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Hydrodynamic and water quality simulation of Thane creek, Mumbai: an impact of sewage discharges

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To assess the impact of sewage discharges on creek water quality, a hydrodynamic and water quality simulation was carried out for Thane Creek. DO and BOD values showed non-compliance up to middle and upper stretches during low tide and even in upper stretch during high tide. FC was found beyond compliance level during low and high tides. Simulated results were correlated with observed tide and current as hydrodynamics and DO, BOD and FC as water quality parameters with correlation coefficients 0.66 to 0.91.

[**Keywords:** Hydrodynamics, water quality, sewage, simulation, creek]

Introduction

India has a long coastline of about 8000 km including shallow bays, creeks and estuaries rich in natural resources[1]. Creeks support a complex food web for aquatic, terrestrial and avian wildlife[2,3,4]. Creeks being small tidal inlets are often the first point of entry of non-point source runoff from upland areas[5,6]. Discharge from domestic, municipal and industrial wastewater is a common practice in most of the coastal cities[7]. Urban runoff and untreated sewage cause depletion in oxygen level and increase in bacterial pollution[8,9]. A variety of illnesses are associated with exposure to polluted coastal waters[10]. Thus, there is a need to plan a monitoring programme to study the effect of pollution on creek water quality. Mathematical models support in developing control strategies for estuarine/creek water quality management[11,12,13,14,15]. Reliability of model depends on how well their structure and parameters describe the fundamental mechanisms[16]. The objective of the study was to assess the impact of sewage and wastewater discharges on creek water quality through hydrodynamic and water quality simulation.

Materials and Methods

Mumbai is one of the fastest growing cities in India with population of 11.9 million as per 2001 census records. The coastline of the city is indented with numerous creeks and bays. Mahim, Manori and Malad creeks and Ulhas estuary on western and Thane creek on eastern front are the main waterways with extensive mudflats that protect mangroves in patches[17]. Creeks and coastal boundary adjacent to Mumbai act as a sink for most of the pollutants[18]. Thane creek receives sewage from open drains and partially treated effluents from Colaba and secondary treated effluent from Ghatkopar and Bhandup wastewater treatment facilities (WWTFs). Study area lies between latitudes 18° 53' to 19° 12'N and longitudes 72° 48' to 73° 1' E (Fig. 1).

MIKE 21, a two-dimensional mathematical model was used to simulate the hydrodynamic and water quality scenario of the creek[19,20]. Many researchers have used this model to simulate hydrodynamic and water quality of creeks, estuaries and coastal environment[14,15]. Hydrodynamic module simulates tide and current behaviour and ECOLab simulates state variables such as Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and Fecal Coliform (FC). These are the important water quality parameters as per Central Pollution Control Board, India - SW-II Standards[21] designated for bathing, contact water sports and commercial fishing. The prescribed limits of DO, BOD and FC are 4 mg/L, 3 mg/L and 100 CFU/100ml, respectively. The model domain was discretized with grid size 100m × 100m and covered an area of 34 × 25 km^2. Topography of the model was created by bathymetry data obtained from surveys and reports[22]. Maximum depth in the model domain was around 15m at the mouth of Thane creek and reduces up to 2m in the upper stretch of the creek along the adjacent areas of tidal influence.

