International Journal of
Pollution: Prevention & Control
ISSN: 3048-6750
Volume 4, Issue 1, 2026
January–June
DOI (Journal): 10.37591/IJPPC
https://journals.stmjournals.com/ijppc
Research IJPPC

Investigation of Pollution Status in River No. 2, Freetown, Sierra Leone, Using Physicochemical and Bacterial Indicators

Yahaya Kudush Kawa[1,*], Gibrilla Thullah[2], Sam Sonny Tommy[2], Victoria Olufemi Danke Kawa[3]

Abstract

This study assessed the physicochemical and bacteriological quality of surface water in the River No. 2 watershed, Sierra Leone, through monthly sampling from March to August 2024 at upstream, midstream, and downstream sites. Analyses included temperature, turbidity, pH, electrical conductivity, total dissolved solids, ammonia, fluoride, sulfite, nitrate, lead, arsenic, chromium, and microbial indicators (Escherichia coli, fecal and non-fecal coliforms). Most physicochemical parameters met the World Health Organization (WHO) drinking-water guidelines. pH (7.0–7.3), total dissolved solids (TDS) (7–17 mg/L), turbidity (0–3 NTU), ammonia, nitrate, and sulfite were within acceptable limits. However, chromium (up to 0.70 mg/L) and fluoride (up to 2.5 mg/L) exceeded WHO standards at some locations, indicating localized contamination. Lead and arsenic were not detected. Water quality index (WQI) results varied by method. The Weighted Arithmetic WQI classified the water as very poor to unfit for drinking (244.5–458.9), while Canadian Council of Ministers of the Environment (CCME) WQI scores (79.3–89.9) indicated "Good" upstream and midstream conditions and "Fair" downstream quality. This discrepancy reflects differences in index sensitivity. Fecal and non-fecal coliforms were detected, though E. coli was absent, suggesting no recent fecal pollution. Overall, the river is suitable for several uses, but elevated fluoride and chromium require targeted intervention and continued monitoring.

Keywords: Freetown, microbial assessment, physicochemical, River No. 2 catchment, water monitoring

INTRODUCTION

Surface water, including rivers, streams, springs, lakes, and reservoirs, is the most accessible source of freshwater for domestic, agricultural, and industrial use. They are closely linked to groundwater systems through recharge, discharge, and subsurface flow processes. As global demand for freshwater increases, concerns regarding water quality and sustainability have intensified. Although water is essential for human survival and ecosystem integrity, its use presents risks associated with chemical, physical, and microbial contamination.

Major rivers worldwide support multiple functions such as drinking water supply, irrigation, hydropower generation, transportation, recreation, fisheries, and waste assimilation. However, these same services often drive degradation; wastewater discharge, agricultural runoff, and industrial activities continue to diminish water quality, particularly in regions lacking effective waste

***Author for Correspondence**
Yahaya Kudush Kawa
E-mail: yahayak.kawa@njala.edu.sl

[1]Senior Lecturer, Chemistry Department, Njala University, Njala, Sierra Leone, West Africa
[2]Student, Institution of Environmental Management and Quality Control, Njala University, Njala, Sierra Leone, West Africa
[3]Lecturer, Department of Mathematics, Milton Margai Technical University, Njala, Sierra Leone, West Africa

Received Date: January 13, 2026
Accepted Date: January 16, 2026
Published Date: February 07, 2026

Citation: Yahaya Kudush Kawa, Gibrilla Thullah, Sam Sonny Tommy, Victoria Olufemi Danke Kawa. Investigation of Pollution Status in River No. 2, Freetown, Sierra Leone, Using Physicochemical and Bacterial Indicators. International Journal of Pollution: Prevention & Control. 2026; 4(1): 11–27p.

management infrastructure. In many low- and middle-income countries, substantial volumes of untreated wastewater enter rivers owing to inadequate sanitation systems and poorly managed landfills.

Surface water quality is influenced by both natural processes, such as erosion, sedimentation, seasonal hydrological variation, and anthropogenic pressures, including urbanization, industrialization, agriculture, dam construction, and accidental chemical release. As rivers are often used as disposal pathways for domestic and industrial effluents, they remain highly vulnerable to pollution. However, the relative contribution of individual stressors remains difficult to quantify, owing to their complex interactions.

The physicochemical and microbiological integrity of river systems is increasingly threatened by the expansion of urban settlements and the growing industrial output. Monitoring these parameters is critical for identifying the sources of contamination and informing effective water resource management. Urban rivers receive substantial pollutant loads from sewage, industrial effluents, agricultural runoff, and stormwater drainage, posing risks to aquatic ecosystems and human health [1–4].

Ensuring safe drinking water requires compliance with established standards that limit the use of hazardous chemicals and pathogenic microorganisms. Microbial contamination is one of the most significant threats to public health. According to the World Health Organization (WHO), hundreds of millions of people still consume unsafe water, and a major proportion of global diarrheal diseases is attributable to contaminated water and inadequate sanitation. Pathogenic microorganisms in surface waters typically originate from human or animal fecal matter. These pathogens enter water bodies via point sources, such as effluent discharges from wastewater treatment plants, or non-point sources, such as stormwater runoff, sewer overflows, and diffuse agricultural inputs.

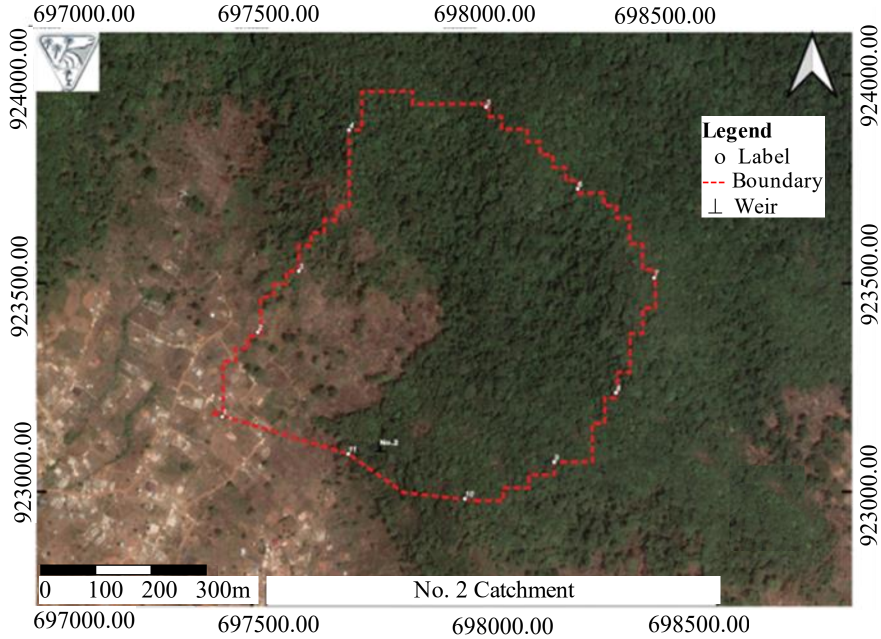
Given the growing pressure on freshwater systems, assessing both physicochemical and microbiological qualities is essential for protecting public health and maintaining ecosystem services. This study contributes to these efforts by evaluating the key water quality parameters in the Sierra Leone River No. 2 watershed.

