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Water Quality Assessment of Panvel Creek (Navi Mumbai) by using the Geographical Information System

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ABSTRACT

Anthropogenic activities like the release of domestic and industrial effluent, deforestation of mangroves, and reclamation of land have severely damaged coastal ecosystems, leading to ecological degradation. Panvel Creek in the Navi Mumbai region of Maharashtra is affected by residential, commercial, and industrial expansion. The Taloja MIDC zone and nearby sewage treatment plants contribute to the deterioration of water quality. The present study aims to study the pollution status of Panvel Creek. Water samples were analysed for physical and chemical properties, and changes in water quality were mapped using GIS software. During the present study, the average temperature was observed to range between 30 °C and 36 °C. Water samples had pH values ranging from 6.33 to 8.06, dissolved oxygen levels ranging from 2 mg/l –6 mg/l, and nitrate concentrations ranging from 1.47 mg/l - 20.30 mg/l. Phosphate levels were high in all locations except near the mouth of Panvel Creek, with the lowest value being 11.93 mg/l. Over the years, various developmental activities within the Navi Mumbai region have exerted anthropogenic pressure on the ecology of the creek.

Key words: *GIS, Panvel Creek, Water pollution*

Introduction

Navi Mumbai has gained recognition as a meticulously planned city and has recently been incorporated into the Smart City Project. Over the past two decades, there has been a significant surge in the demand for information and telecommunications technology. Consequently, Navi Mumbai has emerged as a prominent center for information technology parks and a big communication network in the surrounding areas. Along with the development, many industrial zones, and residential complexes in and around the Navi Mumbai region contributed to the expansion of the secondary sector in this region. However, the city's development has brought about significant alterations to the original land use and coverage, pollution status, and overall environmental conditions of this region.

Panvel Creek has been playing an important role in providing varied ecological services. The area is occupied by swampy wetlands and mangroves which now have been transformed through land

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reclamation into commercial settlements. Deforestation, domestic and industrial effluent discharge, and sand dredging have severely reduced the water quality of the creek. Over a period, the reduction in the quality of water and the increase in the status of pollution have led to a decline in the ecological functioning of Panvel Creek, thereby resulting in low productivity (Pawar, 2007). To prevent further deterioration of the water quality, proper monitoring and assessment of pollution status should be carried out at regular intervals. Further integrated management of creeks, mangroves, and wetlands should be implemented in the developmental plans to protect and conserve the coastal ecosystem.

Remote sensing and geographic information systems have added a new dimension to the field of environmental monitoring and pollution assessment. GIS helps to store and manage spatial data, enabling efficient manipulation, retrieval, interpretation, and presentation. It is a powerful tool for analysis, such as spatial queries that enable users to identify patterns and trends in the environment. GIS software also allows visualizations like maps and charts and presents complex spatial information (Senthil *et al*., 2013). Water quality assessment requires well-organized data collection and statistical analysis. However, collecting data for all desired locations can be impractical, leading to irregular intervals. GIS can help in estimating values for unsampled locations based on available data and spatial variation. GIS software offers varied tools, enabling researchers to study the spatial distribution of pollutants and evaluate the baseline conditions for a large area with multiple sets of discrete data (Jha *et al.,* 2010).

The study aims to gather data on the pollution levels in Panvel Creek and explore the interrelationships between the creek and its surrounding ecosystems. Water samples were collected and analysed for their physico-chemical properties using standard operating procedures to achieve this. In addition, Geographical Information System (GIS) software was used to map the spatial and temporal changes in the water quality. The Kriging feature of Arc GIS was used for the interpolation of data to provide the spatial distribution of water parameters. The impact of developmental activities and the expansion of city limits were also evaluated using a GIS-generated image of the area surrounding Panvel Creek.

Study area - Panvel Creek

Panvel Creek, located at 18°5929.9 N and 73°00’51.0" E in the Raigad district of Maharashtra, lies between Panvel and Belapur cities in the Navi Mumbai region. Rivers like Gadhi, Kasardi, and Ulwe confluence with the creek, which further merges into the Arabian Sea at Belpaur. It has a length of around 12 km and a width of 500 meters at its mouth, gradually narrowing towards the riverine area (Figure 1). The area adjoining Panvel Creek shows the presence of Taloja MIDC, CETP, STP, and holding ponds. The industrial belt in Navi Mumbai is continuously growing and expanding, with the region currently consisting of 5375 industrial plots and a total of 3928 industries, according to the executive summary provided by CIDCO (https://cidco.maharashtra.gov.in). This industrial development also encompasses areas beyond Navi Mumbai, including the Trans Thane Creek (TTC), Taloja, Jawahar, Panvel, and Uran regions.

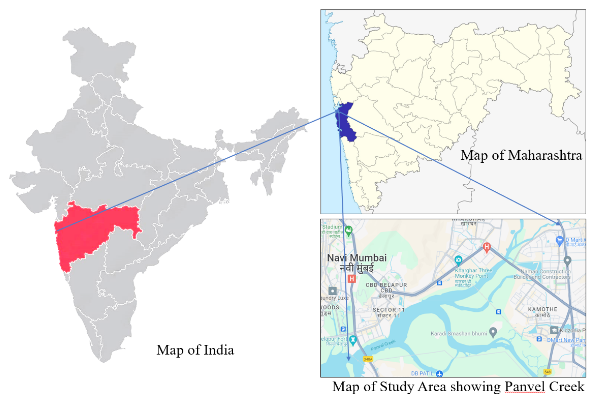

Fig. 1. Map of India, Maharashtra, and Navi Mumbai showing Panvel Creek

Materials and Methods

The present study was carried out in the year 2015, where the study period was divided into three distinct seasons, namely pre-monsoon, monsoon, and post-monsoon. Water samples were collected from 16 different locations using a random stratified sampling technique (Figure 2). On-site measurements of water temperature were carried out using a thermometer, and water samples for the estimation of dissolved oxygen were fixed onsite. The collected samples were brought to the laboratory, and parameters such as dissolved oxygen, pH, and conductivity were determined immediately. The remaining samples were preserved, and further analysis was carried out using standard procedures (Standard Methods for the Examination of Water and Wastewater, 23rd Edition, 2017). Spatial interpolation technique using ArcGIS software (version 10.4) was employed to estimate attribute values across the entire study area using results obtained from sampling locations. By utilizing the Kriging tool, attribute data were generated, allowing for the creation of predictive maps depicting various water parameters across the study area. The developmental projects in the Navi Mumbai region, including infrastructure and transportation initiatives, have significantly affected the ecology of Panvel Creek. Expanding industrial and residential areas necessitates numerous Sewage Treatment Plants (STPs) and Common Effluent Treatment Plants (CETPs) and they were mapped using ArcGIS software. This approach provides a comprehensive overview of the environmental impacts on Panvel Creek.

