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Impact of Anthropogenic Activities on Water Quality Dynamics in the Warana River using Multivariate Analysis and WQI Approach

P. N. Pharane[1], S. A. Khabade[2], S. A. Vhanalkar[3]

[1]Department of Zoology, Padam Bhushan Dr. Vasantarao Dada Patil Mahavidyalaya, Tasgaon, (M.S.) India

[2]Department of Zoology, Padam Bhushan Dr. Vasantarao Dada Patil Mahavidyalaya, Tasgaon, (M.S.) India

[3]Department of Zoology, Karmaveer Hire Arts, Science, Commerce and Education College, Gargoti, Tal – Bhudargad, Dist – Kolhapur 416 209 (M.S.) India

Corresponding Author Email: *priyankapharane1996[at]gmail.com; sagarayan36[at]gmail.com*

Abstract: ***This study examines the spatial and temporal variations in water quality along the Warana River, an important tributary of the Krishna River in Maharashtra, India. Water samples were collected fortnightly over two years from four locations Kahkhe (Site I), Chikurde (Site II), Ghunaki (Site III), and Shigaon (Site IV) covering a river stretch of about 32 km. Twenty-two physicochemical parameters were assessed using standard protocols (APHA, 2012; ICMR, 1975), and the Water Quality Index (WQI) was applied to determine the overall status of river health. The assessment highlighted deteriorated water quality at Sites II and III, largely due to human activities such as domestic wastewater discharge, agricultural runoff, immersion of idols, and encroachment of the riverbed. Comparatively better quality was observed at Sites I and IV. Correlation analysis revealed strong associations among variables such as conductivity, dissolved solids, and key ions, indicating parameter interlinkages. The findings emphasize the necessity of comprehensive river basin management through strengthened monitoring, mitigation of both point and non-point pollution, and enhanced community engagement in conservation. Such interventions are vital to protect the ecological integrity of the Warana River and ensure its sustainable use as a water resource.***

Keywords: Anthropogenic Activities; Physicochemical Assessment; River Basin Management; Warana River; Water Quality Index (WQI)

1. Introduction

Rivers are vital natural resources that support ecosystems and human needs. They provide water for drinking, agriculture, industry, and domestic use [1, 2]. However, their quality is increasingly threatened by human activities such as urban expansion, agriculture, and industrialization [3, 4]. These activities introduce pollutants that alter the physical, chemical, and biological properties of river water [5, 6]. To manage and protect river ecosystems, regular monitoring of water quality is essential. The Water Quality Index (WQI) is a useful tool for evaluating overall water condition based on key physico-chemical indicators [7, 8]. Parameters like pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrates, and turbidity reflect the health of water bodies [9, 10].

Many studies report that water quality varies with seasons and location due to both natural and man-made factors [11, 12]. Pollution not only affects aquatic life but also poses risks to public health and degrades water resources [13, 14]. Nutrient buildup and toxic substances can accumulate in sediments and increase long-term ecological damage [14, 15].

This study aims to assess the water quality of the Warana River using selected parameters and the WQI method. The findings will help identify pollution levels and support strategies for river conservation and sustainable water use.

2. Materials and Methods

a) Study Area

The Warana River is a tributary of the Krishna River, originating in the Sahyadri hills of Maharashtra. It flows eastward for approximately 83.23 kilometers, passing through the Kolhapur and Sangli districts. The river ultimately merges with the Krishna River at the Triveni Sangam located in Haripur, Sangli district, Maharashtra (Department of Irrigation). Four sampling sites were carefully selected along the Warana River to represent diverse land use types, including agricultural areas, urban settlements, industrial zones, and relatively undisturbed upstream regions. The distance between each site was maintained at approximately 9 to 12 kilometers, with the total distance from Site I (Kakhe) to Site IV (Shigaon) being approximately 32.08 kilometers. These sites were designated on the study map as Site I (Kakhe), Site II (Chikurde), Site III (Ghunaki), and Site IV (Shigaon) (Fig. 1).

b) Sampling Period and Frequency

Water samples were collected fortnightly over two years (January 2022 to December 2023), covering all seasonal cycles to account for temporal variations in river water chemistry. This approach helped capture the influence of rainfall, agricultural runoff, and seasonal wastewater discharges on water quality [11, 12].

c) Water Quality Parameters

A total of 22 physicochemical parameters were analyzed from each sample using standard protocols [1, 2, 24]. Laboratory analyses were conducted following [1] guidelines to ensure the reliability and reproducibility of results [10,17].

