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Evaluation of Physicochemical Parameters and Water Quality Index (WQI) in Green River, Akwa Ibom State, Nigeria

Udoh Nkpouto Frederick[1,2], Udotong Uduak Friday[1,2], Shaibu Eneojo Solomon[1,2*], Edu James Inam[1,2]
[1]Department of Chemistry, University of Uyo, Nigeria
[2]International Center for Energy and Environmental Sustainability Research (ICEESR), Nigeria

ABSTRACT

This study evaluated the physicochemical parameters and Water Quality Index (WQI) of the Green River in Akwa Ibom State, Nigeria, across wet and dry seasons to determine its suitability for domestic and agricultural use. Physicochemical parameters including pH, turbidity, total dissolved solids, biochemical oxygen demand, dissolved oxygen, and nutrient concentrations were analyzed following WHO and Nigerian Industrial Standards. Results indicated significant seasonal variations, with acidic pH values (4.38–6.61) and consistently low dissolved oxygen (<5 mg/L), suggesting ecological stress. Elevated phosphate levels (up to 6.06 mg/L) indicated potential eutrophication, while chloride and conductivity values reflected anthropogenic influence. The WQI values varied from 41.1 to 65.1, with December showing the highest water quality and March the lowest, WQI values classified the river water as ranging from poor to very poor, particularly during the dry season. Furthermore, heavy metal risk assessments revealed concerning hazard quotients and cancer risk values for cadmium, lead, and arsenic. The findings highlight the urgent need for improved environmental management and pollution mitigation strategies to safeguard water quality and human health.

Keywords: Physicochemical Parameters, Water Quality Index (WQI), Green River, Risk assessments, Hazard quotient

INTRODUCTION

Water is an essential component of all living systems and plays a fundamental role in sustaining ecological balance, supporting biodiversity, and enabling economic development (Ibuotenang et al., 2025; Obadimu et al., 2025). It is central to agriculture, industry, energy production, domestic use, and urban infrastructure. However, the quality of this vital resource is increasingly threatened by numerous anthropogenic and natural factors. Pollutants from various, unrelated sources have the capacity to disrupt aquatic ecosystems by altering the physical and chemical properties of water bodies (Adigun et al., 2025; Shaibu et al., 2024). Water quality deterioration poses a significant risk to human health, aquatic life, and agricultural productivity, particularly in urban and peri-urban environments where land-use pressure and industrial activities continue to escalate (Ikpi et al., 2024). Among the most prominent anthropogenic influences affecting water quality are quarrying activities, which have become widespread in many developing regions, including Nigeria (Awogbami et al., 2023; Shaibu et al., 2024). Quarrying involves the extraction of rock materials for construction and infrastructure development and includes operations such as vegetation clearance, excavation, drilling, blasting, transportation, and crushing of rocks. Common rock types extracted include granite, limestone, diorite, gneiss, and shale. These operations generate significant amounts of waste materials that are often dumped in unregulated heaps around quarry sites, leading to contamination of surrounding soils, water bodies, and air (Lyashenko et al., 2020). Despite their economic benefits, most quarrying activities lack environmental management frameworks and mitigation plans, particularly in regions where environmental oversight is weak. In many cases, abandoned quarry sites become hotspots for environmental degradation, especially during the rainy season when surface runoff transports sediments and contaminants into nearby rivers, lakes, and wetlands (Inam et al., 2017; Ikpi et al., 2024; Netto et al., 2024).

One of the primary concerns associated with quarrying is its impact on the physicochemical parameters of surface water bodies (Khan et al., 2023; Udousoro & Umoren, 2014). Rainfall and runoff from quarry sites carry a variety of contaminants, including suspended solids, organic matter, and nutrients, which can alter water temperature, turbidity, pH, electrical conductivity, and biochemical oxygen demand (Aleem Muhammad et al., 2018; Jehanzaib et al., 2022; Ram et al., 2021). For example, an increase in total suspended solids (TSS) reduces water clarity and affects aquatic photosynthesis, while high turbidity impairs fish respiration and breeding. Elevated levels of nutrients like phosphates and nitrates can lead to eutrophication—causing algal blooms, oxygen depletion, and fish kills (Lan et al., 2024; Xie et al., 2024). Similarly, altered pH and conductivity levels can disturb the physiological balance of aquatic organisms and limit the use of water for drinking or irrigation (Ighalo & Adeniyi, 2020; Meher et al., 2019). Water bodies such as the Green river , located in Akwa Ibom State, Nigeria, are particularly vulnerable to such disturbances due to their proximity to human settlements, farmlands, and quarry sites (Inam et al., 2015).

