Spatio-Temporal Variations in Water Quality of the Baitarani River Basin, Odisha: A Comparative Study

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Abstract

Human interference has caused considerable deterioration of the Baitarani River in Odisha over time. It is especially susceptible to degradation due to mining activities, the discharge of industrial and domestic wastewater from adjacent enterprises and municipalities.The present study focuses on the variations of water quality in Baitarani River Basin, Odisha, India using Water Quality Index (WQI) technique. Water quality testing was carried out at eight strategically selected locations representing the major river and its tributaries. Nine important physicochemical and biological parameters such as pH, turbidity, total solids, dissolved oxygen (DO), biochemical oxygen demand (BOD), faecal coliform, phosphate, nitrate and WQI were investigated and compared between 2019 and 2024. The findings demonstrate an overall decrease in the quality of the basin's water during the five year period. The average WQI values were found to be decreased at almost all the stations with most prominent decrease at the Champua (S1) and Mushal River at Anandpur (S5). The main factors causing the deterioration of water quality were the increase in turbidity, the microbiological contamination and the enrichment of nutrients. The results indicate the increasing anthropogenic strain exerted on the river basin and the need for regular monitoring and integrated watershed management techniques.

1. Introduction

Rivers are incredibly essential and indispensable resource to mankind, serving not just agricultural and industrial needs but also the necessities of both animals and humans. The expansion of towns, the increasing utilization of water resources, and the passage of time have all culminated in increased burdens on controlling water resources and monitoring anomalous changes in water quality conditions [1](s13201-018-0859-7#CR Sánchez et al. 2007). Globally, surface water supplies meet half of the world's drinking water needs and 40% of industrial demands [2]. It emerges that surface water is an important component of the water cycle and a vital supply for irrigation purposes in agriculture and human consumption. Despite this, the quality and quantity of water used for drinking, as well as the amount and use of water for irrigation, directly affect biodiversity by supporting wetlands and lakes. Surface water contamination has been the subject of several worldwide studies, which have identified chemical patterns in water quality and the potential effects on the environment and human health [3]. Assiri et al. [4] stated that alterations to the water cycle may have consequences for both human society and nature. The water cycle could affect the civilization and environment [5]. Thus, it is imperative to monitor the concentration, distribution, sources, and level of components in order to effectively manage water resources and prevent water pollution.

Water Quality (WQ) is presently a primary focus of research for numerous scientists globally. Various factual and numerical models have been developed because of these advancements and studies; these models assess ground and surface water quality in various parts of the world [6]. Pollution can arise from even future human activities, which may not be observed for years, despite the fact that protecting surface water is costly and difficult [7, 8]. Finding accurate information about water quality is an important part of quality management that includes things like figuring out biological or human health risks, planning for urban growth, controlling pollution, managing water quality, and figuring out how water quality has changed over time [Evaluation of Water Quality using Water Quality]. This study evaluated the Water Quality Index (WQI) based on nine criteria by incorporating essential biological and physicochemical factors, including pH, dissolved oxygen, turbidity, faecal coliform, nutrients (nitrate and phosphate), and a comprehensive assessment [9-12]. Geographical and temporal analyses of river water quality have received more and more focus as of late. A better knowledge of seasonal changes and long-term environmental changes can be gained through temporal analysis, whereas pollution hotspots and the impact of local anthropogenic activities are possible to identify through spatial analysis.

The Baitarani River is a key river system of eastern India and holds a distinctive location due to its ecological, economic and social importance. The river rises from Gonasika Hills in Keonjhar district of Odisha and flows through many geological, biological and socio-economic landscapes before finally draining into the Bay of Bengal. Different populated cities on the bank of the river frequently dump their waste in the river basin with or without minimal treatment which may impair the river water quality [13]. In addition, the river is exposed to contamination by precipitation and agricultural runoff, which can also contaminate the river system [14].

This study aimed at comparing the water quality of the Baitarani River Basin from 2019 to 2024 to identify the primary factors affecting temporal variations in water quality, examining the appropriateness of water for consumption with anticipated outcomes, assessing the spatial-temporal changes over time and facilitating the identification of primary pollution sources at various sites along the river.

