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Tidal and seasonal variations in water quality of Thane creek, Mumbai, India: a statistical analysis

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Water quality of Thane creek was assessed spatially and temporally based on receiving waterbody standards and nutrient parameters. Due to large data set and variation in water quality, statistical analysis was carried out to summarize a data set quantitatively using Box and Whiskers plots. These plots helped to display data spread at a glance, reveal data symmetry and skewness as well as the presence of outliers. Further, Spearman's correlation matrices were generated to establish the relationship between physico-chemical and bacteriological parameters and found to have significant correlation between them. The study reveals that the Thane creek is polluted based on receiving waterbody standards in all the seasons even during low and high tides. The creek water is more polluted in the upper stretch as compared to middle and lower stretches. Immediate attention is required for the improvement in water quality of the creek by enhancement in wastewater collection system, appropriate level of treatment, proper disposal and recycle/reuse of treated effluent rather than discharging into the creek.

[**Keywords:** Creek, Sewage, Wastewater, Water quality]

Introduction

Since ancient time, coastal areas have always fascinated humans for settlement because of transport, food and most valuable ecological resources[1,2]. As a consequence, population, industrialization and economic development in coastal area is losing its environmental value[3,4]. Coastal waters are vulnerable to pollution caused by wastewater, runoff, effluents, land reclamation, recreation and aquaculture, as well as atmospheric deposition and climate change. Coastal water pollution can cause serious public health problems due to recreational activities and damage the ecological system such as coral reefs, mangroves and sea grass community[5,6]. The pollution in coastal waters also affects activities like salt panning, fishing, mariculture, swimming and aesthetics[7]. Therefore, it is imperative to control and prevent further pollution through regular monitoring and effective management of coastal waters[8].

Thane Creek is amongst largest marine bodies in an enclosed area in India and separates Mumbai from the main land[9]. It is rich in natural resources, mangroves and is home for various migratory birds, especially flamingoes[10]. Thane Creek receives a variety of pollutants from the discharges of open drains/nallhas as well as effluents from domestic and industrial waste water treatment facility (WWTF) of the Municipal Corporation of Greater Mumbai, Thane Municipal Corporation, Navi Mumbai Municipal Corporation, Thane Belapur Industrial Association, Maharashtra Industrial Development Corporation, City Industrial Development Corporation and several industries[11]. Even the loading and unloading operations at Mumbai and Jawaharlal Nehru ports and ship-generated waste including bilge contribute to the environmental degradation of it[12]. Various studies have been carried out on the water quality of Thane Creek in small patches[13,14,15]. It has been reported that the creek water quality is deteriorating due to discharges of pollutants (physic-chemical, bacteriological, biological and heavy metals) from domestic and industrial sources.

Presently, the efficiency of sewage collection through sewerage system and treatment of sewage/wastewater are inadequate as compared to its generation in the areas surrounding the Thane Creek. Therefore, huge quantity of untreated sewage and wastewater is directly discharging into Thane Creek through open drains and nallahs[16]. Based on the current practices and previous research studies, the objective of this research study was to assess the seasonal and tidal water quality of the entire creek

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based on receiving waterbody standards SW-II (CPCB, 1993)[7] and nutrient parameters. Due to generation of large data set and variation in seasonal and tidal water quality, statistical analysis was carried out to summarize the data set quantitatively and to establish a relationship between water quality parameters for the comparison of water quality. The study will help in formulating management options for the improvement in water quality of the creek.

Materials and Methods

Study area includes entire Thane Creek (latitude 18°53′26″ to 19°12′0″N and longitude 72°48′31″ to 73°2′08″E) in east side of Mumbai, sampling locations (TCW, TCC, TCE), major drains (DT1-19), locations of WWTF and sewage outfall (**Figure 1**). The creek is divided into three stretches as upper (Sections TC1 to TC4), middle (Sections TC5 to TC8) and lower (Sections TC9 to TC12) stretches. Thane Creek is receiving treated effluent from Colaba outfall (preliminary), and Bhandup and Ghatkopar (secondary) wastewater treatment facilities (WWTFs)[17]. The quantity and quality of effluent discharges through Bhandup WWTF, Ghatkopar WWTF and Colaba outfall and sewage discharges from various drains/nallahs are given in **Table 1**. Bathymetry details of Thane Creek are presented in **Figure 2**. Bathymetry indicates variation in the depth with respect to chart datum. Creek is deeper in the center portion and reduces along the adjacent areas of tidal influence[17]. Maximum depth in the creek (more than 10m) is observed in center portion of lower stretch and further reduced (8 to 10, 6 to 8, 4 to 6, 2 to 4 and up to 2 m) in the adjacent sides of the center portion[18]. Similarly, center portion of creek in the middle and upper stretches are 4 to 6 m deep and 2 to 4m deep respectively and further reduced up to 2m adjacent to either sides.