Description of Study Area

The River No. 2 catchment is located in the western rural district of Sierra Leone, on the southern flank of the Freetown Peninsula. The watershed derives its name from River No. 2, which originates in the forested uplands of the peninsula and flows southwestward before discharging into the Atlantic Ocean at River No. 2 Beach. The catchment encompasses a diverse landscape that includes steep hillslopes, dense forest cover, rural settlements, and coastal–marine ecosystems [5–7].

Geologically, this area is primarily underlain by gabbroic formations. Shallow, stony soils dominate upland slopes, whereas sandy and lateritic soils are characteristic of the lower coastal plain. The region experiences a tropical monsoon climate and receives over 4,000 mm of annual rainfall. The wet season lasts from May to November, during which intense precipitation generates rapid surface runoff and occasional flash flooding due to the steep terrain. In the dry season (December–March), many minor streams contract or disappear, although springs and seasonal tributaries continue to sustain the flow in the main river channel. At the mouth of the river, a lagoon–estuarine system forms, where freshwater mixes with tidal inflows, supporting fisheries and tourism activities.

Ecologically, the upper watershed overlaps with the Western Area Peninsula Forest Reserve (WAPFR), a critical conservation zone that contributes significantly to regional biodiversity and watershed regulation. Despite its protected status, parts of the forest within the River No. 2 basin have been affected by deforestation driven by agricultural expansion, settlement development, and charcoal production. The resulting loss of vegetation increases soil erosion and sediment transport, with implications for downstream water quality and aquatic habitat integrity.



No. 2 Coord. (B)		
Label	X	Y
1	697428.3	923179.7
2	697513.7	923382.6
3	697612.3	923529.1
4	697733.2	923867.5
5	698062.6	923923.0
6	698282.6	923726.5
7	698466.3	923512.9
8	698374.5	923237.3
9	698226.2	923071.1
10	698011.4	922983.1
11	697731.4	923090.6

Figure 1. Map showing the River No. 2 catchment and surrounding areas.

In the lower catchment, the River No. 2 community manages the beach, estuary, and adjacent riparian zones as part of a community-based ecotourism initiative. These environments, which comprise mangrove stands, sandy beaches, and coastal wetlands, are vital for local livelihoods, shoreline protection, and ecological functioning. While ecotourism has generated income for communities, it has also placed additional pressure on land and water resources [8–10].

Catchments face several environmental challenges, including soil erosion, flash flooding, and poor drainage infrastructure. Seasonal water scarcity occurs when major springs diminish during dry months. Recent flooding events affecting both residents and tourism facilities reflect a growing vulnerability to climate-related impacts, such as increased rainfall intensity and sea-level rise. Additional stressors include unmanaged waste disposal, unregulated development, saltwater intrusion, and ongoing coastal erosion, all of which pose risks to the sustainability of the River No. 2 watershed (Figure 1).

MATERIALS AND METHODS

Sample and Sampling Procedures

Water samples were collected from three designated stations along River No. 2: upstream, midstream, and downstream. Sampling was conducted monthly over six months (March–August 2024) to capture the seasonal variability during the wet season. At each site, 500 mL of surface water was collected for physicochemical and microbiological analyses [11–13].

Before sampling, new 500 mL high-density polyethylene (HDPE) bottles were rinsed thoroughly with river water from the respective sites to minimize contamination. Each bottle was then filled below the surface to avoid debris and surface films, sealed immediately, and labeled with the date, time, and sampling location. All the samples were stored in an insulated ice cooler at approximately 4 °C and transported on the same day to the National Water Quality Laboratory of the Ministry of Water Resources in Freetown for analysis.

Research Instruments and Materials

The study employed the following instruments and laboratory materials:

- Electrical conductivity (EC) meter
- Total dissolved solids (TDS) meter
- pH meter

- Lovibond MD-610 colorimeter with reagents and vials for chemical analyses
- Microbiological testing supplies included sterile filter papers, culture media, membrane filtration units, absorbent pads, sterile petri dishes, and surgical spirit for sterilization.

Laboratory Analyses

Physicochemical Analyses

Physicochemical parameters, including temperature, pH, EC, and TDS, were measured using calibrated handheld meters (SD 70-CON for EC and TDS, and digital pH meter for pH). Calibration was performed prior to each sampling session according to the manufacturer's instructions. Measurements were obtained by immersing the instrument probes directly into well-mixed water samples, and stabilized readings were recorded.

Turbidity was determined using a calibrated turbidity meter, and the values were recorded as direct instrument readings. Chemical parameters, except for nitrate, lead, and arsenic, were analyzed using a Lovibond MD-610 photometer and the associated reagent kits. All photometric analyses followed standard colorimetric procedures recommended by the instrument manufacturer to ensure accuracy and reproducibility [14–18].

Bacteriological Analyses

Bacteriological assessments were conducted using the membrane filtration technique following standard microbiological protocols. Prior to analysis, the filtration apparatus was sterilized using surgical spirit and flame sterilization, where appropriate. A 100 mL aliquot of each water sample was filtered through a sterile 0.45 µm pore-size membrane filter to retain bacterial cells. Sterile absorbent pads were placed in labeled petri dishes and saturated with lauryl broth medium. Following filtration, each membrane filter was aseptically transferred onto the prepared absorbent pads to ensure full contact between the membrane and the growth medium. The plates were then incubated at 36 °C for 48–72 h to allow bacterial growth. After incubation, characteristic colonies were enumerated to determine fecal and non-fecal coliform abundances. All procedures were performed under aseptic conditions to minimize contamination [19].

STEPS IN WATER QUALITY INDEX CALCULATION

Weighted Arithmetic Index Method

The water quality index (WQI) was calculated using the weighted arithmetic index approach, incorporating guideline values from the World Health Organization (WHO) and the Bureau of Indian Standards (BIS).

The general formula for the WQI is:

$$WQI = \frac{\sum q_n W_n}{\sum W_n}$$

Where,

q_n= quality rating of the n-th parameter
W_n= unit weight of the n-th parameter

Calculation of the Quality Rating

The quality rating for each parameter was computed using the following expression:

$$q_n = 100\left(\frac{V_n - V_{i0}}{S_n - V_{i0}}\right)$$

Where,

V_n= measured concentration of the n-th parameter
S_n= corresponding standard permissible value
V_{i0}= ideal value of the parameter in pure water

Quality Rating for pH

For pH, the ideal value (Vi0) is 7.0, whereas the permissible limit for marginally polluted water is 8.5. The pH rating was calculated using the following formula:

$$\text{pH} = 100\left(\frac{\text{VpH} - 7.0}{8.5 - 7.0}\right)$$

This method provides a quantitative assessment of overall water quality by integrating multiple physicochemical parameters into a single index value, as shown in Tables 1–3 [20].

Canadian Council of Ministers of the Environment Formula

The Canadian Council of Ministers of the Environment (CCME) was calculated using three factors: scope (F1), frequency (F2), and amplitude (F3).

$$\text{CCME WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

Where,

F1 (scope): The percentage of parameters that did not meet water quality objectives at least once during the period of interest.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100$$

F2 (frequency): The percentage of individual tests that do not meet the objectives.

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100$$

F3 (amplitude): represents the amount by which the failed values exceed the objectives.