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2. Materials and Methods:

2.1. Study area

The Baitarani River is an integral part of the eastern Indian hydrological network and a prominent east-flowing river system in peninsular India. As one of Odisha's six main river systems, it's vital to the state's agricultural sector, fisheries, residential water supply, biodiversity preservation efforts, and economic growth in the surrounding area. The river basin encompasses a portion of Odisha and Jharkhand and runs from around 20°35′N to 22°15′N latitude and 85°10′E to 87°03′E longitude. Over most of its drainage area of around 10,982 km², the basin is located in the Indian state of Odisha. A little fraction of the basin extends into the neighboring state of Jharkhand.

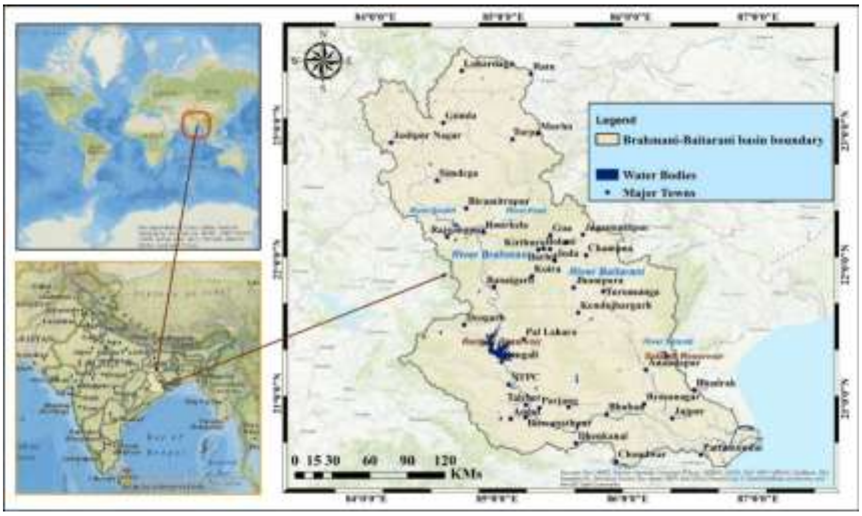

Figure 1: Study area Map of Baitarini River.

2.2. Sampling station

An evaluation of the spatial variance in water quality across the basin had been carried out by identifying eight representative sampling stations along the main river and its major tributaries. Criteria like as accessibility, hydrological significance, tributary, density of population, and population sources were considered when the stations were selected.

Table 1: Description of Sampling Stations in the Baitarani River Basin

Sample code	Sampling station	River/Tributary	Latitude	Longitude
S1	Champua	Baitarani	22°03’57”	85°40’ 24”
S2	Rimuli	Aradei	21°57'55.9"	85°37'16.2"
S3	Keonjhar	Aradei	21.62893	85.58169
S4	Swampatna	Baitarani	21.6319	85.89080
S5	Anandpur	Mushal	21°19'41.6"	86°03'34.8"
S6	Belanahali	Kushei	21.35011	86.05472
S7	Anandpur	Baitarani	21°12’40”	86°07’14”
S8	Akhuapada	Baitarani	20°55’0.7284”	86°23’45.1536”

2.3. Water quality parameters

Comparative assessment was based on the water quality data collected during 2019 and 2024. Sampling and analysis were performed by conventional protocols specified by the American

Public Health Association (APHA). Nine criteria usually used to calculate the National Sanitation Foundation Water Quality Index (NSF-WQI) were considered:

- pH
- Dissolved Oxygen (DO)
- Biochemical Oxygen Demand (BOD)
- Turbidity
- Total Solids (TS)
- Faecal Coliform
- Nitrate (NO_3^-)
- Phosphate (PO_4^{3-})
- Temperature Variation

The metrics chosen are essential markers of physicochemical status, organic pollution, microbiological contamination and nutrient enrichment in freshwater systems.

2.4. Water quality Index (WQI) Calculation

The total quality of the river water has been assessed by adopting the National Sanitation Foundation Water Quality Index (NSF-WQI) technique. NSF-WQI is a composite index that consolidates many water quality measures into one number that represents the overall water quality status.

The index was calculated using:

$$WQI = \Sigma(Wi \times Qi)$$

where:

WQI = Water Quality Index, Wi = Weight assigned to the ith parameter, Qi = Quality rating of the ith parameter

The study used weighting criteria according to the standard NSF-WQI approach where dissolved oxygen, pH, faecal coliform, temperature fluctuation, BOD, nitrate, phosphate, turbidity and total solids were assigned relative value according to their impacts on the water quality.

