



## Research Article

### Assessment of Surface Water Quality and Heavy Metal Contamination in Soils around Bleulen Dumpsite, Ile-Oluji Municipal, Ondo State, Nigeria

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#### ABSTRACT

This study assessed the effects of a municipal solid waste dumpsite on surface water quality, heavy metal of soil and its ecological risks in Ile-Oluji, Ondo State, Nigeria. Water samples and topsoil (5 - 15 cm) were collected bi-monthly for six months from four stations (upstream, mid-stream, downstream, and recovery sites, respectively) and analysed using standard methods. Soil samples were air-dried, digested and examined for cadmium, lead, arsenic, manganese, and iron using AAS PG 990 model. Average water temperature of  $27.97 \pm 0.71^\circ\text{C}$  was recorded at mid-stream station while pH ranges from 6.0 - 7.3 with peak mean value of  $7.08 \pm 0.11$  observed at upstream. Higher mean values of conductivity, total dissolved solids, chemical oxygen demands, calcium and organic matter occurred at downstream while highest metal concentration for Cd ( $4.55 \pm 1.00$  mg/kg), Pb ( $7.29 \pm 0.56$  mg/kg), As ( $1.39 \pm 0.58$  mg/kg) and Fe ( $9981.52 \pm 5371.03$  mg/kg) occurred at the recovery site. Seasonally, pH, TS, OM and COD were higher in dry season compared to wet season. The ecological risk assessment showed that PLI is  $>1$  at mid-stream, downstream and recovery sites. Also, RI value for the stations after the upstream indicated extreme pollution. Water quality deterioration is closely linked to increase in anthropogenic activities and could have contributed to the high heavy metal concentrations recorded in soils across the sampling stations. There is critical need for better waste management procedures to mitigation the level of metals pollution in order to protect freshwater resources and soil health.

**Keywords:** Dumpsite soil; Ecological indices; Heavy metals; Solid waste; Surface water

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#### INTRODUCTION

Rapid urbanization due to increase in human population has led to a notable rise in the generation of municipal solid waste in numerous developing nations, especially within Sub-Saharan Africa (Adesakin *et al.*, 2020). Nevertheless, the infrastructure for waste management, the capacity of institutions, and the enforcement of regulations have not evolved in tandem with these developments. This discrepancy has resulted in ineffective collection

systems, a scarcity of disposal facilities, and practices such as open dumping and uncontrolled incineration. In Nigeria, these issues are exacerbated by fragmented governance, a lack of technical expertise, and insufficient funding, which culminates in the mismanagement of substantial quantities of urban waste, thereby contributing to environmental degradation, public health risks, and socio-economic challenges (Jagun *et al.*, 2023; Zhang *et al.*, 2024; Omokaro *et al.*, 2025). Open dumpsites pose

considerable environmental issues in numerous developing nations, including Nigeria, where insufficient waste management systems frequently lead to the uncontrolled disposal of municipal solid waste. As waste builds up and undergoes decomposition, a variety of physicochemical and biological processes produce leachate, which is formed through the infiltration of rainwater and the degradation of waste (Dong *et al.*, 2009; Igwegbe *et al.*, 2024). This leachate has the potential to permeate surrounding soils and nearby surface waters, serving as a significant conduit for environmental contamination. Typically, it contains high levels of dissolved solids, organic matter, nutrients, toxic metals and pathogenic microorganisms (Mohammed *et al.*, 2025), making dumpsite leachate a serious threat to environmental quality, agricultural productivity, ecosystem stability, and public health (Achudume and Olawale, 2007; Oyewale *et al.*, 2019). Presence of heavy metals in soils around dumpsites vicinities raise significant concerns due to their persistence, lack of biodegradability, and potential impacts on both ecological systems and human health. Numerous research has been conducted in Nigeria that documented increased levels of cadmium (Cd), lead (Pb), arsenic (As), and various other trace metals in soils close to waste disposal sites (Iwegbue *et al.*, 2010; Adelekan and Alawode, 2011; Idowu, 2022; Kolawole *et al.*, 2023; Oloruntoba *et al.*, 2024). The study of Montaño-López and Biswas (2021), highlights the necessity of contextualizing heavy metal enrichment within specific geochemical and socio-environmental contexts, rather than presuming uniform anthropogenic sources. Ile-Oluji, a smaller but rapidly growing town in Ondo State, Nigeria, exemplifies the waste management challenges often faced by many developing nations. Although, the town is witnessing socio-economic progress and a rising population, the waste management infrastructure and institutional capacity have not kept pace, resulting in persistent issues with uncontrolled solid waste disposal.

This research therefore assesses the physicochemical quality of a nearby surface water and concentrations of heavy metals in the Bleulen dumpsite soil in Ile Oluji, Ondo State, Nigeria. The study also evaluates the extent of contamination by dumpsite on water quality and soil properties of the dumpsite. The level of pollution and the contributions of individual metals was also carried out by assessing the ecological risk profile of soil and results of the findings were compared to national standard trends and international risk assessment frameworks.

## **MATERIALS AND METHODS**

### **Study Area**

The Bleulen functional dumpsite is located in Ile-Oluji, in Oluji-Okeigbo Local Government Area of Ondo State, Nigeria. It lies between latitude 07°10'00"N - 07°14'00"N and longitude 004°51'0"-004°52'0"E. It is the largest dumpsite in this Local Government Area of Ondo State (Figure 1).

### **Sampling Station and Sampling Schedules**

Four (4) sampling stations were established on Ile-Oluji stream namely: Station A - Upstream site which is 500m before the point source where the dumpsite waste materials could potentially entered into the streams a result of its nearness to the waterbody (serve as a control site); Station B - Mid-stream (heart of the dumpsite); Station C - Downstream site which is 200 m after the dumpsite; and Station D - Recovery site which is 200 m from station C as presented in Figure 1. The grid coordinates of each station were determined using a portable Global Positioning System (GPS) device (Germin GPS map 76 CSX Model). The surface water and soil samples were collected bi-monthly for a period of 6 months covering both dry and wet season of the year. Surface water samples for physicochemical analysis were collected in sterilized 1litre plastic bottles, which were properly labelled and preserved in a cooler which was immediately transported to the laboratory for further analysis. The topsoil samples (5 - 15 cm) were collected from soils around each of the earlier selected sampling sites using a stainless-steel soil auger and placed into clean polythene bags before being transported to the laboratory for further analysis (APHA, 1995; USEPA, 2009).

### **Physicochemical Analysis of Water Parameters**

Physicochemical parameters of surface water such as: water temperature was determined in situ using mercury in glass thermometer; pH was measured using calibrated pH meter (Hana HI 9813-5); Dissolved Oxygen (DO) was determined through DO meter; while Total dissolved solids (TDS) and electrical conductivity were determined using a conductivity meter (HI 9813-5).

In the laboratory, Calcium ( $\text{Ca}^{2+}$ ), and Magnesium ( $\text{Mg}^{2+}$ ) were analysed using Flame Atomic Absorption Spectrometry (FAAS), while others parameter (Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), and Organic Matter (OM),) were analysed using standard methods according to Golterman *et al.* (1978), Ademoroti (1996) and APHA (2017).

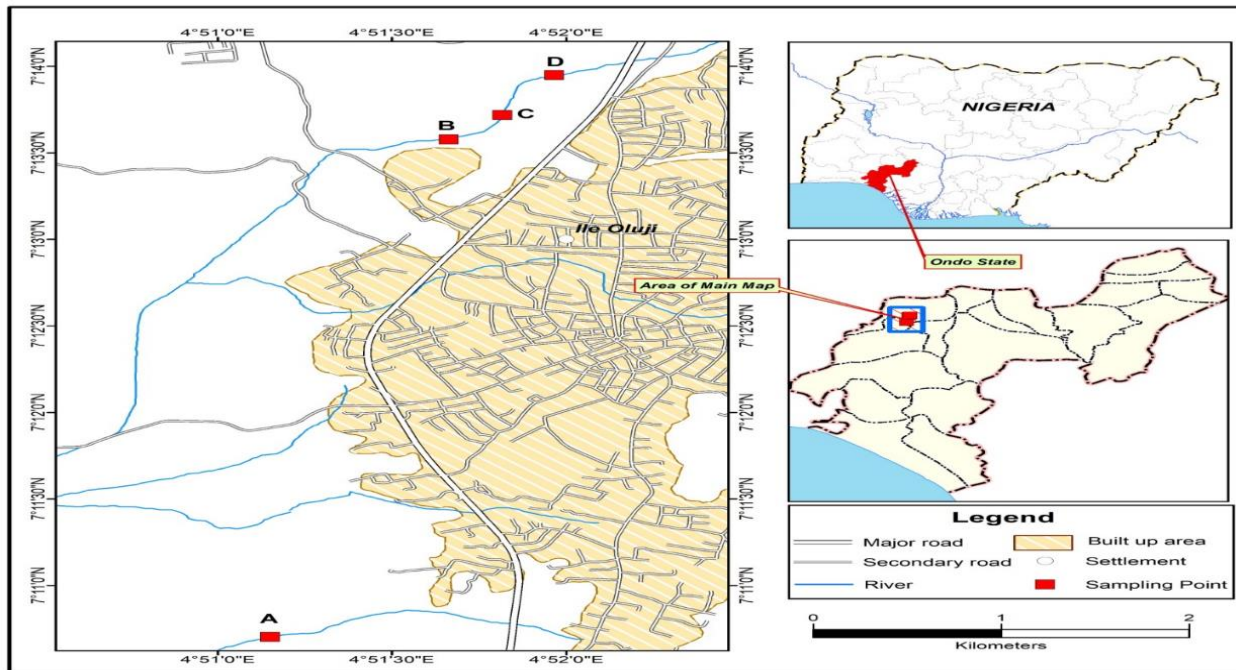
**Heavy Metal Analysis of Soil Samples**