Climatic condition of the study area is hot and humid with annual average rainfall 2500mm. Maximum and minimum temperature varies from 35°C to 40°C and 25°C to 35°C, respectively[11].

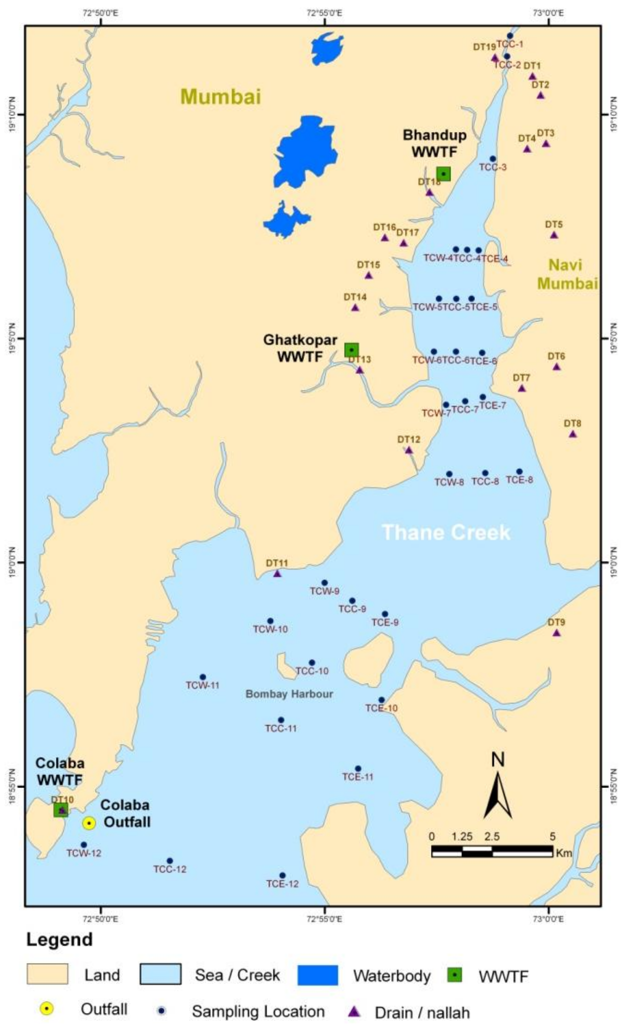

Fig. 1 - Details of study area and sampling locations in Thane creek

Table 1 Details of effluent and sewage discharges in Thane creek[17]

Sr. No.	Discharge Locations	Flow MLD	Characteristics of Effluent/sewage					
			Turbidity NTU	DO mg/L	BOD mg/L	FC CFU/100ml	NH3-N mg/L	PO_4 mg/L
1	Bhandup WWTF	75-80	20 - 40	1-2	26-47	1.3-1.6E+06	11 - 15	0.2 – 1.7
2	Ghatkopar WWTF	85-95	60 - 90	0	37-64	2-2.8E+07	11 - 15	0.4 – 0.6
3	Colaba outfall	15-20	90 - 130	0	142 -192	0.1-8.8E+06	16 - 18	0.3 – 3.5
4	Drains from East and West side of creek	350-375	30 - 120	0-1	30-300	1.2 - 3.4E+07	6 - 30	0.2 - 4

Data collected during 2006 to 2007(pH varies 6.8 – 8 and temperature varies 27 – 28.5 °C)