The Green River is a critical water source for surrounding communities, serving domestic, agricultural, and small-scale industrial needs. However, its proximity to areas of intense anthropogenic activity increases its susceptibility to pollution. Seasonal variations, especially between the wet and dry periods, significantly influence the transport and dilution of pollutants. During the wet season, surface runoff contributes to increased flow rates and higher contaminant loads, while in the dry season, reduced water levels may concentrate pollutants, exacerbating their effects. Understanding the current state of physicochemical water quality is therefore crucial for assessing the health of aquatic ecosystems and the safety of water resources for human use. Key parameters often monitored in such assessments include pH, temperature, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), electrical conductivity (EC), and concentrations of anions like phosphate, nitrate, sulphate, and chloride (Ayek & Zerouali, 2025; Onisogen Simeon et al., 2019). Each parameter offers insights into specific aspects of water quality. For instance, pH influences the solubility of compounds and biological activity, while DO levels reflect the ability of water to support aerobic organisms. Elevated BOD levels may indicate high organic pollution, suggesting the presence of biodegradable waste from agricultural or domestic sources. In addition to analyzing individual parameters, a comprehensive approach such as the Water Quality Index (WQI) is often employed to integrate multiple indicators into a single value that reflects the overall quality of water. The WQI is a powerful tool that simplifies complex water quality data and helps policymakers, stakeholders, and the general public easily understand water health (Inam et al., 2019; Mgbenu & Egbueri, 2019; Tyagi et al., 2020). It also facilitates temporal and spatial comparisons across different sampling sites and seasons. A high WQI score indicates poor water quality, often unsuitable for drinking or agricultural use, while a lower score suggests better water conditions.

The purpose of this study is to assess the physicochemical properties and Water Quality Index (WQI) of the green river across selected sampling locations and seasonal intervals. The research aims to evaluate spatial and temporal variations in water quality, identify potential sources of contamination, and determine the suitability of the river water for domestic and agricultural uses.

METHODOLOGY

The Study Area

The study area is a natural stream channel located in Ibesikpo Asutan Local Government Area of Akwa Ibom State, Nigeria. Geographically, it lies within the coastal plains of the tropical rainforest belt, a zone characterized by high mean annual rainfall of approximately 2500 mm, temperatures ranging between 26°C and 33°C, and relative humidity levels of 65% to 85%. The topography of the area is predominantly flat with gentle undulations surrounding the stream channel, which promotes water ponding and frequent flooding. The stream functions as an ephemeral channel, flowing during the rainy season when groundwater levels are elevated but drying up in the dry season. It serves as a receiving outlet for urban stormwater drainage from the city of Uyo, beginning around latitude 4.973673°N and longitude 7.923694°E and discharging into a larger river at 4.814423°N and 7.864127°E. The receiving water body, the Anyang Nsit River, flows into the Qua Iboe River and provides water for domestic and agricultural use for communities along its banks. Human activities have also altered the channel significantly. The presence of fine sand and gravel deposits has encouraged intensive sand and gravel mining, creating artificial ponds along the stream course. These activities, coupled with the use of chemicals during dredging, have introduced pollutants into the channel, with noticeable changes such as a blue-greenish coloration of ponded water. Consequently, while the stream plays an important hydrological and socio-economic role, it is under significant environmental stress from human exploitation and pollution.

