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# Hydrogeochemical Characterization and Quality Assessment of Groundwater Based on Water Quality Index in Imo state, South Eastern Nigeria

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**ABSTRACT:** Water Quality Index (WQI), Principal Component Analysis (PCA), Correlation matrix, Metal Pollution Index (MPI), Contamination Factor (CF), Pollution Load Index (PLI), Geoaccumulation Index (Igeo), Health Risk Assessment, and Hydrogeochemical facies were used to analyze statistical indexes and hydrogeochemical facies in groundwater resources in Imo state, Nigeria. All across the study area, twenty (20) groundwater samples were collected in a systematic manner. The samples were examined in accordance with the American Public Health Association standard (APHA) method. Findings from the study revealed that WQI, is of poor quality and should only be used for irrigation. Weathering and redox reactions are important in groundwater geochemistry, according to PCA results. TDS and Cl, $HCO_3$ and Zn, Cl; Mg and Ca, Ca and Na were all found to have a positive correlation in the correlation matrix while PH and K, $HCO_3$ and Fe, Cl and $SO_4$ are found to have a negative correlation in the correlation matrix. The findings show that the items have a weak correlation and that there is no relationship between the two variables. Further MPI, CF, and PLI findings revealed that groundwater is pure, the main source of pollution is geological and anthropogenic processes, and there is no pollution in sampled groundwater. Hydrogeochemical trend revealed that groundwater is $Na^{+}+K^{+} > HCO_3^{-}+CO3 > Mg+ > SO4 > Cl^{-} > Ca^{+}$. Based on the finding, pre-use treatment of water resources is strongly advised.

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**Keywords:** Groundwater; geochemical properties; water quality index; Hydrogeochemical Characterization

Water for human consumption and agriculture is stored as groundwater, which is the world's largest liquid freshwater supply (Eyankware, 2018; Eyankware, et al., 2020a). Despite the fact that climate change has caused significant spatial-temporal precipitation variability and has affected reservoir storage volume, groundwater remains an important and reliable source of water; however, pollutants do occasionally reach the aquifer as a result of natural or human factors. Inadequate waste disposal sites, which have an impact on all natural resources, are one of the major threats to the quality of groundwater designated for human use (Akakuru, *et al*., 2021; Agidi, et al., 2022).In unregulated and poorly built municipal landfills, leachate migration from landfills to groundwater is seen as a severe environmental issue (Obasi, et al., 2015; Ezeh, et al., 2015; Omo-Irabor, et al., 2019). Impact on the environment. In this way, it's critical to estimate the risk of pollution of groundwater. Landfills are avoided. The quality of groundwater is currently a major environmental concern. For a variety of reasons, groundwater resource studies have become more important across different local, state, and nations (Sundraiah *et al.*

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2014; Subba Rao 2017; Faten et al. 2016). However, as the quality of the groundwater improves as a result of the influences of geogenic and non-geogenic sources, it becomes an inferior type that will not be acceptable for any future purposes (Subba Rao *et al*. 2021c). Geochemical processes govern groundwater quality, which is influenced by a number of factors. Mineral weathering is linked to lithology and rock weathering (*ref*). Assessment of ground water quality using chemical approach is a very vital tool in classification of groundwater. The determining factors of groundwater quality area dependent on the rate of chemical weathering of the different geologic formation.geology, recharge water quality and rock-water interaction. (Domenico 1972, Satya et al., 2015). More so, sea water invasion which results from intensive absorption of freshwater in coastal regions is another determining factor of groundwater quality. (Sophiya and Syed 2013). Due to a lack of surface water sources, the residents of the study area rely primarily on groundwater resources for drinking and irrigation. The current study region is experiencing deterioration in groundwater quality in some areas due to a lack of proper awareness on the planning of household waste disposal, septic tank leakages, animal wastes, uncontrolled use of chemical composts, leakage from oil spillage, and so on. As a result, the groundwater quality may not be suitable for drinking or irrigation. However, no research has been conducted in the study region so far, hence, the objective of this study is to evaluate the hydrogeochemical characteristics and groundwater quality assessment based on water quality index in Imo state, South Eastern Nigeria.

## MATERIALS AND METHODS

*Description of the study area:* The study area is 42.74 square kilometers in size and is located between latitudes 07° 10'N and 07° 18'N, as well as longitudes 5° 09'E and 05° 16'E in Imo state. The research is being conducted in Nigeria's rain forest zone, which has a wet season from April to October and a dry season from November to March. From February to March, the town experiences the hottest weather, as well as a dry wind (harmattan) from December to early February. The region receives moderate annual rainfall of approximately 1,300 to 1,700 mm, with high humidity during the wet season and low humidity during the dry season, and year-round temperatures ranging from 22°C to 31°C (Iloeje, 1981).

*Geology:* The research area lies in the eastern portion of the Niger Delta Sedimentary Basin, as shown in Fig. 1 by the Niger Delta lithographic units. The units are: Akata Formation, Agbada Formation, and Benin Formation, in order of decreasing age (Opara et al. 2021). The research area, which comprises alluvium, Meander belts, fresh water marshes, and deltaic plain sands, is depicted in Fig. 1. All boreholes in the research region plunge into the younger Benin Formation, and the tertiary residue has a thickness of about 10,000 meters. The Miocene to late development is made up of sand, which is often medium to coarse grained, and stone, which is respectably organized with local focal points of inadequately cemented sand and muds. The Niger Delta Basin, also known as the Niger Delta area, is a right-hand basin in the Niger Delta and the Gulf of Guinea, near to Nigeria's western bank, with thought or demonstrated access to Cameroon, Equatorial Guinea, and Sao Tome and Principe. The bowl is perplexing, and it's worth a lot of money because it houses a quite useful oil framework. With 75,000 km$^2$, 300,000 km$^2$ of all out areas, and 500,000 km2 of silt fill, the Niger Delta is one of the largest subareas (Urom et al. 2021). The Niger Delta Basin was formed during the break of the South American plate and the entrance of the African plate of the south Atlantic during the blasted fracture junction. This basin formed in the late Jurassic and laste.

*Method:* As shown in Fig. 1, twenty (20) water samples were collected at random from hand-dug wells/motorized boreholes. The sampling was done during the dry season, when the water level was lower and the concentrations of cations, anions, and trace elements were more stable. Before collecting water samples from the site, the bottles were washed with clean water, cleaned with cleaning reagents, and thoroughly rinsed with distilled, de-ionized water. pH, electrical conductivity, total dissolved solids, total hardness, magnesium, calcium, chloride, nitrate, sulphate, potassium, sodium, bicarbonate, iron, cobalt, lead, zinc, manganese, mercury, cadmium, and silver were all measured using the APHA (2012) standard (Table 1).

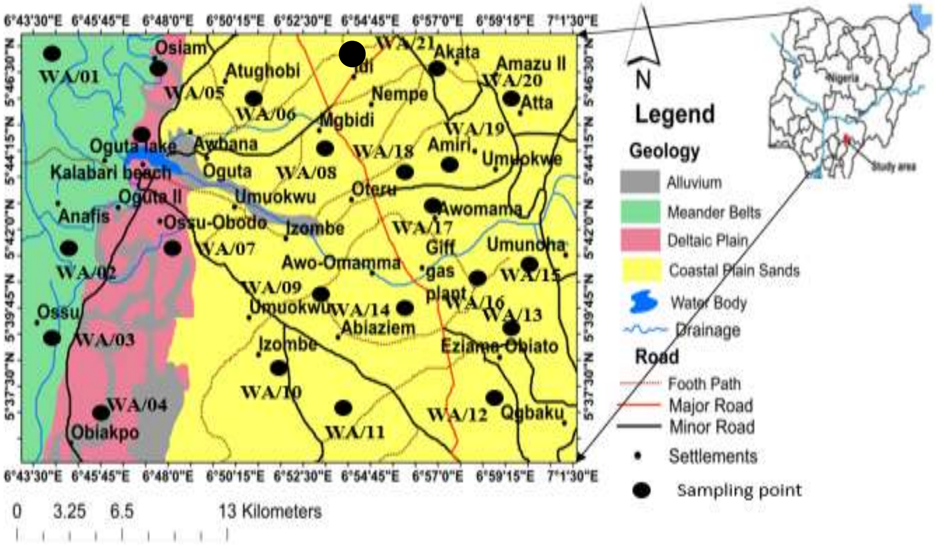


**Fig.1.** The study area's geology map, showing groundwater sample points

**Table 1**. Methods used to analyze physicochemical parameters

| S/No | Parameters | Analytical Method |
|---|---|---|
| 1 | pH | pH meter Hach sensION + PH1 portable pH meter and Hach sensION + 5050 T Portable Combination pH Electrode |
| 2 | Total dissolved solids (TDS) | TDS meters (model HQ14D53000000, USA). |
| 3 | Magnesium ($Mg^{2+}$) | EDTA titrimetric method |
| 4 | Calcium ($Ca^{2+}$) | Titrimetric method |
| 5 | Chloride ($Cl^{-}$) | Titrimetric method |
| 6 | Sulphate ($SO_4^{2-}$) | Turbidimetric method using a UV-Vis spectrometer |
| 7 | Potassium ($K^{+}$) | Jenway clinical flame photometer (PFP7 model) |
| 8 | Sodium ($Na^{+}$) | Jenway clinical flame photometer (PFP7 model) |
| 9 | Bicarbonate ($HCO_3^{-}$) | Titrimetric method |
| 10 | Iron (Fe) | (Flame Atomic Absorption Spectrophotometer) FAAS |
| 11 | Manganese (Mn) | FAAS |
| 12 | Arsenic (As) | FAAS |
| 13 | Zinc (Zn) | FAAS |
| 14 | Copper (Cu) | FAAS |

