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# Assessment of Dumpsite Leachate Impact on Surface and Groundwater Quality in Ile-Oluji, Ondo State, Nigeria

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## *Abstract*

Municipal dumpsites remain major sources of environmental contamination in many developing regions, particularly where open dumping practices persist. This study assessed the impact of active municipal dumpsites on groundwater and surface water quality in Ile-Oluji, Ondo State, Nigeria. Physicochemical parameters, major cations, heavy metals, and microbial indicators were analysed in surface water, groundwater, leachate, and control samples using standard analytical procedures. The Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI) were employed to evaluate the suitability of the water for drinking purposes. Results showed elevated concentrations of electrical conductivity, total dissolved solids, nutrients (nitrate, nitrite, sulphate, and phosphate), and organic pollution indicators in the impacted water samples compared with the corresponding controls. Heavy metals, including Pb (0.13–0.46 mg $L^{-1}$), Ni (0.45–1.05 mg $L^{-1}$), Co (0.10–3.82 mg $L^{-1}$), Fe (0.65–8.07 mg $L^{-1}$), and Mn (0.11–2.95 mg $L^{-1}$), occurred at elevated concentrations in several samples, while cadmium and chromium were below detection limits in water samples but detected in leachate, indicating a potential long-term contamination risk. Microbiological analyses further confirmed faecal contamination of the affected water sources. The computed WQI values ranged from 110.15 to 300.01, indicating that all investigated surface water and groundwater samples were unsuitable for drinking. Similarly, HPI values ranged from 308.98 to 1037.67, far exceeding the critical value of 100, indicating severe heavy metal pollution across all investigated water samples. The findings demonstrate active leachate migration and progressive deterioration of surrounding water resources and underscore the urgent need for improved waste management practices, effective leachate control measures, continuous groundwater monitoring, and appropriate water treatment to safeguard public health and environmental sustainability.

**Keywords:** Municipal dumpsites; Leachate; Surface water; Groundwater; Heavy metals; Water Quality Index; Heavy Metal Pollution Index.

# Introduction

In developing nations like Nigeria, the rapid growth of populations, the process of urbanization, and development have contributed to an increase in solid waste generation and hence have made waste management a pertinent environmental problem (Kaza et al., 2018; UNEP, 2024). Municipal solid waste is diverse and consists of waste products from various sources such as domestic practices that include food wastes, plastics, and fabrics; agricultural processes that include crop residues and agrochemical packaging materials; commercial practices that include waste packages and electronic waste; and industries that emit hazardous chemicals and metals into the environment (Bakare, 2020).

Open dumping is one of the cheapest methods of disposing of municipal solid waste in many developing countries (Olukanni et al., 2017). Although it is economically efficient, poorly managed dumpsites create significant environmental hazards due to leachate formation and hazardous materials that contaminate the surrounding soil, surface, and ground waters (Ferronato & Torretta, 2019). In rainwater, water filters into accumulated waste products and mixes organic and inorganic materials together to form leachate. Contaminated water moves through surface runoff and subsurface filtration into the surrounding waters (Odoh et al., 2024).

The composition of leachate is highly variable across different dumpsites depending on the type of waste, the size of waste particles, moisture level, compactness of waste, age of the dumpsite, site management techniques, and the hydrogeological nature of the site (Aramide, 2023). While leachate contains several types of contaminants, heavy metals continue to form some of the major pollutants due to the persistence, non-biodegradability and potential toxicity of the compounds, even at relatively low levels of pollution (Elemile, 2025). Different from organic contaminants, heavy metals do not degrade easily and can remain present in the environment for a long period of time after being released. During their migration through the soil and water bodies, heavy metals can become accumulated in aquatic life forms, and enter into the food chain and finally become a source of danger for human health. Their presence has been linked to the development of genetic damage and various kinds of chronic diseases (Bakare, 2009; Mekonnen et al., 2020). Continuous exposure to contaminants that are released from municipal dumpsites has also been found to increase the risk of cancer, respiratory diseases and low infant birth weight in adjacent populations (Aramide, 2023).

Since environmental pollution is mainly caused by man, it means that for any successful management of the environment, apart from constant monitoring, there must be proactive steps taken to reduce pollution and conserve ecosystems to ensure sustainable development (Onu et al., 2023).

Groundwater is among the major sources of fresh water and serves as a vital part of the hydrological cycle. Groundwater is stored in permeable rocks referred to as aquifers. Aquifers have adequate capacity to hold water and provide water through extraction wells (Arimieari & Olayinka, 2020). The major threat to the groundwater system is contamination through anthropogenic activities, especially improper waste disposal.

The leachates formed in municipal dump sites are likely to move either vertically or horizontally through the soil profile, causing pollution of the surrounding groundwater and surface water (Odoh et al., 2024). While the breakdown of the

organic wastes occurs, different types of dissolved organic substances are created which change the chemistry of water and increase the mobility of toxic substances such as heavy metals. Moreover, pathogenic organisms and toxic substances from the improperly disposed waste sites could move into groundwater making it unsuitable for domestic uses. The aforementioned contamination is usually linked with anthropogenic activities such as sewage discharges, effluents from industries, and municipal wastes disposal (Arimieari & Olayinka, 2020).

Despite the substantial ability of the soil to retain pollutants via adsorption and other geochemical processes, the abovementioned natural processes cannot be a sufficient barrier for groundwater contamination especially in regions where there are shallow aquifers and constant disposal of wastes (Egbueri et al., 2022a).

In Ile-Oluji, Ondo State, solid wastes are disposed off through open dumping into established dumpsites that have been in use for many years. Household wastes from various places in the town are dumped into these dumpsites especially the Brunelli dumpsite without much engineering practices in place to protect the environment from leachates. The continuing practice of these dumpsites has raised questions on their effect on surface water and groundwater around them. However, despite this concern, little is known about the level of effect caused by the leachate produced from the active dumpsites on water quality, especially in the rainy season when leachate production is high. It is for this reason that the current study assessed the effect of active municipal dumpsites on adjacent surface water and groundwater quality in Ile-Oluji, Ondo State, Nigeria.

**PROBLEM STATEMENT**

Municipal solid waste is largely disposed of through open dumping in Ile-Oluji, Ondo State, where some dumpsites have been in use for several decades. The absence of adequate waste containment and leachate management creates a risk of contamination of the surrounding environment. During rainfall, leachate can be generated and transported through surface runoff and subsurface infiltration into nearby surface water and groundwater. This may introduce nutrients, organic substances, heavy metals and microorganisms into the water bodies and affect their quality. Despite the long-term use of the Brunelli, Bamikemo and Lipanu dumpsites, there is limited information on the extent of their impact on nearby water resources, particularly during periods of high rainfall. There is therefore a need to assess the quality of the affected surface water and groundwater and determine the extent of contamination associated with the dumpsite leachate. The findings will provide useful information for water quality management, environmental monitoring and public health protection in the study area.

**OBJECTIVES OF THE STUDY**

The general objective of this study was to assess the impact of leachate from active municipal dumpsites on the quality of surface water and groundwater in Ile-Oluji, Ondo State, Nigeria.

The specific objectives were to:

i. determine the physicochemical characteristics of surface water and groundwater around the Brunelli, Bamikemo and Lipanu municipal dumpsites and compare them with their respective control samples;
ii. assess the concentrations of major ions, nutrients and organic pollution indicators in the surface water and groundwater around the investigated dumpsites;
iii. determine the concentrations of selected heavy metals and microbiological indicators in the surface water and groundwater samples and assess their levels in relation to drinking-water quality standards;

iv. evaluate the overall quality and suitability of the surface water and groundwater for drinking purposes using the Water Quality Index (WQI); and
v. assess the degree of heavy-metal pollution in the surface water and groundwater using the Heavy Metal Pollution Index (HPI).

**RESEARCH QUESTIONS**

The study was guided by the following research questions:

i. What are the physicochemical characteristics of surface water and groundwater around the Brunelli, Bamikemo and Lipanu municipal dumpsites, and how do they compare with their respective control samples?
ii. What are the concentrations of major ions, nutrients and organic pollution indicators in the surface water and groundwater around the investigated dumpsites?
iii. What are the concentrations of selected heavy metals and microbiological indicators in the surface water and groundwater samples, and how do their levels compare with drinking-water quality standards?
iv. What is the overall quality and suitability of the surface water and groundwater for drinking purposes based on the Water Quality Index (WQI)?
v. What is the degree of heavy-metal pollution in the surface water and groundwater based on the Heavy Metal Pollution Index (HPI)?

**Study Area Description**

The experiment was carried out in Ile-Oluji, which is the administrative headquarter of Ile-Oluji/Oke-Igbo Local Government Area, Ondo State, southwest, Nigeria. The region falls within the humid tropical rainforest and has two climatic seasons, that is, the rainy and dry seasons. During the rainy season, there is an abundance of rainfall, which leads to surface runoff and facilitates the infiltration of water into municipal waste deposits, hence making it possible for leachate production and movement into the surface water and shallow ground water bodies.

In order to make sure that the experiment conducted reflected the reality of municipal waste disposal process in Ile-Oluji metropolis, three actively operating municipal dumpsites in Ile-Oluji Main Town (7.213100N, 4.869000E), Bamikemo (7.301800N, 4.878300E) and Lipanu (7.349700N, 4.893600E) were chosen for research. These dumpsites have been actively used for more than four decades now as the primary waste disposal sites of those particular areas. It was anticipated that such a long-term operation period would lead to the accumulation of contaminants as well as formation of leachate. Thus, it was considered appropriate to conduct this research in order to determine the possible effect of municipal waste disposal on surface water and shallow groundwater resources of that area. The geographical coordinates of each sampling point were obtained via a handheld Global Positioning System (GPS).