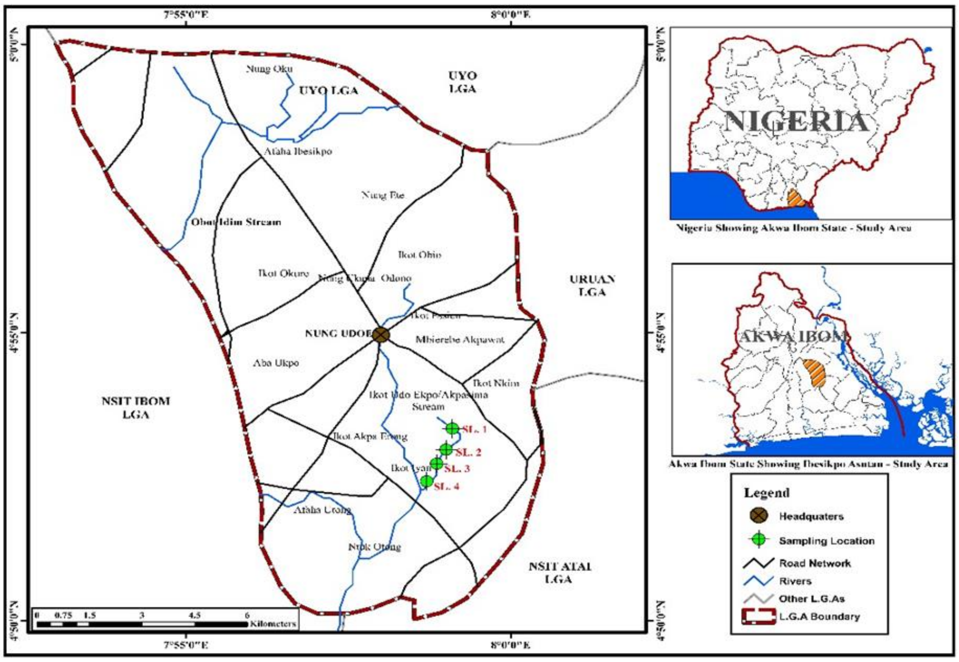


Figure 1: Map of Green River showing sampling stations

Analytical Methods

Physical Analysis

In-situ determination of physical parameters including temperature, pH, total dissolved solids (TDS), turbidity, and electrical conductivity was carried out at each sampling point using calibrated portable meters. Measurements were taken immediately after sample collection to minimize errors due to holding time and environmental changes.

Chemical Analysis

Chemical analyses of the water samples were conducted following standard procedures recommended by the American Public Health Association (APHA, 2017) and the World Health Organization (WHO, 2011). Parameters determined included total hardness, dissolved oxygen (DO), biochemical oxygen demand (BOD), chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{2-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), ammonia (NH_3), and phosphate (PO_4^{3-}). Heavy metals such as chromium (Cr), cadmium (Cd), nickel (Ni), and lead (Pb) were also analyzed using appropriate spectrophotometric and titrimetric methods. The data obtained from these analyses were used in computing the Water Quality Index (WQI) for the different sampling stations in the study area.

Determination of Water Quality Index (WQI)

The Water Quality Index (WQI) of the study stream was computed using the Weighted Arithmetic Water Quality Index (WAWQI) method, as described by Ibrahim and Bitrus (Nzenwa et al., 2021). This method integrates multiple physicochemical parameters into a single index value that reflects the overall quality of the water body.

Assessment of Water Quality Using the Water Quality Index (WQI)

To assess the suitability of the stream water in Ibesikpo Asutan for domestic and other purposes, the measured physicochemical parameters were compared with guideline values provided by the World Health Organization (WHO, 2011) and the Nigerian Industrial Standard (NIS, 2007) for drinking water supply. The computed WQI values were then classified into categories ranging from excellent to unsuitable, thereby providing a holistic measure of the water quality status in the study area.

RESULTS AND DISCUSSION

The physicochemical characteristics of surface water play a crucial role in determining its suitability for domestic, agricultural, and industrial purposes. Variations in parameters such as pH, temperature, dissolved oxygen, turbidity, and nutrient concentrations can significantly influence overall water quality, particularly when assessed across different hydrological seasons. To provide a clearer picture of the seasonal dynamics of the Green River, the physicochemical parameters and Water Quality Index (WQI) for both the wet and dry seasons are presented in Table 1, covering the sampling period from October to March.

Table 1: Physicochemical parameters and WQI of Green River for Wet and Dry Season

Parameter	October	November	December	January	February	March	WHO Standard
Ph	7.1±0.02	7.2±0.01	7.8±0.01	6.8±0.03	6.6±0.04	7.2±0.01	6.5-8.5
Temp (°C)	27.3±0.3	27.0±0.02	28.5±0.32	27.1±0.23	28.0±0.32	26.5±0.16	20-30
TSS (g)	1.5±0.2	1.8±0.2	1.9±0.3	2.1±0.2	1.9±0.2	0.8±0.1	25
Turbidity (mg/l)	0.5±1.2	0.6±1.3	0.5±1.1	1.0±1.2	0.8±0.2	0.3±0.1	1000
TDS (mg/l)	11.0±3.1	12.0±0.9	13.0±2.1	15.0±0.8	13.1±2.1	10.0±1.7	600
EC µs/cm	10.3±0.4	16.2±0.3	18.7±3.1	28.1±1.9	26.7±2.1	19.7±3.5	1000
BOD (mg/l)	1.2±1.3	2.1±0.0	0.4±0.1	2.0±0.1	1.8±0.3	0.20±0.2	5
DO (mg/l)	3.2±0.1	4.8±0.1	4.0±0.2	4.0±0.2	4.3±0.1	4.1±0.1	5
Alkalinity (mg/l)	6.0±0.2	1.4±0.0	4.3±0.3	55.2±3.2	51.3±3.2	65.3±2.1	500
Cl^- (mg/l)	40.5±3.5	44.5±2.3	42.3±2.2	38.8±1.9	41.2±2.1	35.5±2.2	250
NO^{3-} (mg/l)	1.4±0.3	1.9±0.1	2.3±0.2	2.1±0.4	2.0±1.0	1.1±0.9	50
SO_4^{2-} (mg/l)	5.1±1.3	7.1±0.9	8.3±1.1	10.2±0.8	8.7±1.2	9.2±1.9	250
PO_4^{3-}(mg/l)	1.5±0.5	2.0±0.1	1.8±0.3	4.2±1.2	4.9±0.4	1.1±0.4	5
WQI	50.5	55.4	65.1	52.3	52.5	41.1	

