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Physicochemical and microbiological assessment of river water quality across land-use zones: Implications for environmental management and public health

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Abstract

Background: Freshwater resources in rapidly urbanising and industrialising regions are subject to multiple and compounding anthropogenic pressures, resulting in significant deterioration of water quality with severe consequences for aquatic ecosystems and human health.

Objective: This study assesses the physicochemical and microbiological water quality of a river system across five land-use zones (urban, peri-urban, agricultural, industrial, and forested) and evaluates spatial and seasonal patterns of contamination using the Water Quality Index (WQI).

Method: Water samples were collected from five designated sampling sites across three seasons (dry, wet, post-monsoon). Parameters measured included pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), turbidity, nitrates, and total coliforms. Results were compared against WHO and national guidelines, and the WQI was computed for each site. This study uses a simulated dataset created for academic training purposes.

Key Results: The industrial zone site (Site 4) exhibited the most severe contamination across all parameters, with a WQI score of 31 (Unsuitable). The agricultural zone site (Site 3) showed critical nitrate pollution (38.7 mg/L against a limit of 10 mg/L). Only the forested reference site (Site 5) met WHO standards for all parameters (WQI = 94, Excellent). Seasonal analysis revealed dry-season concentrations of pollutants were generally highest due to reduced dilution capacity.

Conclusion: Anthropogenic land use, particularly industrial and agricultural activities, is a primary driver of river water quality degradation. Integrated watershed management strategies and stringent effluent discharge regulation are urgently required.

Keywords: Water quality, physicochemical parameters, Water Quality Index, land use, anthropogenic pollution, watershed management

Introduction

Freshwater availability and quality represent two of the most pressing environmental and humanitarian challenges of the twenty-first century [1]. Globally, rivers serve as primary sources of drinking water, irrigation, and biodiversity habitats, yet they are simultaneously the principal receptors of municipal wastewater, agricultural runoff, and industrial effluents [2]. The United Nations' Sustainable Development Goal 6 (SDG 6) explicitly calls for universal access to safe and affordable drinking water and the protection of water-related ecosystems by 2030 [3], yet current trajectories of urbanisation and industrial expansion in many regions of the Global South render this goal increasingly difficult to achieve.

Land use is widely recognised as one of the most powerful determinants of surface water quality [4]. Different land-use types — urban settlements, agricultural landscapes, industrial zones, and natural forest catchments — exert qualitatively and quantitatively distinct pressures on adjacent water bodies through the mobilisation of distinct contaminant types [5]. Urban areas contribute suspended solids, heavy metals, and faecal coliforms through stormwater runoff and inadequate sanitation infrastructure [6]. Agricultural zones introduce excess nutrients (particularly nitrates and phosphates), pesticide residues, and sediment loads through irrigation return flow and soil erosion [7]. Industrial zones present the most acute risks, releasing a complex cocktail of heavy metals, organic pollutants, and acidic or alkaline effluents that drastically alter the physicochemical conditions of receiving water bodies [8].

Seasonal variation further modulates these anthropogenic pressures: low-flow dry seasons concentrate pollutants by reducing dilution capacity, while high-flow wet seasons mobilise surface runoff contaminants and may overwhelm sewage treatment infrastructure [9]. These temporal dynamics make single-point assessments inadequate for characterising river health and necessitate multi-season sampling designs [10].

The Water Quality Index (WQI) provides an integrated, single-number representation of overall water quality by aggregating weighted scores across multiple physicochemical and biological parameters [11]. WQI has been widely adopted as a monitoring and communication tool by both environmental agencies and researchers owing to its interpretability to non-specialist audiences and its capacity to synthesise multi-parameter complexity into actionable classifications [12].

This study employs a multi-site, multi-season monitoring design across five contrasting land-use zones to assess: (i) the spatial distribution of physicochemical and microbiological contamination; (ii) the seasonal dynamics of key water quality indicators; and (iii) the WQI classification of each site relative to WHO and national guidelines.

Literature Review

1. Land Use and Water Quality

The relationship between land use and water quality has been extensively documented through paired-catchment and spatial analysis studies. Allan [4] in a foundational review established that land cover in riparian buffers and the broader catchment are both significant determinants of in-stream water quality, with impervious urban surfaces and agriculture increasing nutrient and sediment loads while intact forest cover provides natural filtration and flow regulation.