The calculated WQI values were grouped into conventional NSF-WQI categories as:

Table 2: NSF-WQI Classification

WQI Range	Water Quality Status
91–100	Excellent
71–90	Good
51–70	Medium
26–50	Poor
0-25	Very poor

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2.5 Comparative Assessment

To assess the evolution of water quality from 2019 to 2024, a comparative analysis was performed out. We investigated for trends and patterns in space and time by comparing the yearly averages of all metrics and the WQI across all sampling stations.

The WQI was used to measure the degree to which water quality improved or declined over the course of five years. Changes in land use, mining, farming, and the outflow of residential wastewater were considered as potential explanations for the observed station-to-station variations.

Table 3: Station-wise Comparison of Physicochemical and Biological Parameters During 2019 and 2024

	S1 (Baitarani at Champua)						S2 (Aradei at Rimuli)					
Parameters	2019			2024			2019			2024		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
pH	7.03	7.9	7.36	7	8	7.35	6.61	7.96	7.45	7.2	7.8	7.43
Turbidity	0.6	38	5.8	3.7	100	24.62	0.2	10.1	2.1	3.9	160	53.47
Total solids	57	145	96.52	96	367	212.17	67.4	558.6	244.8	156	561	295.92
D.O.	1.98	7.41	5.02	0	6.4	4.55	1.53	6.26	4.61	2.7	7.7	5.38
B.O.D	0.5	2.21	1.19	0.6	3.4	1.94	0.6	2.94	1.28	0.7	4.5	2.33
Faecal Colliform MPN/100ml	20	110 0	272.67	33	1700	523.58	110	2200	782.5	33	1300	492.75
Total phosphate	0	0.16	0.07	0.01	0.04	0.02	0.01	0.3	0.08	0.01	0.1	0.06
Nitrate	0.1	0.64	0.26	0.32	0.77	0.45	0.08	0.57	0.29	0.31	0.72	0.57
WQI	65	76	71	60	69	65	61	73	67	54	69	63

Parameters	S3(Aradei at Keonjhar)						S4 (Baitarani at Swampatna)					
	2019			2024			2019			2024		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
pH	7.11	7.9	7.52	7.2	8.5	7.56	7.1	7.6	7.39	6.8	8	7.28
Turbidity	0.6	22.6	5.88	4	170	43.13	0.3	11.8	4.9	2.8	140	32.01
Total solids	57.2	648	197.04	103	574	249.8	73.4	393.4	123.6	100	433	207.92

D.O.	2.53	7.37	4.53	2.5	7.6	5.8	2.15	5.85	4.2	3.1	7.4	5.65
B.O.D	0.5	1.38	0.92	0.5	2.5	1.42	0.38	1.95	1.14	0.9	4.6	2.01
Faecal Colliform MPN/100ml	20	2200	311.17	110	1700	406.7	20	1700	313.8	23	1300	493.00
Total phosphate	0.01	0.14	0.05	0.01	0.06	0.04	0.01	0.2	0.07	0.01	0.07	0.04
Nitrate	0.09	0.54	0.27	0.02	0.72	0.4	0.11	0.4	0.24	0.2	0.95	0.46
WQI	64	76	70	58	74	67	65	75	70	54	73	66

Parameters	**S5 (Mushal at Anandpur)**						**S6 (Kushei at Belabahali)**					
	2019			**2024**			**2019**			**2024**		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
pH	7.13	8.08	7.42	6.8	8.3	7.60	7.29	8.1	7.74	7.2	8.2	7.60
Turbidity	0.3	18.9	3.08	3.8	160	49.32	0.2	7.8	2.39	3.2	110	22.98
Total solids	89.4	949	233.57	155	665	275.43	101	849.5	284.6	166	409	222.25
D.O.	3.11	5.73	4.6	3.5	7.6	5.40	2.56	6.46	5	4.3	9.4	5.78
B.O.D	0.34	2.56	1.31	1.3	4.5	2.38	0.44	2.21	1.26	0.7	3.7	2.05
Faecal Colliform MPN/100ml	20	2400	397.92	70	2200	420.83	220	7000	1815	220	1700	999.17
Total phosphate	0.01	0.17	0.05	0.01	0.07	0.05	0.01	0.2	0.07	0.01	0.07	0.02
Nitrate	0.12	0.48	0.23	0.2	0.68	0.44	0.1	0.77	0.27	0.32	0.65	0.42
WQI	60	77	70	53	70	64	62	69	66	56	71	65

