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QUALITATIVE ENVIRONMENTAL ASSESSMENT OF DIYALA RIVER WATER UPSTREAM OF ITS CONFLUENCE WITH THE TIGRIS RIVER: AN ANALYTICAL STUDY OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS

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ABSTRACT

The lower reach of the Diyala River, southeast of Baghdad, is a vital river system that is nonetheless suffering severe degradation due to persistent human pressures and infrastructure deficiencies. This study assesses the spatial distribution of major untreated sewage outfalls and quantifies the associated environmental risks to nearby residential and urban communities. This study aimed to assess Diyala River water quality by analyzing a range of physical and chemical characteristics at several monitoring sites during the summer and winter seasons, comparing the results against Iraqi standard limits to determine water suitability and identify key pollution sources. The study measured pH, electrical conductivity, turbidity, dissolved and suspended solids, total hardness, cations and anions, nutrients, organic matter, oils, and heavy metals. The results revealed variations across study sites between the summer and winter seasons; while pH values remained within the standard range (7.3–8), concentrations of dissolved salts, electrical conductivity, and total hardness at certain sites exceeded standard limits for river water, reaching levels of 2,173, 4,180, and 1,800 mg/L, respectively, particularly during the summer. Nitrate and phosphate concentrations at several locations exceeded acceptable limits, reflecting the impact of agricultural activities and untreated domestic wastewater discharged into the river. Meanwhile, elevated levels of Chemical Oxygen Demand (COD) and oil were observed, reaching 105 mg/L and 9.8 mg/L, respectively, at certain sites, indicating organic pollution resulting from discharged wastewater. Lead concentrations also exceeded permissible limits for river water; however, concentrations of other elements remained within the acceptable limits established by the Iraqi Ministry of Environment for river water quality assessment.

Keywords: Diyala River, Polluted Water, Water Assessment, Sewage outfalls, Physicochemical characteristics

1 INTRODUCTION

Surface water resources are among the most critical environmental components upon which human societies rely to meet their diverse needs. Water bodies, including rivers, play a vital role in supplying water for drinking, irrigation, and industrial use, while also contributing to the maintenance of ecological balance and biodiversity (WHO, 2022). However, with the intensification of human activities and the expansion of urban, industrial, and agricultural sectors, surface water quality has become vulnerable to degradation due to the discharge of various pollutants; this necessitates periodic, comprehensive assessments to determine water quality levels and suitability for multiple uses (Qader, 2025). The Diyala River is a major tributary of the Tigris River, flowing through areas with diverse human and agricultural activities that directly or indirectly affect its water quality. Studying the river's water quality is particularly important upstream of its confluence with the Tigris, as this area acts as a transition zone, facilitating the transfer of pollutants and chemical elements into the Tigris. This can impact water quality and related ecosystems (Kareem et al., 2024; IME, 2024). Water quality assessment relies primarily on examining physicochemical indicators that reflect the water's natural and chemical properties, such as temperature, pH, electrical conductivity, total dissolved solids, total hardness, chemical ion concentrations, and various nutrients (APHA, 2023). These indicators provide crucial information regarding environmental changes, pollution levels, and the impact of surrounding activities on the aquatic system. Meanwhile, heavy metals are among the most hazardous environmental pollutants found in surface waters stemming from industrial, agricultural, and domestic discharges, due to their tendency to persist and accumulate in the environment over long periods (Tchounwou et al., 2012). Furthermore, elevated concentrations of elements such as lead, cadmium, chromium, nickel, copper, and zinc can adversely affect living organisms and human health when the water is used for domestic purposes or as drinking water; consequently, monitoring and assessing their levels are fundamental aspects of water quality studies (USEPA, 2024). This study aims to conduct a qualitative environmental assessment of the Diyala River both upstream of its confluence with the Tigris River and at the confluence itself by analyzing a range of physicochemical indicators and heavy metals. It seeks to determine the extent to which the water complies with established environmental standards, identify potential pollution levels and their causes, and provide a scientific basis to support water resource management programs.