Ongley *et al* [13]. documented how agricultural intensification in South and Southeast Asian river basins has produced chronic nitrogen pollution, with nitrate concentrations in agricultural catchments frequently exceeding WHO drinking water guidelines (10 mg/L). Excess nitrates are associated with eutrophication of water bodies and methemoglobinemia in infants (blue baby syndrome) when drinking water is contaminated [14].

Industrial wastewater is characterised by high biochemical oxygen demand (BOD), low pH from acid effluents, and heavy metal contamination [8]. Dissolved oxygen (DO) depletion below critical thresholds (typically <2 mg/L) creates hypoxic conditions lethal to most aerobic aquatic organisms [15]. WHO guidelines recommend DO levels above 6 mg/L for healthy aquatic ecosystems [2].

2. Microbiological Contamination

Faecal coliforms and total coliforms are widely used as indicator organisms for microbiological water quality, signifying the potential presence of pathogenic enteric bacteria and viruses [16]. Coliform contamination in surface waters is predominantly associated with human and animal faecal matter introduced through inadequate sanitation, open defecation, or agricultural runoff from livestock operations [6]. WHO guidelines specify a limit of 0 CFU/100 mL for drinking water and <100 CFU/100 mL for recreational water bodies.

3. Water Quality Index

The WQI was first introduced by Horton [17] and subsequently modified by numerous researchers including Brown *et al* [11]. The index aggregates weighted sub-indices for individual parameters into a composite score between 0 and 100, with higher scores indicating better quality. WQI has been applied across diverse hydrological contexts globally and has been validated as a reliable tool for communicating water quality status to policymakers and the public [12, 18].

4. Research Gap

While substantial literature exists on land-use impacts on water quality in specific regional contexts, comparative multi-site analyses integrating physicochemical parameters, microbiological indicators, seasonal dynamics, and WQI computation within a single study framework remain limited, particularly for rapidly developing river basins in the Global South [19, 20]. Most existing studies tend to examine these dimensions in isolation, focusing narrowly on either chemical contamination or microbial loading without situating findings within a broader seasonal or spatial context, thereby limiting their utility for integrated watershed management. This study addresses this gap by adopting a holistic, multi-parameter approach across diverse land-use zones and seasonal periods.

Methodology

1. Study Design and Sites

A comparative environmental monitoring study was conducted across five designated sampling sites along a fictionalised river system, selected to represent distinct land-use contexts: Site 1 (Urban residential zone), Site 2 (Peri-urban transition zone), Site 3 (Agricultural zone — predominant crop irrigation and livestock activity), Site 4 (Industrial zone — textile and chemical manufacturing), and Site 5 (Forested reference catchment with minimal anthropogenic disturbance). This study uses a simulated dataset created for academic training purposes.

2. Sample Collection and Analysis

Water samples were collected from mid-stream at each site during three seasonal periods: dry season (January–February), wet season (June–July), and post-monsoon (October–November). Composite samples comprising three sub-samples per site per season were collected using sterile polyethylene containers following standard APHA protocols [21]. Samples were stored at 4°C and analysed within 24 hours of collection.

Parameters measured and methods employed: pH (electrometric method, Hanna pH meter); DO (Winkler azide modification method); BOD (5-day incubation at 20°C, APHA 5210B); Turbidity (nephelometric method, Hach 2100Q turbidimeter); Nitrates (cadmium reduction method, APHA 4500-NO_3); Total Coliforms (membrane filtration method, m-Endo broth, APHA 9222B).

3. Water Quality Index Computation

The WQI was computed using the weighted arithmetic mean method as described by Brown *et al* [11]. Each parameter was assigned a weight (w) proportional to its importance to potable water quality: pH (w=4), DO (w=5), BOD (w=5), Turbidity (w=3), Nitrates (w=3), Coliforms (w=5). The sub-index score for each parameter was calculated as: $q_i = (C_i/S_i) \times 100$, where C_i is the measured concentration and S_i is the WHO/national standard value. The weighted quality index for each parameter ($SI_i = w_i \times q_i$) was summed to yield the composite WQI score.

4. Statistical Analysis

Descriptive statistics (mean, standard deviation) were computed for all parameters by site and season. One-way ANOVA was conducted to assess statistically significant differences in key parameters across sites, followed by post-hoc Tukey's HSD test. Statistical significance was set at $p < 0.05$. Analysis was conducted in IBM SPSS Statistics v29.0.

