Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 116 (2015) 955 – 962

Procedia Engineering

www.elsevier.com/locate/procedia

8th International Conference on Asian and Pacific Coasts (APAC 2015)

Coastal water quality monitoring and modelling off Chennai city

Pravakar Mishra*, Uma Sankar Panda, Umakanta Pradhan, C.Saravana Kumar, Subrat Naik, Mehmuna Begum, J. Ishwarya

ICMAM Project Directorate, NIOT Campus, Pallikaranai, Chennai 600100, INDIA

Abstract

Knowing the coastal water quality is vital from the perspectives of coastal resource usage and management. Worldwide, along many urbanized coastal regions, massive input of industrial, agricultural and sewage effluents have tremendous impact by altering the nutrient characteristics, triggering toxic algal blooms affecting biodiversity, fisheries, tourism, recreation and other activities. Since 1990s, extensive monitoring of the coastal waters along the Indian coast have been undertaken by the Ministry of Earth Sciences (MoES). This paper evaluates the seasonal and monthly variations of water quality parameters *viz.*, salinity, pH, dissolved oxygen, nutrients, chlorophyll-*a*, primary productivity, phyto- and zooplankton, pathogen bacteria off Chennai metropolitan. Low dissolved oxygen (~ 5mg/l) levels and high concentration of nutrients (phosphates, nitrates) recorded in the Cooum and Adyar river waters. Water quality data collected on a monthly basis at 30 locations along the coast during January'2013- December'2014 reveals a strong seasonal trend. Excess phosphorous (P) and nitrogen (N) lead to eutrophication resulting occurrence of algal blooms, high chlorophyll-*a* (230.24 mg m^{-3}) and *phaeocystis* sp. a toxin producing bloom was observed during spring (February-April) months along the coast within the breaker's zone. Increase in pathogenic bacteria to an alarming level is recorded and relatively lower concentration is correlated to dilution and rainfall. Phytoplankton species diversity index (*H*) falls under the category of 'Poor' (H=<2.0). Numerical modeling is being applied for assessing the fate and transport of pollutants for development of water quality prediction system for the coast.

Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015

Keywords: water quality, algal bloom, monitoring and modelling, Chennai coast

* Corresponding author. Tel.: +91-44-6678-3591; fax: +91-44-6678-3474.
*E-mail address:*mishra@icmam.gov.in

Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015
doi:10.1016/j.proeng.2015.08.386

1. Introduction

With the rising population pressure and industrialization along coastal regions, coastal waters have increasingly vulnerable to multifarious contaminants through direct disposal of untreated domestic garbage and sewage, pesticides, toxic chemicals run off from hinterlands, radioactive and thermal discharges affecting the adjacent water quality, fisheries, tourism and in a broader sense the entire coastal biodiversity (Throne-Miller, 1999). The alarming situation have projected that by 2015 an estimated 2,45,000km^2 of marine habitat worldwide are going to be affected by hypoxia that have an adverse implications on fisheries and food chain (Corcoran et.al., 2010). Chennai, the fourth largest metropolis in India is one of the best examples of following uncontrolled discharge of sewage practice and high pollution levels in the coastal waters (Shanmugam *et al*., 2007). In view of this, Ministry of Earth Sciences (MoES), Government of India had initiated a monitoring program to assess and forecast the coastal water quality in advance for the benefits of the coastal communities and other stake holders. Usually, three significant tools i.e., observations, theoretical analysis and numerical modelling as appropriate to the properties are applied in water quality studies and observation is the only way to know the real characteristics of the ecosystem, provides a basis for theoretical analysis and numerical modelling (Ji, 2008). Thus, in this paper, a detailed spatio-temporal variations of different water quality indicative parameters *viz*., salinity, pH, dissolved oxygen, nutrients, chlorophyll-*a*, phytoplankton, pathogen bacteria based on real time data are evaluated and a numerical model is developed to predict the scenarios .

