

Modeling of Groundwater Quality Near a Dumpsite Using Principal Component Analysis of Physico-Chemical Parameters

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ABSTRACT

The aim of this study was to determine water quality and develop a predictive model using principal component analysis (PCA) based on physico-chemical characteristics of groundwater sources around a dumpsite. Twelve (12) water samples were collected from groundwater sources around the Solous dumpsite situated in Alimosho Local Government area of Lagos State, Nigeria. Some of the physico-chemical parameters determined in the samples include pH, nitrate content, total hardness, cadmium, iron, lead, manganese, and zinc contents. These were used to determine the water quality index and model using the PCA. The water analysis showed pH levels ranging from 6.15 to 8.55, nitrate concentrations between 1 and 40 mg/L, and total hardness from 17.8 to 720.0 ppm. The concentrations of metals detected included manganese (0.01–0.04 mg/L), zinc (0.05–0.13 mg/L), iron (1.40–12.30 mg/L), lead (0.50–1.20 mg/L), and cadmium (0.03–0.08 mg/L) across all samples. For each of the 12 water samples, the Water Quality Index (WQI) varied between 2636.08 and 3752.60. The PCA revealed that whereas pH (0.865), total hardness (0.741), nitrate (0.816), and manganese (0.770) contents were the significant variables affecting the quality of the water samples within the study region, zinc had the least overall influence on the quality of the various water samples. In conclusion, all of the water samples had a water quality index greater than 300, meaning they were unfit for household (or drinking) use. The pH, total hardness, nitrate and manganese were the four most important variables while zinc was the least variable that influenced the quality of the water samples in this study.

Keywords: Dumpsite, Groundwater, Modelling, principal component analysis (PCA), Water Quality Index

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INTRODUCTION

For both human and industrial development, water is deemed a primary necessity. Due to the rise in population and industrialization, the demand for freshwater has surged over the past decades (Guptal *et al.*, 2017). Groundwater can be discovered nearly everywhere on Earth if one drills deep enough, but the majority of easily accessible groundwater is typically located within 1 km of the Earth's surface (Hess, 2014). Around 24% of global aquifers are significantly overexploited, primarily due to the demand for irrigation in agriculture to support human and livestock populations (Gleeson *et al.*, 2012). Groundwater serves as a crucial water supply source for industries, household use, recreation, commerce, and agricultural purposes (Ogunriola *et al.*, 2021). It is the main sources of potable drinking water which often include shallow and deep hand-dug wells, motorised deep wells, and boreholes (Akinbile, 2012; Oluseyi *et al.*, 2014).

Groundwater contamination can be caused by seawater intrusion or the disposal of untreated sewage water (Algoul *et al.*, 2016). Inadequate waste management at dumpsites can also lead to various negative environmental and health effects due to underground soil bed or aquifer pollution from leachate (Olu and Iyere, 2020). These pollutants also contaminate groundwater, posing significant risks to local users and becoming a major environmental issue (Nagarajan *et al.*, 2012; Olu, 2021). Groundwater contamination with heavy metals from leachate can be harmful to human health. The toxicity which depends on the type of metal waste at the dumpsite, its degradation process, and the organisms exposed to it (Ogunriola *et al.*, 2021).

Various studies have reported on the assessment of water quality using different parameters (physico-chemical and biological) and the diverse methods and techniques for water protection (Shah and Geeta, 2017; Yisa and Jimoh, 2010). One method for evaluating river water quality is the water quality index, which has proven to be

an effective and valuable tool for assessing water quality (Gupta *et al.*, 2017).

A water quality index (WQI) offers a single value that represents the overall water quality at a specific location and time based on multiple water quality parameters (Kumar and Dua, 2009). It condenses vast amounts of water quality data into simple formats for easy reporting to the public and management in a comprehensible manner (Akkaraboyina and Raju, 2012). It aids in understanding the overall water quality status of a water source and has been utilized for both surface and groundwater quality assessment globally over the past few decades (Echoke *et al.*, 2018; Tyagi *et al.*, 2013). Various water quality indices used worldwide include the US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), Oregon Water Quality Index (OWQI), and Weighted Arithmetic Water Quality Index (WAWQI) (Gupta *et al.*, 2017). The water quality index has been formulated using five categories of WQI aggregation methods: additive aggregation method (Horton, 1965), multiplicative aggregation method (Dinius, 1987), geometric average (McClelland, 1974), harmonic average (Dojlido *et al.*, 1994), and minimum operator (Smith *et al.*, 1987a, b).