2 MATERIALS AND METHODS

2.1 Study Area

The study was conducted in the waters of the Diyala River at locations upstream of its confluence with the Tigris River and at the confluence itself, within Baghdad Governorate.

Sampling sites were selected to ensure a representation of the river's environmental characteristics and the impact of surrounding human and agricultural activities; six sampling stations were chosen for the summer and winter seasons, as follows:

- (S1): Point located 2 km upstream of the confluence with the Tigris River
- (S2): Point located 1 km upstream of the confluence with the Tigris River
- (S3): Confluence point where the waters of the Diyala and Tigris rivers mix
- (S4): Bridge point located 5 km upstream of the confluence with the Tigris River
- (S5): Al-Daffafah Village point, located 6 km upstream of the confluence with the Tigris River
- (S6): Military College point, located 8 km upstream of the confluence with the Tigris River

2.2 Sample Collection

Water samples were collected from the mid-stream of the Diyala River at depths ranging from 30 to 50 cm across the study area (Al-Dabbas, 2024). Plastic bottles were used, as well as clean 0.5-liter glass bottles for heavy metal analysis; the latter were acidified with nitric acid to lower the pH to below 2, thereby inhibiting microbial growth and preventing contamination. The bottles were rinsed with water from the sampling site before collection, then filled with the contaminated water samples; the samples were stored in coolers at 4°C and transported directly to the laboratory for analysis within 24 hours) ISO, 2024).

2.3 Field Measurements

Field measurements were conducted directly at the study sites using field instruments, covering water temperature, pH, electrical conductivity, salinity, and turbidity. Measurements were performed in triplicate at each site to enable statistical analysis of the results.

2.4 Laboratory Analyses

Laboratory analyses were conducted in accordance with the standard methods approved by APHA (2023). These included measurements of electrical conductivity and total dissolved solids (TDS); determination of hardness, calcium, and magnesium concentrations via EDTA titration; chloride analysis via titration; and spectrophotometric determination of sulfates, nitrates, and phosphates, in addition to the chemical oxygen demand (COD). Regarding heavy metals, samples were filtered, and concentrations including lead, cadmium, copper, nickel, chromium, iron, and zinc were measured using atomic spectrometry.

2.5 Statistical Analysis

The SPSS statistical software was used to perform statistical analyses. One-way ANOVA was employed to examine significant differences between sites, using the Least Significant Difference (LSD) test at a significance level of $P \leq 0.05$.

3 RESULTS AND DISCUSSION

The digital analytical map (Figure 1) illustrates the spatial and bio-hydrological connection between wastewater discharge points and the final reach of the Diyala River, just before its confluence with the Tigris River. This spatial distribution reveals a cumulative pollution pattern extending from the Rustamiyah outlet in the northeast, through the Diyala Bridge area, to the final discharge point, where pollutants accumulate and concentrate due to hydraulic factors. The map also highlights the environmental and health implications associated with this watercourse, including severe water-quality degradation, threats to surrounding agricultural systems, and escalating health risks for nearby and downstream communities.