2. Material and Methods

2.1. Study area

Chennai city, spreading over an area of 176 km^2 is located on the western seaboard of Bay of Bengal experiences seasonal wind and rainfall pattern (Figure 1). The annual rainfall is about 1250 mm. Two rivers viz., Cooum and Adyar flow criss-crossing the city, carrying major share of domestic sewage and industrial effluents into the coast. Further, activities at Chennai and Ennore port and fishing harbour, waste discharges from thermal power plant, leather ternaries, petroleum and tyre industries impoverish the adjacent coastal water. Three beaches viz., Marina, Elliot and Kottivakam (Thiruvanmiyur) act as are major weekend resort destinations and a number of fishing hamlets disposes non-degradable garbage. On the northern extreme, Ennore creek act as a major effluent transporter, whereas in the southern end, the backwaters at Muttukudu connecting to the sea is used for recreational boating and surfing activities. The coast is characterised by semidiurnal tide of a maximum ~1.2m tidal prism. Seasonal longshore current and littoral drift are active, forms conspicuous sand bar near inlet mouths, thus regular dredging activity are carried out at creek and river mouths by state government agencies to maintain the flushing.

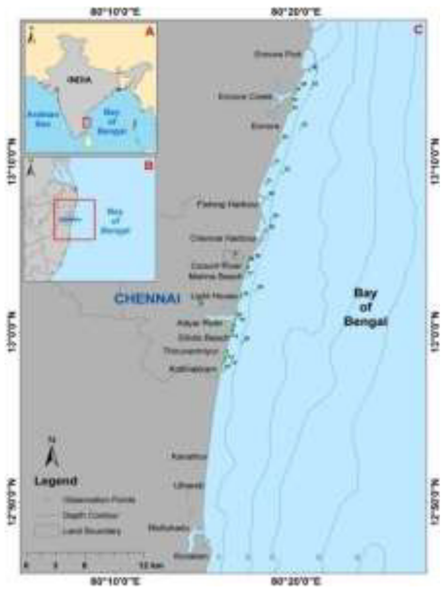


Figure 1. Study area showing sampling locations

2.2. Sampling and data analysis

30 sampling locations extending over 35km from Kottivakam to Ennore were monitored at monthly basis for a number of Physio-chemical and biological parameters during January 2013 to December 2014. The sampling locations are mostly limited from beach to 2km offshore and 9 locations inside the Cooum and Adyar river within 2kms upstream and river mouths are chosen to assess the pollutant loading from these rivers.

Atmospheric and surface seawater temperature (SST) was measured using decimal mercury laboratory thermometer and standard probe. Salinity was determined by Argentometric titration method, pH was recorded by Metrohm pH meter, dissolved oxygen (DO) was analyzed by Winkler's titration method (Strickland and Parsons, 1968), nutrients (NO_2-N, NO_3-N, PO_4-P, SiO_4-Si) were analyzed following the standard protocols of Grasshoff *et al*. (1999). Total suspended solids (TSM) was analyzed by gravimetric method. Chlorophyll-*a* pigment was estimated following

Parsons *et al*., 1992. Phytoplankton species were identified with the help of Sedgwick-Rafter counting chamber taking 1 ml of sample aliquot as per the standard identification protocol and volume of each cell was computed by measuring appropriate morphometric characteristics (Newell and Newell, 1977). Taxonomic classification was carried out and species diversity index was calculated following Shannon-Wiener diversity method. Microbiological analysis for pathogens were made following standard methods (Nagvenkar and Ramaiah, 2009) and data are statistically analysed to delineate the inter and intra-annual changes and their variability.

2.3.Numerical modelling

A MIKE-21 numerical finite element model of 37.5×8 km (300 km^2) domain including major coastal features viz., Adyar, Cooum rivers and Ennore creek and ports with the similar coastal orientation, land topography and available bathymetry was defined (Figure 2). The physical process parameters i.e., wind , density driven and tidal circulation, river run-off, heat and salt flux, turbulent mixing, coriolis effect and bottom friction are included. The ECMWF reanalysis wind and global tide used as forcing parameters with a bed resistance of Manning no =38 to simulate the water level variations and flows in the coastal region.

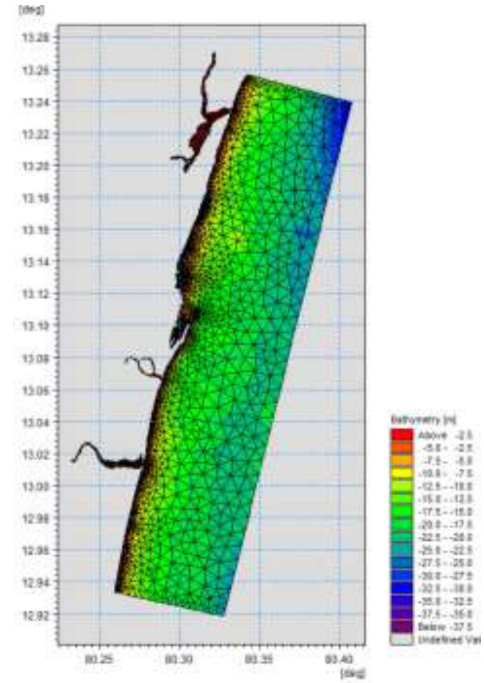


Figure 2. Model domain (37.5x8km)