Soil samples were analysed for selected heavy metals (Pb, As, Cd, Mn, and Fe) using Atomic Absorption Spectrometer (AAS) (PG 990 Model). A 0.5 g of air-dried soil sample was measured into a Teflon beaker and then homogenized. The sample underwent digestion with freshly prepared *aqua regia* solution (9 mL HCl and 3 mL HNO<sub>3</sub>; 3:1 v/v). A total of 12 mL of the acid mixture was introduced to each sample, and the mixture was heated on a hotplate at around 95 °C for 2 hours until complete digestion was accomplished. Following digestion, the solution was allowed to cool to room temperature, filtered through Whatman (Grade 111 mm) filter paper, and diluted to 50 mL with deionized water. The concentrations of metals in the digested samples were analysed using AAS PG 990 Model. Calibration of the instrument was conducted using standard solutions at the corresponding analytical wavelengths of 283.3 nm, 193.7 nm, 228.8 nm, 279.5 nm, and

248.3 nm for the identification of Pb, As, Cd, Mn, and Fe, respectively (Oyewale *et al.*, 2019; Bogdevich *et al.*, 2021; Adesakin *et al.*, 2023).

**Data Analysis**

The generated from this study were subjected descriptive (mean ± Sem) and inferential statistics (Analysis of variances (Anova), and Principal component Analysis (PCA)) were computed for all physicochemical variables of surface water and heavy metals in soil analysis. Differences between sampling station means were compared using one-way analysis of variance (ANOVA). Duncan’s multiple range test was utilized as a post hoc method to compare group means where significant variability was identified at P < 0.05. Principal component Analysis (PCA) were to assessed the interrelationship between physicochemical of surface water and heavy metals concentrations in soil samples using SPSS version 29 and Past version 3.0.



**Figure 1: Map of the Study Area Showing the established Sampling Stations on the surface water around the Bleulen Dumpsite, Ile-Oluji**

**Heavy metal Pollution indices in Soils Samples from Bleulen Dumpsite in Ile-Oluji**

The degree of heavy metal contamination in soil and sediments can be measured using metal pollution indices such as Geo accumulation Index (Igeo), Contamination Factor (CF), Pollution Load Index (PLI), Single Pollution Index (PI), Ecological Risk Index (ERI/RI) and Potential Ecological Risk Index (PERI). To determine the level of pollution present, these

indices employ data on the concentration of heavy metals in the environmental media under investigation and compare them to regulatory criteria or background values. It is possible to gain insight into the degree of heavy metal contamination and their possible effects on ecosystems and human health by analyzing these indices.

**i. Geo accumulation Index (I<sub>geo</sub>)**

In this study, in order to assess the degree of pollution in the municipal wastes dumpsite soil, Geo-accumulation index (I<sub>geo</sub>) was used as:

$$I_{geo} = \log_2 Cn / (1.5 \times Bn) \text{----- (i)}$$

**Where:** Cn is the concentration of the heavy metal in the sample and;

Bn is the concentration of the heavy metal in the unpolluted sample (control).

The correction factor of 1.5 was employed to reduce the impact of potential fluctuations in the background values, which could be ascribed to lithogenic variations present in the sample (Ochiagha *et al.*, 2020). The Geo-accumulation index (I<sub>geo</sub>) classification as outlined by Ochiagha *et al.* (2020) were used in this study as shown in Table 1a.

**ii. Contamination Factor (CF) and Composite Contamination Factor (CCF)**

In order to further evaluate the extent of heavy metal contamination in soils obtained from the selected location within Bleulen Dumpsite at Ile-Oluji in Ondo State, the contamination factor (CF) was determined using the following relationship:

$$CF = \frac{C_{metal}}{C_{background}} \text{----- (ii)}$$

Where: C<sub>metal</sub> is the mean concentration of a given metal in dumpsite soil; and C<sub>background</sub> is the corresponding concentration in the control soil.

**The CF classification key** (Hakanson, 1980):

- CF < 1: Low contamination
- 1 ≤ CF < 3: Moderate contamination
- 3 ≤ CF < 6: Considerable contamination

CF ≥ 6: Very high contamination

**Composite Contamination Factor (CCF)** = ΣCF (Cd + Pb + As + Mn + Fe)

**iii. Pollution Load Index (PLI)**

Also, PLI was calculated as the geometric mean of contamination factors (CFs) for Pb, Cd, Zn, Ni, Cu, and Fe using the relationship:

$$PLI = \sqrt[CF1X CF2X \dots \dots \dots XCFn]{\dots \dots \dots} \text{----- (iii)}$$

Pollution status was classified as: PLI ≤ 1 (unpolluted), PLI > 1 (polluted), PLI ≥ 5 (heavily polluted) (Wang *et al.*, 2011).

**iv. Assessment of the Potential Ecological Risk Index (PERI)**

The Potential Ecological Risk Index (PERI) was utilized to assess the ecological risks associated with heavy metals present in soils from the chosen sampling points within the dumpsite. The methodology established by Hakanson (1980) was employed with the equation:

$$E_r^i = T_r^i \times CF_i \text{----- (iv)}$$

$$RI = \sum E_r^i \text{----- (v)}$$

where: E<sub>r</sub><sup>i</sup> = potential ecological risk factor of metal i

T<sub>r</sub><sup>i</sup> = toxic response factor

CF<sub>i</sub> = contamination factor of metal i

RI = overall potential ecological risk index

Toxic response factors (T<sub>r</sub><sup>i</sup>) used are: Pb – 5; Cd – 30; As – 10; Mn – 1; Fe – 1 (Hakanson, 1980).

The Risk classification followed the method of Yang *et al.* (2009) as indicated in Table 1b for single metal risk (E<sub>r</sub>) and overall ecological risk (RI), respectively.

**Table 1a: Geo-accumulation (I<sub>geo</sub>) index classification**

| (I <sub>geo</sub> ) index | I <sub>geo</sub> class | Pollution level                   |
|---------------------------|------------------------|-----------------------------------|
| >5                        | 6                      | Extremely polluted                |
| >4 – 5                    | 5                      | Heavily to extremely polluted     |
| >3 – 4                    | 4                      | Heavily polluted                  |
| >2 – 3                    | 3                      | Moderately to heavily polluted    |
| >1 – 2                    | 2                      | Moderately polluted               |
| >0 – 1                    | 1                      | Unpolluted to moderately polluted |
| < 0                       | 0                      | Unpolluted                        |

**Table 1b: Categories of Dumpsite Soil Grading According to Ecological and Potential Ecological Risk Factors or Indices**

| Grade | Er value       | ERI grading                 | PERI           | PERI grading                       |
|-------|----------------|-----------------------------|----------------|------------------------------------|
| A     | Er < 40        | Low ecological risk         | PERI < 150     | Low ecological risk                |
| B     | 40 ≤ Er < 80   | Moderate ecological risk    | 150 ≤ RI < 300 | Moderate ecological risk           |
| C     | 80 ≤ Er < 160  | Appreciable ecological risk | 300 ≤ RI < 600 | High ecological risk               |
| D     | 160 ≤ Er < 320 | High ecological risk        | RI ≥ 600       | Significantly high ecological risk |
| E     | Er ≥ 320       | Serious ecological risk     |                |                                    |

