Integrated coastal management of Mumbai metropolitan region

Raj C. Murthy[a,*], Y.R. Rao[a], Arun B. Inamdar[b]

[a] *National Water Research Institute, 867 Lakeshore Road, Burlington, Ont., Canada L7R4A6*
[b] *CSRE, Indian Institute of Technology, Powai, Mumbai, India*

Abstract

Mumbai Metropolitan Region (MMR) is the largest coastal city in India. The region experienced tremendous growth over the years due to rapid industrialization and urbanization. MMR is also the major center of economic activity in India. As a result there is a continuous and constant influx of population from the rest of the country. The high population density and uneven growth rate have resulted in serious environmental problems in the MMR coastal region. This paper discusses several aspects of the MMR coastal region that suffer from a wide variety of environmental as well as socio-economic problems due to unplanned and non-integrated sectoral developmental activities over the years. These problems need to be addressed in developing an Integrated Coastal Management plan for the MMR coastal region.

1. Introduction

Mumbai Metropolitan Region (MMR) extends over an area of 4400 km^2 and comprises of five municipal corporations, 15 municipal towns and seven non-municipal urban centers (Fig. 1). The region is typical of the Deccan Basaltic terrain with flat top mountains bordering the low lying coastal region that is traversed by five major rivers.

The population of MMR presently is in the range of 16 million of which Greater Mumbai contributes 68% and covers only an area of 468 km^2. The population of the MMR in the year 2011 is expected to be 22.4 million of which Greater Mumbai share is likely to be dropped to 58%. Fig. 2 shows the decadal population growth of Mumbai city. The high population density and constant influx of people to this

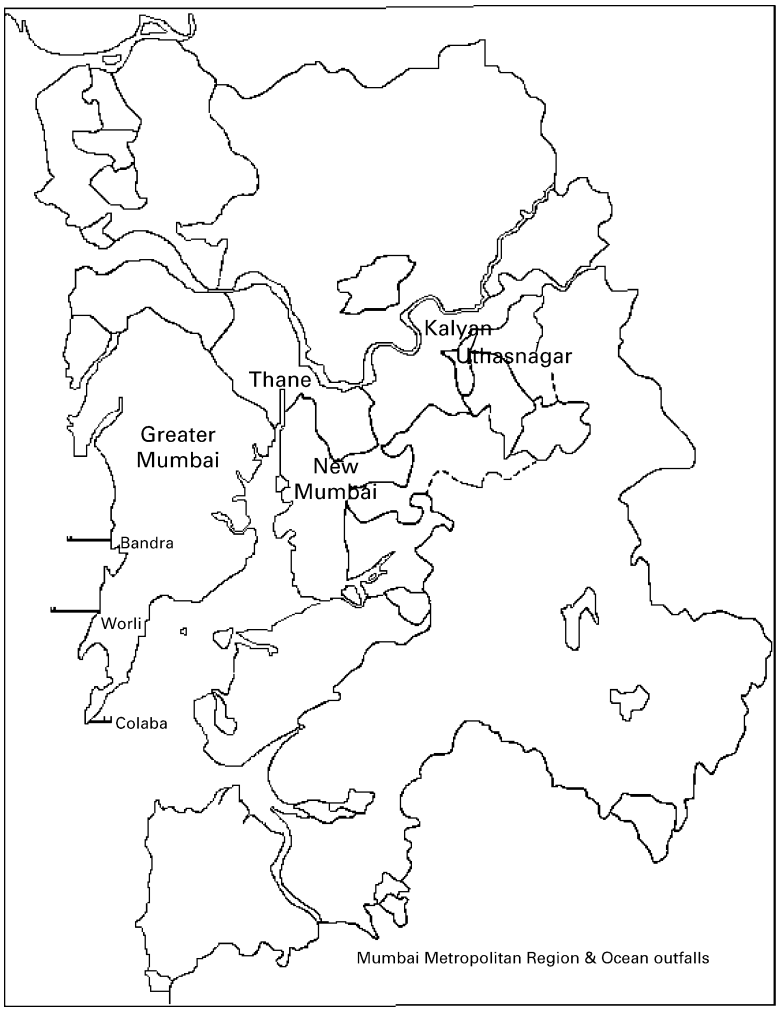

Fig. 1. Mumbai Metropolitan Region.

commercial capital of India are responsible for overall environmental degradation. Parts of the coastal zone of MMR have also become increasingly susceptible to human induced environmental stresses and economic damage by natural geophysical factors such as erosion, siltation and coastal flooding. The waste generation and disposal pressures due to domestic and industrial activities have further contributed to the deterioration of coastal marine water quality and coastal fisheries. Although several attempts have been made by local government to improve the coastal environment, this is hampered by uncontrolled growth of population and economic activity of the region.