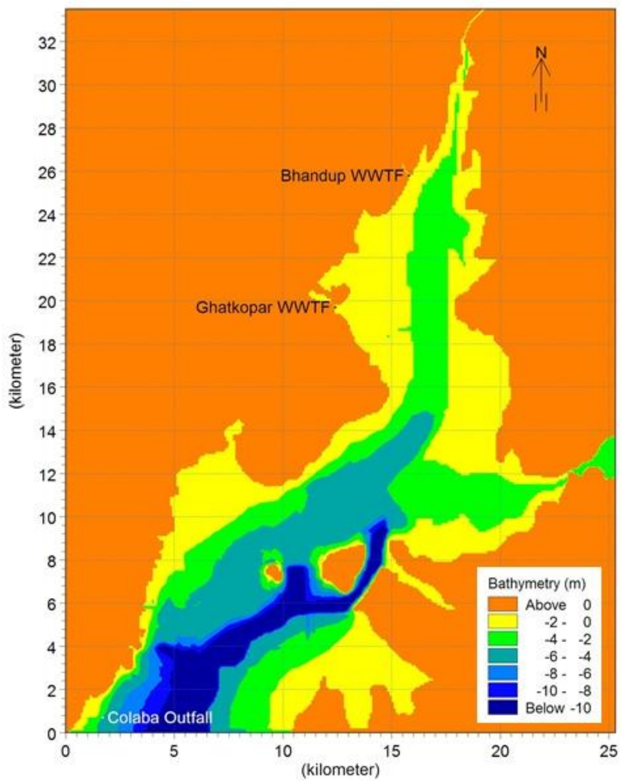

Fig. 2 - Bathymetry of the Thane creek

Water samples were collected, preserved and analysed as per standard methods for the examination of water and wastewater[19]. Total 30 samples were collected from the west, center and east sides of the creek except at the top three locations i.e. TCC 1, TCC 2 and TCC 3, for which samples were collected only at center due to narrow width of the creek (**Figure 1**). Global Positioning System (GPS) was used to trace the sampling locations in water environment. Samples were collected in post-monsoon, winter and pre-monsoon season during low and high tides. Water quality parameters were selected considering SW-II receiving water standards for bathing, contact water sports and commercial fishing designated by Central Pollution Control Board, India (CPCB, 1993). The limits for pH, dissolved oxygen (DO), bio-chemical oxygen demand (BOD), turbidity and fecal coliform (FC) are 6.5-8.5, 4.0 mg/L, 3.0 mg/L, 30 NTU and 100/100ml (MPN), respectively. Other parameters, namely phosphate (PO_4), ammonical nitrogen (NH_3-N) and temperature were also considered as these are essential nutrients and can result into eutrophication of water body and oxygen saturation concentration.

Samples were analysed on site for pH and temperature, whereas, other parameters were preserved and analysed in the laboratory as per analytical methods. The analytical method for each parameter is described in **Table 2**.

Table 2.Analytical method for analysis of water and wastewater[19]

Parameters	Units	Methodology
Physico-chemical		
Temperature	°C	In-situ measurement with mercury filled Celsius thermometer
pH	-	Instrumental – pH meter (Orion 410A)
Turbidity	NTU	Nephelometric (Model-Hack)
Ammonia Nitrogen	mg/L	Distillation as clean up procedure for removal of TDS followed by colorimetric method by Nesslerisation
Phosphate	mg/L	Molybdate reactive orthophosphate with colorimetric Stannous Chloride estimation
DO	mg/L	Modified Winkler method (Iodometeric titration)
BOD	mg/L	3 day – 27°C
Bacteriological		
Fecal Coliform	CFU/ 100 ml	Membrane Filtration Technique

The water quality of the creek was assessed seasonally based on SW-II standards using statistical package MINITAB[20]. Box and Whisker plots were prepared for water quality parameters of post-monsoon, winter and pre-monsoon during low and high tides. This plot is one of the convenient ways for the presentation of numerical data, which gives graphical summary of the data distribution, displaying the median, interquartile range (75th - 25th percentile), skewness and extreme values[21]. Spearman's correlation matrices were also generated to find the association between two or more water quality parameters considering three seasons monitoring data. This provides a non-parametric measure of strength between two variables[22].

Results and Discussion

The water quality of Thane Creek in terms of physico-chemical and bacteriological parameters in post-monsoon, winter and pre-monsoon during low and high tides is presented in **Table 3**. pH of the creek waters was well within SW-II standards (6.5-8.5). Turbidity varied in post-monsoon, winter and pre-monsoon seasons as well as during low and high tides. The turbidity was found above the SW-II standards i.e. 30NTU during low tide in most of the samples. This may be attributed to the resuspension of the sediment during low tide when water depths were less as compared to high tides[23]. During high tide, most of the samples were found within the limit. This was due to the availability of tidal water for dispersion and dilution of suspended matter[24].

Table 3.Observed water quality data (range) in post-monsoon, winter and pre-monsoon during low and high tides

