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### Physico-Chemical Quality of Groundwater in the Vicinity of Municipal Solid Waste Dump Sites in Osogbo, Southwestern, Nigeria

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#### Abstract

The escalating urbanization and industrialization in Osogbo, Southwestern Nigeria, have given rise to heightened apprehensions regarding the integrity of groundwater quality adjacent to municipal solid waste dump sites. This study endeavors to conduct a thorough and holistic evaluation of the physico-chemical parameters of groundwater in the proximity of these waste disposal sites. The investigation delves into the potential environmental repercussions and health risks associated with contemporary waste disposal practices in the region.

The comprehensive assessment encompasses a multifaceted analysis, with a primary focus on discerning the intricacies of pH levels, concentrations of heavy metals, and the presence of organic pollutants in groundwater. These parameters serve as critical indicators of water quality, reflecting the potential contamination emanating from anthropogenic activities. The study strategically selects sampling sites around municipal solid waste dump locations in Osogbo, ensuring a nuanced representation of the diverse groundwater conditions prevalent in the region.

Preliminary results illuminate notable disparities in pH

levels, indicating a potential influence from waste disposal practices. The identification of elevated concentrations of heavy metals, including lead and cadmium, raises alarms about the possible health implications for local communities reliant on this groundwater source. Furthermore, the detection of organic pollutants underscores the multifaceted nature of contamination, necessitating a comprehensive understanding of the pathways through which pollutants infiltrate groundwater.

The findings from this study serve as a clarion call for urgent intervention and strategic planning to address the challenges posed by improper waste disposal. The implications extend beyond environmental considerations to encompass public health and sustainable development. The elucidation of these physico-chemical parameters contributes vital insights for policymakers, environmental agencies, and community stakeholders, guiding the formulation of effective waste management strategies tailored to the unique conditions of Osogbo, Southwestern Nigeria.

**Keywords:** Groundwater, Solid Waste, Nigeria

#### 1. Introduction

Water stands as an indispensable necessity for human survival and is the most abundant natural resource on Earth's surface (Oyinloye and Jegede, 2004). Groundwater, filtered through overburden, stands out as the primary source of potable water and generally exhibits lower contamination levels compared to surface water (Aiyesanmi *et al.*, 2004). Despite its purity, groundwater faces potential contamination from leachates originating in municipal solid waste landfills, impacting both surface water and groundwater quality (Odukoya *et al.*, 2002).

Pollution arises when water from its original sources becomes tainted by domestic, industrial, or agricultural waste, rendering it unsuitable for its intended use. The substances responsible for these undesirable changes are termed "pollutants" (Ekpete, 2002). It is imperative to prevent groundwater pollution resulting from leachate infiltration through soil and rocks, a process that occurs within a defined radius from dump sites and may span many years. In regions where piped water is scarce, especially in both rural and urban areas with inadequate water supply systems, the importance of safeguarding groundwater becomes even more pronounced.

Water may harbor harmful substances detrimental to life, encompassing metals like mercury, lead, and cadmium, pesticides, organic toxins, and radioactive contaminants. While natural water sources inherently contain living organisms vital for biogeochemical cycles in aquatic ecosystems (Cambers and Ghina, 2005), certain microorganisms such as bacteria, protists, parasitic worms, fungi, and viruses can pose threats to human health if present in drinking water. The availability of water, coupled with its physical, chemical, and biological composition, plays a pivotal role in the ability of aquatic environments to sustain healthy ecosystems. As water quality and quantity deteriorate, organisms suffer, leading to the potential loss of ecosystem services (Carr and Neary, 2006).

The required quality of water for human use varies based on specific criteria. Drinking water demands the highest standards of purity, whereas water used for industrial processes may be of lesser quality (Carr and Neary, 2006). The quality necessary to maintain ecosystem health largely depends on natural background conditions. Some aquatic ecosystems exhibit resilience to substantial changes in water quality, while others are highly sensitive to even minor alterations in the physical and chemical makeup of water, resulting in the degradation of ecosystem services and loss of biological diversity. The gradual degradation of physical and chemical water quality due to human influences may not be immediately evident, and subtle adaptations of aquatic ecosystems to these changes may go unnoticed until a significant shift in ecosystem condition occurs. Regular monitoring of the biological, physical, and chemical components of aquatic ecosystems is crucial for detecting extreme situations where the ability of an ecosystem to return to its normal state is stretched beyond its limit.

Recognizing the quality status of groundwater is as crucial as assessing its quantity, as it aids in determining water suitability for various purposes. Variations in groundwater quality in any area are influenced by physicochemical parameters shaped by geological formations and anthropogenic activities (Elango *et al.*, 2005). The assessment of potential pollution sources impacting groundwater quality has garnered significant attention both in the past and present (Siasu, 2008).

Various significant sources of groundwater pollution have been identified, encompassing both anthropogenic and natural factors. These sources include leachate from municipal refuse dumpsites, industrial discharge (liquid waste), domestic waste, saltwater intrusion, application of agricultural chemicals, oil spillage, pipeline vandalism, and geological formations. These diverse origins introduce pollutants such as heavy metals, chlorinated hydrocarbons, phenols, cyanides, pesticides, major inorganic species, and bacteria into the groundwater (Yusuff, 2007).

The increasing population in Nigeria, estimated at about 140 million, highlights the challenge of improper waste disposal practices. Waste is often dumped recklessly without environmental considerations, especially in major cities like Osogbo in Osun State. Inadequate waste disposal schemes further exacerbate the situation (LAWMA, 2005).

Dumpsites in many cities witness the burning of collected wastes, destroying the organic components and oxidizing metals. The ashes left behind, enriched with metals, can percolate the soil, leading to groundwater pollution. Reclaiming land using decaying wastes from dumpsites is another common practice, contributing to the haphazard

disposal of considerable waste within residential areas. Landfills are recognized as a significant threat to groundwater resources (Fatta *et al.*, 1999).

Leachates from dumpsites constitute a major source of heavy metal pollution in both soil and aquatic environments. Nitrate pollution, particularly through rainwater percolation, poses health risks. High levels of nitrate can lead to the formation of nitrosamines, which are potentially carcinogenic. Toxicological studies indicate the adverse health effects of nitrate, including disturbances in blood-oxygen exchange, methemoglobinemia, and the blue baby syndrome.

Heavy metals, another class of pollutants, can adversely affect mental and neurological functions, alter metabolic processes, and induce dysfunction in various human body systems. Lead, for instance, at elevated levels, affects intellectual performance in children and impairs cognitive development in adults. Cadmium, another heavy metal, can cause kidney damage, impair skeletal and reproductive systems, and lead to other health-related problems (Okuo *et al.*, 2007).