Steps

For each failed test, calculate the excursion:

If a test exceeds the objective

$$\text{Excursion} = \frac{\text{Failedvalue}}{\text{Objective}} - 1$$

If a test falls below the objective

$$\text{Excursion} = \frac{\text{Objective}}{\text{Failed value}} - 1$$

Compute the Normalized Sum of Excursions (nse)

$$nse = \frac{\sum \text{Excursion}}{\text{Total number of tests}}$$

Then,

$$F_3 = \frac{nse}{0.01nse + 0.01}$$

Table 1. Water quality classification based on WQI value.

Class	WQI value	Water quality status
I	<50	Excellent
II	50-100	Good water
III	100-200	Poor water
IV	200-300	Very poor water
V	>300	Water unfit for drinking

Table 2. Drinking water standards values, unit weight, and recommended agency.

S.N.	Parameters	Standard values (Sn)	1/Sn	Unit weight (W_n)	Recommended agency
1	PH	8.5	0.1176	0.0047	WHO/BIS
2	Turbidity	5	0.2	0.008	BIS
4	TDS	500	0.002	0.00008	BIS
6	Ammonia	0.5	2	0.08	WHO/BIS
7	Nitrate	45	0.0222	0.0009	BIS
8	Fluoride	1.5	0.6667	0.0267	WHO
9	Chromium	0.05	20	0.8	WHO/BIS
			23.0085	$\sum W_n$=0.92038	

Table 3. CCME water quality index (WQI) rating scale.

WQI value	Rating
95–100	Excellent
80–94	Good
65–79	Fair
45–64	Marginal
0–44	Poor

RESULTS AND DISCUSSIONS

Physicochemical Parameters

Temperature

The mean water temperatures recorded at the upstream, midstream, and downstream stations were 28.6°C, 28.52°C, and 28.4°C, respectively (Table 4). The narrow temperature range indicated minimal thermal variation along the river course during the sampling period. These values are consistent with typical tropical river systems, where surface waters commonly range between 26 °C and 30°C due to high ambient temperatures and low canopy cover. Stable temperature profiles support microbial and chemical processes that influence the overall water quality [21–23].

Turbidity

Turbidity values ranged from 0.0–3.0 NTU upstream, 0.0 NTU at midstream, and 0.0–2.0 NTU downstream (Tables 5 and 6). Mean turbidity levels were 0.6 NTU, 0.0 NTU, and 0.4 NTU for upstream, midstream, and downstream sites, respectively (Figure 2). All turbidity values were substantially below the WHO guideline limit of 5 NTU for drinking water.

These low turbidity levels suggest minimal sediment load and limited disturbance during the sampling period. Recent studies in comparable West African catchments have similarly reported low turbidity in forested or semi-protected watersheds, attributed to reduced erosion and relatively intact riparian vegetation [24–29].

pH

The pH of natural waters typically ranges between 6.5 and 8.5, the recommended WHO guideline for potable water. In the River No. 2 watershed, upstream pH ranged from 7.0–7.2 (mean 7.1), midstream from 7.2–7.3 (mean 7.22), and downstream from 7.0–7.2 (mean 7.1) (Table 4; Figure 3). All values fell within acceptable limits, indicating neutral-to-slightly alkaline conditions.

This finding aligns with recent research showing that rivers draining forested tropical catchments often maintain stable, near-neutral pH levels owing to limited industrial inputs and natural buffering capacity. However, our results contrast with those reported in southern Sierra Leone, where subsurface groundwater sources frequently exceeded WHO pH limits, highlighting the spatial variability in hydrochemical conditions across the region [30, 31].

Electrical Conductivity

The electrical conductivity values were characteristically low across the catchment, reflecting minimal ionic concentration and low mineralization. Upstream EC ranged from 14–28 µS/cm (mean 23.6 µS/cm), midstream from 14–29 µS/cm (mean 23.6 ± 6.39 µS/cm), and downstream from 14–34 µS/cm (mean 24.4 µS/cm) (Table 4; Figure 4).

Such low EC values are typical of lightly disturbed or forest-dominated catchments, where geogenic contributions are limited, and anthropogenic inputs remain low. Similar EC ranges have been reported in recent studies on low-impact tropical watersheds in Ghana, Liberia, and Sierra Leone. These findings suggest that major ionic pollution sources, such as agricultural runoff or wastewater discharge, are currently minimal in the River No. 2 basin [32–34].

Total Dissolved Solids

TDS concentrations ranged from 7.0–14.0 mg/L upstream, 7.0–14.5 mg/L midstream, and 7.0–17.0 mg/L downstream. The mean values were 11.8 mg/L upstream and midstream, and 12.2 mg/L downstream (Figure 5). All values were far below the WHO maximum threshold of 1000 mg/L for safe drinking water.

Low TDS levels indicate minor contributions of dissolved ions from rock weathering or surface runoff. This pattern is consistent with findings from other protected or semi-protected tropical river systems, where low mineral content is attributed to resistant parent rock formations and limited anthropogenic disturbance [35].

Figure 2–10 shows the average concentrations of parameters.

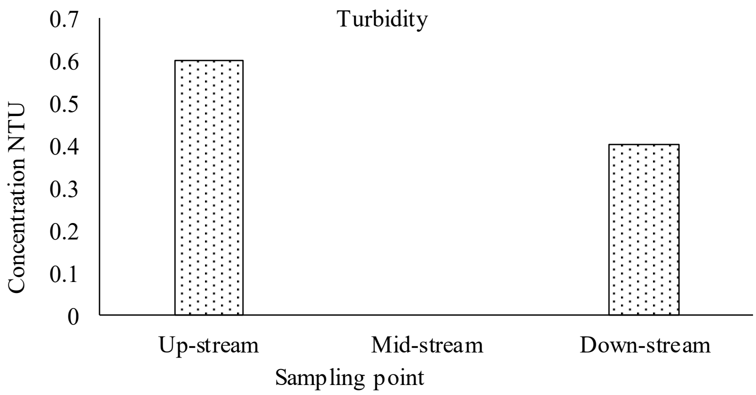


Figure 2. Mean turbidity in the River No. 2 catchment.

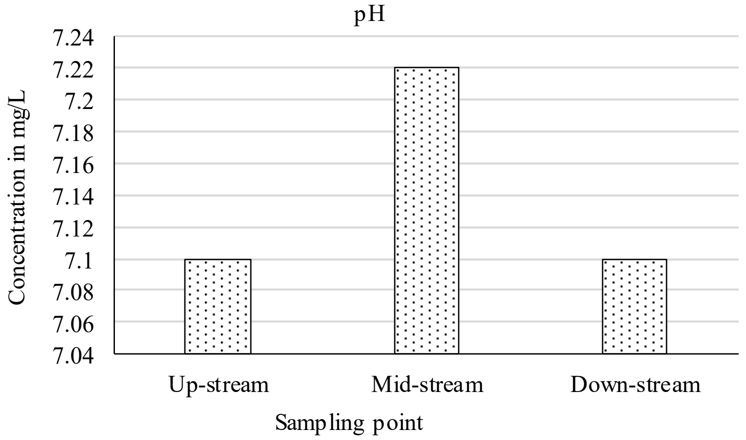


Figure 3. Mean pH level in River No. 2 catchment.