**Water quality index*

The Water Quality Index (WQI) was used to assess the quality of surface and groundwater for human consumption in the study area. Brown et al. (1970), following Horton (1965), developed this index to provide a comprehensive overview of the state of surface and groundwater quality for residential use. WQI, on the other hand, has a few flaws. WQI, for example, may not provide sufficient information on the true state of water quality. Furthermore, many users of water quality data may not find the index adequate. Finally, because the assignment of weights to parameters is left to the user's discretion (Ukah et al., 2020), there may be bias in the calculation. The estimation of WQI in equation 1 was done in two steps:

$$WQI = \frac{\sum_{i=1}^{n} W_i \times Q_i}{W_i} \qquad (1)$$

Where W$i$ denotes the parameter's relative weight and Qi denotes the parameter's quality index.

Phase I: Each parameter tested in the water samples was assigned a relative weight (Wi) based on its value in total water quality. The unit weights of each of the ten parameters studied (pH, $Cl^{-}$, $SO_4^{2}$, $HCO_3$, NO3, $Fe^{2+}$, $Zn^{2+}$, $Ni^{2+}$, $Cr^{3+}$, and $Pb^{2+}$) were calculated using the following formula (Eq. 2):

$$\mathrm{W}i = \frac{k}{S_i} \qquad (2)$$

With Si representing the acceptable standard value of the water quality parameter and k representing the proportionality constant calculated using the formula (Eq. 3):

$$k = \frac{1}{\left(\frac{1}{S_i} = 1, 2, \ldots\ldots\ldots\ldots . i\right)} \qquad (3)$$

Phase 2: Using Eq. (4), we determined the quality index for each parameter:

$$Q_i = \frac{(Va - Vi)}{(Vs - Vi)} \times 100 \qquad (4)$$

Where Va represents the measured value of parameter I, Vi represents the ideal value of parameter I (0 for all parameters except pH, which is 7.0), and Vs represents the WHO-recommended standard for parameter i. When the quality rating is zero, there are no pollutants. A quality rating of 0 Qi 100 indicates that the pollutants have exceeded the allowable limits (McClelland, 1974). Based on the absolute value of the index discovered through computations, the estimated WQI values are divided into four categories: "excellent," "good," "poor," "very poor," and "unfit for drinking."

*Principal Component Analysis (PCA):* Component loading in PCA entailed dividing a large dataset with many variables into a smaller number of linear combinations in the component that accounted for an appropriate fraction of the total data variance and easily associating the variables to the sources or processes via Equation (5).

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(X_{N-}N)^2 \qquad (5)$$

When Xi is the statistical mean, I is the range of variables, and N is the number of outcomes.

*Metal Pollution Index (MPI):* Caeiro et al., (2005) used Equation 6 to evaluate MPI, which calculated the aggregate impact of individual heavy metals on water quality (Horton, 1965; Mohan et al., 1996).

$$MPI = \sqrt[n]{M_1 \times M_2 \times M_3\_\_\_\_\_\_\_\_}\ \mathrm{Mn} \qquad (6)$$

Where *Mn* = concentration of the metal.

*Pollution Load Index (PLI):* The PLI was calculated using Hakanson's (1980); Eyankware and Akakuru, (2022) formula.

$$\mathrm{PLI} = \sqrt[n]{CF1 \times CF2 \times}\, CF3 \times \ldots \times CFn \qquad (7)$$

Where CF represents the contamination factor and n represents the element number.

*Geo-accumulation index (Igeo):* Igeo could be used to assess the presence of toxic materials (Igeo). Eyankware and Akakuru compute it as follows (2022)

$$\mathrm{Igeo} = \log_2 \frac{C_n}{1.5\, B_n} \qquad (8)$$

Where Cn represents the toxic metal n's content and Bn represents the toxic metal n's background, and 1.5 represents the factor of possibility.

*Health risk assessment:* The criteria of the US Environmental Protection Agency were used to determine the non-carcinogenic risk associated with ingesting contaminated river water (USEPA, 1989; see Table 2). The risk was calculated in equation 9 for both children and adults.

$$\mathrm{CDI} = \frac{\mathrm{Cw\ X\ IRW\ X\ EF\ X\ ED}}{\mathrm{BW\ X\ AT}} \qquad (9)$$

where CDI stands for Chronic Daily Intake (mg/kg/day), Cw stands for contaminant concentration in water (mg/L), IRW stands for ingestion rate (for adults, IRW is 2 L/day, while for children, IRW is 1 L/day), EF stands for Exposure Frequency (365 days/year), and ED stands for exposure duration (for adults and children, ED is 70 and 6 hours, respectively) (Bortey-Sam et al., 2015; Duggal et al., 2017; Barzegar et al., 2018).

The hazard quotient (HQ), as defined by Li et al. (2016) and Zhang et al. (2018), was used to assess the non-carcinogenic risk posed by the following elements in equation 10:

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RFD}} \qquad (10)$$

RfD denotes the reference dose (mg/kg/day) for a specific element. According to Duggal et al. (2017) and Barzegar et al. (2017), the RfD for various elements is approximately 0.7 (Fe), 0.3 (Zn), 0.0001 (Hg), 0.03 (Co), and 0.0035 (Co) (2018). (Pb). Finally, using equation 6, the total HQ values for the elements are calculated to determine the hazard index of the water samples (HI).

$$\mathrm{HI} = \sum \mathrm{HQ} \qquad (11)$$

Values greater than one indicate that a specific element's non-carcinogenic risk exceeds the limit of acceptance (HI = 1), while values less than one indicate that the non-carcinogenic risk is within acceptable bounds (USEPA 1989; Su et al., 2017). According to Bortey-Sam et al. (2015) and Barzegar et al. (2015), Table 3 depicts the USEPA (1989) classification of non-carcinogenic risk (2015).

**Table 2**: In 1989, the United States Environmental Protection Agency (USEPA) classified non-carcinogenic risk.

| Risk Level | Hazard Index (HI) | Chronic risk |
|---|---|---|
| 1 | <0.1 | Negligible |
| 2 | 0.1-1 | Low |
| 3 | 1-4 | Medium |
| 4 | >4 | High |

