

Application of Weighted Arithmetic Index Method in Determining The Water Quality Status of Groundwater Samples near Gosa Dumpsite, Federal Capital Territory (FCT), Abuja, Nigeria

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Abstract

Water pollution compromises the safety of drinking water. This study employed the Weighted Arithmetic Index method to assess the quality of groundwater samples (from wells) near the Gosa dumpsite in the FCT, Abuja. Water samples were collected from four different wells near the dumpsite. The physicochemical parameters such as Electrical conductivity (E.C), Total Dissolved Solids (TDS), Total Hardness (T.H), pH, Chlorides (Cl⁻), Sulphates (SO₄²⁻), Nitrates (NO₃⁻), Nitrite (NO₂⁻), Biochemical Oxygen Demand (BOD), Lead (Pb), Chromium (Cr), Cadmium (Cd) among others, were analysed for the water samples. Values were compared with the World Health Organization (WHO) permissible limits. Groundwater samples were collected and analysed using standard procedures. Findings showed that all the water obtained from the four (4) different wells had Water Quality Index (WQI) values that exceeded 100, which makes the water unsuitable for consumption. The overall status of the WQI from the study area is unsuitable for consumption, as indicated by average WQI values higher than 100 (352.6817). The unsuitable state of the water quality in the area may be due to dumpsite leachate infiltration into the neighbouring groundwater. Steady consumption of the unsafe well water close to the dumpsite in Gosa poses a health risk to the consumers. The study suggests that users in the area should properly treat well water before consumption, and it also recommends consistent monitoring of groundwater to ensure that the water is safe and suitable for human use.

1.0 Introduction

In Nigeria and other low-to-medium-income nations, most wastes generated are disposed of in dumpsites. Because the land is cheap and plentiful, landfilling activities become highly desirable, as revealed by Okonofua *et al.* [1] and Nwosu *et al.* [2]. In the developing cities of the world, where landfill policies are not considered, a large proportion of the generated municipal solid waste (MSW) ends up in dumpsites, as reported by Awino and Apitz [3]. When waste is dumped into dumpsites, it poses a significant impact on the environment, especially soil and groundwater. According to Ilaboya *et al.* [4], water is essential for the survival of humanity; the increasing demand for potable water of late has been attributed to rises in both population and industrial levels. Mismanagement and failure to maintain a dumpsite can lead to pollution of surface and sub-surface water, apart from air pollution and land degradation, as revealed by Ferronato and Torretta [5]. The hazardousness of the leachate contaminants varies with their composition and quantity, including the distance of the dumpsite from the water source, as reported by Nyong and Nyong [6]. Pollution of groundwater is more common at a dumpsite where solid waste is discharged. In these dumpsites, the leachate of the decaying organic waste percolates into the nearby water sources. As reported by Ferronato and Torretta [5], the groundwater users and their environment are seriously affected by the pollution impacts of dumpsite activities.

Having enough clean and safe freshwater is vital for all life forms on Earth to survive. According to Shehzadi *et al.* [7] and Breaban

et al. [8], the issues related to the quality of water are enormous and multifaceted, which warrants swift action at the global level. Polluted water can spread diseases. In developing countries, an estimated 1.8 million deaths occur every year due to preventable diseases of water-borne origin, and the majority are young children, as revealed in a study by Wolf *et al.* [9]. According to Nwabor *et al.* [10], an estimate of 1.8 million people was reported to have died from diarrheal diseases every year after consumption of contaminated and unwholesome water. Continuous assessment, management, and monitoring of the quality of drinking water are hence necessary to ensure accessibility to potable and wholesome water by the public as described by Shehzadi *et al.* [7]. The quality of water is mainly expressed by the biological, physical, and chemical characteristics for a particular purpose, as described by Ejiohuo *et al.* [11]. The assessment of the quality of water is key for every living thing in our ecosystem. The quality of water affects the supply of water and helps determine its suitability for specific purposes. Water Quality Index (WQI) is employed to provide an estimation of water quality using multiple water quality parameters to obtain a single value that represents the quality of water in an area, according to Amadi [12]. According to Oni and Fasakin [13], Chidiac *et al.* [14], and Amadi [12], WQI is ideal for calculating the suitability of groundwater for human consumption. According to Al-Janabi and Al-Barmani [15], WQI is a method that uses a single value as an expression of the general quality of water in a particular location. Malaysia, as reported by Fitri *et al.* [16], utilized the Malaysian Department of Environment water quality index method to

assess the quality of water in the country. However, in China, a different method is often utilized according to Zhao *et al.* [17]. In Bangladesh, a different method of assessing the water quality index was reported by Akter *et al.* [18]. However, all the aforementioned countries have similar concepts to indicate the water quality status of their countries. According to Oni and Fasakin [13] and Brown *et al.* [19], the weighted average water quality index (WAWQI) has been reported as an effective technique for evaluating the quality of water to verify how appropriate the water is for a particular purpose. Thus, this research work aims to adopt the use of the weighted average water quality index method in determining the water quality status of groundwater samples near the Gosa dumpsite, FCT, Abuja, Nigeria.

2.0 Materials and Methods

2.1 Area of Study

The study was undertaken in Gosa, Abuja, a municipality in Nigeria. The research took place in the Gosa community, and the study utilised groundwater from dug wells located around the Gosa community, a few metres away from the central Gosa dumpsite, which is currently used as a dumping site for urban solid waste in Abuja, Nigeria. The Gosa study area map is shown in Figure 1. Gosa is a community under the Abuja Municipal Area Council (AMAC), which is located in the Federal Capital Territory (FCT) within latitude 7° 25' N and 9° 20' N of the equator and longitude 5° 45' E and 7° 39' E of the meridian according to Aderoju and Dias [20]. Six local councils make up the FCT, namely, Kuje, Bwari, Gwagwalada, Kwali, Abaji, and

AMAC. Gosa township experiences two seasons, starting with the rainy season, which runs from April to October, followed by the dry season (November to March). Gosa landfill is the largest dumping site in Abuja, located in Gosa village, a remote area. The AMAC bounds the 90-hectare area that makes up the dumpsite in Gosa. According to City Population [21], in 2024, the projected AMAC population as of 2022 was estimated as 1,693,400 with an annual growth rate of 5%.

2.2 Water Sampling Collection Procedure

Four (4) water wells within Gosa's community were chosen to collect water samples near the dumpsite of Gosa. In all, eight water samples were collected from the above wells; duplicate samples were taken from each of the wells and then correctly labelled to avoid sample confusion. An in-depth washing of laboratory glassware and sampling bottles preceded water sample collection. They were sequentially rinsed with deionised, distilled water, followed by 10% nitric acid, and then the sampled water. After the water samples were obtained, they were treated with nitric acid (HNO₃), i.e., pure form, to reduce the pH of the samples, which could prevent any form of metallic precipitation that could otherwise change the nature of the sampled water. Furthermore, this prevented metal from forming precipitates inside the water sample while at the same time preserving the samples from any form of alteration before analysis. Water sample pH values were obtained using a calibrated Metrohm E744 pH meter.