Access to public potable water supplies from government sources in major cities across the country has become increasingly challenging, with more than 70% of the population lacking access to improved water sources (World Bank, 2000). As a result, many people rely on hand-dug shallow wells and a few boreholes with motorized pumps. However, the uncontrolled and haphazard construction of groundwater facilities, especially shallow wells near refuse sites like Oke-bale dump site and Iludun dump site in Osogbo, Osun State, raises health concerns. Overdependence and overabstraction from these facilities may contribute significantly to adverse impacts on the aquifer.

## 2. Materials and Methods

### 2.1 The Study Area

The investigation focused on assessing the physico-chemical quality of groundwater from hand-dug wells and boreholes in close proximity to municipal solid waste dumpsites in Osogbo, Osun State, Southwestern Nigeria. The specific areas covered within the town include Oke-Bale and the Federal Housing Estate in Osogbo, Osogbo Local Government Area, and the Iludun area in Olorunda Local Government Area of Osogbo.

### 2.2 Geographical Location and General Features of Osogbo

Osogbo, serving as the capital of Osun State in Southwestern Nigeria, is strategically positioned approximately 90 kilometers Northeast of Ibadan (Oyo State), 100 kilometers South of Ilorin (Kwara State), and 155 kilometers Northwest of Akure (Ondo State) by road. The town lies within latitudes 07° 46'N and 07° 48'N and longitudes 004° 31'E and 004° 35'E of the Greenwich Meridian, covering an approximate surface area of 270 km<sup>2</sup> (see Fig 1). Established in the late 18th Century, Osogbo originated as a traditional and cultural town, earning its name from the proclamation by the goddess of Osun River. The town boasts a rich heritage in arts and culture (Adenaike, 1991<sup>[6]</sup>; Awe and Albert, 1995). Osogbo municipality serves as the headquarters for both the Osogbo Local Government Area (Osogbo South) and the Olorunda Local Government Area (Osogbo North). According to the

1991 census, the population of Osogbo was 189,733, occupying a total land area of about 2,875 sqkm (Akanji, 1994; Akinola, 1998; Osun, 1992).

Indeed, before the creation of Osun State in August 1991, Osogbo played a crucial role as an administrative and provincial headquarters in the old Western Region. The town's strategic geographical location is characterized by its

proximity to various local government areas. Osogbo is bordered by Atakumosa Local Government Area to the south, Egbedore and Irepodun Local Government Areas to the north, Boripe and Obokun Local Government Areas to the east, and Ede Local Government Area to the west. This positioning within the broader regional context adds to the significance of Osogbo as a hub in Southwestern Nigeria.

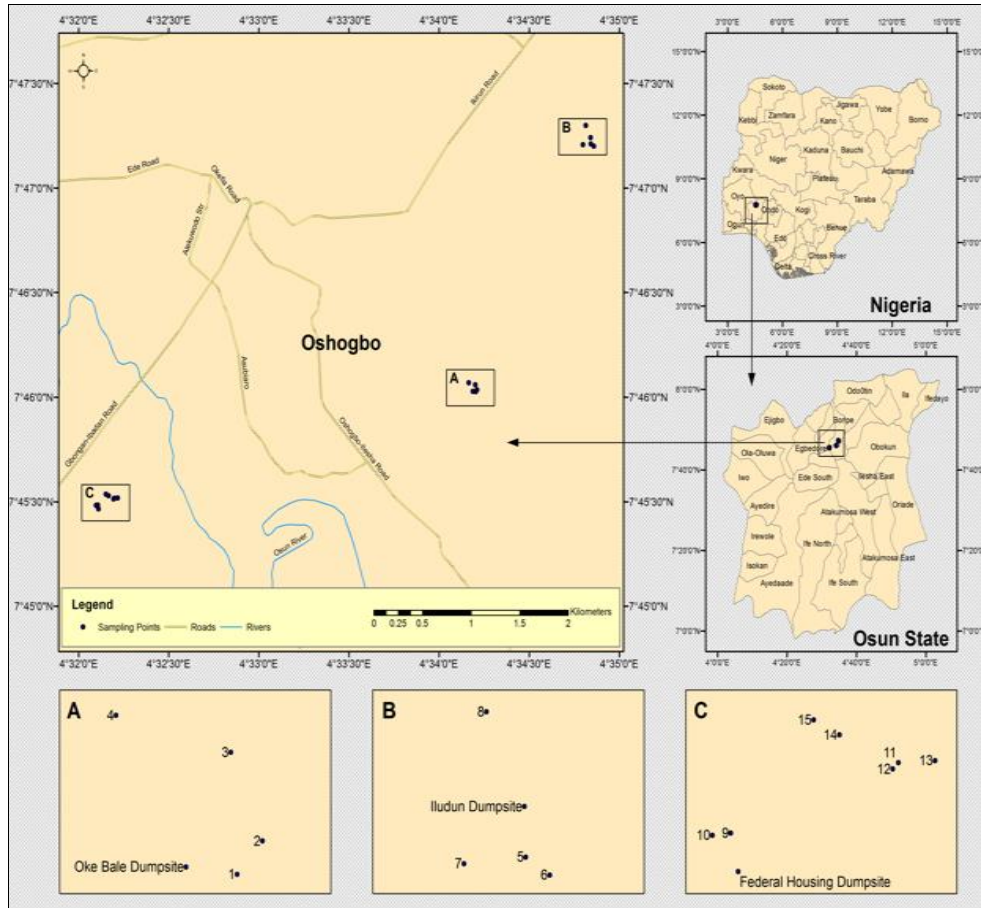


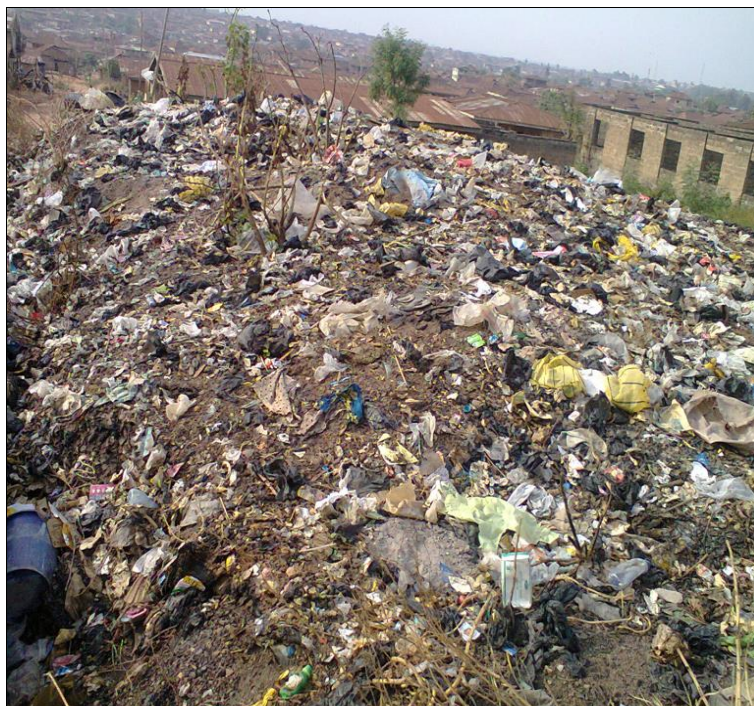
Fig 1: The Map of Osogbo Township Showing the Investigated Dumpsites



Fig 2: Oke-Baale Municipal Dumpsite, Osogbo



**Fig 3:** Iludun Municipal Dumpsite, Osogbo



**Fig 4:** Federal Housing Estate Municipal Dumpsite, Osogbo

### 2.3 Selection and Description of Sampling Stations

Fifteen sampling stations (Stations 1-15) were randomly selected in Osogbo Township. Stations 4,7,14 and 15 were located upstream of underground flow direction representing un-impacted locations. Stations 1, 2, 3,5,6,8,9,10, 11, 12 and

13 were located at various points downstream and flow of groundwater from municipal dumpsites. The grid coordinates of each station were measured and recorded as indicated in Table 1 using a Global Positioning System (GPS) handset.