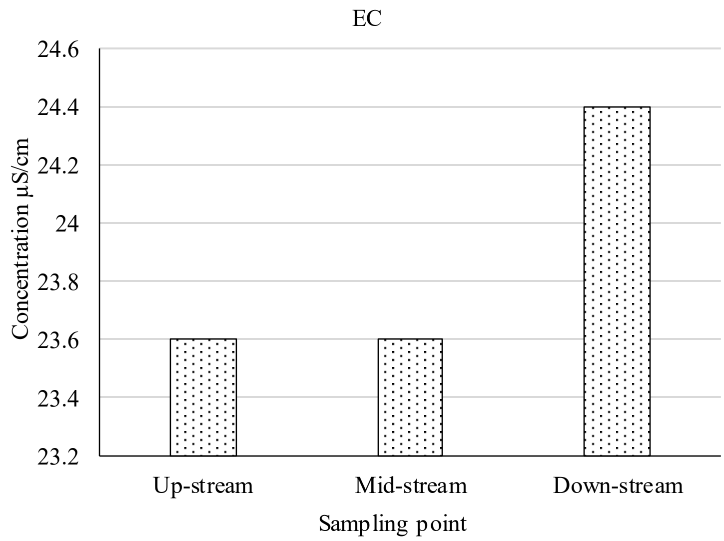


Figure 4. Mean EC level in River No. 2 catchment.

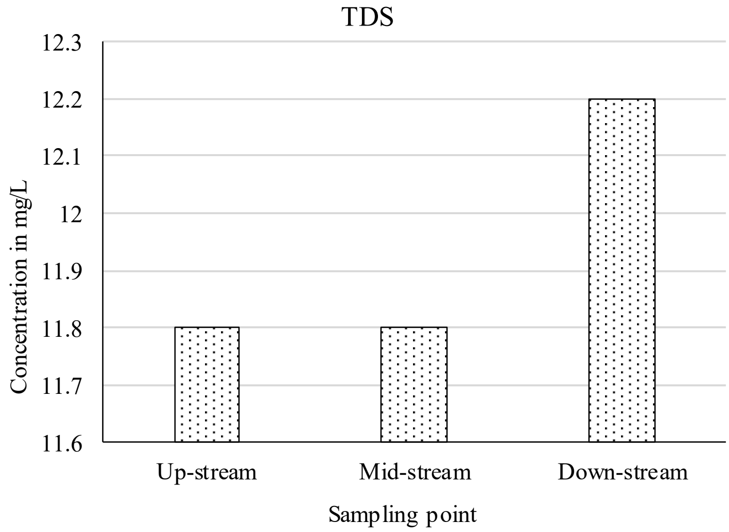


Figure 5. Mean TDS level in the River No. 2 catchment.

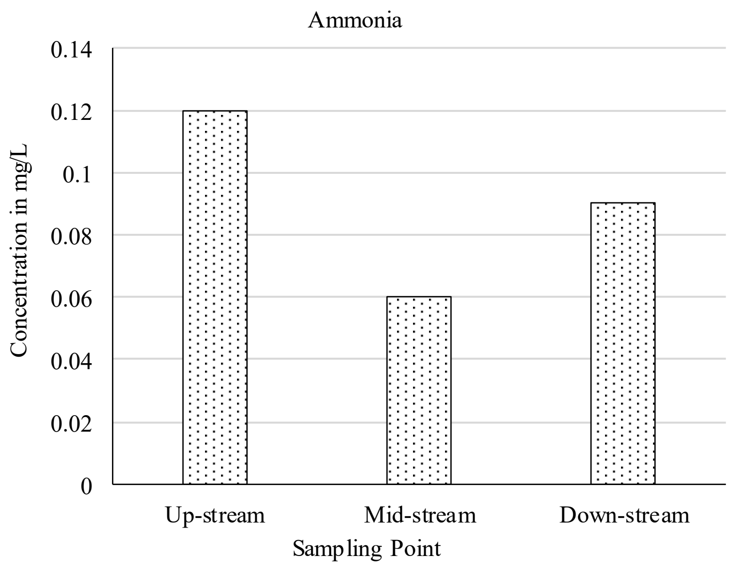


Figure 6. Mean ammonia level in the River No. 2 catchment.

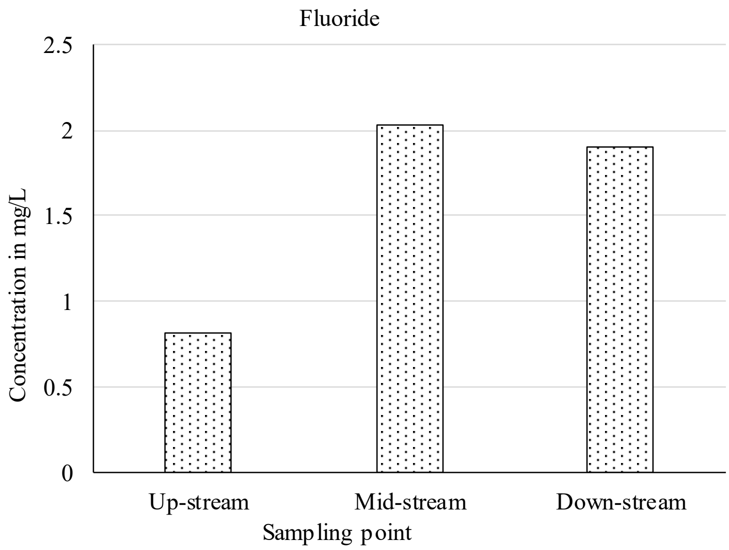


Figure 7. Mean fluoride level in River No. 2 catchment.

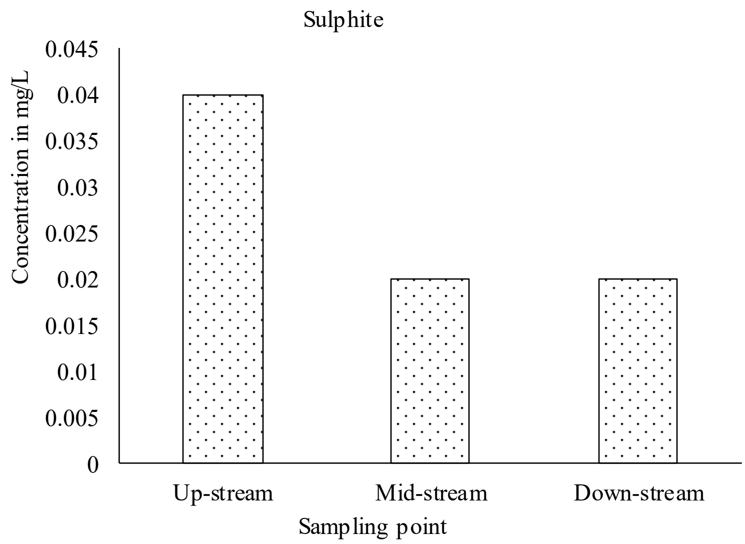


Figure 8. Mean sulfite level in River No. 2 catchment.