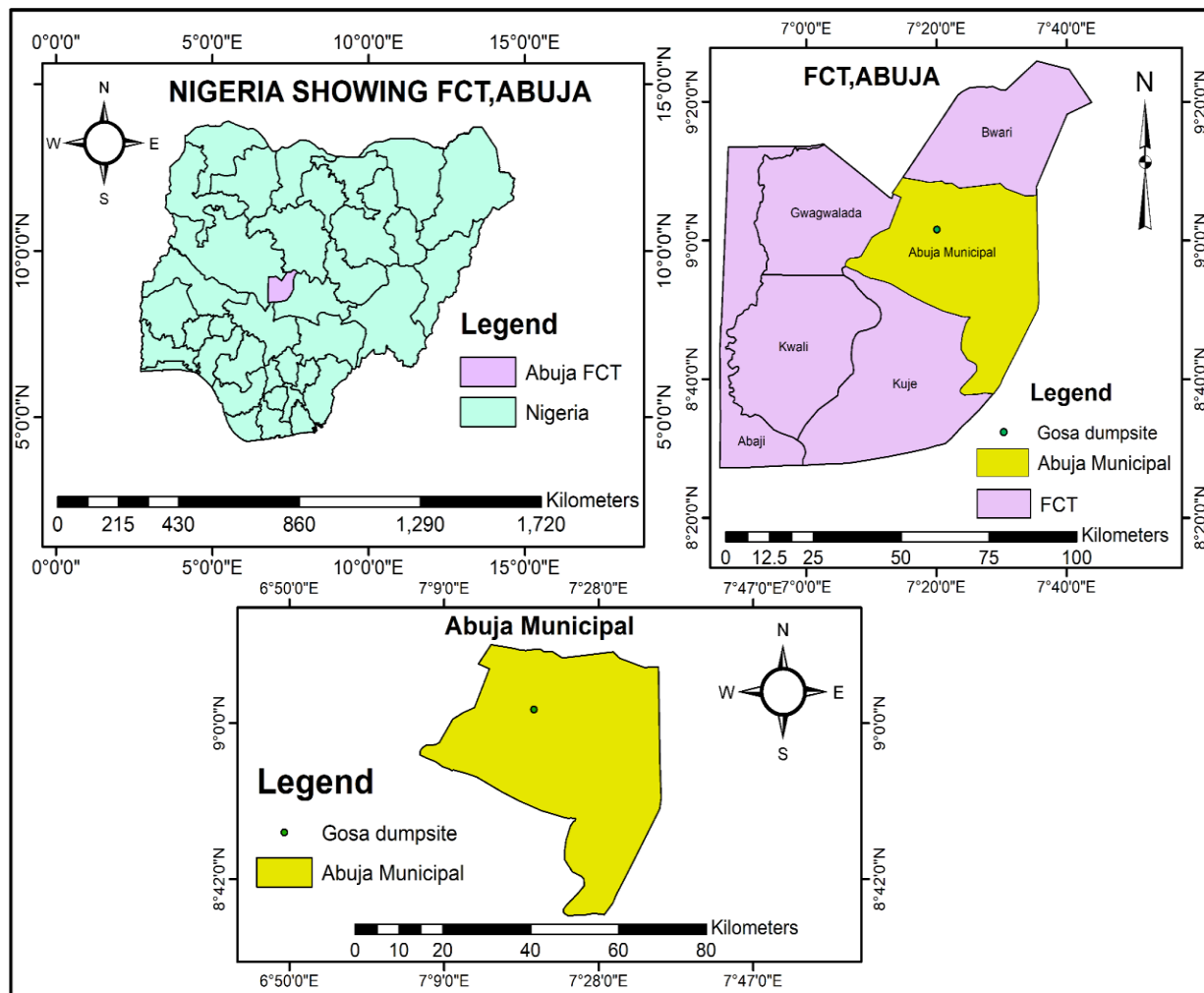


Figure 1: Study area location map

2.3 Elemental Analysis of Water Samples

The acid digestion method adopted by Ogbonna [22] was utilised to analyse the HM concentration of the collected water samples. Each sample was prepared by mixing 100 mL of each sample with 2 mL of concentrated HNO_3 and 1 mL of concentrated HCl . The mixture was subsequently set on heat till the volume reduced to approximately 20 mL, according to Nyambura *et al.* [23]. The specific colour showed that there was complete digestion of the mixture. In a bid to ensure the removal of organic matter

particles from the water samples, which may hinder or interfere with the analysis and improve the ability to detect and be sensitive to metals using atomic absorption spectrophotometry (AAS) in a conical-shaped flask (250 mL), sample digestion was done. During this process, 10 mL of strong nitric acid and 50 mL of water were added and thoroughly mixed. The technique adopted by Alidadi *et al.* [24] was used to cool the mixture after filtering it with a Whatman pore membrane that has a 0.45-micron diameter.

The samples, which were digested, were carefully preserved in plastic bottles at 4 degrees Celsius until analysis. HMs such as Zn, Cu, Cd, Pb, Mn, Cr, etc., from the acidified water samples were analysed via AAS AA240 according to Emmanuel *et al.* [25]. The average metal concentration was calculated using the calibration curve after the acidified water samples were analysed in duplicates. Analysed values were compared with WHO international permissible standards using WHO [26].

2.4 Testing for chemical and physical indicators in water samples

Physicochemical indicators of water samples were conducted, measuring Total Dissolved Solids (TDS), pH, Electrical Conductivity (E.C.), Total Hardness (T.H.), Total Soluble Solids (TSS), Chlorides (Cl^-), Chemical Oxygen Demand (COD), Nitrates (NO_3^-), Nitrite (NO_2^-), Sulphates (SO_4^{2-}), Biochemical Oxygen Demand (BOD), Copper (Cu), Lead (Pb), Magnesium (Mg), Cadmium (Cd), Zinc (Zn), Calcium (Ca), Chromium (Cr) and Manganese (Mn) were analysed for the water samples and compared with the WHO standard as presented in Table 1.