Table 1: The specific coordinate of the sampling points

| | **BRUNELLI** | | | **BAMIKEMO** | | | **LIPANU** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **N** | **E** | **ELE** | **N** | **E** | **ELE** | **N** | **E** | **ELE** |
| **Groundwater (GW)** | $7^0$13’51’’ | $4^0$52’7” | 8600ft | $7^0$18’52’’ | $4^0$53’18’’ | 860ft | $7^0$20’58’’ | $4^0$53’33’’ | 870ft |
| **Surface water (SW)** | $7^0$13’58’’ | $4^0$52’10’’ | 830ft | $7^0$18’51’’ | $4^0$53’18’’ | 860ft | $7^0$20’57’’ | $4^0$53’35’’ | 850ft |

| | BRUNELLI | | | BAMIKEMO | | | LIPANU | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | E | ELE | N | E | ELE | N | E | ELE |
| **Groundwater control (GW ctrl)** | $7^0$13’54’’ | $4^0$52’11’’ | 860ft | $7^0$18’53’’ | $4^0$53’15’’ | 910ft | $7^0$21’1’’ | $4^0$53’35’’ | 890ft |
| **Surface water control (SW ctrl)** | $7^0$14’2” | $4^0$52’16’’ | 810ft | $7^0$18’50’’ | $4^0$53’18’’ | 880ft | $7^0$20’55’’ | $4^0$53’43’’ | 910ft |

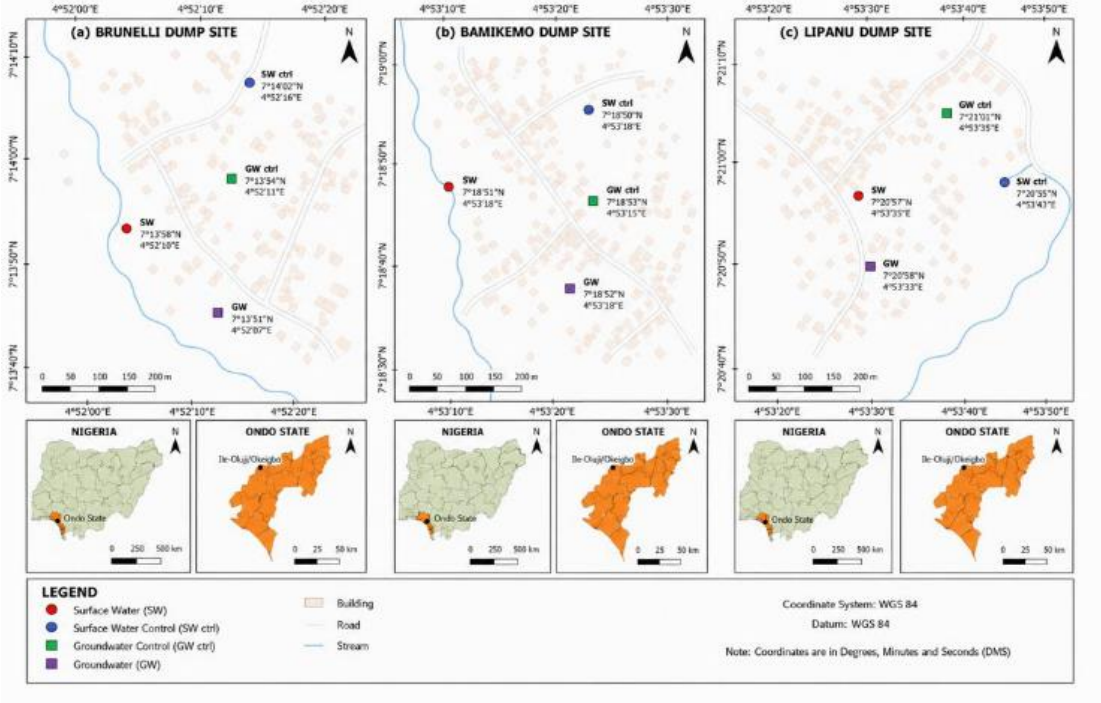



Figure 1: Map of the study area showing the locations of water sampling points around the **(a)** Brunelli**,** (b) Bamikemo, and (c) Lipanu municipal dumpsites



Figure 2: Brunelli dumpsite.



Figure 3: Bamikemo dumpsite



Figure 5: Lipanu dumpsite

**Sample Collection**

Samples of water were taken at the beginning of August 2024 when the rain was at its peak in the region of study. This is because rain increases leachate generation and helps in its movement via surface runoff and subsurface infiltration into other water bodies. Samples from each of the three active municipal dump sites (Brunelli, Bamikemo and Lipanu) included leachate, surface water, groundwater, surface water control and groundwater control.

The groundwater samples were taken from hand dug wells that were located 20 – 25m from the base of each of the dump site while the depths of the wells were from 1.2m to 1.5m. The surface water samples were taken from nearby streams located about 22-25m down slope of each of the respective dump sites in order to investigate whether there is an effect of the leachate that may have been transported through surface runoff. Background water quality of the area for comparative purposes was established by taking samples of control groundwater and surface water at distances of about 700m away from each dump site and beyond the zone of influence of the leachate.

Table 2. Distance of groundwater and surface water sampling points from the investigated dumpsites.

| Dumpsite | Groundwater Distance (m) | Groundwater Depth (m) | Surface Water Distance (m) |
|---|---|---|---|
| **Brunelli** | 22 | 1.5 | 25 |
| **Bamikemo** | 20 | 1.3 | 22 |
| **Lipanu** | 25 | 1.2 | 25 |

Samples meant for physicochemical analysis were taken in clean 4 L HDPE (high density polyethylene) bottles, which were filled completely to avoid headspace so as to prevent contamination of samples from atmosphere and changes in dissolved components during transit. Samples that were to be used for the determination of heavy metals were immediately preserved using concentrated nitric acid ($HNO_3$), ensuring that pH became less than 2 in order to follow recommendations of APHA (2023). Preservation of samples by acidification was aimed at preventing precipitation of metals, minimizing adsorption on the walls of the bottles and maintaining the concentration of dissolved metals. Other water samples for microbial analysis were aseptically taken in sterile amber glass bottles with some amount of headspace. Samples for microbial analysis were kept chilled during transport using insulated ice chests in order to prevent microbial growth and maintain their characteristics until analysis in the laboratory.

All water samples were transported to the laboratory in insulated ice chests and kept at 4 °C until analysis. Low-temperature storage was maintained to minimize physicochemical changes and suppress microbial activity prior to laboratory examination. Measurements of temperature, pH, and dissolved oxygen (DO) were carried out *in situ* immediately after sample collection using calibrated portable instruments to avoid changes associated with sample transportation and storage. Microbiological analyses were completed within 24 h of sample collection, while physicochemical determinations were performed within 72 h in accordance with the procedures outlined in the *Standard Methods for the Examination of Water and Wastewater* (APHA, 2023).

**Determination of Physicochemical Parameters**

The physicochemical characteristics of the water samples were determined in accordance with the procedures described in the *Standard Methods for the Examination of Water and Wastewater* (APHA, 2023). Water temperature, pH and dissolved oxygen (DO) were measured *in situ* immediately after sample collection to minimize changes that could occur during sample transportation and storage. Water temperature was determined using a digital thermometer (Hanna Instruments, Romania), pH was measured with a Hanna HI98107 portable pH meter (Hanna Instruments, Romania), while dissolved oxygen was determined using a Lutron DO-5510 dissolved oxygen meter (Lutron Electronic Enterprise Co., Taiwan). All field instruments were calibrated according to the manufacturers' instructions prior to use to ensure the accuracy and reliability of the measurements.

Electrical conductivity (EC) was measured using a Hanna HI8733 portable conductivity meter (Hanna Instruments, Romania). The instrument was used to determine the ionic strength of the water samples based on their ability to conduct electrical current. Total solids (TS), total dissolved solids (TDS), and total suspended solids (TSS) were determined by the gravimetric method following the procedures described by APHA (2023). Turbidity was measured using a Hach 2100Q portable turbidimeter (Hach Company, USA), which determines the degree of light scattering caused by suspended particles present in the water samples.

Total alkalinity was determined by the acid titration method using standardized hydrochloric acid (HCl), while total hardness was determined by the ethylenediaminetetraacetic acid (EDTA) complexometric titration method in accordance with APHA (2023). Biochemical oxygen demand ($BOD_5$) was determined from the difference between the initial and final dissolved oxygen concentrations following incubation of the samples at $20^0$C for five days. Dissolved oxygen measurements were obtained using the Lutron DO-5510 dissolved oxygen meter. Chemical oxygen demand (COD) was determined using the closed reflux dichromate titrimetric method as described in APHA (2023), which estimates the amount of oxygen required for the chemical oxidation of organic and inorganic oxidizable substances present in the water samples.

Nitrate ($NO_3^-$), nitrite ($NO_2^-$), and phosphate ($PO_4^{3-}$) concentrations were determined using a Jenway 6305 UV/Visible spectrophotometer (Bibby Scientific Ltd., UK) following the procedures described in APHA (2023). Nitrate was analysed by the ultraviolet spectrophotometric method, nitrite by the diazotization spectrophotometric method, and phosphate by the ascorbic acid spectrophotometric method. Sulphate ($SO_4^{2-}$) concentration was determined by the turbidimetric method, while chloride ($Cl^-$) was determined using the argentometric (Mohr) titration method. Oil and grease were determined by the liquid–liquid extraction gravimetric method using *n*-hexane as the extraction solvent. These analytical methods were selected because they provide reliable and widely accepted procedures for the determination of major inorganic ions and organic contaminants in environmental water samples (APHA, 2023).

**Determination of Major Cations and Heavy Metals**

Sodium (Na) and potassium (K) concentrations were determined using a flame emission spectrophotometer, while calcium (Ca), magnesium (Mg), lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), iron (Fe), nickel (Ni), cobalt (Co), copper (Cu), and zinc (Zn) were determined using an Atomic Absorption Spectrophotometer (AAS) following the procedures described in *Standard Methods for the Examination of Water and Wastewater* (APHA, 2023).

Prior to instrumental analysis, water samples designated for metal determination were digested using the nitric acid digestion method. Briefly, 100 mL of each thoroughly mixed water sample was transferred into a clean digestion flask, after which 5 mL of concentrated nitric acid ($HNO_3$, analytical grade) was added. The digest was heated gently using a hot plate to reduce the volume to about 20 mL and to get a clear solution, thus indicating complete oxidation of the organic materials with the release of metals into solution. The digest was cooled to room temperature, filtered using Whatman No. 42 filter paper, put in a 100 mL volumetric flask and made up to the mark using deionized water. The digests were further transferred to acid washed polyethylene bottles and kept at about 40°C before instrumental analysis. Calibration of the instrument was done using relevant standard solutions, and analyses were done in triplicate.Metal concentrations were expressed in mg $L^{-1}$.

