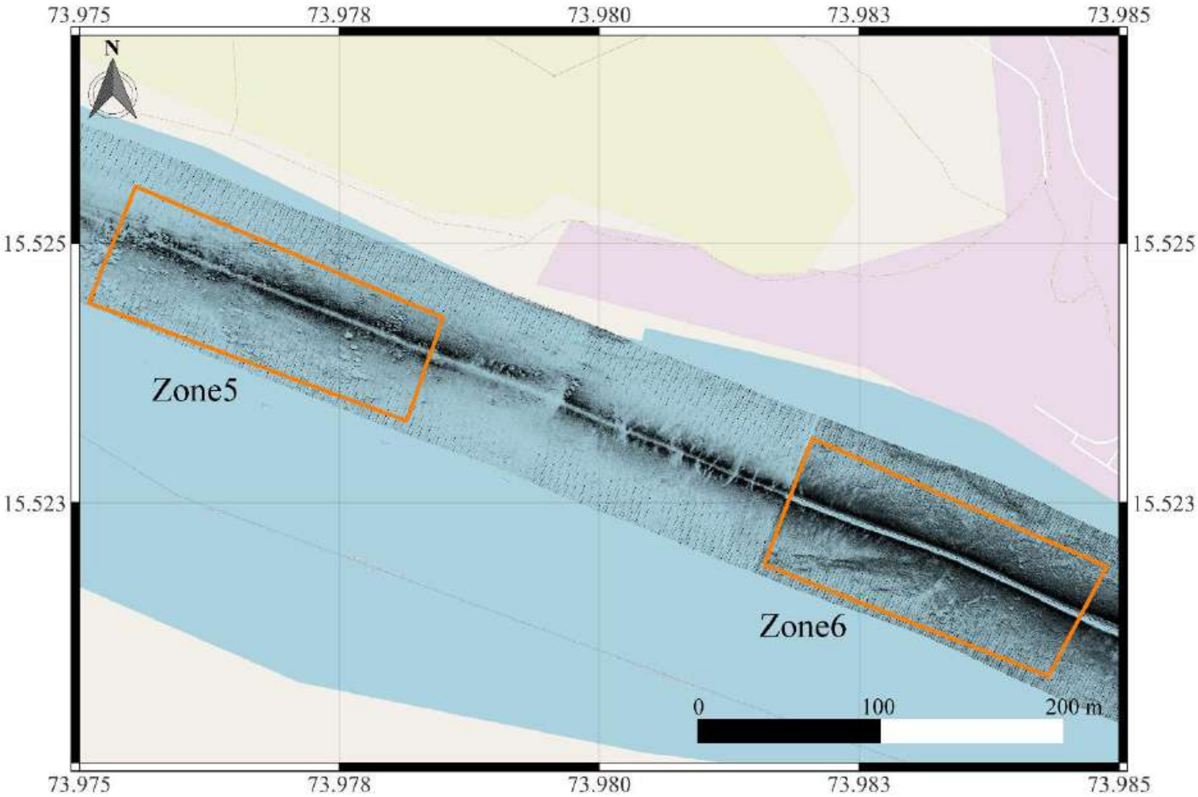
Zone-3 Block Coordinates

S.No.	Longitude	Latitude
1	73.95897	15.54419
2	73.95759	15.54291
3	73.95631	15.54421
4	73.95761	15.54551

Zone-4 Block Coordinates

S.No.	Longitude	Latitude
1	73.96746	15.53564
2	73.96603	15.53487
3	73.96489	15.53696
4	73.96636	15.53770