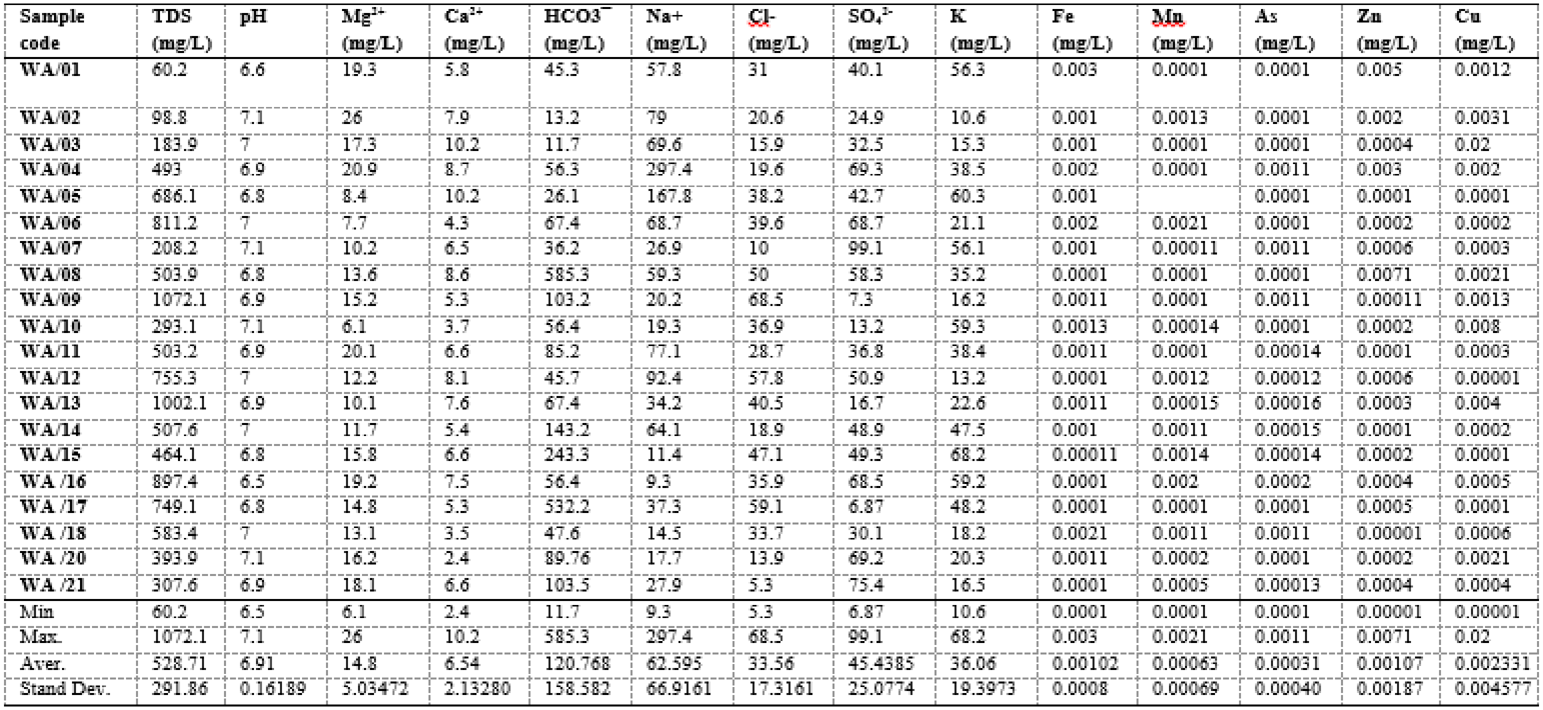
## RESULTS AND DISCUSSION

*Water quality index:* The WQI provides a thorough picture of the quality of surface and ground water for most residential purposes. The Water Quality Index (WQI) is a metric that evaluates the impact of a variety of water quality elements when used together (Eyankware, et al., 2021a). The appropriateness of surface and/or groundwater for human consumption determines the WQI. WQI is a ranking tool that provides a more accurate and convenient way to categorize water. The suitability of groundwater is critical because it influences its availability for a variety of uses such as household, drinking water, irrigation, industry, and so on (Eyankware et al., 2020; Subba Rao et al., 2012; Gopinath et al., 2019). The WQI results for all samples in the study area (Table 4) show that 70% of all samples are of very low quality and should only be used for irrigation. Similarly, 30% of the samples had values above 300. This indicates that the sample is not suitable for drinking and should be processed before it can be used for any purpose. This cross-section demonstrated the country's ability to estimate the water quality of drinking water using WQI, which provides a statement on the combined effect of material boundaries on water. Poor water quality in the area may be due to human activity, which constantly exposes available water sources to unwanted pollution. This result is incomparable to studies conducted in India (Brindha et al., 2020; Gopinath et al., 2019); and Nigeria (Akakuru et al., 2021; Eyankware et al., 2020; Agidi et al., 2022).

*Principal Component Analysis (PCA):* PCA is a pattern recognition technique that attempts to explain the variation of multiple connected variables (Akakuru et al., 2021a&b). It demonstrates the relationship between variables, which simplifies the dataset. PCA derives eigenvalues and eigenvectors from the original data's covariance matrix. The uncorrelated (orthogonal) variables that result from multiplying the original correlated variables by the eigenvectors are known as principal components (PCs) (loadings). The PCs' eigenvalues are used to calculate the variance associated with them, the loadings are used to assess the participation of the original variables in the PCs, and the converted observations are referred to as scores (Helena et al., 2000; Wunderlin et al. 2001; Singh et al. 2004). The results of the PCA in Table 5, it shows that there is loading between elements. For PC1, 50% of the elements had loadings, for PC2, 35.7% of the elements had loading, for PC3, 28.6% of the element had loading while for PC4, 21.4% of elements had loadings. As indicated each part is more prominent, as evidenced by Kaiser's model (Akakaru et al., 2021b), also known as the eigenvalue 1 measure, which is one of the most common rules for describing parts set in the PCA. Must be simply maintained with a unique eigenvalue. From 1.00 decoding. This is because each of the above factors provides a unit of variability in the overall diversity of information gathered. Therefore, parts with eigenvalues greater than 1.00 are expected to explain a more important measure of variance than the variables provide. In this sense, such characteristic parts are the cause of many changes and should be retained, while the parts with an intrinsic value of less than 1.00 are the cause of diversity more than one variable brings.

Nonetheless, the basic goal of PCA is to reduce the set of perceived elements to a more conservative number of parts without jeopardizing the true translation of the referenced information.

**Table 3** shows the study's findings, which include physicochemical and heavy metal levels in groundwater in the study area



| **Sample code** | **TDS (mg/L)** | **pH** | **Mg$^{2+}$ (mg/L)** | **Ca$^{2+}$ (mg/L)** | **HCO3$^{-}$ (mg/L)** | **Na+ (mg/L)** | **Cl- (mg/L)** | **SO$_4^{2-}$ (mg/L)** | **K (mg/L)** | **Fe (mg/L)** | **Mn (mg/L)** | **As (mg/L)** | **Zn (mg/L)** | **Cu (mg/L)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WA/01** | 60.2 | 6.6 | 19.3 | 5.8 | 45.3 | 57.8 | 31 | 40.1 | 56.3 | 0.003 | 0.0001 | 0.0001 | 0.005 | 0.0012 |
| **WA/02** | 98.8 | 7.1 | 26 | 7.9 | 13.2 | 79 | 20.6 | 24.9 | 10.6 | 0.001 | 0.0013 | 0.0001 | 0.002 | 0.0031 |
| **WA/03** | 183.9 | 7 | 17.3 | 10.2 | 11.7 | 69.6 | 15.9 | 32.5 | 15.3 | 0.001 | 0.0001 | 0.0001 | 0.0004 | 0.02 |
| **WA/04** | 493 | 6.9 | 20.9 | 8.7 | 56.3 | 297.4 | 19.6 | 69.3 | 38.5 | 0.002 | 0.0001 | 0.0011 | 0.003 | 0.002 |
| **WA/05** | 686.1 | 6.8 | 8.4 | 10.2 | 26.1 | 167.8 | 38.2 | 42.7 | 60.3 | 0.001 |  | 0.0001 | 0.0001 | 0.0001 |
| **WA/06** | 811.2 | 7 | 7.7 | 4.3 | 67.4 | 68.7 | 39.6 | 68.7 | 21.1 | 0.002 | 0.0021 | 0.0001 | 0.0002 | 0.0002 |
| **WA/07** | 208.2 | 7.1 | 10.2 | 6.5 | 36.2 | 26.9 | 10 | 99.1 | 56.1 | 0.001 | 0.00011 | 0.0011 | 0.0006 | 0.0003 |
| **WA/08** | 503.9 | 6.8 | 13.6 | 8.6 | 585.3 | 59.3 | 50 | 58.3 | 35.2 | 0.0001 | 0.0001 | 0.0001 | 0.0071 | 0.0021 |
| **WA/09** | 1072.1 | 6.9 | 15.2 | 5.3 | 103.2 | 20.2 | 68.5 | 7.3 | 16.2 | 0.0011 | 0.0001 | 0.0011 | 0.00011 | 0.0013 |
| **WA/10** | 293.1 | 7.1 | 6.1 | 3.7 | 56.4 | 19.3 | 36.9 | 13.2 | 59.3 | 0.0013 | 0.00014 | 0.0001 | 0.0002 | 0.008 |
| **WA/11** | 503.2 | 6.9 | 20.1 | 6.6 | 85.2 | 77.1 | 28.7 | 36.8 | 38.4 | 0.0011 | 0.0001 | 0.00014 | 0.0001 | 0.0003 |
| **WA/12** | 755.3 | 7 | 12.2 | 8.1 | 45.7 | 92.4 | 57.8 | 50.9 | 13.2 | 0.0001 | 0.0012 | 0.00012 | 0.0006 | 0.00001 |
| **WA/13** | 1002.1 | 6.9 | 10.1 | 7.6 | 67.4 | 34.2 | 40.5 | 16.7 | 22.6 | 0.0011 | 0.00015 | 0.00016 | 0.0003 | 0.004 |
| **WA/14** | 507.6 | 7 | 11.7 | 5.4 | 143.2 | 64.1 | 18.9 | 48.9 | 47.5 | 0.001 | 0.0011 | 0.00015 | 0.0001 | 0.0002 |
| **WA/15** | 464.1 | 6.8 | 15.8 | 6.6 | 243.3 | 11.4 | 47.1 | 49.3 | 68.2 | 0.00011 | 0.0014 | 0.00014 | 0.0002 | 0.0001 |
| **WA /16** | 897.4 | 6.5 | 19.2 | 7.5 | 56.4 | 9.3 | 35.9 | 68.5 | 59.2 | 0.0001 | 0.002 | 0.0002 | 0.0004 | 0.0005 |
| **WA /17** | 749.1 | 6.8 | 14.8 | 5.3 | 532.2 | 37.3 | 59.1 | 6.87 | 48.2 | 0.0001 | 0.0001 | 0.0001 | 0.0005 | 0.0001 |
| **WA /18** | 583.4 | 7 | 13.1 | 3.5 | 47.6 | 14.5 | 33.7 | 30.1 | 18.2 | 0.0021 | 0.0011 | 0.0011 | 0.00001 | 0.0006 |
| **WA /20** | 393.9 | 7.1 | 16.2 | 2.4 | 89.76 | 17.7 | 13.9 | 69.2 | 20.3 | 0.0011 | 0.0002 | 0.0001 | 0.0002 | 0.0021 |
| **WA /21** | 307.6 | 6.9 | 18.1 | 6.6 | 103.5 | 27.9 | 5.3 | 75.4 | 16.5 | 0.0001 | 0.0005 | 0.00013 | 0.0004 | 0.0004 |
| Min | 60.2 | 6.5 | 6.1 | 2.4 | 11.7 | 9.3 | 5.3 | 6.87 | 10.6 | 0.0001 | 0.0001 | 0.0001 | 0.00001 | 0.00001 |
| Max. | 1072.1 | 7.1 | 26 | 10.2 | 585.3 | 297.4 | 68.5 | 99.1 | 68.2 | 0.003 | 0.0021 | 0.0011 | 0.0071 | 0.02 |
| Aver. | 528.71 | 6.91 | 14.8 | 6.54 | 120.768 | 62.595 | 33.56 | 45.4385 | 36.06 | 0.00102 | 0.00063 | 0.00031 | 0.00107 | 0.002331 |
| Stand Dev. | 291.86 | 0.16189 | 5.03472 | 2.13280 | 158.582 | 66.9161 | 17.3161 | 25.0774 | 19.3973 | 0.0008 | 0.00069 | 0.00040 | 0.00187 | 0.004577 |