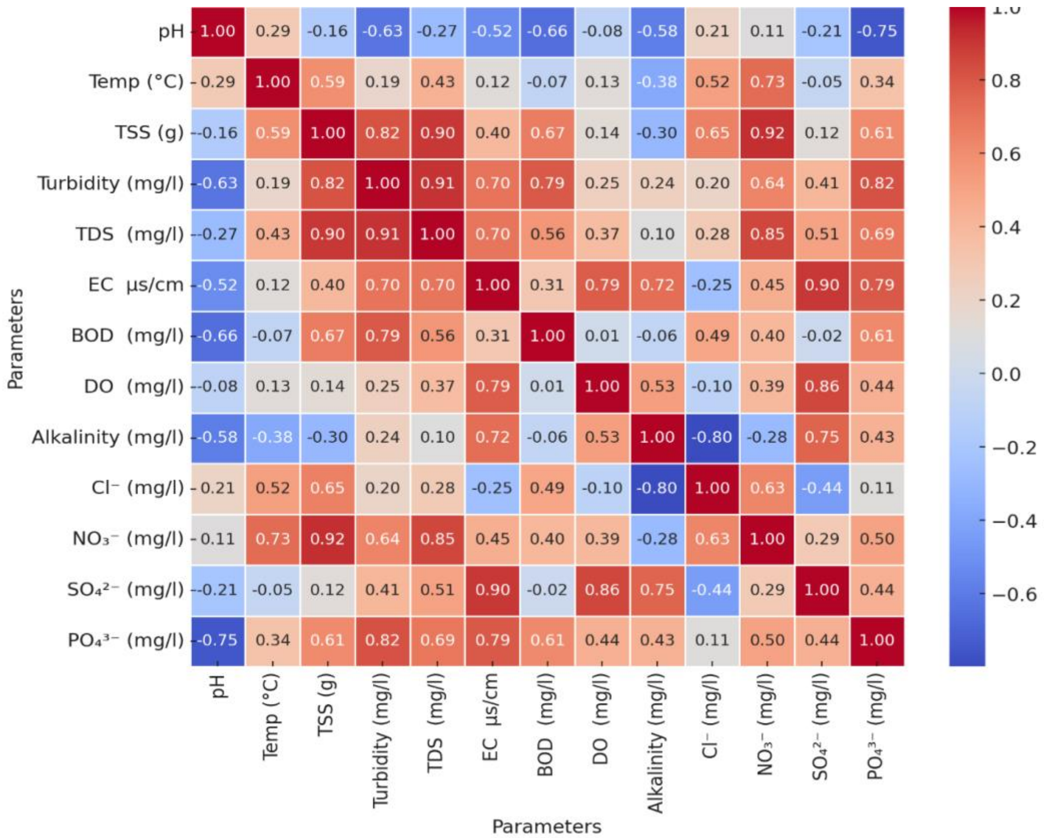


Figure 2: Correlation heatmap of physicochemical parameters in Green River

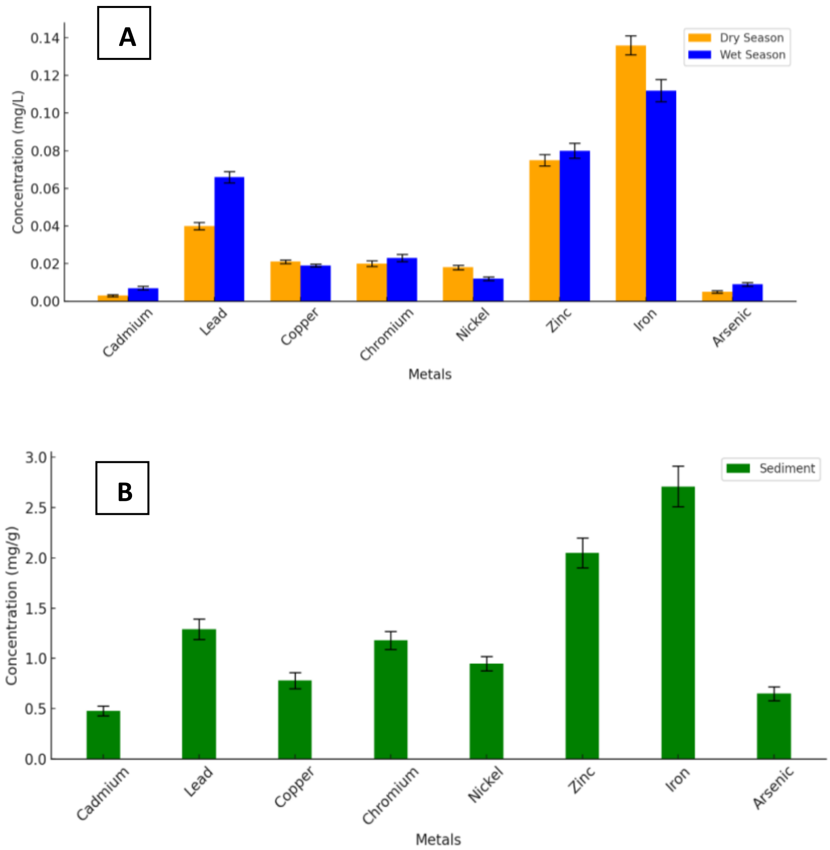


Figure 3: Mean metal concentrations in a) dry and wet seasons and b) sediment in Green River

Table 2: Average daily dose, life-term average daily dose, and hazard quotient, and cancer risk in the dry season of metals in water via ingestion and dermal routes

	Ingestion						Dermal					
	Infants			Adults			Infants			Adults		
Metal	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR
Cr	5.84E-03	1.95E-03	2.92E-03	2.09E-03	6.95E-01	1.04E-03	1.23E-01	4.09E+01	6.13E-02	1.13E-01	3.75E+01	5.63E-02
Cd	1.04E-03	2.08E+02	3.95E-04	3.71E-04	7.43E-01	1.41E-04	7.28E-04	1.46E+00	2.77E-04	6.69E-04	1.34E+00	2.54E-04
Fe	3.93E-02	5.61E-02		1.40E-02	2.00E-02		2.75E-02	3.93E-02		2.53E-02	3.61E-02	
Cu	3.70E-03	9.26E-02		1.32E-03	3.31E-02		2.59E-03	6.48E-02		2.38E-03	5.95E-02	
Pb	3.93E-03	2.81E+03	3.34E-04	1.40E-02	1.00E+01	1.19E-04	2.75E-02	1.96E+01	2.34E-04	2.53E-02	1.80E+01	2.15E-04
Ni	3.02E-03	1.51E-02		1.08E-03	5.39E-02		4.22E-02	2.11E+00		3.88E-02	1.94E+00	
As	8.24E-04	2.75E+03	1.24E-03	2.94E-04	9.81E-01	4.41E-04	1.73E-02	5.77E+01	2.60E-02	1.59E-02	5.30E+01	2.38E-02