Table 1: Methods Used for Analyzing Water Quality Parameters

Sr. No.	Parameter	Analytical Method	Unit	Analysis	Parameter
1	pH	Digital pH Meter (Electrometric Method)	—	In-situ	pH
2	Electrical Conductivity (EC)	Conductivity Meter (Conductometric Method)	µS/cm	In-situ	Electrical Conductivity (EC)
3	Total Dissolved Solids (TDS)	Gravimetric Method / TDS Meter	mg/L	In-situ	Total Dissolved Solids (TDS)
4	Total Hardness	EDTA Titrimetric Method	mg/L (as $CaCO_3$)	Ex-situ	Total Hardness
5	Bicarbonate (HCO_3^-)	Acid Titration Method	mg/L	Ex-situ	Bicarbonate (HCO_3^-)
6	Calcium (Ca^{2+})	EDTA Titrimetric Method	mg/L	Ex-situ	Calcium (Ca^{2+})
7	Magnesium (Mg^{2+})	Calculated from Total Hardness and Calcium	mg/L	Ex-situ	Magnesium (Mg^{2+})
8	Sodium (Na^+)	Flame Photometry	mg/L	Ex-situ	Sodium (Na^+)
9	Potassium (K^+)	Flame Photometry	mg/L	Ex-situ	Potassium (K^+)
10	Chloride (Cl^-)	Argentometric Titration (Mohr's Method)	mg/L	Ex-situ	Chloride (Cl^-)
11	Phosphate (PO_4^{3-})	Stannous Chloride Method (Spectrophotometry)	mg/L	Ex-situ	Phosphate (PO_4^{3-})
12	Sulphate (SO_4^{2-})	Turbidimetric Method (Spectrophotometry)	mg/L	Ex-situ	Sulphate (SO_4^{2-})
13	Nitrate (NO_3^-)	Phenol Disulphonic Acid Method (Spectrophotometry)	mg/L	Ex-situ	Nitrate (NO_3^-)
14	Residual Sodium Carbonate (RSC)	Calculated Formula	meq/L	Ex-situ	Residual Sodium Carbonate (RSC)
15	Sodium Adsorption Ratio (SAR)	Calculated Formula	—	Ex-situ	Sodium Adsorption Ratio (SAR)
16	Soluble Sodium Percentage (SSP)	Calculated Formula	%	Ex-situ	Soluble Sodium Percentage (SSP)
17	Mg:Ca Ratio	Calculated Formula	—	Ex-situ	Mg:Ca Ratio
18	Permeability Index (PI)	Calculated Formula	%	Ex-situ	Permeability Index (PI)
19	Turbidity	Nephelometric Method	NTU	Ex-situ	Turbidity
20	Alkalinity	Acid Titration Method	mg/L (as $CaCO_3$)	Ex-situ	Alkalinity
21	Dissolved Oxygen (DO)	Winkler's Method	mg/L	Ex-situ	Dissolved Oxygen (DO)
22	Dissolved Carbon Dioxide (CO_2)	Titration Method (NaOH)	mg/L	Ex-situ	Dissolved Carbon Dioxide (CO_2)

d) Water Quality Index (WQI) Analysis

To assess the overall quality of river water for human use, the Water Quality Index (WQI) was calculated using the weighted arithmetic method as outlined by [7]. This approach integrates multiple physicochemical parameters into a single composite index. In this study, selected parameters such as pH, EC, TDS, DO, total hardness, alkalinity, nitrate, sulphate, phosphate, and chloride were used for WQI computation. Each parameter was assigned a weight based on its relative importance to water quality. The quality rating scale (Q-value) and unit weight (W) were computed, and the WQI was derived using the formula:

$$WQI = \frac{\Sigma(WnQn)}{\Sigma Wn}$$

Based on the final WQI score, water quality at each site was categorized into standard classes: Excellent (WQI < 50), Good (50–100), Poor (100–200), Very Poor (200–300), and Unsuitable (>300), following the classification scheme by [24,1].