The main problems in MMR coastal region are land use pattern, residential and industrial water supply and waste disposal, transportation-related air, soil and noise

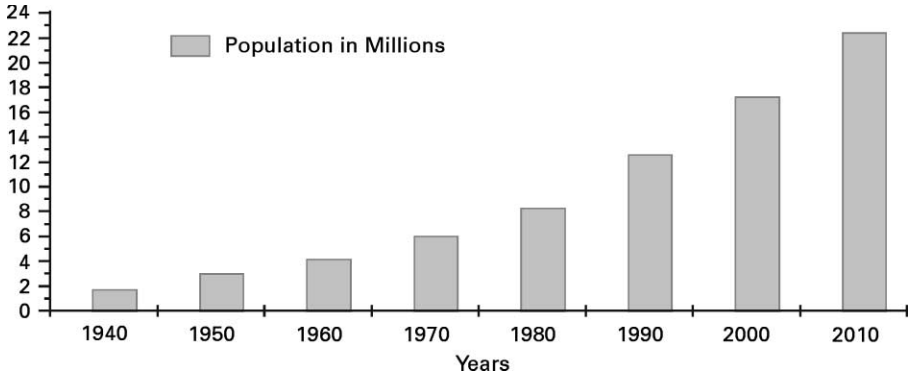

Fig. 2. Decadal population growth in MMR (population in millions).

pollution, coastal marine pollution, depletion of important coastal habitats like wetlands and mangroves. It is necessary to assess the status of various sectors that are associated with these problems before deciding appropriate strategies to address them through integrated coastal management (IACM) measures. This paper discusses these problems and the conflicts amongst the users as potential triggers for initiation of IACM concepts to mitigate the environmental damage and to promote a sustainable developmental plan that may curtail further damage to the MMR coastal ecosystem.

2. Soil and land use

The soils in the region are derived from Deccan trap basalt. Very little land is available for agriculture due to widespread urbanization in Greater Mumbai. Agriculture and forestry were important components of MMR. Both are under severe threat from developmental pressures as the demand for housing and construction keeps increasing with constant influx of people in MMR. The total agricultural area in MMR is reported to be around 1850 km^2 in 1989 of which 55% is fallow, 35% is cropland and the rest is plantation (MMRDA) [1]. A total of 1450 km^2 of area in MMR is covered by forests of which nearly 40% are dense evergreen forests and the rest are sparse forest and scrubland. Encroachment in forest land is common along the fringes of the forest area.

Land filling operation is done with the sole objective of creating land for housing and industries, without adequate geo-hydrological considerations. A total area of nearly 90–100 km^2 is reclaimed in Thane and Mahim creeks resulting in the reduction of tidal flux. Environmental impact assessment studies using models have shown a reduction of tidal prism and reduced near shore currents due to the reclamation in Thane creek [2]. The reclamation of land, indiscriminate sand mining and associated development exerts enormous pressure on the coastal marine ecosystem of the region. From the land use distribution in Greater Mumbai and New

Mumbai (Fig. 3), it can be observed that the land use planning activities are particularly relevant for better environmental management of the MMR coastal region. Land use proposals for 1996–2011 drafted by Mumbai metropolitan region development authority has delineated urbanizable, industrial, forest and green zones in different segments of MMR based on ecological and environmental conditions.

2.1. Water supply and waste disposal

The annual rainfall in the region ranges from 180 to 248 cm mainly during south-west monsoon season (June–September). Fig. 4 shows the monthly average rainfall and air temperatures in Mumbai. Due to decreased capacity of the ground water aquifers in the region, water level rises up to ground level after heavy initial rainfall. Further precipitation would not make any positive contribution to ground water aquifers, and it is lost as run off. Due to the huge demand for land, many low lying areas of the rivers flowing through MMR are reclaimed and this causes floods during monsoon season [3]. This problem is aggravated by poor storm water drainage system of the city. Indiscriminate dumping of solid waste often clogs the combined storm water and municipal waste water drainage system resulting in coastal flooding and inundation during monsoon months.

Nearly 60% of the Greater Mumbai's population live in slums and squatter settlements. Around 3000 MLD of water is supplied to Mumbai city from six reservoirs after treating and disinfecting [4]. Of the total piped supply, domestic supply accounts for 70% whereas commercial and institutional demand is about 10%. Rest of the water is wasted in leakage and thefts. Despite a very low water tariff several areas in MMR have severe water shortages. There is an unequal distribution of water supply. Ground water resources, wherever available, need to be harnessed for residential and agricultural uses. The ever increasing population,