**Microbiological Analysis**

Microbiological testing was carried out in order to establish the total coliforms, Escherichia coli (E. coli), and Salmonella spp., which are indicators of faecal and microbial pollution in water samples. The microbiological testing was done according to the procedure indicated in Standard Methods for the Examination of Water and Wastewater (APHA, 2023).

The membrane filtration method was used for all microbiological analyses due to its compatibility with the analysis of microbial indicators in water samples. Specifically, 100 mL of each water sample was passed through a 0.45 μm sterile membrane filter by means of a vacuum filtration unit. The membrane filters were subsequently placed on respective selective culture media and incubated under optimal conditions.

The total coliform bacteria were analyzed on m-Endo agar medium by incubating the medium for 24 hours at 370C. The Escherichia coli was analyzed by using EMB agar media incubated at 44.50C for 24 hours, while Salmonella spp. was isolated by using Salmonella Shigella (SS) agar and incubated for 24 hours at 370C. The characteristic colonies were then counted and expressed in terms of CFU/100mL. All analyses were done in three replicates, while sterile distilled water served as a negative control to validate the sterility of the process.

**Water Quality Index (WQI)**

Quality of the surface water and ground water samples was determined through the Weighted Arithmetic Water Quality Index (WQI) method that was first introduced by Brown et al. (1972) and later refined by Tiwari and Mishra (1985). WQI is based on multiple physicochemical properties that are converted into a single number that allows one to make conclusions about the drinking suitability of water. It allows evaluating the effect of different water quality parameters together, which makes it possible to compare different samples of water and interpret their quality.

Calculation of the WQI was done using twelve physicochemical properties, which were pH, EC, DO, TDS, turbidity, alkalinity, total hardness, nitrate ($NO_3^-$), nitrite ($NO_2^-$), sulphate ($SO_4^{2-}$), phosphate ($PO_4^{3-}$), and chloride ($Cl^-$). They were chosen because they are the main physicochemical properties determining the water quality for drinking purpose.

The corresponding guideline values recommended by the World Health Organization (WHO, 2022) were adopted as the permissible standards for the computation of the index.

The unit weight (W*i*) assigned to each water quality parameter was calculated according to Equation (1):

$$Wi = \frac{K}{(Si\quad)} \qquad 1$$

$$K = \frac{1}{\sum 1/Si} \qquad 2$$

$$Qi = \frac{Vi}{(Si\quad\quad)} X\ 100 \qquad 3$$

$$QpH = \frac{(VpH\quad -7.0\quad)}{(8.5\quad -7.0\quad)} X\ 100 \qquad 4$$

$$Q_{DO} = \frac{(14.6 - VDO\quad)}{(14.6\quad -5.0\quad)} X\ 100 \qquad 5$$

$$WQI = \frac{\sum WiQi}{\sum Wi} \qquad 6$$

Where W*i* is unit wight of the *i*th parameter, S*i* is WHO permissible standard of the *i*th parameter, K is proportionality constant, Q*i* is quality rating of the *i*th parameter, V*i* is experimentally measured value of the parameter. Because pH and dissolved oxygen have ideal values different from zero, modified quality rating equations were applied; VpH is measured pH value, 7.0 is ideal pH of pure water, 8.5 is upper WHO permissible limit for drinking water, $V_{DO}$ is measured dissolved oxygen concentration ($mgL^{-1}$), 14.6 $mgL^{-1}$ is ideal dissolved oxygen concentration of saturated water at standard conditions, 5.0 $mgL^{-1}$ is minimum WHO permissible value for drinking water

The WHO (2022) drinking water standards were used as reference values for all parameters.

The computed WQI values were subsequently classified into five categories (Excellent, Good, Poor, Very Poor and Unsuitable for drinking) according to the classification proposed by Brown et al. (1972), as presented in Table 3.

Table 3: Water Quality Classification Based on WQI Ranges (Brown et al., 1972)

| WQI Range | Water Quality Classification |
|---|---|
| **0–25** | Excellent |
| **26–50** | Good |
| **51–75** | Poor |
| **76–100** | Very Poor |
| **>100** | Unsuitable for drinking |

**Heavy Metal Pollution Index (HPI)**

The degree of heavy metal contamination in the surface water and groundwater samples was evaluated using the Heavy Metal Pollution Index (HPI) proposed by Mohan et al. (1996). The HPI incorporates the concentrations of certain selected heavy metals into one numeric index, thus making it possible to have an overall evaluation of heavy metal pollution and suitability of water for consumption. Such an analysis makes it possible for the contributions of all the heavy metals to be considered at once.

The calculation of HPI was based on the concentrations of nine selected heavy metals: Pb (lead), Cd (cadmium), Cr (chromium), Cu (copper), Mn (manganese), Zn (zinc), Fe (iron), Ni (nickel), and Co (cobalt). The selection of these metals was based on their significance, persistence, toxicity, and presence in WHO (2022) drinking-water guideline values. The corresponding WHO (2022) guideline values were adopted as the standard permissible limits for HPI computation. Metal concentrations reported as below the analytical detection limit (BDL) were assigned a value of 0.00 mg $L^{-1}$ during HPI calculation to ensure uniform treatment of non-detectable concentrations.

The HPI was computed using the following equation:

$$Wi = \frac{1}{Si} \qquad 7$$

Where W*i* is unit weight of the *i*th heavy metal, S*i* is WHO permissible standard of the *i*th heavy metal and K is proportionality constant.

$$K = \frac{1}{\sum(\frac{1}{Si})} \qquad 8$$

The sub-index (Q*i*) for each heavy metal was determined using:

$$Qi = \frac{Mi}{Si} X\ 100 \qquad 9$$

Where Q*i* is sub-index of the ith heavy metal, M*i* is measured concentration of the heavy metal, S*i* is WHO permissible standard.

The overall Heavy Metal Pollution Index (HPI) was calculated using:

$$HPI = \frac{\sum WiQi}{\sum Wi} \quad 10$$

The Heavy Metal Pollution Index (HPI) values were computed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) by applying the weighted arithmetic equations described by Mohan et al. (1996). The computed HPI values were interpreted using the critical pollution classification proposed by Mohan et al. (1996), whereby HPI values below 100 indicate low heavy metal pollution and water considered acceptable with respect to heavy metal contamination, whereas HPI values greater than 100 indicate critical heavy metal pollution and water unsuitable for drinking due to excessive heavy metal concentrations.

Table 4. Heavy Metal Pollution Index (HPI) Classification

| HPI Range | Pollution Status |
|---|---|
| **< 100** | Low heavy metal pollution (Suitable) |
| **≥ 100** | Critical heavy metal pollution (Unsuitable) |

**RESULTS AND DISCUSSION**

Table 5a: Physicochemical Properties of Water and Leachate around the Brunelli Dumpsite

| | Parameter | L | SW Ctrl | SW | GW Ctrl | GW | STD |
|---|---|---|---|---|---|---|---|
| **1** | Temperature ($^0$C) | 28.6 ± 1.04 | 25.4 ± 1.56 | 25.7 ± 1.32 | 27.6 ± 2.02 | 27.4 ± 2.12 | |
| **2** | pH | 6.96 ± 0.01 | 7.23 ± 0.03 | 6.57 ± 0.09 | 7.53 ± 0.01 | 6.87 ± 0.01 | 6.5-8.5 |
| **3** | EC (µS/cm) | 3851 ± 4.6 | 452 ± 2.13 | 725 ± 7.44 | 322 ± 5.20 | 702 ± 2.15 | ≤ 1500 |
| **4** | DO (mg/L) | 1.55 ± 0.02 | 4.62 ± 0.43 | 6.73 ± 1.22 | 5.49 ± 0.55 | 6.34 ± 0.43 | ≥ 5 |
| **5** | BOD (mg/L) | 61.7 ± 2.05 | 1.23 ± 0.07 | 4.20 ± 0.65 | 1.16 ± 0.04 | 3.84 ± 0.81 | < 3 |
| **6** | COD (mg/L) | 622 ± 6.33 | 30.26 ± 2.12 | 60.9 ± 5.52 | 25.9 ± 1.81 | 55.6 ± 0.69 | < 10 |
| **7** | TS (mg/L) | 1945 ± 4.8 | 180 ± 2.45 | 363 ± 5.15 | 160 ± 2.34 | 351 ± 2.25 | ≤ 1500 |
| **8** | TSS (mg/L) | 24.3 ± 1.18 | 6.8 ± 0.50 | 2.38 ± 0.06 | 0.28 ± 0.01 | 1.84 ± 0.05 | < 25 |
| **9** | TDS (mg/L) | 1921 ± 6.9 | 173 ± 1.79 | 361 ± 8.85 | 160 ± 1.50 | 350 ± 3.15 | ≤ 1000 |
| **10** | Turbidity (NTU) | 25.2 ± 2.62 | 0.46 ± 0.06 | 3.35 ± 0.45 | 0.39 ± 0.01 | 3.06 ± 0.03 | |
| **11** | Alkalinity (mg/L) | 278 ± 5.78 | 43.6 ± 2.53 | 87.3 ± 2.48 | 39.1 ± 2.21 | 84.6 ± 4.02 | ≤ 200 |
| **12** | Hardness (mg/L) | 394 ± 3.91 | 62.4 ± 1.21 | 181 ± 9.21 | 48.3 ± 0.82 | 166 ± 1.48 | 100-500 |
| **13** | Nitrate (mg/L) | 78.8 ± 2.88 | 6.52 ± 0.23 | 22.6 ± 1.58 | 4.45 ± 0.15 | 19.8 ± 0.85 | 50 |
| **14** | Nitrite (mg/L) | 5.35 ± 0.15 | 1.20 ± 0.05 | 3.84 ± 0.18 | 0.75 ± 0.02 | 2.31 ± 0.25 | 3 |
| **15** | Sulphate (mg/L) | 129 ± 1.95 | 14.20 ± 0.62 | 32.9 ± 2.89 | 7.00 ± 0.54 | 28.3 ± 0.35 | 500 |
| **16** | Phosphate (mg/L) | 64.5 ± 3.21 | 1.50 ± 0.15 | 4.87 ± 0.12 | ND | 4.11 ± 0.11 | ≤ 5 |
| **17** | Chloride (mg/L) | 332 ± 6.86 | 21.16 ± 0.64 | 75.3 ± 3.34 | 15.9 ± 0.59 | 71.1 ± 0.88 | 250 |
| **18** | Oil & Grease (mg/L) | 58.9 ± 1.05 | 2.56 ± 0.14 | 9.78 ± 1.65 | 1.92 ± 0.25 | 12.8 ± 0.51 | ≤ 10 |