3. Results and Discussion

In general, most of the studies along east coast of India describes the seasons based on either monsoon i.e., southwest (SW) and northeast (NE) or climatology parameters such as temperature, rainfall or wind regime, viz., summer, SW, post monsoon (transition) and NE. In the present study, the results are described under two seasons i.e., dry (January to June) and wet (July to December) based on the rainfall pattern over Chennai coast.

3.1. Physico-chemical characteristics

Water quality condition of any biota is mainly represented by temperature, salinity, pH, dissolved oxygen (DO), nutrients, algae and pathogens and their variability. Table 1 shows the minimum - maximum ranges and the mean values for coastal and river locations. In the present study, water temperature (WT) ranged from 28.0 to 34.7 ºC with a lowest mean during July and follows the air temperature (AT) trend. Salinity ranged from 5.0 to 35.11 PSU for coastal waters and follows a seasonal trend with the fresh water influx during rainy months. pH was in between 7.17 to 8.7 consistent with the values reported for Bay of Bengal. Dissolved oxygen is the amount of oxygen available in the water for biochemical activity varied between 0 to 12.37 mg/l with a mean of 5.97 to 6.37 mg/l and the biological oxygen demand (BOD) are in between 0.01 to 167.48 mg/l. High BOD associated with low DO mostly observed in the Couum and Adyar river mouths. Anoxia state prevails inside Cooum and Adyar river and hypoxia (<4 mg/l) at mouth regions in low tide phase throughout the year. Well saturated oxygen values (~ 6mg/l) observed in the coastal water (1-2Km) is attributed to wind activity and mixing. Chlorophyll-*a* concentration, a measure of phytoplankton biomass varied from 0.01 to 158.89 mg/m^3, showed a seasonal oscillation during January to April. Nitrite ranged from below detection level (BDL) to 51.42 µM whereas, nitrate varied from BDL to 122.84 µM. Phosphate and Silicate varied between BDL to 212.94 µM and 13.93 to 44.05 µM., respectively. Comparatively, occurrence of high level of phosphate, nitrate and silicate in the coastal water indicate, inputs are predominately from domestic sewage and chemical based industries. Total Suspended Matter (TSM) varied from 5.87 to 160.5 mg/l and are primarily due to dredging activities at the inlets, dispersion of effluents in the nearshore region. Extreme low DO is due to excessive waste water load of nutrients and lethal for the aquatic organisms (Nixon, 1995); the incidence of mass fish kill reported on 30th December 2014 in the Adyar river clearly confirms the observed values.

Table 1. Physico-chemical characteristics of River and coastal waters, Chennai (mean and the ranges during January 2013-December 2014) *[Mean / (Min-Max)]*

	Coastal waters (n=780)		River waters (n=70)	
Seasons	DRY	WET	DRY	WET
AT (^{0}C)	30.42	30.18	31.45	30.71
	(24.5 – 37.5)	(25.0 – 36.5)	(27.0 – 36.2)	(28.1 – 35.5)
WT (^{0}C)	29.11	28.48	30.24	29.17
	(24.5 – 34.7)	(24.5 – 34.5)	(24.9 – 35.1)	(25.3 – 31.69)
Salinity	31.37	30.01	5.4	1.38
	(20.0 - 35.11)	(5.0 – 35.0)	(0 – 30.0)	(0 – 4.15)
pH	7.98	8.11	7.72	7.59
	(7.17 – 8.60)	(7.30 – 8.7)	(7.2 – 8.3)	(7.3 – 8.0)
DO (mg/l)	6.37	5.97	0.48	0.35
	(0 – 12.37)	(0 – 9.98)	(0 – 8.64)	(0 – 2.52)
BOD (mg/l)	6.07	6.82	116.44	104.77
	(0.32 – 148.18)	(0.01 – 167.48)	(19.8 – 203.04)	(59.74 – 167.66)
TSM (mg/l)	34.8	30.77	71.58	55.36
	(11.0 – 160.50)	(5.87 – 140.0)	(14.0 – 216.0)	(16.0 – 85.2)
NO_2 (µ mol L^{-1})	1.3	1.56	2.05	3.75
	(ND– 51.42)	(0 – 16.28)	(0.02 – 13.83)	(1.04 – 7.85)
NO_3 (µ mol L^{-1})	5.13	6.95	4.3	4.99
	(ND – 122.84)	(0 – 66.58)	(0.02 – 52.63)	(0.14 – 22.29)
PO_4 (µ mol L^{-1})	3.94	4.81	71.84	80.49
	(0 – 149. 15)	(ND– 212.94)	(0.54 – 170.63)	(15.83 – 359.12)
SiO_4 (µ mol L^{-1})	14.62	13.05	222.84	238.24
	(0 -387.23)	(0.09 – 361. 08)	(8.41 – 570.68)	(109.47 – 368.15)
NH_4 (µ mol L^{-1})	10.52	15.73	139.84	168.78
	(0 – 175.08)	(0.13 – 159. 73)	(3.59 – 292.43)	NA
Chl-a (mg/m^3)	11.28	6.73	44.82	35.25
	(0.01 -230.24)	(0.04 – 94.74)	(0.72 – 298.10)	(4.59 – 87.12)