**Table 1:** Description and Grid co-ordinates of Investigated Dumpsites and Ground Water Sampling Stations in Osogbo, Osun State, Nigeria

S. No	Dumpsite Location	GPS Location	Ground water	Distance from Dumpsite (metre)	GPS Location	Site Description
1.	ImolefalafiaOke- Baale Dumpsite	N07°46.028' E004°34.187'	HDW-1	30	N07°46.026' E004°34.203'	AlhajiIbahimBolarinwaImole-falafia compound, Oke-Baale
			HDW-2	42	N07°46.035' E004°34.211'	No 6 AlhajiRabiuOladimeji house, Imole-falafia
			HDW-3	45	N07°46.059' E004°34.201'	Katisan compound, Oke-Baale
			HDW-4	91	N07°46.069 ' E004°34.165'	Captain TundeKatisan compound, Oke-Baale
2.	Iludun Dumpsite (Behind ADSGrammar School, testing ground)	N07°47.242' E004°34.841'	HDW-5	27	N07°47.211' E004°34.842'	Mr. BadmusRauf House TiamiyuFaleket street, Iludun
			HDW-6	61	N07°47.200' E004°34.814'	Behind AUD School and central Mosque, Iludun
			HDW-7	64	N07° 47.207' E004°34.798'	Infront of Transword Gospel Church, Iludun
			HDW-8	60	N07°47.300' E004°34.814'	Mr. Obadademowo R. O. house, opposite AUD School toilet
3.	Federal Housing Estate (FHE) dumpsite, Olosan junction, Ogo-OluwaOsogbo	N07°45.465' E004°32.110'	BH-9	43	N007°45.483' E004°32.106'	No 11 AlhajiTajudeenAdejareAzeez street, Ogo-Oluwa
			HDW-10	40	N007°45.482' E004°32.096'	No 10 AlhajiTajudeenAdejareAzeez street, Ogo-Oluwa
			HDW-11	81	N07° 45. 516' E004°32. 197'	Mr. I.O. Alade, No 1 Olufade Street, Ogo-Oluwa
			HDW-12	68	N07°45.513' E004°32.194'	Mr. Adeyemi, No 2 Olufade street, FHE,Olosan
			HDW-13	92	N07°45.517' E004°32.217'	Rev. WoleIdowu, FHE Olosan
			HDW-14	150	N07°45.529 ' E004°32.165'	Mrs Elizabeth Olufade, FHE, Olosan
			HDW-15	176	N07°45.536' E004°32.151'	Mr. Samuel Ojetade. Ajagbe, Ogo-Oluwa

HDW= Hand-dug well, BH= Borehole

## 2.4 Sampling Programme and Field Determinations

Visits to the sites for field survey were carried out four (4) times: two times during dry season (November-March 2013) and two times during dry season (April-October 2013). At each sampling station, the total and static depth of the wells and borehole were estimated in meter (m) using a tape rule and safety rope tied with weight (object). Water samples were collected from the wells with the aid of locally made plastic water drawer which was sterilized with 5% HNO<sub>3</sub> solution, soaked in deionizer water and dried to avoid any form of contamination. Two sets of sterilized, sealed and well labeled sample bottles were used (one set for general physico-chemical analyses while the other was for heavy metals).

The temperatures of the water samples were determined in the field using mercury thermometer while electrolytic conductivity values of the samples were taken immediately after collection using a Jenway Conductivity meter. The pH values were determined using a Lovibond (1000-model) pH comparator.

## 2.5 Laboratory Analysis and Procedures

All the samples (both well water and wastewater) were analysed for physico-chemical parameters namely pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), colour and turbidity, conductivity, alkalinity and some selected heavy metals such as Cadmium, Chromium, Copper, Iron, Manganese, Lead and Zinc were determined using Atomic Absorption Spectrophotometer (AAS). Samples were analysed within the holding time of the respective parameters using standard methods with adequate

quality control measures.

### 2.5.1 Physical Parameters

#### 2.5.1.1 Temperature

Mercury in glass bulb thermometer was used to measure the temperature. The thermometric bulb containing the mercury was vertically immersed in the effluent and water samples in turns and allowed to stand for some minutes till the temperature reading was steady before reading it (Lawson, 2011).

#### 2.5.1.2 Colour

Absorbance Method: The Colorimeter meter was set to a wavelength of 430 nm. The meter was calibrated using distilled water with the knob adjusted to read 100. The sample was shaken to ensure even distribution of dissolved solids and 5 mL aliquot was taken using sample holder (cuvette) and the cuvette was replaced into colorimeter and the measurement was taken. This was done in duplicate per sample, while the colorimeter was calibrated after each reading was obtained.

#### 2.5.1.3 Turbidity

A Colorimeter was set to a wavelength of 540 nm. The meter was calibrated using distilled water with the knob adjusted to read 100 before use. Samples in plastic bottles were shaken vigorously and poured into one of the cuvette to at least two-thirds full and was replaced to the colorimeter for turbidity analysis. The appropriate readings were then taken when the lid cover was closed. Duplicate measurement per sample was taken and instrument

recalibrated after each measurement.

#### 2.5.1.4 Electrical conductivity (EC)

EC was determined with the use of a conductivity meter (Jenway4071). The probe was first rinsed with distilled water, cleaned and then calibrated using 0.01M KCl solution, and then immersed indistilled water again and wiped clean. Thereafter, 50 mL of each sample was poured into already clean container and the probe of the meter was immersed in it at room temperature to read the conductivity. The probe was rinsed again with distilled water and cleaned after each use.