2.5 Weighted Arithmetic Index Technique computation for WQI determination

Various techniques and approaches are mainly used for estimating WQI when comparing the physicochemical parameters of water quality. This study employed the Weighted Arithmetic Water Quality Index (WAWQI) developed by Brown *et al.* [19]. The WAWQI approach categorised the quality of water by examining cleanliness through various indicators and measurements

of water quality like pH, EC, TDS, Cl^- , NO_3^- , TSS, NO_2^- , COD, hardness, BOD, Mg, SO_4^{2-} , Mn, Cr, Cu, Cd, Zn, Pb, and Ca. The WAWQI was estimated through these steps:

1. Unit weight estimation denoted by (T_n) as seen in this equation.

$$T_n = \frac{K}{P_n} \dots \dots \dots \text{Expression 1}$$

$$K = \frac{1}{\left(\frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + \frac{1}{P_4} + \dots \frac{1}{P_n}\right)} = \frac{1}{\sum \frac{1}{P_n}}$$

.....Expression 2

S_n represent the standard desired number of the n^{th} parameters. The addition of the total included factors unit weighted elements equals to one i.e. $\sum T_n = 1$.

2. Sub-index value assessment or quality grading scale (I_n) adopting the below expression

$$I_n = 100 \left(\frac{V_n - V_o}{P_n - V_o} \right) \dots \dots \dots \text{Expression 3}$$

The mean level of the n^{th} parameter is V_n . P_n denotes the standard desired number of the n^{th} parameter. V_o denotes the ideal standards of included water indicators/characteristics (Usually, V_o is taken as zero and used to compute the majority of those indicators, apart from the pH, which is 7. (I_n) represents the quality rating for each parameter, determined by dividing the measured concentration (V_n) in the sampled water by its corresponding permissible standard (P_n) and then multiplying the result by 100.

3. Estimation of the total WQI by adding up the quality grading (I_n) with unit weighting (T_n)

$$WQI = \frac{\sum I_n T_n}{\sum T_n} \dots \dots \dots \text{Expression 4}$$

Since $\sum T_n = 1$, WQI was computed by summation of T_n by I_n using equation 4, where I_n is the quality of the n th indicator, T_n denotes the n th parameter's unit weight, and n is the number of included indicators. WQI was calculated to inform various designated uses of water; in this research, drinking purposes remained considered for water through the WQI, and the WQI ranking scale utilised ranges from 0 to 100, with the ranking/rating expressed equally (Excellent: between 0 and 25, Good: between 26 and 50, Poor: between 51 and 75, Very Poor when it falls between 76 and 100, and unfit for drinking represents values that are higher than 100).

2.6 Data Analysis

A descriptive statistical tool was employed and expressed as the mean of each parameter.

3.0 Results

3.1 Water Quality Parameters

The key physical and chemical (physicochemical) characteristics of HO standard guideline value.

groundwater were assessed, with a summary of the analysed water quality parameters provided in Table 1.

3.1.1 Total Hardness T.H

The T.H. values across the sampled well water ranged from 37.9 to 167.7 mg/L, as revealed in Figure 2. The lowest T.H. value was found in WWSL2 (37.9 mg/L), followed by WWSL3 (51.8 mg/L) and then WWSL4 (63.5 mg/L), and the highest T.H. value was found in WWSL1 (167.7 mg/L). The result showed that the T.H. concentration is within the WHO guideline value (200 mg/L).

3.1.2 pH

The pH values ranged between 7.00 and 7.35, with the lowest pH value found in WWSL4 (7.0), followed by WWSL3 (7.03) and WWSL1 (7.12), and the highest pH value was found in WWSL2 (7.35), as presented in Figure 2. The result of the pH showed the non-acidic nature of the water, and the values were within the WHO standard guideline value.

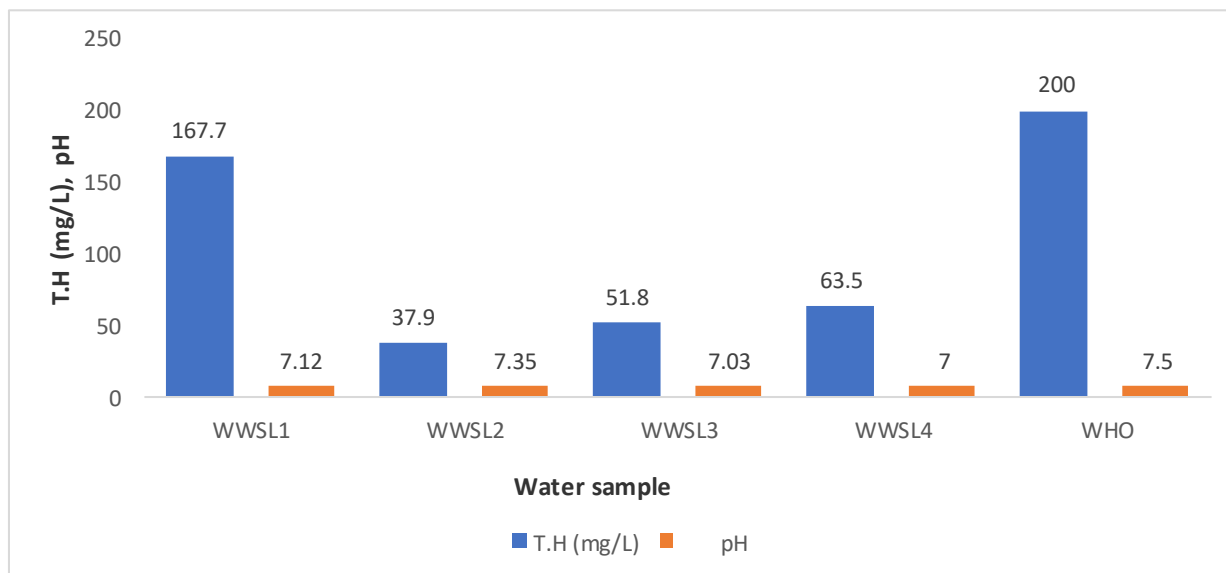


Figure 2: Comparison of T.H and pH with WHO guideline

3.1.3 Electrical Conductivity E.C

The result of E.C. from the analysed samples of well water ranged from 67.5 to 145.1 $\mu\text{S}/\text{cm}$, as revealed in Figure 3, with the minimum value for water obtained from WWSL1 (67.5 $\mu\text{S}/\text{cm}$), followed by WWSL2 (121.3 $\mu\text{S}/\text{cm}$) and then WWSL4 (145.1 $\mu\text{S}/\text{cm}$), and the maximum conductivity value was found in water samples from WWSL3 (148.9 $\mu\text{S}/\text{cm}$). The results showed that all water samples collected and analysed from the four well locations had conductivity values that were within and below the 1000 $\mu\text{S}/\text{cm}$ WHO guideline value.