Water quality modeling serves as a crucial instrument in water body management, enabling the anticipation of pollutant behavior and movement within such environments. Additionally, it reduces the time and expenses associated with logistics, labor, and materials for laboratory examinations (Bai *et al.*, 2011; Howard, 2014; Huang *et al.*, 2012; Manivanan, 2017; Wang *et al.*, 2013), particularly in situations where the study region or facility is inaccessible for on-site experiments due to communal conflicts and specific environmental pollution concerns (Howard *et al.*, 2019). Modeling outcomes under various pollution scenarios using water quality models are crucial elements of environmental

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impact assessments. According to Tizro *et al.* (2014), the primary goals of water quality modeling include: (i) demonstrating cause-and-effect relationships, (ii) identifying pollutant sources impacts, (iii) determining required monitoring levels, (iv) prioritizing further monitoring and management goals, and (v) assessing and projecting future water quality conditions.

Soils and rocks chemical composition can be uttered through the chemical quality of groundwater that flows through them with the aid of mineral dissolution and solubility, oxidation, reduction, and ion exchange (Todd, 1980). Water quality is associated with chemical, physical, and biological attributes of water, typically concerning its appropriateness for a specific use (Khan *et al.*, 2003; Sargaonkar and Deshpande, 2003).

The black box model is a widely used approach for understanding the overall input-output behavior of a system without relying on analytical equations (Banadda *et al.*, 2011; Howard *et al.*, 2019). This model assists users in interpreting and predicting water quality responses to natural events and anthropogenic pollution, aiding in various pollution management decisions (Lai *et al.*, 2013). The developed models are typically employed for forecasting future process values or for use in process control applications. Key aspects of black box modeling include: data preprocessing, model complexity, linearity, and extrapolation. The different black box modeling techniques include standard multivariate methods such as principal component analysis (PCA) and partial least squares (PLS) modeling, time series modeling, artificial neural network modeling, fuzzy modeling, and neuro-fuzzy modeling (Howard *et al.*, 2019).

Principal component analysis (PCA) fully utilizes the variance derived from linear combinations of the original variables (Rencher, 2002). Accounting for the most variance from the variables linear combination is the first principal component.

Accounting for the most variance while being orthogonal to the first from the variables linear combination is the second principal component and this process continues for subsequent components. Eigenvalues measure the variance elucidated by each principal component. Loadings represent the correlation between the original variables and each principal component. Scores are the third outcome of the analysis and essentially represent the values of the components for each observation (Howard *et al.*, 2019).

This study aims to evaluate water quality and create a predictive model utilizing principal component analysis (PCA) based on physico-chemical parameters from groundwater sources near a dumpsite.

METHODOLOGY

Sample collection

The study area in this research work were around the Solous dumpsite which according to Ogunrinola *et al.* (2021) is situated within the longitude 3.43417 E to 3.41750 E and latitude 6.93528 N to 6.95194 N in Alimosho Local Government area of Lagos State, Nigeria. It is surrounded by residential areas, an abattoir, and the Oba stream, which is located around 2.5 kilometers east of the dumpsite. The trash sent to this dumpsite vary in type, from organic to inorganic, hazardous to non-hazardous. Water samples were collected in 60 cl polythene bottles from twelve (12) sampling locations (see Figure 1). and stored at 4°C until further laboratory analysis.

Laboratory Analysis of Water Samples

This study used the American Public Health Association's (2017) suggested standard methods of assessing water quality to determine the concentrations of several physico-chemical parameters. The water samples were then subjected to a comprehensive laboratory study to identify their physico-chemical characteristics, which were then utilized to calculate the overall water quality index for each sample.

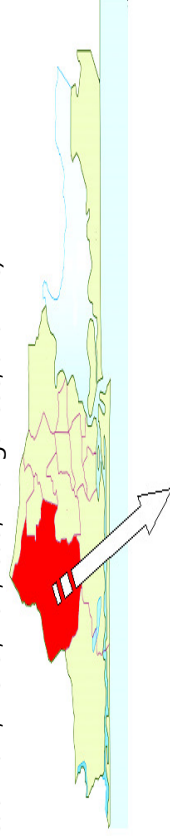
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Electrical Conductivity (EC) refers to the ability of water to conduct an electrical current. Conductivity is essential because it directly influences the quality of water used for drinking and irrigation. Waters with a higher solids content are laxative, but they can also have the opposite effect on persons whose bodies are not used to them, giving the water an unpleasant mineral taste (Shah and Geeta, 2017). The EC were

determined using an Oakton TDS/Conductivity meter (HI 2315, Hanna Instrument). A handheld pH meter (PHS-25) was used to estimate pH. The concentrations of heavy metals (copper, cadmium, nickel, iron, lead, manganese, and zinc)



in various water samples were evaluated using an Atomic Adsorption Spectrophotometer (AAS). (SOLAAR 969 UNICAM SERIES, with air-acetylene flame).