### 2.5.2 Chemical parameters

#### 2.5.2.1 pH

pH of the samples was measured using pH meter already standardized by using buffer solutions of known value before analysis (APHA *et al.*, 1998). It was also determined using lovibond pH comparators.

pH meter procedure: pH meter was standardized with 0.05M potassium hydrogen phthalate ( $\text{KHC}_8\text{H}_4\text{O}_4$ , pH = 4), 0.025M potassium dihydrogen phosphate + 0.025M disodium hydrogen phosphate buffer ( $\text{KH}_2\text{PO}_4 + \text{Na}_2\text{HPO}_4$ , pH = 6.86) and 0.01M sodium borate decahydrate ( $\text{Na}_2\text{B}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$ , pH = 9.18), borax buffer, contained in the pH meter kit. The pH meter probe was inserted in each buffer in turns, read and rinsed in distilled water after which it was wiped cleaned with tissue paper to standardize the meter. After standardization the probe was inserted in water samples and the water samples stirred gently while measuring pH to insure homogeneity before taken the reading. The probe was cleaned after each use by inserting in distilled water and wiped dry with tissue paper.

Lovibond pH comparators procedure: Two cleaned test tubes (one for blank and the other for sample) were inserted in different holes in Lovibond 1,000. Distilled water was poured into one test tube up to a marked point and the other test tube was also filled to the marked point with sample. Ten drops of Bromothymol blue indicator (6.0 – 7.6) or Phenol red (6.8 – 8.4) or Phenolphthalein (8.6 – 10.2) indicator depending on the pH range was added to the sample and swirled to allow uniform mixing. The knob was adjusted until the colour in distilled water test tube matches the colour in the sample test tube and the reading was taken. Duplicate determination per sample was done, while the sample test tube was cleaned after each use.

#### 2.5.2.2 Total dissolved solids (TDS)

TDS was determined simultaneously with electrical conductivity by switching the control knob using Electrical Conductivity (EC) meter, the reading is taken when a stable graph has been shown on the conductivity meter.

#### 2.5.2.3 Total Alkalinity

##### Procedure

Sample (50 mL) was titrated with 0.01M  $\text{H}_2\text{SO}_4$  acid solution using 5 drops of mixed indicator (bromocresol green and methyl red). The end-point colour changed from light green to pink which gives pH range of 4 – 5 peculiar to the mixed indicator. Total alkalinity determined ( $\text{OH}^- + \text{CO}_3^{2-} + \text{HCO}_3^-$ ) in the sample. The result was expressed as total alkalinity. Blank titration (using distilled water) was carried out.

$$\text{Total alkalinity, mg/L CaCO}_3 = A * M * 100,000 / V$$

Where

A = volume of standard acid used,  
M = molarity of standard acid,  
V = volume of sample.

#### 2.5.2.4 Total Acidity

##### Procedure

Sample (50 mL) was titrated with 0.01M  $\text{Na}_2\text{CO}_3$  solution using 5 drops of phenolphthalein indicator. The colour changed from colourless to pink at the end-point.

$$\text{Acidity as mg/L CaCO}_3 = A * M * 100,000 / V.$$

Where

A = volume of the titrand,  
M = molarity of titrand,  
V = volume of sample

**Table 2:** Table showing Parameters Determined, Analytical methods used and References

Parameters	Analytical method/ Instrument	Reference
Temperature	(Thermometer)	APHA <i>et al.</i> , 1998
pH	Electrometry (pH meter)	APHA <i>et al.</i> , 1998
Apparent Colour, Turbidity	Electrometry (Colorimeter)	APHA <i>et al.</i> , 1998
Acidity, Alkalinity	Titrimetry	APHA <i>et al.</i> , 1998
Metals such as Sodium, Potassium, Calcium, Magnesium, Chromium, Copper, Cadmium, Iron, Manganese, Lead, Zinc	Atomic Absorption Spectrometry	APHA <i>et al.</i> , 1998

#### 2.5.3 Digestion of Groundwater Samples

Digestion of the samples was done using standard methods by APHA, *et al.* 1998 to bring metals into solution and to ensure metals present are atomised in AAS machine. Exactly 2.5 mL of concentrated  $\text{HNO}_3$  was added to 25 mL each of the samples in clean Teflon beakers. This was heated on a water bath to concentrate the sample to about 10 mL. Heating continued with periodic addition of 1mL concentrated  $\text{HNO}_3$  until a clear solution was obtained. This was allowed to cool and then transfer into clean 25 mL flask, filled up to mark with distilled water and used for analyses of metals with AAS.

#### Analysis of Heavy Metals

The digested samples were used for the determination of metals with the Atomic Absorption Spectrophotometer (AAS). Part of the digested samples was used directly for metals and cations (Na, K, Ca, Mg, Cr, Cd, Fe, Mn, Cu, Pb and Zn) determination using the Perkin Elmer 400 Atomic Absorption Spectrophotometer. The atomic absorption spectrometry measurement was accomplished at Centre Laboratory, Obafemi Awolowo University, Ile-Ife, Nigeria.

#### 2.5.4 Calibration

The Atomic Absorption Spectrophotometer was calibrated using different concentrations (0.001, 0.002, 0.050, 0.250,

0.500, 0.750, 1.000, 2.000, 2.500, 5.000 and 10.000) mg/L of the metals prepared by dilution from the stock solution (1000) mg/L for the metals. These were used in preparing a calibration curve for the metals.

**2.6 Quality Assurance and Quality Control Measures**

1. The following precautions were taken in order to ensure good results.
2. The reagent bottles and sampling bottles were washed with detergent and subsequently rinsed with tap water and distilled water before use.
3. All sampling bottles were carefully labeled on the field with a permanent marker to prevent mix-up in the laboratory.
4. The various glassware used for titrimetric analysis were washed with detergent and subsequently rinsed with tap water and distilled water before used for any determination for each sample.
5. The various equipment used for the physico-chemical water quality analysis was standardized using the blanks and standards of known concentration before each determination (Ademoroti, 1996 [5], Golterman *et al.*, 1978).
6. The determinations of physico- chemical water quality parameters were done within their individual holding time (Ademoroti, 1996) [5].

**2.7 Statistical Analysis of Data**

The data obtained were analyzed using descriptive statistics, ANOVA, correlation analysis and principal component analysis (PCA), using SPSS 17.

**3. Results and Discussion**

**3.1 Physical Parameters of Water Quality**

**3.1.1 Water Temperature**

During the sampling period, the water temperature exhibited a range from 26.0oC to 31.0oC, with an overall mean±s.e.m of 28.86±0.14oC and a median value of 29.0oC. Station 15 registered the highest mean±s.e.m of 29.63±0.63oC, while station 1 recorded the lowest mean±s.e.m of 28±0.68oC, as presented in Table 3.

The overall mean±s.e.m of water temperature was significantly higher (P < 0.05) in the dry season (29.61±0.13oC) compared to the rainy season (28.10±0.16oC), as illustrated in Table 3. Notably, the Federal Housing Estate dumpsite recorded the highest overall mean±s.e.m of water temperature (29.35±0.18oC), while the Oke–Bale dumpsite had the lowest mean±s.e.m (28.12±0.24oC), indicating a very highly significant difference (P<0.001).