## RESULTS

### Physicochemical Parameters of Water Samples

Water temperature recorded in the study area ranged from 24 - 29 °C with highest mean value (27.97 ± 0.71 °C) observed at mid-stream while the lowest value (25.00 ± 0.91 °C) was recorded at upstream site. There was no significant difference ( $p > 0.05$ ) in temperature values across the stations during this study (Table 2). The pH values recorded in this study fell within the range of 6.0 (slightly acidic) to 7.3 (slightly alkaline) across the stations, but the pH value recorded at upstream site (7.08 ± 0.11) was significantly higher ( $p < 0.001$ ) than other sites. Similarly, electrical conductivity, TS, TDS, COD, Ca<sup>2+</sup>, and OM were all significantly higher ( $p < 0.01$ ) at the downstream site (444.00 ± 148.84 μS/cm; 180.50 ± 40.08 mg/L, 267.63 ± 92.92 mg/L, 11.79 ± 2.66 mg/L, 180.94 ± 59.42 mg/L and 75.94 ± 16.49 mg/L, respectively (Table 2). The TSS mean value was at its peak in mid-stream site (129.15 ± 31.81 mg/L) and there was significant difference ( $p > 0.05$ ) in TSS values obtained across the sampled stations (Table 2). The mean values of BOD, TH and TOC (129.15 ± 31.81 mg/L, 4.33 ± 0.38 mg/L, 208.42 ± 43.53 mg/L and 41.75 ± 12.53 mg/L) were significantly higher in mid-stream site compared to other sites. DO level was higher in recovery site (2.50 ± 0.68 mg/L) during the study, but there was no significant difference ( $p > 0.05$ ) in DO values recorded across the sites (Table 2). All the heavy metals (Cd, Pb, As, Mn and Fe) analysed in soil samples in this study were high, with values of 4.55 ± 1.00 mg/kg, 7.29 ± 0.56 mg/kg, 1.39 ± 0.58 mg/kg, 1.24 ± 0.42 mg/kg, and 9981.52 ± 5371.03 mg/kg recorded at recovery site compared with other sampling sites (Table 3).

Seasonally, significant high mean values of water temperature, EC, TDS, TSS, DO, calcium, magnesium, TH, TOC and BOD (27.16 ± 0.3°C, 306.59 ± 82.03 μS/cm, 132.78 ± 29.87 mg/L, 74.46 ± 18.46 mg/L, 4.61 ± 0.68 mg/L, 145.52 ± 38.98 mg/L, 25.71 ± 7.14 mg/L, 165.05 ± 32.24 mg/L, 27.27 ± 8.53 mg/L and 2.67 ± 0.53 mg/L) were observed during the wet season than in the dry season while pH, TS, COD and OM (6.99 ± 0.16, 99.88 ± 25.13 mg/L, 9.05 ± 2.45 mg/L and 75.56 ± 22.47 mg/L) were higher in the dry season as presented in Table 4. All the heavy metals were higher during the wet season than dry season (Table 5).

As shown in Table 6, the Pearson correlation matrix illustrates significant interconnections among physicochemical parameters of water and soil heavy metals across the study area. Total Suspended Solids (TSS), Total Dissolved Solids (TS), and Biological

Oxygen Demand (BOD) demonstrate strong positive correlations with various heavy metals, notably Cd, Pb, As, Mn, and Fe, which suggests a common source of pollution or co-mobilization. In the upstream station, exceptionally strong positive correlations (for instance, TS–pH  $r = 0.98^*$ , Pb–Cd  $r = 0.99^*$ ) indicate closely related geochemical processes. Mid-stream findings reveal moderate to strong relationships, particularly between organic pollution indicators (COD, TH, TOC) and metals like Pb and As. Downstream and recovery stations exhibit generally stronger and more extensive positive correlations, especially between metals and TS/TSS/BOD, indicating a heightened anthropogenic impact. Negative correlations noted with TOC and certain metals in specific stations imply intricate adsorption–desorption or dilution phenomena. Generally, the table suggests that the degradation of water quality is closely linked to increased concentrations of soil heavy metals within the study area.

The EC, OM, TH, pH, Fe, Cd and TSS correlated with established sampling stations as shown in figure 2. The biplot displays the correlation between water quality metrics and sample stations. The majority of stations (A–D) are grouped close to the center, suggesting comparatively comparable water quality conditions. Strong separation of magnesium (Mg<sup>2+</sup>) on the positive side of Axis 1 indicates a significant impact on water chemistry. The strong correlation between TH and TDS suggests that the concentration of dissolved solids and water hardness are related. On the negative side of Axis 1, TS, COD, Ca<sup>2+</sup>, TOC, and As cluster together, suggesting potential shared causes associated with organic and mineral contamination (Figure 2).

Notably, composite contamination factors reveal a pronounced pollution gradient (recovery > mid-stream > downstream > upstream). The Pollution Load Index (PLI) showed that sampling Point mid-stream and recovery point are classified within the extremely polluted category, whereas downstream site demonstrates severe pollution levels. All affected sites display significantly elevated contamination factors (CF > 6) for metals, thereby affirming considerable anthropogenic enrichment in comparison to upstream site (Table 7). The Potential Ecological Risk Index (RI) revealed a very high ecological risk across all sampling point with the exception of upstream site, with recorded values of 1323.96 (mid-stream), 680.73 (downstream), and 1684.58 (recovery). Recovery site demonstrated the most significant cumulative ecological threat. Cadmium emerged as the main contributor to risk,

aligning with its high contamination factor and elevated toxic-response coefficient. Geo-accumulation indices ( $I_{geo}$ ) further validated the presence of strong to extremely strong pollution levels at the mid-stream and recovery sites, particularly concerning Pb and Cd concentrations ( $I_{geo} > 4$ ). The mid-stream site exhibited moderate to strong levels of contamination. Conversely, Fe-normalized enrichment factors ( $EF < 2$  for the

majority of metals) indicate that while the intensity of contamination is considerable, the influence of lithogenic contributions from Fe-rich lateritic soils partially affects the overall metal concentrations. Generally, the integrated indices consistently highlight recovery site as the primary hotspot for contamination, showcasing evident anthropogenic impacts and significant ecological consequences (Table 8).

**Table 2: Physicochemical Parameters of Surface Water around Bleulen Dumpsite, Ile-Oluji**

| Parameter               | Upstream     |              | Mid-stream    |              | Downstream    |               | Recovery      |              | Anova  |              | WHO     |
|-------------------------|--------------|--------------|---------------|--------------|---------------|---------------|---------------|--------------|--------|--------------|---------|
|                         | Min-Max      | Mean±Sem     | Min-Max       | Mean±Sem     | Min-Max       | Mean±Sem      | Min-Max       | Mean±Sem     | F      | Sig.         |         |
| Water temp.             | 23.00-27.00  | 25.00±0.91   | 26.00-29.00   | 27.92±0.71   | 24.00-29.00   | 26.57±1.04    | 24.00-29.00   | 26.82±1.09   | 1.605  | 0.240        |         |
| pH                      | 6.80-7.30    | 7.08±0.11    | 6.00-7.00     | 6.48±0.21    | 6.90-7.60     | 7.26±0.15     | 6.50-7.20     | 6.88±0.15    | 4.463  | <b>0.025</b> | 6.5-8.5 |
| EC (µs/cm)              | 90.80-180.00 | 130.20±21.09 | 250.00-528.42 | 384.11±60.59 | 150.00-776.00 | 444.00±148.84 | 110.00-300.00 | 184.39±41.18 | 3.299  | 0.058        | ≤1500   |
| TS (mg/L)               | 10.00-40.00  | 24.75±6.39   | 39.32-138.00  | 79.58±21.25  | 86.00-250.00  | 180.50±40.08  | 59.00-131.00  | 101.67±15.92 | 7.095  | <b>0.005</b> |         |
| TDS (mg/L)              | 70.00-100.00 | 87.38±7.54   | 165.40-396.00 | 242.35±53.44 | 90.50-478.00  | 267.63±92.92  | 80.50-250.80  | 131.13±40.13 | 1.461  | 0.274        | ≤500    |
| TSS (mg/L)              | 8.00-20.00   | 11.70±2.78   | 76.60-210.00  | 129.15±31.81 | 36.17±137.00  | 77.04±21.91   | 23.00-100.00  | 57.50±16.82  | 5.308  | <b>0.015</b> | 500     |
| DO (mg/L)               | 4.10-7.17    | 5.44±0.64    | 0.90-2.90     | 1.88±0.42    | 2.90-6.40     | 4.91±0.74     | 3.60-6.80     | 2.50±0.68    | 7.425  | <b>0.005</b> | 4-6     |
| BOD (mg/L)              | 0.70-1.20    | 0.98±0.11    | 3.40-5.20     | 4.33±0.38    | 2.10-3.44     | 2.93±0.29     | 1.60-2.30     | 1.98±0.15    | 31.013 | <b>0.000</b> | ≤5      |
| COD (mg/L)              | 0.90-2.10    | 1.53±0.28    | 5.91-7.10     | 6.24±11.79   | 5.40-21.40    | 11.79±3.66    | 4.90-16.26    | 11.75±2.44   | 5.005  | <b>0.018</b> | ≤5      |
| Ca <sup>2+</sup> (mg/L) | 12.30-53.60  | 28.60±8.90   | 66.77-255.97  | 149.50±39.88 | 40.77-330.00  | 180.94±59.42  | 28.90-179.15  | 102.78±37.98 | 2.640  | 0.097        | 200     |
| Mg <sup>2+</sup> (mg/L) | 10.50-30.80  | 21.43±5.01   | 6.04-16.89    | 8.93±2.66    | 4.78-34.70    | 18.02±6.58    | 3.85-67.98    | 25.32±14.62  | 0.677  | 0.583        | 150     |
| TH (mg/L)               | 30.00-101.00 | 71.59±14.94  | 164.42-339.00 | 208.42±43.53 | 124.38-288.98 | 202.71±33.68  | 109.00-238.50 | 166.67±27.91 | 3.972  | <b>0.035</b> | 250     |
| TOC (mg/L)              | 1.09-5.50    | 3.05±0.92    | 12.03-70.10   | 41.75±12.53  | 18.02-34.00   | 27.41±3.69    | 4.49-23.00    | 9.69±4.45    | 6.421  | <b>0.008</b> | 5       |
| OM (mg/L)               | 6.80-20.40   | 13.25±3.01   | 43.52-90.10   | 67.84±9.73   | 36.80-113.81  | 75.94±16.49   | 37.00-210.49  | 106.04±37.11 | 3.413  | 0.053        | 3       |