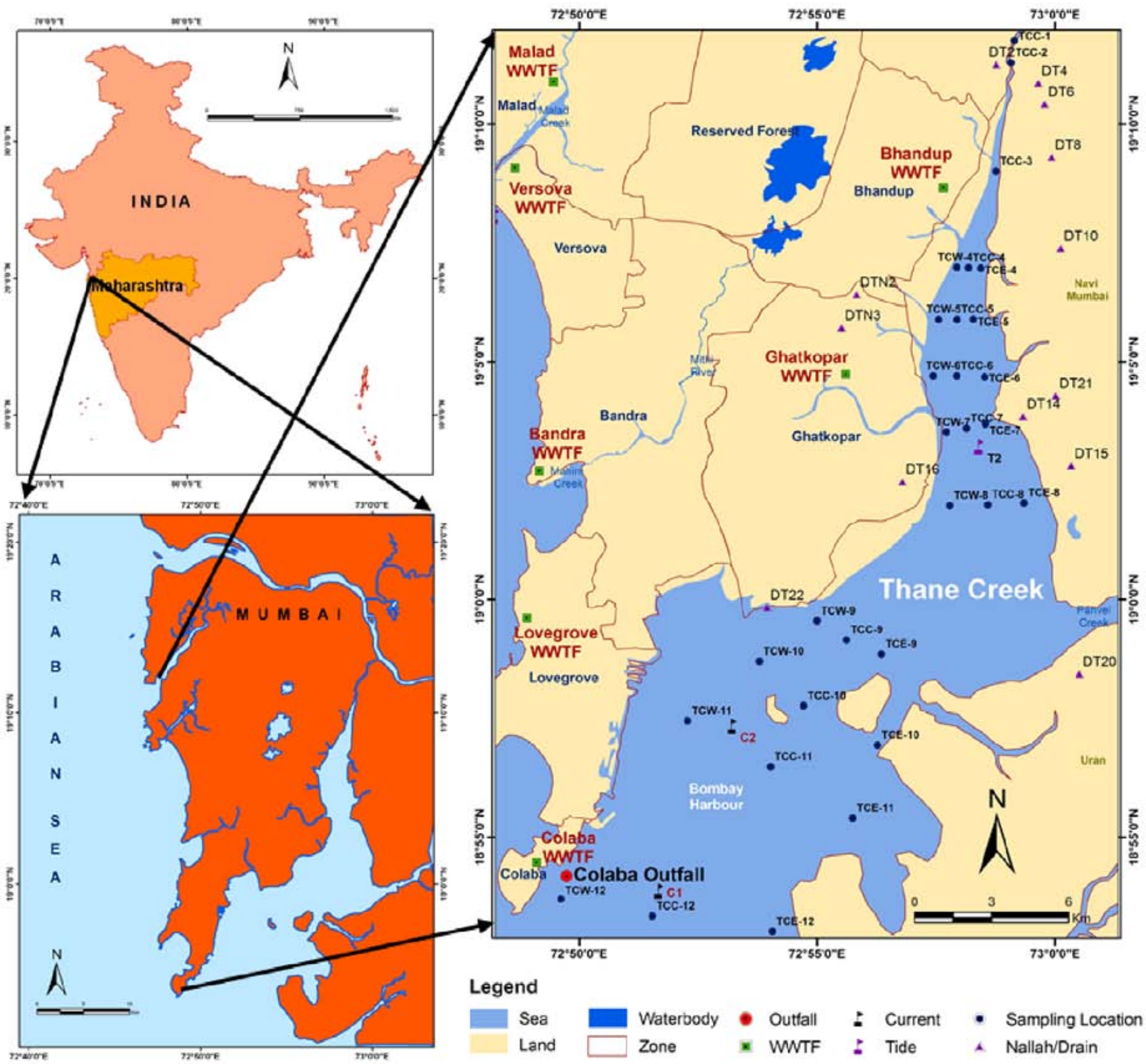


Fig. 1— Details of study area and sampling locations in Thane Creek

Tidal and current data were measured for model conceptualization and validation of the simulated hydrodynamics. Tide elevations were measured for 15 days with 30 minutes interval at the boundaries of the model in the north, south and east directions and one location in the creek (T2 in Fig. 1) near Vashi Bridge using tide pole and transferred to mean sea level (msl). 2D-ACM current meter was also used to measure current speed and direction for 24 hours with 30 minutes interval near Butcher Island (C2 in Fig. 1). Based on tide measurement, tide elevations were assigned at north, south and east boundaries. Bed resistance was also assigned as Manning's number to simulate the hydrodynamics.