Parameters	**S7 (Baitarani at Anandpur)**						**S8 (Baitarani at Akhuapada)**					
	2019			**2024**			**2019**			**2024**		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
pH	7.08	7.8	7.36	7.2	7.9	7.53	6.18	8.32	7.38	7.1	8.2	7.53
Turbidity	0.5	8.8	2.08	3.6	85	16.84	0.3	18.3	4.31	2.4	90	14.18
Total solids	64.7	316	168.13	113	390	209.58	66.6	289	139	121	264	178.58
D.O.	2.77	6.65	5.1	3.1	7.4	5.13	0.22	6.56	3.98	3.5	8.9	5.98
B.O.D	0.57	3.33	1.5	1.4	4.6	2.27	0.39	2.75	1.06	0.8	4.9	2.05

Faecal Colliform MPN/100ml	78	3300	1282.3	130	2300	785.00	68	1700	802.3	460	2300	1420.00
Total phosphate	0.01	0.4	0.08	0.01	0.08	0.05	0.01	0.59	0.1	0.01	0.2	0.07
Nitrate	0.09	1.11	0.39	0.33	0.89	0.47	0.13	0.93	0.32	0.35	0.94	0.58
WQI	64	73	68	59	69	65	61	75	67	62	72	66

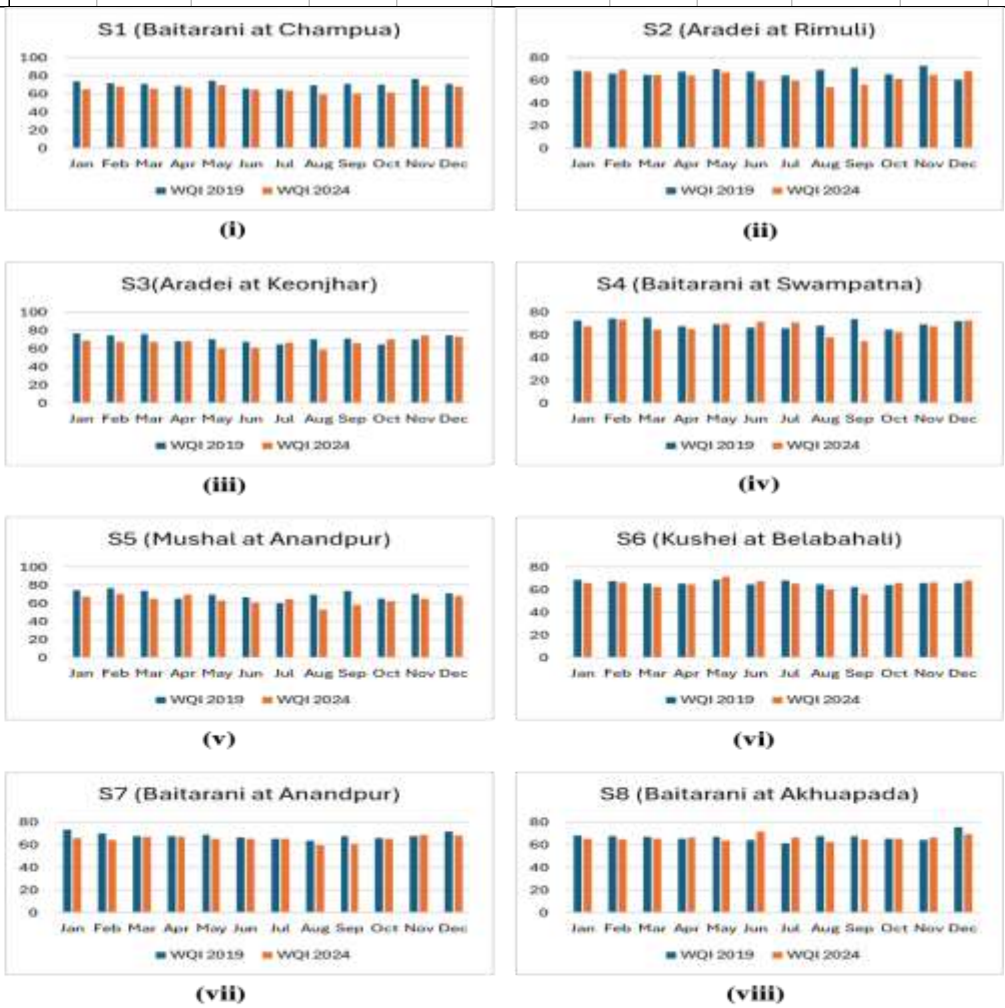

Figure 2: Graphical Representation of the Comparison of Water Quality Index between 2019 and 2024 for different Sampling Locations