Zn	2.40E-03	8.00E-03		8.57E-04	2.86E-03		1.68E-03	5.60E-03		1.54E-03	5.14E-03	

Table 3: Average daily dose, life-term average daily dose, and hazard quotient and cancer risk in wet season of metals in water via ingestion and dermal routes

	Ingestion						Dermal					
	Infants			Adults			Infants			Adults		
Metal	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR
Cr	2.24E-03	7.47E-01	1.12E-03	8.00E-04	2.67E-01	4.00E-04	4.70E-02	1.57E+01	2.35E-02	4.32E-02	1.44E+01	2.16E-02
Cd	2.40E-03	4.80E+00	9.12E-04	8.57E-04	1.71E+00	3.26E-04	1.68E-03	3.36E+00	6.38E-04	1.54E-03	3.09E+00	5.86E-04
Fe	1.85E-02	2.64E-02		6.60E-03	9.43E-03		1.29E-02	1.85E-02		1.19E-02	1.70E-02	
Cu	2.96E-03	7.40E-02		1.06E-03	2.64E-02		2.07E-03	5.18E-02		1.90E-03	4.76E-02	
Pb	2.10E-02	1.50E+01	1.78E-04	7.49E-03	5.35E+00	6.36E-05	1.47E-02	1.05E+01	1.25E-04	1.35E-02	9.62E+00	1.15E-04
Ni	1.68E-03	8.40E-02		6.00E-04	3.00E-02		2.35E-02	1.18E+00		2.16E-02	1.08E+00	
As	8.00E-04	2.67E+00	1.20E-03	2.86E-04	9.52E-01	4.29E-04	1.68E-02	5.60E+01	2.52E-02	1.54E-02	5.14E+01	2.31E-02
Zn	8.00E-04	2.67E-03		2.86E-04	9.52E-04		5.60E-04	1.87E-03		5.14E-04	1.71E-03	

Table 4: Average daily dose, life-term average daily dose, hazard quotient, and cancer risk of metals in sediment via ingestion and dermal routes

