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Hydrogeochemical evaluation of Groundwater Suitability for Drinking and Irrigation Purposes in Coastal Community of Gbaramatu Kingdom, Nigeria

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ABSTRACT: The aim of this paper was to evaluate the hydrogeochemistry of groundwater suitability for drinking and irrigation purposes in Okerenkoko Gbaramatu Kingdom, South-South Region, Nigeria using standard methods. The results obtained in the study indicates that over 70% of the groundwater under investigation fell in the category of C3S1 and C4S1 in the USSL salinity diagram implying high to very high salinity. The concentration of Lead (Pb) in all the samples collected exceeded the recommended value of 0.01 mg/L set by the World Health Organization and the Standard Organization of Nigeria respectively. Groundwater from the study area can only serve as irrigation purpose for salt tolerant crops like the sweet potato, grain-sorghum, sugar beet, cotton and carrot. The production of these crops on the vast arable fallow land will contribute significantly to food security and economic advancement of the study area and the global community at large. Conversely, the groundwater cannot be consumed unless treatment is administered.

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Groundwater depletion and deterioration can trigger water crisis and potential threats to global community by limiting access to clean water for healthy plant and human health through food chain. Water laden with contaminants can be injurious to plants and animals (Omorogieva *et al.,* 2022b; Adimalla *et al.,* 2020; Omorogieva and Tonjoh, 2020; Singh *et al.*, 2020; WHO, 2017; Selinus *et al.,* 2013). Globally, groundwater serves as the primary source of water for irrigation and drinking purpose, especially in the arid areas where there is rarely access to surface water (Nag and Lahiri, 2012), and in the coastal environment where groundwater is interjected with saltwater, and high concentration of other dissolved substances contained in seawater (Gad and El-Osta, 2022; Rajmohan and Elango, 2005; Onwuka and Omomoma, 2017; Akpoborie *et al.,* 2015). Due to the dynamic characteristics of water often influenced by geological formations, natural and anthropogenic processes occurring in the environment, it is very important to characterize the physical, biological and chemical composition of water to ascertain its application especially in crops production on agricultural soils, and drinking purposes (Pivić *et al.,* 2022; El Osta *et al.,* 2022; Eyankware *et al.,* 2021; Omorogieva and Ogieriakhi, 2021; Tonjoh and Omorogieva, 2020; Claudia *et al.,* 2020; Syed *et al.,* 2018). Furthermore, groundwater extraction in low-

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lying coastal zones may be problematic because coastal aquifers are generally fragile and vulnerable to pollution, especially in areas where there is overexploitation, dissolved ions, ion mixing and anthropogenic activities (Akakuru *et al.,* 2021; Chidambaram *et al.,* 2009; Michael *et al.,* 2017; Jiang *et al.,* 2019; Muhammadu *et al.,* 2019). Water being an important component of the ecosystem, scholars across different field of specialty particularly those in the discipline of water resource management, hydrology, geology, hydrogeology and environmental studies have focused attention on the need for water quality monitoring and appraisal with regards to its usage (Pivić *et al.,* 2022; Efobo *et al.,* 2020; Onwuka and Omomoma, 2017; Khodapanah *et al.,* 2006). The study was motivated by the gap in knowledge of the groundwater quality that can be applied on the vast arable land for agricultural activities but lying fallow, and the incessant diagnostic water born related diseases recorded in the study area (Ugwuja, 2022). Okerenkoko federated community; Gbaramatu Kingdom, Nigeria is a coastal community in the southern part of the country located along river Escravos just before the Gulf of Guinea (Ekperusi *et al.,* 2022). The quality of groundwater in the study area is highly influenced by the aquifer materials; recharge sources residence time of dissolved minerals, geochemical reactions including leaching, impacts of transgression and regression (tidal mixing), surface and groundwater interaction and ion exchange (Gad and El-Osta, 2022). On the other hand, open defecation in Escravos River Basin (ERB), leakages in crude oil pipelines, direct and incidental discharge of ocean vessels, incessant oil spillage, and illegal crude oil theft facilitated by tidal mixing of the estuary water system play a pivotal role in the quality of water (Akinwumiju and Orimoogunje, 2013; Abija *et al.,* 2019; Johnbosco and Edebiri, 2019; Tonjoh and Omorogieva, 2020). The specific objectives of the study are to measure the hydraulic head of existing wells; collect groundwater samples from existing boreholes, tube and hand dug wells available in the study area based on standard sampling and analytical methods; analyze for the major ions, fundamental physical, chemical and lead (Pb) metal; calculate for irrigation parameters, and develop sample location and groundwater flow maps of the study area. The outcome will provide first-hand information and guidance for the region and national in particular as well as the global community at large on the best agricultural practice and crop production in such environment, the level of potability and the general condition of the groundwater system in the area. These will eventually create awareness to fast-track the management of groundwater resources at individual, communal, regional and national as well as on a global scale in an area of similar characteristics for the purpose of planning and budgeting, consequently fostering rapid societal development.