The regression analysis of ambient temperature (x-axis) against water temperature (y-axis) during the dry season revealed a highly positive correlation, approximating 1. This positive correlation was consistent during the rainy season, as depicted in the regression of ambient air temperature on water temperature, showing a highly positive correlation (P<0.001).

There was no significant difference (P>0.05) between the highest mean water temperature (28.99±0.30oC) recorded at the unimpacted stations and the lowest mean value (28.81±0.16oC) recorded for the impacted stations. Illustration of the pattern of variation in the concentration of the investigated physical parameters with increasing distance away from the dumpsite in the study area in the table below.

Importantly, the water temperature remained within 100% of the allowable limit (32oC) set by the World Health Organization (WHO) and Nigeria standards for drinking water quality.

**Table 3:** Descriptive Statistics of Water Temperature (°C) at Sampling Stations

Station	N	Min	Max	Mean	Std. error	Stand. Dev	Median	Skewness	Kurtosis	Geom. Mean	Coeff. Var%
1	4	26.0	29.0	28.00	0.68	1.35	28.5	-1.81	3.48	27.97	4.84
2	4	27.5	28.7	28.18	0.27	0.54	28.3	-0.57	-1.71	28.17	1.91
3	4	27.5	29.0	28.48	0.35	0.71	28.7	-1.19	0.44	28.47	2.49
4	4	26.8	29.5	27.83	0.62	1.23	27.5	1.09	0.074	27.81	4.43
5	4	27.5	30.0	28.88	0.55	1.11	29.0	-0.48	-1.70	28.86	3.84
6	4	27.0	30.0	28.50	0.65	1.29	28.5	-3.01E-17	-1.20	28.48	4.53
7	4	28.0	30.2	29.18	0.46	0.93	29.3	-0.43	0.25	29.16	3.17
8	4	27.0	30.0	28.38	0.69	1.38	28.3	0.32	-3.03	28.35	4.85
9	4	27.0	30.5	29.13	0.77	1.55	29.5	-1.14	0.76	29.09	5.31
10	4	28.0	30.7	29.30	0.56	1.12	29.3	0.25	0.58	29.28	3.83
11	4	29.0	30.0	29.50	0.20	0.41	29.5	-6.89E-17	1.50	29.50	1.38
12	4	28.7	30.5	29.43	0.39	0.79	29.3	1.07E+00	0.65	29.42	2.68
13	4	28.0	30.5	29.13	0.55	1.11	29.0	0.48	-1.70	29.11	3.81
14	4	28.5	30.2	29.35	0.35	0.71	29.4	-1.47E-14	0.62	29.34	2.40
15	4	28.0	31.0	29.63	0.63	1.25	29.8	-0.56	0.93	29.61	4.22
1-15	60	26.0	31.0	28.86	0.14	1.10	29.0	-0.35	-0.33	28.84	3.82

**3.1.2 Turbidity**

The turbidity values during the sampling period ranged from 0.37 to 49.37 NTU, with an overall mean±s.e.m of 8.03±1.35 NTU. Station 3 recorded the highest mean±s.e.m value, while Station 15 had the lowest mean±s.e.m of 1.82±0.85 NTU, as details in the table below.

There was no significant seasonal difference (P>0.05) in turbidity, with the seasonal mean±s.e.m of turbidity slightly higher in the rainy season (8.51±8.50 NTU) compared to the dry season (7.55±2.23 NTU) (Table 4). However, a very

highly significant horizontal difference (P<0.001) was observed, notably between Oke–Bale with the highest mean±s.e.m value (12.82±3.67 NTU) and the Federal Housing Estate station with the lowest mean±s.e.m value (3.49±0.76 NTU).

Turbidity values at the impacted stations (9.48±1.77 NTU) were higher than the mean turbidity recorded at the unimpacted stations (4.20±0.91 NTU), with no significant difference (P>0.05).

It is important to note that the mean turbidity value exceeded the permissible level of 5 NTU, as outlined by the World Health Organization (WHO) and Nigeria standards

for drinking water. This indicates a potential concern for the water quality in the study area regarding turbidity levels.

**Table 4:** Descriptive Statistics of Water Turbidity (NTU) at Dumpsite Sampling Stations

Station	N	Min	Max	Mean	Std. error	Stand. Dev	Median	Skewness	Kurtosis	Geom. Mean	Coeff. Var%
1	4	6.9	36.3	16.70	6.67	13.34	11.8	1.76	3.23	13.60	79.87
2	4	0.4	36.3	13.43	7.89	15.78	8.5	1.60	2.87	5.53	117.46
3	4	3.6	49.4	17.52	10.87	21.73	8.5	1.75	3.00	9.67	124.06
4	4	0.4	6.9	3.63	1.89	3.77	3.6	5.35E-18	-6.00	1.59	103.81
5	4	10.2	19.9	15.07	2.11	4.22	15.1	0.00	-1.20	14.61	28.00
6	4	0.4	39.6	15.07	8.90	17.79	10.2	1.19E+00	0.61	5.45	118.09
7	4	3.6	13.4	7.72	2.05	4.11	6.9	1.129	2.23	6.94	53.25
8	4	0.4	23.2	6.90	5.50	10.99	2.0	1.89	3.58	1.84	159.37
9	4	0.4	10.2	2.82	2.45	4.90	0.4	2.00	4.00	0.84	173.95
10	4	0.4	10.2	5.27	2.83	5.66	5.3	2.43E-07	-6.00	1.93	107.43
11	4	0.4	10.2	2.82	2.45	4.90	0.4	2.00E+00	4.00	0.84	173.95
12	4	0.4	6.9	3.63	1.33	2.67	3.6	1.13E-03	1.50	2.41	73.35
13	4	0.4	13.4	4.45	3.09	6.18	2.0	1.66	2.62	1.60	138.97
14	4	0.4	6.9	3.63	1.33	2.67	3.6	-5.62E-04	1.50	2.40	73.40
15	4	0.4	3.6	1.82	0.85	1.70	1.6	0.16	-5.09	1.09	93.62
1-15	60	0.4	49.4	8.03	1.35	10.44	3.6	2.23	5.30	3.03	129.96

### 3.1.3 Apparent Colour

During the study period, apparent colour values in the groundwater ranged from 12.0 to 395.8 Pt.Co, with an overall mean value of 103.16±9.49 Pt.Co and a median value of 91.96 Pt.Co. The data distribution pattern exhibited positive skewness. The highest mean±s.e.m of apparent colour was observed in Station 6 (227.91±79.83 Pt.Co), while the lowest mean±s.e.m of apparent colour was observed in Station 10 (43.98±13.06 Pt.Co).