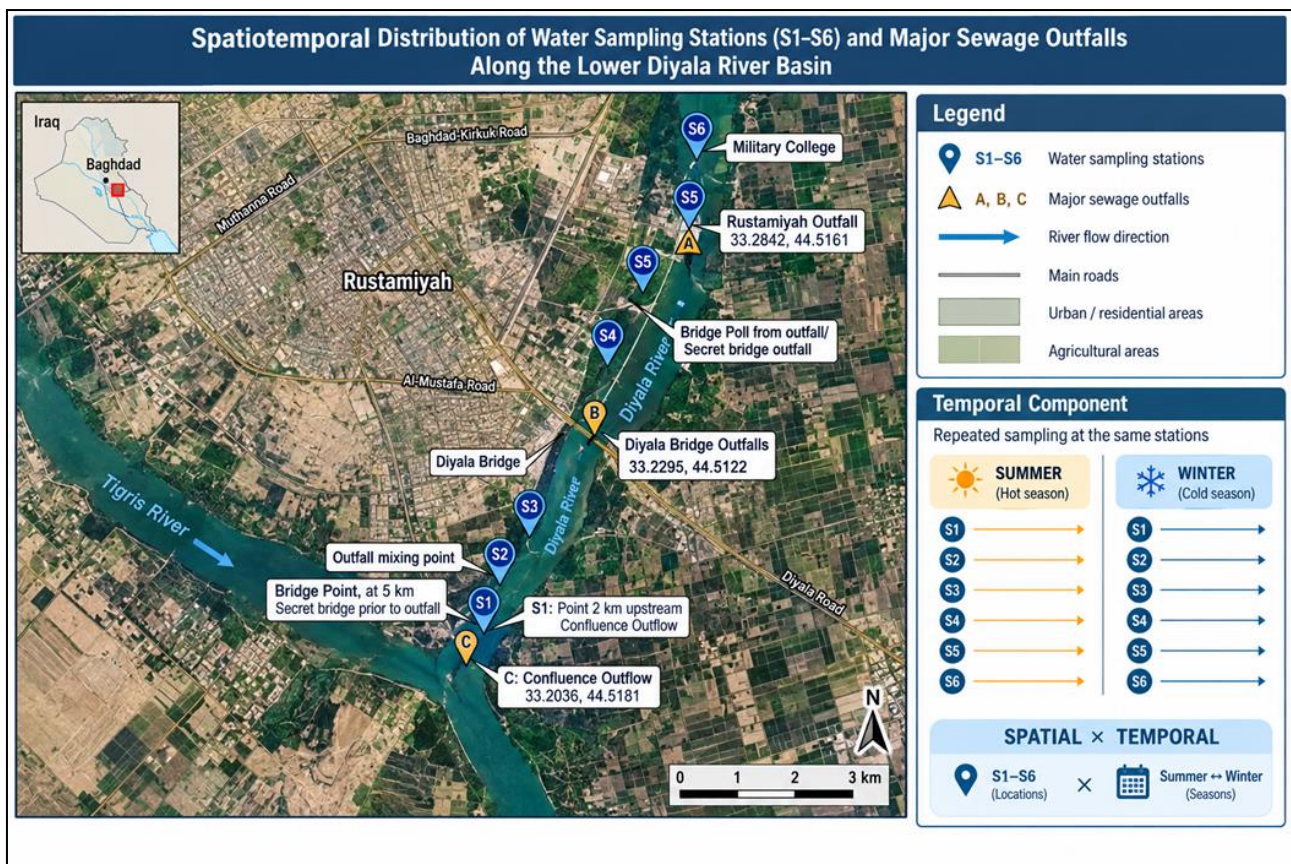


Figure 1: Spatiotemporal Distribution of Water Sampling Stations (S1-S6) and Major Sewage Outfalls Along the Lower Diyala River Basin.

Physicochemical analysis of the Diyala River water during the summer season indicated that pH values ranged from 7.3 to 7.7 across all sampling sites. This reflects relative stability in the water's acid-base balance, showing no direct impact from various pollution sources; this stability is attributed to the presence of carbonates, organic compounds, and bases such as bicarbonates derived from the dissolution of carbonate rocks, as well as geochemical reactions within the water that act as a buffering system, mitigating the effects of pollutants and substances entering the water (Shangguan et al., 2025). The results also revealed significant variations in water quality characteristics among the studied sites. Electrical conductivity (EC) values showed a marked increase at sites S1, S5, and S2, recording 4180, 3590, and 3070 $\mu\text{S}/\text{cm}$,