**EC:** Electrical conductivity, **SW Ctrl:** Surface water Control, **GW Ctrl:** Groundwater Control, **SW:** Surface Water, **GW:** Ground Water, **L:** Leachate, **WHO STD**: Standard

Table 5b: Physicochemical Properties of Water and Leachate around the Bamikemo Dumpsite

| | Parameter | L | SW Ctrl | SW | GW Ctrl | GW | STD |
|---|---|---|---|---|---|---|---|
| **1** | Temperature ($^0$C) | 27.9 ± 1.35 | 26.8 ± 1.83 | 26.3 ± 1.43 | 27.4 ± 1.25 | 27.6 ± 1.42 | |
| **2** | pH | 6.33 ± 0.04 | 6.74 ± 0.05 | 8.08 ± 0.02 | 6.93 ± 0.01 | 6.44 ± 0.04 | 6.5-8.5 |
| **3** | EC (µS/cm) | 2892 ± 8.8 | 429 ± 0.22 | 675 ± 3.84 | 313 ± 1.84 | 475 ± 7.85 | ≤ 1500 |
| **4** | DO (mg/L) | 1.65 ± 0.05 | 6.72 ± 0.45 | 7.05 ± 0.27 | 5.59 ± 0.61 | 5.38 ± 0.55 | ≥ 5 |
| **5** | BOD (mg/L) | 50.9 ± 3.02 | 2.64 ± 0.06 | 2.88 ± 0.08 | 1.19 ± 0.05 | 1.69 ± 0.16 | < 3 |
| **6** | COD (mg/L) | 606 ± 4.17 | 15.6 ± 2.32 | 45.2 ± 4.21 | 12.1 ± 1.06 | 17.6 ± 1.82 | < 10 |
| **7** | TS (mg/L) | 1457 ± 14 | 193 ± 2.21 | 336 ± 6.21 | 154 ± 1.54 | 236 ± 0.82 | ≤ 1500 |
| **8** | TSS (mg/L) | 22.3 ± 1.84 | 3.2 ± 0.14 | 1.32 ± 0.28 | 0.10 ± 0.01 | 0.42 ± 0.17 | < 25 |
| **9** | TDS (mg/L) | 1435 ± 8.4 | 190 ± 6.32 | 335 ± 5.65 | 154 ± 4.41 | 235 ± 3.39 | ≤ 1000 |
| **10** | Turbidity (NTU) | 23.2 ± 1.2 | 0.18 ± 0.03 | 2.31 ± 0.18 | 0.14 ± 0.04 | 0.21 ± 0.01 | |
| **11** | Alkalinity(mg/L) | 244 ± 7.72 | 45.4 ± 3.21 | 61.8 ± 1.14 | 39.2 ± 3.42 | 46.3 ± 3.12 | ≤ 200 |
| **12** | Hardness (mg/L) | 323 ± 5.43 | 64.3 ± 0.93 | 125 ± 0.85 | 58.5 ± 2.11 | 74.3 ± 2.85 | 100-500 |
| **13** | Nitrate (mg/L) | 62.1 ± 0.33 | 3.2 ± 0.13 | 11.7 ± 1.15 | 2.44 ± 0.17 | 3.34 ± 0.59 | 50 |
| **14** | Nitrite (mg/L) | 4.58 ± 0.14 | 0.82 ± 0.02 | 2.11 ± 0.08 | 0.30 ± 0.04 | 0.56 ± 0.07 | 3 |
| **15** | Sulphate (mg/L) | 107 ± 2.85 | 6.46 ± 0.18 | 19.8 ± 2.22 | 4.54 ± 0.26 | 5.51 ± 0.24 | 500 |
| **16** | Phosphate (mg/L) | 41.3 ± 1.87 | 1.25 ± 0.23 | 2.45 ± 0.45 | ND | ND | ≤ 5 |
| **17** | Chloride (mg/L) | 340 ± 5.66 | 23.4 ± 1.67 | 32.4 ± 2.24 | 18.1 ± 1.32 | 22.2 ± 0.12 | 250 |
| **18** | Oil & Grease (mg/L) | 70.3 ± 4.72 | 2.43 ± 0.12 | 15.5 ± 1.19 | 0.74 ± 0.08 | 1.34 ± 0.65 | ≤ 10 |

**EC:** Electrical conductivity, **SW Ctrl:** Surface water Control, **GW Ctrl:** Groundwater Control, **SW:** Surface Water, **GW:** Ground Water, **L:** Leachate, **WHO STD**: Standard

Table 5c: Physicochemical Properties of Water and Leachate around the Lipanu Dumpsite

| | Parameter | L | SW Ctrl | SW | GW Ctrl | GW | STD |
|---|---|---|---|---|---|---|---|
| **1** | Temperature ($^0$C) | 28.4 ± 1.63 | 26.3 ± 1.72 | 27.5 ± 1.67 | 27.6 ± 1.21 | 28.5 ± 1.18 | |
| **2** | pH | 6.73 ± 0.03 | 6.56 ± 0.04 | 7.23 ± 0.05 | 6.08 ± 0.01 | 5.95 ± 0.06 | 6.5-8.5 |
| **3** | EC (µS/cm) | 2506 ± 8.7 | 450 ± 6.34 | 865 ± 12.5 | 337 ± 12.3 | 427 ± 9.84 | ≤ 1500 |
| **4** | DO (mg/L) | 1.56 ± 0.08 | 7.63± 1.18 | 6.54 ± 0.52 | 5.67 ± 1.49 | 4.89 ± 0.54 | ≥ 5 |
| **5** | BOD (mg/L) | 50.2 ± 2.31 | 2.34 ± 0.32 | 3.12 ± 0.21 | 1.69 ± 0.14 | 1.50 ± 0.07 | < 3 |
| **6** | COD (mg/L) | 600 ± 3.91 | 10.46 ± 1.21 | 52.7 ± 3.56 | 9.86 ± 1.02 | 15.7 ± 0.16 | < 10 |
| **7** | TS (mg/L) | 1271 ± 6.0 | 189 ± 9.06 | 442 ± 14.3 | 167 ± 6.03 | 211 ± 5.52 | ≤ 1500 |
| **8** | TSS (mg/L) | 20.2 ± 1.24 | 6.34 ± 0.08 | 7.23 ± 0.05 | 0.16 ± 0.04 | 0.21 ± 0.13 | < 25 |
| **9** | TDS (mg/L) | 1251 ± 7.1 | 182 ± 4.04 | 431 ± 9.11 | 167 ± 6.03 | 210 ± 0.39 | ≤ 1000 |
| **10** | Turbidity (NTU) | 22.7 ± 0.83 | 0.18 ± 0.07 | 2.63 ± 0.06 | 0.13 ± 0.04 | 0.26 ± 0.04 | |
| **11** | Alkalinity(mg/L) | 224 ± 4.58 | 40.5 ± 5.72 | 59.8 ± 6.21 | 37.2 ± 5.21 | 42.8 ± 3.86 | ≤ 200 |
| **12** | Hardness (mg/L) | 310 ± 7.62 | 75.6 ± 3.45 | 133 ± 4.49 | 51.1 ± 4.23 | 98.3 ± 6.76 | 100-500 |
| **13** | Nitrate (mg/L) | 67.5 ± 4.17 | 5.45 ± 0.52 | 7.79 ± 1.05 | 3.25 ± 0.42 | 4.50 ± 0.48 | 50 |
| **14** | Nitrite (mg/L) | 6.96 ± 0.95 | 0.45 ± 0.04 | 1.31 ± 0.32 | 0.27 ± 0.02 | 0.65 ± 0.04 | 3 |
| **15** | Sulphate (mg/L) | 85.7 ± 4.53 | 5.34 ± 0.17 | 9.17 ± 0.98 | 3.17 ± 0.14 | 8.37 ± 1.05 | 500 |
| **16** | Phosphate (mg/L) | 27.4 ± 2.57 | 4.63 ± 0.15 | 10.0 ± 0.12 | 2.18 ± 0.21 | 3.34 ± 0.68 | ≤ 5 |
| **17** | Chloride (mg/L) | 348 ± 5.17 | 19.5 ± 2.12 | 24.5 ± 2.04 | 13.6 ± 1.16 | 20.5 ± 1.54 | 250 |
| **18** | Oil & Grease (mg/L) | 48.7 ± 2.08 | 1.73 ± 0.07 | 15.8 ± 2.14 | 0.77 ± 0.05 | 1.65 ± 0.84 | ≤ 10 |

**EC:** Electrical conductivity, **SW Ctrl:** Surface water Control, **GW Ctrl:** Groundwater Control, **SW:** Surface Water, **GW:** Ground Water, **L:** Leachate, **WHO STD**: Standard

**Physicochemical Characteristics of Surface Water, Groundwater and Leachate**

The physicochemical characteristics of leachate, surface water, groundwater, and their corresponding control samples collected around the Brunelli, Bamikemo, and Lipanu municipal dumpsites are presented in Tables 5a–5c. For most of the physicochemical characteristics analyzed, it was seen that

the leachate had the highest concentrations, followed by the surface water and groundwater from the affected zones, whereas the control samples had the lowest concentrations. This demonstrates that the municipal dumps are the major sources of the pollutant load in the surrounding water bodies. Moreover, the surface water contained higher concentrations of various contaminants as compared to the groundwater from the same zones, which suggests that the surface water receives pollution from the dumps faster through surface runoff as opposed to the groundwater through infiltration. Similar contamination patterns have been reported for municipal dumpsites in other developing regions, where contaminant migration is controlled by rainfall, local hydrogeological conditions, and the physicochemical characteristics of the waste materials (Alao et al., 2023; Odoh et al., 2024).