2.6. Data Analysis

To find the minimum, maximum, and average values of all the water quality measures, descriptive statistics were used. Station-wise analysis and comparative graphical representations were used to assess spatial and temporal patterns.

The findings were analyzed to determine significant pollution hotspots, identify critical factors affecting WQI, and assess whether river water is suitable for a range of applications. The effects of turbidity, fecal coliform contamination, nutrient enrichment, and organic pollution on the general water quality conditions in the Baitarani River Basin were given special attention.

3. Results and Discussion

3.1. Spatial and Temporal variations of Water Quality Index

The WQI was employed to assess the overall water quality condition of the Baitarani River Basin and to analyze geographical and temporal fluctuations from 2019 to 2024. The NSF-WQI findings demonstrated that water quality throughout the basin varied from moderate to good categories during both study years.

Table 4: Comparision of Mean WQI Values (2019 Vs 2024)

Station	2019	2024
S1	71	65
S2	67	63
S3	70	67
S4	70	66
S5	70	64
S6	66	65
S7	68	65
S8	67	66

Figure 3: Mean WQI Comparison (2019 vs 2024)

The overall WQI readings were in the range of 60-77 in 2019 and 53-74 in 2024 indicating a slow deterioration in water quality in five years. While the river system stayed within the permissible range of several designated uses, a significant decline was noted at a number of monitoring stations. This reduction is a sign of increased anthropogenic stress in the basin due to mining, home wastewater outflow, agricultural runoff and land use adjustments. Spatial variation of WQI was observed throughout the basin. Water quality was generally better at stations in the upper and intermediate reaches than that at downstream locations. The relatively higher WQI values recorded at Champua (S1), Keonjhar (S3), Swampatna (S4) and Anandpur–Mushal (S5) indicate reduced buildup of pollutants and improved self-purification capacity. Lower values of WQI suggesting more stress and pollution loading on the environment were seen at stations like Rimuli (S2), Belanahali (S6) and Akhuapada (S8). Spatial variability seen is due to variations in land use, population density, industrial activity, tributary inputs and watershed characteristics within the basin.

3.2. Turbidity and Total Solids

Turbidity is an integral marker for suspended particulate matter in water and has a substantial impact on the health of aquatic ecosystems. The present study established that turbidity was a prominent characteristic contributing to low WQI values in various monitoring stations. Higher turbidity values were especially recorded in the lower regions of the basin. Mining sites, watershed erosion, agricultural runoff and monsoonal surface flow increased the sediment movement and contributed significantly to the suspended sediment load. The upper part of the basin is under heavy mineral extraction activities, which cause more soil disturbance and silt mobilization during rainy events.

Total solids also revealed significant variations between sampling stations. The rise in total solids from 2019 to 2024 is indicative of an increasing anthropogenic effect in the basin. Higher levels of suspended and dissolved solids restrict light penetration and impact photosynthetic activity and aquatic ecosystem conditions. Combined impacts of turbidity and total solids were found substantial in reduction of WQI values at different locations.

Table 5: Mean parameter Comparison

Parameter	2019 Mean Range	2024 Mean Range
pH	7.36–7.74	7.28–7.60
Turbidity	2.08–5.88	14.18–53.47
DO	3.98–5.10	4.55–5.98
BOD	0.92–1.50	1.42–2.38
Faecal Coliform	272–1815	406–1420

3.3. Dissolved Oxygen and Biochemical Oxygen Demand

Dissolved oxygen (DO) and biochemical oxygen demand (BOD) are some of the most important indices of river health and organic contamination. The report also mentions that DO concentrations were within permissible limits at most locations, indicating that the river system can still support aquatic life.