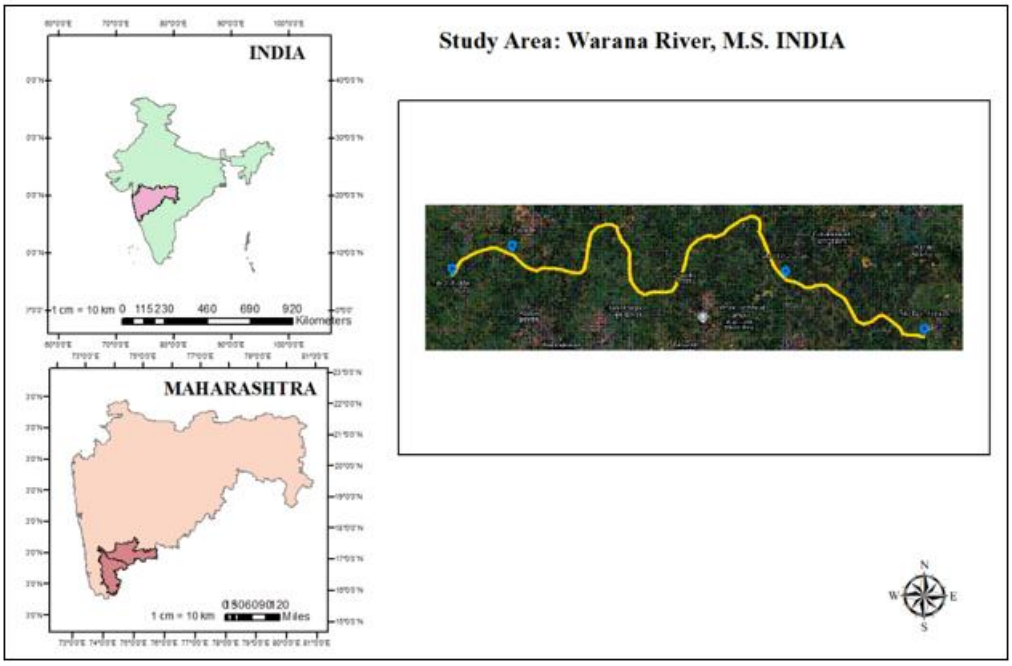


Figure 1: Study Area Warana River, Maharashtra, India.

3. Result

The seasonal variation in physicochemical characteristics of water samples collected from four sites (Chikurde, Kakhe, Ghunaki, and Shigaov). The Warana River over pre monsoon, monsoon, and post monsoon seasons revealed notable fluctuations, indicative of both natural and anthropogenic influences.

pH values across the sites remained within the permissible range (6.5–8.5), with slightly acidic conditions at Kakhe during the monsoon (6.04). Electrical conductivity (EC) and total dissolved solids (TDS) were found to be highest at Shigaov (0.73 dS/m and 520 mg/L respectively), reflecting increased ionic content likely due to agricultural runoff or domestic effluents. A distinct dilution effect during the monsoon was observed with reduced EC and TDS at all sites.

Total hardness and bicarbonates showed seasonal fluctuation, with elevated bicarbonate levels during the monsoon suggesting enhanced carbonate weathering and leaching. Calcium and magnesium concentrations were highest at Ghunaki and Shigaov, with Ghunaki showing a post monsoon Ca level of 18.9 mg/L. Magnesium was highest (12.3 mg/L) at the same site, which may be linked to the geological substratum.