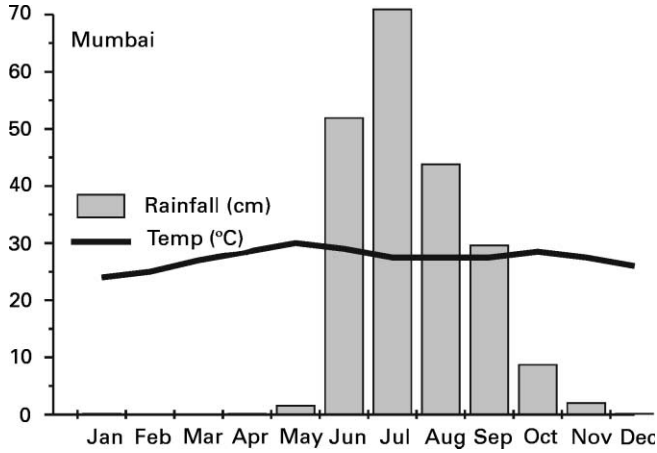

Fig. 3. Mean monthly rainfall (cm) and temperature (°C) in Mumbai.

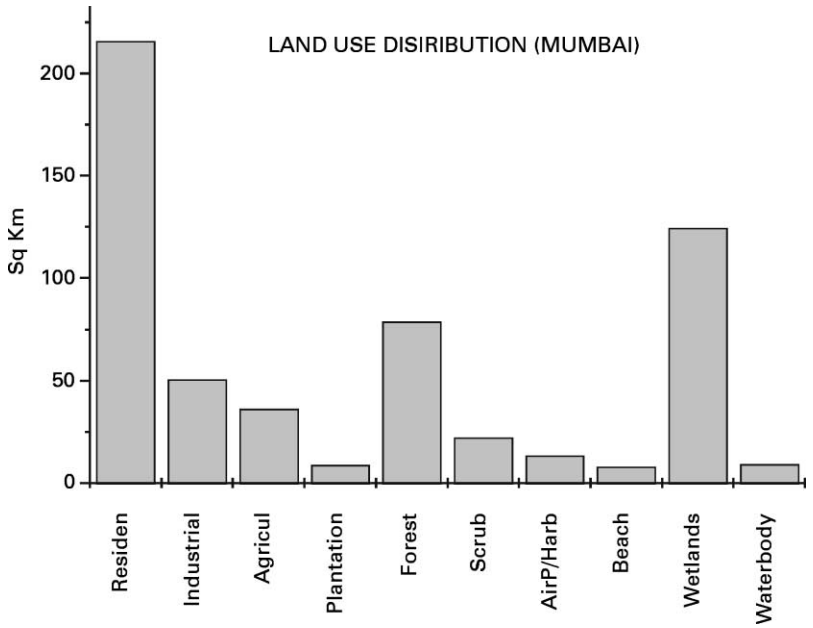

Fig. 4. Land use distribution (km^2) in MMR.

particularly in slum localities of MMR makes the task of equitable distribution of water supply very difficult for the authorities.

An average 90% of the households of Greater Mumbai has sewer connections though in terms of population, however, the coverage is much less owing to the presence of large number of slums and squatter settlements. In areas where the proper sewerage is not available, on-site disposal systems comprising septic tanks, soakage pits and let off to nearest natural streams are installed. The municipal sewage is only partially treated or untreated and is generally discharged into the adjoining sea and creeks. Industrial waste water treatment is provided in some individual cases for large units. In many instances, however, industrial waste water is discharged untreated into the public sewers for co-disposal with domestic waste water. The fluxes of various contaminants entering marine environment through domestic waste water alone are given in Table 1.

The MMR region generates around 7500 tons of solid waste daily through residential, commercial, construction activities, hospitals and industrial activities. Presently this solid waste is dumped at four dumping sites along the creeks. The mixed nature of garbage makes it unsuitable for any bio-processing or energy recovery and hence most of the waste remains unutilized adding to the health risk of inhabitants in and around the dumping sites. Overutilization of dumping grounds and polluted waste has resulted in altering coastal bio-diversity, loss of coastal fisheries and ground water pollution.

Table 1
Waste water characteristics and loads of contaminants entering marine waters off Mumbai on the basis of flow of $1.8 \times 10^6 m^3/d$. Industrial flows averaged about 10% in the total discharges in MMR[a]

Parameter	Average concentration (mg/l)	Load (kg/d)
Dissolved solids	1500	2.7×10^6
Suspended solids	235	4.2×10^5
PH	7.0	—
BOD	250	4.5×10^5
COD	350	6.3×10^5
Total nitrogen	35	6.3×10^4
Total phosphorous	6	1.1×10^4
Oil and grease	7	1.3×10^4
Phenols	0.4	720
Chromium	0.02	36
Manganese	0.6	1080
Iron	2.0	3600
Cobalt	0.03	54
Nickel	0.05	90
Copper	0.08	144
Zinc	0.2	360
Lead	0.05	90
Cadmium	0.01	18

[a] *Source*: Ref. [5].