As a result, retaining parts that are less volatile than those caused by individual factors overcomes the points of PCA. As a result, parts with eigenvalues less than 1.00 are considered defective and are not retained (Subba Rao, 2007). This result may provide insights due to geological processes such as weathering and redox reactions (Akakuru et al., 2021b; Egbueri, 2019; Yahaya et al., 2021; Eyankware and Akakuru, 2022).

*Correlation matrix:* Correlation matrices are a useful tool for determining the relationship between two variables. Normally, the correlation coefficient ranges between -1 and +1. The relationship has a negative slope or anti-correlation if the r-value is close to -1. If r is close to +1, the relationship is said to have a positive slope or to be correlated. The points are said to be uncorrelated if the value is equal to zero (Srivastava et al., 2014). TDS and Cl, $HCO_3$ and Zn, Cl; Mg and Ca, Ca and Na were all found to have a positive correlation in the correlation matrix while PH and K, $HCO_3$ and Fe, Cl and $SO_4$ are found to have a negative correlation in the correlation matrix(Table 7). The results show that there is a weak correlation between the items and that there is no relationship between the two variables. That is, if one variable moves in one direction, the other variable moves in a completely unrelated direction. This also suggests that heavy metals in groundwater are primarily sourced from anthropogenic sources (Eyankware et al. 2021; Agidi et al. 2022; Akakuru et al. 2022).

**Table 4: Results of the Water quality index**

| Sample code | qi*wi | | | | | | | | | | | | WQI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mg** | **Ca** | **$HCO_3$** | **Na** | **Cl** | **$SO_4^{2}$** | **K** | **Fe** | **Mn** | **As** | **Zn** | **Cu** | |
| WA/01 | 0.772 | 0.0145 | 0.11325 | 0.1445 | 0.0496 | 4.45511 | 0.14075 | 333.333 | 0.0625 | 100 | 0.02 | 0.03 | 439.1352 |
| WA/02 | 1.04 | 0.01975 | 0.033 | 0.1975 | 0.03296 | 2.76639 | 0.0265 | 111.111 | 0.8125 | 100 | 0.008 | 0.0775 | 216.1251 |
| WA/03 | 0.692 | 0.0255 | 0.02925 | 0.174 | 0.02544 | 3.61075 | 0.03825 | 111.111 | 0.0625 | 100 | 0.0016 | 0.5 | 216.2703 |
| WA/04 | 0.836 | 0.02175 | 0.14075 | 0.7435 | 0.03136 | 7.69923 | 0.09625 | 222.222 | 0.0625 | 1100 | 0.012 | 0.05 | 1331.915 |
| WA/05 | 0.336 | 0.0255 | 0.06525 | 0.4195 | 0.06112 | 4.74397 | 0.15075 | 111.111 | 0 | 100 | 0.0004 | 0.0025 | 216.916 |
| WA/06 | 0.308 | 0.01075 | 0.1685 | 0.17175 | 0.06336 | 7.63257 | 0.05275 | 222.222 | 1.3125 | 100 | 0.0008 | 0.005 | 331.948 |
| WA/07 | 0.408 | 0.01625 | 0.0905 | 0.06725 | 0.016 | 11.01001 | 0.14025 | 111.111 | 0.06875 | 1100 | 0.0024 | 0.0075 | 1222.938 |
| WA/08 | 0.544 | 0.0215 | 1.46325 | 0.14825 | 0.08 | 6.47713 | 0.088 | 11.1111 | 0.0625 | 100 | 0.0284 | 0.0525 | 120.0766 |
| WA/09 | 0.608 | 0.01325 | 0.258 | 0.0505 | 0.1096 | 0.81103 | 0.0405 | 122.2221 | 0.0625 | 1100 | 0.00044 | 0.0325 | 1224.208 |
| WA/10 | 0.244 | 0.00925 | 0.141 | 0.04825 | 0.05904 | 1.46652 | 0.14825 | 144.4443 | 0.0875 | 100 | 0.0008 | 0.2 | 246.8489 |
| WA/11 | 0.804 | 0.0165 | 0.213 | 0.19275 | 0.04592 | 4.08848 | 0.096 | 122.2221 | 0.0625 | 140 | 0.0004 | 0.0075 | 267.7492 |
| WA/12 | 0.488 | 0.02025 | 0.11425 | 0.231 | 0.09248 | 5.65499 | 0.033 | 11.1111 | 0.75 | 120 | 0.0024 | 0.00025 | 138.4977 |
| WA/13 | 0.404 | 0.019 | 0.1685 | 0.0855 | 0.0648 | 1.85537 | 0.0565 | 122.2221 | 0.09375 | 160 | 0.0012 | 0.1 | 285.0707 |
| WA/14 | 0.468 | 0.0135 | 0.358 | 0.16025 | 0.03024 | 5.43279 | 0.11875 | 111.111 | 0.6875 | 150 | 0.0004 | 0.005 | 268.3854 |
| WA/15 | 0.632 | 0.0165 | 0.60825 | 0.0285 | 0.07536 | 5.47723 | 0.1705 | 12.22221 | 0.875 | 140 | 0.0008 | 0.0025 | 160.1089 |
| WA/16 | 0.768 | 0.01875 | 0.141 | 0.02325 | 0.05744 | 7.61035 | 0.148 | 11.1111 | 1.25 | 200 | 0.0016 | 0.0125 | 221.142 |
| WA/17 | 0.592 | 0.01325 | 1.3305 | 0.09325 | 0.09456 | 0.763257 | 0.1205 | 11.1111 | 0.0625 | 100 | 0.002 | 0.0025 | 114.1854 |
| WA/18 | 0.524 | 0.00875 | 0.119 | 0.03625 | 0.05392 | 3.34411 | 0.0455 | 233.3331 | 0.6875 | 1100 | 0.00004 | 0.015 | 1338.167 |
| WA/20 | 0.648 | 0.006 | 0.2244 | 0.04425 | 0.02224 | 7.68812 | 0.05075 | 122.2221 | 0.125 | 100 | 0.0008 | 0.0525 | 231.0842 |
| WA/21 | 0.724 | 0.0165 | 0.25875 | 0.06975 | 0.00848 | 8.37694 | 0.04125 | 11.1111 | 0.3125 | 130 | 0.0016 | 0.01 | 150.9309 |