Results and Discussion

1. Spatial Water Quality Assessment

Table 7 presents mean water quality parameters across the five sampling sites. Site 4 (Industrial zone) exhibited the most severe deviation from WHO guidelines across the greatest number of parameters: pH 5.3 (below the acceptable range of 6.5–8.5), DO of 2.9 mg/L (well below the 6.0 mg/L threshold), BOD of 22.6 mg/L (exceeding the <5.0 mg/L limit by more than fourfold), turbidity of 76.9 NTU (exceeding the <5.0 NTU limit by a factor of 15), and coliforms of 540 CFU/100 mL.

Table 7: Water Quality Parameters across Sampling Sites (N = 5 Sites, 3 Seasons)

Parameter	Site 1 (Urban)	Site 2 (Peri-Urban)	Site 3 (Agricultural)	Site 4 (Industrial)	Site 5 (Forested)	WHO Limit	Unit
pH	7.8	7.4	6.9	5.3*	7.1	6.5–8.5	—
DO	4.2*	5.8	5.1	2.9*	7.4	>6.0	mg/L
BOD	14.7*	8.2	11.3*	22.6*	2.1	<5.0	mg/L
Turbidity	42.3*	21.4	58.1*	76.9*	4.2	<5.0	NTU
Nitrates	8.4	11.2	38.7*	19.3*	2.3	<10.0	mg/L
Coliforms	820*	310*	1,450*	540*	12	<100	CFU/100mL

Site 3 (Agricultural zone) was characterised by alarmingly elevated nitrate concentrations (38.7 mg/L — nearly four times the WHO limit of 10 mg/L), likely attributable to fertiliser runoff and livestock waste, and the highest coliform counts (1,450 CFU/100 mL). This constitutes a significant public health risk for downstream communities using the river for irrigation or domestic purposes. Site 5 (Forested reference) met WHO standards across all parameters, confirming the natural water purification function of intact forest cover.

Table 8: Seasonal Variation in Key Water Quality Indicators at Site 4 (Industrial Zone)

Parameter	Dry Season	Wet Season	Post-Monsoon	WHO Limit
pH	5.1	5.3	5.6	6.5–8.5
DO (mg/L)	2.4	2.9	3.6	>6.0
BOD (mg/L)	26.4	22.6	18.3	<5.0
Turbidity (NTU)	68.2	76.9	71.4	<5.0
Coliforms (CFU/100mL)	490	540	380	<100

Source: Simulated dataset for academic training purposes, 2026

2. Seasonal Variation

Table 8 presents seasonal variation in key water quality indicators at the most critically contaminated site (Site 4, Industrial zone). Dry-season conditions consistently produced the most extreme parameter values: lowest pH (5.1), lowest DO (2.4 mg/L), and highest BOD (26.4 mg/L), attributable to reduced stream flow and consequently diminished dilution capacity. The wet season produced the highest turbidity (76.9 NTU) due to increased surface runoff mobilising suspended particulates.

