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An impact of sewage pumping failure on coastal water quality of Mumbai, India

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A model was conceptualised to emulate the behaviour of coastal water during high and low tides and the impact of the pump failure in present and projected future scenarios was estimated on it. The model was validated before being used for failure scenario simulation. The study indicates that potential adverse effects on water quality are imminent in case of sewage pumping station failure and warrants better planning and management in terms of diversionary and evacuation routes and preparedness plans.

[**Keywords:** Pumping station, pump failure, sewage, water quality]

Introduction

Since time immemorial, civilizations have flourished around inland as well as littoral waterbodies. Today around 44% of the world populace lives on the coasts[1] and the average density of people in coastal regions is three times higher than the global average density[2]. With increasing human settlements, coastal waters have become vulnerably exposed to anthropogenic ills like habitat degradation, population growth and urbanization, pollution, etc.[3-6]. Wastewater disposal further poses a sinister threat to coastal water quality. Effluents in coastal regions are generally disposed in the ocean owing to its massive assimilation capacity and the discharge of untreated or partially treated effluents into water systems has been a common practice in many developing countries for the past few decades[7,8]. Many times, untreated waste from open drains also mixes with the coastal water directly. High concentrations of enteric bacteria that originate mainly from human excreta besides other wastes can damage the ecosystem considerably[9]. Hence, there is an urgent need to effectively design new and sustainable approaches for managing coastal resources in order to maintain a balance between coastal resource conservation and rapid economic development[10-12].

The ability to understand and predict the fate of contaminated water bodies under different scenarios is exigent. Mathematical models are usually employed to make such predictions. By coupling hydrodynamic and biologic processes, models can determine plume evolution, enabling the prediction of ambient concentrations over time[13,14]. Furthermore, the use of modelling tools can complement the traditional sampling and monitoring techniques in order to achieve adequate water quality management strategies. The use of numerical models to assess pollution effects caused by sewage discharge or other contamination sources in different receptive media has become widespread[15-20]. Ecological water quality modelling specifically addresses many of the biological and chemical factors that are absent in the simple input-output models[21-25]. The present study aims to estimate the impact of failure of five pumping stations (PSs) located along the western coastline of Mumbai, India, on the water quality of adjoining waterbody using hydrodynamic and water quality simulations under present and projected future scenarios.

Materials and Methods

Mumbai, the largest cosmopolis in western India, is a coalesced landmass encompassed by the Arabian Sea on the west and Thane Creek on the east. It houses more than 16 million dwellers[26] and spreads over an area of 603 km^2. It is divided into seven sewerage zones delineated by the Municipal Corporation of Greater Mumbai for collection and treatment of sewage/wastewater. After proper treatment, the effluent is then disposed into coastal and creek water. Fig. 1a shows the map of the study area including the sewerage zones and the sampling locations. The study area lies between latitude 18°52'51"N to 18°52'54"N and longitude 72°41'43"E to 72°52'11"E. Location of the five studied pumping stations (Vallabh Nagar, Chimbai, Nepean Sea Road, Harvey Road, and Afghan Church), outfalls (Erangal, Bandra and Worli), wastewater treatment facilities (WWTFs) and drains as well as the bathymetry details are presented in Fig. 1b.

To simulate the behaviour of coastal water with regards to parameters like Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO) and Faecal Coliform (FC), and estimate the impact of pump failure on it, a hydrodynamic model was conceptualised. These water quality parameters were preferred due to their relevance with SW-II standards, Central Pollution Control Board, India for bathing, contact water sports and commercial fishing. The simulation was performed in 2D using the Hydrodynamic and Ecolab modules of MIKE 21 software[27,28].

