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Ecological Study of South West Coast of India: Monitoring and Marine Environment

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ABSTRACT

Marine environment monitoring of south west India has tended to focus on site specific methods of investigation. It is required to improve marine monitoring and design monitoring networks. This paper may be achieved by developing and testing innovative and cost-effective monitoring systems, as well as indicators of environment status. Here we present several recently developed methodologies and technology to improve marine environmental indicators and monitoring methods. The term ecology is derived from Greek word "oikos" means house hold of the earth planet physicochemical properties of costal waters of Goa were significantly affected by freshwater input from land runoff and low saline backwaters during southwest monsoon period. The highest concentration for all the nutrients and dissolve oxygen was absented during south west monsoon period. On the other hand, salinity and chl-a where at there minimum level during this period. A significant increase in nitrate, silicate, turbidity, phosphorus and conversely decrease in dissolve oxygen and chl-a concentration was noticed during 2020 as compared to earlier reported values from this coastal area. Present studies on the settlement pattern of organisms in the coastal waters of Goa revealed a wide venation in the colonization of macrobiotics as the weekly panels were observed. Life supporting activities such as respiration, feeding, metabolism, and cooling water quality with chemically and biologically.

Key words : ecological, south-west coast, marine environment, monitoring

INTRODUCTION

The Indian coastal zone, with a length about 7510 km, is one of the most densely populated coastal regions of the world. India's population of 1270 million, 1710 million people live along the coastal districts. The coastal lands in India have become the most sought-after zones for major economic activities and urbanization, making the coastal ecosystems vulnerable to reclamation and land use modifications. Added to this is the impact of sea level rise due to global warming. Sewage discharge and coastal erosion are the other major concerns of the coastal zones. Daily more than 3000 million litres of domestic sewage are regularly added to the coastal waters. Coastal ecosystems all over the world are subjected to various intensities of anthropogenic pressures largely due to industrialization and overexploitation by increasing population. Like the ancient civilization, modern industrialization and settlements are also concentrating on fragile landscapes like the coastal zone.

Ecology is the study of inter-relationship of organisms with physical as well as biotic environments. Organisms and environment are interrelated and interdependent. Any change in the environment affects the living organisms and vice-versa. An ecosystem is the structural and functional unit of ecology. It is a community of living organisms along with the abiotic components interacting together through energy flows and nutrient cycles.

Ecology is the study of relationships between organisms and their surroundings. This study is fundamental to an understanding of biology because organisms cannot live as isolated units. The activities which comprise their lives are dependent upon, and closely controlled by, their external circumstances, by the physical and chemical conditions in which they live and the populations of other organisms with which they interact. In addition, the activities of organisms have effects on their surroundings, altering them in various ways. Organisms therefore exist only as parts of a complex entity made up of interacting inorganic and biotic elements, to which we apply the term ecosystem. Hydro graphic and chemical features such as temperature, pH, salinity, dissolved oxygen, carbon dioxide content, suspended matter, nutrients, chlorophyll and water transparency play a significant role in the productivity of a coastal ecosystem (Strauss, 1989).

Temperature, one of the most important factors, particularly in the marine environment, influences the life of organisms by regulating various physiological processes such as metabolism, growth, reproduction and distribution. Its role is all the more important in a tropical environment wherein the maximum temperature during summer is close to the lethal temperature limit of many marine organisms. Even subtle changes in temperature for a short span of time can bring about large differences, particularly in biological composition (Kinne, 1970).

Dissolved oxygen is essential to all forms of life for respiratory functions. Salinity is another important parameter which affects chemical and biological processes. Salinity and temperature together influence the physico-chemical properties of seawater (Satpathy, 1996). Nutrient content in an aquatic environment is a measure of the productivity of the system (Harvey, 1960) and therefore, it is important to gather information about their distribution and behavior in different coastal ecosystems. Although, the life supporting processes in marine coastal ecosystems require many inorganic substances, nitrogen, phosphorous and silicon are considered to be more important than the others, as they play a key role in phytoplankton abundance, growth and metabolism (Raymont 1980; Grant and Gross 1996). Therefore, studies pertaining to the source of origin, distribution pattern and rate of utilization of these inorganic components have become imperative scientific research in coastal areas in the last few decades. The distribution and behavior of nutrients in the coastal environment, particularly in the nearshore waters and estuaries, exhibit considerable variations depending upon the local conditions such as rainfall, quantum of fresh water inflow, tidal incursion and also biological activities like uptake by phytoplankton and regeneration. Many workers have studied the distribution and cycling of nutrients in the temperate and Polar waters and their role in the productivity of the coastal and offshore waters has been duly recognized. These studies have shown the existence of a regular seasonal cycle of nutrients with high concentrations (in surface waters) in winter and low in spring and summer. The low levels in summer months have been attributed to the outburst of phytoplankton populations which utilize nutrients for their growth and multiplication.