The effluent from WWTFs and outfall as well as sewage discharges from drains were assigned as sources of pollution in the model input. The details of input flows and their characteristics are explained in Table 1. Data required for model conceptualization and validation were collected during 2006 and 2007. Water samples were collected from creek, WWTFs and drains and locations were traced using global positioning system (GPS). Samples were collected from west, centre and east sides of the creek at every section along the length during low and high tides (TCW, TCC, and TCE in Fig. 1). The creek was divided into three stretches on the basis of sampling sections as upper (section - 1 to 4), middle (section - 5 to 8) and lower (section - 9 to 12) stretches. Samples were collected and analysed for water quality parameters such as DO, BOD and FC as per standard methods[23]. Observed DO, BOD and FC values were assigned at the boundaries and also in the background level to initiate the model. Influence of tidal water is comparatively less at north and east boundaries of the model. Based on the observed water quality, DO and BOD values were assigned at these boundaries as 3.5 mg/L and 5 mg/L, respectively. FC values observed at north and east boundaries were $1.45x10^5$ CFU/100ml and $2.2x10^4$ CFU/100ml, respectively and assigned in the model domain. Due to the impact of tidal water at south boundary, water quality parameters were assigned at this boundary with varying concentration of BOD (1 to 2 mg/L), DO (6 to 8 mg/L) and FC ($4x10^2$ to $4.5x10^4$ CFU/100ml). Forcing features as salinity and temperature were also specified in the model domain with values 32 psu and 29º C, respectively. Various physical constants, coefficients and decay rates for BOD and FC processes were also defined in the model based on the literatures. For BOD, 1st order decay rate at 20º C was specified as 0.1/d[24] and for FC 1st order decay rate at 20º C was used as 0.12/d[25,26].

Results & Discussion

Hydrodynamic simulation in terms of water depth during low and high tides is presented in Fig. 2. Influence of tidal water can be visualized in the creek in terms of changes in water depth during low and high tides. Water depth increases significantly adjancent to main channel of creek during high tide (2-6m) and reduces considerably during low tide (0-2m). Influence of tidal water can also be clearly observed in the main channel.

Table 1 Details of effluent and sewage discharges in Thane creek

Sr. No.	Discharge Locations	Flow MLD	Effluent/sewage Water Quality		
			BOD mg/L	DO mg/L	FC CFU/100ml
1	Bhandup WWTF	75-80	42	1-2	1.6E+06
2	Ghatkopar WWTF	85-95	37	0	2.8E+07
3	Colaba outfall	15-20	189	0	1.5E+06
4	Drains from East and West side of creek	350-375	30-300	0-1	1.2 - 3.4E+07