Statistically, environmental parameters are applied to cluster and factor analysis to understand their similarity, interdependence and variance by classifying into groups. The cluster analysis and dendogram showed that all the 13 physico-chemical parameters in both dry and wet seasons fall into two distinct groups (Figure 3a & b). During Dry season, cluster 1 (AT, WT and Salinity) and cluster 2 (pH, DO, NO_2, NO_3, BOD and PO_4) represents the physical factors and nutrient input from the point sources, while TSM, Chl-*a* and SiO_4 act independently indicating the mixing in nearshore waters, primary production with better radiation and role of land runoffs. During wet season Cluster 1 (AT, WT, Salinity) and Cluster 2 (pH, DO, NO_2, NO_3, Chl-*a*, PO_4) represents fairly like dry seasons, however, independent loading of TSM, BOD and SiO_4 can be attributed to the run offs/ sewage discharged due to heavy precipitation during NE monsoon months.

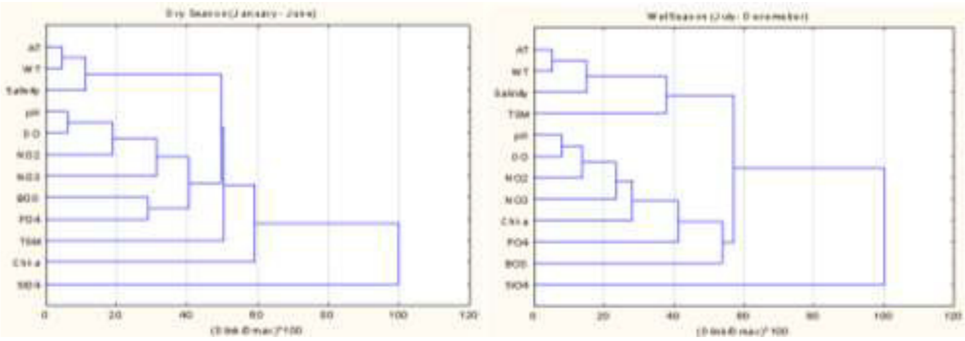


Figure 3. Dendogram from **c**luster analysis a) dry season and b) wet season for water quality parameters.

Factor analyses were employed to identify the major driving forces in the system during different seasons. Three significant factors (eigen value >1) were identified in both the seasons with total variance of 62.49 and 57.76% respectively. Factor 1 for both the seasons (1/3rd of the total variance) with positive loading of BOD, TSM, PO_4 and SiO_4 indicates the major impact of sewages to the coastal waters, while negative loading of salinity and DO implies the degradation at mixing zones. The positive loading of Chl-*a* during wet season may attributed to better production with the availability of surplus nutrients and conducive environment. Factor 2 (1/4th of total variance) with positive loading of air and water temperatures and negative loading of pH indicates that physical factors play a major role next to the sewage. Factor 3, with positive loading of nitrogenous compounds in both the season shows the influence of nitrogen input from the land runoffs.

Table 2. Factor loadings of hydrographic and water quality parameters during wet and dry period.