respectively, compared to the other sites, indicating a clear variation in the concentrations of dissolved salts and ions across the study locations. This significant rise in EC is attributed to the heightened impact of agricultural, industrial, and domestic discharges rich in dissolved ions; conversely, the mixing of the Diyala River with the Tigris River at the confluence point (S3) resulted in relative dilution that lowered EC values. This pattern was also reflected in the Total Dissolved Solids (TDS) and Total Hardness (T.H.) levels, which peaked at these same sites. This confirms the direct correlation between increased electrical conductivity and elevated concentrations of salts and dissolved elements (Nassrullah et al., 2026). Turbidity (Tur) reached its highest values at sites S6 and S4, recording 280 and 240 NTU, respectively, but dropped to 130 NTU at the confluence point due to dilution; this indicates a distinct difference in the quantity of suspended and colloidal matter carried by the water. The elevated turbidity at certain sites can be attributed to increased erosion of sediments and suspended organic matter caused by water flow or waste discharge, whereas lower levels at other sites resulted from the settling of heavier particles. Increased turbidity reduces light penetration in the water, thereby affecting photosynthesis in aquatic organisms and leading to the degradation of the aquatic environment (Messner et al., 2023). Nutrient concentrations, specifically phosphate and nitrate, showed a marked increase at site S1 compared to other sites, reaching 10.3 mg/L and 20.3 mg/L, respectively; this indicates elevated organic and agricultural pollution and the potential for eutrophication driven by various human activities, alongside high levels of oils, Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC) at this site. COD values peaked at sites S1 and S2 compared to other locations, reaching 105 mg/L and 71 mg/L, respectively. Elevated Chemical Oxygen Demand (COD) levels indicate the presence of significant quantities of chemically oxidizable organic and inorganic substances originating from industrial, domestic, and agricultural waste; conversely, lower concentrations result from water dilution, which contributes to improved water quality. The results revealed slight variations in oil concentrations across the sites; the highest values were recorded at sites S1, S2, and S6, at 9.8, 9.2, and 9 mg/L, respectively, compared to the other sites. This elevation reflects the impact of human and industrial activities, specifically factories and workshops that discharge untreated waste into the rivers. Oils constitute a significant pollutant affecting oxygen transfer between air and water, thereby adversely impacting aquatic organisms (WHO, 2022). Sodium concentration peaked at 556 mg/L at point S1, then dropped to 231 mg/L at point S3 due to dilution by Tigris River water. This elevated sodium level is attributed to agricultural drainage inputs, the chemical weathering of salt-rich rocks, and wastewater discharged into the rivers. The results also revealed variations in calcium and magnesium concentrations across all sites, attributed to the dissolution of calcareous rocks in the riverbeds and the contribution of agricultural drainage water discharged into the rivers. Furthermore, a direct relationship exists between elevated total hardness and increased concentrations of calcium and magnesium in the water (Nassrullah et al., 2026). Regarding heavy metals, lead and copper concentrations ranged from 0.06 to 0.14 mg/L and 0.05 to 0.09 mg/L, respectively, while the concentrations of other elements were very low (below the detection limit (BDL)). The study indicated a clear decrease in the concentration of lead and copper at the point of confluence and dilution with the Tigris River. The high concentration of heavy metals resulted from the discharge of industrial wastewater into the river without treatment, which led to an increase in their concentration in the waters of the Diyala River (Table 1).

Table 1: Physical and chemical water quality parameters of the Diyala River at selected sites before and after its confluence with the Tigris River in the summer season

test	LSD	S2	S1	S3	S4	S5	S6
pH	-	7.7	7.7	7.7	7.3	7.6	7.7
Ec (μS/cm)	70.5	3070 c	4180 a	1929 d	1982 d	3590 b	1985 d
Tur (ntu)	18.2	c 183	140 d	130 d	240 b	200 c	280 a
TDS (ppm)	-	1736	2173	1035	1091	1977	1092
TSS (ppm)	7.89	b 25	a 40	c 17	25 b	30 b	25 b
T.H (ppm)	-	1420	1800	800	800	1500	810
Ca (ppm)	-	330	430	220	200	300	210
Mg (ppm)	-	114	128	79	73	121	69
PO4 (ppm)	-	2.2	10.3	1.6	1.9	2.7	5.5
NO3(ppm)	-	7.0	20.3	12.3	1.3	4.6	1.3
Na (ppm)	-	513	556	231	285	535	247
K (ppm)	-	14.6	9.4	14.3	14.6	9.3	14.5
S (%)	-	1.6	2.4	0.9	3.0	2.0	3.0