2.2. Transportation

Transportation networks are of paramount importance to the changes in land use pattern of the region and greatly influence the environmental status. With the increase in population, the total number of vehicles in Mumbai also increased considerably. This led to the traffic congestion and severe noise and air pollution. This problem is aggravated by many poorly maintained vehicles and roads. Suburban rail service takes significant amount of passenger traffic in MMR covering a distance of approximately 400 km. However, slum developments along the railway tracks and flooding of low lying areas due to combined effect of clogged drains and high tide waters during rainy season disrupts the rail traffic on many occasions. The suburban rails are overcrowded indicating the inadequacy of the transportation facilities. The present locations of both domestic and international airports are also responsible for many traffic problems during peak hours.

Vehicular transport system contributes nearly 70% of total air pollutants' load. Fig. 5 shows the total emission loads per day during 1995. There are 22 air quality monitoring stations in Mumbai that continuously monitor the ambient air quality. Although SO_2 concentrations have reduced over the years, the NO_x and SPM concentrations are increasing. The annual average of all 22 stations during 1991 have shown that SO_2 concentrations of $28\,\mu g/m^3$ NO_x of $45\,\mu g/m^3$ and SPM are about 270 ppm. The main sources of SPM are from road excavation, construction activity, smoke and dust from solid waste combustion and burning of wood and dung cakes

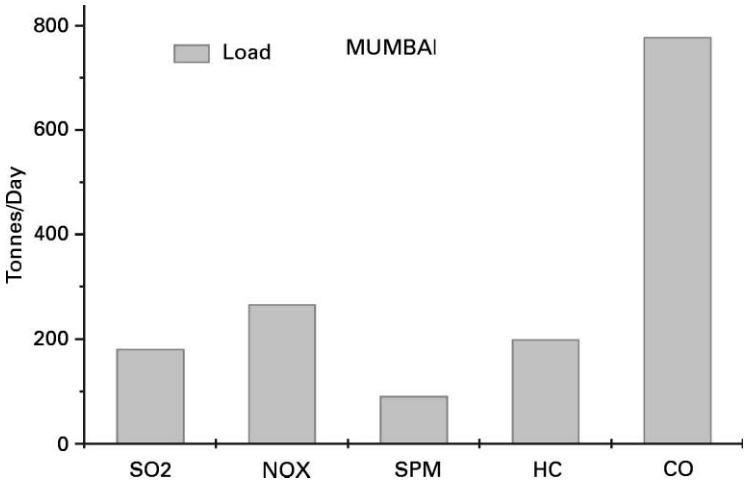

Fig. 5. Air pollutant load (ton/d) in MMR.

as fuel. Besides, high levels of NH_3 indicate rampant open air defecation and urination. Carbon monoxide levels at few stations have shown high values of 30–46 ppm due to the poor maintenance of transport vehicles. Mumbai has very high incidence of chronic respiratory problems arising out of extreme air pollution problems. The average noise levels exceed 78 db, and in some areas peak noise levels are as high as 95–100 db, while the Central Pollution Control Board's (CPCB's) recommended day time levels for residential areas are around 55 db.

2.3. Industrialization

As mentioned earlier, the MMR coastal region is considered as the industrial capital of India with around 9000 industries ranging from chemicals, fertilizers, iron and steel, oil refineries, and thermal power. The industrial estate program launched by Government of India has created vast numbers of small scale industries imposing considerable strain on services like housing, water supply, sewerage and transport facilities. This has contributed to the growth of slums and substandard housing and congestion. Industrial pollution in the MMR has not been fully assessed, but the main sources are gaseous emissions, solid and liquid wastes, toxic and hazardous wastes.

The siting of industries is dependent on availability of land and the desired quantity and quality of water. Some of the industries require large amounts of cooling water; for this purpose sea water is utilized. Industrial units are required to implement consent conditions regarding waste water disposal under Water Prevention and Control of pollution Act 1974, on an individual basis. Waste water after adequate treatment to conform to the standards can be discharged into public sewerage pipelines, rivers and creeks. Water pollution occurs depending upon the

type and location of discharge, quantity, quality of waste water and time duration of exposure to land surface and water body. The total BOD load from all industrial sources going into various receiving water bodies is estimated to be around 24.3 ton/d. The industries generate around 508 tons of solid waste in a day and most of this is either disposed to land filling operations. Although 60% of polluting industries in the country are located in MMR, the local pollution control agency has not yet identified any specific site for industrial waste disposal. In the absence of this, hazardous and toxic industrial waste mixed with domestic waste are dumped at the four sites identified for solid waste disposal.