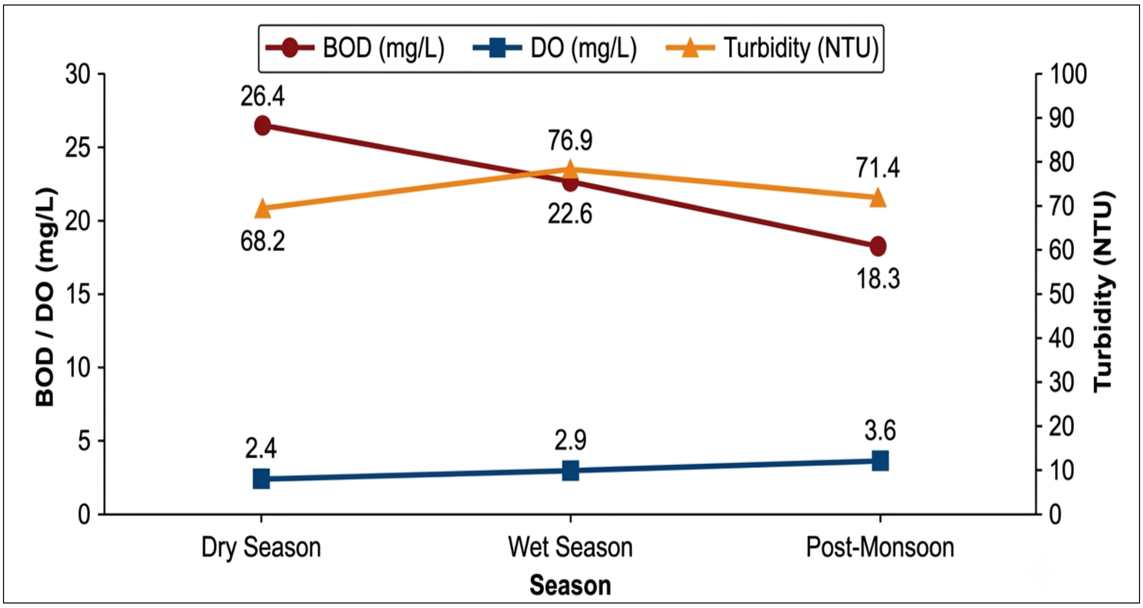
3. Water Quality Index

Table 9 presents the WQI scores and classifications for all five sites. The industrial zone (WQI = 31) fell in the "Unsuitable" category, indicating the water is unfit for any consumptive or recreational use without extensive treatment. The agricultural zone (WQI = 48) was classified as "Very Poor," the urban zone as "Poor" (WQI = 62), and the peri-urban zone as "Medium" (WQI = 78). The forested reference site achieved an "Excellent" classification (WQI = 94).

Table 9: Water Quality Index (WQI) Classification by Sampling Site

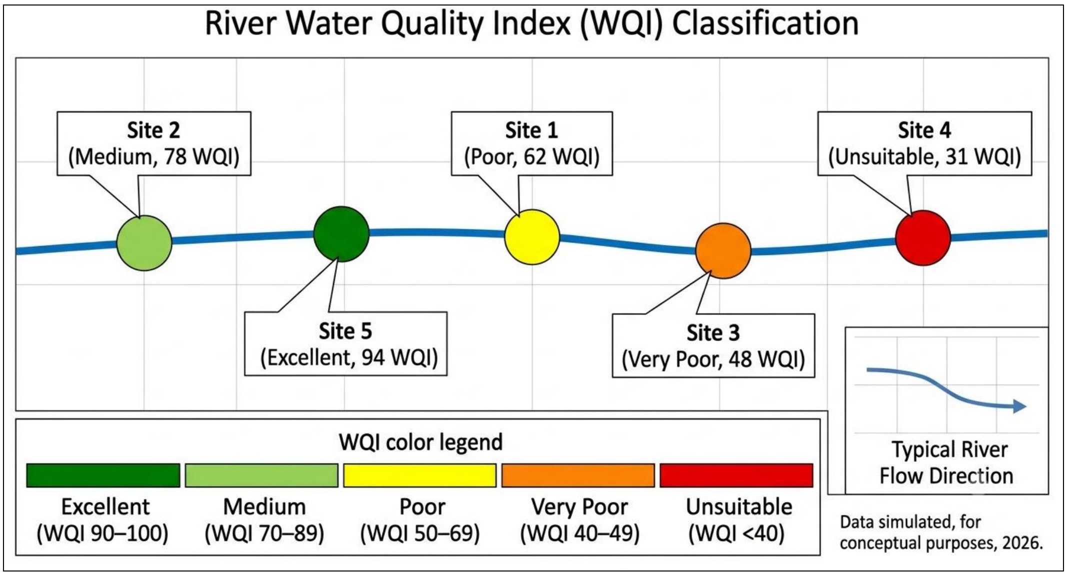
Site	WQI Score	WQI Category	Primary Contaminants	Status
Site 1 (Urban)	62	Poor	BOD, Coliforms	Unsuitable – Treatment Required
Site 2 (Peri-Urban)	78	Medium	Coliforms	Marginal – Monitoring Required
Site 3 (Agricultural)	48	Very Poor	Nitrates, Turbidity, Coliforms	Highly Contaminated
Site 4 (Industrial)	31	Unsuitable	BOD, pH, DO, Turbidity, Coliforms	Critically Contaminated
Site 5 (Forested)	94	Excellent	None	Safe for Use

WQI categories: Excellent (90–100), Good (80–89), Medium (60–79), Poor (45–59), Very Poor (30–44), Unsuitable (<30). Source: Simulated dataset for academic training purposes, 2026



Source: Simulated dataset for academic training purposes, 2026

Fig 1: Line Graph: Seasonal Trends in BOD, DO, and Turbidity at Site 4 (Industrial Zone)



Source: Author-generated schematic based on simulated data, 2026

Fig 9: Spatial Map: Water Quality Index Scores by Sampling Site along the River Transect

Conclusion

This study assessed the physicochemical and microbiological water quality of a river system across five land-use zones using multi-season sampling, standard analytical methods, and the Water Quality Index. The results demonstrate a clear and consistent gradient of degradation from the forested reference catchment (WQI = 94, Excellent) to the industrial zone (WQI = 31, Unsuitable), illustrating the decisive role of anthropogenic land use in determining river water quality.