REVIEW OF LITRATURE

In the tropical waters the amount of published work on the subject of nutrients is relatively small as compared to the temperate region. The earliest published work is from the waters off North-east Australian coast. Subsequently, reports from Java Sea (Delsman, 1939), Singapore straits (Kow, 1953), and tropical areas of the Pacific Ocean have appeared. The earliest published data on nutrients from the Indian subcontinent is that of Chidambaram & Menon (1945) for the Malabar Coast. The first attempt to study and understand the distribution and seasonal cycle of nutrients from the Bay of Bengal is that of Jayaraman (1951). This was followed by Ramamurthi (1953), Jayaraman (1954), George (1953), Seshappa (1953). More recent additions to these data from various coastal waters in the Bay of Bengal have also been made (Panigrahy et al., 1984; Sasmal et al., 1986; Gouda and Panigrahy, 1996; Panigrahy et al., 2006). Although a large amount of information with respect to general hydrography and biology of Kalpakkam, southeast coast of India, is available (Nair and Ganapathy, 1983; Nair, 1985; Satpathy et al. 1987; Satpathy and Nair 1990; Satpathy and Nair, 1996; Satpathy, 1996a) the data on nutrients have been scarce. Moreover, continuous and systematic study on nutrients has not been reported so far. In view of this, a study was organized to estimate nutrient (nitrite, nitrate, ammonia, total nitrogen, phosphate, total phosphorous and silicate) contents in the coastal waters of Kalpakkam over a period of two years (February, 2006 to February, 2008) with the following objectives: I) to study the seasonal variations in nutrient content, II) to find out any major change over the years due to anthropogenic impacts, III) to create baseline data for future impact studies and IV) to assess any change in physico-chemical properties of the coastal water during the post Tsunami period. The present study has put particular emphasis on various aspects of nutrients dynamics, in addition to general hydrographic parameters. In this chapter a detailed account of the hydrographic features including nutrient distribution in the coastal waters of Kalpakkam is discussed. Phytoplankton, as the basis of trophic chain, constitutes the most important biological community in any aquatic system (Monbet, 1992; Cloern, 1999; Sin et al., 1999). About 95% of the total production in marine ecosystem is contributed by the phytoplankters. For assessing fisheries yield, knowledge on the rate of gross primary productivity is important. Hence, the abundance of phytoplankton can be considered as the best index for quantitative assessment of fisheries potential of an area. In addition, the phytoplankton assemblages are often used as the indicators of water quality including pollution. As a matter of fact, predicting changes in dominance & diversity of phytoplankton, as the indicators of water quality, has promoted analysis of this community using different strategies, such as long-term monitoring of dominant 3 species and their relationship with seasonal changes of environmental conditions. The progressive changes in the phytoplankton community structure are thought to be mainly due to differential effects of changing physical, chemical and biological factors on individual species and it has been a recurrent subject of investigation in the recent literature. During the past, extensive work has been carried out pertaining to qualitative and quantitative ecology of phytoplankton from both the east and west coasts of India (Chandran, 1985; Mani et al., 1986; Devassy and Goes, 1988). However, such studies in the southeast coast of India in general and in the Kalpakkam coastal water in particular are very scanty. The only study pertaining to the phytoplankton ecology of Kalpakkam coastal waters had been carried out by Sargunam (1994) almost one & half decade ago. Moreover, there is no published data on phytoplankton ecology from this locality except for the fact that they are available in the form of unpublished data. Keeping this view in the backdrop, recent results of studies (2006-2008) on i) qualitative & quantitative abundance of phytoplankton, ii) seasonal variations in phytoplankton community organization and iii) the influence of environmental variables on phytoplankton species assemblage in the Kalpakkam coastal waters, southeast coast of India are also discussed in this chapter.

INDICATORS OR COMPNENTS OF MARINE ECOSYSTEM

Physical, biogeochemical, biological and ecological processes are an important component of marine ecosystem function. Together with the status and trends of marine habitats, communities and species groups, they provide an indication of the health of the marine ecosystem (e.g. Rombouts et al. 2013). Ecosystem health affects the services provided by the environment, and the industries and societies that use the marine environment, either directly (e.g., fishing) or indirectly (e.g., carbon sequestration and climate).

Considerable effort has gone into identifying important ecosystem components and processes associated with each key ecological feature, and the biological variables that have high commonality across the features, which could therefore comprise essential variables for measurement and monitoring (Hayes et al. 2015). To date, this process has been completed for 32 of the 53 key ecological features. For pelagic key ecological features, identified indicators include biogeochemical (nutrients) and biological (phytoplankton) indicators at the bottom of the food web, and predators (large pelagic predatory fish and seabirds) at the top of the food web. In shelf systems, identified indicators include those that are habitat forming (macroalgae and coral; see Hayes et al. 2015). Further detail on Australian and global efforts to identify key indicators for measurement and monitoring is provided in Sustained Ocean monitoring.

Overall, biophysical and ecological indicators of marine health within the Australian marine environment are in good condition, although several indicators are highly spatially and temporally variable. The methods used to measure each indicator are also variable. Current monitoring of many indicators is not spatially and temporally comprehensive enough to capture such dynamics in a robust manner. Therefore, assessment at a national scale and determination of trends for these indicators are difficult. Where indicators are highly dynamic (i.e., there is high variability), it is often difficult to distinguish trends from variability (i.e., the signal from the noise). Care must be taken in deriving trends across short time series, because these may capture only a portion of a highly variable signal and may not be indicative of longer-term trends (Hobday & Evans 2013, Harrison & Chiodi 2015). In addition, interpreting any observed trends requires identifying and understanding the relevant components of ecosystem structure, which can vary depending on interpretation, and between different areas or systems.

1. Water column turbidity and transparency

In oceanic and outer continental-shelf waters, the major determinant of turbidity, transparency and colour is the biomass of phytoplankton, whereas, in inshore regions, sediment flows from river systems or land run-off and high tidal flows have the most influence. Observations from the network of IMOS National Reference Stations show low suspended solids across all stations except Darwin.

2. Microbial processes and ocean productivity

Marine waters typically contain 10,000–1000,000 microbial (bacteria, archaea and unicellular algae) cells per millilitre, belonging to hundreds to thousands of different species (Fuhrman et al. 1989, Morris et al. 2002). This highly diverse and abundant community has an intimate connection with its environment. Marine microbial assemblages are the first to respond to changes in the chemical and physical properties of the surrounding water. Microbes also shape the marine environment by:

- driving most of the biogeochemical cycles
- supporting phytoplankton and primary productivity
- contributing to the ocean carbon pump (the uptake of carbon by phytoplankton through photosynthesis in the upper ocean and transfer of this carbon to the ocean's interior)
- sequestering carbon in 'recalcitrant' forms (i.e., resistant to decomposition)
- removing a wide range of organics and pollutants (e.g. Follows & Dutkiewicz 2011, Kujawinski 2011).