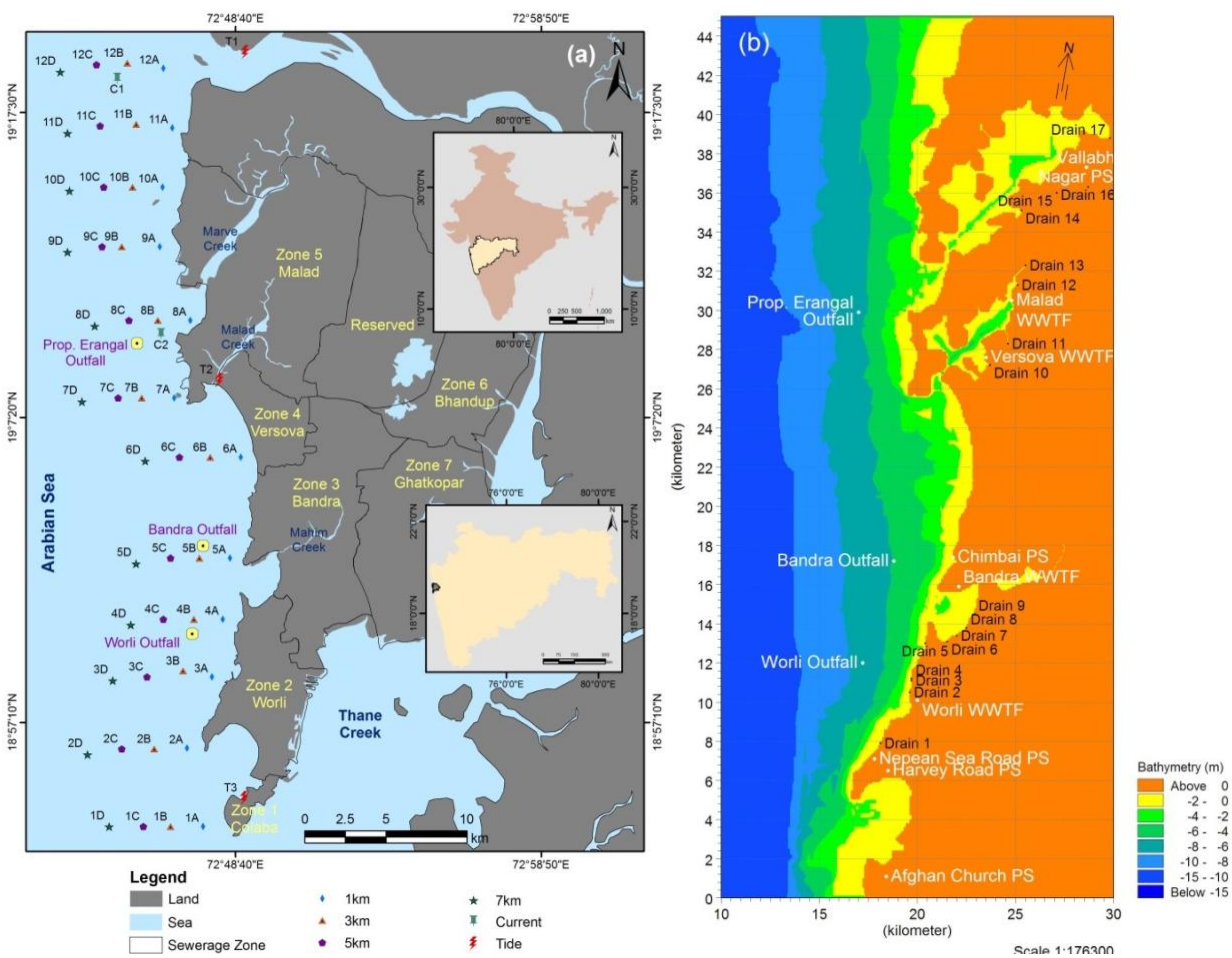


Fig. 1 - Base map including (a) sampling locations, sewerage zones and locations of tide and current measurements and (b) bathymetry details with location of pumping stations (PS), outfalls, WWTFs and drains in west coast

The bed topography of the model was generated using bathymetry data collected from surveys and reports[29]. Bathymetry of west coast varies up to 20m below mean sea level within the study area, reducing to below 2m near the shoreline. Bathymetry of Malad and Mahim creeks varies from 4 to 6m in middle stretches and reduces to below 2m in the upper stretches. Tidal elevations were measured for 15 days at three locations (T1, T2 and T3) using tide pole (Fig. 1) and transferred to mean sea level. The time series of current data was also measured for 24 hours using 2D-ACM current meter for tide velocity and direction at two locations (C1 and C2) as shown in Figure 1a. Water quality was monitored at distances of 1 km, 3 km and 5 km (during low tide) and 7 km (during high tide) from the western coastline at 12 sections as well as at the 2 existing outfalls (Figure 1a). Water specimens were acquired from drains, creeks (Marve, Malad and Mahim) and WWTFs existing on the west coast (Figure 1a). Samples were collected, preserved and analysed as per standard procedures[30].

The model domain area was about 30 x 45 km^2, divided into 135,000 grids of size 100m x 100m. The model boundary was defined at Vasai (North – T1), Colaba (South – T3) with zero-flux boundary condition at open boundary (West) (Fig. 1a). The details of flow and wastewater characteristics in terms of BOD, DO and FC at PSs, WWTFs, outfalls and drains are presented in Table 1. DO was observed nil in the existing treated effluent. The simulation results for water quality are assessed as per SW-II standards according to which under ideal conditions, BOD should be below 3 mg/L, DO should be above 4 mg/L and FC should be below 100 CFU/100ml[31].

Thes simulation was performed for present hydrodynamic and water quality condition of west coast without pump failure considering 50% wastewater collection from the existing sewerage systems, 100% preliminary treatment at Worli, Bandra and Malad WWTFs, 100% secondary treatment at Versova WWTF and disposal of effluent from Bandra and Worli outfalls. Validation of the model was performed by comparing the observed hydrodynamics (water depth, velocity and current) and water quality (BOD, DO and FC) with the simulated results for low and high tides.

The validated model was then used for simulation of following worst-case failure scenarios and assumptions:

Case I – Present Condition with 100% pump failure

- No improvement in treatment, pumping station overflows or collection efficiency

Case II –Projected Future Scenario (2025) with 100% pump failure

- Improvement in wastewater collection (100%) and treatment (100%)
- Projected future flow of sewage and its characteristics
- New proposed outfall for disposal of treated effluent from Versova and MaladWWTFs