Nevertheless, in stations that were affected by the accumulation of organic matter and the discharge of domestic effluent, there were localized reductions in DO. However, small increases in BOD were seen in 2024 compared to 2019. High concentrations of BOD mean high microbial breakdown of organic material, which uses dissolved oxygen and can be damaging to aquatic life.

Throughout the basin, there was an inverse association between DO and BOD. Dissolved oxygen concentrations were generally lower in the areas with increased organic loading. The detected BOD values were below the critical contamination levels but the developing pattern indicates the necessity for continuing monitoring and proper management of wastewater.

3.4. Microbial contamination

Throughout the Baitarani River Basin, a significant spatial variation in microbial contamination was detected through fecal coliform analysis. Several monitoring stations revealed high faecal coliform counts, indicating contamination from residential sewage, livestock operations, open defecation practices and poor sanitation infrastructure.

One of the most significant parameters that influences WQI values was identified as microbial contamination. High concentrations of faecal coliform bacteria make water unsafe to drink and may even be harmful to the public's health. Communities with direct access to untreated river water might therefore be susceptible to water-borne illnesses.

Microbial contamination from 2019 to 2024 is ongoing and indicates that sanitation-related difficulties are still a major environmental issue in the basin. The improvement of sewage treatment plants and rural sanitation systems is essential to minimize the microbiological contamination and improve the general health of the rivers.

3.5. Nutrient Enrichment

Nitrate and phosphate are key nutrients regulating the productivity of the water column and functioning of the ecosystem. The amounts of both nutrients were below permitted limits in most of the monitoring stations during the trial period. However, limited increases were noted in areas affected by agricultural activity and disposal of household wastewater.

Nutrient enrichment is mainly from fertilizer application, surface runoff from cultivated fields, inputs from livestock waste and city sewage. Although the nutrient levels were not high enough to cause severe eutrophication, the increasing trend found at several stations implies increasing anthropogenic influence.

Eventually, the structure of aquatic ecosystems may be impacted, dissolved oxygen availability may be reduced, and excessive algal growth may be promoted by continuous nutrient loading. Hence, nutrient management should be viewed as an important component of watershed conservation measures.

3.6. Comparative Assessment of Water Quality (2019-2024)

Throughout the five-year study period, the comparative analysis revealed a general degradation in water quality throughout the Baitarani River Basin. In comparison to 2019, the majority of monitoring stations indicated lower WQI values in 2024, suggesting that environmental degradation is progressing. The main indicators of degradation were a rise in turbidity, total solids, faecal coliform levels, and localized nutrient enrichment. According to these findings, there is an increasing amount of pressure from both point and non-point sources of pollution.

The main pollution inputs in the middle and lower reaches are domestic wastewater discharge and agricultural runoff, whereas sediment loading and turbidity are largely contributed by mining activities in the upper watershed. The declining WQI values observed throughout the basin are indicative of the cumulative impact of these activities.

The findings underscore the importance of coordinated river basin management, ongoing water quality monitoring, effective wastewater treatment, responsible mining operations, and enhanced agricultural management to ensure the long-term ecological health of the Baitarani River system.

3. Discussion

The present study assessed spatio-temporal variation of water quality in Baitarani River Basin by utilizing National Sanitation Foundation Water Quality Index (NSF-WQI). The outcomes indicated that the water quality conditions of the river basin were found to be medium to good for both years of the study. However, a significant decrease in the values of WQI was recorded from 2019 to 2024. This trend reflects the increasing environmental pressure on the river system and the expanding impact of anthropogenic activities in the basin. High turbidity impairs the visual quality of water, interferes with photosynthesis, change aquatic habitat and transfer of pollutants. Microbial pollution was another key aspect that influenced water quality. The observed increase in faecal coliform concentrations at different monitoring sites indicates the effect of home sewage effluent, poor sanitation infrastructure, livestock operations, and other anthropogenic pollution sources. According to Shrestha et al. (2023) [15], the low DO contentatX-(8), was produced by rash discharge containing nutrients and organic matter that build near the river, as well as increased levels of microbial activity during organic matter breakdown.