Water temperature showed only minor variation among the leachate, impacted water samples, and their respective control samples across the three dumpsites. Surface water temperatures ranged from 25.7 to 27.5 °C, whereas groundwater temperatures varied between 27.4 and 28.5 °C. The relatively narrow temperature range observed suggests that leachate infiltration had only a limited influence on the thermal characteristics of the investigated water bodies. Nevertheless, the recorded temperatures are favourable for microbial metabolism and biochemical processes involved in the decomposition of municipal solid waste, thereby promoting the generation of leachate and the transformation of dissolved organic matter. Similar temperature ranges have been reported in tropical aquatic environments affected by municipal waste disposal, where ambient climatic conditions exert a greater influence on water temperature than localized contamination sources (Alao et al., 2023).

The pH of the studied water samples was found to be slightly acidic to slightly alkaline throughout the three dumpsites. The pH of surface water had variations from 6.57 to 8.08 while groundwater pH was from 5.95 to 6.87. Majority of the water samples analyzed fell within the WHO guideline recommendation for drinking water which is 6.5-8.5 (WHO, 2022). However, groundwater collected around Bamikemo and Lipanu dumpsites were noted to have slightly acidic properties. This could have been caused by the infiltration of groundwater with leachate that has organic acids resulting from the biodegradation process of municipal wastes by microbes in addition to other biogeochemical reactions taking place in the subsurface environment. Environmental-wise, slightly acidic properties are crucial since they lead to an increase in the mobilization of trace metals due to easy dissolution. This finding is in agreement with the high concentrations of metals like Pb, Fe, Mn, Ni, and Co recorded in this study. Moreover, earlier studies indicated that acidic leachate was one of the major factors responsible for the increased mobility of heavy metals in the groundwater of municipal dumpsites (Odoh et al., 2024).

The EC, TDS, TS, alkalinity, total hardness, and chloride showed a relatively similar pattern of spatial distribution in the three dumpsites with a clear enrichment in terms of their higher concentration in the surface water and groundwater affected by the presence of the dumpsites compared to their controls.

In the surface water, the EC varied from 429-452 µS/cm in the controls to 675-865 µS/cm in the impacted sites, while for the groundwater, the variation was from 313-337 µS/cm in the controls to 427-702 µS/cm in the impacted sites. Even though all the readings of EC were below the guideline limit of 1500 µS/cm stipulated by WHO for drinking water quality (WHO, 2022), the significant rise above the controls is attributable to higher amounts of ions in the water resulting from the migration of leachate. Similarly, TDS showed an increase from its controls to a level below the allowable limit of 1000 mg/L set by the WHO. The reason why TDS rises significantly alongside EC is that electrical conductivity is mainly determined by dissolved ionic species in water.

The increases in TS, alkalinity, hardness, and chloride further underscore the impact of leachate on the receiving water bodies. Increase in TS shows that there is an increase in loading of dissolved and suspended solids, while the increase in alkalinity and hardness is attributed to the enrichment of

bicarbonates, carbonates, calcium, and magnesium due to decomposition of municipal waste and dissolution of minerals. The same applies to increases in chloride, which can be used as evidence of leachate contamination since it is highly soluble and conserved chemical that easily migrates through runoff and infiltration without being reduced. These findings confirm the fact that continuous disposal of municipal waste leads to progressive enrichment of ionic content of surface and groundwater around the dumpsites under study. Increases in EC and TDS related to leachate migration have also been reported in municipal dumpsites in Nigeria and other developing nations (Alao et al., 2023; Yahaya et al., 2024).

Total Suspended Solids (TSS) and turbidity generally had lesser value compared to most other physicochemical variables assessed in the study area. Even though TSS values did not exceed the acceptable limits in either the impacted or control water samples, an increase was recorded in turbidity in the surface water and ground water samples near the municipal dumpsites. This may be attributed to the introduction of suspended organic materials, soil particles, colloidal substances, and other suspended particles emanating from the decaying municipal waste in the surrounding environment. Turbidity is an important environmental parameter as it results in reduced light penetration and hinders photosynthesis in aquatic environments; it also favors the transport of organisms or pollutants bound to the suspended solids (WHO, 2022). In this study, the relatively lower values of TSS in tandem with higher values of EC and TDS imply that a significant amount of contaminant transport happened in dissolved state, though there was contamination by suspended materials as well.

From the findings on DO, $BOD_5$ and COD, it can be concluded that there is considerable organic contamination in the water bodies that are affected by the dumpsites studied. Leachate samples from all three dumpsites were found to have very low levels of dissolved oxygen (1.55-1.65 mg/L) with relatively high $BOD_5$ (50.2-61.7 mg/L) and COD (600-622 mg/L), thus showing considerable microbial breakdown of easily degradable organic matter in the waste material. In general, the affected surface water and groundwater had relatively higher values of $BOD_5$ and COD than their respective control samples. High $BOD_5$ is an indication that there is a higher rate of oxygen utilization in the decomposition of the organic material, while the increase in COD suggests that the affected waters contain oxidizable organic and inorganic substances. The increase in both $BOD_5$ and COD values, alongside the reduction in dissolved oxygen content, clearly demonstrate the degradation of water quality as a consequence of long-term leachate movement from the municipal dumps. There are similar reports on the deterioration of water quality in relation to waterbodies located near active dumpsites as a consequence of increased organic loading (Alao et al., 2023; Odoh et al., 2024).

Composition of nutrients in the water tested also provides proof of the impact of municipal landfill site leachates on the surrounding aquatic ecosystem. Higher concentrations of nitrate ($NO_3^-$), nitrite ($NO_2^-$), sulphate ($SO_4^{2-}$), and phosphate ($PO_4^{3-}$) were observed in the impacted surface water and groundwater samples compared to the respective control samples in the three sampling areas, pointing to increasing nutrient pollution due to leachate dispersion in the surroundings. Despite nitrate concentrations being lower than the WHO guideline value of 50 mg $L^{-1}$ for drinking-water, the increased levels of nitrate in the impacted samples suggest that there was a mineralization of nitrogenous organic matter with the release of inorganic forms of nitrogen. Nitrite values were comparatively higher in the Brunelli surface water sample when compared to the other sampling locations, suggesting an ongoing process of nitrogen cycle and recent organic contamination. Sulphate values were comparatively higher in the impacted waters, due to the dissolving of sulphate-containing chemicals, and microbial degradation of organic compounds within the dump sites. Phosphate values were relatively higher in the Lipanu surface water sample (10.0 mg $L^{-1}$) which suggests a high loading of phosphorous due to the decomposition of

domestic wastes, food waste, detergents, and phosphate-rich wastes. This enrichment of nutrients is significant since it leads to the eutrophication of water bodies through excessive algal growth, which increases microbial activities and consequently lowers the levels of dissolved oxygen in the water body. Similar patterns of nutrient enrichment due to municipal dumpsite leachate have been documented in other tropical areas due to prolonged disposal of waste in the dump sites (Alao et al., 2023; Odoh et al., 2024).

The amount of oil and grease in the water samples varied from one sampling point to another based on the type of waste and the degree of spread of the leachates from the three municipalities. High amounts were obtained in the samples collected at the surface waters surrounding the Bamikemo (15.5 mg $L^{-1}$) and Lipanu (15.8 mg $L^{-1}$) dumpsites and also in the sample collected at the Brunelli (12.8 mg $L^{-1}$) groundwater site. All these amounts were above the maximum limit of 10 mg $L^{-1}$ recommended by NESREA for the discharge of surface water and indicated that the sources of contamination were the hydrocarbons in municipal solid waste, such as lubricating oils, plastics, and petroleum products. The environmental importance of the existence of these hydrophobic substances lies in the fact that they can create surface films which limit oxygen diffusion through the water-air interface, hence limiting the amount of dissolved oxygen in the water. Moreover, the presence of oil can negatively impact the aesthetic value of the water as well as making it less suitable for domestic use. The high levels of oil and grease found in this study serve as additional proof of contamination of water with leachates and are consistent with the higher values of $BOD_5$ and COD found in the contaminated water, implying severe pollution with organic material.

Comparing the three dumpsites investigated, the highest levels were usually recorded by Brunelli in most physicochemical parameters including nitrate, nitrite, chloride, dissolved ions, and indicators of organic pollutants. This may be attributed to the longer time it has been in use since it favored the generation of more leachate and consequently more contaminants being mobilized in the surrounding water bodies. Similar findings have been made in cases of older municipal dumpsites where prolonged use led to a higher loading of contaminants in the surface and groundwater bodies (Alao et al., 2023).

In general, from the physicochemical analysis conducted, the leachate generated in the studied dumpsites has had a negative impact on the quality of surrounding water bodies. From the higher levels obtained in the polluted samples compared to the control samples, it can be deduced that surface runoff was the main pollutant pathway whereas groundwater pollution involved slow leachate infiltration in the underground.