	Ingestion						Dermal					
	Infants			Adults			Infants			Adults		
Metal	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR	LADD (mg/kg/day)	HQ	CR
Cr	3.60E-03	1.20E+00	1.80E-03	2.57E-04	8.57E-02	1.29E-04	3.02E-01	1.01E+02	1.51E-01	2.78E-01	9.26E+01	1.39E-01
Cd	5.80E-04	1.16E+00	2.20E-04	4.14E-05	8.29E-02	1.57E-05	1.62E-03	3.25E+00	6.17E-04	1.49E-03	2.98E+00	5.67E-04
Fe	5.84E-03	8.34E-03		4.17E-04	5.96E-04		1.64E-02	2.34E-02		1.50E-02	2.15E-02	
Cu	2.40E-03	6.00E-02		1.71E-04	4.29E-03		6.72E-03	1.68E-01		6.17E-03	1.54E-01	
Pb	1.08E-02	7.70E+00	9.16E-05	7.70E-04	5.50E-01	6.55E-06	3.02E-02	2.16E+01	2.57E-04	2.77E-02	1.98E+01	2.36E-04
Ni	4.66E-04	2.33E-02		3.33E-05	1.66E-03		2.61E-02	1.30E+00		2.40E-02	1.20E+00	
As	4.74E-04	1.58E+00	7.11E-04	3.39E-05	1.13E-01	5.08E-05	3.98E-02	1.33E+02	5.97E-02	3.66E-02	1.22E+02	5.48E-02
Zn	6.00E-04	2.00E-03		4.29E-05	1.43E-04		1.68E-03	5.60E-03		1.54E-03	5.14E-03	

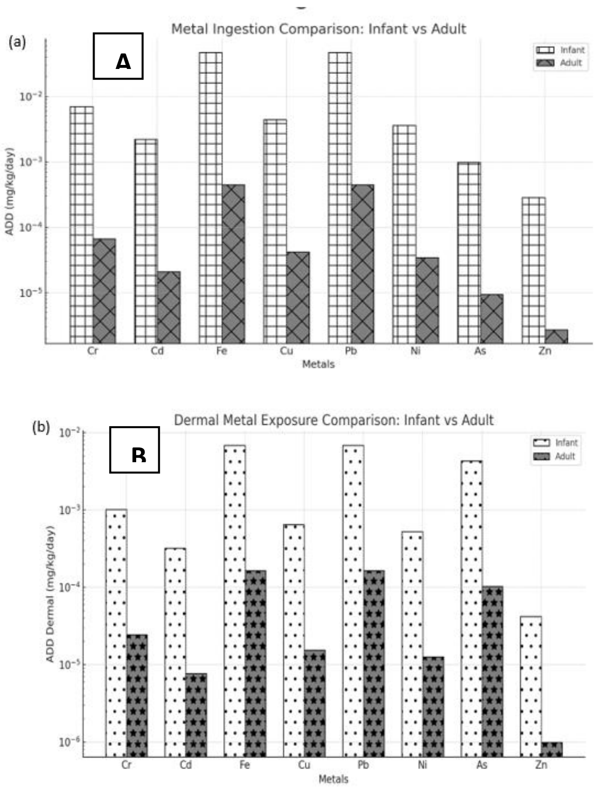


Figure 4: Average daily dose of metals in water in dry season through a) ingestion and b) dermal route

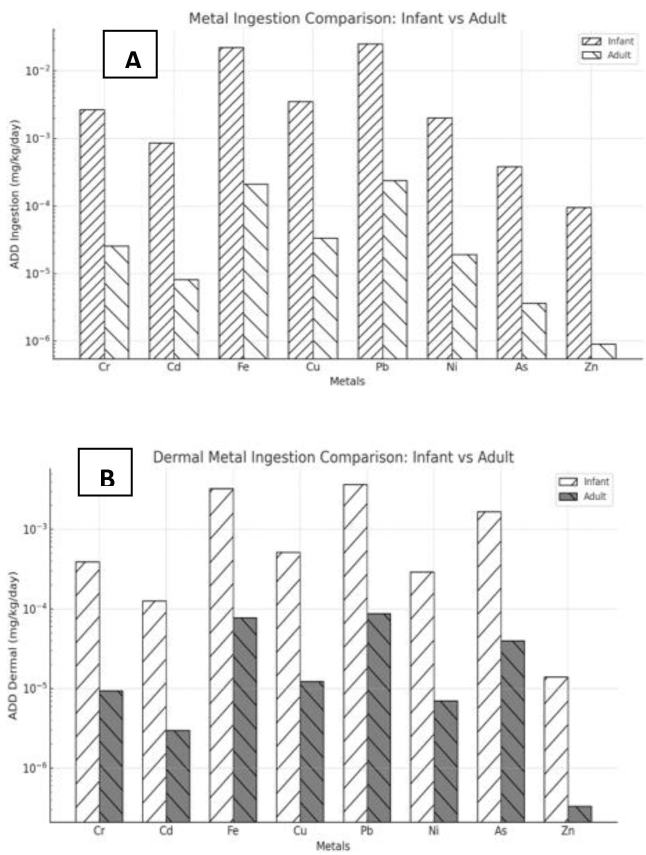
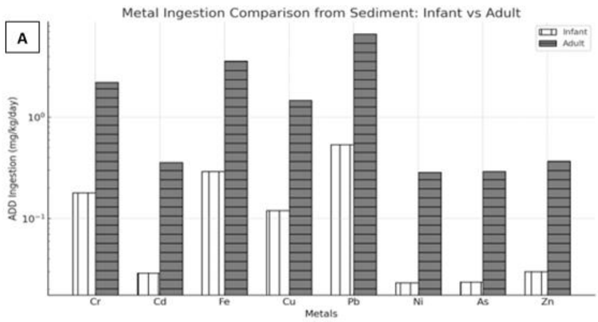