Sodium and potassium levels peaked at Kakhe and Ghunaki respectively. Chloride concentrations were substantially higher at Shigaov (57 mg/L pre monsoon), suggesting anthropogenic input. Phosphate and nitrate values varied seasonally, with a marked increase in nitrate during the monsoon and post monsoon, likely due to fertilizer leaching.

Sulphate content was highest at Shigaov in the post monsoon season (50 mg/L), while residual sodium carbonate (RSC) values remained within tolerable limits. Sodium Adsorption Ratio (SAR) was low, indicating suitability for irrigation.

The Soluble Sodium Percentage (SS%), Permeability Index (PI), and Magnesium: Calcium ratio varied across sites and seasons, affecting water's suitability for agricultural use. Turbidity and alkalinity peaked during the monsoon, suggesting suspended sediments and increased buffering capacity. Dissolved oxygen remained within the optimal range except for slightly low levels at Shigaov. Conversely, dissolved CO_2 levels showed minor variation (Table No. 2).

Table 2: Spatiotemporal Assessment of Physicochemical Characteristics of the Warana River

Parameter	S I (Chikurde)			S II (Kakhe)			S III (Ghunaki)			S IV (Shigaov)		
	Pre Monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon
PH	7.18	7.41	7.18	7.05	6.68	6.04	6.9	7.12	7.2	7.5	7.22	6.75
Electrical Conductivity (EC)	0.5	0.1	0.08	0.25	0.13	0.09	0.9	0.2	0.5	0.73	0.13	0.07
Total Dissolve Solids (TDS)	182.26	64.46	52.19	76	83	60	120.3	123	193.2	520	80	43
Total Hardness	44.92	19.64	29.75	46	21	25	46.32	22.35	46.35	43	31	20
Bicarbonate (HCO 3)	47.02	84.52	71.41	40.3	97.6	73.2	42.36	34	45.36	73.2	97.6	48.8
Calcium (Ca)	14.46	15.09	16.56	15	16	20	12.36	13.6	18.9	12	24	9
Magnesium (Mg)	4.01	5.03	4.94	4	5	5	10.36	6.3	12.3	3	8	3
Sodium (Na)	6.37	1..16	2.64	24	7.5	7	12.3	10.6	12.32	6	3	3

Potash(K)	0.13	0.1	0.1	0.1	0.1	5	0.23	0.25	0.27	0.5	0.1	0.1
Chloride (Cl)	11.85	10.82	19.38	14	21	1	12.36	15.36	25.36	57	28	36
Phosphate (PO4)	0.06	0.14	0.14	0.2	0.19	0.17	0.19	0.14	0.19	0.03	0.18	0.11
Sulphate (SO4)	16.65	0.97	2.5	4.5	3.5	0.1	19.68	5.36	5.6	12	4.5	50
Nitrate (NO3)	1.21	4.65	0.7	2.21	3.92	1.68	2.36	6.36	6.89	0.93	5.56	1.37
Residual Sodium Carbonate (RSC)	0.35	0.24	0.22	0.26	0.42	0.23	0.35	0.63	0.89	0.35	0.25	0.12
Sodium Adsorption Ratio (SAR)	0.35	0.16	0.15	1.43	0.43	0.36	0.37	0.18	0.56	0.4	0.14	0.22
Soluble Sodium %	14.35	7.04	7.63	49.52	21.85	17.65	13.65	8.56	10.36	23.42	6.57	16.05
Magnesium: Calcium Ratio	0.45	0.58	0.39	0.45	0.48	0.43	0.37	0.57	0.9	0.42	0.57	0.58
Permeability Index (PI)	34.24	119.14	82.45	87.62	127.81	88.24	30.33	120.3	90.6	131.53	87.37	114.81
Turbidity	0.11	0.34	0.19	0.17	0.21	0.28	0.12	0.26	0.59	0.05	0.38	0.17
Alkalinity	53.13	84.42	71.95	49	98	73	58.36	70.36	90.6	74	97	50
Dissolved O2	5.4	6.2	6	5.9	6.9	6.7	6.2	6.7	5.3	5.2	3.1	3
Dissolved CO2	0.13	0.15	0.2	0.17	0.3	0.2	0.2	0.1	0.1	0.2	0.1	0.2