Understanding of marine microbial communities in Australia's waters is an emerging field. The high throughput genomics methods that allow assessment of communities at relevant spatial and temporal scales have only been available for the past 4-5 years. Because of the emerging nature of this field, generation of baseline databases of microbial community compositions linked to physical, chemical and higher-level biological parameters in the Australian environment has only just started. Therefore, an assessment of microbial communities is not possible at this time, and it is not clear how the assessment in 2011 was achieved. Once generated, these baselines will provide an in-depth understanding of how the state of the marine environment is reflected in the microbial community structure and allow more definitive assessments in future SoE reports.

Global Environment Facility monitoring, reporting and indicators

The Global Environment Facility (GEF) ensures regular reporting of results from its portfolio of projects through the reporting of indicators. The GEF 6 (2014-2018) Focal Areas Strategy for IW includes a number of outcomes and indicators (see Annex 2 for GEF 6 Indicators). The GEF 7 Focal Areas Strategy (GEF, 2018) for IW is focused on the following strategic objectives:

1. **Strengthening Blue Economy opportunities:** which includes strategic action: 1) sustaining healthy coastal and marine ecosystems; 2) catalyzing sustainable fisheries management; and, 3) addressing pollution reduction in marine environments.

2. **Improve management in the Areas Beyond National Jurisdiction (ABNJ):**

3. **Enhance water security in freshwater ecosystem:** which includes strategic action:

1) advance information exchange and early warning;

2) enhance regional and national cooperation on shared freshwater surface and groundwater basins; and,

3) invest in water, food, energy and environmental security.

Sea Levels and Sea Level Fluctuation along the Coast:

There is no monitoring station along the coast to measure the actual sea level fluctuation, and so a definitive chronology of sea level events in modern times is still awaited (Karlekar, 2000). Many of the geomorphological features on the coast, however, indicate a slightly higher sea level during the early Holocene period. Cliffs formed by wave action and shore platforms are very frequent along the coast. The shoreline terraces and the two / three generations of fossil dune ridges provide some convincing evidence of former shorelines. The wide coastal plains and the narrow shoreline terraces appear to be covered with Tertiary sand.

Fig. 4. An example of shoreline terraces along the Konkan coast.

Fig. 5. A typical fossil beach dune ridge along the Konkan coast.

The land between 2 and 10 m ASL provides evidence for numerous shore marks (Karlekar, 2000). Extensive flat plains on the late Holocene sediments suggest their development from tidal basins. There is no data to suggest that major storm accretion happened along this coast for at least the last 3000 years, and the fossil deposits found inland cannot be attributed to stormy episodes. About 6000 BP the sea was more or less at the present level. Between 6000 and 2000 BP the seal level gradually rose to 6 m ASL. Studies so far suggest that the highest sea level was attained around 3000 years BP (Guzder et al., 1975; Dikshit, 1976; Karlekar, 1981; Kale and Rajaguru, 1985; Bruckner, 1987; Hashimi, 1995). There is no convincing data yet to mark the sea level changes during the last 500 years.

Despite the lack of actual sea level measurements, some geomorphic features along the coast have been used to infer a general rise in sea level during the last few years. The features are: breaching of the beach ridges, scouring of ancient tidal channels, submergence and decaying of mangroves (Karlekar, 1986), breaching and undercutting of anti-erosion walls, appearance of offshore mud on sandy beaches and an overall increase in the salinity of well water along the coast. The disaggregation of sand accumulation forms and the redistribution of sediments in the bays and the creeks, e.g. at Shrivardhan (Karlekar, 1997), Kelshi (Karlekar, 2000) and Karli, also indicate a recent rise in sea level along the Konkan coast.

1. pH

pH values ranged from 7.7-8.4 in surface waters and 7.7-8.3 in bottom waters. The highest and lowest monthly average values for both surface and bottom waters were observed during February and May 2006 respectively. The monthly average values showed that it gradually decreased from February to June and remained almost constant from June to August with a noticeable increase from August (Figure-2.1a) during 2006. However, during the second year of study it did not show any particular trend. Relatively low values were observed during the post-monsoon period and it gradually increased up to summer. A decline in pH values was noticed during SW monsoon period although 2007 values were relatively high as compared to the same period of 2006.

2. Salinity

The observed surface and bottom salinity values ranged from 23.38-35.97 psu and 25.41- 35.97 psu respectively. The lowest and highest salinity values were observed in the month of November and May/June respectively. As expected, the salinity values at this coast was at its lowest during NE monsoon and increased after the NE monsoon period and reached the peak during summer. This is attributed to the dilution of coastal water by the addition of fresh water from the two backwaters adjoining this location during NE monsoon period and this dilution decreased in the subsequent months (January - August) resulting in an increase in salinity level. It remained almost constant during summer showing a typical oceanic salinity until the arrival of SW monsoon. It started decreasing from the month of August reaching a minimum in November. Though there was no distinct variation in the surface and bottom salinity of any individual location, marginally high bottom water salinity was observed at all the locations as evident from the station-wise average values.

3. Dissolved Oxygen

The DO contents varied between 3.3-7.1 mg l-1 and 4.4-6.9 mg l-1 for surface and bottom samples respectively. The surface values, as expected, were marginally higher than the bottom values throughout the study period. The monthly average values showed a decrease in concentration of DO from February to May after which it increased gradually up to January (Figure-2.3a) during the first year of study. Gradual decrease in DO was noticed after the cessation of NE monsoon to summer and peak values were observed during pre-monsoon (NE monsoon) periods (August/September). No clear trend in DO content was observed with respect to stations (Figure-2.3b) although the surface concentration remained higher than the bottom at all the locations. A noticeable increase in DO observed from October to January could be attributed to the input of DO rich freshwater from the adjoining backwaters during the NE monsoon period. In aquatic systems, oxygenation is the result of an imbalance between the process of photosynthesis, degradation of organic matter, reaeration and physico-chemical properties of water.