Figure 5: Average daily dose of metals in water in wet season through a) ingestion and b) dermal route



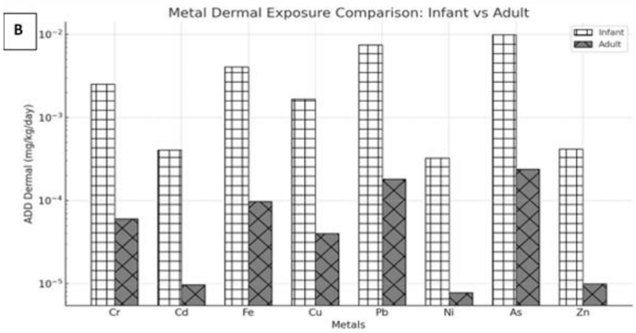


Figure 6: Average daily dose of metals in sediment through a) ingestion and b) dermal route

The evaluation of physicochemical parameters and Water Quality Index (WQI) of Green River across wet and dry seasons, as presented in Table 1, provides vital insights into its ecological condition, anthropogenic influences, and suitability for domestic and agricultural use. Seasonal variations were evident in most parameters, confirming the strong influence of rainfall, runoff, and human activities on water quality. pH values ranged between 4.38 and 6.61 across sites (Figure 1), with several stations falling below the WHO (2007) permissible range of 6.5–8.5, indicating acidification, particularly in the dry season, likely caused by quarry dust, mining effluents, and agricultural residues (Migaszewski et al., 2018; Udousoro & Umoren, 2014). Such low pH increases heavy metal solubility, threatens aquatic life, and reduces suitability for human consumption. Temperature (24–28 °C) remained within tropical norms and below the WHO limit of 40 °C (Figure 2), though slightly elevated wet-season values suggest microbial activity and organic matter decomposition that reduce dissolved oxygen (DO) (Romanus et al., 2018). Total suspended solids (TSS) and turbidity were within WHO limits but showed spatial variation, with higher values at Mbiakong in the wet season, likely due to sediment-laden runoff from sand mining (Adjovu et al., 2023; Adjovu et al., 2023). Electrical conductivity (EC) values (15.5–85.73 µS/cm) remained below the WHO threshold of 250 µS/cm, though elevated values at Annua in the wet season reflected ionic inputs from fertilizers and wastewater (Choramin et al., 2015; Ighalo & Adeniyi, 2020). Biochemical oxygen demand (BOD) values (1.58–2.22 mg/L) were below the WHO standard, but DO concentrations (3.78–4.87 mg/L) fell short of the 5 mg/L limit, reflecting organic enrichment and impaired aquatic respiration. Nutrient levels showed low nitrates and sulphates but consistently high phosphates, reaching 6.06 mg/L in the dry season, above the WHO guideline of 5 mg/L, linked to agricultural runoff and detergents (Adigun et al., 2025; Liu et al., 2021; Ofon et al., 2022; Svm et al., 2022). Chloride values (6.83–25.77 mg/L) were below the 350 mg/L limit, but elevated concentrations in Annua during the dry season suggest wastewater intrusion (Hussein Farh et al., 2023). Collectively, these parameters yielded WQI values (Table

1) classifying water quality as "poor" to "very poor," with deterioration in the dry season due to pollutant concentration, consistent with studies in other quarrying-impacted rivers (Awogbami et al., 2023; Ikpi et al., 2024).