3. Coastal marine environment

Most of the industries in MMR region are clustered in three large industrial areas namely Thane–Belapur belt, Kalyan–Ulhasnagar–Ambernath belt, western shore of Thane creek and around Patalganga river. These industries manufacturing a wide range of products such as dyes, pharmaceuticals, fine chemicals, plastics, petro and agrochemical, fertilizers, and refined petroleum products release the waste water to Thane creek, Ulhas and Patalganga rivers. A rough estimate of industrial wastewater generated by these industries is about $5 \times 10^5\,m^3/d$. The domestic wastewater generated in Mumbai city which amounts to $2 \times 10^6\,m^3/d$ is released untreated or partially treated to the marine environment transporting 450 tons of BOD, 63 tons of nitrogen, 11 tons of phosphorus, 0.18 tons of Cu, 0.36 tons of Zn and 0.09 tons of Pb every day [5]. In addition many industries are located at other places of MMR release their waste waters to nearby rivers, estuaries and creeks which acts as conduits to the coastal zone. During the period of 1959–1974, phospate–phosphorus concentrations in the nearshore zones of MMR increased by about 40% from 0.82 to $1.13\,\mu mol/dm^3$ and later to $2\,\mu mol/dm^3$ in 1984 [6]. Comparison of various data records over the years has shown that there is a significant deterioration of water quality in the coastal and marine waters around Mumbai (Fig. 6). Thane and Mahim creeks are probably the most polluted locations with heavy increase in N, P and significant depletion of dissolved oxygen.

Mahim bay and Thane creek were once bestowed with good fisheries, flourishing Oyster beds and lush fringing mangroves. These regions used to be visited by a number of migratory birds. Due to the recent industrial and domestic activities and high pollution concentrations, birds are hardly seen there and fisheries are non-existent. Initially the waste waters flowing into these coastal waters were untreated, but during the last two decades partially treated waste water is being released. Ocean outfalls and effluent treatment plants will improve the coastal water quality by discharging the waste material at a sea location from where any risk of pollution coming back to shore is minimum. Two ocean outfalls at Bandra and Worli and several effluent treatment plants were constructed by Mumbai Water Supply and Sewerage Board with the help of World Bank. Environmental assessment studies before the implementation of these outfalls have shown significant improvement of physico-chemical characteristics of coastal waters at those regions.

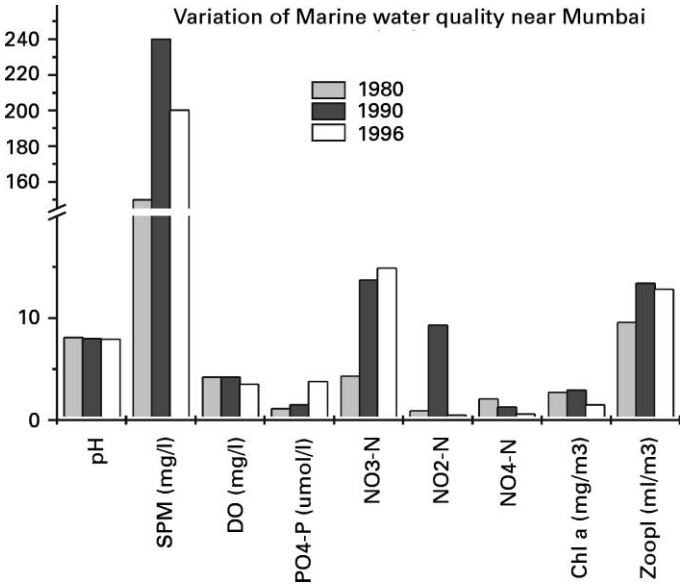

Fig. 6. Marine water quality measurements off Thal near Mumbai.

The concentration of H_2S–S found in Mahim bay waters range from 1.5 to 98.4 μmol/dm^3, depending upon the tidal stage. High levels of coliform bacteria ranging from 600 to 1900 nom/l[1] are observed in coastal waters off Versova, Thane and Mahim creeks. The release of the effluents containing hydrocarbons has heavily contaminated the Mumbai's coastal waters. The main sources of oil pollution in this region are oil tankers and merchant ships sailing along the trade and tanker routes as well as to ports of Mumbai. In the near shore area of Mumbai High oil field, the concentrations of dissolved/dispersed hydrocarbons range from 2–46 μg/dm^3 in the water column and 4–32 μg/g (dry wt) in sediments [7]. An exceptionally high concentration of lead (820 μg/l) and cadmium (336 μg/l) were observed in Thane creek, while the mercury concentration is 778 μg/l. Sediments along Ulhas river and Bassein creek and at some near shore stations have also shown high concentrations of lead.

Massive increase in benthic productivity and then depletion shows the damage done by the pollution to the coastal environment. Nutrients from domestic and industrial sources have led to increase of biomass formation in MMR. Mahim bay has shown unusual growth of algae with abnormally high chlorophyll-a (82–98.3 mg/m^3). Thane creek exhibited low values of dissolved oxygen and that has further destroyed the marine flora and fauna.