	Dry Season			Wet Season		
	Factor (1)	Factor (2)	Factor (3)	Factor (1)	Factor (2)	Factor (3)
AT	-0.049	0.873	-0.015	-0.125	0.869	-0.079
WT	-0.061	0.831	-0.011	-0.020	0.828	-0.092
Salinity	-0.801	0.377	0.026	-0.835	0.073	0.024
pH	-0.126	-0.638	-0.217	-0.172	-0.552	-0.566
DO	-0.666	-0.134	0.033	-0.509	-0.460	-0.089
BOD	0.836	-0.038	-0.111	0.626	0.019	0.088
TSM	0.520	0.169	0.057	0.620	-0.182	0.085
NO_2	-0.001	0.079	0.868	0.304	-0.187	0.597
NO_3	0.055	0.069	0.878	-0.103	-0.026	0.746
PO_4	0.904	-0.051	0.077	0.760	0.053	0.199
SiO_4	0.846	-0.047	0.020	0.741	0.175	0.359
Chl-a	0.427	0.000	0.208	0.608	0.030	-0.223
Eigenvalue	3.836	2.172	1.491	3.593	2.046	1.292
% Total (variance)	31.966	18.099	12.425	29.942	17.048	10.768
Cumulative (%)	31.966	50.065	62.489	29.942	46.990	57.758

3.2. Phytoplankton

Phytoplankton analysis enumerated presence of total 162 species consisting of 102 diatoms, 41 dinoflagellates, 6 cyanobacteria, 6 green algae, 5 cocolithophores, 2 silicoflagellates and 1 cryptomonads species. Diatoms dominate followed by dinoflagellates, cyanobacteria and green algae, cocolithophores, silicoflagellates and cryptomonads. Some of the species *viz.*, *Rhizosolenia setigera, R. alata, Skeletonema costatum, Thalassiothrix longissima, Asterionellopsis glacialis, Dinophysis caudata* and *Ceratium furca* are predominant. The diversity index characterizes species abundance and richness of ecosytem. Diversity indices for Cooum and Adyar river was least diverse in terms of species richness (Shannon-Wiener index, *H*' and Margalef, *d'*) whereas the evenness (*J*') was least in the shore stations suggesting dominance of certain species (e.g., *Asterionellopsis glacialis* and *Chaetoceros* sp.). The phytoplankton density ranged from a minimum of 26010 to 98700 Nos./l in the offshore water to Adyar river mouth whereas the diversity index values ranged between 2.16 to 2.89 in the Kovalam shore and in the offshore water between fishing harbour and Ennore port (Figure 4). On the basis of Shannon-wiener species diversity index (*H*'), nearshore waters off Chennai fall in the range of mostly Fair Poor (2.0 - 2.67) category.

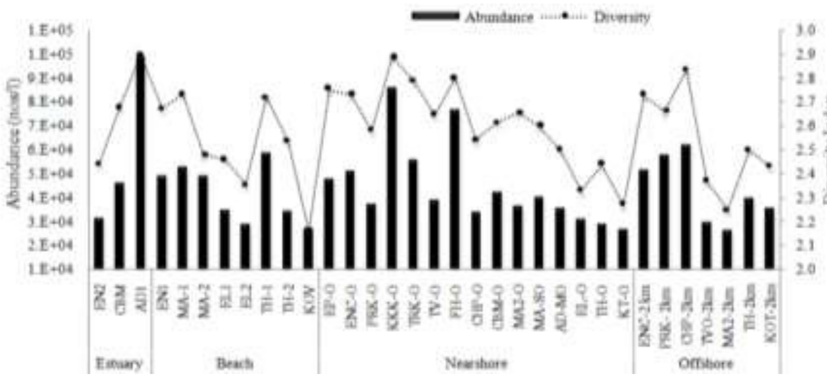


Figure 4. Distribution of phytoplankton abundance (nos/l) and species richness index