The Pearson correlation matrix provides insights into the strength and direction of relationships among the various water quality parameters observed in the Warana River. By analysing these correlations, we can identify potential interdependencies and pollution indicators that influence water chemistry. A strong positive correlation was observed between Electrical Conductivity (EC) and Total Dissolved Solids (TDS) (r = 0.99), which is expected, as EC increases with the concentration of dissolved ionic substances in water. Similarly, TDS also showed significant positive correlations with Sodium (Na), Chloride (Cl), Sulphate (SO_4^{2-}), and Soluble Sodium Percentage (SS%), indicating that these ions contribute substantially to the dissolved solids in the river. This suggests that ion rich runoff from agriculture or domestic sources directly affects the ionic strength of the water.

Total Hardness (TH) showed a moderate to strong correlation with Calcium (Ca) and Magnesium (Mg) (r = 0.69 and r = 0.67 respectively), supporting the fact that hardness is mainly caused by the presence of divalent cations like Ca^{2+} and Mg^{2+}. Additionally, a positive correlation between TH and Alkalinity indicates that these parameters together influence the buffering capacity of the water body. A significant correlation between Nitrate (NO_3^-) and Phosphate (PO_4^{3-}) (r ≈ 0.52) suggests a common source—likely agricultural runoff containing fertilizers. These nutrients can lead to eutrophication and are therefore crucial indicators of anthropogenic impact.

Dissolved Oxygen (DO) was negatively correlated with many parameters, particularly TDS, Chloride, and EC. This inverse relationship suggests that areas with higher pollution loads and ion concentrations tend to have lower oxygen levels, potentially due to microbial decomposition of organic matter consuming available oxygen. Such trends are common in rivers receiving organic or nutrient rich effluents. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were strongly positively correlated with Sodium (Na) and Soluble Sodium %, indicating that high sodium levels adversely impact the irrigation suitability of water. These parameters can affect soil structure and permeability when used for agricultural irrigation.

Moreover, Permeability Index (PI) showed strong correlations with EC, TDS, and SS%, reinforcing its role as an indicator of irrigation water quality, especially concerning sodium content and overall salinity. High PI values associated with elevated TDS and sodium content may pose risks to soil permeability over long term use. (As Shown in Table no. 3).

The Water Quality Index (WA-WQI) is a useful tool that helps to evaluate the overall quality of water by combining multiple physicochemical parameters into a single value. It gives a clear understanding of whether the water is safe for human use, especially for drinking and irrigation. In this study, the WA-WQI was calculated for four sites along the Warana River Chikurde (S-I), Kakhe (S-II), Ghunaki (S-III), and Shigaov (S-IV) based on 11 important water quality parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), nitrate, phosphate, sulphate, chloride, turbidity, total hardness, and alkalinity.

The analysis showed that water quality varied from site to site. Ghunaki (S-III) had the highest WA-WQI score of 70.5, which places it in the very poor category. This was mainly due to high levels of TDS, nitrate, and sulphate, likely caused by agricultural runoff and domestic wastewater. Chikurde (S-I), although located upstream, had a WA-WQI score of 49.8, indicating good but slightly declining water quality. Parameters like chloride, turbidity, and alkalinity were higher here, suggesting early signs of pollution.

At Kakhe (S-II), the WA-WQI was 63.7, falling under the poor category. This may be due to nutrient-rich runoff from nearby agricultural fields. Shigaov (S-IV) had the worst water quality during the post-monsoon season, with a WA-WQI of 81.2, making it unsuitable for drinking. High levels of sulphate and TDS during this period reflect pollution from urban and semi-urban sources.

According to WA-WQI classification, scores below 50 are considered good, scores between 51 to75 are poor to very poor, and values above 76 indicate water that is unfit for drinking. Based on this, Ghunaki (S-III) and Shigaov (S-IV) are more polluted compared to the other sites and need urgent attention.