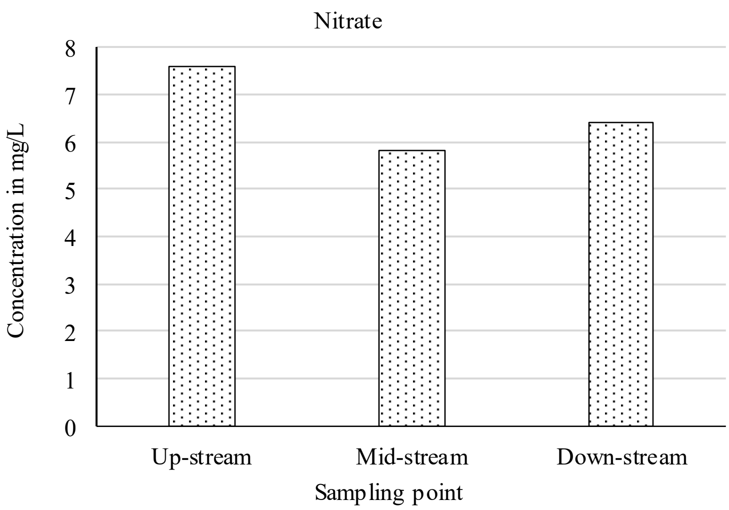


Figure 9. Mean nitrate level in River No. 2 catchment.

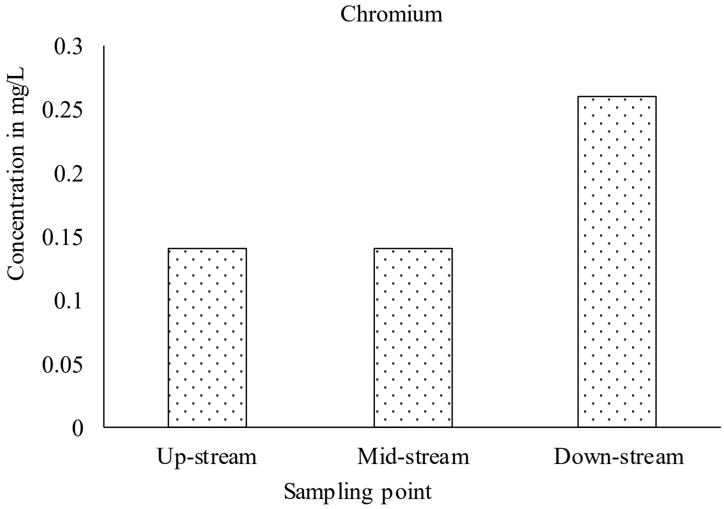


Figure 10. Mean chromium level in River No. 2 catchment.

Table 4. Physicochemical summary results for the River No. 2 catchment.

	Upper stream			Middle stream			Down stream		
Parameters	***Min***	***Max***	***Mean***	***Min***	***Max***	***Mean***	***Min***	***Max***	***Mean***
Temperature	26.7	29.6	28.78	26.8	29.8	28.92	26.8	29.9	29.12
Turbidity	0.0	3.0	0.6	0.0	0.0	0.0	0.0	2.0	0.4
pH	7.0	7.2	7.1	7.2	7.3	7.22	7.0	7.2	7.1
EC	14	28	23.6	14	29	23.6	14	34	24.4
TDS	7.0	14	11.8	7.0	14.5	11.8	7.0	17	12.2
Ammonia	0.08	0.15	0.12	0.03	0.09	0.06	0.08	0.09	0.09
Fluoride	0.56	0.93	0.81	1.0	2.5	2.03	1.0	2.5	1.9
Sulphite	0.02	0.05	0.04	0.02	0.03	0.02	0.03	0.04	0.02
Nitrate	6.0	10	7.6	5.0	6.0	5.8	6.8	8.0	6.4
Lead	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arsenic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chromium	0.10	0.18	0.14	0.12	0.18	0.14	0.13	0.7	0.26

Ammonia (NH_3)

Ammonia is an important water quality indicator that reflects the potential contamination from domestic sewage, agricultural runoff, and microbial activity. Although no health-based guidelines exist for ammonia in drinking water, elevated ammonia levels can signal organic pollution.

In the River No. 2 catchment, ammonia concentrations ranged from 0.08–0.15 mg/L upstream, 0.03–0.09 mg/L midstream, and 0.08–0.09 mg/L downstream. The mean values were 0.12 mg/L, 0.06 mg/L, and 0.09 mg/L for upstream, midstream, and downstream, respectively (Figure 6). All measured values were below WHO advisory levels, suggesting minimal anthropogenic or microbial ammonia input into the river system. These findings are consistent with those of other low-impact tropical watersheds where ammonia concentrations typically remain below 0.2 mg/L [36].

Fluoride (F^-)

Fluoride naturally originates from fluorine-bearing minerals in rocks, particularly in phosphate-rich formations. The measured fluoride concentrations were 0.81 mg/L upstream, 2.03 mg/L midstream, and 1.9 mg/L downstream (Figure 7). Except for the upstream station, which remained within the WHO guideline of 1.5 mg/L, the midstream and downstream levels exceeded this limit, indicating potential geogenic enrichment or anthropogenic contributions from agricultural inputs.

High fluoride concentrations in tropical river systems have been associated with the weathering of fluoride-bearing minerals and the use of phosphate-based fertilizers. Long-term consumption of water with elevated fluoride levels can pose health risks, including dental and skeletal fluorosis, highlighting the need for monitoring in affected communities [37].

Sulfite (SO_3^{2-})

The WHO does not provide health-based guidelines for sulfites in drinking water, but it can indicate localized pollution, especially from industrial and agricultural runoff. In this study, upstream sulfite concentrations ranged from 0.02–0.05 mg/L (mean 0.04 mg/L), showing the highest variability and suggesting point-source contamination. Midstream concentrations were lower and more stable, ranging 0.02–0.03 mg/L (mean 0.02 mg/L), likely reflecting reduced pollution inputs and natural filtration processes. Downstream levels ranged from 0.02–0.04 mg/L, with a mean of 0.02 mg/L (Figure 8).

These findings are consistent with other studies in West African catchments, where upstream industrial or agricultural activities increased sulfite variability, while mid- and downstream river segments tended to stabilize due to dilution and natural attenuation.

Nitrate (NO_3^-)

Nitrate is a key water quality parameter because of its health implications, particularly for infants (blue baby syndrome). These sources include nitrogenous fertilizers, wastewater, and natural nitrogen cycling.

In the River No. 2 catchment, nitrate concentrations ranged from 3 to 8 mg/L upstream, 4–8 mg/L midstream, and 4–8 mg/L downstream. Mean concentrations were 5.4 mg/L, 5.8 mg/L, and 5.8 mg/L, respectively (Figure 9), well below the WHO drinking-water limit of 50 mg/L. These low levels indicate a limited influence of nitrogenous fertilizers or sewage in the study area, consistent with findings from similar tropical rivers with minimal anthropogenic pressure [38].

Arsenic (As) and Lead (Pb)

Monitoring arsenic and lead is critical because of their severe public health impact. Both elements were below the detection limits at all sampling points in the River No. 2 catchment, indicating minimal contamination from natural or anthropogenic sources. This aligns with reports from other low-industrialized tropical watersheds where these heavy metals are often undetectable in surface water.

Chromium (Cr)

Chromium levels were elevated above the WHO permissible limits (0.05 mg/L) in all sampling segments. Upstream concentrations ranged from 0.10–0.18 mg/L (mean 0.14 mg/L), midstream 0.12–0.18 mg/L (mean 0.14 mg/L), and downstream 0.13–0.70 mg/L (mean 0.26 mg/L) (Figure 10). Higher downstream values suggest potential cumulative inputs from industrial, agricultural, or domestic activities along the river course.

Elevated Cr concentrations have been documented in rivers in developing countries, where industrial discharges and urban runoff are inadequately managed. Continuous monitoring and mitigation are recommended to prevent ecological and public health impacts [39].