Phytoplankton bloom frequently occurs along the coast during January to April can be coined with spring bloom of east coast of India. *Asterionellopsis glacialis* and *Phaeocystis globossa* blooms were noticed in Chennai coastal water on 8/2/2013 and 27/3/2013, respectively. *Phaeocystis globossa* is a toxin producing bloom (Rogers, and Lockwood,1990) observed in the nearshore waters with high chlorophyll-a content of 230.24 mg/m^3. Beach goers, ignorant of the blooms and its post-indications venturing to nearshore waters could contaminate themselves and get infection (Figure 5a). In-*situ* Chlorophyll-*a* and TSM data were compared with synchronous Oceansat-2 and MODIS-Aqua sensors of 8-10 February, 2013 (Figure 5b). High Chlorophyll-*a* (~19.45mg/m^3) and total suspended matter (TSM) (~45-50 mg/l) was noticeable in the optical signature of OCM2 and a good correlation was found between observed data and satellite derived chlorophyll (r^2=0.97) and TSM (r^2=0.85) was observed (Dash *et al*., 2013). During 13-15, January 2015, blooms of diatom (*Asterionellopsis glacialis;* cell density: 2.9 x 10^6 Nos./l*), Cyanobacteria (Trichodesmium thiebautii;* cell density: 2.1 x 10^6 Nos/l*)* and green algae *(Chlorella salina;* cell density: 3.4 x 10^6 Nos./l) repeated and high Chlorophyll-*a* values (84.89 ~127.20 mg/m^3) observed could be attributed to nutrient load. Dredging activities at Adyar and Cooum rivers and better inflow of nutrients, conducive temperature and light might be triggering such bloom and the southerly longshore current disperses the bloom within surf zone changing the colour of the nearshore water all along the Chennai coast.

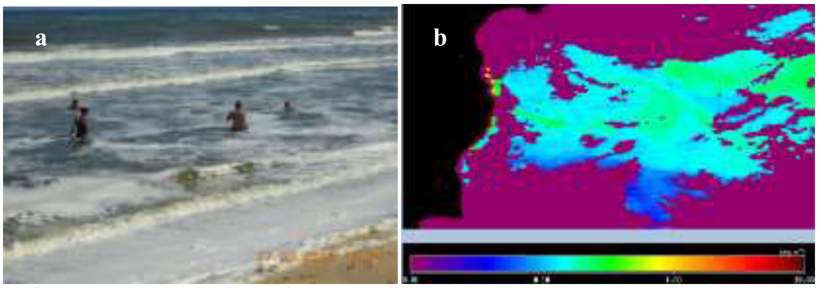


Figure 5. a) Algal bloom of *Phaeocystis globossa* at Marina beach and (b) Chlorophyll-a MODIS image (8/2/2013) for Chennai coast.

3.3. Microbiology

Bacteria are tiny single-cell microorganisms coexist in millions can sustain in extreme temperature, pressure and/ or chemical concentrations well known for their pathogenic behaviour. United States Environmental Protection Agency (USEPA) limits occurrence of 235 to 580 CFU (Colony-Forming Unit) per 100ml is safe for bathing, swimming or recreational purposes. In order to quantify the level of bacteria and their variations in Chennai coastal waters, Total vibrio (TV), Total coliforms (TC), Fecal coliforms (FC), *Escherichia coli* (EC)*, Vibrio cholerae, Salmonella* and *Enterococci* spp. are monitored at monthly basis. Invariably, higher than the permissible limit was observed throughout the year (Figure 6) demonstrates the ubiquitous distribution of pathogenic bacteria. The overall ranges (CFU/ml) were TC (2 x 10^2-1.8 x 10^7), FC (1 x 10^2 - 4.2 x 10^5), EC (2 x 10^1 - 2.6 x 10^5) and *Enterococci* spp. (1 x 10^1- 3.0 x 10^5), *Vibrio cholera* like organisms (0 - 3.2 x 10^4), *Shigella* spp. (1.0 x 10^1 - 2.4 x 10^5) and *Salmonella* spp. (0- 3.2 x 10^4) . The distribution of bacteria suggests that the primary cause of such high bacterial population is due to untreated sewage effluents brought by Adyar and Cooum and open defecation in the beaches. Relatively, higher values are recorded during January, February and March (dry seasons) and with the rain and land runoff, their presence decline to an extent due to dilution.

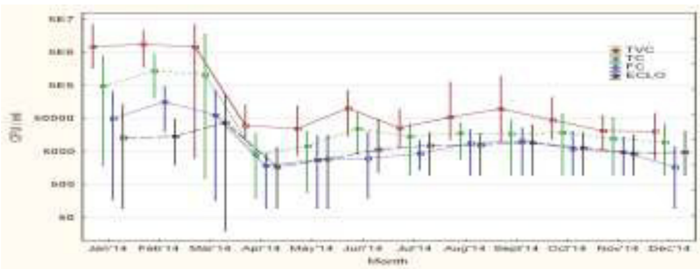


Figure 6. Monthly distribution of bacteria in the coastal waters of Chennai.