Sample collection site around Solous Dumpsite



Fig. 1: Map of sample collecting sites (extracted from Alimosho Local Government, Lagos, where the Solous dumpsite is located)

Water Quality Index Modelling

The water quality index was generated for each sample of water taken from various boreholes to analyze the variation in overall water quality at each borehole location. The water quality index

was modelled using twelve (12) essential physico-chemical characteristics. The physico-chemical parameters chosen are pH, nitrate content, electrical conductivity (EC), phosphate, total hardness (TH), copper, cadmium, nickel, iron,

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lead, manganese, and zinc contents. The basic steps in modeling the water quality index are as follows:

Parameter Weightage Determination: To calculate the water quality index, we must first determine the weight of each of the identified characteristics. Parameters with greater allowed limits are less dangerous because they do not significantly alter the quality of the water sample even when present in high concentration. Weightage of examined parameters has an inverse connection with their permitted limitations. Therefore

$$W_n = \frac{1}{S_n} \tag{Eqn. 1}$$

Where;

W_n = Unit weight of the different parameters tested

S_n = Standard values of selected parameters (WHO Standard Permissible Limit)

Quality Rating or Sub Index of Selected Parameters: A rating scale was created for the range of values of each parameter. The rating scale ranges from 0 to 100 and is broken into five intervals. The rating $q_n = 0$ indicates that the parameter present in water exceeds the standard maximum allowable limits, and the water is badly polluted. On the other hand, $q_n = 100$ indicates that the parameter present in water has the highest desirable value. This scale is a modified version of the rating scale provided by Tiwari and Mishra (1985) and is calculated as follows:

$$q_n = \frac{100(V_n - V_{io})}{(S_n - V_{io})} \tag{Eqn. 2}$$

Where:

q_n = Quality rating or sub index

V_n = Laboratory test result for each parameter tested

S_n = Standard value of each parameter tested (WHO standard for drinking water)

V_{io} = ideal value of selected parameters tested (in pure water $V_{io} = 0$ for all parameters tested except pH which is 7.0)

Water Quality Index Calculation: Essentially, a Water Quality Index (WQI) is a set of criteria that can be used to assess the overall quality of a water sample. pH, nitrate content, electrical conductivity (EC), phosphate, total hardness (TH), copper, cadmium, nickel, iron, lead, manganese, and zinc contents. The numerical value was then multiplied by a weighting factor that reflects the test's significance to water quality. The total of the obtained values was combined together to calculate an overall water quality index. It is essentially a mathematical method for determining a single value from several test results. The WQI result indicates the level of water quality at a certain water sample location.

The Water Quality Index (WQI) was calculated for each water sample location using the mass balance equation of the form:

$$(100) - \left(\frac{\sum W_n q_n}{\sum W_n} \right) \tag{Eqn.3}$$

Ground Water Quality Analysis Using Principal Component Analysis

Statistical computations for ground water modeling utilizing principal component analysis (PCA) at $p < 0.05$ were performed using SPSS 26. The PCA analysis will help in extracting the component factor, which determines how well the component factors explain the variation in the overall water quality of samples gathered around the dumpsite.

RESULTS AND DISCUSSION

Table 1 shows that the pH ranges from 6.15 to 8.55, and with the exception of samples 1 (6.15)

and 11 (8.55), all other samples meet WHO and SON requirements. This is consistent with findings reported by Ogunrinola *et al.* (2021), Oluseyi *et al.* (2014), and Majolagbe *et al.* (2017). Acidic water drinking has been associated to a number of diseases, including cancer, ulcers, and intestinal growth (Klaassen *et al.*, 1986; Ogunrinola *et al.*, 2021).

Electrical conductivity (EC) is important because it measures cations, which affect flavor and thus have a substantial impact on user acceptance of drinkable water (Alobaidy *et al.*, 2010; WHO, 2004). It is an indirect measurement of total dissolved salts. High conductivity can be caused by natural weathering of specific sedimentary rocks or by anthropogenic sources such as industrial and sewage discharge (WHO, 2004). Table 1 shows that the electrical conductivity (EC) of the 12 samples ranged from 83.1 to 6570 $\mu\text{S}/\text{cm}$. Samples 5, 6, 11, and 12 all exhibited EC levels that are above the WHO and SON limits. Electrical conductivity is an indicator of the quantity of total dissolved ions, such as heavy metals, in water (Oyem *et al.*, 2014), hence high

EC values suggest a significant ion-exchange between soil and water (Ogunrinola *et al.*, 2021).