Note: pH- potential hydrogen ion, EC- electric conductivity, TS- total solids, TDS-total dissolved solids, TSS-total suspended solids, DO- dissolved oxygen, BOD- biological oxygen demands, COD-chemical oxygen demands, Ca<sup>2+</sup>-calcium, Mg<sup>2+</sup>-magnesium, TH-total hardness, TOC-total organic carbon, OM-organic matter, Min-minimum, Max-maximum, Sem- Standard error of mean

**Table 3: Physicochemical Parameters of Soil around Bleulen Dumpsite, Ile-Oluji**

| Metals    | Upstream     |              | Mid-stream   |                 | Downstream    |                  | Recovery         |                 | Anova  |              | WHO       |
|-----------|--------------|--------------|--------------|-----------------|---------------|------------------|------------------|-----------------|--------|--------------|-----------|
|           | Min-Max      | Mean±Sem     | Min-Max      | Mean±Sem        | Min-Max       | Mean±Sem         | Min-Max          | Mean±Sem        | F      | Sig.         |           |
| <b>Cd</b> | 0.12-0.23    | 0.16±0.03    | 1.12-6.00    | 3.79±1.04       | 0.10-4.18     | 2.44±0.99        | 2.10-6.89        | 4.55±1.00       | 4.851  | 0.020        | 0.8 - 3.0 |
| <b>Pb</b> | 0.13-0.76    | 0.29±0.16    | 3.14-2.81    | 6.99±1.71       | 1.06-4.11     | 2.81±0.68        | 6.10-8.60        | 7.29±0.56       | 12.396 | <b>0.001</b> | 50-85     |
| <b>As</b> | 0.03-0.05    | 0.04±0.04    | 0.08-1.34    | 1.82±0.81       | 0.08-2.98     | 1.33± 0.61       | 0.04-2.84        | 1.39±0.58       | 1.722  | 0.215        | 0.2       |
| <b>Mn</b> | 0.01-0.03    | 0.02±0.00    | 0.05-3.08    | 1.08±0.69       | 0.05-1.20     | 0.44±0.27        | 0.20-2.17        | 1.24±0.42       | 1.781  | 0.204        | ≤2000     |
| <b>Fe</b> | 50.00-400.00 | 241.67±75.92 | 609-21190.00 | 5951.63±5080.75 | 2010-11880.00 | 3925.75±11880.00 | 1109.00-23990.00 | 9981.52±5371.03 | 1.062  | 0.401        | ≤5000     |

Note: Cd-cadmium, Pb-lead, As-Arsenic, Mn-Manganese, Fe-iron, Min-minimum, Max-maximum, Sem- Standard error of mean and WHO-world Health organization

**Table 4. Seasonal Variation of physicochemical parameters of Surface Water around Bleulen Dumpsite, Ile-Oluji**

| Season                  | Dry season    |              | Wet season   |              | Anova |       |
|-------------------------|---------------|--------------|--------------|--------------|-------|-------|
|                         | Min-Max       | Mean±Sem     | Min-Max      | Mean±Sem     | F     | Sig.  |
| Water temp.             | 23.00-29.00   | 26.00±0.93   | 26.00-29.00  | 27.16±0.37   | 1.346 | 0.265 |
| pH                      | 6.00-7.60     | 6.99±0.16    | 6.30-7.34    | 6.86±0.13    | 0.392 | 0.541 |
| EC (µs/cm)              | 100.00-610.00 | 264.75±63.88 | 90.80-776.00 | 306.59±82.03 | 0.162 | 0.693 |
| TS (mg/L)               | 20.00-244.00  | 99.88±25.13  | 10.00-250.00 | 93.37±27.63  | 0.030 | 0.864 |
| TDS (mg/L)              | 70.00-478.00  | 109.96±55.77 | 79.52-250.80 | 132.78±29.87 | 1.198 | 0.292 |
| TSS (mg/L)              | 8.00-210.00   | 63.25±23.23  | 8.80-150.00  | 74.46±18.46  | 0.142 | 0.712 |
| DO (mg/L)               | 0.90-6.80     | 4.25±0.72    | 1.60-7.17    | 4.61±0.68    | 0.133 | 0.721 |
| BOD (mg/L)              | 0.90-4.60     | 2.43±0.46    | 0.70-5.20    | 2.67±0.53    | 0.120 | 0.734 |
| COD (mg/L)              | 1.90-21.40    | 9.05±2.45    | 0.90-13.84   | 6.60±1.73    | 0.667 | 0.428 |
| Ca <sup>2+</sup> (mg/L) | 12.30-179.15  | 85.39±24.19  | 27.60-330.00 | 145.52±38.98 | 1.718 | 0.211 |
| Mg <sup>2+</sup> (mg/L) | 3.85-21.79    | 11.13±2.51   | 6.24-87.98   | 25.71±7.14   | 3.710 | 0.075 |
| TH (mg/L)               | 75.34-288.98  | 159.64±26.07 | 30.00-339.00 | 165.05±32.24 | 0.017 | 0.898 |
| TOC (mg/L)              | 1.09-32.56    | 13.68±4.55   | 3.00-70.10   | 27.27±8.53   | 1.975 | 0.182 |
| OM (mg/L)               | 10.10-210.49  | 75.56±22.47  | 6.80-98.93   | 55.97±98.93  | 0.574 | 0.461 |

Note: pH- potential hydrogen ion, EC- electric conductivity, TS- total solids, TDS-total dissolved solids, TSS-total suspended solids, DO- dissolved oxygen, BOD-biological oxygen demands, COD-chemical oxygen demands, Ca<sup>2+</sup>-calcium, Mg<sup>2+</sup>-magnesium, TH-total hardness, TOC-total organic carbon, OM-organic matter, Min-minimum, Max-maximum, Sem- Standard error of mean

**Table 5. Seasonal Variation of heavy metals in Soil around Bleulen Dumpsite, Ile-Oluji**

| season | Dry season      |                  | Wet season    |                 | Anova |       |
|--------|-----------------|------------------|---------------|-----------------|-------|-------|
|        | Min-Max         | Mean±Sem         | Min-Max       | Mean±Sem        | F     | Sig.  |
| Cd     | 0.10-6.00       | 2.36±0.86        | 0.13-6.89     | 3.10±0.83       | 0.389 | 0.543 |
| Pb     | 0.13-8.37       | 3.85±1.17        | 0.14-10.98    | 4.84±1.25       | 0.306 | 0.589 |
| As     | 0.03-2.84       | 0.83±0.40        | 0.04-3.89     | 1.46±0.47       | 0.997 | 0.335 |
| Mn     | 0.01-2.17       | 0.58±0.27        | 0.02-0.69     | 0.81±0.38       | 0.254 | 0.622 |
| Fe     | 200.00-23990.00 | 8966.25±1094.031 | 50.00-3192.14 | 1084.03±3192.00 | 5.003 | 0.042 |

Note: Cd-cadmium, Pb-lead, As-Arsenic, Mn-Manganese, Fe-iron, Min-minimum, Max-maximum, Sem- Standard error of mean and WHO-world Health organization