Comparison and Interpretation of Water Quality Index Results

The water quality of the River No. 2 catchment was evaluated using two WQI approaches: the *Weighted Arithmetic WQI* and the *Canadian Council of Ministers of the Environment WQI (CCME WQI)*. Physicochemical data collected from three sampling locations (upstream, midstream, and downstream) were analyzed using both methods to provide a comprehensive assessment of water quality. While both indices assess deviations from standard limits, they differ in their computational approach and sensitivity to parameter exceedances.

Table 5. Weighted arithmetic water quality index for upper and middle streams at River No. 2 catchment.

					Upper stream					Middle stream				
S.N.	***Parameters***	***Standard values (S_n)***	***1/S_n***	***Unit weight (W_n)***	***Observed values***	***Quality rating (q_n)***	***Weighted (W_nq_n)***	***Parameters***	***Standard values (S_n)***	***1/Sn***	***Unit weight (W_n)***	***Observed values***	***Quality Rating (q_n)***	***Weighted (W_nq_n)***
1	pH	8.5	0.1176	0.0047	7.10	6.67	0.031	pH	8.5	0.1176	0.0047	7.22	14.67	0.0069
2	Chromium (mg/L)	0.05	20.0	0.8	0.14	280	224	Chromium (mg/L)	0.05	20.0	0.8	0.14	280	224
3	Nitrate (mg/L)	45	0.022	0.0009	7.60	16.89	0.015	Nitrate (mg/L)	45	0.0222	0.0009	5.80	12.89	0.0116
4	Fluoride (mg/L)	1.5	0.6667	0.0267	0.81	-38.0	-1.014	Fluoride (mg/L)	1.5	0.6667	0.0267	2.03	206	5.50
5	Ammonia (mg/L)	0.5	2.0	0.08	0.12	24	1.92	Ammonia (mg/L)	0.5	2.0	0.08	0.06	12	0.96
6	Turbidity (NTU)	5	0.2	0.008	0.6	12.0	0.096	Turbidity (NTU)	5	0.2	0.008	0.0	0.0	0.0
7	TDS (mg/L)	500	0.002	0.00008	11.8	2.36	0.0002	TDS (mg/L)	500	0.002	0.00008	11.8	2.36	0.0002
			23.0085	ΣW_n =0.92038	225.0482		$\Sigma(W_nq_n)$ =225.0482			23.0085	ΣW_n =0.92038			$\Sigma(W_nq_n)$ = 230.4787
					WQI= 244.5					WQI= 250.4				

Weighted Arithmetic WQI

Using the Weighted Arithmetic method, the WQI values for the upper, middle, and downstream stations are 244.5, 250.4, and 458.9, respectively (Tables 5 and 6). These values fall within the "very poor" to "extremely poor" categories, indicating that water is unfit for drinking or household use. Elevated concentrations of fluoride (1.9–2.03 mg/L) and chromium (0.14–0.26 mg/L), which exceeded the WHO permissible limits of 1.5 mg/L and 0.05 mg/L, respectively, were the primary contributors to the high WQI values. The Weighted Arithmetic approach is highly sensitive to extreme deviations in individual parameters, which explains why even a single significantly exceeded parameter, such as Cr, can dramatically inflate the overall WQI [40].

CCME WQI

The CCME WQI produced moderate values of *89.9, 83.8, and 79.3* for the upper, middle, and downstream stations, respectively (Table 7). According to the CCME classification, these values indicate "Good" water quality in the upstream and midstream regions and "Fair" water quality downstream. The CCME WQI evaluates water quality based on three components: *scope (F_1), the percentage of parameters exceeding guidelines; frequency (F_2), the proportion of failed tests; and amplitude (F_3), the magnitude of deviation from objectives. By emphasizing the frequency and scope of non-compliance rather than extreme outliers, the CCME WQI provides a more balanced and ecologically relevant assessment of surface water quality (Tables 7 and 8).

Comparison and Interpretation

Both indices demonstrated a downstream decline in water quality, primarily driven by increasing fluoride and chromium levels, suggesting contributions from both geogenic and anthropogenic sources

Table 6. Weighted arithmetic water quality index for the downstream at River No. 2 catchment.

	Down Stream						
S.N.	***Parameters***	***Standard values (S_n)***	***$1/S_n$***	***Unit weight (W_n)***	***Observed values***	***Quality rating (q_n)***	***Weighted (W_nq_n)***
1	pH	8.5	0.1176	0.0047	7.1	6.67	0.031
2	Chromium (mg/L)	0.05	20.0	0.8	0.26	520	416
3	Nitrate (mg/L)	45	0.022	0.0009	6.4	14.22	0.013
4	Fluoride (mg/L)	1.5	0.6667	0.0267	1.9	180	4.806
5	Ammonia (mg/L)	0.5	2.0	0.08	0.09	18	1.44
6	Turbidity (NTU)	5	0.2	0.008	0.4	8	0.064
7	TDS (mg/L)	500	0.002	0.00008	12.2	2.44	0.0002
			23.0085	ΣW_n =0.92038			$\Sigma(W_nq_n)$ =422.3542
	WQI= 458.9						

Table 7. Stepwise CCEM WQI computation for each stream.

Component/step	**Upper stream**	**Middle stream**	**Down stream**
Total Parameters (n)	12	12	12
Failed Parameters	1(Chromium)	2 (Fluoride, Chromium)	2 (Fluoride, Chromium)
F_1= (Failed ÷ n) ×100	(1/12) ×100 = 8.33	(2/12) ×100 = 16.67	(2/12) ×100 = 16.67
Failed Test	1	2	2
F_2= (Failed Tests ÷Total Tests) ×100	(1/12) ×100 = 8.33	(2/12) ×100 = 16.67	(2/12) ×100 = 16.67
Excursion (s)	Cr: (0.14/0.05 -1) = 1.8	F: (2.03/1.5 - 1) = 0.353; Cr: (0.14/0.05 -1) = 1.8	F: (1.9/1.5 – 1) = 0.267; Cr: (0.26/1.5 - 1) = 4.2
∑ Excursion	1.8	2.153	4.467
nse= ∑ Excursion ÷12	1.8 / 12 = 0.15	2.153 /12 = 0.18	4.467/12 = 0.37
F_3 = nse÷ (0.01nse + 0.01)	0.15 / 0.0115 = 13.04	0.18/ 0.0118 =15.25	0.37/ 0.0137 =27.00
CCME WQI	100 -√ (8.33^2 + 8.33^2 + 13.04$^{2)}$/1.732 =89.9	100 - √ (16.67^2 + 16.67^2 + 15.25$^{2)}$/ 1.732 =83.8	100 - √ (16.67^2 + 16.67^2 + 27.00^2)/ 1.732 =79.3

Table 8. The final summary.

Sampling point	F_1	F_2	F_3	CCME WQI	Water quality category	Main parameters exceeding limits
Upper Stream	8.33	8.33	13.04	89.9	Good	Chromium
Middle Stream	16.67	16.67	15.25	83.8	Good	Fluoride, Chromium
Down Stream	16.67	16.67	27.00	79.3	Fair	Fluoride, Chromium

Table 9. Bacteriological summary results for the River No. 2 catchment.