Table 6a: Metal concentration (mg/L) in water and leachate around Brunelli dumpsite.

| | L | SW Ctrl | SW | GW Ctrl | GW | STD |
|---|---|---|---|---|---|---|
| **Na** | 533 ± 7.61 | 52.4 ± 4.65 | 160 ± 5.42 | 60.5 ± 2.81 | 180 ±4.30 | - |
| **Mg** | 11.6 ± 1.17 | 7.32 ± 1.40 | 10.4 ± 1.18 | 6.22 ± 1.15 | 10.50 ± 1.20 | - |
| **K** | 115 ± 3.26 | 24.54 ± 1.52 | 125 ± 3.67 | 30.1 ± 0.85 | 140.44 ± 3.50 | - |
| **Ca** | 165 ± 13.4 | 38.36 ± 5.42 | 85.1 ± 2.60 | 44.2 ± 3.21 | 75.34 ± 3.62 | - |
| **Pb** | 3.55 ± 0.16 | 0.18 ± 0.21 | 0.46 ± 0.33 | 0.16 ± 0.03 | 0.41 ± 0.03 | 0.01 |
| **Cd** | 0.55 ± 0.08 | BDL | BDL | BDL | BDL | 0.003 |
| **Cr** | 4.32 0.25 | BDL | BDL | BDL | BDL | 0.05 |
| **Cu** | 2.76 ± 0.46 | BDL | 0.14 ± 0.02 | BDL | 0.08 ± 0.02 | 2.00 |
| **Mn** | 3.42 ± 0.15 | 0.08 ± 0.01 | 1.24 ± 0.06 | 0.07 ± 0.01 | 1.05 ± 0.03 | 0.10 |
| **Zn** | 2.64 ± 0.37 | 0.46 ± 0.03 | 1.99 ± 0.07 | 0.32 ± 0.02 | 0.82 ± 0.22 | 3.00 |

| | L | SW Ctrl | SW | GW Ctrl | GW | STD |
|---|---|---|---|---|---|---|
| **Fe** | 12.8 ± 0.23 | 0.52 ± 0.03 | 0.75 ± 0.01 | 0.44 ± 0.05 | 0.65 ± 0.14 | 0.30 |
| **Ni** | 2.26 ± 0.34 | 0.73 ± 0.05 | 1.05 ± 0.03 | 0.65 ± 0.06 | 0.45 ± 0.10 | 0.07 |
| **Co** | 4.34 ± 0.82 | BDL | 0.65 ± 0.01 | BDL | 1.33 ± 0.82 | 0.05 |

**L:** Leachate, **SW Ctrl:** Surface water Control, **GW Ctrl:** Groundwater Control, **SW:** Surface Water, **GW:** Ground Water, **BDL:** Below Detectable Limit, **WHO STD**: Standard.

Table 6b: Metal concentration (mg/L) in water and leachate around Bamikemo dumpsite.

| | L | SW Ctrl | SW | GW Ctrl | GW | STD |
|---|---|---|---|---|---|---|
| **Na** | 472 ± 4.55 | 124 ± 2.54 | 190 ± 4.28 | 100 ± 2.48 | 110 ± 2.81 | - |
| **Mg** | 16.0 ± 1.05 | 7.42 ± 0.83 | 11.4 ± 1.19 | 5.34 ± 0.41 | 10.7 ± 1.04 | - |
| **K** | 74.3 ± 2.13 | 37.53 ± 2.56 | 74.8 ± 3.75 | 40.4 ± 3.34 | 83.2 ± 1.83 | - |
| **Ca** | 175 ± 3.75 | 42.54 ± 2.43 | 69.1 ± 4.01 | 46.3 ± 2.81 | 72.2 ± 3.21 | - |
| **Pb** | 2.06 ± 0.26 | 0.12 ± 0.03 | 0.32 ± 0.02 | 0.08 ± 0.01 | 0.17 ± 0.01 | 0.01 |
| **Cd** | 0.08 ± 0.01 | BDL | BDL | BDL | BDL | 0.003 |
| **Cr** | 2.37 ± 0.58 | BDL | BDL | BDL | BDL | 0.05 |
| **Cu** | 1.97 ± 0.24 | 0.10 ± 0.06 | 0.15 ± 0.03 | BDL | 0.05 ± 0.01 | 2.00 |
| **Mn** | 2.17 ± 0.05 | 0.04 ± 0.04 | 0.11 ± 0.02 | 0.02 ± 0.01 | 0.76 ± 0.18 | 0.10 |
| **Zn** | 2.20 ± 0.11 | 0.58 ± 0.03 | 1.51 ± 0.08 | 0.46 ± 0.05 | 1.06 ± 0.09 | 3.00 |
| **Fe** | 6.74 ± 0.52 | 2.56 ± 0.13 | 8.07 ± 0.15 | 1.46 ± 0.24 | 5.90 ±0.84 | 0.30 |
| **Ni** | 1.27 ± 0.21 | 0.24 ± 0.02 | 1.02 ± 0.01 | 0.14 ± 0.03 | 0.67 ± 0.08 | 0.07 |
| **Co** | 0.26 ± 0.04 | 0.12 ± 0.01 | 3.33 ± 0.67 | 0.04 ± 0.01 | 0.10 ± 0.02 | 0.05 |

**L:** Leachate, **SW Ctrl:** Surface water Control, **GW Ctrl:** Groundwater Control, **SW:** Surface Water, **GW:** Ground Water, **BDL:** Below Detectable Limit, **WHO STD**: Standard

Table 6c: Metal concentration (mg/L) in water and leachate around Lipanu dumpsite.

| | L | SW Ctrl | SW | GW Ctrl | GW | STD |
|---|---|---|---|---|---|---|
| **Na** | 440 ± 7.72 | 124 ± 1.32 | 170 ± 4.12 | 130 ± 2.04 | 187 ± 11.0 | - |
| **Mg** | 20.5 ± 2.10 | 2.23 ± 0.32 | 9.73 ± 0.47 | 4.35 ± 0.82 | 10.1 ± 0.72 | - |
| **K** | 62.8 ± 2.82 | 48.6 ± 2.34 | 66.5 ± 2.25 | 42.2 ± 2.26 | 55.3 ± 3.18 | - |
| **Ca** | 192 ± 4.45 | 32.4 ± 2.56 | 58.0 ± 3.11 | 39.6 ± 2.12 | 62.1 ± 6.77 | - |
| **Pb** | 2.33 ± 0.46 | 0.15± 0.01 | 0.25 ± 0.04 | 0.12 ± 0.02 | 0.13 ± 0.06 | 0.01 |
| **Cd** | 0.16 ± 0.04 | BDL | BDL | BDL | BDL | 0.003 |
| **Cr** | 2.97 ± 0.52 | BDL | BDL | BDL | BDL | 0.05 |
| **Cu** | 1.66 ± 0.06 | 0.08 ± 0.01 | 0.24 ± 0.05 | 0.03 ± 0.01 | 0.14 ± 0.24 | 2.00 |
| **Mn** | 0.85 ± 0.03 | 0.04 ± 0.01 | 2.95 ± 0.17 | 0.06 ± 0.01 | 0.45 ± 0.15 | 0.10 |
| **Zn** | 1.07 ± 0.02 | 1.12 ± 0.23 | 1.76 ± 0.45 | 1.08 ± 0.04 | 1.49 ± 0.05 | 3.00 |
| **Fe** | 7.31 ± 0.48 | 0.57 ± 0.03 | 1.03 ± 0.04 | 0.76 ± 0.06 | 2.24 ± 0.12 | 0.30 |
| **Ni** | 0.53 ± 0.08 | 0.28 ± 0.21 | 0.65 ± 0.07 | 0.22 ± 0.23 | 0.57 ± 0.12 | 0.07 |
| **Co** | 0.74 ± 0.05 | 0.05 ± 0.01 | 3.82 ± 0.25 | 0.03 ± 0.01 | 0.16 ± 0.04 | 0.05 |

**L:** Leachate, **SW Ctrl:** Surface water Control, **GW Ctrl:** Groundwater Control, **SW:** Surface Water, **GW:** Ground Water, **BDL:** Below Detectable Limit, **WHO STD**: Standard

**Major Cations and Heavy Metals in Surface Water, Groundwater and Leachate**

The concentrations of the major cations and heavy metals in the leachates, surface waters, groundwaters and their corresponding control samples in the vicinity of the Brunelli, Bamikemo and Lipanu waste disposal sites have been tabulated in Table 6a-6c. A clear pattern was found to exist at the three sites, where the leachates contained the highest concentrations of most of the metals, the surface waters and groundwaters had the second highest concentrations, while the control samples had the lowest concentrations of the metals. This is an indication that leachate from the municipal waste disposal site is the major source of the dissolved metals in the adjacent water bodies.

It is evident that the dominant cations (Na, K, Mg and Ca) had consistently high concentrations in the contaminated surface and ground waters relative to their corresponding controls at all the sampled dumpsites. Although there are no WHO guidelines for the acceptable levels of sodium, potassium, magnesium and calcium in drinking water with regard to human health effects, an increase in the concentrations of these ions is commonly seen as evidence of increased mineralisation caused by the contamination of leachates. The significantly high concentrations of sodium ion in the contaminated surface (160-190 mg/L) and ground (110-187 mg/L) waters indicate a great ionic enrichment due to dissolution of inorganic materials from municipal solid waste.

Similar increments were noted for potassium, calcium, and magnesium ions, signifying the significance of decomposed domestic waste, food waste, building debris, ash, and other inorganic matter in contributing to the ionic make-up of the surrounding waters. The high amounts of these major ions support the results in electrical conductivity and total dissolved solids seen in the physicochemical analysis and reinforce the impact of dumpsite leachate on the mineralization of water (Alao et al., 2023; Odoh et al., 2024).

There was variability in the concentration of toxic heavy metals at different sites; however, there was evidence of contamination by leachate in all of them. The concentrations of lead in impacted surface water (0.25-0.46 mg/L) and groundwater (0.13-0.41 mg/L) greatly exceeded the permissible limit set by WHO of 0.01 mg/L. Lead is a non-essential and highly toxic metal, whose occurrence in water bodies is normally attributed to battery, electronic waste, paints, plastic and metal scrap littered at municipal dumpsites. There is a serious public health concern regarding the elevated lead levels recorded in this study because lead poisoning leads to neurotoxicity, kidney damage and development impairment especially in children. This observation is consistent with other studies conducted at active municipal dumpsites whereby continuous waste disposal led to leakage of heavy metals into surface water and groundwater through leachate (Alao et al., 2023; Yahaya et al., 2024).

Cadmium and chromium were not detectable in any surface water or groundwater samples, but both cadmium and chromium were detected in the leachate samples from both dumpsites. This indicates that while the metals are produced within the waste material, they might currently be held within the waste and surrounding soils by adsorption and precipitation. Nevertheless, their occurrence in leachate indicates a potential long-term contamination risk because changes in pH, redox conditions and groundwater chemistry may enhance their future mobilisation into surrounding water resources. Continuous environmental monitoring is therefore necessary to detect any subsequent release of these highly toxic metals into potable water sources.