**Table 6. Pearson Correlation matrix showing the interrelationship between physicochemical parameters of surface water and heavy metals of soil**

| Upstream   |        |       |       |       |       |       |        |       |       |       |       |
|------------|--------|-------|-------|-------|-------|-------|--------|-------|-------|-------|-------|
|            | Water  |       |       |       |       |       |        | Soil  |       |       |       |
|            | pH     | TS    | TSS   | BOD   | COD   | TH    | TOC    | Cd    | Pb    | As    | Mn    |
| H          |        |       |       |       |       |       |        |       |       |       |       |
| TS         | 0.98*  |       |       |       |       |       |        |       |       |       |       |
| TSS        | -0.90  | -0.85 |       |       |       |       |        |       |       |       |       |
| BOD        | 0.93*  | 0.86* | -0.88 |       |       |       |        |       |       |       |       |
| COD        | 0.46   | 0.50  | -0.69 | 0.27  |       |       |        |       |       |       |       |
| TH         | 0.77*  | 0.66  | -0.91 | 0.90* | 0.45  |       |        |       |       |       |       |
| TOC        | -0.52  | -0.48 | 0.83* | -0.49 | -0.90 | -0.74 |        |       |       |       |       |
| Cd         | -0.73  | -0.66 | 0.95* | -0.76 | -0.75 | -0.93 | 0.94*  |       |       |       |       |
| Pb         | -0.81* | -0.75 | 0.98* | -0.82 | -0.74 | -0.93 | 0.90*  | 0.99* |       |       |       |
| As         | -0.37  | -0.32 | 0.73  | -0.37 | -0.86 | -0.68 | 0.98*  | 0.89* | 0.83* |       |       |
| Mn         | -0.37  | -0.32 | 0.73  | -0.37 | -0.86 | -0.68 | 0.98*  | 0.89  | 0.83* | 0.99* |       |
| Fe         | 0.99*  | 0.99* | -0.91 | 0.92* | 0.51  | 0.77* | -0.56  | -0.74 | -0.83 | -0.40 | -0.40 |
| Mid-stream |        |       |       |       |       |       |        |       |       |       |       |
| pH         |        |       |       |       |       |       |        |       |       |       |       |
| TS         | -0.53  |       |       |       |       |       |        |       |       |       |       |
| TSS        | 0.68   | -0.13 |       |       |       |       |        |       |       |       |       |
| BOD        | 0.42   | -0.64 | 0.67  |       |       |       |        |       |       |       |       |
| COD        | -0.21  | -0.33 | 0.28  | 0.80* |       |       |        |       |       |       |       |
| TH         | -0.27  | -0.31 | 0.22  | 0.76* | 1.00  |       |        |       |       |       |       |
| TOC        | 0.18   | -0.85 | 0.16  | 0.83* | 0.77* | 0.76* |        |       |       |       |       |
| Cd         | 0.84*  | -0.58 | 0.88* | 0.83* | 0.34  | 0.28  | 0.51   |       |       |       |       |
| Pb         | 0.38   | -0.55 | 0.71  | 0.99* | 0.82* | 0.78* | 0.78*  | 0.82* |       |       |       |
| As         | 0.26   | -0.56 | 0.60  | 0.99* | 0.89* | 0.86* | 0.83*  | 0.73* | 0.99* |       |       |
| Mn         | -0.03  | -0.38 | 0.45  | 0.89* | 0.98* | 0.97* | 0.77*  | 0.51  | 0.91* | 0.96* |       |
| Fe         | 0.83*  | 0.02  | 0.84* | 0.23  | -0.29 | -0.35 | -0.25  | 0.71* | 0.26  | 0.11  | -0.10 |
| Downstream |        |       |       |       |       |       |        |       |       |       |       |
| pH         |        |       |       |       |       |       |        |       |       |       |       |
| TS         | -0.01  |       |       |       |       |       |        |       |       |       |       |
| TSS        | -0.59  | 0.76* |       |       |       |       |        |       |       |       |       |
| BOD        | 0.42   | 0.78* | 0.21  |       |       |       |        |       |       |       |       |
| COD        | 0.94*  | 0.32  | -0.33 | 0.70  |       |       |        |       |       |       |       |
| TH         | 0.59   | 0.80* | 0.23  | 0.92  | 0.83* |       |        |       |       |       |       |
| TOC        | -0.94  | -0.30 | 0.36  | -0.71 | -1.00 | -0.82 |        |       |       |       |       |
| Cd         | 0.06   | 0.99* | 0.72  | 0.80* | 0.39  | 0.84* | -0.37  |       |       |       |       |
| Pb         | 0.20   | 0.97* | 0.58  | 0.90* | 0.52  | 0.91* | -0.51  | 0.98* |       |       |       |
| As         | -0.49  | 0.87* | 0.91  | 0.52  | -0.16 | 0.42  | 0.17   | 0.83* | 0.76* |       |       |
| Mn         | 0.90*  | 0.43  | -0.18 | 0.71  | 0.99* | 0.88* | -0.98  | 0.50  | 0.61  | -0.05 |       |
| Fe         | 0.88*  | 0.46  | -0.13 | 0.68  | 0.97* | 0.88* | -0.95* | 0.52  | 0.62  | -0.03 | 0.99* |
| Recovery   |        |       |       |       |       |       |        |       |       |       |       |
| pH         |        |       |       |       |       |       |        |       |       |       |       |
| TS         | 0.01   |       |       |       |       |       |        |       |       |       |       |
| TSS        | 0.24   | 0.53  |       |       |       |       |        |       |       |       |       |
| BOD        | -0.01  | 0.99* | 0.39  |       |       |       |        |       |       |       |       |
| COD        | -0.76  | -0.03 | -0.73 | 0.08  |       |       |        |       |       |       |       |
| TH         | -0.64  | 0.40  | -0.47 | 0.50  | 0.90* |       |        |       |       |       |       |
| TOC        | 0.71   | 0.45  | 0.85* | 0.35  | -0.90 | -0.63 |        |       |       |       |       |
| Cd         | 0.33   | 0.87* | 0.84* | 0.80* | -0.51 | -0.10 | 0.82*  |       |       |       |       |
| Pb         | 0.47   | 0.86* | 0.73* | 0.81* | -0.51 | -0.09 | 0.83*  | 0.98  |       |       |       |
| As         | -0.44  | 0.84* | 0.08  | 0.88* | 0.52  | 0.83* | -0.11  | 0.47  | 0.45  |       |       |
| Mn         | -0.01  | 0.99* | 0.38  | 0.99* | 0.10  | 0.51  | 0.34   | 0.79* | 0.80* | 0.89* |       |
| Fe         | -0.06  | 0.16  | -0.73 | 0.31  | 0.69  | 0.75  | -0.51  | -0.24 | -0.10 | 0.47  | 0.32  |