Parameters	Sampling point	Min	Max	Mean
E. coli	Upper stream	0.0	0.0	0.0
	Middle stream	0.0	0.0	0.0
	Down stream	0.0	0.0	0.0
Fecal coliforms	Upper stream	34	50	42
	Middle stream	32	59	48
	Down stream	33	49	41
Non-fecal coliforms	Upper stream	10	18	14
	Middle stream	8	27	21
	Down stream	6	32	14

along the river. The Weighted Arithmetic WQI portrays a more critical scenario, highlighting the potential health risks from toxic elements, making it particularly suitable for drinking water assessment. Conversely, the CCME WQI presents a moderate evaluation suitable for ecological and surface water monitoring, as it is less influenced by sporadic exceedances.

The disparity between the two indices emphasizes the importance of methodological selection: the Weighted Arithmetic WQI is effective for identifying *human health risks*, whereas the CCME WQI provides a broader *ecosystem perspective*. Combining these approaches offers a comprehensive understanding of the river's water quality, showing that while catchment No. 2 experiences localized contamination from fluoride and chromium, its overall physicochemical status is moderately impacted and requires *continuous monitoring and pollution control measures* to prevent further downstream deterioration.

Microbial Assessment of Drinking Water

The microbiological quality of water from the River No. 2 catchment was evaluated using *E. coli*, fecal coliforms, and non-fecal coliforms as indicators of contamination [41].

E. coli

Across all sampling locations and periods, *E. coli was undetectable* in all water samples (Table 9). As a primary indicator of recent fecal contamination, the absence of *E. coli* suggested that River No. 2 water did not contain detectable levels of recent human or animal fecal pollution during the study period. This finding aligns with similar studies in tropical rivers, where the absence of *E. coli* indicated a safe microbial quality for potable water.

Fecal Coliforms

Fecal coliform counts were generally higher than those of *E. coli*, varying between sampling sites and over time (Table 9). Fecal coliforms, while originating from fecal matter, can survive and even multiply under certain environmental conditions. The elevated counts at specific locations may reflect possible historical fecal contamination or environmental niches favorable to their persistence rather than recent pollution events. Spatial and temporal variability highlight differences in local environmental conditions, anthropogenic inputs, or both.

Non-Fecal Coliforms

Non-fecal coliforms, which primarily originate from environmental sources rather than fecal matter, were detected at lower concentrations than fecal coliforms. Their distribution showed similar temporal and spatial trends, with occasionally higher counts at certain locations. Despite the absence of *E. coli*, the predominance of fecal coliforms over non-fecal coliforms may indicate low-level or historical fecal contamination or environmental conditions that favor fecal coliform persistence.

Interpretation

Overall, the microbial assessment indicated that while *recent fecal contamination is absent* (as evidenced by zero *E. coli*), the presence of fecal coliforms at variable levels indicated potential *historical contamination or environmental factors supporting bacterial persistence*. Regular monitoring is recommended, particularly in areas with elevated fecal coliform counts, to ensure the continued microbiological safety of water for domestic and drinking purposes.

CONCLUSIONS

The assessment of the River No. 2 catchment indicates that, overall, the water quality remains moderately good, with most physicochemical and microbiological parameters falling within the WHO drinking water guidelines. Parameters such as low turbidity, stable pH, and minimal TDS suggest that the river provides suitable conditions for both ecological integrity and domestic use.

However, localized water quality concerns were observed, particularly elevated fluoride and chromium concentrations in the midstream and downstream segments, which exceeded the WHO permissible limits. These elevated levels may have originated from natural geogenic sources, agricultural runoff, or anthropogenic activities. Although *E. coli* was undetectable, the presence of fecal and non-fecal coliforms highlights intermittent contamination, likely linked to surrounding human settlements, livestock, or other environmental factors.

The application of the two WQI approaches provided complementary insights into river health. The Weighted Arithmetic WQI classifies water quality as very poor to extremely poor, reflecting the high influence of fluoride and chromium exceedances on drinking water suitability. In contrast, the CCME WQI indicated good to fair water quality, emphasizing that the river largely supports ecological functions, despite localized contamination. The downstream decline in water quality observed across both indices underscores the cumulative effects of pollutant input along the river continuum. The contrast between the indices highlights the importance of method selection, with the CCME WQI being more suitable for ecological monitoring, and the Weighted Arithmetic WQI being more appropriate for assessing human drinking water safety.

To safeguard the River No. 2 catchment, integrated watershed management is recommended, including routine monitoring, public education on water pollution, improved waste management, and stricter enforcement of environmental regulations. Such interventions are essential for maintaining the long-term sustainability of the river ecosystem and ensuring the safety of its water for human use, particularly under increasing pressures from urbanization, tourism, and deforestation.

REFERENCES

1. Abdel-Dayem S. Water quality management in Egypt. Int J Water Resour Dev. 2011;27:181–202. doi:10.1080/07900627.2010.531522.
2. Rahman A, Jahanara I, Jolly YN. Assessment of physicochemical properties of water and their seasonal variation in an urban river in Bangladesh. Water Sci Eng. 2021;14(2):139–148. doi:10.1016/j.wse.2021.06.006.
3. Ibrahim TNBT, Othman F, Mahmood NZ, Abunama T. Seasonal effects on spatial variations of surface water quality in a tropical river receiving anthropogenic influences. Sains Malaysiana. 2021;50(3):571–593. doi:10.17576/jsm-2021-5003-02.
4. American Public Health Association, American Water Works Association. Standard methods for the examination of water and wastewater. 24th ed. Washington (DC): American Public Health Association, American Water Works Association, Water Environment Federation; 2023.