CO ₃ (ppm)	-	3.7	5.2	1.7	30.8	40.7	80.3
HCO ₃ (ppm)	-	350	300	300	190	99	48
Oil (ppm)	-	9.2	9.8	8	7	5	9
COD (ppm)	19.61	b 71.0	a 105.0	c 30.0	31.2 c	44 c	29 c
TOC (ppm)	5.55	b 23	a 35	a 30	20 b	34 a	19 b
Pb (ppm)	-	0.019	0.015	0.013	0.14	0.11	0.06
Cu (ppm)	-	0.07	0.09	0.05	0.05	0.08	0.07
Zn (ppm)	-	BDL	BDL	BDL	BDL	BDL	BDL
Cr (ppm)	-	BDL	BDL	BDL	BDL	BDL	BDL

Table (2) indicates that all analyses performed on water samples from the six sites during the winter season showed a marked decrease in electrical conductivity (EC), total hardness, cation and anion concentrations, and organic content compared to the summer analyses. The results reveal a clear disparity between the two seasons regarding the physicochemical properties of the Diyala River water, attributed to the climatic and hydrological changes associated with summer and winter and their impact on the concentrations of various pollutants and ions. These variations align with findings from numerous studies confirming that seasonal changes are among the most significant factors influencing surface water quality, driven by fluctuations in flow rates, evaporation, dilution, and the volume of discharges entering rivers. Hydrological studies have indicated an inverse relationship between river discharge and dissolved salt concentrations; increased water flow leads to lower concentrations of dissolved substances, whereas rising temperatures during summer accelerate evaporation, thereby increasing the concentration of dissolved salts and various ions in the water (Hamad et al., 2012).

The pH values were similar between the summer and winter seasons, ranging from 7.3–7.7 and 7.7–8.0, respectively; this indicates that the water maintained a neutral to slightly alkaline nature throughout the study period. This stability is attributed to the role of bicarbonate and carbonate compounds in regulating the water's ionic balance, as numerous studies have shown that pH is among the most stable characteristics in rivers compared to other chemical indicators (Saha et al., 2023). The results also indicated higher turbidity and Total Suspended Solids (TSS) levels during winter compared to summer; turbidity at site S5 rose to 380 NTU in winter, up from 200 NTU at the same site in summer, alongside a noticeable variation in TSS values between the two seasons. This is attributed to increased rainwater runoff, which causes soil and sediment erosion and the resuspension of materials settled on the riverbed, thereby increasing the concentration of suspended particles. Furthermore, the results showed lower concentrations of cations. Concentrations ranged from 120–487 mg/L to 231–556 mg/L for sodium and from 40–77 mg/L to 69–128 mg/L for magnesium during the winter and summer seasons, respectively. This can be attributed to the increased volume of water entering the river during winter, which dilutes the concentration of dissolved ions (Nassrullah et al., 2026). Elevated calcium and magnesium concentrations during summer are linked to higher evaporation rates, whereas potassium showed only slight variations between the two seasons, indicating that its primary sources, associated with soil and agricultural fertilizers, remained relatively stable throughout the study period, specifically, sodium, calcium, and magnesium, in winter compared to summer.