**Table 5:** PCA of the samples

| | | **Components** | | | |
|---|---|---|---|---|---|
| | **Communalities** | **1** | **2** | **3** | **4** |
| TDS | 0.679756 | **-0.72276** | -0.16845 | -0.04099 | 0.356818 |
| pH | 0.639903 | 0.375018 | **-0.64395** | -0.28462 | -0.05986 |
| Mg | 0.425936 | **0.40761** | **0.507778** | 0.038106 | -0.02234 |
| Ca | 0.578907 | 0.277041 | **0.64838** | -0.27265 | -0.08615 |
| $HCO_3$ | 0.630051 | **-0.56113** | **0.547631** | -0.12264 | -0.01548 |
| Na | 0.617388 | **0.513712** | 0.340714 | 0.051171 | **0.484544** |
| Cl | 0.876893 | **-0.80877** | 0.125519 | -0.26687 | 0.368516 |
| $SO_4$ | 0.694021 | 0.331156 | 0.079699 | **0.724036** | -0.2319 |
| K | 0.353713 | -0.22513 | 0.287997 | **0.454961** | -0.11444 |
| Fe | 0.593849 | **0.466475** | -0.25476 | 0.132874 | **0.541933** |
| Mn | 0.415313 | -0.26565 | -0.19923 | **0.463304** | -0.30067 |
| As | 0.642838 | 0.194242 | -0.23927 | 0.213644 | **0.708672** |
| Zn | 0.677581 | 0.159289 | **0.771308** | 0.039468 | 0.236081 |
| Cu | 0.737556 | **0.421234** | -0.01211 | **-0.70712** | -0.24486 |
| **Eigen Value** | | **0.562332** | **1.791268** | **0.422674** | **1.620868** |
| **Variance (%)** | | **21.57902** | **16.69256** | **13.42568** | **10.69897** |
| **Cumm. Variance (%)** | | **21.58** | **38.27** | **51.7** | **62.4** |

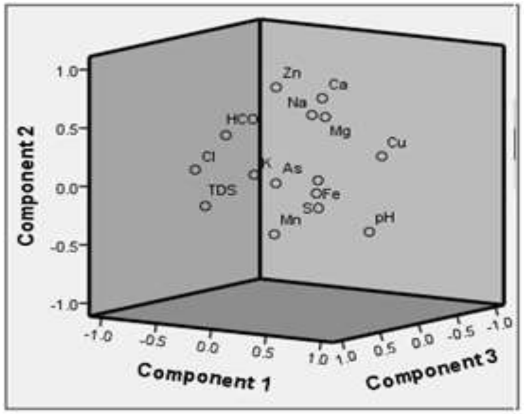
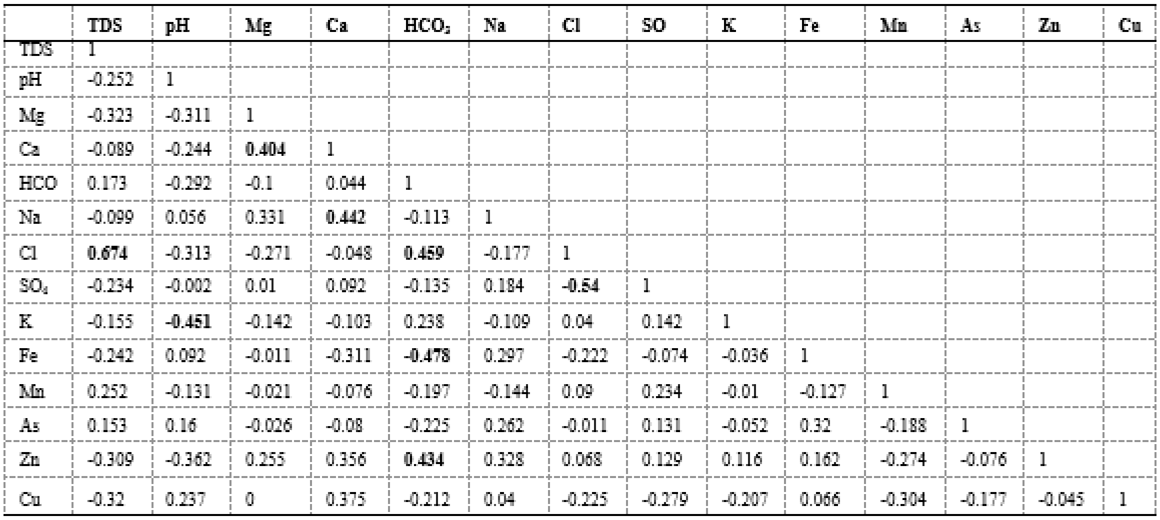


**Fig 2**: Component plot showing the loadings of elements

.

**Table 6:** Correlation Matrix



| | TDS | pH | Mg | Ca | HCO$_3$ | Na | Cl | SO | K | Fe | Mn | As | Zn | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDS | 1 | | | | | | | | | | | | | |
| pH | -0.252 | 1 | | | | | | | | | | | | |
| Mg | -0.323 | -0.311 | 1 | | | | | | | | | | | |
| Ca | -0.089 | -0.244 | **0.404** | 1 | | | | | | | | | | |
| HCO | 0.173 | -0.292 | -0.1 | 0.044 | 1 | | | | | | | | | |
| Na | -0.099 | 0.056 | 0.331 | **0.442** | -0.113 | 1 | | | | | | | | |
| Cl | **0.674** | -0.313 | -0.271 | -0.048 | **0.459** | -0.177 | 1 | | | | | | | |
| SO$_4$ | -0.234 | -0.002 | 0.01 | 0.092 | -0.135 | 0.184 | **-0.54** | 1 | | | | | | |
| K | -0.155 | **-0.451** | -0.142 | -0.103 | 0.238 | -0.109 | 0.04 | 0.142 | 1 | | | | | |
| Fe | -0.242 | 0.092 | -0.011 | -0.311 | **-0.478** | 0.297 | -0.222 | -0.074 | -0.036 | 1 | | | | |
| Mn | 0.252 | -0.131 | -0.021 | -0.076 | -0.197 | -0.144 | 0.09 | 0.234 | -0.01 | -0.127 | 1 | | | |
| As | 0.153 | 0.16 | -0.026 | -0.08 | -0.225 | 0.262 | -0.011 | 0.131 | -0.052 | 0.32 | -0.188 | 1 | | |
| Zn | -0.309 | -0.362 | 0.255 | 0.356 | **0.434** | 0.328 | 0.068 | 0.129 | 0.116 | 0.162 | -0.274 | -0.076 | 1 | |
| Cu | -0.32 | 0.237 | 0 | 0.375 | -0.212 | 0.04 | -0.225 | -0.279 | -0.207 | 0.066 | -0.304 | -0.177 | -0.045 | 1 |

*Metal Pollution Index (MPI):* MPI has proven to be a useful technique in the classification of groundwater. The MPI of very pure water is 0.3 or lower, whereas the MPI of pure water is 0.3 to 1.0. Those with an MPI of 1.0 to 2.0 are considered minimally affected in Class III, while those with an MPI of 2.0 or higher are considered severely affected in Class IV. Water samples with MPIs ranging from 4.0 to 6.0 are classified as severely affected in Class V, and those with MPIs greater than 6.0 are classified as gravely affected in Class VI. The results in Table 7 show that the entire sample is less than 0.3, implying that the samples are very pure.

*Contamination Factor (CF):* In groundwater studies, CF was used to calculate the concentration ratio of heavy metals to background levels. The pollution factor values are explained using the following criteria: CF <1, low pollution; 1 ≤ CF ≥ 3, unhealthy; 3 ≤ CF ≥ 6, severe contamination; CF C> 6 , Very high load. (Bhutian et al., 2017; Akakuru et al., 2021). The CF of this study shows that the concentrations of all parameters are well below 1 (unhealthy), as shown in Table 7. This result indicates that geological processes are the primary source of pollution. This also implies that anthropogenic activities in the area have had little effect on the available water resources. This result is comparable to that of Bhutian et al. (2017) for India and Nigeria (Yayaha et al., 2021).

*Pollution Load Index (PLI):* PLI is an efficient method for determining the toxicity of heavy metals in representative samples (Akakuru, et al., 2021b; Yang et al., 2011). The most common PLI categories are unpolluted (PLI1), unhealthy (PLI> 2), severely polluted (2PLI> 3), and very heavily polluted (3> PLI). According to this, the groundwater concentration value in the survey area was less than 1 (Table 7). That means there is no pollution, which contradicts the study conducted in India (Gopinath et al., 2019; Bhutian et al., 2017), but it is consistent with the study conducted in Nigeria by Yahyaya *et al*. (2021). This result is also consistent with the CF result in this study.

*Geo-accumulation index (Igeo):* Muller (1979) developed the geoaccumulation index (Igeo) to examine the amount of pollution of vital concentrations in waste, water, biomass, and soil, and it has been widely used in researching their contamination status all over the world (Eyankware and Akakuru, 2022).