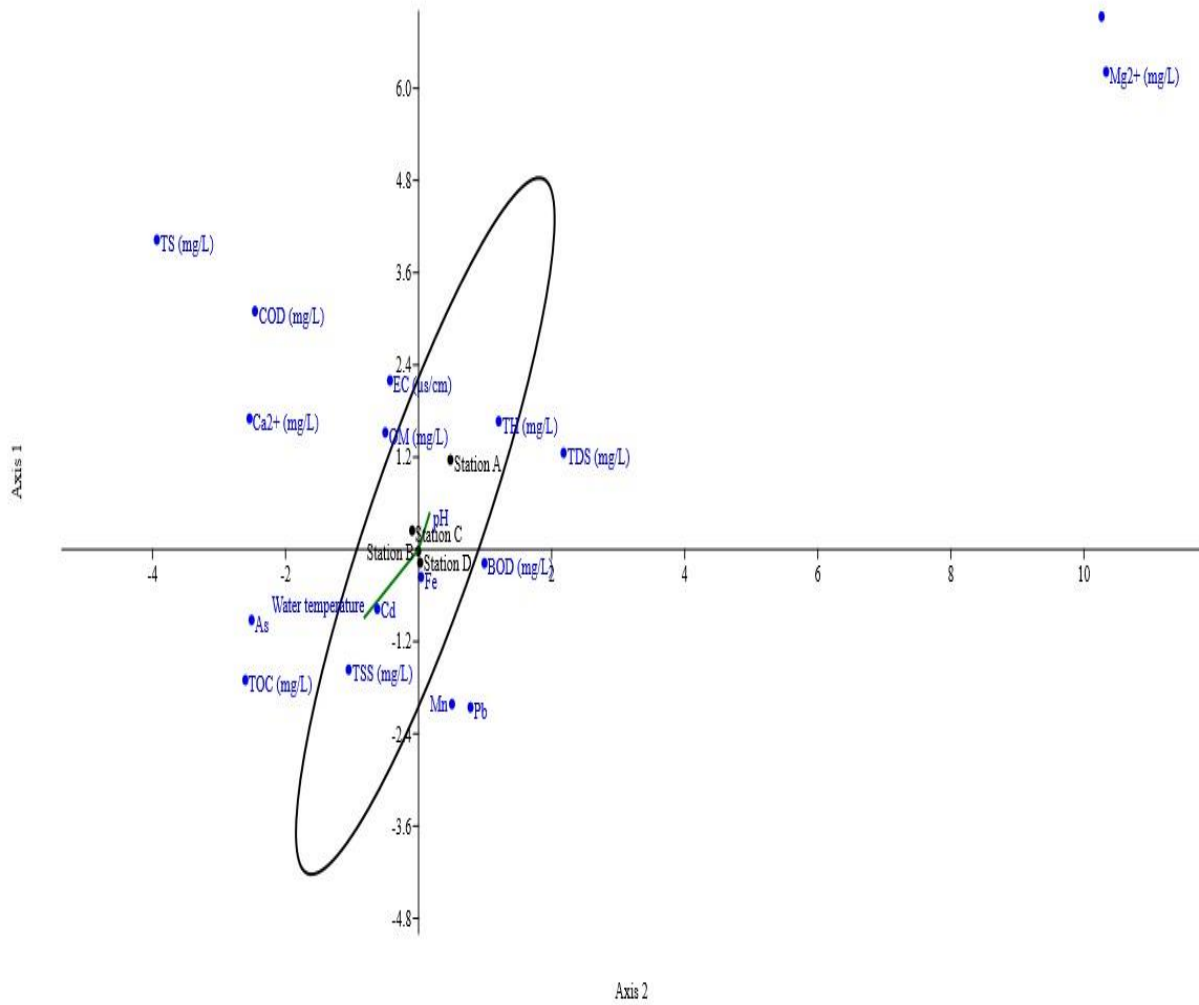


Figure 2: Principal component Analysis (PCA) showing the interrelationship between physicochemical of surface water and heavy metals concentrations in soil samples

Table 7: Composite Contamination Factor (CCF) and Pollution Load Index (PLI) of Soils from Bleulen Dumpsite in Ile-Oluji, Ondo State

| Sampling Point | Contamination Factor |       |       |       |       | CCF ( $\Sigma$ CF) | PLI   | Pollution Status   |
|----------------|----------------------|-------|-------|-------|-------|--------------------|-------|--------------------|
|                | Cd                   | Pb    | As    | Mn    | Fe    |                    |       |                    |
| upstream       | 1                    | 1     | 1     | 1     | 1     | 5                  | 1     | Unpolluted         |
| Mid-stream     | 26.08                | 39.14 | 29.50 | 14.00 | 36.94 | 145.67             | 25.05 | Extremely Polluted |
| Downstream     | 11.54                | 18.00 | 21.25 | 22.00 | 10.08 | 82.87              | 15.62 | Severely Polluted  |
| Recovery       | 31.23                | 47.71 | 39.75 | 51.50 | 60.08 | 230.26             | 43.59 | Extremely Polluted |

Note: Cd-cadmium, Pb-lead, As-Arsenic, Mn-Manganese, Fe-Iron,

**Table 8: Integrated Ecological Risk Assessment Indices of Soils from Bleulen Dumpsite in Ile-Oluji, Ondo State**

| Sampling Point | CCF    | PLI   | RI      | Igeo (Cd) | Igeo (Pb) | Igeo (As) | Igeo (Mn) | EF (Cd) | EF (Pb) | EF (As) | EF (Mn) |
|----------------|--------|-------|---------|-----------|-----------|-----------|-----------|---------|---------|---------|---------|
| upstream       | 5.00   | 1.00  | 47.00   | -0.58     | -0.58     | -0.58     | -0.58     | 1.00    | 1.00    | 1.00    | 1.00    |
| Mid-stream     | 145.67 | 25.05 | 1323.96 | 4.12      | 4.70      | 4.30      | 3.22      | 0.71    | 1.06    | 0.80    | 0.38    |
| Downstream     | 82.87  | 15.62 | 680.73  | 2.94      | 3.58      | 3.83      | 3.88      | 1.14    | 1.79    | 2.11    | 2.18    |
| Recovery       | 230.26 | 43.59 | 1684.58 | 4.38      | 4.99      | 4.73      | 5.10      | 0.52    | 0.79    | 0.66    | 0.86    |

**Key:** CCF = Composite Contamination Factor; PLI = Pollution Load Index; RI = Potential Ecological Risk Index; Igeo = Geo-accumulation Index; EF = Enrichment Factor (Fe-normalized)

## DISCUSSION

The findings in this study indicate a distinct trend regarding the influence of human activities and seasonal variations on water quality across the study area. Water temperature exhibited a relatively consistent range (24 - 29 °C) across the sampling sites, a characteristic feature of tropical ecosystems that is not expected to directly impose stress on aquatic organisms. The water temperature range in this study was similar to the temperature range reported by Adedeji *et al.* (2018), Oyewale *et al.* (2018), Adesakin *et al.* (2020) and Ayejoto *et al.* (2023) on studies carried out in on various waterbodies across Nigeria. Nevertheless, these temperatures may still affect oxygen concentrations and biological processes within the water body (Saenger and Holmes, 2018; Johnson *et al.*, 2024). The pH range of 6.0 to 7.3 indicates generally suitable conditions, with the upstream location exhibiting a slightly more neutral pH. This observation likely indicates reduced disturbance at the source, whereas the minor decrease observed downstream may be associated with organic pollution and decomposition activities. Comparable patterns have been documented in surface waters across Nigeria, where downstream areas frequently display evidence of heightened human impact. This was in consonance with the findings of Oyewale *et al.* (2018), Adesakin *et al.* (2020) and Jolaosho *et al.* (2025) who reported a similar pH range of 6.15 and 7.25 in Olosuru Stream in Ikire, Osun State, Kubanni reservoir in Samaru, Kaduna State and Lekki Lagoon in Lagos State, respectively. A significant rise in electrical conductivity, total dissolved solids, and chemical oxygen demand observed at the downstream location indicates the accumulation of pollutants as water traverses the system. These metrics are commonly employed as indicators of contamination stemming from runoff, sewage, and various anthropogenic sources. Increased COD and BOD levels, especially noted at the mid-stream site, further imply substantial organic loading and continuous microbial decomposition, which may lead to

diminished oxygen availability (Lacalamita *et al.*, 2024). This explains the generally low dissolved oxygen levels observed in this study, which may not support sensitive aquatic organisms.

Indicators of organic pollution (BOD, COD, TOC, OM) were markedly elevated at Mid-stream and downstream stations, with COD levels surpassing the WHO guidelines. Leachate from municipal waste disposal sites generally comprises intricate organic compounds and microbial metabolites that raise oxygen demand and organic carbon levels in receiving waters (for instance, elevated COD and TOC values in proximity to landfills) such as the findings of Saghi *et al.* (2024) who reported up to 90,000 mg/L COD on leachate samples from Iranian metropolises and Igwegbe *et al.* (2024) who attributed varying degrees of elevated values of organic compounds in ground and surface water bodies across Nigeria to the impact of leachates on soil properties in their review report. Such conditions may promote heterotrophic microbial activity, resulting in increased oxygen consumption and possibly causing hypoxic micro zones detrimental to aquatic life.

The correlation between leachate from dumpsites and the deterioration of water quality has been noted in various contexts across Nigeria. For instance, the groundwater quality near the Olusosun dumpsite in Lagos showed considerable physicochemical changes associated with its closeness to landfill leachate, which included an increase in metals and ions that exceeded safe limits as one approached the site (with water quality improving as the distance from the dumpsite increased) (Emmanuel *et al.*, 2025). Comparable patterns have been documented in other urban areas where solid waste disposal is common, underscoring the impact of leachate movement on the degradation of nearby water resources and raising concerns regarding their safety for human consumption (Udofia and Udiba, 2016).