The results also revealed a marked decrease in phosphate and nitrate concentrations during winter compared to summer; concentrations ranged from 1.6–10.3 mg/L and 0.1–9.4 mg/L for phosphate and from 1.3–20.3 mg/L and 0.1–6.1 mg/L for nitrate, for the summer and winter seasons, respectively. This decline reflects the impact of increased water discharge and dilution, as well as the consumption of these nutrients by aquatic organisms and algae. Furthermore, the results indicate that sources of agricultural pollution and organic matter are more pronounced during summer due to lower water levels and elevated nutrient concentrations (Al-Obaidy et al., 2024). Bicarbonate concentrations also decreased in winter compared to summer, reflecting the influence of seasonal changes, varying dissolution rates, and geochemical reactions on carbonate and bicarbonate content (Suntikoon et al., 2025). COD and oil concentrations peaked during the summer compared to winter at most sites; the highest COD value was 105 mg/L at site S1 in summer, whereas the same site recorded 80 mg/L in winter. Similarly, oil concentration reached its maximum at site S1 during summer (9.8 mg/L), compared to 3.3 mg/L at the same location during winter. This increase is linked to the concentration of organic matter and petroleum pollutants during the summer, resulting from reduced water volume and elevated rates of organic decomposition; conversely, higher river discharge during the winter led to the dilution of organic loads and a reduction in pollutant concentrations. These findings align with environmental studies indicating that Chemical Oxygen Demand (COD) values often rise during dry seasons due to the concentration of organic matter and reduced natural dilution efficiency (Gobana et al., 2025).

Table 2: Physical and chemical water quality parameters of the Diyala River at selected sites before and after its confluence with the Tigris River in the winter season

Test	LSD	S2	S1	S3	S4	S5	S6
pH	-	7.7	7.9	7.9	7.7	7.9	8.0
Ec ($\mu\text{S}/\text{cm}$)	73.5	1555 c	2390 a	990 d	899 c	1709 b	1010 d
Tur (ntu)	18.2	230 b	187 c	130 c	270 a	380 a	299 a
TDS (ppm)	-	1101	1550	643	588	1100	657
TSS (ppm)	7.89	b 32	a 51	b 29	30 b	43 b	28 c
T.H (ppm)	-	760	998	520	490	810	488
Ca (ppm)	-	166	229	76	99	198	101
Mg (ppm)	-	60	77	42	32	77	40
PO ₄ (ppm)	-	0.2	0.2	0.1	4.9	1.7	2.6
NO ₃ (ppm)	-	6.1	3	4.6	1.3	0.1	1.9
Na (ppm)	-	300	487	150	125	299	120
K (ppm)	-	6.6	4.4	6.3	5.6	3.9	6.9
S (%)	-	0.8	1.3	0.5	0.4	0.9	0.6
CO ₃ (ppm)	-	133	129	200	300	329	177
HCO ₃ (ppm)	-	190	290	218	166	140	200
Oil (ppm)	-	2.3	3.3	4.7	2.7	3.7	4.1
COD (ppm)	19.61	b 51.0	a 80.0	b 22.0	21.7 c	33.4 c	35.7 c
TOC (ppm)	5.65	b 29	a 65	c 20	30 b	33 b	18 c
Pb (ppm)	-	0.01	0.01	0.01	0.13	0.19	0.10
Cu (ppm)	-	0.10	0.08	0.07	0.08	0.05	0.09
Zn (ppm)	-	BDL	BDL	BDL	BDL	BDL	BDL
Cr (ppm)	-	BDL	BDL	BDL	BDL	BDL	BDL

A slight variation was observed in the concentrations of heavy metals, specifically lead and copper, between the two seasons. The highest lead concentration, 0.14 mg/L, was recorded at the S4 bridge site during the summer, whereas it was 0.13 mg/L at the same site during the winter. Regarding copper, the highest concentration was 0.09 mg/L at site S1, while the concentration at the same site was 0.08 mg/L during the summer and winter seasons, respectively. This variation in heavy metal concentrations is attributed to the runoff-driven transport of sediments and soil laden with these elements, as well as the discharge of industrial and domestic wastewater into the rivers throughout the seasons (Gunes, 2022).