4. Turbidity

The turbidity values ranged from 1.69-17.76 NTU for surface water and 1.85-92.77 NTU for bottom water. The lowest and highest values for surface water were obtained during January and May respectively, whereas, lowest and highest bottom values were encountered in February and April respectively. Monthly average values showed relatively high water turbidity during post-monsoon/summer (NE monsoon) during both the years of study.. However, during 2007-08 a secondary peak in turbidity was noticed during the pre-NE monsoon period. It has been reported that the wave action increases during the post-NE monsoon and summer due to the northerly wind and the northward current prior to the onset of the SW monsoon [resulting in turbulent condition in the coastal waters favoring the resuspension of the bottom sediment due to stirring action that causes low water transparency. This perhaps could be the plausible reason for bottom water showing higher turbidity than the surface as otherwise expected between surface and bottom waters. Moreover, the role of phytoplankters for the increased turbidity values in April and May can't be overlooked, as phytoplankton production in summer is generally high as compared to the remaining periods of the year at this location.

5. Nitrite

Nitrite concentration varied from BDL –5.23 µ mol l-1 in surface samples and BDL – 4.73 µ mol l-1 in bottom samples. The highest concentrations for surface and bottom samples were observed during December, whereas, BDL values for surface and bottom samples were observed on several occasions. Marginally high bottom concentration of nitrite was noticed in almost all the observations except on some occasions during November and December when the surface concentrations remained higher. Monthly average values showed that nitrite concentration gradually increased from February to August after which it sharply decreased in October (Figure-2.5a) during 2006-07. However, an abrupt increase in nitrite concentration during December was noticed which coincided with the NE monsoon. In the second year, relatively high values were observed during NE monsoon period only. There was no significant variation among the stations as can be seen from the station-wise average values (Figure-2.5b). Concentration of nitrite in the surface water was marginally high as compared to the bottom at all the stations except the 1st and 5th location, wherein surface and bottom concentration was almost same. At the other three locations the bottom water concentration was slightly high as compared to the surface

7. Ammonia

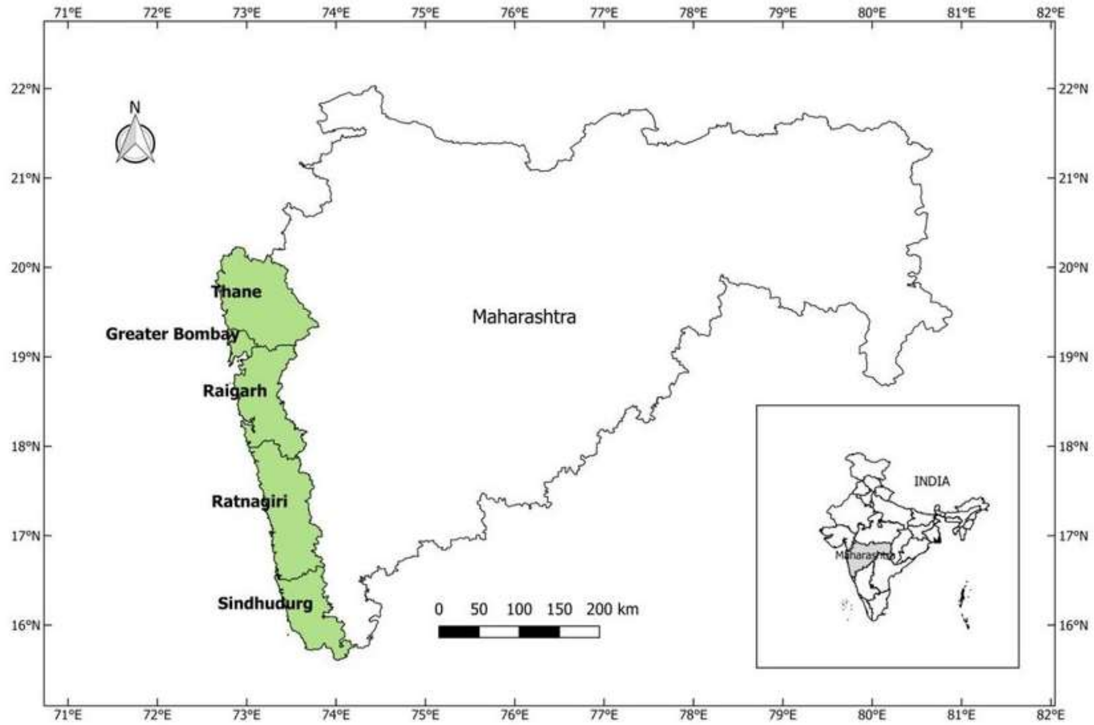
Throughout our observations the ammonia values did not show any typical trend and BDL values were observed on may occasions in both surface and bottom water samples. The highest surface (11.74 µ mol l-1) and bottom (9.65 µ mol l-1) concentrations were observed in the month of April and September respectively. The monthly average values showed that ammonia concentration remained almost below 1 µ mol l-1 from February to August and an increase was noticed during September and November during 2006-07, when the average value exceeded 2.5-3 µ mol l-1. During 2007-08 an additional peak of ammonia was observed during summer apart from the pre-monsoon and monsoon peaks as observed during 2006-07. The station-wise average values showed that surface water concentration of ammonia was marginally high at the 3rd location as compared to that of the other 4 locations, however, the bottom values did not show any significant trend. Sampling locations, the 3rd location alone showed higher ammonia content in the surface water than the bottom water. Ammonia, the chief excretory product of marine invertebrates, is also well known as a nutrient, which is preferred over nitrate by the phytoplankton community in certain environmental conditions.

8. Total Nitrogen (TN).

Values of TN ranged from 3.74- 267.68 µ mol l-1 and 3.53-285.73 µ mol l-1 for surface and bottom samples respectively. Highest and lowest surface and bottom values were observed during November and July respectively. High concentration of TN is, in conjunction with other factors, often associated with algal blooms, as well as dense aquatic plant growth. This can lead to a considerable alternation in the water quality and will have an impact on the aquatic life ultimately. TN values observed at this coast remained relatively low during summer which coincided with the relatively high phytoplankton productivity at this period of time as can be seen from the chl-a values.