Igeo≤ 0 (essentially unpolluted), 0 < Igeo ≤ 1 (unpolluted), 1 < Igeo ≤ 2 (respectably contaminated), 2 < Igeo ≤ 3 (modestly to emphatically dirty), 3 < Igeo ≤ 4 (firmly contaminated), 4 < Igeo ≤ 5 (unequivocally to incredibly contaminated), and Igeo ≥ 5 (very contaminated) are the characterizations of (Igeo) and their separate translations (Urom et al. 2021; Agidi et al. 2022; Usman et al. 2022). From the results in Table 7, it shows that 100% of the samples are unpolluted. This result is in conformity with the earlier results of CF, and PLI in this study which showed that there is relatively no direct effect of the anthropogenic activities in the area on the groundwater resources. This study is in line with the study done in .Nigeria (Agidi *et al*, 2022; Eyankware and Akakuru 2022)

**Table 7:** CF, PLI, Igeo and MPI in the study area

| Sample code | CONTAMINATION FACTOR | | | | | PLI | Igeo | MPI |
|---|---|---|---|---|---|---|---|---|
| | **Fe** | **Mn** | **As** | **Zn** | **Cu** | | | |
| WA/01 | 0.075 | 1.18E-06 | 0.00002 | 3.57E-05 | 3.33E-05 | 4.58E-11 | 0.01507 | 1.34E-08 |
| WA/02 | 0.025 | 1.53E-05 | 0.00002 | 1.43E-05 | 8.61E-05 | 9.70E-11 | 0.005044 | 2.84E-08 |
| WA/03 | 0.025 | 1.18E-06 | 0.00002 | 2.86E-06 | 0.000556 | 3.06E-11 | 0.005133 | 8.94E-09 |
| WA/04 | 0.05 | 1.18E-06 | 0.00022 | 2.14E-05 | 5.56E-05 | 1.24E-10 | 0.010094 | 3.63E-08 |
| WA/05 | 0.025 | 0 | 0.00002 | 7.14E-07 | 2.78E-06 | 0 | 0.005022 | 0 |
| WA/06 | 0.05 | 2.47E-05 | 0.00002 | 1.43E-06 | 5.56E-06 | 1.40E-11 | 0.010045 | 4.10E-09 |
| WA/07 | 0.025 | 1.29E-06 | 0.00022 | 4.29E-06 | 8.33E-06 | 1.59E-11 | 0.005064 | 4.67E-09 |
| WA/08 | 0.0025 | 1.18E-06 | 0.00002 | 5.07E-05 | 5.83E-05 | 1.32E-11 | 0.000528 | 3.86E-09 |
| WA/09 | 0.0275 | 1.18E-06 | 0.00022 | 7.86E-07 | 3.61E-05 | 1.42E-11 | 0.005571 | 4.16E-09 |
| WA/10 | 0.0325 | 1.65E-06 | 0.00002 | 1.43E-06 | 0.000222 | 1.84E-11 | 0.006572 | 5.40E-09 |
| WA/11 | 0.0275 | 1.18E-06 | 0.000028 | 7.14E-07 | 8.33E-06 | 2.32E-12 | 0.005527 | 6.80E-10 |
| WA/12 | 0.0025 | 1.41E-05 | 0.000024 | 4.29E-06 | 2.78E-07 | 1.00E-12 | 0.00051 | 2.94E-10 |
| WA/13 | 0.0275 | 1.76E-06 | 0.000032 | 2.14E-06 | 0.000111 | 1.92E-11 | 0.005548 | 5.63E-09 |
| WA/14 | 0.025 | 1.29E-05 | 0.00003 | 7.14E-07 | 5.56E-06 | 6.21E-12 | 0.005027 | 1.82E-09 |
| WA/15 | 0.00275 | 1.65E-05 | 0.000028 | 1.43E-06 | 2.78E-06 | 2.24E-12 | 0.000562 | 6.57E-10 |
| WA /16 | 0.0025 | 2.35E-05 | 0.00004 | 2.86E-06 | 1.39E-05 | 9.66E-12 | 0.000518 | 2.83E-09 |
| WA /17 | 0.0025 | 1.18E-06 | 0.00002 | 3.57E-06 | 2.78E-06 | 7.64E-13 | 0.000507 | 2.24E-10 |
| WA /18 | 0.0525 | 1.29E-05 | 0.00022 | 7.14E-08 | 1.67E-05 | 1.33E-11 | 0.010586 | 3.90E-09 |
| WA /20 | 0.0275 | 2.35E-06 | 0.00002 | 1.43E-06 | 5.83E-05 | 1.04E-11 | 0.005535 | 3.04E-09 |
| WA /21 | 0.0025 | 5.88E-06 | 0.000026 | 2.86E-06 | 1.11E-05 | 3.48E-12 | 0.000511 | 1.02E-09 |
| **Min** | 0.0025 | 0 | 0.00002 | 7.14E-08 | 2.78E-07 | 0 | 0.000507 | 0 |
| **Max.** | 0.075 | 2.47E-05 | 0.00022 | 5.07E-05 | 0.000556 | 1.24E-10 | 0.01507 | 3.63E-08 |
| **Aver.** | 0.025513 | 7.06E-06 | 6.34E-05 | 7.69E-06 | 6.47E-05 | 2.21E-11 | 0.005149 | 6.47E-09 |
| **Stand Dev.** | 0.020011 | 8.16E-06 | 8.05E-05 | 1.34E-05 | 0.000127 | 3.25E-11 | 0.004023 | 9.51E-09 |

*Health risk assessment:* Drinking water contaminated with heavy metals poses many health risks. Most metals are highly polluting, making locals more vulnerable to the health risks associated with metal consumption. Heavy metals in water can cause stains on objects and linen, sticky coatings, and deposits in water pipes, in addition to an unpleasant taste in beverages (WHO, 2011; Mgbenu and Egbueri, 2019). Despite the lack of health-based temperature guidelines, hot water has been found to promote the growth of bacteria harmful to the human system, causing taste, odor, color and corrosion problems (WHO, 2011; Mgbenu) and Egbueri, 2019).

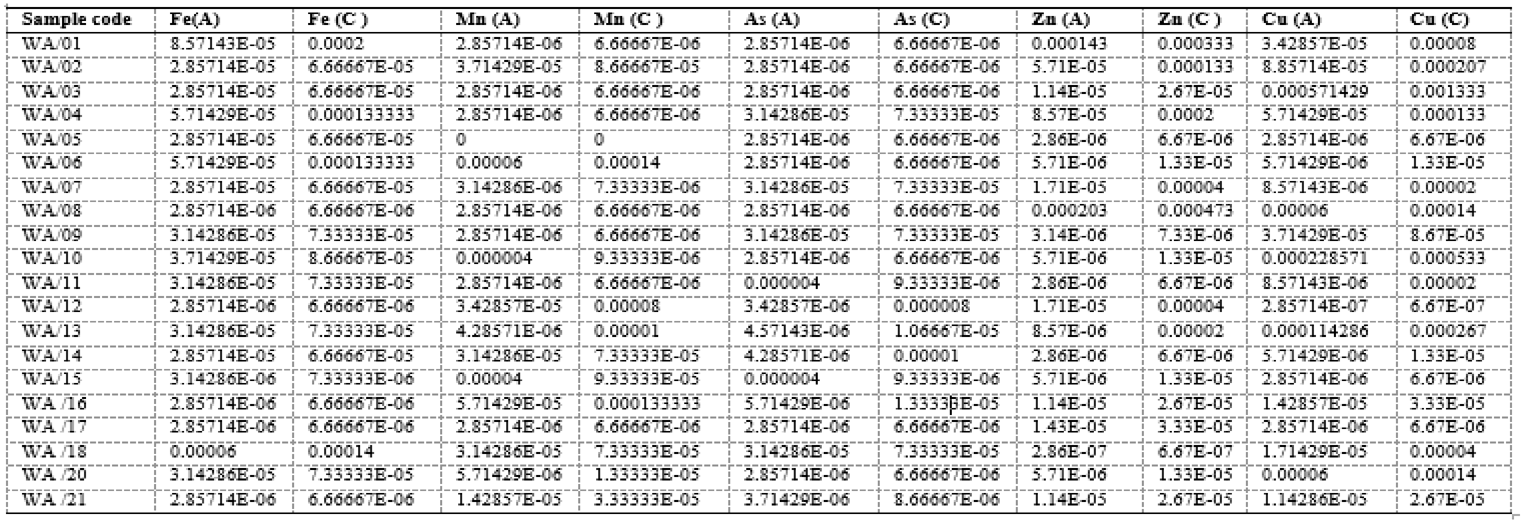
Human health risk assessment is the method used in this study to determine the magnitude of the adverse health effects associated with human exposure to environmental hazards. The four major stages of risk assessment are hazard identification, exposure assessment, dose-response assessment, and risk characterization (Kollunu, *et al.,* 1996; Paustenbach, 2002). Obiri et al. (2006) developed a method for identifying hazards.

Asante-Duah (2002) includes a review of key literature to identify potential health concerns associated with metals and metalloids. The extent, duration, and order of heavy metal exposure are determined as part of the exposure assessment. The amount of metal and metalloids required to cause various degrees of health effects that can lead to illness is determined by dose-response analysis. Finally, risk characterization entails determining the likelihood of heavy metals causing cancer or other diseases in the target population (Eyankware, *et al.,* 2022d). The HI results in Table 9 show that children have a higher HI for all parameters than adults. Anthropogenic sources may be the primary source of the study area's increased HI.