3.4.. Modelling

Knowledge on the tide (surface elevation) and current flow pattern are basic requirement to understand the hydrodynamics and process. MIKE-21 HD was engaged to simulate the water level and current flow pattern for two different time, 15 December 2013 to 4 January 2014 and 17 November to 7 December 2014 with a time step of 300sec in consistent with hydrodynamics observations made at different locations in the model domain. The validation for surface elevation during November 2014 off Cooum river at 6m water depth is attained (Figure 7a) and a good correlation coefficient ($r^2 = 0.91$) was achieved between the observed and simulated values showing the calibration and capability of the model.

The flow pattern for the domain was generated and particle tracking was performed, the simulated output validated with observed GPS drifter tracks for December' 2013 (Figure 7b). The flow signifies that the transport and dispersion of suspended particles / sewage and pollutants discharged from Cooum river is moving southerly parallel to the coast and partly reaching the Marina beach in consistent with our observations.

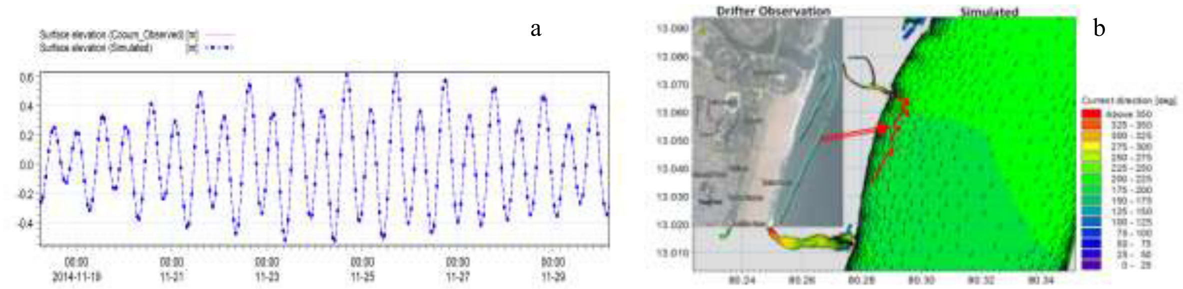
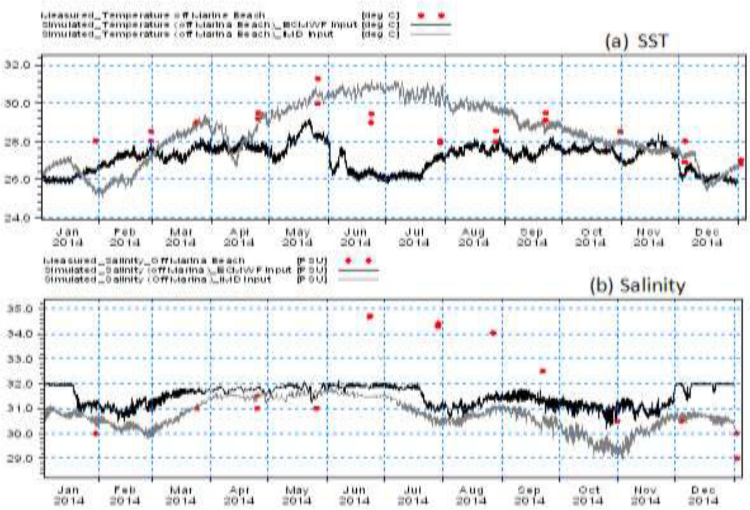


Figure 7. Validation of a) water level off Cooum River mouth and b) current and simulated tracks with GPS drifter during December 2014.

The model was hindcasted for the year 2014 with a time step of 3hours output for hydrodynamics and water quality in order to validate the model performance. The temperature-salinity model solves the advection–dispersion equation for dissolved or suspended substances, including salinity and temperature and the linear decay. Different scenarios of water quality indicative parameters (temperature, salinity and oxygen) were generated to set up an optimum model. Two different data sets i.e., IMD and ECMWF reanalysis wind, temperature and meteorological parameters were used to simulate temperature, salinity and oxygen and validated off Marina beach (Figure 8a, b & c). Simulated values are close to observations except salinity during June to September may be attributed to variation in evaporation rates, freshwater influx and rainfall. Otherwise, the model clearly demonstrates the capability of simulating flow and water quality scenarios on an annual and seasonal basis.