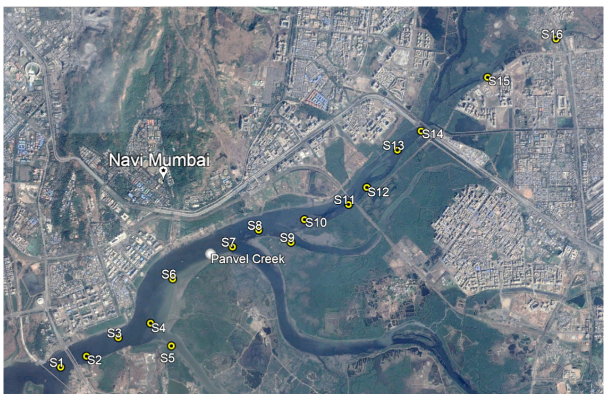

Fig. 2. Satellite image of Panvel Creek showing Sampling Locations – Google Earth

Statistical analysis plays a crucial role in comprehending the fluctuations of water quality metrics across seasons, periods, and spatial dimensions. Various factors influence the quality of surface water, and the application of statistical tools aids in gaining a deeper understanding of these influences and their variations over time and space. Correlation Analysis and Principal Component Analysis (PCA) serve as valuable tools for comprehending the interrelations among parameters within the creek. These statistical techniques aid in uncovering how different variables are associated with each other and in identifying the underlying patterns and structures within the dataset.

Physico-chemical analysis of water parameters

Physico-chemical analysis of water parameters (pH, conductivity, temperature, dissolved oxygen, total suspended solids, salinity, phosphate, and nitrate) was carried out for all 16 study locations within the Panvel Creek during the pre-monsoon, monsoon, and post-monsoon seasons (Table 1, 2 and 3). The results are interpreted with the help of maps generated following the interpolation technique using the Kriging tool in ArcGIS software.

Results and Discussion

Drastic changes in the pH value can cause stress on the physiological systems of organisms and damage

Table 1. Physio-chemical Analysis of water samples - Pre-Monsoon (PRM)

Sampling location	pH	Cond ds/m	Temp ° C	TSS mg/l	DO mg/lit	Salinity ‰	Nitrate mg/l	Phosphate mg/l
1	7.83	36.65	33	656	5.6	42.03	2.14	2.65
2	7.68	41.45	33.5	930	3.45	39.68	11.32	12.45
3	7.55	36.3	34	823	4.58	40.65	10.67	14.65
4	7.57	36.45	33.5	829	3.35	41.59	17.88	20.45
5	7.56	36.4	35	782	5.67	45.18	9.07	13
6	7.53	36.05	35	662	5.66	42.77	7.9	14.7
7	7.5	35.5	35.5	662	5.52	34.6	9.78	13.5
8	7.63	35.15	36	560	5.54	34.32	7.67	12.5
9	7.62	41.2	36.5	609	5.75	32.74	10.75	14.15
10	8.06	36.95	36	663	5.66	28.02	9.41	10.8
11	7.55	36.85	36.5	718	5.74	28.81	12.55	15.85
12	7.66	36.65	37	712	5.69	25.57	15.62	19.95
13	7.59	37.35	37.5	729	5.91	23.35	18.04	23.9
14	7.64	37.85	37.5	832	5.46	22.53	19	24.95
15	7.51	3.9	37.5	529	2.34	8.09	18.45	23.5
16	7.42	2.2	37.5	489	2.23	1.23	20.3	22.3

the reproduction process (Quadros *et al*, 2001). Alterations in the pH value of creek water can be fatal to aquatic life, with serious consequences including mollusk shell thinning, altered plankton community structure, and possibly even mass aquatic mortality (Roychowdhury *et. al*, 2019). The maximum pH value was reported at location 10, i.e., 8.06, in the pre-monsoon period (Table 1), whereas the lowest value was found at location 16, i.e., 6.33, in the post-monsoon period (Table 3). The pH values were found to be comparatively lower in the monsoon season due to dilution by rainwater (Table 2). pH values are within the permissible range as per the Water Quality Standards for coastal waters and marine outfalls for SW-I Waters (for salt pans, shell fishing, mariculture, and ecologically sensitive zones), i.e., 6.5 to 8.5, except for location 16. This indicates the pH value of the creek within the study is suitable for the growth of aquatic life (Velsamy *et al.*, 2013). The red colour in the interpolated map indicated a higher pH, (Figures 3, 4, and 5) which is observed in all seasons near estuarine areas with high tidal influence and less in river water, where maximum wastewater discharge is reported. The study

Table 2. Physio-chemical Analysis of water samples – Monsoon (MN)

Sampling location	pH	Cond ds/m	Temp ° C	TSS mg/l	DO mg/l	Salinity ‰	Nitrate mg/l	Phosphate mg/l
1	7.23	36.85	30.5	457	6.15	44.9	0.8	3.6
2	7.25	36.35	30	444	6.3	36.88	3.16	16
3	7.32	36.4	30	563	6.25	37.79	2.07	14.55
4	7.25	36	30.5	556	5.85	39.15	4.27	19.35
5	7.14	36.75	29.5	667	5.35	33.97	6.21	13.5
6	7.2	36.45	30.5	665	5.6	34.51	6.31	14.63
7	7.16	35.6	30	796	5.65	32.33	7.91	11.93
8	7.24	35.2	30	877	5.6	33.42	6.05	12.94
9	7.16	36.35	30.5	774	5.3	30.58	7.62	14.22
10	7.25	37.05	30.5	874	5.15	29.57	8.25	13.47
11	6.79	36.9	30.5	719	4.8	26.85	10.72	15.6
12	6.82	36.55	31	623	4.5	26.3	10.19	21.36
13	6.46	37.4	26.5	619	4.3	24.32	11.8	25.13
14	6.57	37.75	31.5	554	2.3	21.12	12.7	26.46
15	6.49	5.85	31.5	509	0.3	8.87	13.55	24.12
16	6.49	4.4	32	510	0.2	6.46	14.4	23.15

Table 3. Physio-chemical Analysis of water samples-Post Monsoon (PSM)

Sampling location	pH	Cond ds/m	Temp ºC	TSS mg/l	DO mg/l	Salinity ‰	Nitrate mg/l	Phosphate mg/l
1	7.53	43.3	32	573	5.63	36.14	1.47	3.66
2	7.26	41.4	32	599	5.29	34.62	8	17.75
3	7.54	39.75	32	775	5.6	32.92	9.11	20.7
4	7.75	37.05	32	666	4.74	34.71	15.25	23
5	7.43	37	32.5	513	4.45	37.89	8.96	16.2
6	7.51	36.5	32.5	598	4.72	39.69	6.97	14.15
7	7.89	35.5	33	555	4.72	34.52	8.48	13.85
8	7.58	35.95	33.5	676	5.07	32.81	6.29	13.85
9	7.35	35.05	33.5	545	5.02	28.76	11.06	25.25
10	7.97	36	33.5	557	4.58	28.57	9.88	19.75
11	7.8	35	33.5	626	4.61	25.46	11.61	22.05
12	7.64	32.6	33.5	478	4.31	23.62	13.8	23.7
13	7.24	32.6	33.5	434	3.32	23.49	16.15	25.4
14	7.51	23.65	34	374	3.35	19.51	13.89	30.4
15	7.62	15.35	34	446	0.9	2.34	15.38	29.7
16	6.33	11.5	34	467	0.6	1.86	13.33	26.16

on the water quality assessment of Vashi Creek using the Nemerow Pollution Index, revealed pH levels ranging from 7.1 to 8.1 at Airoli Bridge, and 7.2 to 8.1 at Vashi Bridge (Chordiya *et al.,* 2021).