3.1.4 Total Dissolved Solids TDS

The mean concentration as found in TDS from the analysed sampled groundwater obtained from the Gosa community ranged between 37.8 mg/L and 99.0 mg/L, as shown in Figure 3, with the lowest TDS found in WWSL1 (37.8 mg/L), followed by WWSL2 (78 mg/L) and then WWSL3 (89 mg/L), and the highest TDS value was found in WWSL4 (99.0 mg/L). The result indicates that all water sampled from the four well locations did not exceed the TDS limit of the WHO (500 mg/L).

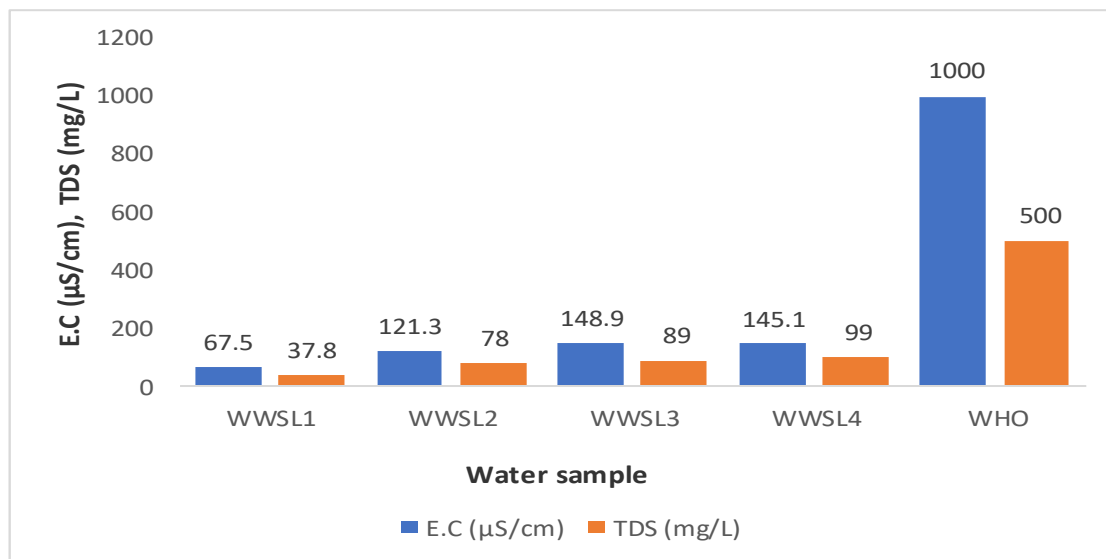


Figure 3: E.C and TDS comparison with WHO guideline value

3.1.5 Total Soluble Solids TSS

The TSS concentration from analysed groundwater wells ranged between 13 mg/L and 184.5 mg/L, as presented in Figure 4, with the lowest TSS value found in WWSL4 (13 mg/L), followed by WWSL3 (25 mg/L)

and WWSL2 (99 mg/L), and the highest TSS value was found in WWSL1 (184.5 mg/L). Two (2) out of the four (4) well water sample locations were beyond the TSS limit of the WHO (25 mg/L).

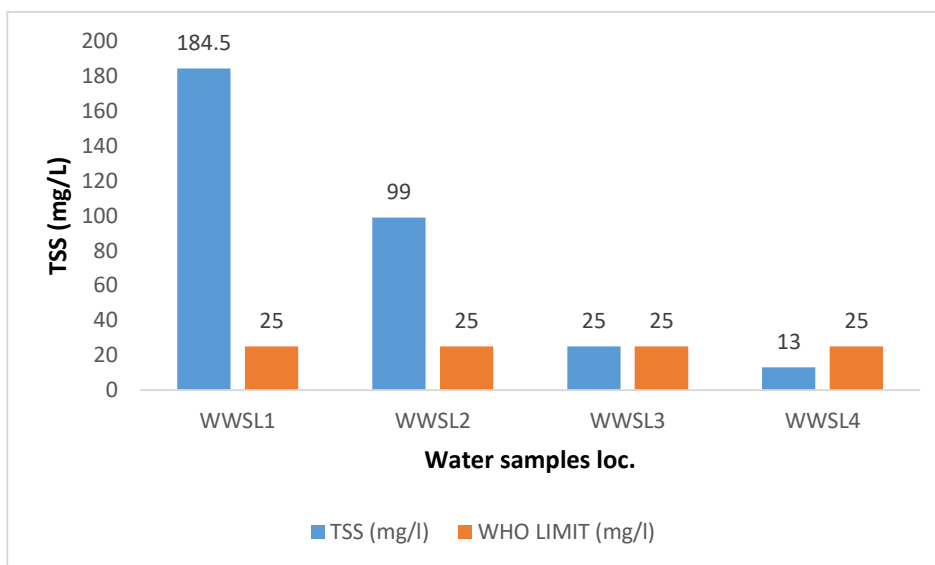


Figure 4: TSS comparison with WHO guideline limit

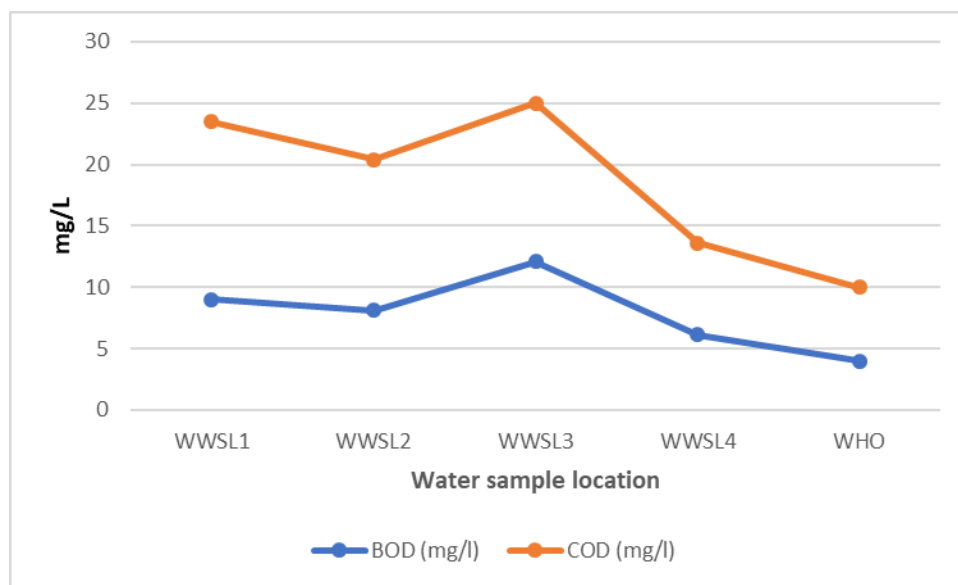


Figure 5: BOD comparison with COD values and WHO limit

3.1.6 Biochemical Oxygen Demand BOD

The concentration of BOD ranged between 6.15 and 12.1 mg/L, as presented in Figure 5, and the lowest value was found in WWSL4 (6.15 mg/L), followed by WWSL2 (8.1 mg/L), then WWSL1 (9 mg/L), and the highest value was found in WWSL3 (12.1 mg/L). BOD results from all the analysed well water surpassed the WHO BOD limit (4 mg/L).