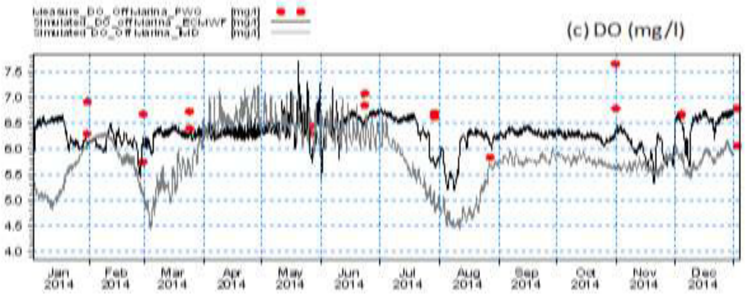


Figure 8. Spatial validation of a) Temperature, b) Salinity and c) Dissolved Oxygen (mg/l)

Conclusions

Presence of high level of pathogens, occurrence of toxic blooms, eutrophication and depleted oxygen levels are the key issues along Chennai coast arising due to untreated sewage brought by Adyar and Cooum rivers. Numerical model approach is applied and validated with the hydrodynamics and water quality parameters for Chennai coast. The model is potential enough to generate predictive scenarios. As the number of observations at validation points are less, model is underestimated to partially during the SW monsoon months, however, good agreement is observed for the rest of the year. This might be attributed to variation in evaporation rates, freshwater influx, rainfall and offshore boundary fluxes which needs to be relooked. Particle tracking model exhibits the influence of major recreational beaches due to the pollutants discharged and transported from adjacent river mouths. The present pollutant level is an impending public health issue and needs to be addressed immediately. Sewage treatment plants, proper restoration programs for Adyar and Cooum rivers, awareness among stake holders and coastal communities would assuage the present pollution levels. In many developed countries, coastal waters exceeding the standards are closed for bathers and beachgoers. Hence, regular monitoring and forecast of the water quality needs to be integrated with automated sensor based monitoring systems that would enhance the predictive system and benefit the coastal community.

Acknowledgements

The authors are grateful to Secretary, Ministry of Earth Sciences, New Delhi and Project Director, ICMAM-PD, Chennai for their kind guidance, support and encouragement. The program is funded by Ministry of Earth Sciences, Government of India.

References

Corcoran, E., Nellemann,C., Baker, E., Bos, R., Osborn, D., Savelli., H., 2010. Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal. pp. 85.

Dash, S. K., Matin, S., Usha, T., Mishra, P., 2013.Monitoring of water quality at Chennai coast using remote sensing data, Proceeding of HYDRO 2013 INTERNATIONAL. IIT Madras, India. paper #161.

Grasshoff, K., Kremling, K., Ehrhardt, M. 1999: Methods of seawater analysis. 3rd Ed. Verlag Chemie Weinheim Germany.

Ji , Z. - G., 2004 . Use of physical sciences in support of environmental management. Environmental Management 34, 159 – 169.

Nagvenkar, G.S., Ramaiah, N. 2009: Abundance of sewage-pollution indicator and human pathogenic bacteria in a tropical estuarine complex, Environmental Monitoring Assessment 155, 245-256.

Newell, G.E., Newell, R.C. 1977: Coastal marine eutrophication: A practical guide , 5th ed. London: Hutchinson Educational.

Nixon S, W., 1995. Coastal marine eutrophication: A definition, social causes, and future concerns. Ophelia 41, 199–219.

Parsons, T. R., Maita, Y., Lalli, C. M., 1992. A Manual of chemical and biological methods for sea water analysis. Pergamon Press, Oxford, New York.

Rogers, S., Lockwood, S.J., 1990. Observations on coastal fish fauna during a spring bloom of Phaeocystis pouchetii in the eastern Irish Sea. Journal of Marine Biological Association UK 70, 249 – 253.

Shanmugam, P., Neelamani, S., Yu-Hwan, A., Philip, L. and Gi-Hoon, H. 2007. Assessment of the levels of coastal marine pollution of Chennai city, Southern India. Water Resource Management 21,187-1206.

Strickland, J. D. H., Parsons, T. R. S., 1968. Determination of dissolved Oxygen. In A Practical Handbook of seawater Analysis. Fisheries Research Board of Canada, Bulletin 167, 71- 75.

Thorne-Miller, B.1999.The living Ocean- understanding and protecting marine Biodiversity. Island Press, USA, pp.214.