The mean values of apparent colour were higher during the rainy season (110.09±12.07 Pt.Co) than in the dry season (96.22±14.75 Pt.Co), but no significant difference ( $P > 0.05$ ) in seasonal variation was observed, as indicated in Table 4.9. However, there was a highly significant difference ( $P < 0.01$ ) among the dumpsites (Table 4.10). The apparent colour of impacted stations (113.04±11.95 Pt.Co) was greater than the mean value of unimpacted stations (75.97±11.68 Pt.Co) with no significant difference ( $P > 0.05$ ), as shown in Table 4.11. Figure illustrates the pattern of variation in the concentration of the investigated physical parameters with increasing distance away from the dumpsite in the study area.

It is noteworthy that the mean value of apparent colour exceeded the allowable limit of 15 Pt.Co according to the Nigerian standards guideline for drinking water (Table 4.12), indicating a potential concern for the water quality in the study area regarding apparent colour levels.

## 3.2 Chemical Parameters of Water Quality

### 3.2.1 Water pH

The groundwater pH observed during the sampling period ranged from 5.5 to 7.0, with an overall mean±s.e.m of 6.10±0.04 and a median value of 6.1. Station 7 recorded the highest overall mean±s.e.m of groundwater pH (6.65±0.13), while Station 2 had the lowest mean±s.e.m (5.83±0.13).

There was no significant seasonal difference ( $P > 0.05$ ) in the pH of the investigated groundwater (Table 3). However, a very highly significant horizontal difference ( $P < 0.001$ ) was observed at different dumpsites. The highest overall mean±s.e.m of pH at Iludun dumpsite and the lowest overall mean±s.e.m observed in Oke-Bale dumpsite (6.06) and

Federal Housing Estate dumpsite (6.06) were significantly different.

A significant ( $P < 0.05$ ) difference was noted between the mean pH of the impacted stations (6.06±0.039) and that of the unimpacted stations (6.23±0.08).

### 3.2.2 Total Dissolved Solids (TDS)

In this study, TDS values ranged from 32 to 1104 mg/L, with an overall mean of 171.96 mg/L. Station 1 recorded the highest overall mean±s.e.m (344.50±46.55 mg/L), while Station 9 had the lowest mean±s.e.m (65.05±4.79 mg/L). The mean TDS was higher during the dry season (188.6±97.49 mg/L) than in the rainy season (155.26±17.08 mg/L), but no significant seasonal difference was observed ( $P > 0.05$ ). A very highly significant horizontal difference in TDS was noted, especially between the highest mean value observed in Oke-Bale and the lowest mean value at Iludun. There was no significant difference ( $P > 0.05$ ) between the mean TDS at the impacted stations (185.47±26.32) and the greater mean value for the unimpacted stations (134.79±25.19). The mean total dissolved solids recorded fell below 1000 mg/L for WHO and 500 mg/L of Nigerian standards for drinking water.

### 3.2.3 Electrolytic Conductivity

The observed values of conductivity in the study area ranged from 48.6 to 980  $\mu\text{S}/\text{cm}$ , with an overall mean of 268.1±24.5  $\mu\text{S}/\text{cm}$  and a median value of 163.5  $\mu\text{S}/\text{cm}$ . The data distribution exhibited positive skewness. The highest overall mean was recorded in Station 1 (623.75±124.31  $\mu\text{S}/\text{cm}$ ), while the lowest mean±s.e.m (114.50±6.99  $\mu\text{S}/\text{cm}$ ) was recorded in Station 7. There was no significant seasonal difference ( $P > 0.05$ ) in the conductivity of the water. On the other hand, there was a very highly significant difference ( $P < 0.001$ ) at different dumpsites. The mean conductivity at the unimpacted stations (230.21±45.38  $\mu\text{S}/\text{cm}$ ) was lower than mean conductivity (281.93±29.12  $\mu\text{S}/\text{cm}$ ) at the impacted stations, showed the pattern of variation in the concentration of the investigated chemical parameters with increasing distance away from the dumpsite in the study area. The mean conductivity recorded was below 250  $\mu\text{S}/\text{cm}$



for WHO and 1000 µS/cm of Nigerian standards for drinking water.

**3.2.4 Total Acidity**

The concentrations of water total acidity during the sampling period were within the range of 6 and 76 mgCaCO3L-1 with an overall mean concentration of 25.9 mgCaCO3L-1. The lowest mean concentration of acidity was recorded in Station 6 (11.50±2.22 mgCaCO3L-1), while the highest mean concentration was recorded in Station 4 (38.5±12.55 mgCaCO3L-1). The overall mean±s.e.m acidity was slightly higher (P > 0.05) during the dry season (27.93±3.62 mgCaCO3L-1) than for the rainy season (23.87±2.76 mgCaCO3L-1). There was no significant difference (P > 0.05) along the horizontal variation of acidity. The mean value of acidity for the impacted stations (27.14±2.70 mg/L) was greater than the mean value for the unimpacted stations (22.50±4.20 mgCaCO3L-1) with no significant difference (P>0.05) showed the pattern of variation in the concentration of the investigated chemical parameters with increasing distance away from the dumpsite in the study area. The mean value of total acidity recorded was above 0.3 mgCaCO3L-1 of WHO and Nigerian standards for drinking water.

**3.2.5 Total Alkalinity**

The concentrations of alkalinity during the study period were in the range of 0.8 and 44 mgCaCO3L-1, with the overall mean±s.e.m and median of 14.20±1.27 mgCaCO3L-1 and 12 mgCaCO3L-1 respectively. The distribution was positively skewed. Station 8 had the highest mean±s.e.m (28±5.60 mgCaCO3L-1), while Station 15 had the lowest mean±s.e.m of 3.4±1.32 mgCaCO3L-1. There was no significant seasonal difference (P>0.05) in Alkalinity, and also there was no significant difference among the different dumpsites (P > 0.05). The mean alkalinity of the unimpacted stations (12.41±2.26 mgCaCO3L-1) was lower than the mean alkalinity of the impacted stations (14.86±1.53 mgCaCO3L-1), but no significant difference (P>0.05) showed the pattern of variation in the concentration of the investigated chemical parameters with increasing distance away from the dumpsite in the study area. The alkalinity values were all within the permissible level of 500 mgCaCO3L-1 according to WHO and Nigeria standard for drinking water.