5. Balali GI, Yar DD, Afua Dela VG, Adjei-Kusi P. Microbial contamination, an increasing threat to the consumption of fresh fruits and vegetables in today's world. Int J Microbiol. 2020;2020(1):3029295. doi:10.1155/2020/3029295. PubMed PMID: 32565813.
6. Behbahaninia A, Mirbagheri SA, Khorasani N, Nouri J, Javid AH. Heavy metal contamination of municipal effluent in soil and plants. J Food Agric Environ. 2009;7(3-4):851–856.
7. Brown RM, McClelland NI, Deininger RA, O'Connor MF. A water quality index—crashing the psychological barrier. In: Thomas WA, editor. Indicators of Environmental Quality. Environmental Science Research. Vol. 1. Boston (MA): Springer; 1972. p. 173–182. doi:10.1007/978-1-4684-2856-8_15.
8. Canadian Council of Ministers of the Environment. Canadian water quality guidelines for the protection of aquatic life: CCME water quality index user's manual, 2017 update. Canadian environmental quality guidelines. Winnipeg (MB): Canadian Council of Ministers of the Environment; 2017.
9. Chapman DV. Water Quality Assessments: A Guide to the Use of Biota, Sediments and water in Environmental Monitoring. Boca Raton, FL: CRC Press; 2021. doi:10.1201/9781003062103.
10. Donovan E, Unice K, Roberts JD, Harris M, Finley B. Risk of gastrointestinal disease associated with exposure to pathogens in the water of the Lower Passaic River. Appl Environ Microbiol. 2008;74(4):994–1003. doi:10.1128/AEM.00601-07. PubMed PMID: 18156342.
11. Ezzat SM, Mahdy H, Abo-State MA, Abd El Shakour EH, Elbahnasawy MA. Water quality assessment of River Nile at Rosetta Branch: Impact of drains discharge. Middle East J Sci Res. 2012;12(4):413–423. doi:10.5829/idosi.mejsr.2012.12.4.1694.
12. Fatema K, Wan Maznah WO, Isa MM. Spatial variation of water quality parameters in a mangrove estuary. Int J Environ Sci Technol. 2015;12(6):2091–2102. doi:10.1007/s13762-014-0603-2.
13. Duncan AE, de Vries N, Nyarko KB. Assessment of heavy metal pollution in the sediments of the River Pra and its tributaries. Water Air Soil Pollut. 2018;229(8):272. doi:10.1007/s11270-018-3899-6. PubMed PMID: 30147192.
14. Kallon HDS, Margai J. Assessment of groundwater quality: A case study of Sierra Rutile mining communities southern Sierra Leone. Res Rev J Ecol Environ. 2019;7(2):11–15.
15. Kamara D, Bah D, Sesay M, Maruta A, Sesay BP, Fofanah BD, et al. Evaluation of drinking water quality and bacterial antibiotic sensitivity in wells and standpipes at household water points in Freetown, Sierra Leone. Int J Environ Res Public Health. 2022;19(11):6650. doi:10.3390/ijerph19116650. PubMed PMID: 35682235.
16. Zhigalenok Y, Tazhibayeva A, Kokhmetova S, Starodubtseva A, Kan T, Isbergenova D, et al. Hexavalent chromium at the crossroads of science, environment and public health. RSC Adv. 2025;15(27):21439–21464. doi:10.1039/D5RA03104D. PubMed PMID: 40567474.
17. Agunwamba JC, Maduka CN, Ofosaren AM. Analysis of pollution status of Amadi Creek and its management. J Water Supply Res Technol Aqua. 2006;55(6):427–435. doi:10.2166/aqua.2006.036.
18. Laghzal A, Salmoun F. Contribution to the bacteriological characterization of some sources in the region of Tangier Tetouan (Morocco). Larhyss J. 2014;(20):71–78.
19. Mensah-Akutteh H, Buamah R, Wiafe S, Nyarko KB. Raw water quality variations and its effect on the water treatment processes. Cogent Eng. 2022;9(1):2122152. doi:10.1080/23311916.2022.2122152.
20. Berego YS, Sota SS, Ulsido MD, Beyene EM, et al. Assessment of quality of drinking water based on the water quality index method in Hawassa Zuria Woreda, Sidama Regional State, Ethiopia [Preprint]. Qeios. 2023. doi:10.32388/DNX6O2.
21. Santana AJ, dos Santos WNL, Silva LOB, das Virgens CF. Removal of mercury(II) ions in aqueous solution using the peel biomass of Pachira aquatica Aubl.: Kinetics and adsorption equilibrium studies. Environ Monit Assess. 2016;188:293. doi:10.1007/s10661-016-5266-7. PubMed PMID: 27084802.
22. Akanbi OA, Joseph GD, Olayiwoola JO. Comparative study of nitrate evaluation and bacteriological characterisation of shallow groundwater in adjoining towns around Oyo area, SW Nigeria. Glob J Geol Sci. 2025;23(1):1–11. doi:10.4314/gjgs.v23i1.1.

23. Shil S, Singh UK, Mehta P. Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS. Appl Water Sci. 2019;9(7). doi:10.1007/s13201-019-1045-2.
24. Debassi B, Allaoua N, Ghanem N, Hafid H, Benacherine M, Chenchouni H. Assessment of water quality of groundwater, surface water, and wastewater using physicochemical parameters and microbiological indicators. Sci Prog. 2025;108:368504251348544. doi:10.1177/00368504251348544. PubMed PMID: 40528420.
25. Noori MD. Comparative analysis of weighted arithmetic and CCME water quality index estimation methods, accuracy and representation. In: IOP Conf Ser Mater Sci Eng. Vol. 737. Bristol: IOP Publishing; 2020. p. 012174. doi:10.1088/1757-899X/737/1/012174.
26. Qadir A, Malik RN, Husain SZ. Spatio-temporal variations in water quality of Nullah Aik-tributary of the River Chenab, Pakistan. Environ Monit Assess. 2008;140(1):43–59. doi:10.1007/s10661-007-9846-4.
27. Liji TM, Sreelesh R, Upendra B, Sreelash K, Maya K, Padmalal D. Assessment of the hydro-geochemical characteristics of a tropical river catchment in the southern Western Ghats, India. J Earth Syst Sci. 2024;133(4):221. doi:10.1007/s12040-024-02419-8.
28. Ezzehra Sghiouer FE, Nahli A, Bouka H, Chlaida M. Monitoring of faecal contamination and physicochemical variables in surface waters in Oued Inaouène (Upper Sebou, Morocco). J Ecol Eng. 2022;23(11):33–40. doi:10.12911/22998993/153397.
29. Kate S, Kumbhar S, Jamale P. Water quality analysis of Urun-Islampur City, Maharashtra, India. Appl Water Sci. 2020;10:95. doi:10.1007/s13201-020-1178-3.
30. Singh KP, Malik A, Mohan D, Sinha S. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—a case study. Water Res. 2004;38:3980–3992. doi:10.1016/j.watres.2004.06.011.
31. Wats RK, Grover AS, Kumar R, Wats M. Status of surface water quality in River Markanda and its correlation with groundwater quality and health of the residents of Shahabad, Kurukshetra, Haryana, India—a case study. Int J Health Econ Dev. 2019;5(1):1–11.
32. Fayiah M, Kandeh B, Izah SC, Saccoh S. Rural water management status, threats, and prospects: A case study of Sierra Leone. In: Water Resources Management for Rural Development. Amsterdam: Elsevier; 2024. p. 263–274. doi:10.1016/B978-0-443-18778-0.00006-4.
33. Barrie A, Agodzo SK, Frazer-Williams R, Awuah E, Bessah E. A multivariate statistical approach and water quality index for water quality assessment for the Rokel River in Sierra Leone. Heliyon. 2023;9(6):e16196. doi:10.1016/j.heliyon.2023.e16196.
34. Singh S, Jayaram R. Attainment of water and sanitation goals: A review and agenda for research. Sustain Water Resour Manag. 2022;8(5):146. doi:10.1007/s40899-022-00719-9.
35. Wang Y, Wang P, Bai Y, Tian Z, Li J, Shao X, et al. Assessment of surface water quality via multivariate statistical techniques: A case study of the Songhua River Harbin region, China. J Hydro-environ Res. 2013;7(1):30–40. doi:10.1016/j.jher.2012.10.003.
36. World Health Organization. The World Health Report 2002: Reducing Risks, Promoting Healthy Life. Geneva: World Health Organization; 2002.
37. World Health Organization. Nitrate and Nitrite in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality. Geneva: World Health Organization; 2003.
38. World Health Organization. Guidelines for Drinking-Water Quality. Geneva: World Health Organization; 2004.
39. World Health Organization. Guidelines for Drinking-Water Quality. Geneva: World Health Organization; 2004.
40. Dore MH. Global Drinking Water Management and Conservation. Cham: Springer International Publishing; 2015. doi:10.1007/978-3-319-11032-5.
41. Zhang Z, Tao F, Du J, Shi P, Yu D, Meng Y, Sun Y. Surface water quality and its control in a river with intensive human impacts—a case study of the Xiangjiang River, China. J Environ Manage. 2010;91(12):2483–2490. doi:10.1016/j.jenvman.2010.07.002.