The total hardness of water is a measure of the amount of calcium and magnesium present. Total Hardness (TH) is a significant indicator of water quality, whether it is used for domestic, industrial, or agricultural reasons (Alobaidy *et al.*, 2010). Table 1 shows that the total hardness value ranged from 17.8 to 720.0 ppm, which is consistent with what Yusuf (2007) reported in his study. Samples 8 and 9 exhibited TH levels higher than the WHO permitted limit (500 ppm). The high overall hardness value makes the water insufficient for laundry chores and produces excessive scale buildup.

The most common source of phosphate is fertilizer runoff from agricultural or residential cultivated land into surface waters during storms. High phosphate levels induce muscular injury, difficulty in breathing, and kidney failure (Nyamangara *et al.*, 2013). Table 1 shows that phosphate concentrations range from 1.00 to 2.00 mg/L, which is greater than the WHO acceptable limit of 0.30 mg/L.

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Table 1: Physico-chemical characteristics of the water samples collected

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|------------------|------|-------|-------|-------|-------|------|------|-------|-------|------|-------|-------|
| pH | 6.15 | 6.50 | 7.46 | 7.18 | 7.83 | 8.02 | 7.89 | 7.51 | 7.49 | 7.55 | 8.55 | 8.23 |
| E.C (µS/cm) | 83.1 | 187.0 | 122.5 | 153.5 | 1406 | 1676 | 288 | 359 | 353 | 78.2 | 6570 | 2940 |
| T.H (ppm) | 17.8 | 53.4 | 17.8 | 17.8 | 124.6 | 89.0 | 35.6 | 720.0 | 530.0 | 17.8 | 356.0 | 267.0 |
| Nitrate (mg/L) | 2.5 | 2.5 | 1.5 | 2.5 | 10 | 40 | 5.0 | 2.5 | 1.5 | 1.0 | 2.5 | 10 |
| Phosphate (mg/L) | 1.00 | 1.00 | 1.00 | 1.00 | 1.50 | 1.50 | 1.00 | 1.50 | 1.50 | 1.50 | 1.75 | 1.00 |
| Copper (mg/L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cadmium (mg/L) | 0.08 | 0.08 | 0.05 | 0.04 | 0.05 | 0.07 | 0.07 | 0.06 | 0.05 | 0.03 | 0.06 | 0.06 |
| Nickel (mg/L) | 0.14 | 0.12 | 0.16 | 0.12 | 0.19 | 0.15 | 0.16 | 0.14 | 0.14 | 0.12 | 0.17 | 0.18 |
| Iron (mg/L) | 1.50 | 1.80 | 3.40 | 3.90 | 1.50 | 1.40 | 1.60 | 12.30 | 4.70 | 2.20 | 9.10 | 5.30 |
| Lead (mg/L) | 0.60 | 0.50 | 0.70 | 0.80 | 1.20 | 0.80 | 0.80 | 0.70 | 0.70 | 1.10 | 0.90 | 0.90 |
| Manganese (mg/L) | 0.01 | 0.01 | 0.01 | 0.00 | 0.02 | 0.03 | 0.04 | 0.04 | 0.03 | 0.01 | 0.01 | 0.01 |
| Zinc (mg/L) | 0.07 | 0.06 | 0.06 | 0.07 | 0.13 | 0.06 | 0.06 | 0.06 | 0.06 | 0.08 | 0.06 | 0.05 |

E.C- Electrical Conductivity, T.H- Total Hardness

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Table 2: World Health Organization (WHO) and Standard Organisation of Nigeria (SON) limits values and Weightage Parameters