The presence of chloride, phosphate, and nitrate in untreated sewage discharge can raise the conductivity levels in the water, exerting stress on aquatic life. Spatial variations were observed within the study area with decreasing conductivity from location1 to location 14. The conductivity values were found to be in the range of 2.2–43.3 ds/m throughout the study period (Tables 1, 2, and 3). Low conductivity levels were observed at locations 15 and 16, which are drastically affected by industrial wastewater discharge from the Taloja MIDC region. Industries can release various chemicals into water bodies through their effluent, which can potentially contribute to reduced conductivity in creek water. Acids, heavy metals, or organic solvents such as oil can tend to reduce the conductivity of water. According to the Surface Water Quality Standards (as

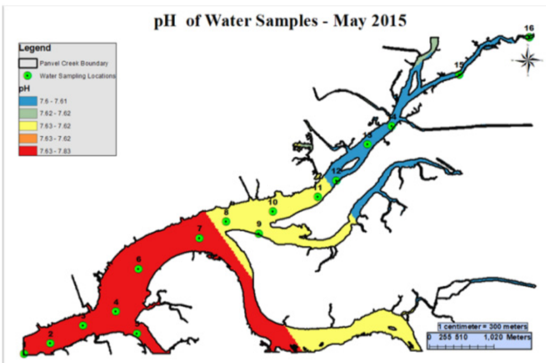

Fig. 3. pH of water samples (PRM)

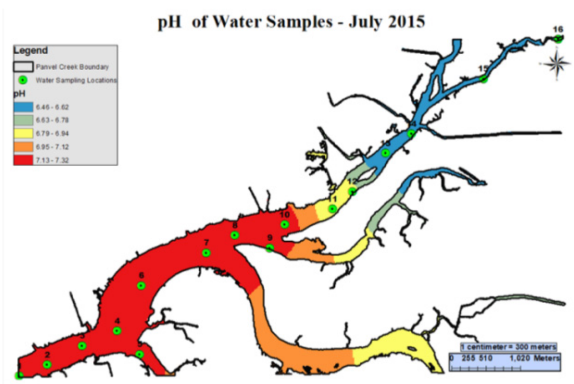

Fig. 4. pH of water samples (MN)

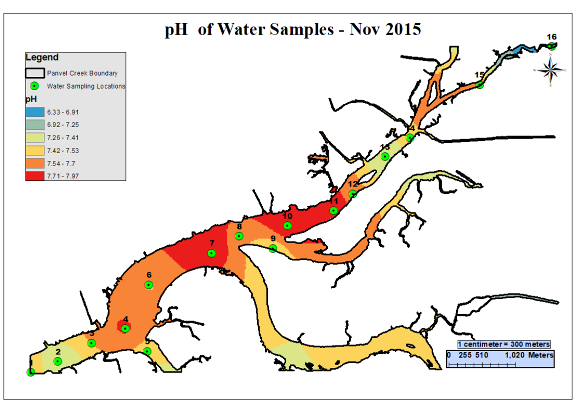

Fig. 5. pH of water samples (PSM)

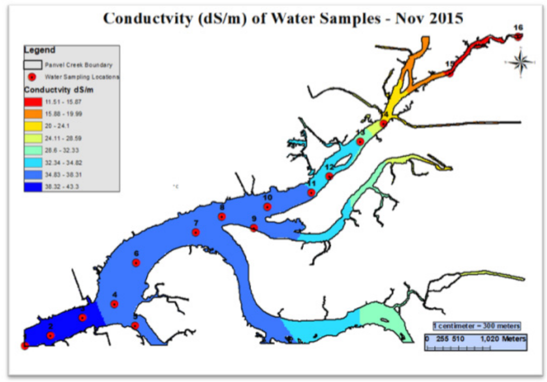

Fig. 6. Conductivity of water samples (PRM)

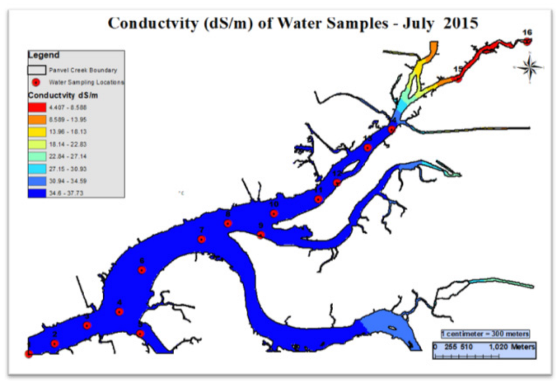

Fig. 8. Conductivity of water samples (PSM)

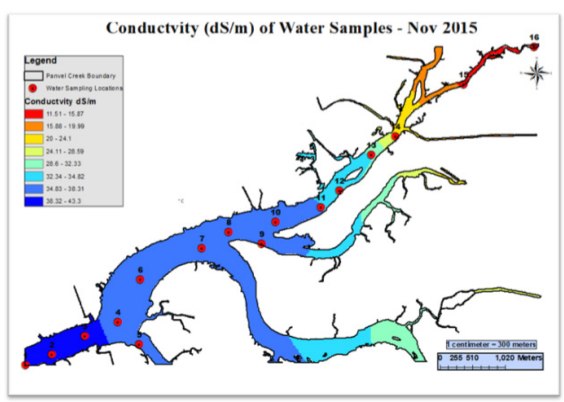

Fig. 7. Conductivity of water samples (MN)

per IS 2296), Class D: Water for Fish Culture and Wildlife Propagation, the conductivity of water should not exceed 1 ds/m. In comparison with the standard, the entire study area showed a higher value of conductivity. The blue colour in the map indicates higher conductivity in all seasons, whereas it was observed to be lower towards the study location near Gadhi, Ulwe, and Kasardi River (Figures 5, 6 and 7).

Water temperature has a significant impact on other water parameters like dissolved oxygen, phosphates, etc. Temperature levels showed minimal spatial variations, whereas prominent seasonal variations were observed during the present study. The average temperature levels were around 36 °C in the pre-monsoon (Table 1), 30 °C in the monsoon (Table 2), and 33 °C in the post-monsoon season (Table3). A higher water temperature was observed towards the riverine side of the creek. The spatial distribution of temperature values is also indicated on the map for three sampling seasons (Figure 9, 10, and 11).