Sr.	Sampling	pH		Temperature ºC		DO (mg/L)		BOD (mg/L)	
No.	Location	LT	HT	LT	HT	LT	HT	LT	HT
1	TC1	7.5-7.6	7.0-7.5	28-29	28	1.1-2.1	0.9-4.3	8-18.8	3.6-8.4
2	TC2	7.6-7.7	7.3-7.7	28-29	28-28.5	0.7-2.9	0.5-4.3	5.6-8	2.4-14.4
3	TC3	7.5	7.0-7.6	28-30	28-28.5	1.6-4.8	1-6.6	5.6-6.5	3.2-10.8
4	TC4C	7.4-7.7	7.6	28-29.5	28-28.5	0.5-3.2	0.8-3	6.4-9.2	1.6-5.2
5	TC4E	7.6-7.7	7.6-7.7	28-29.5	28	0.9-5.4	1-4.2	4.4-7.2	1-3.6
6	TC4W	7.5-7.7	7.6	28.5-29.5	28.5	0-3.1	1-2.9	2.4-11.2	1.5-4.4
7	TC5C	7.6-8.2	7.7-8.1	28.5-29	28.5	0.5-3.2	0.7-3.7	5.2-7.6	1.4-4
8	TC5E	7.6-8.1	7.5-8.1	28.5-29	28.5	1-3.6	01-Apr	4.8-6.6	1-2.4
9	TC5W	7.5-8.1	7.6-8.2	28-29	28-28.5	0.5-3.3	1.4-3.8	4-8.4	1-2.8
10	TC6C	7.6-8.0	7.6-8.0	28-29.5	28-28.5	1-2.8	1.8-3.9	5.6-7.2	1.2-2.14
11	TC6E	7.5-8.1	7.6-8.0	28-29.5	28	1.2-2.3	2-3.8	3.6-6.8	1-3.2
12	TC6W	7.3-8.2	7.6-8.1	28.5-29.5	28.5	1.7-3.8	1.7-3.1	5.6-8.4	1.2-2.8
13	TC7C	7.0-7.6	7.0-7.5	28.5-29	28-28.5	1.1-3.8	2.4-4.2	4-18.4	1.4-2.8
14	TC7E	7.4-7.6	7.4-7.6	28-29	28-29	1.3-3.3	0.5-4	5-18.6	2.4-15.2
15	TC7W	7.0-7.7	7.0-7.6	28-29.5	28-29	1.3-3.5	0-3.9	4-18.4	2.2-15.6
16	TC8C	7.6-7.9	7.6-8.1	29-30	29	1.5-2.6	3.7-5.4	2.9-7.6	1.2-4
17	TC8E	7.6-8.2	7.7-8.1	29-30	29-29.5	2-3.3	4.1-5.3	1-6.4	1.6-5.2
18	TC8W	7.6-7.9	7.7-8.0	29-30	29-30.5	1.7-4.5	4-5.4	1-7.2	1.2-6
19	TC9C	7.5-7.7	7.5-8.1	28-30	28-30.5	2.8-4.8	4.8-5.9	2-3.6	1.1-2.2
20	TC9E	7.6-8.0	7.6-8.0	28-30	28-30.5	3.3-5.6	5.1-5.8	1.2-2.6	1-3.2
21	TC9W	7.6-8.0	7.6-8.0	28-30	28-29.5	2.6-4.9	5.1-5.6	1.6-4.1	1-3.4
22	TC10C	7.5-8.0	7.6-7.9	28-29.5	28-30.5	5-5.7	5.5-6	2.8-4.6	1-3.6
23	TC10E	7.6-8.1	7.7-8.0	28.5-29	28-30.5	5.2-5.4	5.2-5.8	1.2-4.2	1-2.4
24	TC10W	7.7-8.0	7.7-8.0	28-30.5	28.5-29.5	3.5-5	4-5.6	1.2-2.8	1-2.8
25	TC11C	7.7-8.0	7.5-8.1	28-30.5	28.5-29	4.2-5.6	5-5.7	1-3.6	1-4.4
26	TC11E	7.5-8.2	7.5-8.0	28-29..5	28-29.5	4.1-5.3	4.9-5.4	1.6-3	2.6-2.8
27	TC11W	7.5-8.1	7.6-8.1	28-29	27-28	4.3-5.4	5.8-5.9	1-5.4	1.1-3
28	TC12C	7.6-8.0	7.5-8.1	28-29.5	27.5-29	5.2-6.8	5.2-6.7	1.4-4.4	1-2.8
29	TC12E	7.7-7.8	7.6-8.0	29-30.5	27-28	4.9-6.2	5.1-6.5	1.3-4.8	1.4-3.6
30	TC12W	7.6-8.1	7.6-8.1	29-30.5	28-28.5	5.1-5.6	05-Jun	1.6-3.6	1.4-4.8

DO- dissolved oxygen, *BOD*- biochemical oxygen demand, *LT* - low tide, *HT* - high tide

Table 3.contd…….