The Coast of Maharashtra

The Maharashtra coast, popularly known as Konkan coast, lies between 150 45’ - 200 00’ N latitudes and 680 00’ - 730 30’ E longitudes. It is a narrow zone between the Western Ghats to the east and the Arabian Sea to the west trending NNW-SSE in general. The Sahyadris Western Ghats run parallel to the coast. The Dudh, the Vaitarna, the Ulhas, the Amba, the Kundalika, the Vashishthi, the Savitri are major coastal rivers draining into the Arabian Sea in the west. The coastal region is hilly, narrow, dissected with transverse ridges of the Western Ghats, extending as promontories at many places. It is characterized by pocket beaches flanked by rocky cliffs of Deccan basalt, estuaries and patches of the mangroves along it. Beaches of the Maharashtra coast are small, crescent shaped and flanked by promontories. They are termed as pocket beaches as they are pocketed between headlands. They are observed southwest of Dahanu, Andheri, north of Alibag, Vadamirya and Rajapur creek. Long and linear beaches are observed near Guhaghar and Malvan. Mudflats are observed mainly along the estuaries and bay. They are broad at the mouth and gradually taper down. They are observed near Thane creek, Panvel creek, Vasai creek, on the bank of the Kundalika River and along the Rajapur creek. Mangroves are mainly observed along the intertidal region of estuaries and creeks. Large patches of mangroves occur along the Panvel creek, the Vasai creek, the Thane creek and the Dharamtar creek, along estuaries of the Vasishtha, the Savitri and the Kundalika rivers. Coastal dunes are found with Casuarina plantation near Malvan and Devgarh.



The Central coastal segment of Maharashtra, south of the Raygad, is the Ratnagiri coastal sector from south of the Savitri River (Map Sheet no. 47G01NW) to north of the Vijayadurg creek (Map Sheet no. 47H06SW). Along this sector the Savitri, the Jog, the Vashishti, the Shastri, the Kajvi and the Machkandi rivers get discharged into the Arabian Sea. Rocky coasts form a larger portion of this coastal region and a considerable length of the coast is stable. Mangroves are observed along the Savitri River, north of Velas, shown in Plate 28. Plate 29 shows the coastal segment north of Velas (Map Sheet no. 47G01NW). South of Velas upto Sakhari the coast is almost stable in nature. South of Sakhari, Padale (Map Sheet no. 47G01NW), Panchgaon, south of Jog River upto Palandwadi and Murud, the coast is eroding to stable in nature. Plates 30-32 show the coast around Murud. Some small segments of erosion are observed around Bhandariwadi (Map Sheet no. 47G02NE). The segment from Kolthare to Bhiv Bandar, the coast is almost stable in nature (Map Sheet no. 47G02NE, 47G02SE). Erosion is observed north of Vashishti River mouth (Map Sheet no. 47G02SE), where a significant portion of coastal region has undergone erosion. Plate 4 shows the severity of erosion at the northern bank of the Vashishti River mouth. Field checks have been conducted along this region. Plates 33-34 show the protection measures at the site to resist the erosion. South of the Vashishti River, along coastal segment of Kalhal Wadi, Palshet, Budhelwadi (Map Sheet no. 47G03NE), Sakhri Agar, Narvan, Sankdol (Map Sheet no. 47G03SE), Bhandarwadi (Map Sheet no. 47G04NE), Kumbharwadi, Malgund (Map Sheet no. 47G08NW), Kajarwadi, Vada Mirya (Map Sheet no. 47G08SW, Plate 35-37), Ratnagiri, Kasop (Map Sheet no. 47H05NW), Bandheri, Purangad (Map Sheet no. 47H05SW), Bokarwadi (Map Sheet no. 47H06NW), south of Rajapur creek (Map Sheet no. 47H06SW) almost stable nature of coast is observed, except small segments of erosion around Guhagar and north of Velneshwar (Map Sheet no. 47G03NE), north of Bhandarpule (Map Sheet no. 47G08NW). Some accretion is observed north of Bhatya creek (Map Sheet no. 47H05NW), south of Wadavetye (Map Sheet no. 9 47H06NW). Plate 5 shows the stable rocky coast south of the Rajapur creek (Map Sheet no. 47H06SW) in the Ratnagiri district. The southern coastal segment along the Maharashtra coast covers the Sindhudurg region and comprises of the coastal stretch between Gharwadi (Map Sheet no. 47H06SW) to Redi (Map Sheet no. 48E10NE). The Vagothan and the Karli form the major river discharges along this coastal region. This segment also comprises of rocky coastal region almost stable in nature. The pocket beaches that lie between the rocky out crops are subjected to coastal dynamics. Notably, the accretions are mainly at the river mouths, where the spits are observed to grow towards southern directions. The region south of Vijaydurg creek, along Gharwadi (Map Sheet no. 47H06SW), Girya Kathar (Map Sheet no. 47H07NW), Advawadi, Tand Vali (Map Sheet no. 47H08NE), Malvan (Map Sheet no. 47H08SE), Bhogvewadi, Medhavadi, Nivitiwadi (Map Sheet no. 48E09NW), Dabos (Map Sheet no. 48E09SE) are almost stable in nature, except few small straight segments of erosion around Shelgulwadi, Tembaldegwadi (Map Sheet no. 47H07SE), Pirawadi (Map Sheet no. 47H08NE, Plates 38-39), Kolamb (Map Sheet no. 47H08SE), Tarkarli (Map Sheet no. 47H08SE, Plates 41-42), Ubhadanda, Valagar, (Map Sheet no. 48E09SE, Plates 43-44), Redi (Map Sheet no. 48E10NE). Accretion is observed along the Kalavali creek mouth (Map Sheet no. 47H08SE) and the Karli River mouth (Map Sheet no. 48E08NW). This confirms the southern growth of the spits at the river/creek mouths. Plate 6 shows the extensive southern growth of the spit at Kalavali creek mouth. Plate 40 shows the field photograph of the spit at the river mouth.

Figure 1 shows the accreting length, eroding length and stable shoreline of Maharashtra coast.