In addition, the heavy metal risk assessments provided a more comprehensive understanding of the ecological and human health threats posed by metal contamination in Green River across wet and dry seasons, with cadmium (Cd), lead (Pb), and arsenic (As) consistently showing hazard quotients (HQ) and cancer risk (CR) values exceeding internationally accepted thresholds. The Table 2, which represents the dry-season water exposure pathways, revealed that Pb HQ values exceeded unity by several magnitudes, suggesting that even at relatively low concentrations, bioaccumulation and chronic exposure through ingestion and dermal contact pose substantial non-carcinogenic risks. Cadmium and arsenic also exhibited high HQ values, confirming their strong toxicological influence. These results are particularly concerning for infants and children, who are more vulnerable to heavy metal uptake due to higher intake rates relative to body weight, aligning with earlier findings in mining-impacted Nigerian rivers where lead and cadmium contamination were linked to elevated cases of developmental and neurological disorders (Akpan, 2024). Table 3, which captured the wet-season water exposure data, showed slightly reduced HQ and CR values compared to the dry season, a reduction attributable to dilution effects caused by higher water volume during rainfall events. Nevertheless, even with dilution, values remained above safe thresholds, confirming that seasonal variability mitigates but does not eliminate risks. Arsenic, in particular, maintained elevated cancer risk values, highlighting its persistence in aquatic systems and corroborating global reports of As contamination in river systems downstream of quarrying and agricultural landscapes (Kumar & Puri, 2012).

The table 4 further expanded this assessment by quantifying sediment exposure pathways, demonstrating that sediments act as both reservoirs and secondary sources of heavy metals in aquatic ecosystems. The HQ and CR values in sediments for Pb, Cd, and As were significantly higher than those of the water columns, particularly in the dry season, suggesting that heavy metals adsorb strongly onto sediment particles and can be released back into the water under changing redox conditions, thereby prolonging exposure risks. This finding is consistent with global studies emphasizing that sediments are long-term sinks for contaminants, contributing to delayed ecological recovery even when water quality appears temporarily improved (Aleem Muhammad et al., 2018). Furthermore, Figures 3–6 provided a clear visualization of these patterns, reinforcing the data from average daily dose, life-term average daily dose, and hazard quotient, and cancer risk of metals in water and sediment via ingestion and dermal routes (Tables 2–4). Similarly, the figure 3 compared mean heavy metal concentrations across wet-season water, dry-season water, and sediment samples, showing that Pb, Cd, As, and Cr levels were elevated in both water and sediment matrices, but with sediments generally retaining higher concentrations. This suggests that sediments serve as the primary contaminant reservoirs, gradually releasing metals into the water column under physical or chemical disturbance. Figure 4 presented the average daily dose (ADD) of metals in dry-season water exposures, with ingestion pathways dominating exposure risk across all age groups.

The dominance of ingestion over dermal pathways underscores the vulnerability of local communities relying on the river for drinking water or irrigation, confirming ingestion as the most significant contributor to non-carcinogenic and carcinogenic risks. Figure 5 depicted wet-season exposure risks and, while values were slightly reduced due to dilution, the graph still highlighted ingestion risks for Pb and As above recommended safe levels. This emphasizes that rainfall-driven dilution cannot compensate for the continuous input of contaminants from anthropogenic sources such as quarrying, agricultural runoff, and wastewater. Figure 6, which illustrated sediment exposure pathways, revealed that sediment-associated risks were disproportionately higher compared to those of the water column, with Pb and As dominating the profiles. This aligns with previous findings from the Niger Delta and other mining-impacted environments, where sediments were identified as persistent sinks for toxic metals, later contributing to bioaccumulation in benthic organisms and higher trophic levels (Akpan et al., 2024; Moses et al., 2023; Obadimu et al., 2025; Okon et al., 2019). However, the persistence of high HQ and CR values across both wet and dry seasons indicates chronic risk exposure, with sediments acting as long-term reservoirs of contamination, thereby prolonging ecological degradation and public health hazards. These findings highlight the urgent need for integrated monitoring systems, strict regulation of quarrying and agricultural runoff, and the adoption of sustainable water management strategies to protect both human health and aquatic ecosystems.

CONCLUSION

The assessment of physicochemical parameters and WQI revealed that the Green River is under significant environmental stress from quarrying, agricultural runoff, and domestic effluents. While most parameters were within WHO limits, acidic pH, low dissolved oxygen, and elevated phosphate concentrations compromised water quality. The poor to very poor WQI ratings further confirm the river's limited suitability for direct consumption and agricultural use, especially in the dry season when pollutants are concentrated. Heavy metal contamination, particularly cadmium, lead, and arsenic, poses additional health risks through ingestion and dermal exposure pathways, with hazard quotients and cancer risks exceeding permissible limits. These results underscore the vulnerability of surface water bodies in anthropogenically impacted regions and emphasize the need for continuous monitoring, pollution control, and the implementation of sustainable water management practices. Effective policy interventions and community engagement are essential to mitigate further degradation and ensure the long-term ecological and socio-economic sustainability of the Green River ecosystem.

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