Dissolved Oxygen (DO) values lower than 4 mg/l indicate hypoxic conditions, which is highly unfavorable for the sustenance of aquatic life. A considerable amount of variation was observed in the dissolved oxygen concentration spatially and seasonally during the present study. Dissolved oxygen concentrations varied from approximately 0.2 mg/l to 6.3 mg/l throughout the sampling periods. The DO value was observed to be higher at the mouth of the creek at location S2 (6.3 mg/l), where considerable wave action was observed. Lower DO values were observed upstream at locations 13, 14, 15, and 16 due to the influence of anthropogenic activities such as sewage and effluent discharge (Table 1, 2, and 3). Reduced DO levels during the post-monsoon (Table 3) period may be attributed to reduced oxygen solubility at elevated temperatures and increased microbial activity associated with the decomposition of organic matter. As per the water quality standard for marine water (class SW 1) by the MPCB (not less than 3.5 mg/l for aquatic life), the DO levels at locations 15 and 16 were below

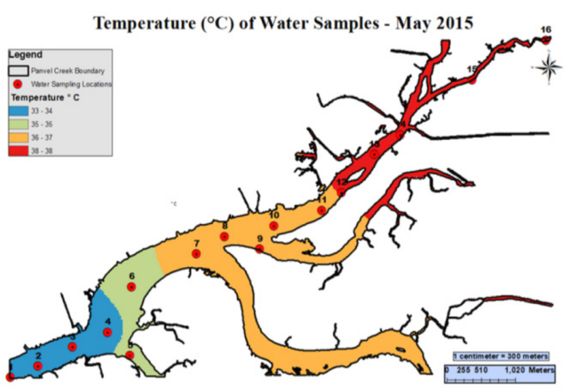

Fig. 9. Temperature of water sample (PRM)

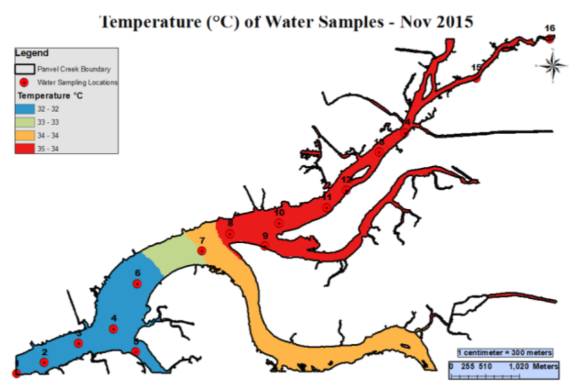

Fig. 11. Temperature of water samples (PSM)

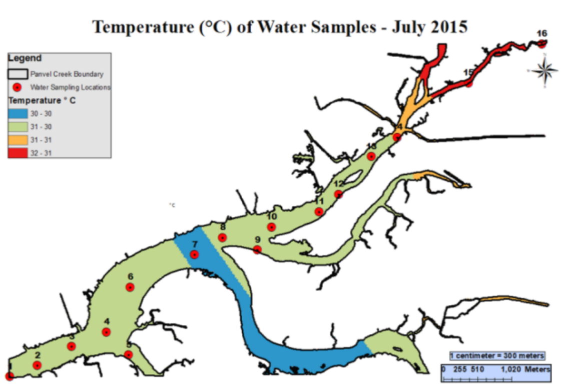

Fig. 10. Temperature of water samples (MN)

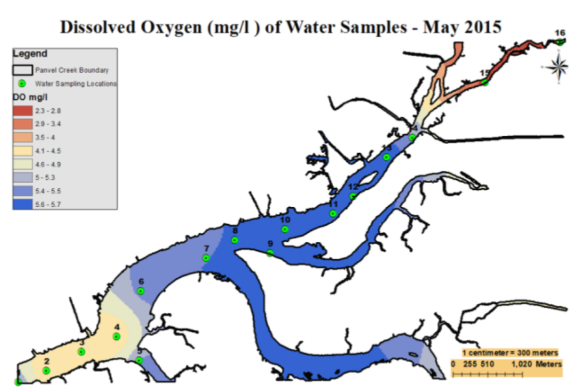

Fig. 12. D.O. of water samples(PRM)

standards throughout the study period. In Karanja Creek, the dissolved oxygen levels were recorded between 4.6 mg/l and 5.2 mg/l, while in Panvel Creek, they ranged from 4.6 mg/l to 5.6 mg/l (Pawar 2007). The values of dissolved oxygen are presented in blue indicating a high level of oxygen near the mouth of the creek in monsoon (Figure 13) and post-monsoon seasons (Figure 14).

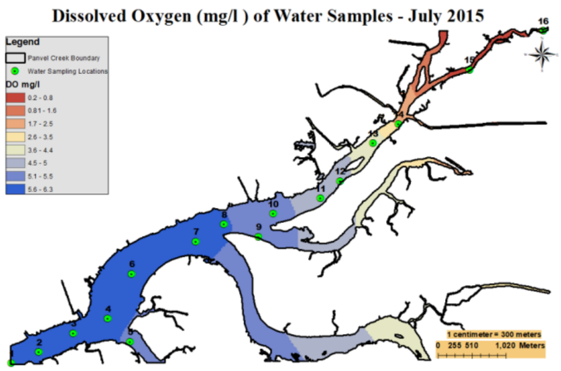

Fig. 13. D.O. of water samples(MN)

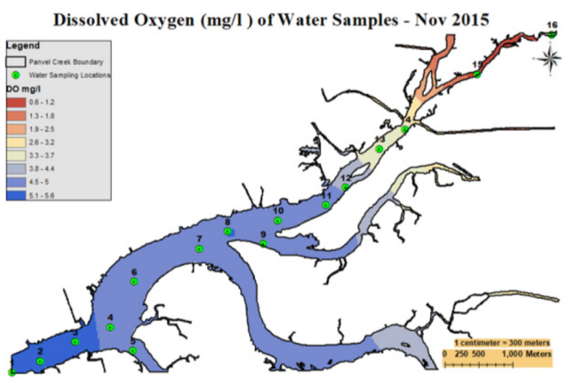

Fig. 14. D.O. of water samples (PSM)

The salinity levels in estuaries and creeks are observed to be on the higher side due to the inflow of saline water from the sea and oceans. Salinity ranged from 1.86‰ to 45.18‰ across sampling locations (Table 2, and 3). Salinity levels showed relatively low seasonal variation, whereas prominent spatial variation was observed during the present study. The higher salinity range denoted with a dark blue colour on the map was observed from locations 1 to 8 and a gradual decrease from locations 9 to 16 in the riverine (Figures 15, 16, and 17). The salinity was reported to be higher in the pre-monsoon (Table 1) due to a reduction in the flow of freshwater from the riverine end and evaporation induced by higher temperatures during the summer. Higher salinity in creeks and estuaries is reported in many coastal areas on the west coast of the country. Salinity variations were studied for Kasheli, Trombay, Vashi, Vasai, and Mumbra region indicating seasonal fluctuations driven by the region's heavy monsoon rainfall and the resulting freshwater runoff from upstream sources (Thomas *et al.*, 2022). The salinity of Thane Creek was also found to be around 32‰.in a study carried out in 2004 (Quadros *et al.*, 2004).