Table 1 Quantity and quality of wastewater discharge in west coast, Mumbai

Sr. No.	Pumping Station / WWTF	Disposal by	Untreated / Treated Effluent								
			Present Condition			Case I (Present Condition with 100% pump failure)			Case II (Future Scenario with 100% pump failure)		
			Qty	BOD	FC	Qty	BOD	FC	Qty	BOD	FC
Pumping Station											
1	Vallabh Nagar	MaladWWTF	38.6	120	1 x 10^7	38.6	120	1 x 10^7	232.1	120	1 x 10^7
2	Chimbai	BandraWWTF	5.2	105	1 x 10^7	5.2	105	1 x 10^7	39.4	105	1 x 10^7
3	Nepean Sea Road	WorliWWTF	3.7	145	1 x 107	3.7	145	1 x 107	14.1	145	1 x 107
4	Harvey Road	WorliWWTF	3.1	158	1 x 107	3.1	158	1 x 107	33.6	158	1 x 107
5	Afghan Church	ColabaWWTF	6.4	105	1 x 10^7	6.4	105	1 x 10^7	48.6	105	1 x 10^7
WWTF											
6	Malad*	Malad Creek	97	164	2 x 10^7	58.5	164	2 x 10^7	614.9	100	1 x 10^5
7	Versova*	Malad Creek	87	24	5 x 10^7	87	24	5 x 10^7	325	100	1 x 10^5
8	Bandra	Outfall	344	122	1 x 10^7	339	122	1 x 10^7	688.6	100	1 x 10^5
9	Worli	Outfall	301	170	3 x 10^6	294.2	170	3 x 10^6	445.3	100	1 x 10^5
Drains/ Nallahs											
10	Non point discharge	Fore shore / Creek	76 – 349	65 – 290	1x10^6 – 1x10^7	76 - 349	65 - 290	1x10^6 – 1x10^7	-	-	-

Qty – Quantity in MLD – Million Litres per Day, BOD in mg/L and FC in CFU / 100ml
*Presently effluents discharge into Malad creek, whereas in future scenario it will dispose through proposed Erangal outfall.

Results and Discussion

Hydrodynamic and water quality simulations were performed for present condition without pump failure. Simulation results of hydrodynamic Fig. 2(a, b) and water quality parameters BOD (Fig. 3a), DO (Fig. 4a) and FC (Fig. 5a) are presented spatially and tidally. BOD complies with the SW-II standard in the coast except in the creeks and at the outfalls where noticeable plumes are observed. Creeks are especially critical due to direct discharge of drain water with BOD above 10 mg/L (Fig. 3a). Further, DO does not comply with recommended standards throughout the coastline for both tides (Fig. 4a). FC is precarious in the study area including outfalls and coastline (Fig.

5a). During high tide, FC concentration reduces due to tidal dilution, though not significantly, because of high concentration of bacteria already existing in the background environment and no treatment for FC removal at the existing treatment facilities.

Validation of the model was performed by comparing hydrodynamic and water quality findings with the in situ sampled observations. Comparison of simulated and observed water depth at Versova Jetty (mouth of Malad creek) in west coast is presented in Fig. 6a. Similarly, current velocity and direction at 1 km from sea shore around Erangal and 5 km seaward side around Vasai were compared under observed and simulated conditions (Fig. 6b and 6c). The correlation coefficient for water depth based on observed and simulated values was found to be 0.97. Further, coefficients for current velocity at Erangal and Vasai were estimated at 0.65 and 0.7 respectively and coefficients for current direction were 0.75 and 0.8 respectively. Variations in observed and simulated water quality parameters (BOD, DO and FC) during low and high tides in the west coast are presented in scatter plots in Fig. 7a, 7b and 7c respectively. Coefficients for BOD, DO and FC were estimated at 0.7, 0.7 and 0.75 respectively during low tide and 0.65, 0.7 and 0.72 respectively during high tide. Thus, a good correlation between observed and simulated values validates the model for prediction of pump failure scenarios.