| Parameters | WHO (2017) | Weightage (W _n) (WHO) | SON (2015) | Weightage (W _n) (SON) |
|------------------|------------|-----------------------------------|------------|-----------------------------------|
| pH | 6.5-8.5 | 0.154-0.118 | 6.5-8.5 | 0.154-0.118 |
| E.C (µS/cm) | 400 | 0.003 | 1000 | 0.001 |
| T.H (ppm) | 500 | 0.002 | 150 | 0.006 |
| Nitrate (mg/L) | 50 | 0.02 | 50 | 0.02 |
| Phosphate (mg/L) | 0.30 | 3.33 | - | - |
| Copper (mg/L) | 2.00 | 0.5 | 1.00 | 1 |
| Cadmium (mg/L) | 0.003 | 333.33 | 0.003 | 333.3 |
| Nickel (mg/L) | 0.07 | 14.29 | 0.02 | 50 |
| Iron (mg/L) | 0.30 | 3.33 | 0.30 | 3.3 |
| Lead (mg/L) | 0.01 | 100 | 0.01 | 100 |
| Manganese (mg/L) | 0.40 | 2.5 | 0.20 | 5 |
| Zinc (mg/L) | 3.00 | 0.33 | 3.00 | 0.3 |
| ΣW _n | | 457.67-457.63 | | 493.08-493.05 |

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Table 3: Quality Rating (qr_n) of physico-chemical characteristics of the water samples collected using WHO limit values

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|---------|---------|
| pH | 170 | 100 | -92 | -36 | -166 | -204 | -178 | -102 | -98 | -110 | -310 | -246 |
| E.C (µS/cm) | 20.78 | 46.75 | 30.63 | 38.38 | 351.50 | 419.00 | 72.00 | 89.75 | 88.25 | 19.55 | 1642.50 | 735 |
| T.H (ppm) | 3.56 | 10.68 | 3.56 | 3.56 | 24.92 | 17.8 | 7.12 | 144 | 106 | 3.56 | 71.2 | 53.4 |
| Nitrate (mg/L) | 5.00 | 5.00 | 3.00 | 5.00 | 20.00 | 80.00 | 10.00 | 5.00 | 3.00 | 2.00 | 5.00 | 20.00 |
| Phosphate (mg/L) | 333.30 | 333.30 | 333.30 | 333.30 | 666.60 | 500.00 | 500.00 | 333.30 | 500.00 | 500.00 | 583.30 | 333.30 |
| Copper (mg/L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cadmium (mg/L) | 2666.67 | 2666.67 | 1666.67 | 1333.30 | 1666.67 | 2333.30 | 2333.30 | 2000.00 | 1666.67 | 1000.00 | 2000.00 | 2000.00 |
| Nickel (mg/L) | 200.00 | 171.43 | 228.57 | 171.43 | 271.43 | 214.29 | 228.57 | 200.00 | 200.00 | 171.43 | 242.86 | 257.14 |
| Iron (mg/L) | 500.00 | 600.00 | 1133.30 | 1300.00 | 500.00 | 466.60 | 533.30 | 4100.00 | 1566.60 | 733.3 | 3033.3 | 1766.60 |
| Lead (mg/L) | 6000.00 | 5000.00 | 7000.00 | 8000.00 | 12000.0 | 5000.00 | 8000.00 | 8000.00 | 7000.00 | 11000.00 | 9000.00 | 9000.00 |
| Manganese (mg/L) | 2.50 | 2.50 | 2.50 | 0.00 | 5.00 | 7.50 | 10.00 | 10.00 | 7.50 | 2.50 | 2.50 | 2.50 |
| Zinc (mg/L) | 2.30 | 2.00 | 2.00 | 2.30 | 4.30 | 2.00 | 2.00 | 2.00 | 2.00 | 2.60 | 2.00 | 1.60 |

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Table 4: Quality Rating (qn) and Weightage (Wn) of physico-chemical characteristics of the water samples collected using WHO limit values (Wqn)

| Parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|------------------------|-----------|------------|------------|---------|------------|------------|------------|------------|------------|------------|------------|------------|
| pH | 26.18 | 15.40 | -14.17 | -5.54 | -25.56 | -31.42 | -27.41 | -15.71 | -15.09 | -16.94 | -47.74 | -37.88 |
| E.C (µS/cm) | 0.06 | 0.14 | 0.09 | 0.12 | 1.05 | 1.26 | 0.22 | 0.27 | 0.26 | 0.06 | 4.93 | 2.21 |
| T.H (ppm) | 0.01 | 0.02 | 0.01 | 0.01 | 0.05 | 0.04 | 0.01 | 0.29 | 0.21 | 0.01 | 0.14 | 0.11 |
| Nitrate (mg/L) | 0.10 | 0.10 | 0.06 | 0.10 | 0.40 | 1.60 | 0.20 | 0.10 | 0.06 | 0.04 | 0.10 | 0.40 |
| Phosphate (mg/L) | 1099.89 | 1099.89 | 1099.89 | 1099.89 | 2199.78 | 1650.00 | 1650.00 | 1099.89 | 1650.00 | 1650.00 | 1924.89 | 1099.89 |
| Copper (mg/L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cadmium (mg/L) | 888801 | 888801 | 555501 | 444389 | 555501 | 777689 | 777689 | 666600 | 555501 | 333300 | 666600 | 666600 |
| Nickel (mg/L) | 2858.00 | 2449.73 | 3266.27 | 2449.73 | 3878.73 | 3062.20 | 3266.27 | 2858.00 | 2858.00 | 2449.73 | 3470.47 | 3674.53 |
| Iron (mg/L) | 1650.00 | 1980.00 | 3739.89 | 4290.00 | 1650.00 | 1539.78 | 1759.89 | 13530.00 | 5169.78 | 2419.89 | 10009.89 | 5829.78 |
| Lead (mg/L) | 600000 | 500000 | 700000 | 800000 | 1200000 | 500000 | 800000 | 800000 | 700000 | 1100000 | 900000 | 900000 |
| Manganese (mg/L) | 6.25 | 6.25 | 6.25 | 0.00 | 12.50 | 18.75 | 25.00 | 25.00 | 18.75 | 6.25 | 6.25 | 6.25 |
| Zinc (mg/L) | 0.69 | 0.60 | 0.60 | 0.69 | 1.29 | 0.60 | 0.60 | 0.60 | 0.60 | 0.78 | 0.60 | 0.48 |
| ZW^{qn} | 1494442.1 | 1394353.13 | 1263599.89 | 1252224 | 1763219.24 | 1283931.81 | 1584362.78 | 1484098.34 | 1265183.57 | 1439809.82 | 1581969.53 | 1577175.77 |

E.C - Electrical Conductivity, T.H - Total Hardness

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Nitrate, a dissolved inorganic solid, has been shown to connect with salinity and total dissolved solids (TDS) (Annapoorani *et al.*, 2014; Igboekwe *et al.*, 2011; Yan *et al.*, 2015). Some undesirable health issues, such as age-related macular degeneration (AMD), diabetes, gastrointestinal and thyroid dysfunction, have been associated to elevated nitrate levels in drinking water (Aschebrook-Kilfoy *et al.* 2012; Klein *et al.* 2013). Methemoglobinemia (blue baby syndrome), particularly in babies, has

been established as one of the severe health impacts of prolonged exposure to nitrate as a pollutant in groundwater (Jalili *et al.*, 2018; Radford *et al.*, 2018; Soleimani *et al.*, 2018). Nitrate levels in this investigation ranged from 1 to 40 mg/L, as shown in Table 1. Olu *et al.* (2021) reported the same findings. Table 2 shows that none of the samples had nitrate levels higher than the WHO permitted nitrate threshold of 50 mg/L.

Table 5: Water quality index (WQI) for the water samples collected

| Samples | $\frac{\sum W_n q_n}{\sum W_n}$ | WQI |
|---------|---------------------------------|---------|
| 1 | 3265.32 | 3165.32 |
| 2 | 3046.63 | 2946.63 |
| 3 | 2760.94 | 2660.94 |
| 4 | 2736.08 | 2636.08 |
| 5 | 3852.60 | 3752.60 |
| 6 | 2805.37 | 2705.37 |
| 7 | 3461.80 | 3361.80 |
| 8 | 3242.73 | 3242.73 |
| 9 | 2764.40 | 2764.40 |
| 10 | 3145.96 | 3145.96 |
| 11 | 3456.57 | 3456.57 |
| 12 | 3446.10 | 3446.10 |

Heavy metals like cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) can cause cancer, mutation, neurotoxicity, and teratogenicity. Manganese (Mn) concentrations in Table 1 ranged between 0.01 and 0.04 mg/L, which is lower than the WHO permitted limit of 0.40 mg/L seen in Table 2. Also, zinc (Zn) levels ranged between 0.05 and 0.13 mg/L, which is less than the WHO allowed limit of 3.00 mg/L, as shown in Table 2.

Copper (Cu) was not found in all of the water samples. Table 1 shows that the iron concentration in the samples ranged between 1.40 to 12.30 mg/L, which is greater than the WHO acceptable limit of 0.30 mg/L, as shown in Table 2. The high iron level found in the water samples causes precipitation difficulties (Longe and Balogun, 2010), which could be attributed to the high concentration of iron-

based waste materials generated by home and industrial wastes (Ogunrinola *et al.*, 2021).