**3.2.6 Total Hardness**

In this study, the observed values of total hardness ranged from 1.71 to 64.69 mgCaCO3L-1 with an overall mean±s.e.m of 26.53±2.44 mgCaCO3L-1 and median value of 18.7 mgCaCO3L-1. The lowest overall mean hardness was recorded in Station 9 (3.85±1.12 mgCaCO3L-1), while the highest overall mean of hardness was recorded in Station 1 (50.48±1.35 mgCaCO3L-1). The mean value of hardness in the rainy season (27.18±3.30 mgCaCO3L-1) was slightly greater than the mean value in the dry season (25.88±3.63 mgCaCO3L-1). On the other hand, there was a very highly significant difference (P<0.001) among the dumpsites. There was no significant difference between the lowest mean of total hardness recorded for the unimpacted stations (24.77±4.58 mgCaCO3L-1) and the higher mean value recorded for the impacted stations (27.17±2.90 mgCaCO3L-1) showed the pattern of variation in the concentration of the investigated chemical parameters with increasing distance away from the dumpsite in the study area. The mean total hardness value was below the permissible level of 100 mgCaCO3L-1 and 150 mgCaCO3L-1 according to WHO and Nigerian standards for drinking water, respectively

**3.2.7 Heavy Metals**

**3.2.7.1 Lead**

The concentrations of lead during the study period were within the range of 0.007 mg/L – 0.101 mg/L. The overall mean value and median values were 0.033±0.0026 mg/L and 0.026 mg/L, respectively. The highest overall mean±sem (0.046±0.02 mg/L) and the lowest mean±sem (0.021±0.005 mg/L) per station were recorded in Stations 13 and 4, respectively. Whereas there was a very highly significant seasonal difference (P<0.001) in which the mean rainy season value (0.047±0.003 mg/L) was much greater than the mean dry season value (0.019±0.002 mg/L). There was no significant difference (P>0.05) in mean values for the three different dumpsites. The highest mean lead was recorded among the unimpacted stations (0.03±0.004 mg/L), while the lowest mean lead for the impacted stations (0.03±0.03 mg/L) showed the pattern of variation in the concentration of the investigated heavy metals with increasing distance away from the dumpsite in the study area. The mean value of lead was above the permissible limit of 0.01 mg/L according to WHO and Nigerian standards for drinking water quality.

**Table 5:** Descriptive Statistics of the Lead (mg/L) at the Dumpsite Sampling Station

Station	N	Min	Max	Mean	Std. error	Stand. Dev	Median	Skewness	Kurtosis	Geom. mean	Coeff. Var (%)
1	4	0.02	0.06	0.04	0.01	0.02	0.041	4.26E-01	-1.90	0.03	47.15
2	4	0.01	0.05	0.02	0.01	0.02	0.021	1.53E+00	2.06	0.02	66.84
3	4	0.02	0.04	0.03	0.00	0.01	0.021	-3.23E-01	-4.17	0.028	27.55
4	4	0.01	0.03	0.02	0.00	0.01	0.031	9.27E-01	0.29	0.02	44.06
5	4	0.02	0.06	0.03	0.01	0.02	0.020	1.95E+00	3.81	0.02	73.11
6	4	0.01	0.04	0.03	0.01	0.01	0.023	1.03E+00	2.07	0.02	46.83
7	4	0.01	0.06	0.03	0.01	0.03	0.014	8.92E-01	-0.92	0.02	89.03
8	4	0.01	0.05	0.03	0.01	0.02	0.023	7.47E-02	-5.57	0.02	69.00
9	4	0.01	0.06	0.04	0.01	0.02	0.023	-8.67E-18	-4.84	0.03	62.97
10	4	0.01	0.05	0.04	0.01	0.02	0.024	-5.49E-01	-2.84	0.03	58.34
11	4	0.01	0.07	0.04	0.01	0.03	0.023	1.37E-01	-5.11	0.03	72.10
12	4	0.01	0.08	0.04	0.02	0.03	0.033	8.69E-02	-5.42	0.03	79.13
13	4	0.02	0.10	0.05	0.02	0.04	0.03	1.25E+00	0.69	0.03	87.20
14	4	0.02	0.05	0.04	0.01	0.01	0.042	-6.16E-01	-1.04	0.04	29.69
15	4	0.02	0.05	0.04	0.01	0.02	0.043	-1.41E-01	-4.20	0.04	39.27
1-15	60	0.01	0.10	0.03	0.02	0.02	0.032	0.93	0.58	0.03	61.20

### 3.2.7.2 Cadmium

The concentrations of cadmium during the study period ranged from 0 to 0.031 mg/L with an overall mean±sem of 0.016±0.001 mg/L and median value of 0.02 mg/L. The distribution was positively skewed. There was no significant difference ( $P>0.05$ ) both in the seasonal variation and in horizontal variation of Cadmium. The mean value of Cadmium at the unimpacted stations (0.008±0.003 mg/L)

was greater than the mean value of cadmium at the impacted stations (0.0079±0.002 mg/L), but there was no significant difference ( $P>0.05$ ) between them showed the pattern of variation in the concentration of the investigated heavy metals with increasing distance away from the dumpsite in the study area. The mean value of cadmium was above the permissible limit of 0.003 mg/L according to WHO and Nigerian standards for drinking water quality.

**Table 6:** Descriptive Statistics of the Cadmium (mg/L) at the Dumpsite Sampling Station

Station	N	Min	Max	Mean	Std. error	Stand. Dev	Median	Skewness	Kurtosis	Geom. Mean	Coeff. Var (%)
1	4	0.001	0.061	0.015	0.005	0.01	0.023	-0.84	0.57	0.01	70.09
2	4	0.01	0.068	0.017	0.003	0.01	0.024	-0.07	-5.59	0.02	41.04
3	4	0.012	0.076	0.019	0.003	0.01	0.022	-1.13	2.23	0.02	26.49
4	4	0.013	0.085	0.021	0.003	0.01	0.021	0.21	1.12	0.02	32.91
5	4	0.010	0.052	0.013	0.003	0.01	0.013	2.00	4.00	0.01	46.15
6	4	0.009	0.059	0.015	0.003	0.01	0.021	-0.02	-5.87	0.01	41.19
7	4	0.009	0.066	0.017	0.004	0.01	0.023	-6.44E-16	-5.85	0.01	49.11
8	4	0.008	0.063	0.016	0.004	0.01	0.015	0.27	-3.93	0.01	51.42
9	4	0.006	0.062	0.016	0.004	0.01	0.024	-0.18	-5.00	0.01	56.86
10	4	0.003	0.054	0.014	0.006	0.01	0.011	0.05	-5.63	0.01	86.07
11	4	0.004	0.079	0.019	0.006	0.01	0.022	-1.25	1.68	0.02	57.04
12	4	0.002	0.053	0.013	0.006	0.01	0.014	0.25	-4.31	0.01	92.10
13	4	0.000	0.060	0.015	0.006	0.01	0.022	-0.42	-0.42	0.00	79.63
14	4	0.000	0.060	0.015	0.006	0.01	0.024	-3.01E-17	-1.20	0.00	86.07
15	4	0.000	0.071	0.018	0.008	0.02	0.021	-0.35	-3.96	0.00	86.10
1-15	60	0.000	0.031	0.016	0.001	0.01	0.023	-0.19	-1.10	0.00	55.53

### 3.2.7.3 Zinc

The concentrations of zinc were within the range of 0 and 0.085 mg/L with an overall mean±sem of (0.02±0.0025 mg/L) and median value of 0.014 mg/L. The highest mean±sem of Zinc was recorded in Station 13 (0.044±0.017 mg/L), while the lowest mean±sem of Zinc was recorded in Station 7 (0.0043±0.0018 mg/L). The mean value in the dry season (0.02±0.003 mg/L) was the same as the mean value in the rainy season (0.02±0.004 mg/L) (Table 4.41). On the

other hand, there was no significant difference in the horizontal variation of zinc. The mean concentration zinc recorded for the impacted stations (0.02±0.003 mg/L) was the same as the mean zinc recorded for the unimpacted stations (0.02±0.004), and there was no significant difference ( $P>0.05$ ). The mean value of zinc was below the permissible level of 3 mg/L according to Nigerian standards and WHO for drinking water quality, and there was 100% compliance with the standards.