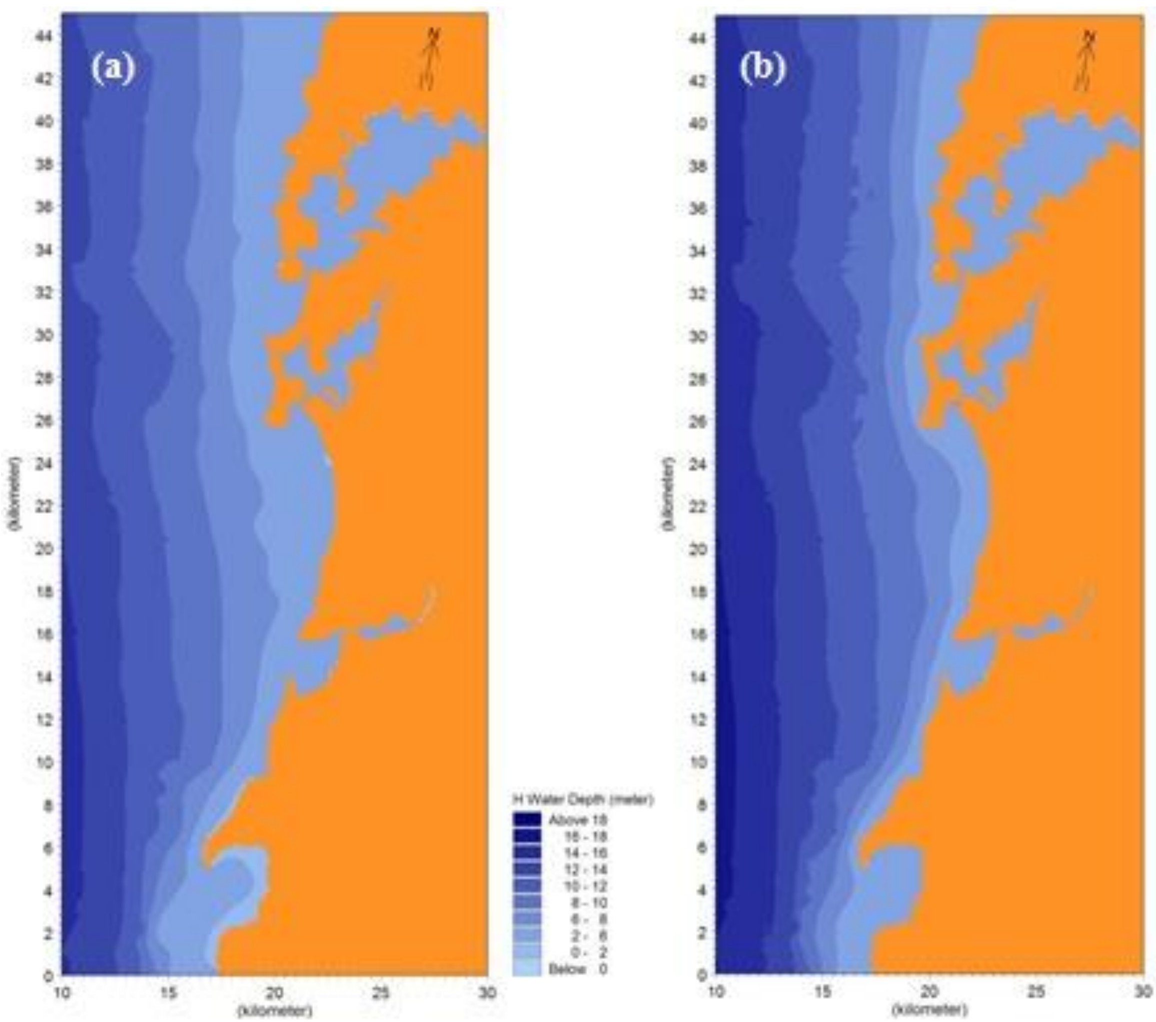


Fig. 2 - Hydrodynamic simulation of water depth in west coast in present condition (a) low tide and (b) high tide