3.1.7 Chemical Oxygen Demand COD

The concentration of COD ranged between 13.6 mg/L and 25 mg/L, and the lowest value was found in water from WWSL1 (45 mg/L), followed by WWSL2 (56.1 mg/L) and WWSL4 (63.05 mg/L), with WWSL4 having the highest value (78.5 mg/L), as shown in Figure 5. Results of COD indicate that all water samples exceeded the WHO COD limit (10 mg/L).

3.2 Anions

The concentration of NO_2^- ranged between 0.08 and 0.25 mg/L, as presented in the table, with the lowest concentration found in WWSL3 (0.08 mg/L), followed by WWSL1 (0.09 mg/L), then WWSL4 (0.20 mg/L), and the highest value was found in WWSL2 (0.25 mg/L). Only WWSL2 (0.25 mg/L) exceeded the WHO permissible limit. The concentration of NO_3^- ranged between 3.55 and 4.45 mg/L, with the lowest concentration found in WWSL2 (3.55 mg/L), WWSL1 (3.9 mg/L), and then WWSL3 (4.2 mg/L), and the highest value was found in WWSL4 (4.45 mg/L). The concentration of NO_3^- is within the WHO limit in all the sampled water. The result of SO_4^{2-} showed a range between 34 mg/L and 64 mg/L, with the lowest value found in water from WWSL4 (34 mg/L), followed by WWSL3 (50 mg/L), then WWSL1 (58.7 mg/L), and WWSL2 (64 mg/L), which had the highest value. The concentration of Cl^- ranged between 45 mg/L and 78.5 mg/L, and the lowest value was found in water from WWSL1 (45 mg/L), followed by WWSL2 (56.1 mg/L), then

WWSL4 (63.05 mg/L), and the highest value was in WWSL4 (78.5 mg/L). These values are within the WHO permissible limit.

3.3 Heavy Metals HMs

The result of the analysis done on the sampled water and other parameters used is shown in Table 1. The mean HMs followed the order of $Zn > Mn > Cr > Cu > Pb$ and Cd.

3.3.1 Copper Cu

Concentration of Cu in the sampled well water ranged between 0.001 and 0.22 mg/L, as revealed in Table 1, and the lowest concentration was found in the water sample from WWSL4 (0.001 mg/L), followed by WWSL3 (0.02 mg/L) and then WWSL2 (0.19 mg/L), and the highest value was from WWSL1 (0.22 mg/L). The concentrations of Cu in water samples from WWSL1 to WWSL4 are within the WHO standard (2 mg/L).

3.3.2 Zinc Zn

Zn concentration from the sampled well water ranged between 2.1 and 8.95 mg/L, as presented in Table 1, with the lowest concentration found in WWSL2 (2.1 mg/L), followed by WWSL1 (2.9 mg/L) and then WWSL4 (3.5 mg/L), and the highest value was found in WWSL3 (8.95 mg/L). The result indicated that WWSL2 (2.1 mg/L) and WWSL1 (2.9 mg/L) had values that do not exceed the WHO standard (3 mg/L); on the other hand, WWSL3 (8.95 mg/L) and WWSL4 (3.5 mg/L) had values higher than the WHO limit.

3.3.3 Manganese Mn

The result showed that Mn levels in the sampled water varied between 0.09 mg/L and

0.25 mg/L; the lowest concentration was found in WWSL4 (0.09 mg/L), followed by WWSL1 (0.23 mg/L) and then WWSL3 (0.25 mg/L), and the highest value was from WWSL2 (0.9 mg/L), as shown in Table 1. The result showed that only water samples from WWSL2 (0.9 mg/L) exceeded the WHO threshold (0.4 mg/L).

3.3.4 Cadmium Cd

Concentration of Cd in the sampled well water ranged between 0.004 and 0.01 mg/L, as presented in Table 1. The lowest value was found in well water from WWSL3 (0.004 mg/L), followed by WWSL4 (0.005 mg/L) and then WWSL2 (0.006 mg/L), and the highest concentration was found in WWSL1 (0.01 mg/L). The result indicated an exceedance of the concentration of Cd across the locations beyond the WHO-recommended limit (0.003 mg/L).

3.3.4 Lead Pb

Pb levels in the sampled well water varied between 0.002 and 0.18 mg/L, as revealed in Table 1. The lowest concentration of Pb was found in water samples from WWSL4 (0.002 mg/L), followed by both water samples from WWSL2 (0.07 mg/L) and WWSL3 (0.07 mg/L), and the highest value was found in WWSL1 (0.18 mg/L). The result showed that three (3) out of the four (4) sampled well waters have values; WWSL1 (0.18 mg/L), WWSL2 (0.07 mg/L), and WWSL3 (0.07 mg/L) that surpassed the WHO recommended limit (0.01 mg/L), except WWSL4 (0.002 mg/L), which was within the WHO guideline limit.

3.3.5 Chromium Cr

Cr levels from sampled well water ranged between 0.002 and 0.5 mg/L, as revealed in Table 1. The lowest concentration of Cr was found in WWSL4 (0.002 mg/L), followed by WWSL2 (0.02 mg/L) and then WWSL1 (0.03 mg/L), and the highest concentration was found in WWSL3 (0.5 mg/L). Three (3) out of the four (4) sampled well waters had Cr values: WWSL1 (0.03 mg/L), WWSL2 (0.02 mg/L), and WWSL4 (0.002 mg/L) that obeyed and adhered to the WHO tolerable

limit (0.05 mg/L), except WWSL3 (0.5 mg/L), which exceeded the WHO recommendation limit.

3.4 Physicochemical parameters used for WQI

The heavy metals and physicochemical parameters assessed for WQI determination included Cr, Pb, Cd, Mn, Mg, Ca, Zn, Cu, pH, EC, TDS, TSS, T.H, Cl⁻, SO₄²⁻, NO₃⁻, NO₂⁻, COD, and BOD (Table 1).