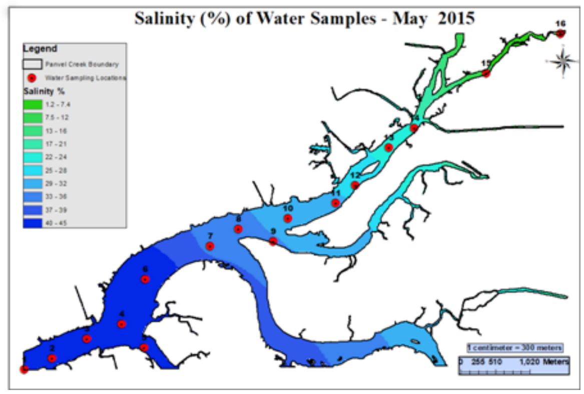

Fig. 15. Salinity of water samples (PSM)

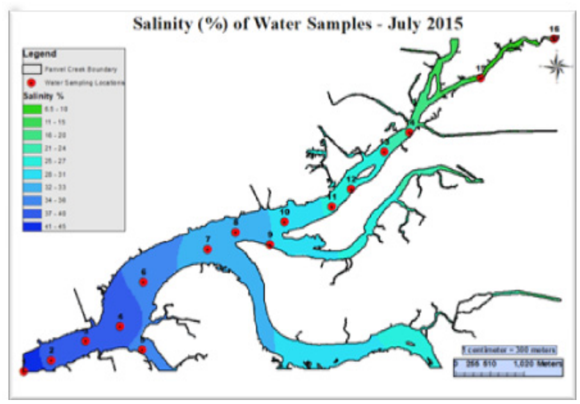

Fig. 16. Salinity of water samples (MN)

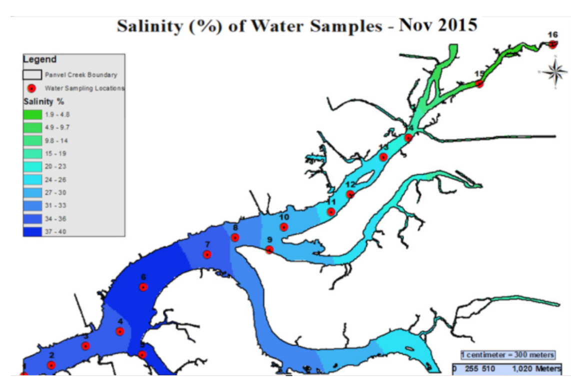

Fig. 17. Salinity of water samples (PSM)

Elevated Total Suspended Solids (TSS) values in the creek reduce clarity and light penetration levels in the water. High levels of suspended solids pose significant risks to fish, such as gill damage and breathing difficulties due to clogged gills (Paddy, 2010). This leads to weaker immunity, stunted growth, and higher chances of death. Total suspended solids concentrations showed fluctuations, ranging from approximately 374 mg/l to 930 mg/l. Higher TSS values during the monsoon seasons (Table 2) indicate sediment load and particulate matter transport influenced by increased precipitation and runoff associated with ongoing developmental projects. As per the Environmental Status Report Panvel Municipal Corporation for the year 2020-21, the industries in Taloja and nearby areas discharge waste directly into the Kasadi River. During pollution monitoring of Vashi Creek, the values of total suspended solids (TSS) were observed within the range of 40 to 1220 mg/l (Tambe and Gotmare, 2017). The green colour in the map indicates the high value of TSS (Figures 18, 19, and 20).

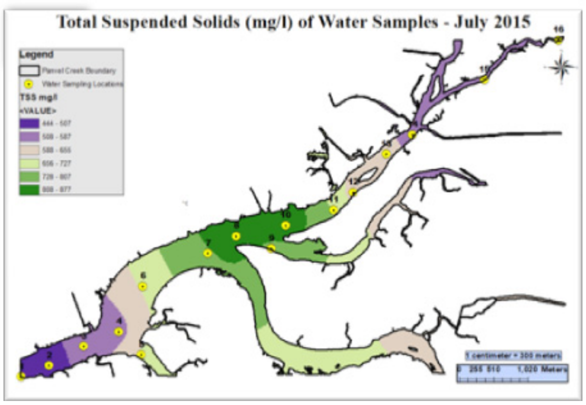

Fig. 18. TSS of water samples(PSM)

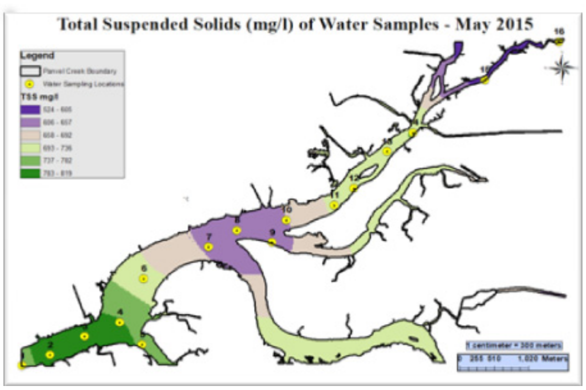

Fig. 19. TSS of water samples(MN)

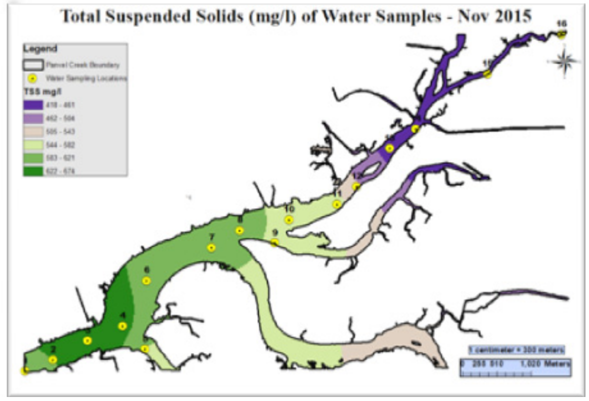

Fig. 20. TSS of water samples(PSM)

Nitrogen enrichment has detrimental impacts on the quality of water in aquatic ecosystems. Industrial wastewater discharge is the predominant cause of nitrate pollution in most of the coastal regions in and around Mumbai, Thane, and Navi Mumbai (Quadros and Athalye, 2012). Nitrate levels within the study area demonstrated distinct spatial and seasonal variations, ranging from 0.8 mg/l to 20.3 mg/l. higher levels of nitrate were observed towards the estuarine end at locations 13, 14, 15, and 16, while lower values were observed at location 1. The highest concentration of nitrate is found at sampling location 16 during the pre-monsoon (Table 1) and lower at location 1 during the monsoon (Table 2). Wastewater treatment facilities and sewage water outlets were identified as one of the important causes of nitrate pollution. According to the general discharge standard for environmental pollutant Part A effluent, the maximum permissible limit for nitrate is 10 mg/l for inland surface water and 20 mg/l for marine and coastal water (https://cpcb.nic.in). This suggests that the nitrate level within the study was found to be on the higher side. During the water quality assessment of Shewa Creek in the year 2023, nitrate concentrations were found to be elevated, ranging from 20.3 to 32.0 µg/l, 28.04 to 36.8 µg/l, and 32.86 to 47.54 µg/l in the pre-monsoon, monsoon, and post-monsoon seasons, respectively (Thakkar, 2023). The concentration of Nitrates is observed higher towards the riverside in all seasons where industrial discharge is reported from MIDC zones near the Taloja region which is reflected in interpolated maps created by using GIS software (Figures 21, 22, and 23).

The primary sources of phosphate in aquatic environments are untreated domestic and industrial effluents and agricultural runoff (Anitha and Kumar, 2013). Like the trend observed with nitrate concentration, a comparable pattern was also noted with phosphate concentration.