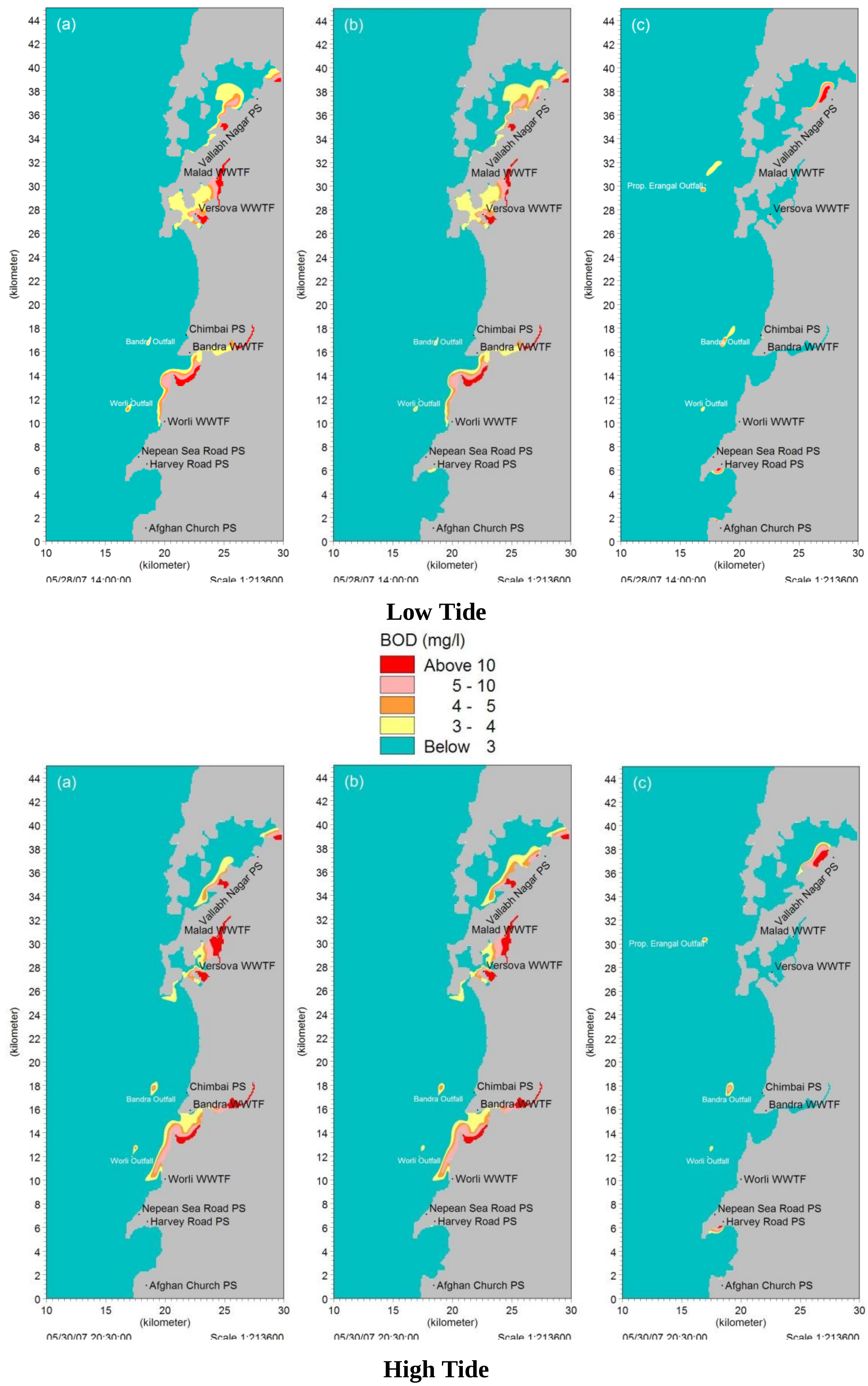


Fig. 3 - Spatial and tidal distribution of BOD in west coast (a) present condition (b) present condition with 100% pump failure (c) future scenario with 100% pump failure

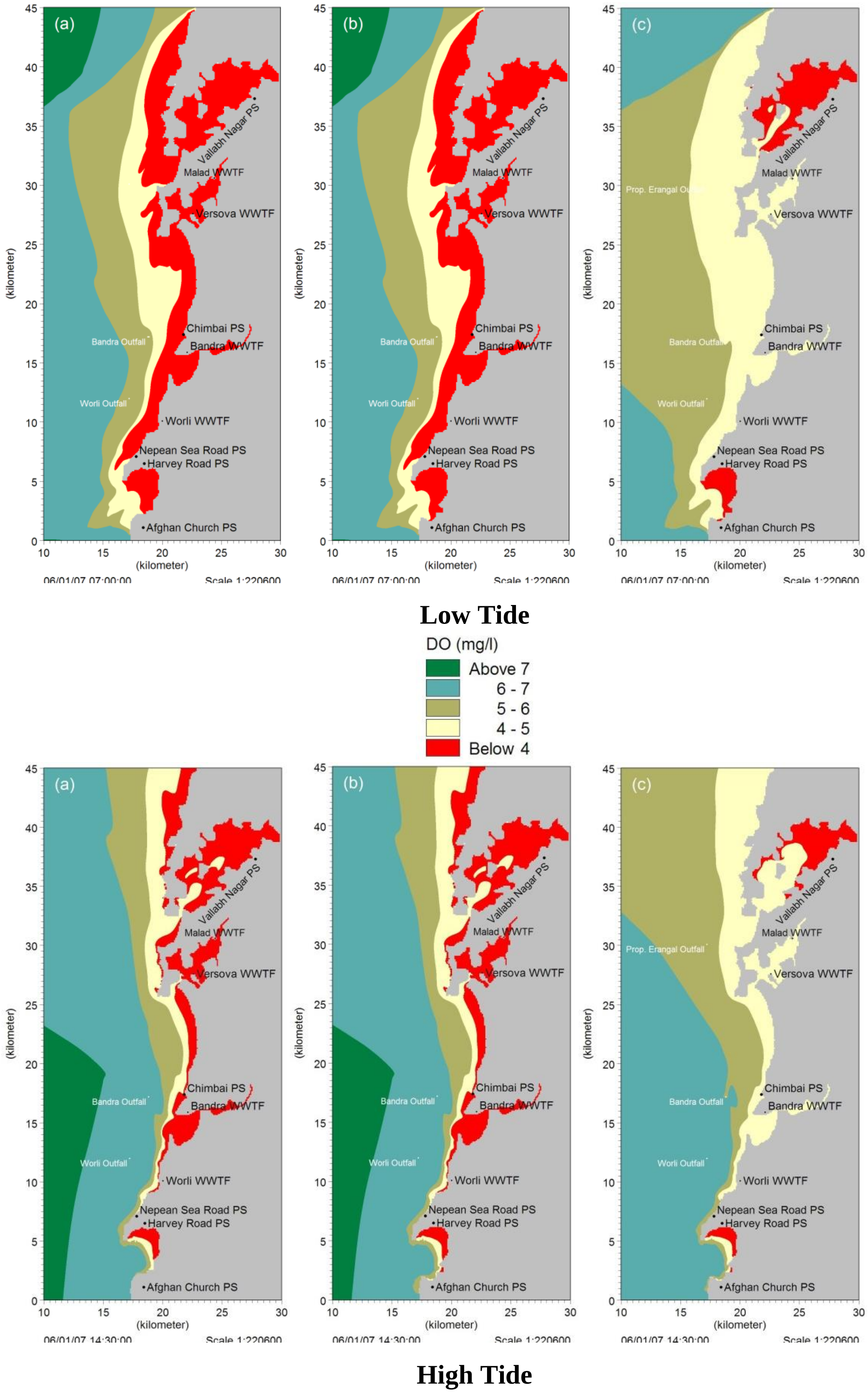


Fig. 4 - Spatial and tidal distribution of DO in west coast (a) present condition (b) present condition with 100% pump failure (c) future scenario with 100% pump failure