Data collected during 2006 to 2007

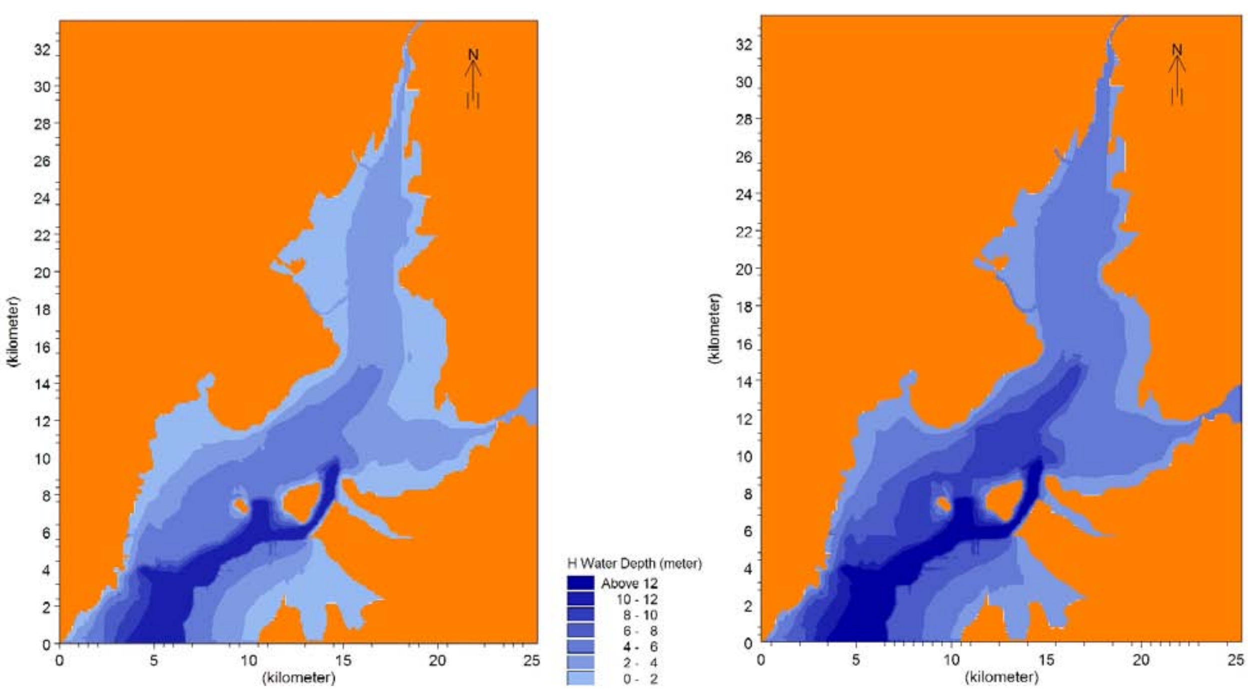


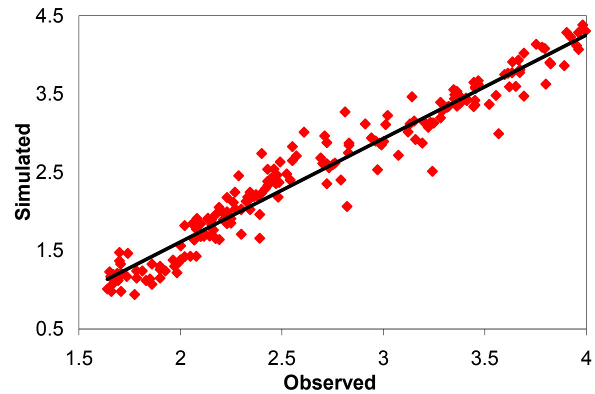
Fig. 2 - Simulated water depth during low and high tides

Validation of the hydrodynamic model was performed by comparing simulated and observed water depth, current velocity and direction. Observed water depth near Vashi bridge (T2) was compared with simulated water depth and found to be strongly correlated with coefficient 0.97 (Fig. 3a). A similar trend was observed for current speed and direction near Butcher Island (location C2) with correlation coefficients 0.66 and 0.86 respectively (Fig. 3b & 3c).

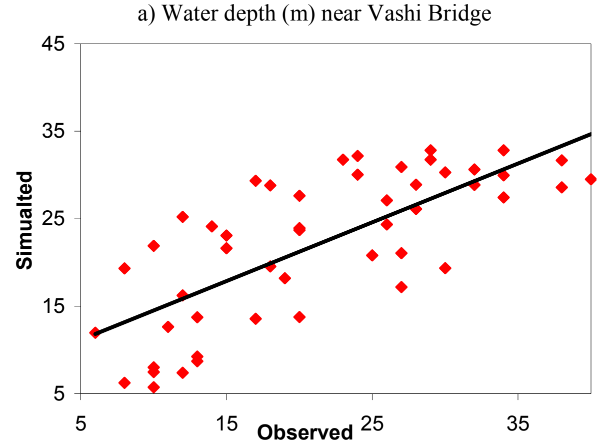
Validated hydrodynamic model was further used for water quality simulation using Ecolab module of MIKE 21. Water quality simulation results for DO, BOD and FC during low and high tides are presented in Fig. 4a to 4c respectively. The colours of legend were assigned based on SW-II standards to identify compliance and non-compliance levels of water quality in the creek water. DO is found below 4 mg/L during low tide in two-third part of the Thane creek.

However, DO values improve in the range of 4 to 5mg/L in middle stretch and 5 to 7mg/L in lower stretch during high tide. DO is less than 4 mg/L in upper stretch due to narrow width of the creek, less water available for dilution and discharges of sewage and wastewater from open drains and nallahs (Fig. 4a). Impact of sewage and effluent discharges can be noticed along the adjacent sides of creek with DO values less than 4 mg/L.