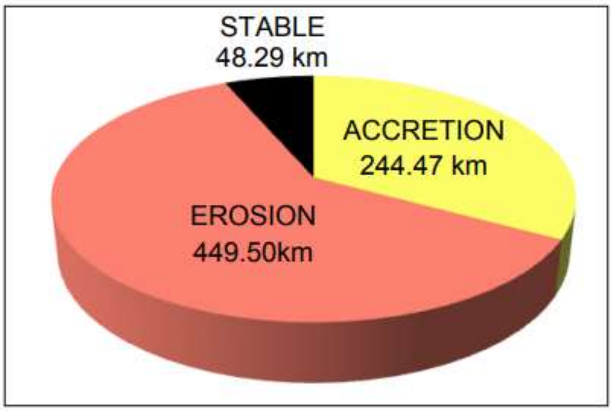


Figure 1: Status of coastal erosion, accretion and stable nature of Maharashtra coast (Total coastal length of 742.26 km does not include length of mouth of estuary, rivers, creeks and their inner parts).

The Coast of Goa

The coastal tract in the state of Goa lies between 14°48' N and 15°48'N and between75°40'E and 74°20'E. Lying adjacent to the Konkan coast of Maharashtra, this coastal belt is considered a part of the Konkan coastal belt. It is a narrow coastal strip located at the foot of the Western Ghats. The height of the Western Ghats here is nearly 1000 m, while the plians at the foothills lie at about 100 m ASL. The land between the foothills and the sea is about 40 km wide.This region is characterised by several small hills scattered all over the area. Physiographically the region can be broadly classified into: (1) the coastal tract, (2)sub-Ghat region, and (3) the high ranges of the Western Ghats.

Temperature in Goa is moderate, with not much seasonal variation. May is the hottest month, while January and February are usually the coldest. Rest of the year usually experiences a tropical weather. Rainfall is copious, and is received mainly during the rainy season from June to September, when the whole of Konkan coastal tract receives high rainfall from the Southwest monsoon. The highest rainfall is received during July while the driest month is February.

Mining is one of the principal sources of Goa's industrial and trade development. It offers considerable scope for employment also. Iron ore is the leading commodity for mining, and occupies the pride of place in Goa's economy. Other mine resources include manganese ore and ferro-manganese ore. Some of the most productive and important mines are located in the northern and eastern parts of Goa.

Goa is also famous worldwide for its golden beaches. Several pocket beach segments are now open to international tourists, and these remain crowded almost throughout the year. The income generated by the state from these beach-based 'tourism industry' competes for high ranks with the revenue generated from mining and industries. Agriculture is also an important economic activity in Goa. Fishing, both in freshwater and in open sea, is the most dominant economic activity along the coastal strip. Rice cultivation predominates inland. Goa has done much to develop its agriculture, and the farmers now get a better return for their labour. Rice along with fish is the staple diet of the people.

The Central coastal segment of Goa comprises of regions around the Aguada and Marmagao Bay. The Mandovi and Zuari rivers discharge into these respectively. This region is between south of Shinken upto Vasco. This coastal stretch is majorly stable in nature (Map Sheet no. 48E14NW), except few small segments of erosion. Coco beach, south of Shinken (Map Sheet no. 48E15NW) is a pocket beach showing local erosion. Protection measures are implemented here shown in Plate 55. Eroding segment is also observed near Dona Paola. The famous Miramar beach is located in this segment near Karanjnalen. Sea walls have been constructed at several locations around Miramar, Dona Paola, Cabo Hill, Campal to protect the coast and remedial measures have been taken for stabilizing unstable slopes of Cabo Hill. In South Goa sector, long linear beaches, rocky cliffs, headlands are observed. Pocket beaches are formed between rocky headlands. Segments of erosion, accretion as well as stable nature occur in the South Goa sector. The coastal stretch along Bobdan, south of Vasco (Map Sheet no. 48E15NW), Kimsavlin, Arosin, Sernabalim (Map Sheet no. 48E15SE), near Kavllesi (Map Sheet no. 48E16NE) and south of Talpona upto Mahi (48J01NW) shows accretion. Plate 61 shows the spit near Mahi. Erosion is observed around Betalbatim, between Kolva and Majorda. Uprooting of Casuarina plantation due to coastal erosion and protection measures taken near Betalbatim (Map Sheet no. 48E15SE) are depicted in Plate 57-59. Erosion is also observed along South of Betul, upto Kanagini and between Parven to Agonda (Map Sheet no. 48E16SE). Small segments of stable coast occur along Dabolim, Arosin, south of Sernabalim (Map sheet no. 48E15SE), Bogmoha, Chukolna

(Map Sheet no. 48E15SW, Plate 56). A long stretch of stable beaches is observed from Fatrade almost upto Betal (Map Sheet no. 48E16NE, Plate 9- 10). Stable coast at Karmona, north of Kavlessi is shown in Plate 60. Beautiful sandy beaches (Benaulim, Varca, Betul) occur along this segment. The rocky cliffs in the southern region, from Cape Rama to Loliem near Karnataka border constitute the stable coastal stretch (Map Sheet no. 48E16SE, 48I04SW, 48J01NW, Plate 11, 62).

Figure 2 shows the accreting length, eroding length and stable shoreline of Goa coast.

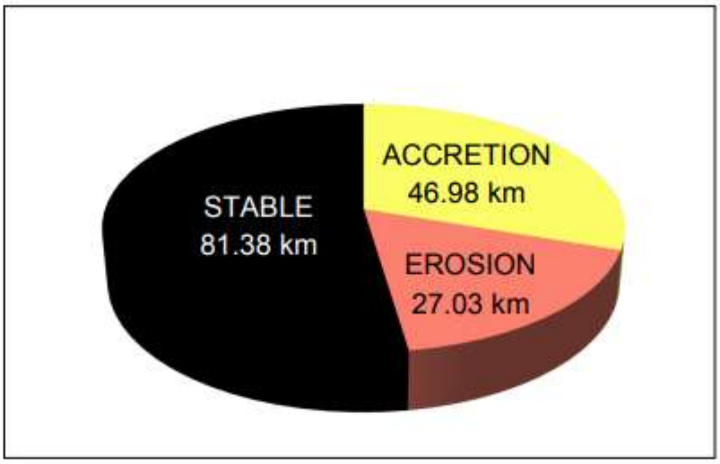


Figure 2: Status of coastal erosion, accretion and stable nature of Goa coast (Total coastal length of 155.39 km does not include length of mouth of estuary, rivers, creeks and their inner parts).