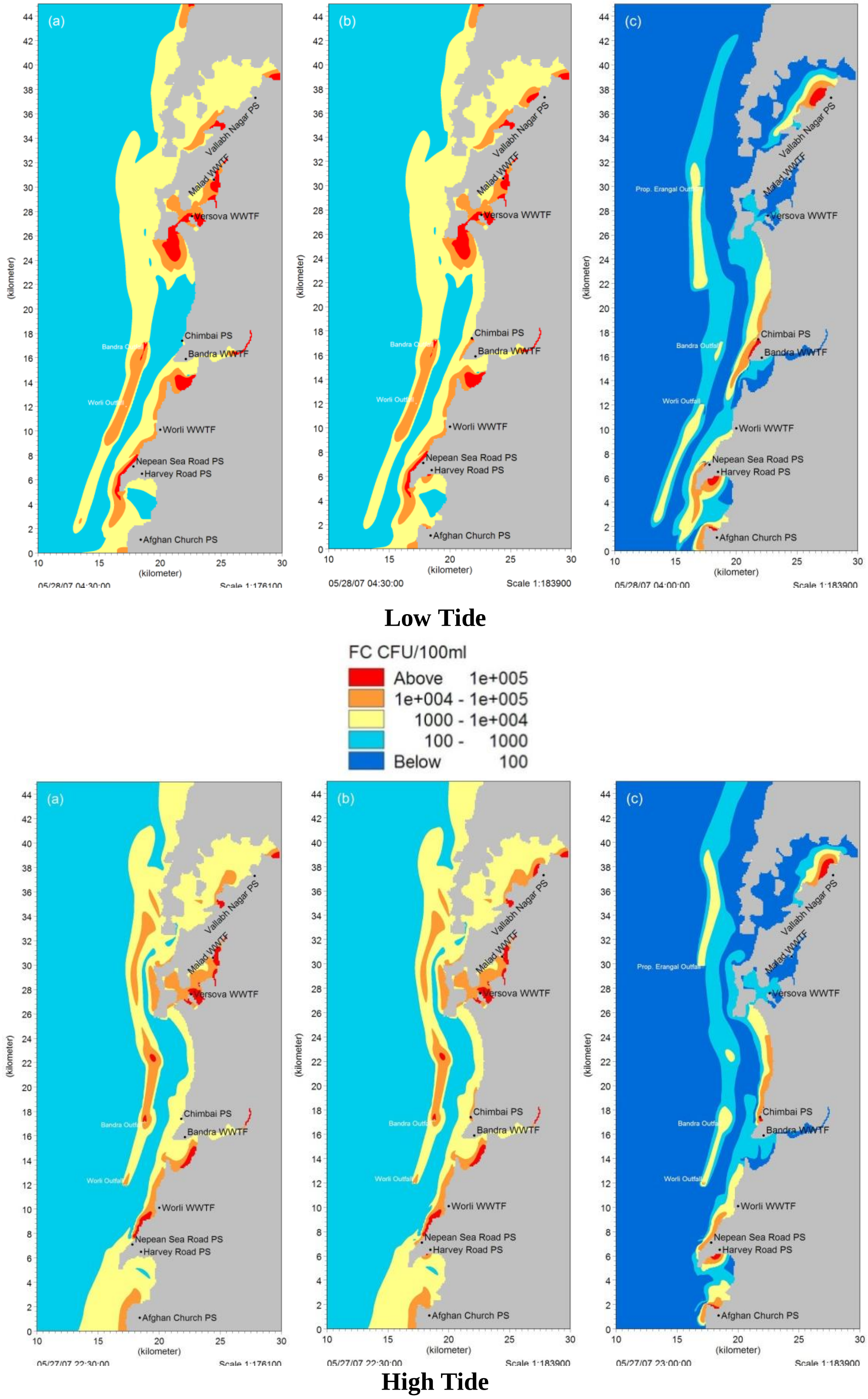
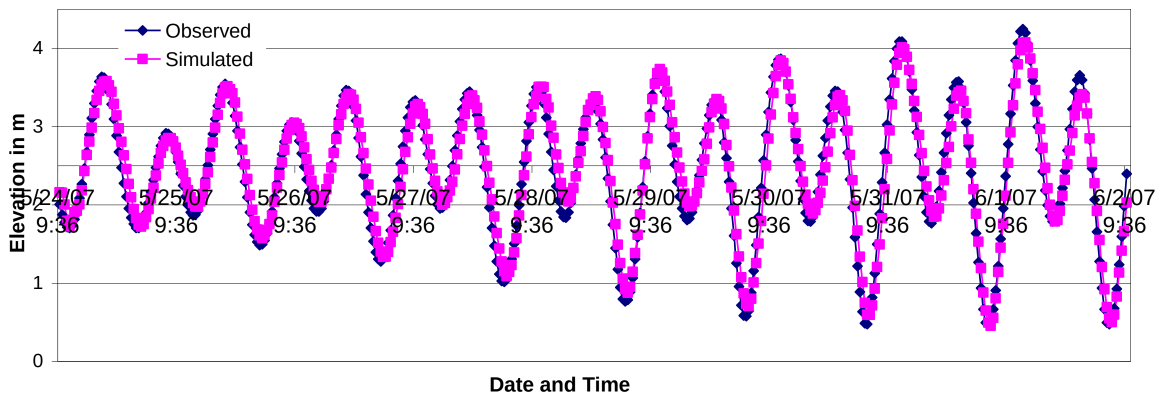
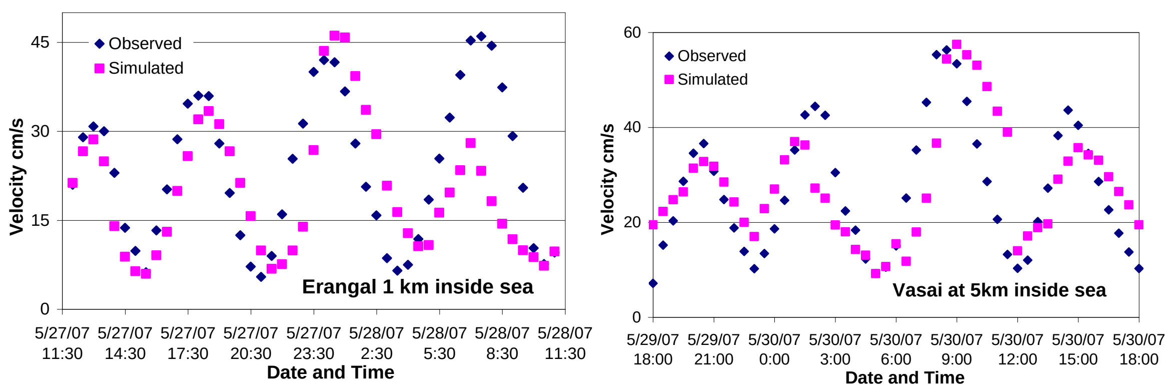