Higher levels were observed towards the riverine end, while the lowest concentration was observed at location 1, near the mouth of the creek. The highest phosphate level was reported at location14, i.e., 30.4 mg/l for post-monsoon (Table 3), while it was low at location 1, i.e., 2.65 mg/l during pre-monsoon (Table 1). The phosphate levels in the creek water were very high, indicating pollution due to the discharge of wastewater by industries and sewage treatment facilities in the region. Comparison with General Standards for Discharge of Environmental Pollutants, Part A- Effluent revealed that the phosphate levels were beyond the permissible limit at all locations except for location 1. The phosphate concentration in the Mahul Creek water fluctuated within the range of 6.19 to 112.85 mg/l. (Singare, 2014). The interpolated maps indicate the spatial distribution of pollutants and reflect higher concen-

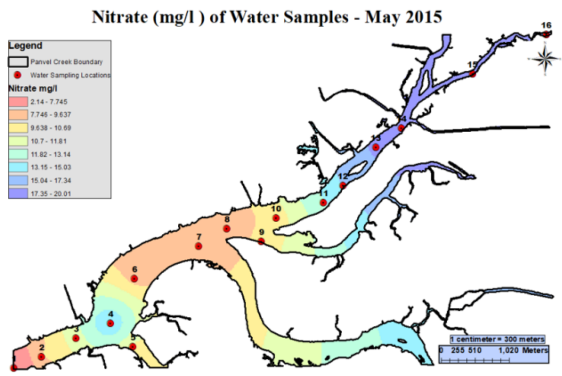

Fig. 21. Nitrate of water samples (PSM)

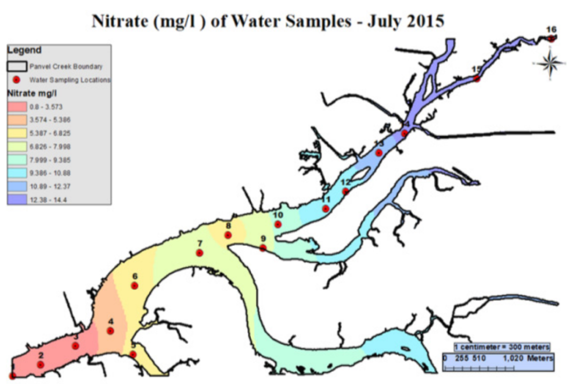

Fig. 22. Nitrate of water samples (MN)

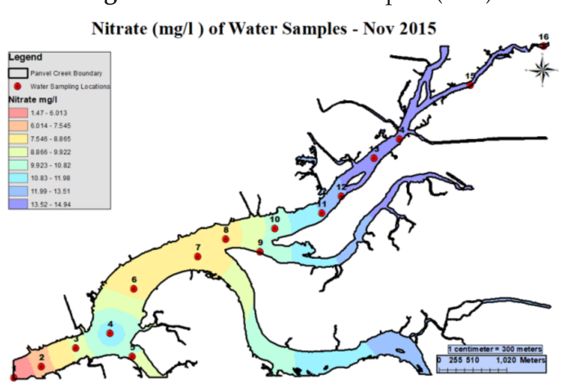

Fig. 23. Nitrate of water samples (PSM)

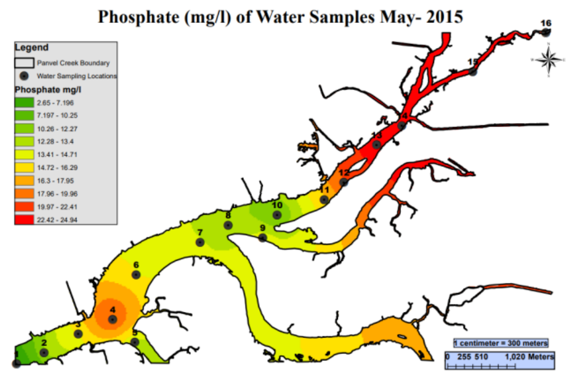

Fig. 24. Phosphate of water samples (PSM)

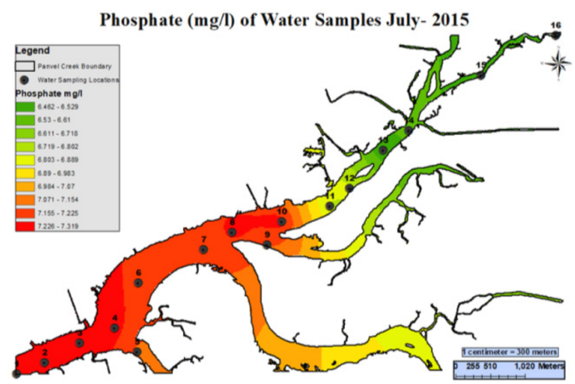

Fig. 25. Phosphate of water samples (MN)

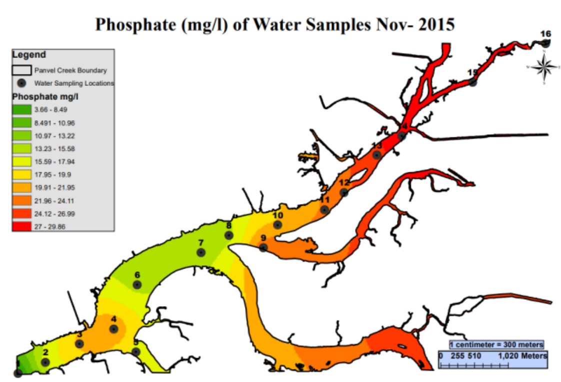

Fig. 26. Phosphate of water samples (PSM)

trations towards the mouth of the creek in the Monsoon (Figure 25) in comparison to pre-monsoon (Figure 24) and post-monsoon seasons (Figure 26).

Statistical Analysis of Water Samples

Several environmental elements influence the characteristics of surface water. Human activities further problematize this condition and affect surface water quality. The statistical analysis helps to understand seasonal, temporal, and spatial variations in the parameters. Water quality metrics in surface water are affected by a wide range of factors that can be better understood by the application of statistical tools such as correlation analysis and principal component analysis (PCA). Correlation analysis plays a crucial role in water pollution studies as it helps identify relationships between different water quality parameters. By quantifying the degree of association between variables, correlation analysis provides valuable insights into the potential sources and mechanisms of pollution. Whereas PCA condenses variables from data into a small number of factors called principal components. These new components formed by dimension reduction are based on correlation among variables and thus better explain patterns in the data.