Sr.	Sampling	Turbidity (NTU)		FC (CFU/100ml)		NH3-N (mg/L)		PO_4(mg/L)	
No.	Location	LT	HT	LT	HT	LT	HT	LT	HT
1	TC1	12- 47	9.1-41	1.1-6.4E+5	0.1-3.3E+5	1.15-7.5	0.65-5.2	0.26-1.04	0.09-1
2	TC2	12-37	15.5-29	0.6-5.4E+5	1.0-5.9E+5	0.6-7.6	0.55-6.9	0.3-1.03	0.07-1.05
3	TC3	12- 37	18.7-34	2.2-3.1E+5	0.8-2.6E+5	2.1-4.9	0.55-5.8	0.04-0.33	0.08-0.89
4	TC4C	26-71	38-150	2.6-5.1E+4	1.9-4.0E+4	0.44-4.6	0.71-3.4	0.06-0.69	0.26-0.31
5	TC4E	17-84	14.1-55	0.2-6.4E+5	2.9-5.1E+4	0.74-4.9	0.41-3.6	0.07-0.52	0.32-0.32
6	TC4W	41-50	42-75	2.3-9.1E+4	3.7-8.0E+4	0.56-5.5	0.36-2.6	0.06-0.68	0.2-0.32
7	TC5C	30-68	32-47	2.4-3.3E+4	1.9-2.8E+4	0.5-3.1	0.56-0.9	0.08-0.54	0.17-0.18
8	TC5E	16-110	30-50	2.8-4.8E+4	1.2-4.2E+4	1.55-2.5	0.49-1.5	0.09-0.53	0.04-0.21
9	TC5W	21-100	14-59	2.6-6.3E+4	1.1-4.2E+4	0.4-3.9	0.43-1.5	0.07-0.56	0.04-0.23
10	TC6C	23-100	16-47	1.7-2.3E+4	1.2-1.9E+4	0.4-2.3	0.4-0.9	0.08-0.42	0.11-0.16
11	TC6E	34-74	26-32	1.3-3.3E+4	1.4-3.2E+4	0.3-1.9	0.3-0.6	0.09-0.41	0.16-0.27
12	TC6W	16-62	31-35	1.3-3.9E+4	2.2-3.7E+4	2.2-3.5	0.46-0.9	0.09-0.5	0.13-0.18
13	TC7C	23-47	26-54	0.7-2.3E+4	0.6-1.4E+4	2.5-8.2	0.45-1.6	0.7-1.49	0.12-1.57
14	TC7E	33-69	11.8-42	0.9-3.7E+4	0.9-2.0E+4	2.6-11.08	0.61-3.37	0.04-0.32	0.09-0.94
15	TC7W	28-48	14.6-44	2.3-3.6E+4	1.1-2.2E+4	1.45-6.5	0.51-1.07	0.32-0.61	0.13-6.1
16	TC8C	37-62	16.8-32	0.2-1.9E+4	0.1-1.8E+4	0.28-0.5	0.12-0.32	0.04-0.6	0.05-0.2
17	TC8E	22-54	32-43	0.4-2.2E+4	0.2-1.9E+4	0.32-2.75	0.09-0.35	0.05-1.1	0.1-0.41
18	TC8W	29-51	28-44	0.6-2.4E+4	0.5-2.1E+4	0.39-0.9	0.12-0.25	0.04-0.8	0.12-0.4
19	TC9C	19-50	13-46	0.2-1.9E+4	0.1-1.3E+4	0.24-1.5	0.08-0.32	0.34-1.8	0.1-0.12
20	TC9E	15-42	28-55	0.4-1.9E+4	0.4-1.4E+4	0.29-0.9	0.04-0.43	0.24-0.5	0.2-0.2
21	TC9W	54-77	37-73	0.7-2.4E+4	0.6-2.3E+4	0.16-0.64	0.11-0.34	0.12-0.4	0.3-0.3
22	TC10C	27-112	8.9-45	3.5-3.9E+3	2.1-3.2E+3	0.16-0.2	0.06-0.24	0.09-0.09	0-0
23	TC10E	17-134	16.4-46	3.5-4.1E+3	1.2-3.8E+3	0.2-0.24	0.03-0.03	0.2-0.2	0.1-0.1
24	TC10W	66-73	77-80	3.4-4.2E+3	2.2-4.2E+3	0.21-0.21	0.08-0.08	BDL	0.1-0.1
25	TC11C	35-54	36-57	1.4-2.4E+3	1.1-1.4E+3	0.21-0.24	0.05-0.32	0.08-0.08	0.1-0.2
26	TC11E	40-62	24-48	0.3-2.9E+3	1.5-2.6E+3	0.1-0.12	0.03-0.3	0.1-0.1	0.07-0.07
27	TC11W	40-64	18-42	2.9-3.7E+3	2.3-2.8E+3	0.21-0.21	BDL	BDL	BDL
28	TC12C	34-130	10.6-30	6.2-7.5E+2	4.0-6.4E+2	0.1-0.25	0.01-0.27	0.09-0.14	0.04-0.04
29	TC12E	46-57	15-37	7.2-8.8E+2	5.1-5.9E+2	0.14-0.27	0.08-0.25	0.07-0.07	BDL
30	TC12W	15-36	12.3-46	0.9-3.9E+3	0.6-3.7E+3	0.12-0.21	0.04-0.28	0.06-0.3	BDL