There are distinct spatial differences in heavy metal concentrations throughout the dumpsite sampling stations. Lead (Pb) demonstrated moderate levels, signifying a marked enrichment in comparison to

background concentrations. However, cadmium (Cd) revealed the highest levels among the analysed metals, indicating considerable contamination that is likely associated with dumpsite operations. The elevated mean concentrations of Pb and Cd at the recovery station likely indicate the influence of solid waste leachate and refuse decomposition typical of poorly managed dumpsites, where metal-bearing materials accumulate and mobilize into surrounding soils. This pattern aligns well with documented cases in Nigeria that dumpsites often act as significant sources of heavy metal pollution, with Pb, Cd, and other metals exceeding background levels due to municipal waste inputs and leachate migration (Oyewale *et al.*, 2019; Adedinni *et al.*, 2023; Adesakin *et al.*, 2023). Seasonally, the majority of parameters exhibited elevated levels during the wet season, probably as a result of runoff transporting sediments, nutrients, and pollutants into the water. This observation is consistent with recent research by Agunbiade and Adebawore (2026) who reported that rainfall substantially enhances contaminant loading in tropical aquatic ecosystems. In contrast, some parameters (e.g., pH and COD) were higher in the dry season, probably due to reduced dilution. Generally, the study indicates a progressive deterioration in water quality as one moves from upstream to downstream, with seasonal precipitation exacerbating pollution levels. These trends underscore the synergistic impacts of anthropogenic activities and natural hydrological processes on freshwater ecosystems. The strong correlations between heavy metals and physicochemical parameters analysed in this study indicate shared sources and coupled geochemical controls. The association of Fe and other metals with pH, total suspended solids, and organic indicators (BOD, TOC) suggests that metal mobility is largely regulated by pH and organic matter interactions. According to the work of Li *et al.* (2024), organic carbon has been shown to significantly enhance the release and transport of metals such as Cd and Pb in environmental systems. The clustering of Cd, Pb, and As with BOD, COD, and TDS at mid-stream and downstream locations indicates growing anthropogenic inputs. These connections are frequently associated with urban runoff and wastewater discharge, where organic matter promotes metal complexation and bioavailability (Dan *et al.*, 2022). Spatial variability further supports heterogeneous pollution sources across the sampling stations.

Pollution indices frequently reveal significant contamination with a clear gradient (recovery > mid-stream > downstream > upstream). Significant anthropogenic enrichment is confirmed by elevated CF and PLI values, and significant ecological risk is indicated by high RI values. Comparable research such as the work of Ferreira *et al.* (2022) and Gogoi *et al.* (2024) shows that the combined indices (CF, Igeo, EF, and RI) are useful for determining the level of pollution and ecological risks in contaminated soils. Considering its elevated mobility, bioavailability, and toxicity even at low concentrations, cadmium was the main source of ecological concern. Strong to severe pollution is further indicated by the high Igeo values for Pb and Cd. The overall pattern is primarily anthropogenic, even when EF values (<2) indicate a limited lithogenic effect. This compares well with the work of Saleem *et al.* (2024) who reported an elevated Igeo for Cd in surface soil samples collected from the farmlands of Grand Forks County, North Dakota.

Generally, the integrated ecological assessment of soil samples in this study identifies the recovery and mid-stream sites as contamination hotspots, reflecting cumulative anthropogenic impacts and significant ecological risk, thereby emphasizing the need for targeted management and continuous monitoring of the study area.

The PCA biplot suggests that dissolved ions ( $Mg^{2+}$ , TH, and TDS) largely control the water chemistry, likely through natural mineral dissolution. The close grouping of COD, TOC, and BOD points to organic pollution from human activities such as domestic or agricultural runoff, while Pb, Mn, and As indicate localized metal contamination. The clustering of Stations A–D near the origin further suggests similar water quality conditions across the sites. Comparable PCA-based patterns have been reported in recent water quality studies (Ubuoh *et al.*, 2024; Hammoumi *et al.*, 2024; Jolaosho *et al.*, 2025).

## CONCLUSION

This study concluded that the surface water quality deteriorated progressively from upstream to downstream as a result of uncontrolled dumpsite activities and seasonal runoff. Also, increased levels of EC, TDS, BOD, COD, TOC, and OM, coupled with low dissolved oxygen, signified considerable organic and chemical pollution, as well as ecological stress. Heavy metal concentrations rose at recovery sites, exhibiting significant spatial variations in Cd and Pb ( $p < 0.05$ ). Furthermore, Cd, As, and Fe levels surpassed WHO limits in certain areas, presenting risks to both

ecological integrity and public health. Pollution indices, correlation analyses, and PCA revealed moderate to severe contamination driven by anthropogenic and geochemical influences, underscoring the necessity for continuous monitoring and effective pollution management.

#### **Limitation of the Study**

This research presents multiple limitations. The lack of a control site hinders comparative analysis, and the restricted sampling range may fail to account for long-term variations. Furthermore, the absence of hydrological flow mapping and leachate sampling limits the evaluation of contaminant transport and off-site migration.

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#### **Authors' Contributions**

**Conceptualization:** Christianah Ekundayo Amosu, Abayomi Tolulope Oyewale and Ebenezer Temitope Adebayo; **Data curation:** Christianah Ekundayo Amosu and Ebenezer Temitope Adebayo; **Formal analysis:** Olawepo Gabriel Kehinde; **Methodology:** Abayomi Tolulope Oyewale and Ebenezer Temitope Adebayo; **Software:** Christianah Ekundayo Amosu; **Supervision:** Abayomi Tolulope Oyewale and Ebenezer Temitope Adebayo; **Writing – original draft:** Abayomi Tolulope Oyewale; **Writing – (review and editing):** Ebenezer Temitope Adebayo.

#### **Ethical Approval**

This is not applicable

#### **Consent to Participate**

This is not applicable

#### **Consent to Publish**

All authors have thoroughly reviewed and approved the final version of the manuscript

#### **Competing Interests**

All authors declare that there are no conflicts of interest to disclose

#### **Data Availability Statement**

Data used in this study will be made available on request

#### **REFERENCES**

Achudume, A. C., and Olawale, J. T. (2007). Microbial pathogens of public health significance in waste dumps and common sites. *Journal of environmental biology*, 28(1), 151.  
Adedeji, A. A., Adesakin, T. A., Bolawa, O. P., Nkado, H. C., Oladimeji, E. B., Ogunmola, A. O. and

Salahudeen, A. F. (2018). Impact of Abattoir effluent on water quality, plankton community and microbial load of Opa River, Ile-Ife, Nigeria. *Environtropica* volume 15 page 30-54.

Adedinni, M. O., Arogundade, A. B., Ore, O. T., Adenika, C. I., Adebayo, A. S., Akinlade, G. O., and Oyekunle, J. A. O. (2023). Geophysical and geochemical study of the contaminant impact of Oke-Tage solid waste dumpsite, Southwestern Nigeria. *Scientific Reports*, 13(1), 4704.

Adelekan, B. A., and Alawode, A. O. (2011). Contributions of municipal refuse dumps to heavy metals concentrations in soil profile and groundwater in Ibadan Nigeria. *Journal of Applied Biosciences*, 40, 2727-2737.

Ademoroti, H. (1996). *Standard Methods for Water and Effluents Analysis*, Foludex Press Ltd., Ibadan, p. 182.

Adesakin, T. A., Ehikhamele, I. E., Ogunrinola, O. F., Oloyede, O. O., Adedeji, A. A., Odufuwa, P.T., Aimienoho, A., Aduwo, A. I. and Adewumi, E. A. (2023). Using benthic macroinvertebrates as bioindicators to evaluate the impact of anthropogenic stressors on water quality and sediment properties of a West African Lagoon. *Heliyon* 9 e19508 pages 1-15

Adesakin, T. A., Oyewale, A. T., Bayero, U., Mohammed, A. N., Aduwo, I. A., Ahmed, P. Z., et al. (2020). Assessment of bacteriological quality and physicochemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. *Heliyon* 6:e04773.

Agunbiade, R. O., and Adebawore, A. A. (2026). Physicochemical Examination of Water Quality from Ero Dam, Ekiti State, Nigeria. *Journal of Life and Bio-Sciences Research*, 7(01), 01-10.

APHA/AWWA/WEF (1995). Standard methods for the examination of water and wastewater. 19<sup>th</sup> ed., American Public Health Association (APHA), the American Water Works Association (AWWA) and the Water Environment Federation (WEF), 120 pages. Washington, DC.

APHA/AWWA/WEF (2017). Standard Methods for the Examination of Water and Wastewater. 23rd Edition, American Public Health Association, American Water Works Association, Water Environment Federation, Denver.

Ayejoto, D. A., Egbueri, J. C., Agbasi, J. C., Omeka, M. E., Unigwe, C. O., Nwazelibe, V. E., and Pande, C. B. (2023). Influence of seasonal changes on the quality of water resources in southwestern Nigeria: a review. *Climate change impacts on Nigeria: environment and sustainable development*, 423-447.