The results of the current study were compared against the standards established in the "Regulation on the Protection of Rivers and Public Waters from Pollution" (No. 25 of 1967), issued by the Iraqi Ministry of Environment (2022). While some physicochemical parameters fell within permissible environmental limits, others exceeded them, reflecting variations in water quality across the study sites. pH values ranged from 7.3 to 8.0, falling within the standard range of 6.5 to 8.5, indicating that the Diyala River water maintains a neutral to slightly alkaline nature; this suggests the aquatic environment remains sound and has not been subjected to significant pollution.

Regarding TDS values across the two seasons, they ranged from 588 to 2,173 mg/L, showing a marked increase at several locations, particularly during the summer. This reflects higher concentrations of dissolved salts resulting from reduced water discharge, high evaporation rates, and the impact of water discharged into the rivers; indeed, elevated TDS levels are a primary cause of river water quality deterioration. The results indicated that nitrate concentrations at site S1 exceeded the permissible limit of 15 mg/L, reaching 20.3 mg/L during the summer season, suggesting the impact of nitrogen-fertilizer-laden runoff entering the rivers, whereas concentrations decreased in winter due to increased water flow from rainfall. Phosphate concentrations ranged from 0.1 to 10.3 mg/L, exceeding the standard limit of 0.4

mg/L at most sites. This indicates an increase in the volume of water discharged into the rivers, specifically agricultural runoff and household wastewater containing detergents. Results also showed elevated concentrations of total hardness, calcium, magnesium, and sodium at certain sites during the summer, reaching 1800, 430, 128, and 556 mg/L, respectively, driven by high levels of dissolved salts resulting from the natural weathering of carbonate rocks. Meanwhile, turbidity and (TSS) levels rose significantly during the winter, reaching up to 380 NTU and 1550 mg/L at some locations, due to the erosion of soil and sediments caused by increased surface runoff. COD values showed a significant increase, peaking at 105 mg/L at site S1. Oil concentrations also rose at certain locations, reaching a maximum of 9.8 mg/L during the summer season, levels that exceeded the permissible limits of 40 mg/L and 5 mg/L, respectively. Peak concentrations of the heavy metals lead and copper during the study period were recorded at 0.19 mg/L and 0.1 mg/L, respectively, whereas standard specifications dictate that these should not exceed 0.01 mg/L and 1.0 mg/L.

4 CONCLUSION

The water quality of the Diyala River has been influenced by natural, industrial, and anthropogenic factors, clearly affecting the water's physical and chemical characteristics. pH values remained within Iraqi standard limits, indicating stability in the aquatic environment; however, electrical conductivity, total dissolved solids, total hardness, and major ion concentrations showed elevated levels at several study sites, particularly during summer, due to reduced water discharge, high evaporation rates, and the influx of drainage water into the river. The results indicated that nitrate and phosphate concentrations exceeded permissible environmental limits at certain sites, increasing the likelihood of eutrophication and the associated decline in aquatic ecosystem quality. Furthermore, elevated levels of Chemical Oxygen Demand (COD), as well as oils and greases, evidenced organic pollution at some study sites, reflecting the intensity of human, agricultural, and industrial activities in those areas. The results indicated that lead concentrations exceeded permissible limits, whereas copper concentrations remained within the limits specified for river water; meanwhile, zinc and chromium concentrations in the water were very low. It is recommended to strengthen continuous environmental monitoring programs, curb pollution sources, improve wastewater treatment efficiency, and implement integrated water resources management, thereby contributing to improved water quality and the preservation of the river's environmental sustainability.

Recommendations

The findings highlight the urgent need for strengthening sewage treatment infrastructure along the lower reach of the Diyala River to reduce untreated discharges. Regular monitoring of key pollutants particularly dissolved salts, nutrients, COD, and heavy metals, should be institutionalized to ensure compliance with Iraqi water quality standards. Priority should be given to controlling agricultural runoff and domestic wastewater inputs, alongside implementing community awareness programs to mitigate human pressures on the river system.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

Author Contributions

All authors contributed to the conception and design of the study, data collection, analysis, and interpretation. They jointly participated in drafting the manuscript, revising it critically for intellectual content, and approved the final version for submission.

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