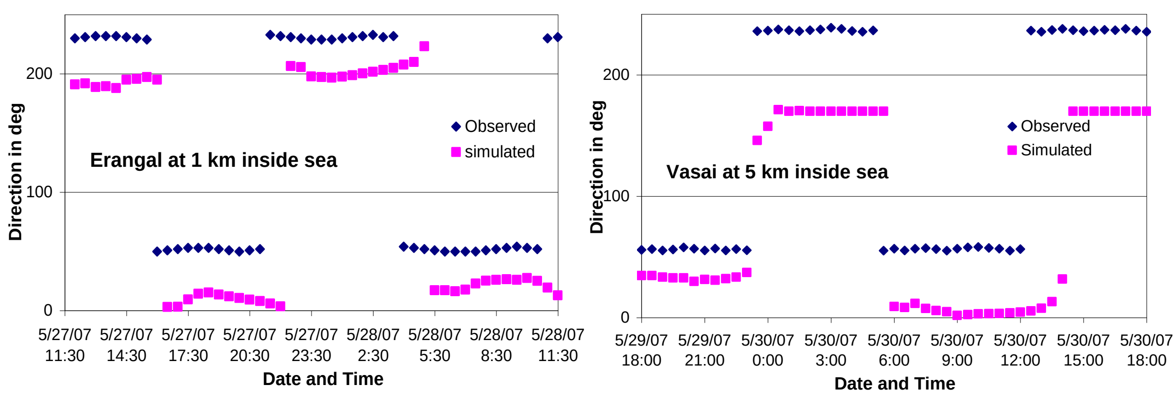
Fig. 5- Spatial and tidal distribution of FC in west coast (a) present condition (b) present condition with 100% pump failure (c) future scenario with 100% pump failure



a) Water Depth at Versova Jetty (Mouth of Malad Creek)



b) Current Velocity



c) Current Direction

Fig. 6- Comparison of observed and simulated a) Water Depth b) Current Velocity and c) Current Direction

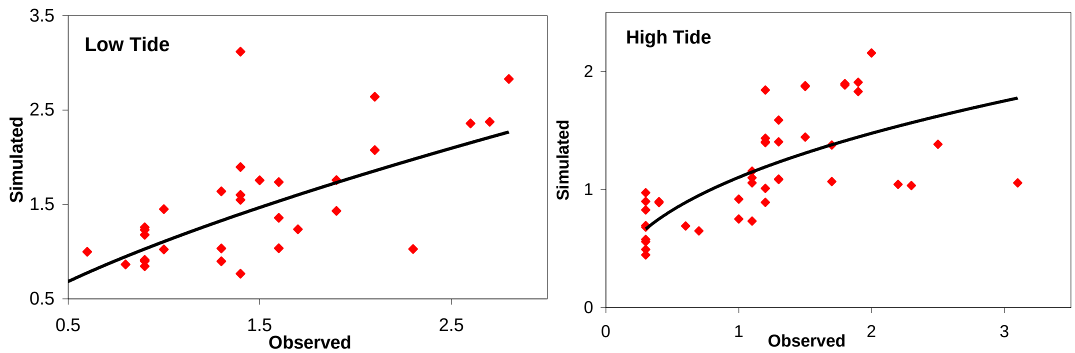
Case I: 100% pump failure under present condition

This case considers 100% pump failure at PS under the present condition which implies that sewage is not conveyed to WWTFs and further to the respective outfalls. This entails maximum deterioration in water quality adjoining the PSs and a reduction in effluent quantity reaching the outfalls. No significant changes were observed in the hydrodynamics for both tides except in areas adjoining the PSs and hence the images for the same have not been included. The spatial and tidal distribution of water quality parameters (BOD, DO and FC) is presented in Fig. 3b, 4b and 5b respectively. Results of simulation for this case are similar to present condition without pumping failure except in areas adjoining the PSs. This may be due to the assumption of no improvement in efficiency of wastewater collection and existing treatment conditions. BOD is observed critical in areas bordering Vallabh Nagar and Harvey Road PSs as well as in the creeks during both tides (Fig. 3b). However, BOD values around the outfalls improve as the quantity of effluent reaching the outfalls is reduced due to pump failure; though they are above recommended standards. No major change in DO levels is observed due to pumping failure in the simulation except around Afghan Church PS.