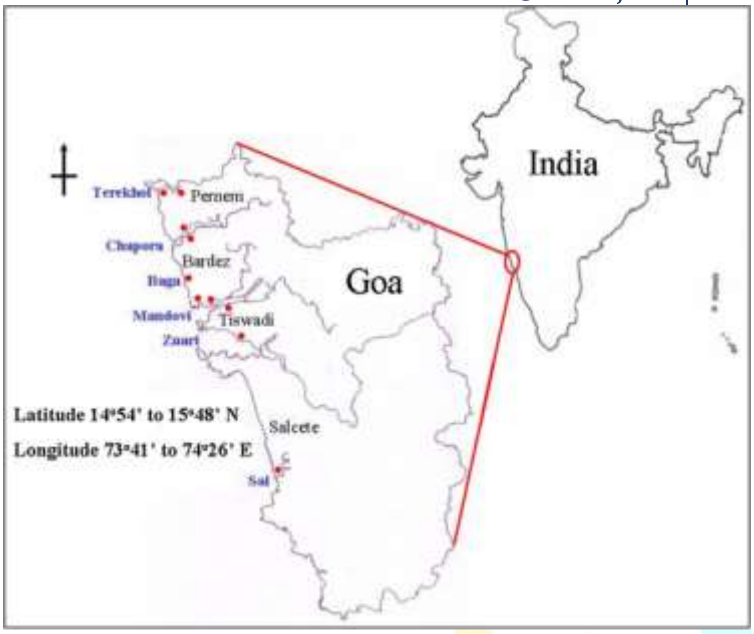
SOCIO-ECONOMIC ASPECT

The North Konkan coastal belt, to the north of Mumbai, has an average width of 15-20 km. The Mumbai-Delhi railway track and the Mumbai-Ahmedabad National Highway run through this coastal strip, and provide excellent glimpses of intensive garden farming, besides the views of rice fields. The region enjoys the advantages of a very effective transport network and a close link with Mumbai. The influence of Mumbai is significant in its primary economic activities and the occupational structure of the population. One frequently comes across large orchards of chikoo and mango, as well as coconut groves and dairy farms, all of which have a thriving market in Mumbai. Many large settlements in this plain work as contact towns and market centres of the Mumbai megalopolis. Nearer the lush green forested hills, inhabited by the tribals, the urban centres provide lucrative jobs to the tribal folks. Timber trade is an important activity near the hills.

The irregular coastal tract of Middle Konkan, often interspersed with hilly terrain, has its cultivated lands confined only to the narrow riverine plains and along the coastal flats. Croplands constitute less than 30% of the total area, where rice is the principal crop. Irrigation is highly localized. A relatively sparse population, with a density of 175 per sq km, lives in small villages and sometimes in widely spaced individual huts.In the coastal tract of South Konkan, subsistence farming is dominant, as the area is largely stony and barren with shallow soils, interspersed with laterite plateau. Large-scale migration of people, especially men, from the region to Mumbai and its suburbs for job has disturbed the sex ratio. Many villages in this coastal belt are dominated by women who tend to the fields.

The Mandavi and Zuvari estuaries

Form the largest tidal system along Goa coast.The large embayment at the entrance of the Mandavi estuary, Aguada Bay has very complex flow patterns of tidal flow and sedimentation. The siltation in the channel is essentially due to deposition of the suspended sediments due to tidal flows, as well as sand incursion due to littoral drift. Mudflats are found mainly along such estuaries and creeks.



Miramar beach is 3 km long and 85 m wide. The dune zone at the back of this beach is short. The headlands at Aguda Fort, Dona Paula and Marmgao are 72m, 35 m and 75 m high, respectively, and show sea cliffs having height of 10 to 12 m above sea level and narrow shore platforms with a width rarely exceeding 10 m.

Fig. 13. Field sites from Keri to Ganapatipule.

Fig. 14. Road from Ratnagiri to Ganapatipule

Ratnagiri: Sea cliffs, Shore platforms and Sea caves are the major landforms seen from Bhagavati Fort (or Ratnadurga) headland (Fig. 15). The headland is a 75 m tall promontory on the Ratnagiri sea shore. It has divided the Ratnagiri shore into northern and southern coastal segments. Ratnadurga, popularly known as Bhagavati Fort, with an area of 120 acres, is situated on this hill. The fort is surrounded by sea. The Legendary Hero from Maharashtra during the Mughal Period, Chatrapati Shri Shivaji Maharaj won the fort in 1670 from the king, Adilshah. The fort was used as a watch tower for keeping vigil on the pirates. A lighthouse is situated in the fort, which guides the ships/vessel's travelling in the Sea (Fig. 16). A beautiful temple to Goddess Bhagavati is also situated here. Devotees from far-flung areas visit the temple, especially during the famous Navaratri festival in October. The fort is in ruins now. One can see the entire Ratnagiri city from this fort.

Fig. 15. Google Earth image of the Bhagavati Fort area.

Fig. 16. Field sites between Bhagavati Hill and Sakhartar Creek.

Impressive sea cliffs, shore platforms and notches and caves characterize the coast.The destructive impact of waves along this coast is often far greater than is generally expected. Cliffing is the dominant process. Average height of the cliffs is around 9 m. Overhangs and notches slightly above the influence of the present-day waves characterize the lower sections of the cliffs. The near-absence of quarrying material at the foot of the cliffs suggests insignificant sub-aerial erosion. The shore platforms at the foot of the cliffs are a striking feature in the area. Their average width rarely exceeds 30 m. The platforms are intertidal and are shaped by abrasion and water layer weathering.

Fig. 17. Sea cliff, cave and shore platform at Ratnagiri.