FC- fecal coliform, *NH3-N*ammonical nitrogen, *PO4* - phophate, *LT* - low tide, *HT* - high tide, BDL- below detection limit

Observed water quality for DO shows non-compliance of standard (4.0 mg/L) in upper and middle stretches during low and high tides due to discharges of sewage and wastewater through drains and WWTFs. Even narrow width of the creek in upper stretch does not receive enough tidal water for dilution. At the lower stretch, the DO was found within the SW-II standards due to availability of tidal water and more depth of the creek helps in dilution of pollutant. BOD was found in the range of 1 to 18.6 mg/L in all the three seasons during low and high tides. The concentration of BOD was more at upper and middle stretches during low tide, while it improved due to availability of tidal water for dilution during high tide. East side of the creek was comparably less polluted than west side in the middle stretch, this may be attributed to more number of discharges of sewage and effluent from drains and

WWTFs. FC was observed in the range of 4.0×10^2 to 5.9×10^5CFU/100ml and not complying the SW-II standards (100/100ml MPN) in the entire creek, which indicates bacterial pollution from sewage discharges. The range of NH_3-N and PO_4 in creek waters was 0-11.08 mg/L and 0-2.6 mg/L respectively, in post-monsoon, winter and pre-monsoon samplings during low and high tides. Like all other parameters, concentration of NH_3-N and PO_4 also gets diluted during high tide. Temperature was recorded in the range of 27-30.5 ^{o}C in post-monsoon, winter and pre-monsoon during low and high tides. Range of temperature indicates that there is not much variation in temperature of creek waters.

For statistical assessment of water quality in Thane Creek, Box and Whiskers plots were generated to represent water quality against SW-II standards. Box and whiskers plots for pH, temperature, DO, BOD, turbidity, FC, NH_3-N and PO_4 are presented through **Figure 2a** to **Figure 2h** respectively. pH was found within SW-II standard during low and high tides (**Figure 2a**). There was variation in pH during winter and it was negatively skewed in all the seasons including low and high tides except in post-monsoon during low tide. Temperature did not show much variation in the readings of post-monsoon (28.9±0.8^{o}C), winter (28.8±0.8^{o}C), and pre-monsoon (28.7±0.7^{o}C) (**Table 2** and **Figure 2b**). Although, the temperature during low tide (29±0.7^{o}C) was observed slightly higher as compared to high tide (28.5±0.7^{o}C). This may be due to the inflow of heated water from shallow creek zone and also heat exchange with the atmosphere[25]. Distribution of DO shows variation in post-monsoon, winter and pre-monsoon data and also during low and high tides (**Figure 2c**). DO was positively skewed during low tide in all seasons data and at high tide during winter, whereas negatively skewed during high tide in post-monsoon and pre-monsoon. More than 50% of the data was found below standards during low tides in all the seasons monitoring. BOD was positively skewed in post-monsoon, winter and pre-monsoon, even during low and high tides (**Figure 2d**). Concentration of BOD was more during low tide, whereas more than 50% of the data was found within SW-II standards during high tide due to dilution effect of tidal water. Outliers were also observed during post-monsoon and winter during low and high tides and extreme outliers in winter and pre-monsoon during low tide.

Turbidity was positively skewed in all the seasons during low and high tides; it also showed outliers and extreme outliers (**Figure 2e**). Turbidity was found within SW-II standards in more than 50% of the winter data during low and high tides, whereas near about 75% of the data was found above the SW-II limits in post-monsoon and pre-monsoon. This may be due to the post effect of monsoon considering resuspension of the suspended matter coming from surface runoff during monsoon and post-monsoon. During pre-monsoon, the wind-driven turbulent mixing is considerably strong in the Arabian Sea which contributes the high level of turbidity[26]. FC was positively skewed in all the seasons during low and high tides (**Figure 2f**). It was found to be above SW-II standards due to high concentration of FC already present in the background environment and no treatment available for FC removal in WWTFs. NH_3-N and PO_4 were positively skewed in all seasons during low and high tides (**Figures 2g** and **2h**). The concentrations of NH_3-N and PO_4 were more in low tide as compared to high tide. This may be due to the discharge of sewage and wastewater from the drains and treatment facilities as well as less depth of water available for dilution during low tide while concentrations were lowered during high tide due to mixing of tidal water[27]. Variation in concentration of NH_3-N and PO_4 was more in winter and also showed outlier and extreme outliers.