3.1. Coastal oceanography

The general coastal circulation off Mumbai is dominated by the annual cycle of monsoon winds. Shetye and Shenoi [8] studied the behavior of coastal circulation in

the coastal region of India using a long term climatology of winds and ship drift climatology (Figs. 7a and b). It can be noticed from these figures that during the northeast monsoon period (October–January), the coastal current flows northward due to the longshore density gradient and during the rest of the season the currents are mainly towards south. Barotropic surface tides at the semi-diurnal and diurnal frequencies are responsible for dispersion of pollutants in the coastal areas of Mumbai. The nearshore waters of Mumbai are subjected mainly by semi-diurnal tides, and there exists an asymmetry in both period and range. Vertical variation of current velocities is marginal (Figs. 7c and d). The tidal ranges at Mumbai are 1.6 and 3.9 m during neap and spring, respectively. The tidal currents off Thal, near Mumbai are in the range from 1.0 m/s during spring to 60 cm/s during neaps [9]. The spatial variability of near shore currents is considerable due to the presence of rocky outcrops, tidal creeks, bays and islands. The pollutants discharged from Mumbai will not have any impact beyond a distance of 4 km from the shores because of dilution, dispersion and flushing, thus suggesting that offshore disposal from marine outfalls will improve marine water quality.

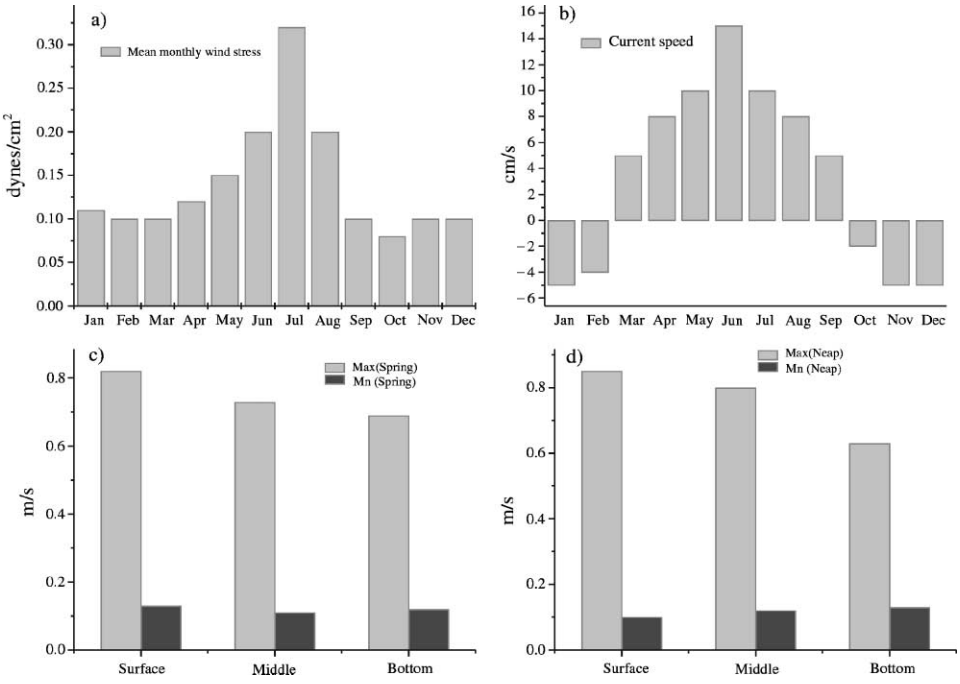

Fig. 7. Monthly variation of: (a) longshore wind stress and (b) current speed and spring (c) and neap (d) tidal currents.

3.2. Recreation and tourism

Marine pollution comprising industrial and domestic loads as well as hydrocarbons and tar deposits led to spoiling of most of the beaches and beach waters around Mumbai. The sea water is not fit for bathing purposes due to heavy suspended load. The fouling smell and unaesthetic coastal areas resulted in the MMR coastal region unsuitable for recreation and tourism. Sand mining is another major culprit that has deprived the Mumbai beaches of its natural charm.

3.3. Wetlands and mangroves

Wetlands are highly productive and valuable interface between land and sea that provide unique habitats for a wide variety of flora and fauna. They are also essentially cleansers of our coastal environment. They aid in flood control, shoreline stabilization and support the food chain. The MMR coastal region once possessed abundant wetlands exhibiting significant ecological diversion but many of which are converted to create land either for construction purposes or to site industries around Thane and New Mumbai. In addition to this, municipal agencies and industries use wetlands for garbage and debris dumping activity. This has resulted in their destruction along with development of some low lying flood prone areas that created problems for storm water drainage.