Table 1: Water quality indicators used for computation

Parameters	WHO [26]	WWSL1	WWSL2	WWSL3	WWSL4	RANGE
Cr (mg/l)	0.05	0.03	0.02	0.5	0.002	0.002 - 0.5
Pb (mg/l)	0.01	0.18	0.07	0.07	0.002	0.002 - 0.18
Cd (mg/l)	0.003	0.01	0.006	0.004	0.005	0.004 - 0.01
Mn (mg/l)	0.4	0.23	0.9	0.25	0.09	0.09 - 0.25
Zn (mg/l)	3	2.9	2.1	8.95	3.5	2.1 - 8.95
Cu (mg/l)	2	0.22	0.19	0.02	0.001	0.001 - 0.22
pH	6.5 - 8.5	7.12	7.35	7.03	7	7 - 7.35
E.C (μS/cm)	1000	67.5	121.3	148.9	145.1	67.5 - 148.9
TDS (mg/l)	500	37.8	78	89	99	37.8 - 99
TSS (mg/l)	25	184.50	99	25	13	13 - 184.5
Total Hardness (mg/l)	100-300	167.7	37.9	51.8	63.5	37.9 - 167.7
Chlorides CL ⁻ (mg/l)	250	45	56.1	78.5	63.05	45 - 78.5
Sulphates SO ₄ ²⁻ (mg/l)	100	58.7	64	50	34	34 - 64
Nitrates NO ₃ ⁻ (mg/l)	50	3.9	3.55	4.2	4.45	3.55 - 4.45
Nitrites NO ₂ ⁻ (mg/l)	0.2	0.09	0.25	0.08	0.2	0.08 - 0.25
BOD (mg/l)	<5	9	8.1	12.1	6.15	6.15 - 9
COD (mg/l)	10	23.5	20.4	25	13.6	13.6 - 23.5
Mg (mg/l)	0.2	2	2.4	4.4	4.9	2 - 4.9
Ca (mg/l)	75	10.5	11.5	18	22.5	11.5 - 22.5

Note: The WHO standard for the following parameters were used; pH (7.5), BOD (4 mg/l) and T.H (200 mg/l), WWSL represents (Well Water Sample Location)

Table 2: Weighted Arithmetic Water Quality Index (WAWQI) computation in sampled water from the study location

Indicators	WWSL1 (Vn)	WWSL2 (Vn)	WWSL3 (Vn)	WWSL4 (Vn)	WHO [26] Standard (Pn)	$\frac{1}{Pn}$	$K = \frac{1}{\sum \frac{1}{Pn}}$	$Tn = \frac{K}{Pn}$	Ideal Standard (Vo)
Cr	0.03	0.02	0.50	0.002	0.05	20.00	0.00214	0.04280	0
Pb	0.18	0.07	0.07	0.002	0.01	100.00	0.00214	0.21402	0
Cd	0.01	0.006	0.004	0.005	0.003	333.333	0.00214	0.71340	0
Mn	0.23	0.90	0.25	0.09	0.40	2.50	0.00214	0.00535	0
Zn	2.90	2.10	8.95	3.50	3.00	0.333	0.00214	0.00071	0
Cu	0.22	0.19	0.02	0.001	2.00	0.50	0.00214	0.00107	0
pH	7.12	7.35	7.03	7.00	7.50	0.133	0.00214	0.00029	7
E.C	67.50	121.30	148.9	145.1	1000	0.001	0.00214	0.00000	0
TDS	37.80	78.00	89.00	99.00	500	0.002	0.00214	0.00000	0
TSS	184.50	99.00	25.00	13.00	25.00	0.04	0.00214	0.00009	0
T.H	167.70	37.90	51.80	63.50	200	0.005	0.00214	0.00001	0
Cl ⁻	45.00	56.10	78.50	63.05	250	0.004	0.00214	0.00001	0
SO ₄ ²⁻	58.70	64.00	50.00	34.00	100	0.01	0.00214	0.00002	0
NO ₃ ⁻	3.90	3.55	4.20	4.45	50.00	0.02	0.00214	0.00004	0
NO ₂ ⁻	0.09	0.25	0.08	0.20	0.20	5.00	0.00214	0.01070	0
BOD	9.00	8.10	12.10	6.15	4.00	0.25	0.00214	0.00054	0
COD	23.50	20.40	25.00	13.6	10.00	0.10	0.00214	0.00021	0
Mg	2.00	2.40	4.40	4.90	0.20	5.00	0.00214	0.01070	0
Ca	10.50	11.50	18.00	22.50	75.00	0.0133	0.00214	0.00003	0
						$\sum(1/Pn) =$ 467.2443	$\sum Tn = 1$		

Table 2: Weighted Arithmetic Water Quality Index (WAWQI) computation in sampled water from the study location (Continued)

Indicators	In				InTn			
	WWS L1	WWS L2	WWS L3	WWS L4	WWS L1	WWS L2	WWS L3	WWS L4
Cr	60.00	40.00	1000	4.00	2.56825	1.7122	42.8042	0.1712
Pb	1800	700	700	20.00	385.2374	149.8146	149.8146	4.2804
Cd	333.333	200	133.333	166.666	237.8007	142.6805	95.1201	118.9000
Mn	57.50	225	62.50	22.50	0.307655	1.2039	0.3344	0.1204
Zn	96.666	70.00	298.333	116.666	0.068962	0.0499	0.2128	0.0832
Cu	11.00	9.50	1.00	0.05	0.011771	0.0102	0.0011	0.0001
pH	24.00	70.00	6.00	0.00	0.006849	0.0200	0.0017	0.0000
E.C	6.75	12.13	14.89	14.51	1.44E-05	0.0000	0.0000	0.0000
TDS	7.56	15.60	17.80	19.80	3.24E-05	0.0001	0.0001	0.0001
TSS	738	396	100.00	52.00	0.063179	0.0339	0.0086	0.0045
T.H	83.85	18.95	25.90	31.75	0.000897	0.0002	0.0003	0.0003
Cl ⁻	18.00	22.44	31.40	25.22	0.000154	0.0002	0.0003	0.0002
SO ₄ ²⁻	58.70	64.00	50.00	34.00	0.001256	0.0014	0.0011	0.0007
NO ₃ ⁻	7.80	7.10	8.40	8.90	0.000334	0.0003	0.0004	0.0004
NO ₂ ⁻	45.00	125	40.00	100.00	0.481547	1.3376	0.4280	1.0701
BOD	225.00	202.50	302.50	153.75	0.120387	0.1083	0.1619	0.0823
COD	235.00	204	250.00	136.00	0.050295	0.0437	0.0535	0.0291
Mg	1000	1200	2200	2450	10.70104	12.8412	23.5423	26.2175

Ca	14.00	15.333	24.00	30.00	0.0004	0.0004	0.0007	0.0009
WQI = AVERAGE WQI					637.4211	309.8586 <i>352.6817</i>	312.4859	150.9614