The water quality parameters are dependent on each other, therefore Spearman's correlation coefficient matrices (confidence interval – 95%) were formulated for post-monsoon, winter and pre-monsoon data collected during low and high tides to establish a relation amongst them (**Table 3a** to **3c**). Correlation coefficient describes the dependency between the water quality parameters, whether the relation is positive or negative. From the correlation matrix it was observed that, pH did not show any strong relationship with other parameters as there was not much variation in pH range. Turbidity was correlated with FC and nutrient parameters but not up to significant level in post-monsoon, winter and pre-monsoon. DO showed inverse and strong correlation with BOD, FC, NH_3-N and PO_4; indicating oxygen consumption by microorganisms from sewage discharges[24].

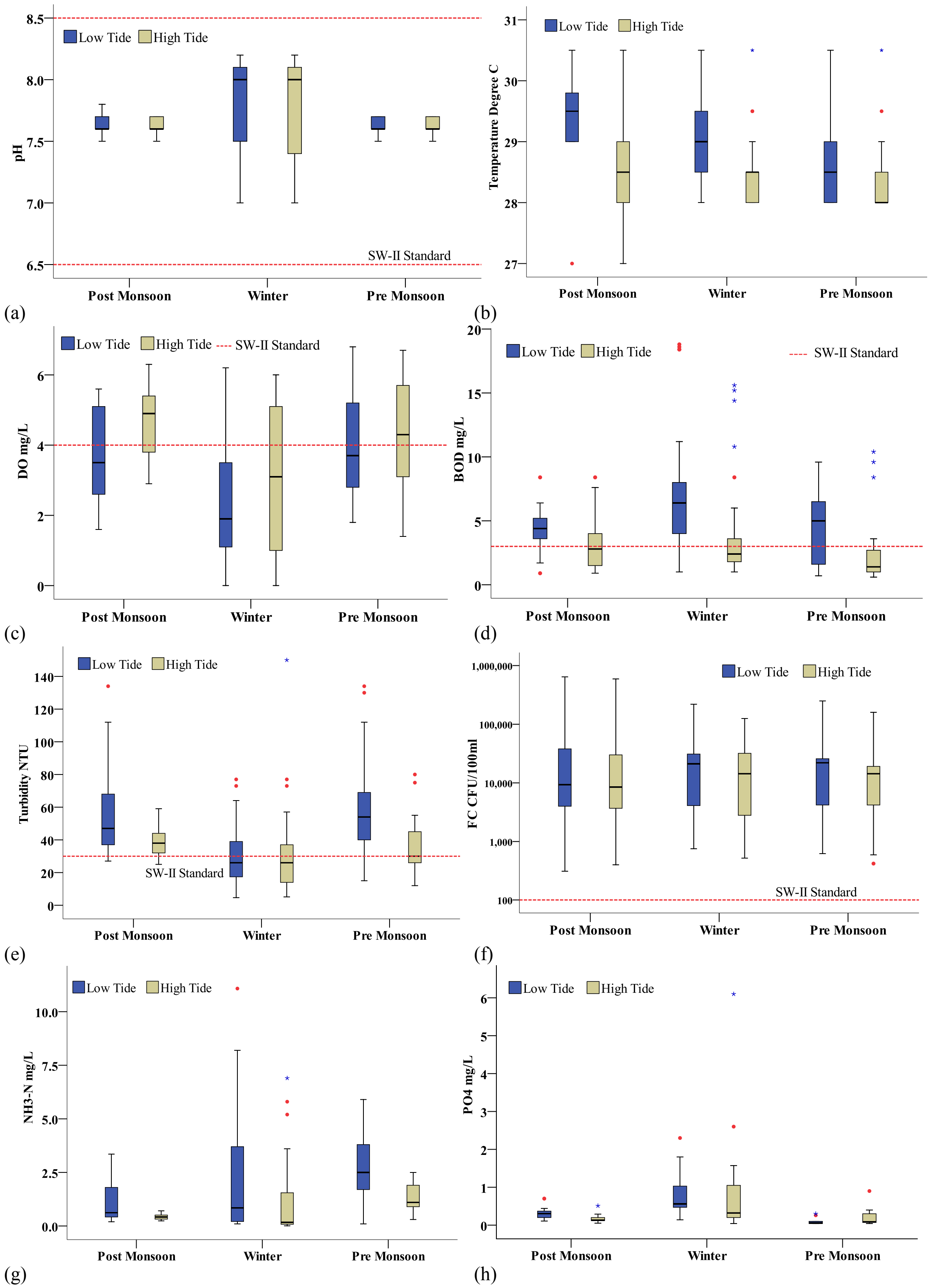

Fig. 3 - Box and Whiskers plots for a) pH, b) Temperature, c) DO, d) BOD, e) Turbidity, f) FC, g) NH_3-N, and h) PO_4