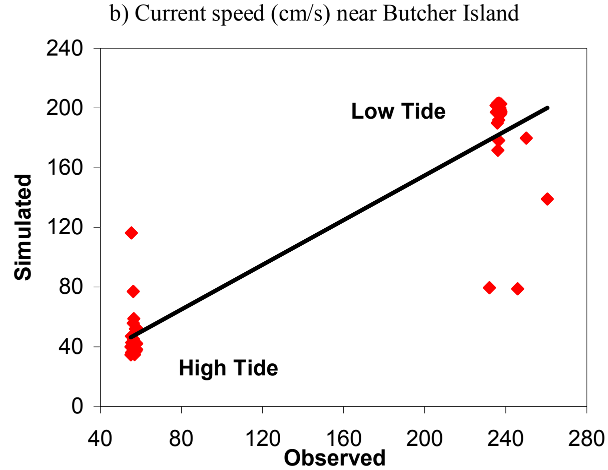
BOD values are more than 3 mg/L during low and high tides in impacted zones of effluent discharges from WWTFs and sewage/wastewater discharges from drains. During high tide, BOD improves due to the influence of tidal water, still adjacent sides of creek exhibit BOD in the range of 3-4 mg/L (Fig. 4b). Upper stretch of the creek exhibits high concentration of BOD due to the narrow channel and less tidal water for dilution and flushing.Excluding these areas, BOD is found below 3 mg/L and ensured compliance with SW-II standards. Water quality of creek in terms of bacterial pollution showed non-compliance according to SW-II standards during low and high tides. During low tide, FC is found above $1x10^5$ CFU/100ml in upper and middle stretches and $1x10^4$ - $1x10^5$ CFU/100ml in lower stretch. During high tide, improvement is observed up to middle stretch, still upper stretch exhibit FC above $1x10^5$ CFU/100ml (Fig. 4c). This is due to the no treatment for FC in the existing WWTFs and presence of high concentration in the background environment. Discharge from Colaba outfall however does not affect the creek water quality except for FC due to sufficient water depth available. Although, Colaba outfall is near to south boundary of model and maintains the simulation results especially for FC during low and high tide since south boundary is defined with varying concentration of FC and other water quality parameters.