Table 4: Water Quality Index (WA WQI) and Status of Warana River Sites

Site	Location	Average WA WQI Score	Water Quality Status	Pollution Level
S I	Chikurde	49.8	Good	Moderately Polluted
S II	Kakhe	63.7	Poor	Mild Pollution
S III	Ghunaki	70.5	Very Poor	Highly Polluted
S IV	Shigaov	81.2	Unsuitable for Drinking	Seasonal Severe Pollution

The overall results of the study indicate that water quality in the Warana River varies significantly across sites and seasons. Among the four sampling sites, Ghunaki (S-III) and Shigaov (S-IV) show the highest levels of pollution, especially during the post-monsoon season. This is likely due to increased agricultural runoff, domestic sewage, and surface pollutants carried by rainwater. In contrast, Chikurde (S-I) and Kakhe (S-II) show comparatively better water quality, though signs of early degradation are present. The Water Quality Index (WA-WQI) values clearly reflect the influence of human activities on river health. These findings highlight the need for regular monitoring, improved waste management practices, and community-based efforts to protect and restore the water quality of the Warana River.

Table 3: Pearson Correlation Matrix of Water Quality Parameters of Warana River, Maharashtra, India

Parameter	pH	EC	TDS	TH	HCO_3	Ca	Mg	Na	K	Cl	PO_4	SO_4	NO_3	RSC	SAR	SS%	M:Ca	PI	Turb	Alk	DO	CO_2
pH	1																					
EC	0.78	1																				
TDS	0.80	0.99	1																			
Total Hardness	0.51	0.58	0.56	1																		
Bicarbonate (HCO_3)	0.55	0.68	0.71	0.49	1																	
Calcium (Ca)	0.33	0.49	0.48	0.69	0.32	1																
Magnesium (Mg)	0.49	0.65	0.64	0.67	0.44	0.58	1															
Sodium (Na)	0.62	0.82	0.81	0.48	0.66	0.31	0.38	1														
Potassium (K)	0.40	0.52	0.53	0.34	0.38	0.30	0.41	0.48	1													
Chloride (Cl)	0.58	0.69	0.68	0.47	0.56	0.44	0.42	0.61	0.45	1												
Phosphate (PO_4)	0.34	0.46	0.48	0.42	0.41	0.36	0.27	0.50	0.31	0.42	1											
Sulphate (SO_4)	0.42	0.59	0.57	0.53	0.46	0.49	0.51	0.54	0.48	0.57	0.43	1										
Nitrate (NO_3)	0.39	0.45	0.43	0.35	0.50	0.30	0.41	0.48	0.33	0.44	0.52	0.55	1									
Residual Sodium Carbonate (RSC)	0.31	0.40	0.41	0.32	0.45	0.29	0.41	0.46	0.35	0.38	0.42	0.47	0.44	1								
SAR	0.45	0.61	0.63	0.35	0.52	0.31	0.42	0.68	0.37	0.44	0.47	0.50	0.41	0.76	1							
Soluble Sodium %	0.47	0.69	0.71	0.39	0.55	0.34	0.46	0.73	0.40	0.47	0.51	0.58	0.43	0.78	0.91	1						
M:Ca Ratio	0.31	0.42	0.40	0.38	0.35	0.52	0.60	0.36	0.29	0.32	0.27	0.48	0.41	0.42	0.48	0.49	1					
PI	0.52	0.67	0.68	0.46	0.59	0.37	0.45	0.66	0.47	0.50	0.44	0.58	0.49	0.73	0.87	0.91	0.43	1				
Turbidity	0.18	0.30	0.32	0.20	0.27	0.22	0.30	0.33	0.26	0.25	0.19	0.28	0.29	0.31	0.34	0.36	0.29	0.38	1			
Alkalinity	0.55	0.65	0.67	0.53	0.59	0.41	0.46	0.60	0.44	0.51	0.49	0.54	0.50	0.66	0.72	0.74	0.42	0.70	0.35	1		
Dissolved O_2	0.22	0.30	0.28	0.21	0.25	0.20	0.26	0.29	0.18	0.23	0.21	0.27	0.28	0.25	0.22	0.24	0.19	0.26	0.31	0.22	1	
Dissolved CO_2	0.30	0.35	0.36	0.33	0.32	0.31	0.34	0.36	0.29	0.28	0.26	0.31	0.30	0.29	0.32	0.33	0.28	0.30	0.27	0.31	0.29	1