Correlation analysis of water parameters

Correlation analysis plays a pivotal role in understanding and forecasting changes in the water quality of Panvel Creek. By examining the relationships between different parameters, such as pH, dissolved oxygen levels, and pollutant concentrations, correlation analysis enables us to anticipate shifts in water quality over time. This predictive capability is invaluable for identifying potential environmental risks and taking proactive measures to mitigate them. Moreover, by analyzing monitoring data, correlation analysis provides essential context and insights into how different variables interact and influence each other within the ecosystem of Panvel Creek. This deeper understanding empowers decision-makers to make more informed choices regarding environmental management strategies, ultimately leading to more effective and sustainable outcomes for the creek and its surrounding environment.

pH exhibited a strong positive correlation with dissolved oxygen (DO), i.e., 0.76313, which is often observed in aquatic environments where pH can influence the solubility of oxygen in water. Alkaline conditions can enhance the stability of oxygen molecules in the water and make it easier for oxygen to dissolve in the water. Similar findings have also been reported in the water quality assessment of the Brahmani River using correlation and regression analysis (Nayak, 2020). pH indicates a strong positive relationship with electrical conductivity (EC), i.e., 0.71823; total suspended solids (TSS), i.e., 0.73797; and salinity, i.e., 0.74642. pH levels affect the ionisation of compounds in water, leading to changes in the concentration of ions, leading to high concentrations of EC, TSS, and salinity (Butler and Ford, 2017; Rusydi, 2018). An increase in pH value leads to higher concentrations of ions in the water, thereby increasing its electrical conductivity. According to the water quality data report of the National Water Monitoring Program from coastal creeks, 2022 (https://cpcb.nic.in), higher conductivity was reported at Mahim, Thane, and Vasai Creeks in Maharashtra, showing high pH values. pH values showed a moderate negative correlation with nitrate, i.e., -0.6599, and phosphate, i.e., -0.6262. Electrical conductivity (EC) demonstrated a strong positive correlation with total suspended solids (TSS), i.e., 0.7707, and salinity, i.e., 0.88736. The presence of suspended solids in water, including particles like silt, clay, and organic matter, can harbour ions that enhance the electrical conductivity of the water. Conductivity and total dissolved solids exhibit a

Table 4. Correlation Analysis of Water Parameters

	pH	EC	Temp	TSS	DO	Salinity	Nitrate	Phosphate
pH	1							
EC	0.71823	1						
Temp.	-0.4994	-0.6715	1					
TSS	0.73797	0.7707	-0.5216	1				
DO	0.76313	0.96444	-0.6829	0.79183	1			
Salinity	0.74642	0.88736	-0.8466	0.73621	0.91804	1		
Nitrate	-0.6599	-0.6058	0.68657	-0.4786	-0.7413	-0.8096	1	
Phosphate	-0.6262	-0.5237	0.62142	-0.4022	-0.6817	-0.7272	0.96248	1

positive correlation, influencing the salinity levels in coastal waters (Thomas *et al.*, 2022). These interrelated parameters are integral to comprehending the environmental dynamics within an ecosystem. Electrical conductivity also showed a moderate negative correlation with temperature, i.e., -0.6715, nitrate, i.e., -0.6058, and phosphate, i.e., -0.5237 concentration. Generally, temperature is positively correlated with salinity, as the evaporation of water at high temperatures leads to an increase in salt concentration. In this study, temperature showed a strong negative correlation with salinity, i.e., -0.8466, which might be due to the high mixing rate of fresh water at the time of sampling. It also specifies a moderate negative correlation with dissolved oxygen (DO), i.e., -0.6829, and a moderate positive correlation with nitrate, i.e., 0.68657, and phosphate, i.e., 0.62142. Total suspended solids (TSS) displayed a strong positive correlation with dissolved oxygen (DO), i.e., 0.79183, and salinity, i.e., 0.73621. Dissolved oxygen and salinity are significant parameters in assessing water quality. With increasing salinity, there is an exponential decline in dissolved oxygen levels which can lead to threaten survival of aquatic life. Salinity, the level of dissolved salts in water, plays a crucial role in regulating fish physiology and osmoregulation. Different fish species have different thresholds for tolerating salinity levels, and fluctuations in salinity can disturb ion balance, osmotic regulation, and reproductive functions. However, in this research, the value of dissolved oxygen (DO) exhibited a strong positive correlation with salinity, i.e., 0.91804, which might be due to the exchange of gases with the atmosphere. The dissolved oxygen displays a strong negative correlation with nitrate, i.e., -0.7413. This correlation highlights the complex interaction between nutrient dynamics, biological activity, and oxygen availability in aquatic environments. High nitrate levels can lead to oxygen depletion and the promotion of anaerobic conditions, eventually impacting the health of aquatic ecosystems. Salinity demonstrated a strong negative correlation with nitrate, i.e., -0.8096 (Basu *et al.,* 2021), and a strong negative correlation with phosphate, i.e., 0.7272. Nitrate and phosphate exhibited a strong positive correlation with each other, i.e., 0.96248. Both nitrate and phosphate can originate from similar anthropogenic and natural sources. Agricultural runoff, wastewater discharges, and erosion from land are common sources of both nutrients.

Principal Component Analysis of water parameters

Out of a total of 8 Principal Components (PCs), the first four PCs explained around 97% of the total variance in the data and thus were further used to explore loadings of various parameters.

Table 5. Principal Components Analysis

PC	Eigenvalue	% variance	Cumulative % variance
1	5.97879	74.735	74.735
2	0.94466	11.808	86.543
3	0.532918	6.6615	93.2045
4	0.265841	3.323	96.5275
5	0.194125	2.4266	98.9541
6	0.0493676	0.61709	99.57119
7	0.0243476	0.30435	99.87554
8	0.0099504	0.12438	99.99992

Table 6. Factor loading for selected variables

Parameter	PC 1	PC 2	PC 3	PC 4
pH	0.3402	0.1651	0.5589	-0.3986
EC	0.3664	0.327	-0.1679	0.4995
Temperature	-0.3274	0.1697	0.6984	0.4855
TSS	0.322	0.5042	0.1538	-0.3671
DO	0.3894	0.1748	-0.0124	0.4591
Salinity	0.3963	0.0096	-0.2255	0.0076
Nitrate	-0.3513	0.4848	-0.1668	-0.0611
Phosphate	-0.3272	0.5632	-0.2631	-0.0809

The Principal Component Analysis revealed interesting trends with all loading to a moderate extent. PC1 explained 74.74% of the variation in the data but did not show significant loading for any of the parameters. PC2 accounted for 11.8% of the variation and showed moderately positive loadings on values of TSS and Phosphate indicating the possibility of their common source. PC3 had positive loadings on pH and temperature; whereas, PC4 showed moderate to weak loading on EC.PC1 and PC2 have explained about 87% of the data and thus were considered to draw the Biplot. Sampling locations 15 and 16 are on the far left of the biplot and are separated from other locations and parameters like DO, pH, and EC indicating significantly lower levels of these parameters, which is corroborated by experimental values (Tables 1, 2 and 3). This could be attributed to a heavy influx of sewage and wastewater discharge observed at the site. Sewage water contributed organic waste that reduced DO levels; which along with effluent discharge diluted the water resulting in lowered pH and salinity values. On the other hand, locations 3, 4, and 10 show moderate to elevated values of these parameters indicating relatively less pollution.