Mangroves are the most important component of coastal ecosystem that are known to keep the shoreline intact against tidal currents by preventing soil erosion. They also provide habitat for several wildlife marine species, including birds, shrimps and fishes. Certain slum dwellers have indiscriminately removed mangroves for the purpose of fuelwood, and the space is reclaimed for buildings and construction activities. Although some mangrove plantations have taken place in MMR, their success is limited. The loss of wetlands and mangroves in the MMR has led to the destruction of buffer zone. This has resulted in coastal erosion at some places and siltation at other places. The siltation of Mumbai harbor has substantially added to the cost of dredging in the port.

4. Approach to integrated coastal management

In the previous section, we have attempted to present the current state of environment of the MMR coastal region. The unplanned development, high population density imposes severe restrictions on resources and conflicts among stakeholders. The population of MMR will continue to grow along with the need for resources such as housing, fresh water, energy and transportation network. Therefore, the main IACM challenges before MMR are: (1) to maintain aesthetic and recreational water quality of the coastal waters surrounding the region, (2) to maintain viable commercial and recreational fishing in the face of increased urban, industrial and municipal pollution, and land reclamation,

(3) to maintain maritime navigation and viable ports, (4) disposal of solid, waste water and dredged materials in an environmentally safe way, and (5) housing, water supply and transportation.

Often, there are conflicts among various interest groups such as: (a) the use of wetlands and mangroves for land development has negative impact on port management, loss of property due to coastal erosion and fishery resources, (b) waste disposal activities affects the coastal water quality, fisheries, recreation and tourism, (c) unplanned land reclamation procedures will lead to the loss of tidal flushing resulting in polluted beaches, and (d) use of forestry and agricultural land for developmental purposes resulted in poor air quality and elimination of greenery. In this context, there are needs and opportunities for continuing research in natural and social sciences particularly in areas of public policy, education, conservation and protection, waste water treatment technology, water supply, etc.

Presently, there are several legislation and acts available for coastal management of the MMR region [10]. The CPCB at the federal level and Maharastra Pollution Control Board at provincial level exercise the authority to control waste discharges for the purpose of water and air (Prevention and Control of Pollution) Act, 1974. Under Environment (Protection) Act, 1986 Coastal Regulation Zone (CRZ) rules were formed to regulate the activities in the coastal areas. CRZ plans are being drawn up coastal states under this act. Ministries of Environment and Forest at the federal and provincial levels have taken several important steps for conservation of mangroves, wetlands and coral reefs in the region. MMR has an industrial siting policy since 1973. These acts and directives are aimed at the management of the marine coastal areas, though an approach towards IACM is yet to crystallize clearly.

Integrated Coastal Management (IACM) is a continuous, and adaptive process that consists of a set of tasks, typically carried out by several public and private entities [11]. The main objectives of the IACM are to restore and maintain ecological integrity of coastal ecosystem and to maintain important human values and uses associated with the coastal resources. On the guidelines of the IACM, we must first identify our immediate and long term goals for the MMR and range of environmental areas that require further attention. Base line data on ecosystems, habitats, population, employment, land use pattern, industries and other sectors have to be regularly collected and processed. This will include compilation of all available data and analysis of physical processes, freshwater resources, meteorological and geophysical information. Much of this information already exists with different agencies. Nevertheless, it is important to collate and classify this information in the form of maps, thematic directories and/or computerized data bases such as the geographical information system (GIS). It is also important to identify societal needs and values within the MMR.

Although the geographical or administrative extent of the MMR is well demarcated, it is equally important to delineate the coastal areas of concern in

both landward and seaward directions, watershed area, and other areas dictated by important related terrestrial and marine processes. An assessment and comparison of risks to ecological systems and human health should be completed by relevant authorities in the MMR.

Coastal problems cannot be managed successfully as separate issues, such as pollution or wetland loss or fisheries depletion. These issues are inter-related. Risk management decisions should be made through the consideration of priority problems in the light of available management options, human and financial scenarios. The environmental assessment studies carried out for Thane, Versova and Mahim creeks should be done under varying conditions to identify the exact sources and nature of problems. A systematic study of physical, biological, chemical and geological processes under the present conditions as well as projected scenarios of urbanization, industrialization, global warming and sea level rise should be considered in formulating strategies of the IACM for the MMR region.

Although the ocean outfalls (at present at three locations, Fig. 1) would improve water quality standards at a few stretches, many upper reaches of creeks and few coastal locations have less tidal flushing and low freshwater flows. Alternative strategies have to be employed in these locations. It is seen that some of the storm water runoff from the MMR during monsoon period results in pollution levels of the same order of magnitude as treated or untreated sewage. Actual loadings due to these non-point sources for Mumbai has to be collected and analyzed for developing a proper management option. Towards this, ecological and water quality based mathematical and statistical models should be developed to the MMR coastal region to arrive at reasonable predictions.