a) Water depth (m) near Vashi Bridge

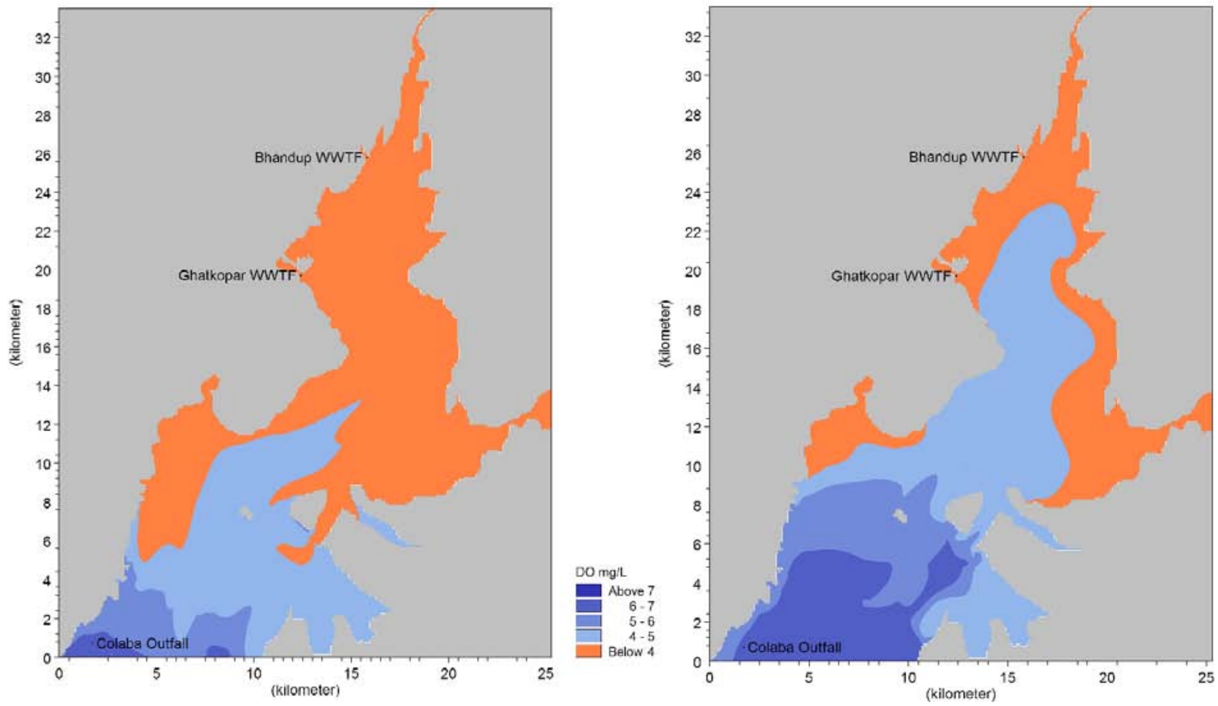


b) Current speed (cm/s) near Butcher Island

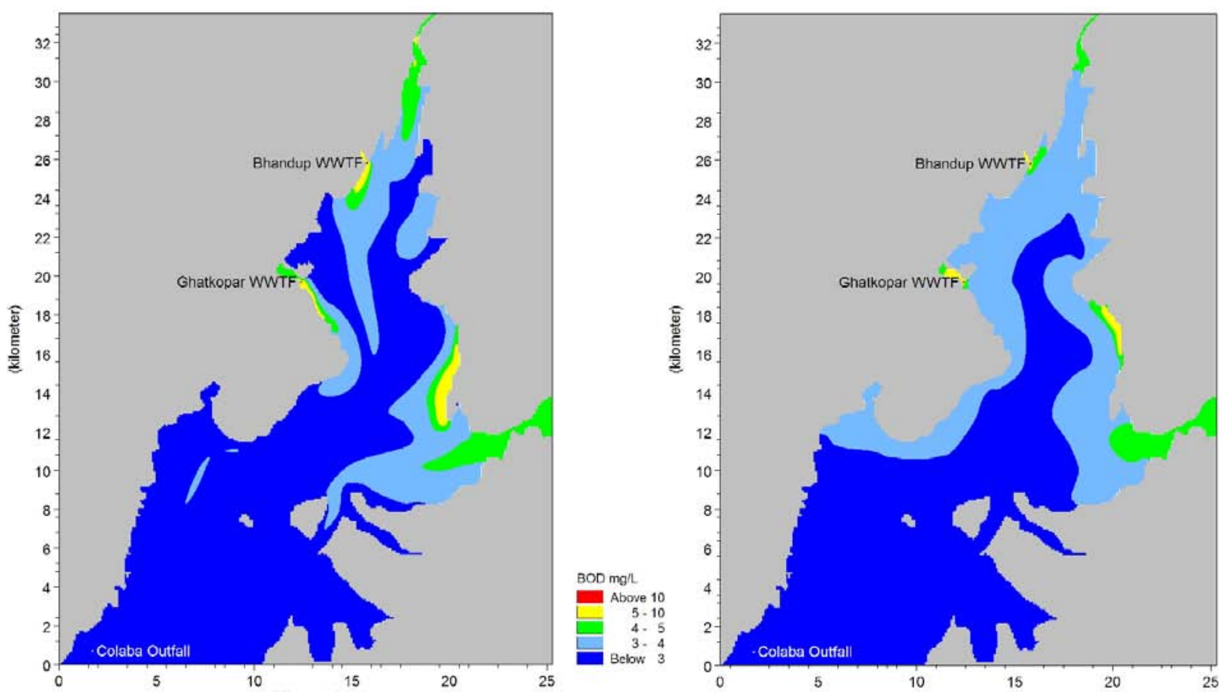