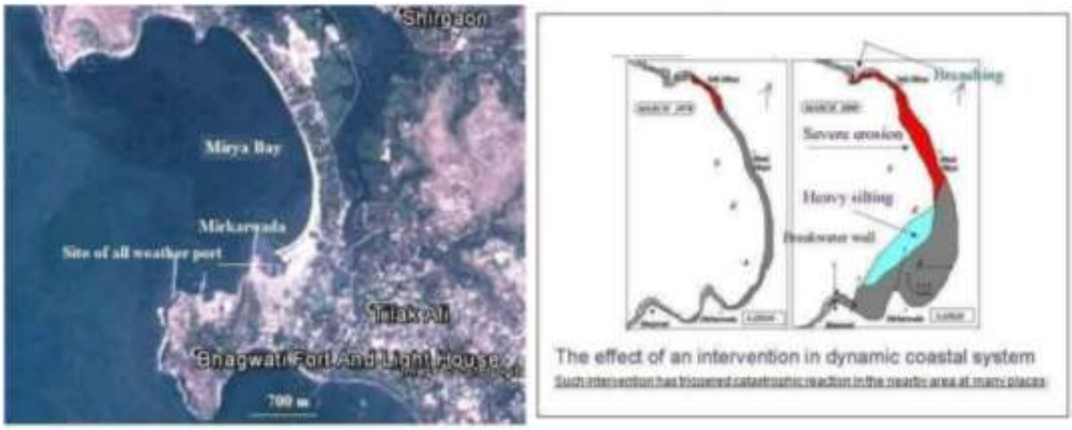


Fig. 18. Mirkarwada harbour and the Mirya Bay.

The caves on this coast have developed on basalts and laterite. A 7 m high cave in the area is fronted by a long narrow and deep channel, which is produced along the weaker zone. An all-weather port can be seen at Mirkarwada harbour in the southern part of Mirya Bay to the north (Fig. 18). The total area of Mirya Bay is about 6 sq. km. Since the construction of a commercial harbour in 1981, the 3.5 km long beach is suffering from severe erosion near the northern end, and severe siltation to the south (Fig. 18). The modern beaches and dunes of the area are backed by old, fossilized beaches and dunes. The fossil deposits are more or less parallel to the shore. The deposits are calcareous, sandy and shelly in nature (Fig. 19). Mirya village is situated on such a fossil dune and beach ridge. The fossil deposits suggest a higher sea-level in this part of the coast 2800 years BP.

The Tidal inlet at Sakhartar is distinct, especially due to its tidal and fresh water regime. The major sedimentary environments of the inlet are the tidal flats associated with the high tide, low tide, sub-tidal and inter-tidal regimes, as well as the sand banks, mangrove swamps and scoured tidal channels. The mid-inlet sectors are invariably the areas of silty-clayey bars. On an average the depth of the tidal inlet varies from 1 m near the head to about 4 m near the tidal mouth. Saline inter-tidal mud flats are the prime areas of sedimentation in the creek.

Fig. 19. A typical fossil dune and beach ridge profile near Mirya

Fig. 20. Google Earth image of the tidal inlet at Sakhartar.

North Goa Coast

The beach at Keri is quite steep, composed mainly of fine sand. As one travels along the sea face to the south (Fig. 36) the beach becomes broader. The wind and wave action continuously rework the beach sand, forming many micro-features on the beach. The coast here is also characterized by stable sand dunes in their pristine forms. The fore- and mid-dunes are not very prominent. The backshore is well protected by a thick plantation of Casuarina plants. The creek is characterized by many sand lenses, sand bars, tidal mud flats and mangrove swamps.

At **Arambol** (15.7° N / 73.7° E) the sandy shore has very welldeveloped fore- and middunes, which are well covered with Spinifex plants. A sweet-water body is located adjacent to the beach at the base of the hill.

Mandrem beach in this sector has long stretches of sandy shore with mature sand dunes that are well-protected by vegetation. Apart from the mature backshore dunes, one can also see here the embryo dunes, as well as the fore- and middunes.

Ashvem (15.6° N / 73.7°E), slightly to the south, has a mixed shore with sandy and rocky beaches. The coastal dunes are well protected by plantation.

Morjim preserves a good sandy shore with well-developed dune system. The backshore dunes are not well stabilized, but the embryo dunes and the fore and mid dunes are relatively better preserved.

South of Chapora Fort, and especially at **Vagator**, low sand dunes are common over a limited stretch. It comprises of a rocky coast with some sandy pockets. Similarly, at Anjuna, there are extensive sand dunes covered by vegetation. Many dunes are also degraded. One can clearly see many disturbed chaotic strandlines at several places along the shoreline in this sector.

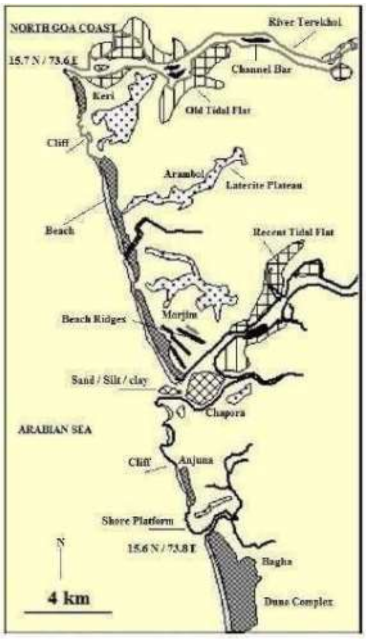


Fig. 36. Map of the beaches to the south of Keri.

Conclusion:

In this study, a climatology- based analysis of various physical oceanographic parameters is attempted to understand the annually recurrent up-welling and down welling phenomena along the south-west coast of India. The main findings of this paper are listed below.

A. Up-welling along the south-west coast of the India starts at the subsurface level during march/April at the southern tip of India and it is intensified from May to September during the south-west monsoon.

B. Up-welling was more dominant along the southern latitudes compared to north.

C. Strong Ekman drift was observed along the south-west coast of India during the summer monsoon to drive significant vertical circulation along the coast.

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