The population pressure, poor maintenance of pipes and poor metering neutralizes the significant improvements achieved in water supply. The successful implementation of proper water supply and maintenance systems and enforcement of strict measures on defaulters require financial and human resources and political will. Programs to detect leaks in water supply systems, improving the metering as well as billing and collection, and upgradation of networks and connections will rehabilitate the existing system. It is also necessary to supply fully treated water at regular hours to decrease the incidence of water related diseases. Since the major chunk of population in MMR lives in slums with poor sanitation facilities, a plan should be evolved to improve the general quality of water supply and waste disposal for these regions.

There are several institutions and agencies such as the Mumbai Metropolitan Region Development Authority, Greater Mumbai Municipal corporation and other municipal corporations; Provincial and Central pollution boards, Mumbai city transport, Mumbai Police, Port trusts, etc. function separately and are responsible for various activities and enforcement of laws in the MMR coastal region. There appears to be a minimum of direct interaction between these federal, provincial and municipal governments. A centralized establishment specializing in coastal and marine affairs whose function would be

to oversee the ongoing coastal activities and to coordinate between these agencies, is necessary.

5. Conclusions

Mumbai Metropolitan Region is the largest metropolitan coastal city in India. Due to lack of proper planning and unprecedented population growth, and rapid industrialization the region suffers from inadequate housing, water supply and transportation. On the marine side the region suffers from depletion of coastal habitats like mangroves and wetlands and severe coastal pollution. The fouling smell and deteriorated aesthetics made the coastal areas unsuitable for recreation and tourism development.

The government of India has introduced several directives aimed at the management of coastal marine areas but an approach towards an integrated coastal zone management is yet to develop. There are many agencies under the federal and provincial governments functioning independently, and hence lack coordination for enforcing the existent laws to protect the MMR coastal region. A centralized establishment specializing in coastal and marine affairs whose function would be to oversee the ongoing coastal activities and to coordinate between various agencies will be necessary for properly implementing these regulations. For sustainable development of coastal resources of the MMR these laws and regulations need to be strengthened and proper enforcement on defaulters has to be carried out rigorously. While standards based regulatory system may be essential to providing a basic framework of governance, other techniques such as economic incentives, stream-lined management and proper land use policy would be appropriate for particular problems. An integrated approach for waste management (waste water and solid waste) in the MMR is needed urgently. For IACM to be effective, monitoring of coastal and terrestrial environments is essential. The results of monitoring should be made useful as a feedback mechanism to modify management actions. The lack of environmental awareness among politicians and policy makers makes it difficult to implement sustainable development programs. In the MMR, the degree of concern of the environment among ordinary citizens and local administrative officials is highly variable. An IACM plan for Mumbai should have a central objective to increase the understanding for environmental concerns, especially in relation to the coastal environment. Finally, if public awareness and public expectations and values are ignored it may be difficult to implement any IACM management measures.

Acknowledgements

The authors wish to thank Dr. G. Narayana Swamy, National Institute of Oceanography, Goa, India for useful discussions and for providing water quality

data and to Dr. Ghosh Bobba, NWRI, Canada for providing rainfall and temperature data.

References

[1] MMRDA. Draft Regional Plan for Mumbai Metropolitan Region 1996–2011, 1995.
[2] Patil BM, Shukla VP, Ghosh LK. Mathematical model study for reclamation in Thane creek. Proceedings of the Indian National Conference on Harbour and Ocean Engineering, 1997. p. 171–81.
[3] Phansalkar AG, Kapileswar PS, Phanikumar M, Verma SJ. Flood abating for an estuary for Mumbai Metropolis. Proceedings of the Indian National Conference on Harbour and Ocean Engineering, 1997. p. 1246–55.
[4] Central Pollution Control Board. Status of water supply and waste water generation, collection, treatment and disposal in metrocities (1994–95), 1997. p. 59.
[5] Zingde MD. Marine pollution—what are we heading for? In: Somayajulu BLK, editor. Ocean science—trends and future directions. New Delhi: Indian National Science Academy, 1989.
[6] Zingde MD. Waste water effluents and coastal marine environment of Mumbai. Proceedings of the Seminar on Seawater Quality Demands. Defense Research and Development Organisation, Government of India; 1985. p. 201–3.
[7] Qasim SZ, Sengupta R. Some problems of coastal pollution in India. Marine Pollution Bulletin 1988;19:100–6.
[8] Shetye SR, Shenoi SSC. Seasonal cycle of surface circulation in the coastal north Indian ocean. Proceedings of the Indian Academy of Sciences (Earth and Planetary Sciences), 1988. p. 9753–62.
[9] Swamy GN, Suryanarayana A. Nearshore circulation in relation to effluent disposal off Thal, Maharastra, West Coast of India. Mahasagar 1992;25:31–8.
[10] Central Pollution Control Board. Coastal pollution. Parivesh News letter 1996;2:1–16.
[11] Bower BT, Turner RK. Characterising and analysing benefits from integrated coastal management (IACM). Ocean & Coastal Management 1998;38:41–66.