c) Current direction (degree) near Butcher Island

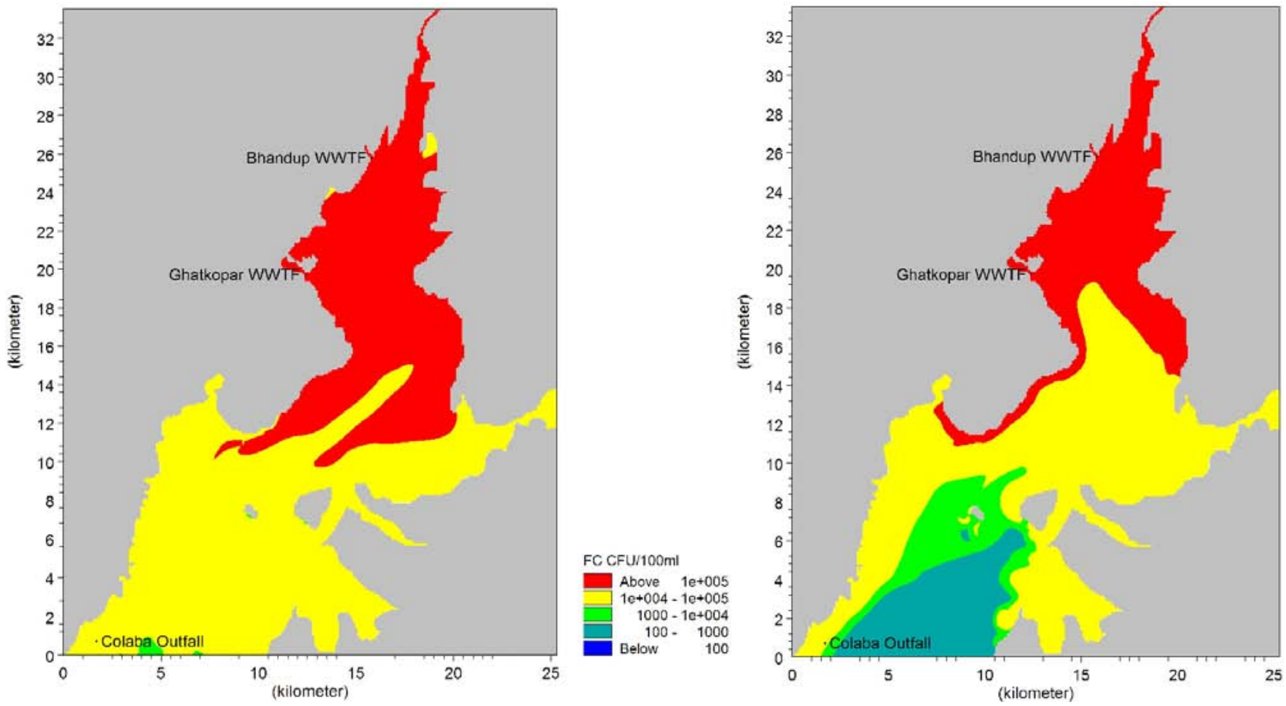
Fig. 3 - Scatter plots for hydrodynamic parameters