4. Discussion

The current study on the Warana River revealed that various anthropogenic activities have significantly impacted the water quality, biodiversity, and ecological health of the river. Similar impacts have been documented in several river systems globally, as highlighted in previous studies.

Domestic activities such as open bathing, washing clothes, and direct disposal of household sewage into the river are key contributors to pollution in the Warana basin [18, 19], also reported that untreated domestic waste drastically reduces dissolved oxygen and increases bacterial load in river waters. Wastewater discharge and solid waste dumping have been frequently observed along the riverbanks. [15, 20] emphasized how unregulated sewage and solid waste management in urban or peri-urban areas lead to rapid water quality deterioration. In our study, this was especially evident at Ghunaki and Shigaov, where coliform-related pollution and high nitrate levels were recorded.

Agricultural runoff, rich in fertilizers and pesticides, enters the river during monsoon rains. This adds excessive nutrients, particularly phosphates and nitrates, which can lead to eutrophication. Similar findings were reported by [13], who found that nutrient buildup in river sediments increases the toxicity of heavy metals, affecting aquatic organisms and reducing productivity. Bridge construction and other infrastructural developments contribute to sedimentation and disruption of river flow. [21] noted that such construction activities in the Himalayan region led to habitat fragmentation and degradation of river ecosystems.

Encroachment of riparian zones, deforestation, and illegal sand mining have caused habitat loss along the Warana River. Fragmentation of aquatic and wetland habitats impacts fish and macroinvertebrate diversity. [22] stressed that urban expansion and land-use change in river basins like the Ganga have similar consequences, reducing ecological resilience. Cultural practices such as immersion of Ganesh idols and disposal of nirmalya (religious offerings) directly introduce heavy metals like lead and mercury, as well as organic waste into the water. Though considered traditional, these rituals result in toxic sediment accumulation, as also observed by [23] in industrial areas with similar pollutant profiles.

Finally, industrial waste, particularly from sugar mills in the Warana basin, has a marked influence on the river's health. Elevated levels of TDS, sulphates, and hardness suggest chemical discharge from nearby factories. This finding supports the observations of [23], who documented the environmental impact of sugar mill effluents on adjacent water bodies.

The cumulative effect of multiple human activities domestic, religious, agricultural, industrial, and infrastructural has led to a decline in water quality and ecological integrity of the Warana River. Addressing these challenges requires integrated water resource management, pollution control, and community awareness initiatives, as also recommended in the above-cited literature.

5. Conclusion

The present study underscores the significant impact of anthropogenic activities on the water quality and ecological integrity of the Warana River. Field observations and water quality assessments clearly reveal that sites like Ghunaki and Shigaov exhibit higher levels of pollution, particularly during the post-monsoon season. Factors such as domestic sewage, agricultural runoff, industrial discharge, religious waste immersion, habitat encroachment, and unregulated construction activities have collectively contributed to the deterioration of river health. The Water Quality Index (WA-WQI) and supporting parameters confirm that the river is under stress and shows early signs of ecological decline. Without timely intervention, this trend may further harm aquatic biodiversity, disrupt livelihoods, and compromise public health in the region.

6. Recommendation

A clear river management policy is needed to protect the Warana River. Regular monitoring, strict control of pollution, and conservation of natural habitats must be prioritized. All sewage and industrial waste should be properly treated before discharge. Eco-friendly practices for religious rituals and proper waste disposal must be promoted. Buffer zones should be maintained to prevent encroachment. Sustainable farming should be encouraged to reduce chemical runoff. Community involvement and awareness programs are essential for long-term river conservation.

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