- Bogdevich, O., Culighin, E., and Ene, A. (2021). Atomic absorption spectroscopy for metal analysis. *Chapter, 3*, 21-36.
- Dong, S. G., Tang, Z. H., Liu, B. W., and Orodu, O. D. (2009, July). Numerical modeling of the environment impact of landfill leachate leakage on groundwater quality-A field application. In *Proceedings of International Conference on Environmental Science and Information Application Technology* (pp. 265-268).
- Emmanuel, A. O., Olawale, A. A., Luqmon, P. A., and Aisha, M. (2025). Geospatial Effects of Landfill Leachate on Groundwater Physicochemical Properties around Olusosun Dumpsite, Lagos, Nigeria. *Journal of Civil Engineering, 16(2)*, 196-209.
- Ferreira, S. L., da Silva Junior, J. B., dos Santos, I. F., de Oliveira, O. M., Cerda, V., and Queiroz, A. F. (2022). Use of pollution indices and ecological risk in the assessment of contamination from chemical elements in soils and sediments—Practical aspects. *Trends in Environmental Analytical Chemistry, 35*, e00169.
- Gogoi, N., Sarma, A., Choudhury, M., Samanta, P., Faizan, M., and Sadhak, S. (2024). Soil heavy metal pollution and ecological risk assessment in disturbed and undisturbed soil of Morigaon, Assam. *Discover Environment, 2(1)*, 13.
- Golterman, H. L., Clymo, R. S. and Ohnstand, M. A. M. (1978). *Methods for Physical and Chemical Analysis of Freshwater*. 2nd edition, IBP Handbook No 8., Blackwell Scientific Publication, Oxford. 213pp
- Hakanson, L. (1980). An ecological risk index for aquatic. Pollution control: A sedimentological approach. *Water Research, (14)*: 975–1001.
- Hammoumi, D., Al-Aizari, H. S., Alaraidh, I. A., Okla, M. K., Assal, M. E., Al-Aizari, A. R., and Bejjaji, Z. (2024). Seasonal variations and assessment of surface water quality using water quality index (WQI) and principal component analysis (PCA): a case study. *Sustainability, 16(13)*, 5644.
- Idowu, G. A. (2022). Heavy metals research in Nigeria: a review of studies and prioritization of research needs. *Environmental Science and Pollution Research, 29(44)*, 65940-65961.
- Igwegbe, C. A., López-Maldonado, E. A., Landázuri, A. C., Ovuoraye, P. E., Ogbu, A. I., Vela-García, N., and Białowiec, A. (2024). Sustainable municipal landfill leachate management: Current practices, challenges, and future directions. *Desalination and Water Treatment, 320*, 100709.
- Iwegbue, C. M., Nwajei, G. E., Ogala, J. E., and Overah, C. L. (2010). Determination of trace metal concentrations in soil profiles of municipal waste dumps in Nigeria. *Environmental geochemistry and health, 32(5)*, 415-430.
- Jagun, Z. T., Daud, D., Ajayi, O. M., Samsudin, S., Jubril, A. J., and Rahman, M. S. A. (2023). Waste management practices in developing countries: a socio-economic perspective. *Environmental Science and Pollution Research, 30(55)*, 116644-116655.
- Johnson, M. F., Albertson, L. K., Algar, A. C., Dugdale, S. J., Edwards, P., England, J., Gibbins, C., Kazama, S., Komori, D., MacColl, A., Scholl, E., Wilby, R., Roque, F., and Wood, P. J. (2024). Rising water temperature in rivers: Ecological impacts and future resilience. *Wiley Interdisciplinary Reviews: Water, 11(4)*, e1724.
- Jolaosho, T. L., Elegbede, I. O., Ndimele, P. E., Marouani, M., Yusuf, A. O., Omoregha, J. K., Mustapha, A. A., Hungbo, J. J. and Rasaq, M. F. (2025). Seasonal and spatial variations of physicochemical parameters and heavy metals in surface water of interconnected Nigeria lagoons experiencing distinct anthropogenic disturbances. *Scientific Reports, 15(1)*, 38816.
- Kebede, A. A., Olani, D. D., Edesa, T. G., and Damtew, Y. T. (2016). Heavy metal content and physicochemical properties of soil around solid waste disposal sites. *American Journal of scientific and Industrial research, 7(5)*, 129-139.
- Kolawole, T. O., Iyiola, O., Ibrahim, H., and Isibor, R. A. (2023). Contamination, ecological and health risk assessments of potentially toxic elements in soil around a municipal solid waste disposal facility in Southwestern Nigeria. *Journal of Trace Elements and Minerals, 5*, 100083.
- Lacalamita, D., Mongioví, C., and Crini, G. (2024). Chemical oxygen demand and biochemical oxygen demand analysis of discharge waters from laundry industry: monitoring, temporal variability, and biodegradability. *Frontiers in Environmental Science, 12*, 1387041.
- Li, C., Zhang, Y., Chen, R., Wang, N., Liu, J., and Liu, F. (2024). Influence of mineralized organic carbon in marine sediments on ecological heavy metal risk: Bohai Bay case study. *Environmental Research, 240*, 117542.
- Mohammed, A. N., Bayero, U., Adesakin, T.A., Yusuf, A., Abubakar, M., and Garba, S. H. (2025). Assessment of soil physicochemical properties and heavy metals concentrations from major abattoir sites in Kaduna Metropolis, Nigeria. *Soil and Sediment Contamination: An International Journal*, Volume 10(1080) page 1-20.
- Montaño-López, F., and Biswas, A. (2021). Are heavy metals in urban garden soils linked to vulnerable

- populations? A case study from Guelph, Canada. *Scientific reports*, 11(1), 11286.
- Nanda, S., and Berruti, F. (2021). Municipal solid waste management and landfilling technologies: a review. *Environmental chemistry letters*, 19(2), 1433-1456.
- Ochiagha, K. E., Okoye, P. A. C., and Eboagu, N. C. (2020). The geo-accumulation index of some heavy metals in the roadside soils of Onitsha south local government area Anambra state, Nigeria. *Science Journal of Chemistry*, 8(3), 42-47.
- Oloruntoba, A., Omoniye, A. O., Shittu, Z. A., Ajala, R. O., and Kolawole, S. A. (2024). Heavy metal contamination in soils, water, and food in Nigeria from 2000–2019: A systematic review on methods, pollution level and policy implications. *Water, Air, & Soil Pollution*, 235(9), 586.
- Omokaro, G. O., Michael, I., Efeni, O. S., Adeyanju, O. I., and Obomejoro, J. (2025). Waste management in Nigeria: Systemic failures, circular economy pathways and sustainable solutions. *Environmental Development*, 101363.
- Oyewale, A. T., Adesakin, T. A., and Aduwo, I. A. (2019). Environmental impact of heavy metals poultry waste discharge into olosuru stream, Ikire Southwest Nigeria. *Journal of Health and Pollution*, volume 9(22) page 1-10
- Oyewale, A. T., Adesakin, T. A., Oyedeji, O., Aduwo, I. A., and Bakare, M. K. (2018). Impact assessment of poultry discharge on the physicochemical and microbiological water quality of Olosuru stream in Ikire Southwest Nigeria. *Journal of water resource and protection*, volume 10(30) page 1061-1082
- Saenger, P., and Holmes, N. (2018). Physiological, temperature tolerance, and behavioral differences between tropical and temperate organisms. In *Pollution in tropical aquatic systems* (pp. 69-95). CRC Press.
- Saghi, M. H., Nadimi, H., Eslami, A., Alavi Bakhtiarvand, S. N., Oghazyan, A., Setoudeh, S., and Sargolzaei, M. S. (2024). Characteristics and pollution indices of leachates from municipal solid waste landfills in Iranian metropolises and their implications for MSW management. *Scientific Reports*, 14(1), 27285.
- Ubuoh, E. A., Nwogu, F. U., Ossai-Abeh, E. Q., Ikwemesi, J. C., Oke, A. O., and Umoh, J. D. (2024). Evaluation of hydro-chemical facies and surface water quality dynamics using multivariate statistical approaches in Southern Nigeria. *Scientific Reports*, 14(1), 31600.
- Udofia, L. E., and Udiba, U. U. (2016). Assessment of the impact of solid waste dumps on ground water quality, Calabar Municipality, Nigeria. *Journal of Advance Research in Pharmacy and Biological Science (ISSN 2208-2360)*, 2(4), 10-21.
- USEPA (2009). National Drinking water standards. United States Environmental Protection Agency, <http://www.epa.gov/safewater/>
- Wang, Y., Yang, Z., Shen, Z., Tang, Z., Niu, J., and Gao, F. (2011). Assessment of heavy metals in sediments from a typical catchment of the Yangtze River, China. *Environmental Monitoring and Assessment*, 172(1), 407-417.
- Yang, J., Wang, Q., Wang, Q., and Wu, T. (2009). Heavy metals extraction from municipal solid waste incineration fly ash using adapted metal tolerant *Aspergillus niger*. *Bioresource technology*, 100(1), 254-260.
- Zhang, Z., Chen, Z., Zhang, J., Liu, Y., Chen, L., Yang, M., ... and Yap, P. S. (2024). Municipal solid waste management challenges in developing regions: A comprehensive review and future perspectives for Asia and Africa. *Science of the Total Environment*, 930, 172794.