*Hydrogeochemical Facies:* The hydrochemical evolution, grouping, and areal distribution of groundwater's major dissolved constituents (major cations and major anions) can be graphically depicted (Akakuru *et al*., 2015, Akakuru *et al.,* 2017; Eyankware *et al*., 2021b). This study examined hydrochemical facies variation using Piper trilinear diagrams, Scholler plots, and Durov plots.

*Piper Trilinear and Durov plots:* The Piper Trilinear plot (Piper, 1944) is one of the most successful graphical representations in groundwater quality investigations; it aids in understanding shallow groundwater geochemistry and highlights chemical interactions more precisely than other plotting methodologies (Akakuru *et al.,* 2013; Eyankware *et al.,* 2020).

**Table 8:** CDI in the study area



| Sample code | Fe(A) | Fe (C ) | Mn (A) | Mn (C ) | As (A) | As (C) | Zn (A) | Zn (C ) | Cu (A) | Cu (C) |
|---|---|---|---|---|---|---|---|---|---|---|
| WA/01 | 8.57143E-05 | 0.0002 | 2.85714E-06 | 6.66667E-06 | 2.85714E-06 | 6.66667E-06 | 0.000143 | 0.000333 | 3.42857E-05 | 0.00008 |
| WA/02 | 2.85714E-05 | 6.66667E-05 | 3.71429E-05 | 8.66667E-05 | 2.85714E-06 | 6.66667E-06 | 5.71E-05 | 0.000133 | 8.85714E-05 | 0.000207 |
| WA/03 | 2.85714E-05 | 6.66667E-05 | 2.85714E-06 | 6.66667E-06 | 2.85714E-06 | 6.66667E-06 | 1.14E-05 | 2.67E-05 | 0.000571429 | 0.001333 |
| WA/04 | 5.71429E-05 | 0.000133333 | 2.85714E-06 | 6.66667E-06 | 3.14286E-05 | 7.33333E-05 | 8.57E-05 | 0.0002 | 5.71429E-05 | 0.000133 |
| WA/05 | 2.85714E-05 | 6.66667E-05 | 0 | 0 | 2.85714E-06 | 6.66667E-06 | 2.86E-06 | 6.67E-06 | 2.85714E-06 | 6.67E-06 |
| WA/06 | 5.71429E-05 | 0.000133333 | 0.00006 | 0.00014 | 2.85714E-06 | 6.66667E-06 | 5.71E-06 | 1.33E-05 | 5.71429E-06 | 1.33E-05 |
| WA/07 | 2.85714E-05 | 6.66667E-05 | 3.14286E-06 | 7.33333E-06 | 3.14286E-05 | 7.33333E-05 | 1.71E-05 | 0.00004 | 8.57143E-06 | 0.00002 |
| WA/08 | 2.85714E-06 | 6.66667E-06 | 2.85714E-06 | 6.66667E-06 | 2.85714E-06 | 6.66667E-06 | 0.000203 | 0.000473 | 0.00006 | 0.00014 |
| WA/09 | 3.14286E-05 | 7.33333E-05 | 2.85714E-06 | 6.66667E-06 | 3.14286E-05 | 7.33333E-05 | 3.14E-06 | 7.33E-06 | 3.71429E-05 | 8.67E-05 |
| WA/10 | 3.71429E-05 | 8.66667E-05 | 0.000004 | 9.33333E-06 | 2.85714E-06 | 6.66667E-06 | 5.71E-06 | 1.33E-05 | 0.000228571 | 0.000533 |
| WA/11 | 3.14286E-05 | 7.33333E-05 | 2.85714E-06 | 6.66667E-06 | 0.000004 | 9.33333E-06 | 2.86E-06 | 6.67E-06 | 8.57143E-06 | 0.00002 |
| WA/12 | 2.85714E-06 | 6.66667E-06 | 3.42857E-05 | 0.00008 | 3.42857E-06 | 0.000008 | 1.71E-05 | 0.00004 | 2.85714E-07 | 6.67E-07 |
| WA/13 | 3.14286E-05 | 7.33333E-05 | 4.28571E-06 | 0.00001 | 4.57143E-06 | 1.06667E-05 | 8.57E-06 | 0.00002 | 0.000114286 | 0.000267 |
| WA/14 | 2.85714E-05 | 6.66667E-05 | 3.14286E-05 | 7.33333E-05 | 4.28571E-06 | 0.00001 | 2.86E-06 | 6.67E-06 | 5.71429E-06 | 1.33E-05 |
| WA/15 | 3.14286E-06 | 7.33333E-06 | 0.00004 | 9.33333E-05 | 0.000004 | 9.33333E-06 | 5.71E-06 | 1.33E-05 | 2.85714E-06 | 6.67E-06 |
| WA /16 | 2.85714E-06 | 6.66667E-06 | 5.71429E-05 | 0.000133333 | 5.71429E-06 | 1.33333E-05 | 1.14E-05 | 2.67E-05 | 1.42857E-05 | 3.33E-05 |
| WA /17 | 2.85714E-06 | 6.66667E-06 | 2.85714E-06 | 6.66667E-06 | 2.85714E-06 | 6.66667E-06 | 1.43E-05 | 3.33E-05 | 2.85714E-06 | 6.67E-06 |
| WA /18 | 0.00006 | 0.00014 | 3.14286E-05 | 7.33333E-05 | 3.14286E-05 | 7.33333E-05 | 2.86E-07 | 6.67E-07 | 1.71429E-05 | 0.00004 |
| WA /20 | 3.14286E-05 | 7.33333E-05 | 5.71429E-06 | 1.33333E-05 | 2.85714E-06 | 6.66667E-06 | 5.71E-06 | 1.33E-05 | 0.00006 | 0.00014 |
| WA /21 | 2.85714E-06 | 6.66667E-06 | 1.42857E-05 | 3.33333E-05 | 3.71429E-06 | 8.66667E-06 | 1.14E-05 | 2.67E-05 | 1.14286E-05 | 2.67E-05 |

**Table 9:** H.Q and HI in the study area

| Sample code | Fe(A) | Fe © | Mn (A) | Mn © | As (A) | As (C) | Zn (A) | Zn © | Cu (A) | Cu (C) |
|---|---|---|---|---|---|---|---|---|---|---|
| WA/01 | 0.000122449 | 0.000286 | 6.21118E-05 | 0.000145 | 0.009524 | 0.022222 | 0.000476 | 0.001111 | 0.000857 | 0.002 |
| WA/02 | 4.08163E-05 | 9.52E-05 | 0.000807453 | 0.001884 | 0.009524 | 0.022222 | 0.00019 | 0.000444 | 0.002214 | 0.005167 |
| WA/03 | 4.08163E-05 | 9.52E-05 | 6.21118E-05 | 0.000145 | 0.009524 | 0.022222 | 3.81E-05 | 8.89E-05 | 0.014286 | 0.033333 |
| WA/04 | 8.16327E-05 | 0.00019 | 6.21118E-05 | 0.000145 | 0.104762 | 0.244444 | 0.000286 | 0.000667 | 0.001429 | 0.003333 |
| WA/05 | 4.08163E-05 | 9.52E-05 | 0 | 0 | 0.009524 | 0.022222 | 9.52E-06 | 2.22E-05 | 7.14E-05 | 0.000167 |
| WA/06 | 8.16327E-05 | 0.00019 | 0.001304348 | 0.003043 | 0.009524 | 0.022222 | 1.9E-05 | 4.44E-05 | 0.000143 | 0.000333 |
| WA/07 | 4.08163E-05 | 9.52E-05 | 6.8323E-05 | 0.000159 | 0.104762 | 0.244444 | 5.71E-05 | 0.000133 | 0.000214 | 0.0005 |
| WA/08 | 4.08163E-06 | 9.52E-06 | 6.21118E-05 | 0.000145 | 0.009524 | 0.022222 | 0.000676 | 0.001578 | 0.0015 | 0.0035 |
| WA/09 | 4.4898E-05 | 0.000105 | 6.21118E-05 | 0.000145 | 0.104762 | 0.244444 | 1.05E-05 | 2.44E-05 | 0.000929 | 0.002167 |
| WA/10 | 5.30612E-05 | 0.000124 | 8.69565E-05 | 0.000203 | 0.009524 | 0.022222 | 1.9E-05 | 4.44E-05 | 0.005714 | 0.013333 |
| WA/11 | 4.4898E-05 | 0.000105 | 6.21118E-05 | 0.000145 | 0.013333 | 0.031111 | 9.52E-06 | 2.22E-05 | 0.000214 | 0.0005 |
| WA/12 | 4.08163E-06 | 9.52E-06 | 0.000745342 | 0.001739 | 0.011429 | 0.026667 | 5.71E-05 | 0.000133 | 7.14E-06 | 1.67E-05 |
| WA/13 | 4.4898E-05 | 0.000105 | 9.31677E-05 | 0.000217 | 0.015238 | 0.035556 | 2.86E-05 | 6.67E-05 | 0.002857 | 0.006667 |
| WA/14 | 4.08163E-05 | 9.52E-05 | 0.00068323 | 0.001594 | 0.014286 | 0.033333 | 9.52E-06 | 2.22E-05 | 0.000143 | 0.000333 |
| WA/15 | 4.4898E-06 | 1.05E-05 | 0.000869565 | 0.002029 | 0.013333 | 0.031111 | 1.9E-05 | 4.44E-05 | 7.14E-05 | 0.000167 |
| WA/16 | 4.08163E-06 | 9.52E-06 | 0.001242236 | 0.002899 | 0.019048 | 0.044444 | 3.81E-05 | 8.89E-05 | 0.000357 | 0.000833 |
| WA/17 | 4.08163E-06 | 9.52E-06 | 6.21118E-05 | 0.000145 | 0.009524 | 0.022222 | 4.76E-05 | 0.000111 | 7.14E-05 | 0.000167 |
| WA/18 | 8.57143E-05 | 0.0002 | 0.00068323 | 0.001594 | 0.104762 | 0.244444 | 9.52E-07 | 2.22E-06 | 0.000429 | 0.001 |
| WA/20 | 4.4898E-05 | 0.000105 | 0.000124224 | 0.00029 | 0.009524 | 0.022222 | 1.9E-05 | 4.44E-05 | 0.0015 | 0.0035 |
| WA/21 | 4.08163E-06 | 9.52E-06 | 0.000310559 | 0.000725 | 0.012381 | 0.028889 | 3.81E-05 | 8.89E-05 | 0.000286 | 0.000667 |
| **HI** | **0.000833061** | **0.001944** | **0.007453416** | **0.017391** | **0.60381** | **1.408889** | **0.00205** | **0.004782** | **0.033293** | **0.077683** |