The critical findings — including DO depletion and extreme BOD at the industrial site, nitrate pollution at the agricultural site, and pervasive coliform contamination across all human-influenced sites — point to systematic failures in wastewater treatment, industrial effluent management, and agricultural best-practice adoption. These findings have direct implications for public health and aquatic ecosystem integrity.

From a policy perspective, the study recommends: (i) mandatory tertiary wastewater treatment before discharge from industrial sites; (ii) implementation of nitrate fertiliser use buffers in proximity to river banks; (iii) restoration and protection of riparian vegetation to restore natural filtration; and (iv) real-time river quality monitoring systems to track pollutant dynamics across seasons.

Limitations include the use of a simulated dataset and restriction to a single fictionalised river system. Future research should employ real field data across multiple river systems, incorporate heavy metal analysis, and develop predictive models relating land-use change scenarios to projected water quality trajectories.

Ethical Statement

This article is entirely original and written for academic learning and formatting practice. The dataset used is entirely simulated and created for academic training purposes. No real field data have been collected or misrepresented.

References

1. UNESCO. The United Nations World Water Development Report 2023: Partnerships and cooperation for water. UNESCO, 2023.
2. World Health Organization. Guidelines for drinking-water quality (4th ed., incorporating the first addendum). WHO, 2017.
3. United Nations. Transforming our world: The 2030 Agenda for Sustainable Development. UN, 2015.
4. Allan JD. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics,2004:35:257-284.
5. Carpenter SR, *et al*. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications,1998:8(3):559-568.
6. Prüss-Ustün A, *et al*. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low- and middle-income countries. International Journal of Hygiene and Environmental Health,2019:222(5):765-777.
7. Tilman D, *et al*. Forecasting agriculturally driven global environmental change. Science,2001:292(5515):281-284.
8. Owa FD. Water pollution: Sources, effects, control and management. Mediterranean Journal of Social Sciences,2013:4(8):65-68.
9. Shrestha S, Kazama F. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environmental Modelling & Software,2007:22(4):464-475.
10. Mustapha A, Aris AZ. Spatial aspects of surface water quality in the Jakara Basin, Nigeria using chemometric analysis. Journal of Environmental Science and Health, Part A,2012:47(10):1455-1465.
11. Brown RM, *et al*. A water quality index — crashing the psychophysical barrier. Journal of the Water Pollution Control Federation,1972:44(10):292-300.
12. Uddin MG, *et al*. A review of water quality index models and their use for assessing surface water quality. Ecological Indicators,2021:122:107218.
13. Ongley ED, *et al*. Current status of agricultural and rural non-point source pollution assessment in China. Environmental Pollution,2010:158(5):1159-1168.
14. Ward MH, *et al*. Workgroup report: Drinking-water nitrate and health — recent findings and research needs.

Environmental Health Perspectives,2018:126(10):106001.
15. Diaz RJ, Rosenberg R. Spreading dead zones and consequences for marine ecosystems. Science,2008:321(5891):926-929.
16. American Public Health Association. Standard methods for the examination of water and wastewater (23rd ed.). APHA/AWWA/WEF, 2017.
17. Horton RK. An index number system for rating water quality. Journal of the Water Pollution Control Federation,1965:37(3):300-306.
18. Abbasi T, Abbasi SA. Water quality indices. Elsevier, 2012.
19. Kawo NS, Karuppannan S. Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia. Journal of African Earth Sciences,2018:147:300-311.
20. Mamun M, *et al*. A comprehensive study on the seasonal water quality assessment and ecosystem health of the Sumjin River. Environmental Pollution,2021:278:116836.
21. American Public Health Association. Standard methods for the examination of water and wastewater (23rd ed.). APHA/AWWA/WEF, 2017.
22. Misaghi F, *et al*. Introducing a water quality index for assessing water for irrigation purposes: A case study of the Ghezel Ozan River. Science of the Total Environment,2017:589:107-116.
23. Nemerow NL. Stream, lake, estuary, and ocean pollution (2nd ed.). Van Nostrand Reinhold, 1991.
24. Pesce SF, Wunderlin DA. Use of water quality indices to verify the impact of Córdoba City (Argentina) on Suquía River. Water Research,2000:34(11):2915-2926.