Zones 5 – 6



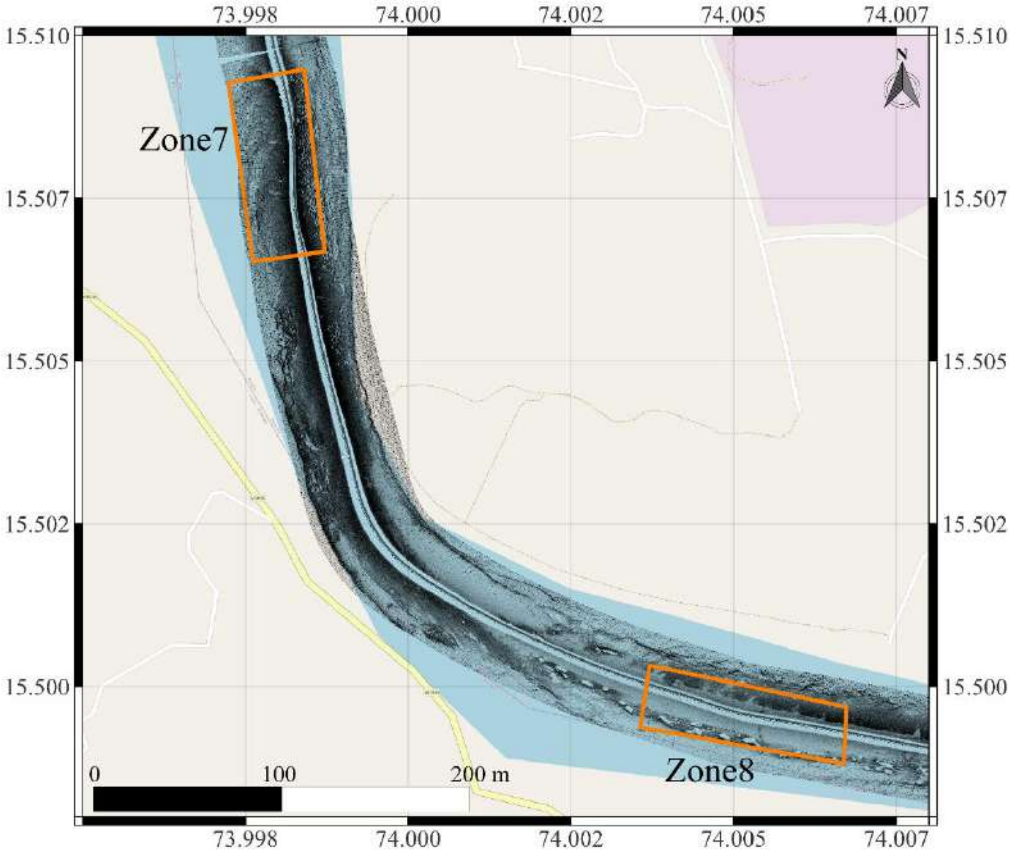
Zone-5 Block Coordinates

S.No.	Longitude	Latitude
1	73.9785	15.52428
2	73.97815	15.52329
3	73.97509	15.52442
4	73.97554	15.52554

Zone-6 Block Coordinates

S.No.	Longitude	Latitude
1	73.98488	15.52188
2	73.98432	15.52083
3	73.98158	15.52190
4	73.98205	15.52312

Zones 7 – 8



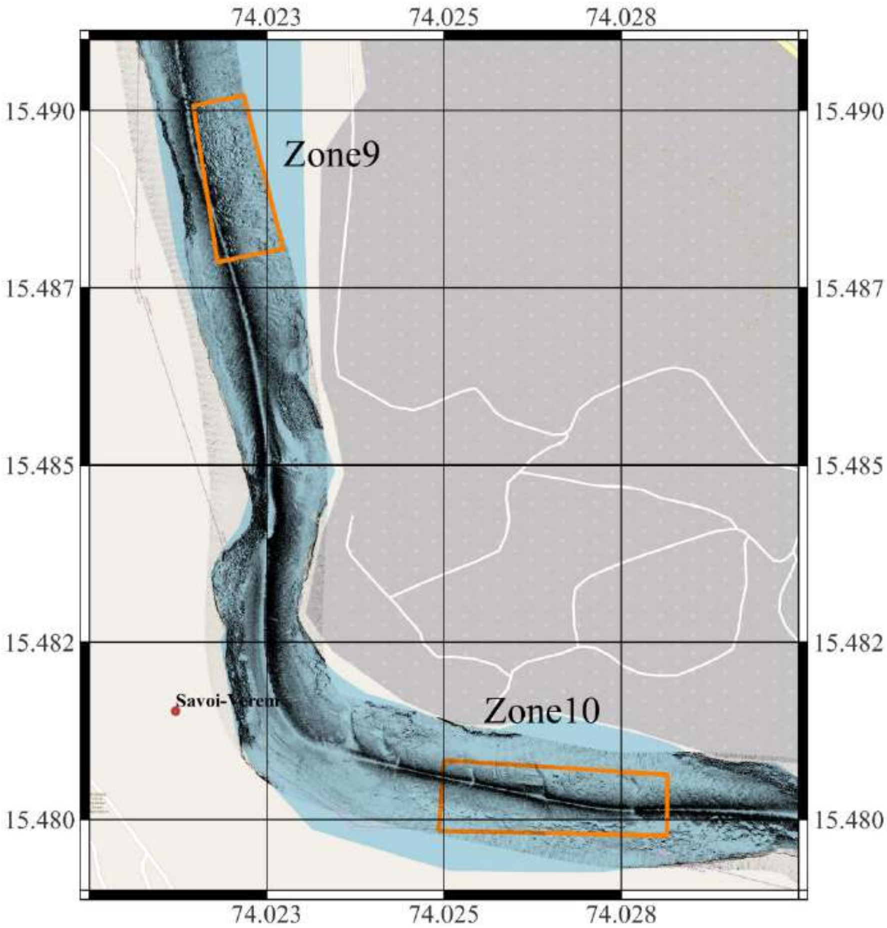
Zone-7 Block Coordinates

S.No.	Longitude	Latitude
1	73.99872	15.50668
2	73.99761	15.50653
3	73.99724	15.50927
4	73.9984	15.50948

Zone-8 Block Coordinates

S.No.	Longitude	Latitude
1	74.00673	15.49968
2	74.00669	15.49881
3	74.00356	15.49937
4	74.00370	15.50032

Zones 9 – 10



Zone-9 Block Coordinates

S.No.	Longitude	Latitude
1	74.02274	15.48805
2	74.02181	15.48786
3	74.02146	15.49007
4	74.02218	15.49022

Zone-10 Block Coordinates

S.No.	Longitude	Latitude
1	74.02815	15.48062
2	74.02814	15.47977
3	74.02492	15.47983
4	74.02500	15.48083

Identied Sand Mining Zones with quantity

S. No.	Zones	Area (ha)	Volume (Cubic m)	Weight (Tons)
1	Zone1	4.7	52919	84376
2	Zone2	4.2	47290	75399
3	Zone3	4.1	38224	61158
4	Zone4	4.55	44599	71359
5	Zone5	4.3	76043	121669
6	Zone6	4.45	78696	125914
7	Zone7	3.79	90901	145442
8	Zone8	3.1	47485	75976
9	Zone9	2.2	40544	64870
10	Zone10	3.5	71437	114299

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