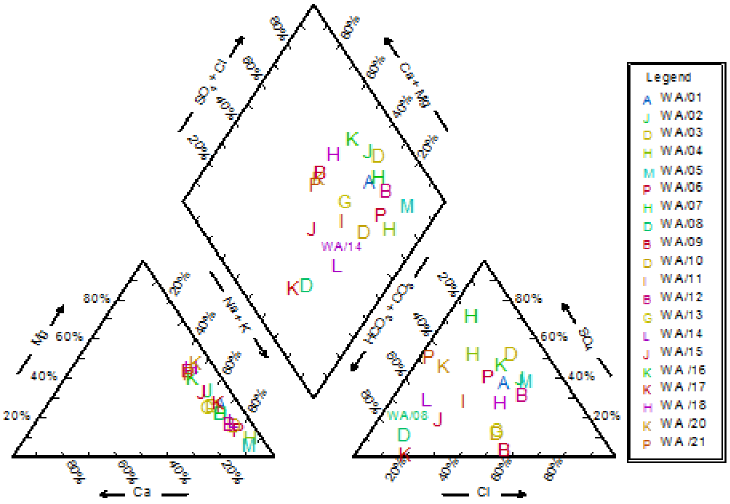


**Fig 3:** Piper diagram

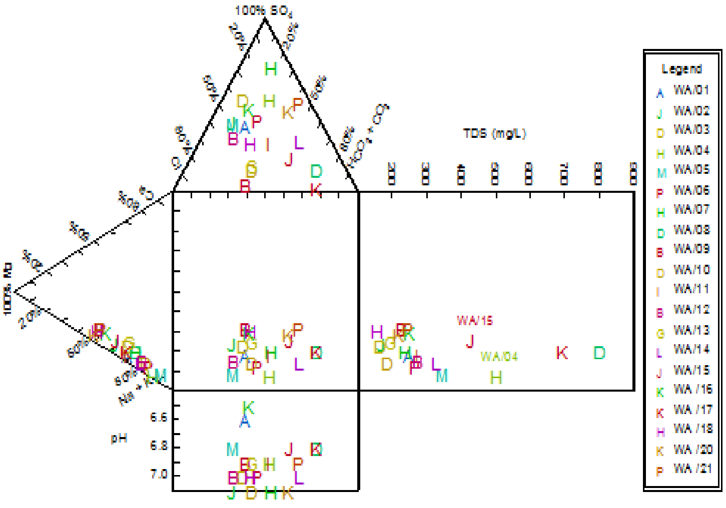


**Fig. 4:** Durov diagram

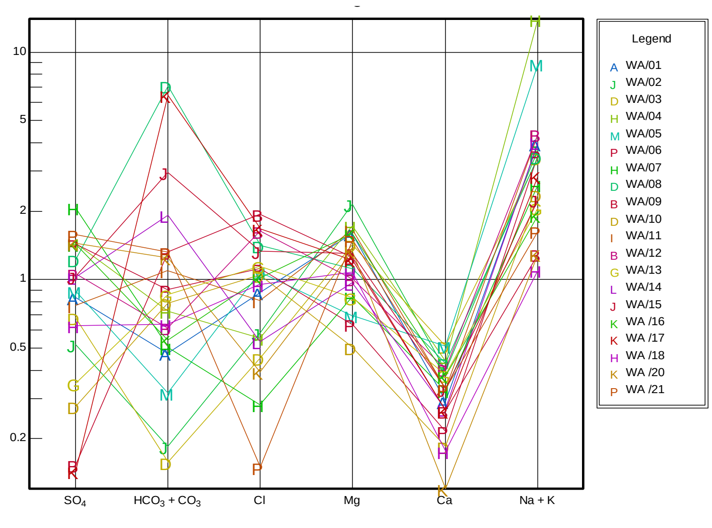


Fig. 5: Schoeller Semi-logarithm plot

From the Piper and Durov plots (Figs. 3 and 4), it shows that79.2% of the water sample had Na +K had as the major ionic specie while 20.8% had no dominant ionic specie within the cation area, while within the anion area, it has 25%, 20% and 5% of ionic dominances of $HCO_3+CO_3$, $SO_4$, and Cl respectively, with 50% of its samples having no dominant ionic specie. In the same vein, the geochemical zone of the samples are 7 (which is the sodium chloride type (60%), and the 9 (mixed type (40%)). Sodium chloride and most other chloride salts have high solubility. Depending on the temperature, the dissolution limit for NaCl is about 35.5 weight percent. As shown in the analysis of the table, many wells show significant chloride and alkali metal concentrations. When the concentration reaches a level comparable to seawater (3.5% by weight or more), they are called brine. A medium-concentration source that contains enough NaCl to produce a salty taste is brackish water. The following mechanism can produce high salt springs: a salt water spring from the evaporative bed in the catchment area of the spring; sources contaminated by anthropogenic sources, especially salt used in de-icing roads; coastal fountain affected by inrush current; and well to drain oil field brine.

*Schoeller Semi-logarithm chart:* Another relationship technique that uses direct diagrams is the Schoeller Semi-logarithm chart. The most popular charts for communicating water quality use math or logarithmic scales (Sakram et al., 2013).

The chart proposed by (Schoeller, 1977) depicts a collection of investigations on equidistant verticals, the number of which depends on the number of constituents being communicated. This diagram is especially useful for examining waters with low focus and waters with a wide range of fixation (Sakram et al., 2013; Saha et al., 2019; Olofinlade et al., 2018).
The Schoeller graph of the review region (Figure 5) uncovers a hydrogeochemical pattern of $Na^{+}+K^{+} > HCO_3^{-}+CO_3 > Mg^{+} > SO_4 > Cl^{+} > Ca^{+}$ in the request for the most noteworthy to the least constituent. The information's Schoeller semi-logarithmic plots confirmed the previous plot's water type. The pinnacles represent the most common particles in the water tests, while the box represents the less common particles. This plot corresponds to the Piper and Durov plots in this study. The similarity of the hydrogeochemical movement trend, on the other hand, implies that the groundwater must have originated from the same source (Akakuru *et al*. 2017; 2021a)

*Conclusion:* Groundwater quality assessments have been conducted to assess the impact of human activities on groundwater quality. The hydrogeochemical facies results revealed that 79.2 percent of the water samples had Na +K as the major ionic specie, while 20.8 percent had no dominant ionic specie within the cation area, and 25 percent, 20 percent, and 5 percent of its samples had no dominant ionic specie within the anion area, with 25 percent, 20 percent, and 5 percent of its samples having no dominant ionic specie. Similarly, the geochemical zones of the samples are 7 (which is the sodium chloride type (60 percent)) and 9 (mixed type) (40 percent). Sodium chloride and most other chloride salts are highly soluble. The temperature-dependent dissolution limit of NaCl is 35.5 weight percent. In order of most significant to least significant constituent, the Schoeller graph of the review region reveals a hydrogeochemical pattern of $Na^{+}+K^{+} > HCO3 +CO3 > Mg^{+} > SO4 > Cl^{-} > Ca^{+}$. The Schoeller semi-logarithmic plots of the data confirmed the previous plot's water type. Nevertheless, appropriate remedial treatment for groundwater is recommended in areas where trace elements exceed the WHO recommended upper limit. As a result, it is possible to conclude that the groundwater in the study area is "safe" for drinking and domestic use.

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