BOD was positively correlated with FC, NH_3-N and PO_4. Presence of BOD, FC and nutrients in coastal water reveals that sewage discharges contain organic waste, fecal matter and nutrients. FC was positively correlated with nutrient parameters i.e. NH_3-N and PO_4. This may be associated with multiplication of coliform bacteria reflecting the undesirable problems associated with excess nutrient addition to the water environment[28]. NH_3-N and PO_4 were positively correlated indicating contribution of nutrient in the coastal water through sewage discharges containing organic matter and inorganic nutrients[29]. Temperature did not show any significant correlation with other parameters as there was not much variation in temperature. Therefore, it was not included in the correlation matrix.

Table 3a.Spearman's correlation matrix of water quality data in post-monsoon

Parameter	Low Tide							High Tide						
	pH	Turb	DO	BOD	FC	NH_3-N	PO_4	pH	Turb	DO	BOD	FC	NH_3-N	PO_4
pH	1							1	-0.022	0.215	-0.218	-0.130	-0.215	-0.229
Turb	-0.017	1							1	-0.216	0.048	0.121	0.372	-0.047
DO	0.145	-0.006	1							1	-0.678	-0.727	-0.687	-0.759
BOD	-0.561	-0.019	-0.562	1							1	0.602	0.296	0.760
FC	-0.276	0.334	-0.333	0.401	1							1	0.695	0.749
NH_3-N	-0.344	0.224	-0.285	0.280	0.402	1							1	0.361
PO_4	-0.025	0.427	-0.336	0.165	0.565	0.623	1							1

(Significance level – 95%)

Table 3b.Spearman's correlation matrix of water quality data in winter

Parameter	Low Tide							High Tide						
	pH	Turb	DO	BOD	FC	NH_3-N	PO_4	pH	Turb	DO	BOD	FC	NH_3-N	PO_4
pH	1							1	0.368	0.446	-0.343	-0.359	-0.501	-0.797
Turb	0.344	1							1	0.112	-0.086	-0.038	-0.097	-0.492
DO	0.210	0.290	1							1	-0.108	-0.886	-0.907	-0.239
BOD	-0.342	-0.259	-0.800	1							1	0.038	0.036	0.522
FC	-0.283	-0.485	-0.849	0.795	1							1	0.912	0.041
NH_3-N	-0.294	-0.410	-0.839	0.866	0.872	1							1	0.301
PO_4	-0.409	-0.278	-0.264	0.297	0.151	0.126	1							1

(Significance level – 95%)

Table 3c.Spearman's correlation matrix of water quality data in pre-monsoon

Parameter	Low Tide							High Tide						
	pH	Turb	DO	BOD	FC	NH_3-N	PO_4	pH	Turb	DO	BOD	FC	NH_3-N	PO_4
pH	1							1	0.319	-0.156	0.105	0.353	0.003	0.025
Turb	-0.025	1							1	-0.253	0.119	0.237	0.211	-0.034
DO	0.114	0.250	1							1	-0.257	-0.489	-0.566	0.053
BOD	0.004	-0.050	-0.566	1							1	0.477	0.198	0.322
FC	-0.018	-0.166	-0.671	0.590	1							1	0.571	0.098
NH_3-N	0.062	-0.182	-0.653	0.727	0.765	1							1	-0.512
PO_4	0.036	0.049	-0.529	0.439	0.468	0.420	1							1

(Significance level – 95%)

Conclusion

The water quality analysis of the Thane Creek indicates that the creek water is polluted based on SW-II standards in all the seasons. Water is more polluted in the upper stretch of the creek due to narrow width and less availability of tidal water for dilution, whereas comparably good in middle and lower stretches due to availability of tidal water.

Water quality was found to be worse in pre-monsoon as compared to post-monsoon and winter. Water quality also shows high concentration of pollutants during low tide, which gets diluted during high tide due to tidal influence. The water quality in terms of FC is not complying standards in any seasons in the entire creek. The presence of BOD, FC, NH_3-N, PO_4 and less availability of DO in creek water indicates discharge of sewage and wastewater into creek waters. As per statistical analysis using Box and Whiskers plots, it is observed that pollutant parameters are varying in the entire Thane Creek during low and high tides of all the seasons. These plots help in assessing the seasonal and tidal distribution of water quality, data symmetry, skewness as well as outliers. Significant relationships amongst water quality parameters were observed indicating dependency on each other. The study reveals that immediate attention is required for improvement in water quality of the creek by enhancement in existing wastewater collection system, appropriate level of treatment, proper disposal and recycle/reuse of treated effluent rather than discharging into the creek.

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