Note: All parameters have unit expressed as mg/L, except E.C ($\mu\text{S}/\text{cm}$) and pH that is unitless. Ideal standard (Vo) for most parameters is zero (0) aside pH that is 7. The WHO standard for the following parameters were used; pH (7.5), BOD (4 mg/L) and T.H (200 mg/L) WWSL represents (Well Water Sample Location)

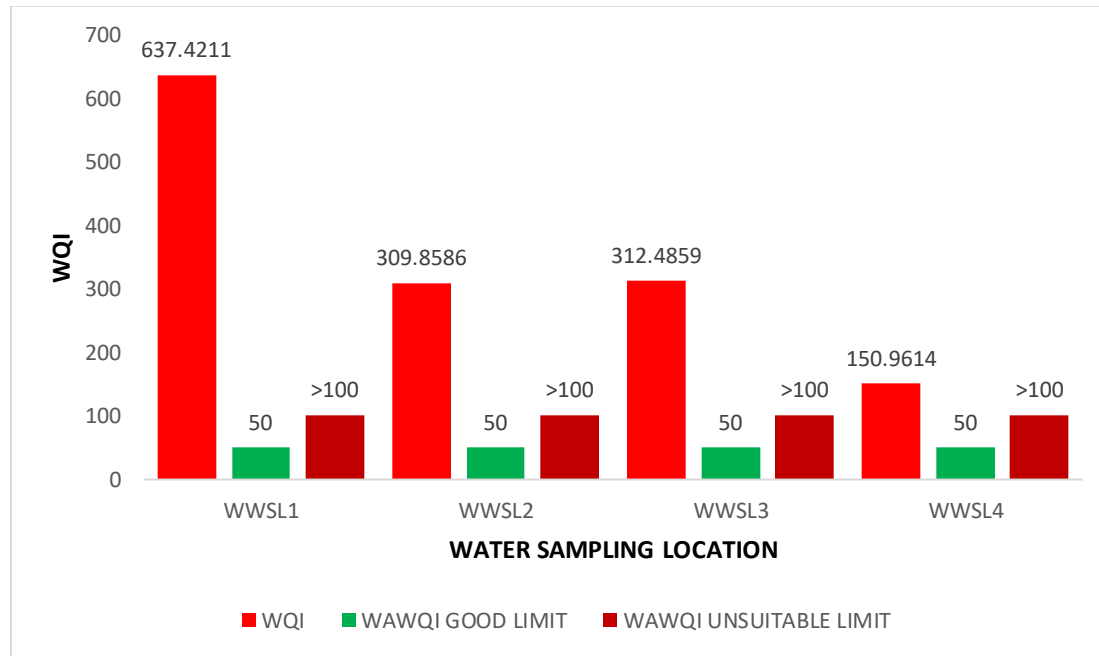


Figure 6: Comparison of WQI values with WAWQI limit for the sampled water locations

The WQI computed for the sampled water, as presented and compared with the WAWQI limit in Figure 6, showed the range of WQI from 150.9614 to 637.4211. It indicated that the lowest WQI value was found in WWSL4 (150.9614), followed by WWSL2 (312.4859)

and then WWSL3 (309.8586), and the highest WQI was found in WWSL1 (637.4211). The result showed WQI values were higher than the good and unsuitable WAWQI limits, with values higher than 100 (>100).

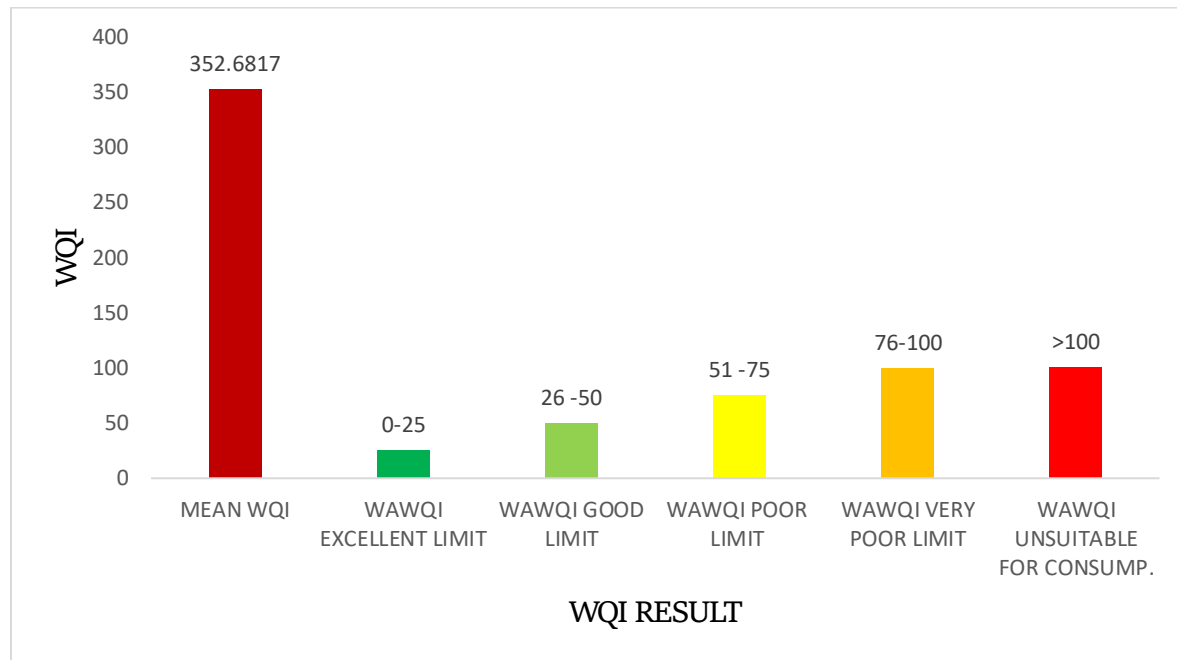


Figure 7: Comparison of mean WQI values with WAWQI limit for the sampled water locations

The overall WQI computed for the sampled water, as shown in Figure 7, indicated a mean WQI value of 352.6817. This value is above

the excellent (25), good (50), poor (75), and unsuitable (>100) limits.