a) DO during low and high tides



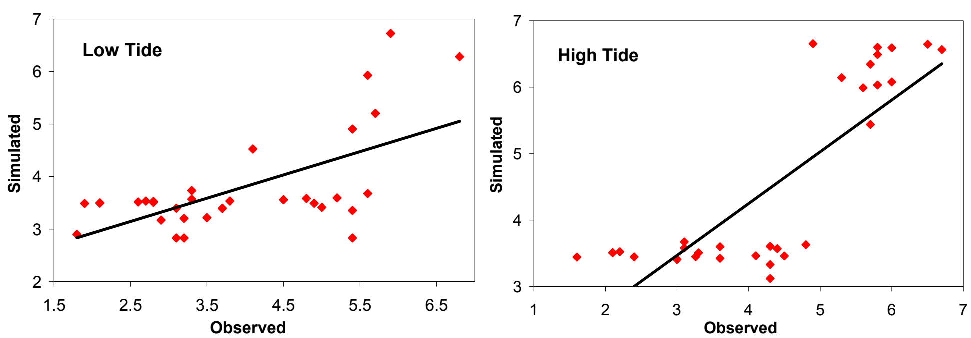
b) BOD during low and high tides



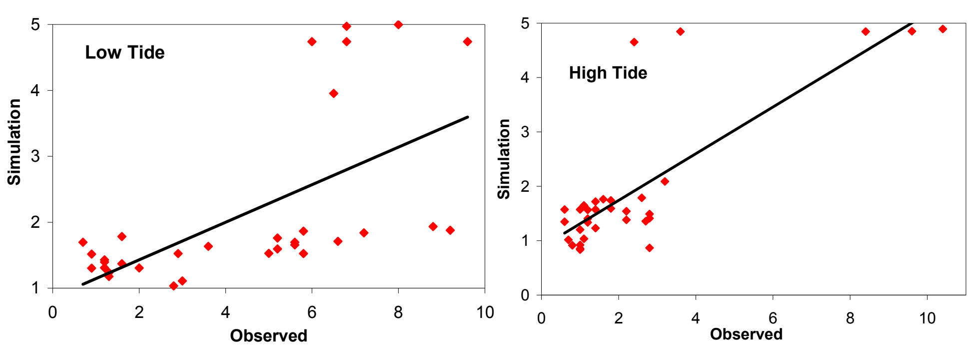
c) FC during low and high tides

Fig. 4 - Simulation of water quality parameters

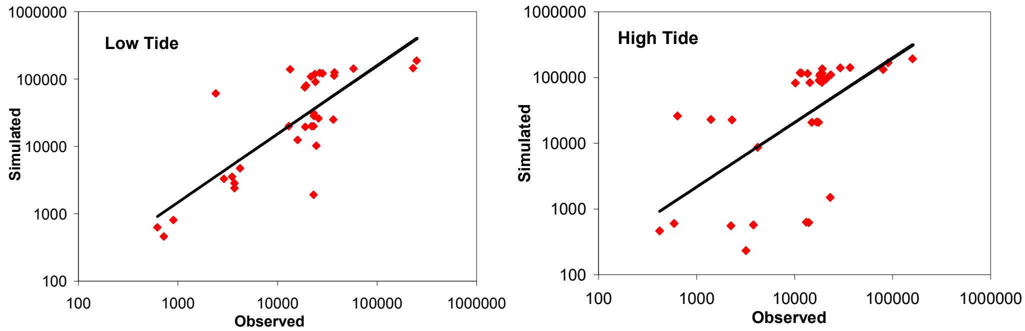
Validation of the water quality simulation was performed by comparing simulated and observed water quality parameters. Observed water quality (DO, BOD and FC) was compared to simulated values with correlation coefficients in the range of 0.78 to 0.91 (Fig. 5a, b, c) during low and high tides.



a) DO (mg/L)



b) BOD (mg/L)



c) FC (CFU/100ml)

Fig. 5 - Scatter plots for water quality parameters

This implies that model is validated for hydrodynamic and water quality parameters. The model can be further used for predicting management scenarios to improve the water quality of the creek.

Conclusion

Hydrodynamic and water quality simulations of Thane creek confirm the impact of sewage discharges on creek water quality. Simulated results were strongly correlated with observed values of hydrodynamic and water quality parameters. DO was found below SW-II standards up to middle and upper stretches during low tide and improved during high tide upto middle stretch in the creek. BOD values were above the standards in the discharge zones of effluent and sewage. Upper stretch of creek exhibited high BOD due to the narrow channel and less availability of tidal water for dilution and flushing. FC values suggested high bacterial contamination in the creek and showed non-compliance with SW-II standards. This is due to no treatment for FC in the wastewater treatment facilities and existence of high concentration in the background environment of creek. The validated model for the existing condition can be utilised for predicting various hydrodynamic and water quality scenarios considering estimated future flow of sewage/wastewater, improvement in wastewater collection system, appropriate level of treatment and disposal. After further appropriate treatment, the resulting effluent can be reused and recycled rather than discharging into the creek.

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