Lead is a dangerous metal that accumulates in the human body. Lead exposure in humans can cause memory loss, hearing problems, and digestive troubles (Olu *et al.*, 2022; Singh Sankhla *et al.*, 2019). According to Table 1, the quantity of lead in all samples in this investigation ranges between 0.50 to 1.20 mg/L, which exceeds the WHO permitted limit of 0.01 mg/L, as shown in Table 2. Table 3 shows that the Quality Rating (qr) for lead spans between 5,000.00 and 12,000.00, which contributes to the high WQI value across all samples. Table 4 shows the quality rating (qn) and Weightage (Wn) of physico-chemical

characteristics of the water samples collected using WHO limit values.

Cadmium is frequently found naturally in sediments, where it coexists with other elements, and its buildup can contribute to the development of "Itai-Itai" disease, a human condition characterized by bone weakening and fractures (Bhatnagar and Sillanpää, 2009). Table 1 shows that Cd concentrations in the samples varied from 0.03 to 0.08 mg/L, which is higher than the WHO's permitted limit of 0.003 mg/L, as shown in Table 2. Table 3 shows that the Quality Rating (qn) for Cd spans from 1000.00 to 2666.67, which contributes to the high WQI value across all samples.

Exposure to high amounts of nickel has been found to have chronic harmful effects as carcinogens in animals and people (Mohod and Dhote, 2013). The Ni concentrations in this investigation ranged between 0.12 to 0.19 mg/L, which is higher than the WHO permitted limit of 0.07 mg/L, as shown in Table 2.

The WQI's usefulness is demonstrated by its use as an instrument in the authorities' management plans to improve water quality in the area (Ojște and Breabăn, 2012; Paiu and Breabăn, 2014). Adimalla (2020) and Olu *et al.* (2021) classify groundwater quality into five categories based on WQI values: excellent (<50), good (50-100), bad (100-200), very poor (200-300), and unfit for drinking (>300). WQI, which was employed in this work to evaluate the quality of the water samples, was also used in studies by Adimalla *et al.* (2018), Effendi *et al.* (2015), and Gupta *et al.* (2017) to assess the quality of water for drinking.

WQI, which was employed in this work to evaluate the quality of the water samples, was also used in studies by Adimalla *et al.* (2018), Effendi *et al.* (2015), and Gupta *et al.* (2017) to assess the quality of water for drinking. Usoh *et al.* (2023), Ahaneku and Animashaun (2013), Singh *et al.* (2012), and Etim *et al.* (2013) all revealed high WQI values in their studies, indicating that pollution has a significant impact on water quality.

Table 6: PCA loading component matrix of physico-chemical characteristics for the water samples

| | Component | | | |
|------------------|-------------------|--------|--------|--------|
| | 1 | 2 | 3 | 4 |
| Mean ± S. D | | | | |
| pH | 7.53 ± 0.68 | 0.865 | | |
| E.C (µS/cm) | 1184.69 ± 1911.10 | 0.665 | 0.304 | -0.609 |
| T.H (ppm) | 187.23 ± 234.61 | 0.364 | 0.741 | 0.328 |
| Nitrate (mg/L) | 6.79 ± 10.91 | | 0.816 | |
| Phosphate (mg/L) | 1.31 ± 0.36 | 0.763 | -0.329 | |
| Cadmium (mg/L) | 0.06 ± 0.02 | -0.364 | 0.415 | 0.620 |
| Nickel (mg/L) | 0.015 ± 0.03 | 0.732 | 0.341 | 0.341 |
| Iron (mg/L) | 4.06 ± 3.44 | 0.344 | 0.735 | -0.519 |
| Lead (mg/L) | 0.79 ± 0.22 | 0.725 | -0.463 | -0.420 |
| Manganese (mg/L) | 0.02 ± 0.01 | 0.02 | 0.458 | 0.307 |
| Zinc (mg/L) | 0.07 ± 0.02 | 0.394 | -0.741 | 0.770 |
| Eigenvalue | | 3.442 | 2.486 | 1.932 |
| % Variance | | 31.294 | 22.596 | 17.563 |
| Cumulative % | | 31.294 | 53.890 | 71.453 |
| | | | | 83.057 |