DO and biochemical oxygen demand were used to illuminate the organic pollution state of the river. Dissolved oxygen concentrations were typically sufficient to maintain aquatic life; however localized declines were noted at stations receiving organic waste inputs. At the same time, minor increases in biochemical oxygen demand reflect increased microbial breakdown of organic materials. Fish can die in low-oxygen water. Thus, fish require an oxygen concentration of about 2 to 5 mg/L depending on the species. Also, the increased pollution of the organic compounds causes dissolved oxygen to disappear [14]. These conditions are normally connected with the discharge of residential wastewater and organic pollutants. The inverse relationship that was identified between dissolved oxygen and biological oxygen demand further confirms the impact of organic loading on the quality of the river water.

The comparison between 2019 and 2024 shows that the water quality degradation is not sudden but slow. This pattern shows the presence of cumulative consequences from various sources of contamination, rather than one dominant source of contaminant. The results reveal the linked effects of mining activities, agricultural practices, domestic wastewater discharge, land-use changes and population growth on the river water quality.
The results of the present analysis are comparable with the data reported from various river systems in India where rising anthropogenic activities are leading to decreasing water quality and ecological degradation. Similar studies have identified the main causes of deterioration of water quality in riverine ecosystems as turbidity, microbial contamination, organic pollution and nutrient enrichment [14, 15-17]. results of this study confirm the significance of integrated watershed management techniques that include point and non-point source contamination together.
Das (2023) [18] reported that the main factors contributing to the decline of water quality in the basin were urbanization, agricultural activities, discharge of residential sewage, landfills and anthropogenic disturbances. Likewise, the present study showed a drop in WQI values from 2019 to 2024 at all the monitoring stations, where increased turbidity, faecal coliform contamination and organic pollution were identified as the main contributors to the decline in water quality. The agreement of both studies reinforces the conclusion that growing anthropogenic pressures continue to adversely affect the ecological condition of the Baitarani River Basin and emphasizes the need for integrated watershed management and pollution control measures [19].

Special focus should be paid to the control of sediment inputs from mining areas, improvements to the municipal wastewater treatment facilities, expansion of rural sanitation coverage, and promotion of sustainable farming practices. Such actions would lower pollutant loads and improve the long-term ecological health of the river system.
Finally, the analysis reveals that the Baitarani River Basin is presently under moderate water quality conditions but the falling tendency for the period of five years is an early warning signal. Continued anthropogenic strain necessitates comprehensive intervention to prevent further degradation of water quality and compromising of the river's ecological and socio-economic functions. Thus, proactive conservation and management techniques are needed to ensure sustainable exploitation of this critical freshwater resource.

4. Conclusion

The present study was intended to analyze the regional and temporal fluctuation of water quality of Baitarani River Basin, Odisha, India, by doing a comparative analysis of water quality status during 2019 and 2024 using National Sanitation Foundation Water Quality Index (NSF-WQI).

Eight strategically selected monitoring stations encompassing the main river channel and its tributaries were studied for nine critical physicochemical and biological characteristics. The results revealed that the overall water quality of Baitarani River Basin was moderate to good in both the research periods. However, when comparing the WQI values of 2019 and 2024, a progressive degradation of the water quality was seen at various monitoring locations. The WQI values were between 60–77 in 2019 and 53–74 in 2024, which shows growing environmental strain in the basin. The observed decline, however, is indicative of the growing impact of anthropogenic activities even while the river system continues to support a number of approved uses.
DO concentrations were generally within permissible limits but some localised reductions and concomitant increases in biochemical oxygen demand showed organic contamination at some places. Nitrate and phosphate concentrations generally were within acceptable limits at most monitoring stations; however, some localized nutrient enrichment indicated increasing impact from agricultural runoff and domestic wastewater sources.

The study findings suggest the following recommendations:

1. Develop a long-term river water quality monitoring strategy for all main tributaries and important pollution hotspots.

2. Upgrade wastewater treatment facilities in urban and semi-urban regions to reduce microbiological and organic pollutants.

3. Promote sustainable mining practices and sediment management methods in upstream catchment areas.

4. Promote eco-friendly agriculture techniques to reduce nutrient runoff into the river system.

5. Improvement of rural sanitary facilities and knowledge of the people on water pollution and river protection.

6. Implementation of a comprehensive river basin management system integrating government agencies, local communities, industries and environmental partners.

The Baitarani River Basin is presently under moderate water quality conditions and the downward trend of water quality in the period of 2019-2024 is a harbinger of increasing environmental stress in the basin. The ecological integrity, economic worth and long-term sustainability of this significant river system can be preserved by continuous monitoring, effective pollution control measures and sustainable watershed management.

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