**Table 7:** Descriptive Statistics of the Zinc (mg/L) at Dumpsite Sampling Station

Station	N	Min	Max	Mean	Std. error	Stand. Dev	Median	Skewness	Kurtosis	Geom. mean	Coeff. Var (%)
1	4	0.011	0.038	0.024	0.006	0.012	0.024	6.96E-02	-3.50	0.02	51.22
2	4	0.006	0.022	0.014	0.003	0.007	0.015	-2.27E-01	1.41	0.01	45.97
3	4	0.001	0.017	0.009	0.004	0.007	0.009	1.42E-01	-2.51	0.01	81.55
4	4	0.007	0.014	0.011	0.001	0.003	0.011	-5.17E-01	1.65	0.01	26.72
5	4	0.000	0.009	0.0045	0.002	0.004	0.005	-1.23E-15	-1.20	0.00	86.07
6	4	0.004	0.015	0.009	0.002	0.005	0.009	3.92E-01	-2.44	0.01	55.18
7	4	0.000	0.009	0.004	0.002	0.004	0.004	4.04E-01	1.59	0.00	86.72
8	4	0.014	0.064	0.043	0.011	0.021	0.048	-1.14E+00	2.15	0.04	48.62
9	4	0.005	0.083	0.037	0.018	0.037	0.032	5.94E-01	-2.58	0.02	100.16
10	4	0.008	0.033	0.017	0.006	0.011	0.013	1.70E+00	3.12	0.01	66.37
11	4	0.008	0.021	0.014	0.003	0.009	0.013	3.16E-01	-3.98	0.01	45.76
12	4	0.012	0.030	0.021	0.004	0.009	0.022	-7.93E-02	-4.41	0.02	40.55
13	4	0.009	0.085	0.044	0.017	0.034	0.041	3.68E-01	-2.10	0.03	76.92
14	4	0.015	0.054	0.027	0.009	0.018	0.019	1.95E+00	3.84	0.02	69.48
15	4	0.005	0.039	0.022	0.009	0.017	0.022	5.73E-16	-5.48	0.06	79.43
1-15	60	0.000	0.085	0.020	0.002	0.019	0.014	1.74	2.82	0.00	96.38

## 4. Discussion

### 1. Temperature and Turbidity:

- Similar studies in urban areas with dumpsites (Banwo, 2006) [12] reported variations in water temperature influenced by sunlight. Turbidity findings align with Asante *et al.* (2008), attributing high turbidity to runoff and pollutant transport.

### pH and Acidity:

- Comparable results in Imevbore (1985) and WHO

(2007) reported pH ranges, supporting the idea of acidity in groundwater due to organic matter and atmospheric CO<sub>2</sub>.

### TDS and Conductivity:

- Similar findings by Olajire and Imeokpara (2001) and Olaniya and Saxena (1997) regarding TDS and conductivity levels, linking higher values to seepage and runoff from polluted areas.

### Total Hardness and Alkalinity:

- Corroborated results with Lakshmanan *et al.* (2003) and Abdul-Rasak *et al.* (2009) regarding total hardness and alkalinity variations, indicating proximity to dumpsites and their impact on water quality.

### Metal Concentrations (Lead, Zinc, Manganese, Iron)

- Similar observations by Moturi *et al.* (2004) and Lakshmanan *et al.* (2003) regarding metal concentrations, emphasizing the impact of dumpsite content on heavy metal levels in groundwater.

### 5. Conclusion

This study conducted a comprehensive analysis of groundwater quality in the vicinity of municipal dumpsites in Osogbo, Osun State. The investigation covered both impacted and unimpacted groundwater sources, considering various physical, chemical, and heavy metal parameters. The key findings and conclusions are as follows:

**1. Groundwater pollution:** The study revealed that leachates from municipal dumpsites have led to groundwater pollution, with higher concentrations of pollutants observed closer to the dumpsites. The impact of this pollution decreased with increasing distance from the dumpsite locations.

**2. Sanitation conditions:** The composition of the dumpsites, especially at Oke-Bale, indicated very poor sanitation conditions in the study areas. This emphasizes the need for proper waste management practices to prevent environmental contamination.

**3. Seasonal variations:** Distinct seasonal variations were observed in various water parameters, including air temperature, water temperature, true color, pH, TDS, electrolytic conductivity, total acidity, nitrate, sodium, potassium, magnesium, iron, cadmium, manganese, dissolved oxygen, dissolved oxygen saturation, and biochemical oxygen demand. Concentrations were generally higher in the dry season compared to the rainy season.

**4. Compliance with standards:** Groundwater quality in the study area did not meet the international guidelines set by the World Health Organization (WHO) and Nigerian Standards for drinking water supply. The concentrations of several parameters exceeded the permissible limits, indicating that the groundwater is not suitable for drinking without appropriate treatment.

**5. Depth impact:** The only borehole in the investigated area exhibited less impact compared to typical hand-dug wells, possibly due to its greater depth. This suggests that well construction and protection play a crucial role in preventing contamination.

### 6. Recommendations

Based on the findings, the following recommendations are proposed:

- Public awareness:** Conduct public awareness and enlightenment programs to educate residents on maintaining a safe distance from dumpsites when siting hand-dug wells. Emphasize basic sanitary rules and hygiene practices to prevent point source contamination.
- Legislation and enforcement:** Implement and enforce government legislation against indiscriminate dumping of domestic and industrial waste into open dumpsites. Effective waste management practices can significantly reduce groundwater pollution.

- Integrated solid waste management:** Adopt the principles of integrated solid waste management, including waste reduction, sorting, coding, composting, re-use, screening, compaction, and sizing. This approach minimizes waste volume and extends the usability of disposal sites.
- Well construction and protection:** Ensure proper construction and protection of hand-dug wells used as sources of potable water. This includes measures to prevent surface contaminants from entering the well.
- Water disinfection:** Regularly disinfect or chlorinate drinking water from unlined hand-dug or shallow wells. Boiling water under pressurized conditions is also recommended to eliminate pathogenic organisms.
- Clean water handling:** Keep receptacles and materials used for drawing water from hand-dug wells clean and protected from contamination. Pre-wash these materials with disinfectant before use.
- Increased monitoring:** Increase the frequency of sampling and analysis of water in the study areas to effectively monitor the impact of dumpsites on human health and the environment. Regular monitoring is essential for identifying potential risks and implementing timely interventions.

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