Among the transition metals investigated, manganese (Mn), iron (Fe), nickel (Ni), and cobalt (Co) were consistently detected at higher concentrations in the impacted water samples than in their corresponding controls, indicating substantial enrichment associated with municipal dumpsite leachate. Manganese concentrations reached 2.95 mg $L^{-1}$ in surface water and 1.05 mg $L^{-1}$ in groundwater, while iron concentrations ranged from 0.65 to 8.07 mg $L^{-1}$, exceeding commonly accepted aesthetic and operational guideline values for drinking water. Nickel concentrations (0.45–1.05 mg $L^{-1}$) also

exceeded the World Health Organization (WHO) health-based guideline value of 0.07 mg $L^{-1}$ (WHO, 2022), whereas cobalt concentrations were consistently higher in the impacted samples than in the corresponding controls. The high levels of these metals can be attributed to the weathering and corrosion of metallic waste, disposed batteries, domestic appliances, automobiles, among others. Other than interfering with the aesthetics of the water because of metallic taste, staining, and discolored water, there can be potential health problems like neurological disorders and renal damage when people are exposed to these high levels of metals for long periods. The same observations have been made around active municipal dump sites due to the formation of leachates which lead to contamination of heavy metals in surface water and groundwater (Alao et al., 2023; Yahaya et al., 2024).

The levels of copper and zinc were found to be considerably lower in comparison with the rest of the heavy metals being studied. The copper concentration in the water samples was below the acceptable value of 2.0 mg/L as set by WHO standards, whereas zinc concentrations, though showing enrichment as compared to the control samples, were still below the acceptable limit of 3.0 mg/L. The lower concentration of the mentioned metals can be attributed either to limited contamination with municipal wastes or limited mobility under the current hydrogeochemical conditions. However, the steady elevation above the background levels suggests that these heavy metals continue to enrich in water bodies due to leaching. In the tropical environment, Cu and Zn remain trapped within the waste body or in the surrounding soils through complexation with organic matter and precipitation as relatively insoluble carbonates (Alao et al., 2023).

Among the three dumpsites studied, higher concentrations of most of the heavy metals and major cations were observed at the Brunelli site, especially in the case of lead, nickel, manganese and sodium, whereas Bamikemo had unusually high concentrations of iron and Lipanu had the highest manganese and cobalt concentrations in contaminated surface waters. Such discrepancies may well have been caused by age difference in the dumpsites as well as variation in composition, volume and operating time of the wastes. Brunelli is the major dumpsite of Ile-Oluji and has acted as such for decades and has received domestic, commercial and institutional wastes over time. Such accumulation and decomposition of wastes would create leachate that is richer in metals.

In summary, the findings indicate that leachate from a municipal dumpsite has significantly influenced the metal content in the nearby surface water and groundwater. The higher concentrations found in surface water than in groundwater suggest that surface runoff continues to be the main mechanism of transportation of metals in solution, while the contaminated groundwater is indicative of the gradual leaching of metal-containing leachate through the soil. Exceedances of WHO guidelines for the concentrations of lead, iron, nickel, cobalt, and manganese in the water bodies in question clearly show that there are health concerns associated with the use of these water sources.

Table 7a: Microbial properties of Surface Water, Groundwater, and Leachate around Brunelli dumpsite.

| Microbes (cfu/ml) | L | SW Ctrl | SW | GW Ctrl | GW |
|---|---|---|---|---|---|
| **Coliform** | 805.00 ± 5.00 | 112.50 ± 4.25 | 1040.00 ± 25.5 | 64.70 ± 1.53 | 956.00 ± 2.08 |
| **E-coli** | 405.00 ± 5.69 | 48.20 ± 2.10 | 520.00 ± 3.35 | 33.10 ± 4.65 | 479.00 ± 4.76 |
| **Salmonela** | 450.00 ± 0.58 | 18.60 ± 1.15 | 201.00 ± 1.53 | 12.30 ± 0.58 | 153.00 ± 0.58 |

Table 7b: Microbial properties of Surface Water, Groundwater, and Leachate around Bamikemo dumpsite.

| Microbes (cfu/ml) | L | SW Ctrl | SW | GW Ctrl | GW |
|---|---|---|---|---|---|
| **Coliform** | 750.00 ± 10.58 | 120.40 ± 3.15 | 653.00 ± 2.89 | 69.70 ± 0.58 | 523.00 ± 2.89 |
| **E-coli** | 375.00 ± 6.69 | 52.10 ± 1.85 | 328.00 ± 9.94 | 35.10 ± 4.89 | 263.00 ± 8.01 |
| **Salmonela** | 395.00 ± 4.58 | 15.80 ± 0.92 | 123.00 ± 1.00 | 10.70 ± 1.15 | 19.30 ± 1.15 |

Table 7c: Microbial properties of Surface Water, Groundwater, and Leachate around Lipanu dumpsite

| Microbes (cfu/ml) | L | SW Ctrl | SW | GW Ctrl | GW |
|---|---|---|---|---|---|
| **Coliform** | 726.00 ± 1.53 | 118.50±2.10 | 2263.00 ± 2.65 | 57.00 ± 1.00 | 726.00 ± 1.53 |
| **E-coli** | 364.00 ± 2.52 | 44.20±1.45 | 1132.00 ± 3.11 | 29.00 ± 3.60 | 364.00 ± 1.75 |
| **Salmonela** | 424.00 ± 0.58 | 21.10±0.85 | 501.00 ± 1.00 | 18.30 ± 0.58 | 287.00 ± 1.73 |

**Microbiological Quality of Surface Water, Groundwater and Leachate**

Microbiological properties of the leachate, surface water, groundwater and their respective control samples obtained from the vicinity of the Brunelli, Bamikemo and Lipanu dumpsites are shown in Tables 7a-7c. It is evident from the data provided in the tables that microbial counts were consistently high for leachate and contaminated water samples compared to control samples in all the three tested dumpsites. Higher levels of total coliforms, E. coli and Salmonella spp. found in both surface water and groundwater samples demonstrate that the leachate formed in the municipal dumpsites was responsible for microbial contamination of nearby water bodies, as well as fecal pollution of the aquatic environment (Yahaya et al., 2024). Surface water contained a significantly greater number of microbes compared to groundwater, which suggests that surface runoff was the major transport mechanism for microorganisms from the dumpsites into the nearby waters, while groundwater contamination was most likely associated with the gradual seepage of the leachate. The similar trends have been observed for the other active municipal dumpsites, as the leachate movement resulted in the introduction of pathogens into the nearby surface and groundwater (Alao et al., 2023; Odoh et al., 2024).

Counts of total coliforms were found to be the most prevalent among all microbial indicators tested at all the examined dumpsites. In surface water samples, total coliform counts varied from 653 to 2263 CFU $mL^{-1}$, whereas, in groundwater samples, counts ranged from 523 to 956 CFU $mL^{-1}$, which is much higher than those recorded in the corresponding control samples. An extremely high number of coliforms in the Lipanu surface water sample (2263 CFU $mL^{-1}$) clearly indicates the existence of intense microbiological pollution related to continuous leachate discharge into the aquatic environment. Total coliforms are often used as indicator organisms in sanitary water quality tests due to the fact that their presence indicates contamination by organic materials and the potential presence of pathogens. Even though total coliforms do not represent pathogenic microorganisms, they serve as an indicator of poor hygiene conditions and the presence of pathogens in water (WHO, 2022).

Presence of E. coli in all contaminated surface water and groundwater samples makes the case of recent faecal contamination more certain since E. coli bacteria is mainly derived from the intestine of warm-blooded animals. Count values of E. coli in surface water varied from 328 to 1132 CFU $mL^{-1}$, while those in groundwater ranged between 263 and 479 CFU $mL^{-1}$, significantly higher compared to those of the controls. The maximum level of E. coli occurred in the Lipanu surface water, suggesting high faecal pollution around this dump site. The presence of E. coli in groundwater is especially noteworthy since groundwater is supposed to be protected from microbial contamination due to overlying soil layer. This means that natural ability of soil to attenuate any contaminants has been weakened due to prolonged infiltration of leachate through soil.

In the same manner, Salmonella was found to be present in all leachate and impacted waters, with surface water having counts ranging from 123 to 501 CFU $mL^{-1}$ while groundwater had 19.3 to 287 CFU $mL^{-1}$. While it is true that groundwater had lesser counts of the pathogenic bacteria compared to the surface water, the presence of Salmonella in groundwater presents an equally grave health problem due to the fact that it means contamination of potable sources by microorganisms. The high counts of Salmonella found in the Lipanu surface water and Brunelli groundwater serve as another indication of

the effects of unregulated municipal waste dumping on the quality of the environment. These could come from decaying garbage, animal waste, sewage-contaminated waste, among others.

According to the World Health Organization (2022) guidelines on drinking-water quality, drinking water meant for human consumption should be free from all detectable levels of E. coli and thermotolerant coliforms in every 100 mL sample collected while pathogenic organisms like Salmonella should not be present (World Health Organization, 2022). The presence of these microbial organisms in the surface water and groundwater is, therefore, an indication that the water sources being studied are unsuitable for drinking due to the presence of these harmful microorganisms. Consumption of this water can increase the incidence of waterborne illnesses such as gastroenteritis, typhoid fever, dysentery and other enteric infections.

Of the three dumping sites that were studied, Lipanu showed higher microbial contamination levels in the surface water, especially of the total coliforms, E. coli, and Salmonella bacteria, while Brunelli showed higher microbial numbers in the groundwater samples. This could possibly be attributed to the differences in the nature of waste, age of the dumping site, hydrology, and closeness of the neighboring water sources to the active dumping areas. However, the high levels of microbial contamination detected in the affected water compared to those of the control definitely point out to the fact that municipal dumping sites are sources of pathogens that can contaminate water.

Conclusively, the microbiological results support those obtained from the physicochemical and heavy metals analyses by giving more insight on how uncontrolled dumping sites have seriously affected the quality of water resources in the vicinity. The combination of high microbial levels, higher levels of organics pollution, as well as high levels of dissolved pollutants suggest that the leachate produced from the said dumping sites has contaminated the surface and ground waters.