Sampling locations 12 to 16 showed higher nitrate and phosphate concentrations and are most often associated with sewage disposal and wastewater discharge. These sampling locations are situated close to the MIDC area of Taloja and Kalmaboli, where wastewater is discharged from either point or non-point sources. Sampling location S15 is surrounded by Kalamboli STP and Kalamboli Holding Pond, whereas sample 16 has a point source from Taloja CETP along with other sewage water released from the nearby area. In addition, this creek area experiences a narrowing of the waterway, which reduces the chance of dilution with creek water, thus observing incremental pollution levels in the form of elevated nitrates and phosphates. It can also originate from both natural and human-made sources, including agricultural runoff, detergents, wastewater discharge, and sewage (Deya and Vijay, 2022). Many researchers have determined creek water quality and have found a positive correlation between wastewater discharge and higher concentrations of nitrate and phosphates. Nitrate in surface water primarily originates from wastewater discharge, agricultural activities, and surface runoff.

Location1 is on the extreme right side of the field and has been distinctly positioned opposite other locations. The lowest levels of pollutants (nitrates and phosphates) in comparison to the pollution status at other sampling locations. This sampling location is situated near the mouth of the creek, with a higher influence of the tide and the mixing rate with the seawater. Research on the complex tidal variations of Thane Creek reveals that the highest mixing rate occurs at the mouth of the creek, with current strength gradually diminishing from downstream to upstream throughout all seasons (Thomas *et al.*, 2022).

Locations S2, S5, S6, S7, and S8 are clustered together and located in the opposite direction of the pollution status of nitrates and phosphates, indicating better water quality in the creek. The water quality is found to be better due to the dense cover of mangroves around the sampling locations. Mangroves remove both organic and inorganic nutrients from the water column, which improves the quality of the water. Mangroves reduce the amounts of nitrate and phosphorus in contaminated water by denitrification and soil-nutrient burial, which prevents eutrophication on the shore and downstream. Research on the role of mangrove forests in filtering pollutants and sediment indicates a significant negative correlation, as mangrove sediments act as filtering agents for pollutants in the water (Patel *et al.*, 2013). The results of this investigation demonstrated that planted buckets submerged in 100% sewage for a week experienced a notable elimination of phosphorus, total phosphorous, and ammonium-nitrogen (Kondo *et al.*, 2013). These correlation analyses can be used to determine the other variables in the region. The correlation analysis values and their significance levels are useful in determining the best water quality management and treatment strategies.

Impacts of Developmental Activities on Panvel Creek

The application of Geographic Information Systems

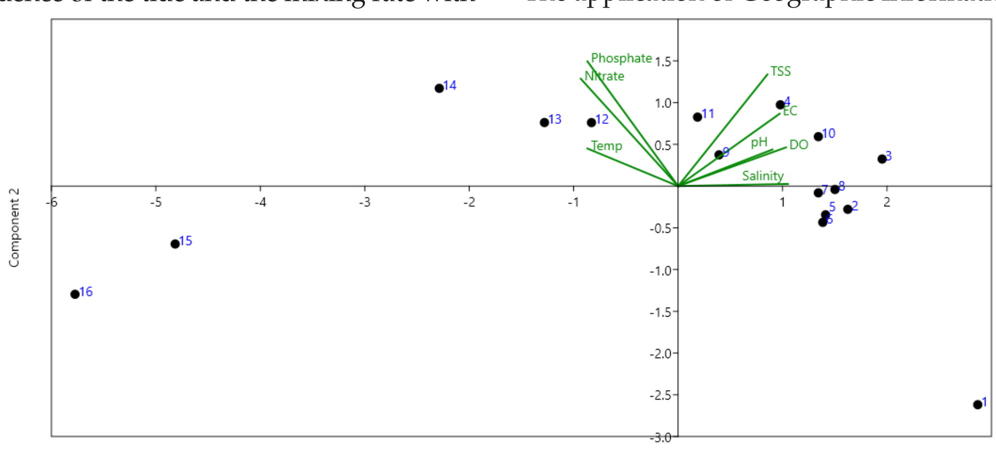

Fig. 21. Principal Components Analysis of Water Parameters

(GIS) and Remote Sensing techniques offers a useful way to evaluate the effects of developmental activities precisely and methodically. This methodology facilitates a thorough assessment of the complex interrelationships between various settings and the corresponding beneficial or detrimental outcomes. Our knowledge of the general environmental conditions in the area can be improved by utilizing ArcGIS to analyze land use and land cover patterns. Thus enabling us to get insights into Panvel Creek's pollution levels and related environmental challenges. Wetlands and marshy areas, which once made up a significant percentage of the region's terrain, have been significantly lost because of the ongoing development of Navi Mumbai. These wetlands support a wide variety of wildlife, including mudflats, salt marshes, and mangroves. Still, the environment has undergone a significant transformation due to the execution of multiple large-scale construction projects intended to promote commercial and economic growth by the government in Navi Mumbai, including the Navi Mumbai International Airport, the Mumbai Trans-Harbor Link Roadproject, and the Navi Mumbai Metro projects. Among the several treatment plants in the region, one of the biggest is the Taloja Common Effluent Treatment Plant. Untreated sewage and effluents from sewer lines, STPs, and CETPs in the city are discharged into the creek. These developmental projects along with other anthropogenic activities within the city have a detrimental influence on the environmental conditions of Panvel Creek. All these developmental projects along with STP and CETP are mapped by using Arc GIS software which gives a cumulative representation of environmental impacts adjoining Panvel Creek as indicated in the map (Figure 22).

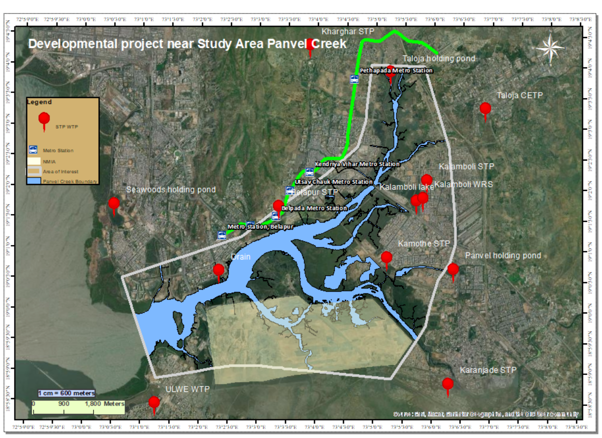

Fig. 22. Map showing developmental projects and wastewater treatment plants

Conclusion

The study reveals significant seasonal and spatial fluctuations in physicochemical parameters influenced by regional climate and freshwater-seawater exchange, with no consistent distribution pattern identified across sampling periods. Lower conductivity and dissolved oxygen levels near S14, S15, and S16 indicate wastewater discharge from wastewater treatment facilities. Elevated phosphate and nitrate levels from S2 to S4, where mangroves are scarce, contrast with areas of dense mangrove cover, highlighting their filtration capacity. Extremely high phosphate and nitrate levels from S11 to S16 are linked to upstream wastewater flow and narrower creek width. These findings underscore the considerable environmental changes in Panvel Creek due to Navi Mumbai's development, including infrastructure expansion, encroachment on mangroves and wetlands, and increased population and industrial activity. Wastewater discharge and commercial activities like shipbuilding and sand dredging further contribute to pollution and land use alterations. Conservation efforts, including regular pollution monitoring and integrated management of creeks, mangroves, and wetlands, are crucial for preserving the ecological balance in the coastal ecosystem and benefits to surrounding areas.

Conflict of Interests

The authors declare that they have no conflict of interests.

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