A PCA was done on each group (physicochemical) specified by the original cluster analysis, providing a good grasp of which parameters were responsible for the most variation in each group. Similar analyses were conducted by Bu *et al.* (2010), Jucui *et al.* (2011), Singh *et al.* (2004), Varol and Sen (2009), Batur and Maktav (2019), Benkov *et al.* (2023) and Zhang *et al.* (2009) for water from the Jinshui basin, the Jinghe River of Shaanxi Province, China, the Gomti River basin, India, the Behrimaz basin, Turkey, the Lake Gala, Turkey, Struma River Catchment, Bulgaria and the Xiangjiang basin, China respectively. In the PCA for the water samples, all extracted Principal Components PCs from variables with eigenvalues greater than 1.00 were retained and examined. The total sample variance of the four retrieved PCs was approximately 83.06%, which was made up of PC1 (31.294), PC2 (22.596), PC3 (17.563), and PC4 (11.605). The first loadings display around 32% of the total variance (Table 6). According to Islam & Mostafa (2022a, b) and Yusuf *et al.* (2022), the parameters that contribute the most to the

components usually share a high degree of similarity. Figure 2 depicts a component plot in rotated space. Table 6 shows that the first component factor is most strongly connected with pH (0.865), electrical conductivity (EC) (0.665), phosphate (0.364), nickel (0.732), and lead (0.725), with pH having the biggest impact. The second component factor is most closely related to total hardness (T.H) (0.741), cadmium (0.415), iron (0.735), and manganese (0.458), with T.H concentration having the greatest influence. The third component factor has the highest correlation with nitrate (0.816) and cadmium (0.620), with nitrate having the greatest influence. The fourth component factor is most strongly connected with T.H, manganese, and zinc, with Mn exerting the greatest influence. According to the results of Table 6, zinc has the least influence on the overall quality of the various water analyzed. In addition, pH, total hardness, nitrate, and manganese are the three most critical variables influencing the quality of water samples in the research area.

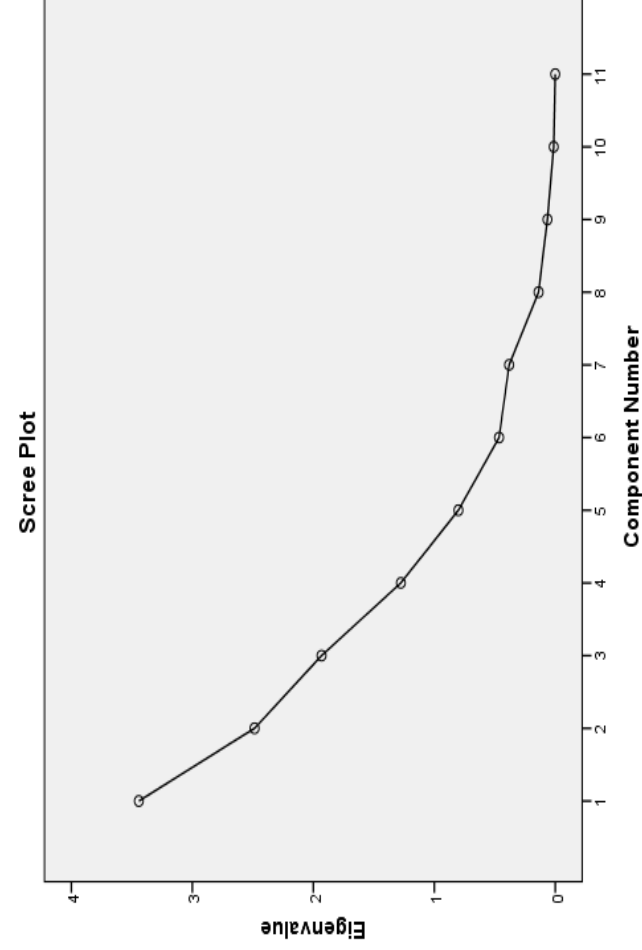


Fig. 2: Scree plot showing factors with high significant influence

CONCLUSION

This work has added to the current literature on how effluents from dumpsites that find their way into groundwater aquifers near them affect the appropriateness of the water for drinking and domestic use. The water quality index for all water samples was greater than 300, and the quality rating (q_p) of Pb and Cd levels contributed to the high WQI value across all samples. In this investigation, the four most important variables influencing the quality of water samples were pH, total hardness, nitrate, and manganese contents, with zinc content being the least important

AUTHORS' CONTRIBUTION

ANAGA, S.O.: Developed experimental design of the research and the manuscript first draft.
 NOBLE-OKEREKE, H.: Involved in samples collection and manuscript development.
 UNAEZE, C.H.: Worked on the data analysis and edited the manuscript,
 YUSUF, H.O.: Involved in the data interpretation and manuscript editing

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CONFLICT OF INTEREST

The authors conducted this study without any conflict of interest or biased motives.

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