Table 3: WAWQI Classification Ranking

S/N	Rating of the quality of water	WQI Scale
i.	[Excellent]	[0-25]
ii.	[Good]	[26-50]
iii.	[Poor]	[51-75]
iv.	[Very poor]	[76-100]
v.	[Unsuitable for consumption]	[>100]

4.0 Discussion

The total hardness value of the analysed well water showed decreased levels from WWSL1 to WWSL2 but increased from WWSL3 to WWSL4. The result showed that the T.H. concentration is within the WHO guideline

value (200 mg/L) in all the sampled water. The maximum T.H. levels obtained in this study are lower than the 369 mg/L reported value from research carried out in Suleja, Nigeria, by Mahi *et al.* [27]. The maximum T.H. as reported in the present study is higher than the 35.9 mg/L reported by Oni and

Fasakin [13] and the 112 mg/L values of a WQI research conducted by Okonofua *et al.* [1] near the Igbatoro dumpsite in Ondo State, Nigeria. The pH values of the sampled water from the four well stations were within the WHO guideline range, as shown in Table 1. However, the pH values in this study are higher than the values (5.6 – 6.0) reported by Oni and Fasakin [13]. The concentration of EC increases from WWSL1 to WWSL3 and decreases in WWSL4. The increase in EC might be due to minerals dissolving and diluting their deposits, accounting for well water due to precipitation and percolation of leachates. However, the EC levels from the sampled water were within the WHO acceptable limits. The highest value of EC from the current research is lower than 309 $\mu\text{S}/\text{cm}$ reported by Okonofua *et al.* [1] in their research on the WQI of well water near the Igbatoro dumpsite in Ondo State, Nigeria. Likewise, the value of EC in this study is lower than 1167.8 $\mu\text{S}/\text{cm}$ reported by Mahi *et al.* [27].

As reported by Adimalla and Venkatayogi [28], water palatability depends on the TDS in it, which shows the amount of dissolved minerals and salts present in the water. TDS concentration decreased across the water samples obtained from WWSL1 to WWSL4, but was still within the WHO limits.

This study reported a lower COD value than in a study by Oni and Fasakin [13], who reported a COD value range of 160 to 183.5 mg/L. The existence of higher COD values in the analysed water could be due to leachates and dissolved organic matter from the dumpsite, which percolate to the groundwater. BOD levels showed high

concentrations in all the water from the sampled wells, which exceeded the WHO permissible limit. Cl^- ion concentration increases across the sampled water from WWSL1 to WWSL3 and decreases in WWSL4. The concentration of Cl^- is within the WHO permissible limit in all the sampled water. Sulphate ion present in the sampled water revealed an increase, especially in water from WWSL1 to WWSL2, and then decreased from WWSL3 to WWS2. Sulphate concentration is within the WHO limit in all the sampled water. Nitrate concentration decreases from WWSL1 to WWSL2 and then increases from WWSL3 to WWSL4. Only WWSL2 (0.25 mg/L) exceeded the WHO permissible limit. Calcium and magnesium concentrations were noticed to increase across all the sampled water from the well locations; this increase might be due to anthropogenic sources, potentially originating from leachates from the dumpsite, or due to natural weathering of rocks or soil minerals. Enrichment of well water with higher concentrations of Mg and Ca could increase water hardness from the sampled wells through the formation of CaSO_4 and MgSO_4 salts. However, the concentrations of Mg and Ca do not exceed the WHO limit.

HM concentrations in the sampled water indicate higher Pb values that exceeded the WHO permissible limits in all the sampled wells. Poor intellectual development has been reported due to high exposure to Pb levels among the children, as reported by Akinola *et al.* [29], and erectile dysfunction, cardiovascular health issues, and organ damage or even death, according to Dashtizadeh *et al.* [30] and Debnath *et al.*

[31]. The concentration of Cr was found to be low from WWSL1, WWSL2, and WWSL4, except for WWSL3, which has higher values above the WHO permissible boundaries. The concentration of Cd from samples of water from WWSL2, WWSL3, and WWSL4 overshoot the limit of WHO, except for WWSL1, which was within the acceptable limits. High Cd levels are dangerous; if ingested, they can lead to renal cancer and kidney diseases, as revealed by Hameed *et al.* [32]. Health effects such as haemorrhagic injury, hypertension, atherosclerosis, and cardiovascular pathologies have been reported due to human exposure to high levels of Cd, as reported in a study by Purushottam and Bynigeri [33].

Mn concentration from water samples obtained from WWSL1, WWSL3, and WWSL4 conformed to WHO threshold values, apart from samples of water obtained from WWSL2 that exceeded the WHO acceptable limits. Zn quantity in water from WWSL3 as well as WWSL4 did not conform and had values that exceeded the WHO acceptable limits, except for water samples from WWSL1 and WWSL2 that fell within and conformed with the WHO acceptable values. Cu levels in all the sampled water conformed and were within the WHO safe acceptable limits.

The computed WQI for all four sampled well water indicates the water samples were unsuitable for consumption, as they were far above the good WQI rating of between 26 and 50, with higher values above 100, especially WQI values for WWSL1 (637.421), WWSL2 (309.858), WWSL3 (312.485), and WWSL4 (150.961). The

computed overall average WQI value is 352.682; this means the well water obtained from the assessed location is unsuitable for consumption, as the WQI has values that exceeded 100 (352.682); this also indicates that the water quality did not conform to the excellent quality ranking (see Table 3). The reason for the high WQI values might be due to leachates that might percolate due to improper waste dumping in the area. The WQI value (352.682) in this research is higher than the WQI value (10.47) observed by Shuaibu *et al.* [34] and that of the WQI value (337) as documented by Oni and Fasakin [13] in their Nigerian study. However, the WQI value in this study is lower than the WQI (2047) that Mgbenu and Egbueri documented [35].

5.0 Conclusion

WQI is a user-friendly and uncomplicated tool that combines various biological, chemical, and physical parameters, identified as metrics, into one value that signifies water quality. This method allows for a straightforward and easily interpretable representation of water quality. Water quality scoring is employed to evaluate the status of various water sources, with each scoring specifically designed for distinct assessment purposes. The study adopted the use of the WAWQI method, its mathematical forms, and composition to estimate the quality of groundwater in community wells near the Gosa dumpsite. Results indicated that WAWQI can be a simple but powerful tool for estimating the implications associated with unmitigated dumping activities on immediate groundwater quality. The WAWQI method indicates that the overall

groundwater quality in the immediate community wells near the Gosa dumpsite is considered unsuitable and unfit for drinking, as it contains elevated WQI values that exceeded 100. The study suggests the need for more research in this location and its environs. To evaluate the health issues linked to exposure to unsuitable as well as unsafe water quality on human health, especially among the children and adult consumers of the well water in the Gosa community. The need to check and monitor the activities of the Gosa dumpsite is highly recommended as a matter of urgency. Regular monitoring of groundwater samples, especially hand-dug wells in this location, should be consistent to verify that the water meets potable standards for human use.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

OAO collected the data, provided direction on the research, and drafted the manuscript. EO performed descriptive analysis and discussed the results. JTS handled the correspondence with the journal and designed the study area map. BYA edited and finalized the article for submission.

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