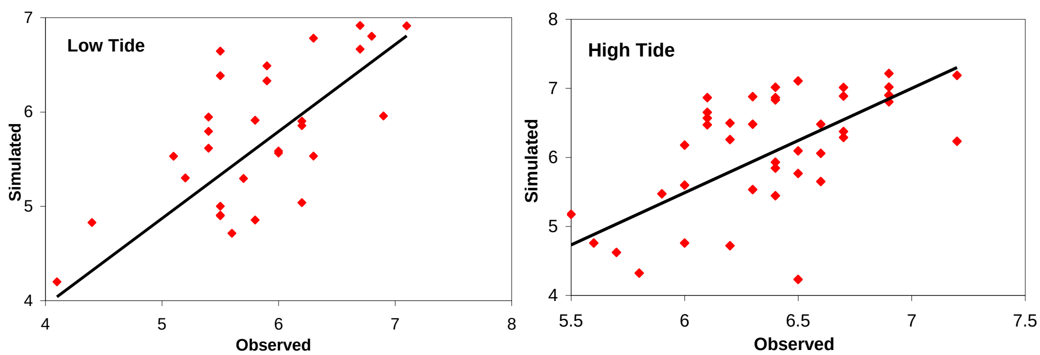
Similarly, FC is highly critical in the areas adjoining the PSs as well as the outfalls during low tide.

Case II: 100% pump failure under future condition

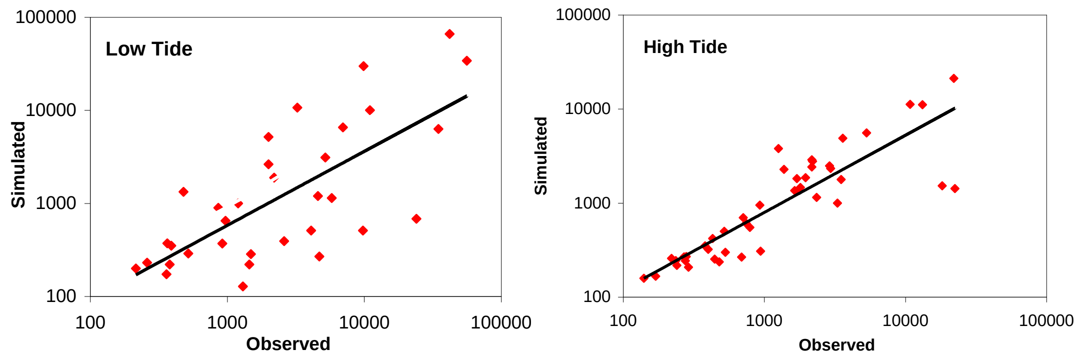
This scenario considers increased projected flow of sewage for the year 2025 with the assumption of 100% wastewater collection, treatment and disposal of treated effluent through existing and proposed outfalls. No significant changes were observed in the hydrodynamics for both cases except in areas adjoining the PSs and hence the images for the same have not been included. The spatial and tidal distribution of water quality parameters (BOD, DO and FC) is presented as Fig. 3c, 4c and 5c respectively. The deterioration in water quality is observed adjoining the regions of PSs and outfalls. A significantly positive change can be seen in the creek and coastal water quality due to improvement in collection of the drain and sewer water into city sewerage system. For both tides, BOD complies with recommended standards except near Vallabh Nagar PS, Harvey Road PS and outfalls. The extent of BOD plume is increased at Bandra outfall and a new plume is seen at proposed Erangal outfall due to discharge of huge treated effluent as compared to present condition (Fig. 3c). Worli outfall shows decrease in plume due to deeper bathymetry and better effluent treatment. During both tides, DO is observed to conform recommended standards along the coast except in Marve Creek and shoreline between Harvey Road and Afghan Church PSs (Fig. 4c). FC complies with the standards in the coast except impact zones of PSs and outfalls although there is an improvement in FC in the creeks and outfalls due to secondary level of treatment (Fig. 5c). However, no particular treatment assumed for FC removal is assumed in the scenario. FC can be further improved by providing more advanced treatment. The bigger extent of FC contamination can be seen in areas near PSs due to increased flow quantities.



a) BOD



b) DO



c) FC

Figure 7.Scatter plots for observed and simulated a) BOD b) DO and c) FC

Conclusion

The future scenario is formulated under ideal conditions of wastewater collection, treatment and disposal to assess the potential impact of pumping failure on coastal water quality. Simulation results show that pumping station failure at Nepean Sea Road and Chimbai would cause less damage to coastal water quality and land hazard due to close vicinity to the waterbody and deeper bathymetry for dilution. However, maximum damage to habitation is expected at Afghan Church, Harvey Road and Vallabh Nagar pumping stations as they are located in thickly populated areas of the city. Also, as Vallabh Nagar PS has the highest quantity of sewage in both failure cases, most damage is anticipated in Marve Creek. Further, despite assumed ideal conditions in the future scenario and an improved water quality (BOD and DO), FC contamination is still prominently visible. This promulgates that pumping failure can lead to serious harm to water quality of west coast and better management plans with diversionary routes for sewage flow towards coast are the need of the hour to minimize impact on land.

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