Table 8: Water Quality Index (WQI) of surface water and groundwater around the investigated dumpsites.

| Sample | WQI | Classification | Rank |
|---|---|---|---|
| **Brunelli SW** | 300.01 | Unsuitable | 1 |
| **Brunelli GW** | 279.03 | Unsuitable | 2 |
| **Lipanu SW** | 276.41 | Unsuitable | 3 |
| **Bamikemo SW** | 221.28 | Unsuitable | 4 |
| **Lipanu GW** | 116.32 | Unsuitable | 5 |
| **Bamikemo GW** | 110.15 | Unsuitable | 6 |

**Note:** Water quality classification based on the Weighted Arithmetic Water Quality Index: Excellent (0–25), Good (26–50), Poor (51–75), Very Poor (76–100), and Unsuitable for drinking (>100), adapted from Brown et al. (1972) and Tiwari and Mishra (1985).

**Water Quality Index (WQI)**

Table 8 shows the WQI values for surface water and groundwater near the Brunelli, Bamikemo and Lipanu municipal dumpsites. The calculated WQI values were between 110.15 and 300.01, where all the sampled water values exceeded the critical value of 100, which means that they cannot be used for drinking water purposes following the criteria for the weighted arithmetic WQI evaluation. This clearly shows a serious level of contamination of water quality due to the combined effect of the physicochemical substances present as a result of the municipal dumpsite leachates. In contrast to the evaluation of individual water quality indicators, the WQI combines several physicochemical attributes

in one numeric value for a comprehensive evaluation of water suitability for human use (Tyagi et al., 2013; Egbueri et al., 2022a).

The water sources that were studied include: Brunelli surface water, which had the highest WQI value (300.01); Brunelli groundwater (279.03); Lipanu surface water (276.41); Bamikemo surface water (221.28); Lipanu groundwater (116.32); Bamikemo groundwater (110.15). In this context, the higher values of WQI around Brunelli and Lipanu suggest greater deterioration of water quality in those places. This is because of the age of dumpsite, nature of the wastes disposed, amount of waste and duration of operation that determines the volume and chemical composition of the leachate formed. Brunelli, being the primary municipal dumpsite for Ile-Oluji for several decades is expected to contain mixed municipal wastes that can produce mature leachate full of salts and nutrients among other substances.

The higher WQI scores were primarily attributed to the joint effect of high levels of conductivity, total dissolved solids, nitrite, phosphate, chloride, and other dissolved ionic compounds, along with high organic pollutant indices present in the affected water sources. Despite some of the individual pollutants being within the permissible WHO guidelines, the joint occurrence of multiple pollutants caused an increase in the pollution load of the water source, thereby indicating that even the individual compliance of the pollutants with the prescribed guidelines does not make a water source fit for consumption. This demonstrates the utility of WQI as a comprehensive index that considers the cumulative impacts of multiple pollutants in a water source, rather than individual parameters. This phenomenon has been noted in several studies conducted recently, which demonstrated increased conductivity, enrichment in nutrients, and total dissolved solids as the primary reasons behind higher WQI scores of the affected water bodies owing to the leachate of municipal dumpsites (Egbueri et al., 2022b; Boateng et al., 2023). Surface water always had higher values of WQI than the respective samples of groundwater from the three dumpsites due to the higher vulnerability of surface water to pollution. The reason is that the surface water is characterized by the high vulnerability to pollution as a result of surface runoff that carries pollutants directly to the nearby streams and drainage ditches. In turn, pollution of groundwater is mostly a result of slow movement of the leachate through the unsaturated soil zone, when some natural protective mechanisms, such as adsorption, ion exchange, degradation by microorganisms, etc., may decrease its mobility for some time. Still, higher values of WQI of groundwater indicate that natural protection mechanisms were not fully effective.

The outcomes of the WQI support the individual physicochemical tests mentioned above, especially the increased levels of electrical conductivity, dissolved solids, nutrients, and organic pollutants noted in the affected water samples compared to their respective control samples. All these factors reflect increasing levels of mineralization, nutrient enrichment, and organic pollution due to ongoing production of leachates in the municipal dumpsites. Such a decline in water quality is not an unusual phenomenon, since there have been reports of the same occurring in active municipal dumpsites in many developing nations, where there was uncontrolled disposal of solid waste, which led to WQI levels exceeding the permissible levels for drinking water (Egbueri et al., 2022b; Boateng et al., 2023; Rani et al., 2024).

In conclusion, the results obtained from the analysis of WQI clearly show that the municipal dumpsite leachates have had an adverse effect on the quality of surface and ground waters surrounding the studied dumpsites. From the classification of water samples as unfit for consumption, it is clear that there may be serious public health threats associated with the use of such water. This calls for proper solid waste management practices, construction of sanitary landfill sites in place of the currently existing open dumpsites, leachate collection and treatment, and constant monitoring of ground water quality.

Table 9: Heavy Metal Pollution Index (HPI) of surface water and groundwater around the investigated dumpsites.

| Sample | HPI | Heavy Metal Pollution Status |
|---|---|---|
| **Brunelli SW** | **1037.67** | Critical Pollution |
| **Brunelli GW** | **963.79** | Critical Pollution |
| **Bamikemo SW** | **964.76** | Critical Pollution |
| **Bamikemo GW** | **402.25** | Critical Pollution |
| **Lipanu SW** | **890.29** | Critical Pollution |
| **Lipanu GW** | **308.98** | Critical Pollution |

**Note:** HPI values **<100** indicate low heavy metal pollution, whereas **HPI >100** indicates critical heavy metal pollution and water unsuitable for drinking due to heavy metal contamination.

**Heavy Metal Pollution Index (HPI)**

Table 9 shows the Heavy Metal Pollution Index (HPI) value of surface water and groundwater collected at the vicinity of the Brunelli, Bamikemo and Lipanu dumpsites. The HPI values obtained varied between 308.98 and 1037.67 with all the investigated water samples having higher values than the critical pollution index of 100 (Prasad & Bose, 2001). This shows high level of heavy metal pollution in the waters such that they cannot be used as potable water. The results show that leachate formation from the investigated municipal dumpsites has highly impacted the quality of surface water and groundwater.

In terms of the measured water resources, Brunelli surface water had the highest HPI score (1037.67), while Bamikemo surface water had the second-highest (964.76), followed by Brunelli groundwater (963.79), Lipanu surface water (890.29), Bamikemo groundwater (402.25), and Lipanu groundwater (308.98). It can be deduced that higher HPI scores obtained at Brunelli and Bamikemo suggest high metal contamination of these areas due to long-time waste disposal and constant production of leachate. Brunelli has functioned as one of the biggest landfills in the city of Ile-Oluji for more than 40 years. Consequently, various wastes have accumulated in this area and released toxic metals into the surroundings (Alao et al., 2023).

The increased values of HPI seen in this study were due to the high levels of Pb, Ni, Fe, Mn, and Co, some of which were higher than their permissible values in drinking water. This is because the permissible levels of these heavy metals are relatively low; thus, contributing to HPI (Mohan et al., 1996). The presence of all of them together in the environment is critical because prolonged exposure to them causes several health issues like neurological and renal disorders, developmental issues, and others, especially with untreated surface and groundwater being used for domestic purposes (WHO, 2022).

Water sources on the surface usually had higher HPI values than the groundwater sources, which is an indication of higher vulnerability to heavy metals contamination. This implies that water runoff on the surface is the major process used by leachate containing metals to enter the streams while groundwater contamination occurs as a result of slow infiltration of leachate into the subsurface (Odoh et al., 2024). While geochemical processes like adsorption, ion exchange, and precipitation may limit mobility of heavy metals in the subsurface, high HPI values recorded in all groundwater samples show that these processes are not enough to limit movement of metals (Rajkumar et al., 2020).

HPI determination corroborates the heavy metals' findings by providing evidence that the combination of different heavy metals causes more concern in the environment as compared to when the individual

metals are considered in their own right. While the levels of copper and zinc were still within the allowable limits, the high levels of Pb, Ni, Fe, Mn, and Co resulted in an HPI which was very much higher than the critical limit. In similar studies in areas with municipal dumping sites, high HPI values were obtained due to the continual production of leachates from the dumpsites and their resultant pollution of the surrounding water resources (Egbueri et al., 2022b; Boateng et al., 2023; Rani et al., 2024). From the HPI analysis, it is clear that the water sources examined have been heavily polluted by the heavy metals due to municipal waste disposal.

**Conclusion**

This study focused on the effects of leachate formed by the use of three active municipal dumpsites in the quality of the adjacent surface and ground waters in Ile-Oluji, Ondo State, Nigeria, through the investigation of their physicochemical properties, heavy metals concentrations, microbial analysis, Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI). It is clearly evident from this study that the open dumping practices have resulted in the contamination of water quality in and around these dumpsites.

The levels of dissolved ions, nutrient ions, organic pollutants and some heavy metals were higher than those present in the control samples, indicating the degradation of water quality over the time. The presence of total coliforms, Escherichia coli and Salmonella also indicated that there was microbial contamination in the studied water bodies due to faecal pollution, which could pose health hazards to humans. Despite the difference in the extent of water pollution at all the three dumpsites, the Brunelli dumpsite proved to have more influence on water pollution, mainly due to its longer use.

The calculated Water Quality Index showed that all the studied water samples were unsuitable for drinking, with the most contaminated surface water samples having the poorest water quality. Also, the Heavy Metal Pollution Index revealed that all the studied water samples surpassed the critical pollution limit, thus indicating a heavy metal contamination and that the polluted water samples were not safe for consumption without undergoing appropriate purification process. The combination of physicochemical, microbial, heavy metal, WQI, and HPI evaluation gave a clear insight into how much the leachate polluted the surrounding water samples.

In summary, the study clearly indicates the danger that the unregulated disposal of municipal solid wastes poses to surface water and shallow groundwaters in Ile-Oluji.

It is hence advisable for the existing open dumpsites to be gradually substituted by well-engineered sanitary landfills with proper leachate collection and treatment facilities. There should be regular testing of water quality in both the ground and surface water near municipal solid waste dumps in order to detect pollution at an early stage. The government agencies responsible for environmental regulations concerning waste disposal need to ensure that these rules are strictly adhered to. Public sensitization programs aimed at curbing illegal dumping of wastes should be strengthened. Additionally, households using wells in areas near municipal dumpsites need to ensure that their drinking water is subjected to the proper treatment. Future research should focus on the behavior of emerging pollutants in various seasons and the risks involved with prolonged exposure to such pollutants.

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