MATERIALS AND METHODS

Site Description, Geology and Groundwater condition of the study area: The study area (Okerenkoko) is an estuary environment and one of the largest communities in Gbaramatu kingdom, Niger Delta region of Nigeria. It is situated along the ERB on the coordinate of 5.386111N, 5.620556E and 5.393611N, 5.633889E, respectively (Fig.1). Fishing is the main occupation of the people, with a few involving in farming, hunting and lumbering activities. The community is the host to the foremost Nigeria Maritime University (NMU). The dimension of the study area is 2.1 km by 2.4 km (5.04 km2) land mass (Fig.1). It is accessible by air and the coastal waterways, and its adjoining creeks. The mangrove trees in the area perform the function of offshore long drift and wave energy breakers, consequently protecting the shoreline of the coastal communities from flooding and other related coastal hazards. Climatically, it is a tropical rain forest characterized by heavy rainfall, high temperature and humidity of about 60% (Tonjoh and Omorogieva 2020). The soil characteristic is milky-white to brownish-grey in colour, fine grain size and well sorted. The geology of the area belongs to the Mangrove Swamp Formation (MSF), one of the recently deposited suits of sediments overlying the Warri Sombreiro (Deltaic Plain Sands) Formation in the Niger Delta Sedimentary Basin (Akpoborie *et al.,* 2015). The MSF and the Warri Sombreiro Formation, is an extension of the Benin Formation, the youngest of the Niger Delta Sedimentary Basin (Edegbai *et al.,* 2019).

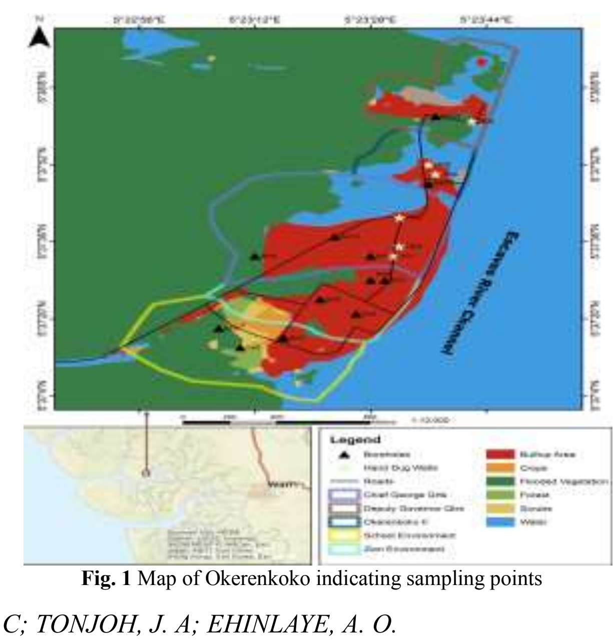

Fig. 1 Map of Okerenkoko indicating sampling points

The groundwater in the study area is tapped from the shallow aquifer of the Mangrove Swamp Formation (MSF) with a depth range 30 – 50m. Previous studies indicated that the groundwater contain high level of microorganisms (*e-coli, coliform, staphylococcus spp.*), moderate to low pH, moderate to high level dissolved of metals, hardness and turbidity (Tonjoh and Omorogieva, 2020; Ugwuja, 2022; Adebayo, 2022). The poor groundwater quality may be attributed to the unconfined nature of the aquifer and the soil characteristics, ranging from fine to coarse grain sizes which allow the infiltration of contaminants through rainfall and groundwater movement into the shallow unconfined aquifer as well as saltwater interaction and ion exchange within the system (Gad et al. 2018; Li *et al.,* 2019a; Adebayo, 2022; Gad and El-Osta, 2022; Ugwuja, 2022). Furthermore, it was observed that during the peak of dry season, salinity and hardness of the groundwater is extremely high; requiring enormous amount of soap to form lather. On the other hand, at the peak of wet season, the salinity and hardness becomes low due to dilution factor.

Sampling Procedures, Parameters and Analysis: The community was divided into five (5) grids based on the number of quarters; these include School Environment (SE), Zion Environment (ZE), Okerenkoko II (OK), Chief George Quarter (CGH) and the Deputy Governor Quarter (DGQ) as indicated in Table 1.

Table 1: Field data report (n=10)

S/N	Latitude	Longitude	Hydraulic Head (SWL)	Source	Code	Elevation	CWL	Sample Point
1	5.387778	5.621111	1.67	BH3	SE	15.861	14.191	SE/Main Staff Quarter
2	5.390556	5.6225	0.44	BH4	ZE	8.681	8.241	Zion Main Quarter
3	5.389167	5.623333	1.2	BH5	ZE	15.096	13.896	Zion Main Quarter (BW)
4	5.391111	5.625833	1.1	BH8	OKII	14.429	13.33	Zion/General Hospital
5	5.391944	5.625833	0.63	HD1	OKII	7.196	6.57	OKII Junction
6	5.389722	5.626944	0.3	BH10	OKII	17.4	17.10	Adjacent University Road
7	5.393611	5.630556	0.33	HD4	CGH	10.321	9.991	Chief George House
8	5.393333	5.63	0.4	BH11	CGH	7.93	7.53	Chief George House
9	5.395	5.633611	0.75	HD6	DGH	9.875	9.13	Deputy Governors' House
10	5.393611	5.633889	0.76	BH12	DGH	11.456	10.696	Deputy Governors' House

Note: SE (School Environment), ZE (Zion Environment), OKII (Okerenkoko II), CGH (Chief George House) and DGH (Deputy Governors' House) and General Hospital

A total number of ten (10) composite groundwater samples from existing boreholes and hand-dug wells were collected systematically in a single survey during the peak of wet season. The Coordinates (Longitude and Latitude); groundwater source; Static Water Level (SWL) also refer to as hydraulic head (HD); Corrected Water Level (CWL); Sample Code, and the altitude of sampling points were recorded in the field with the aid of the Global Positioning System (GPS), and a deep meter (Table 1). The samples collected include seven (7) composite groundwater from existing boreholes (BH), and three (3) hand-dug (HD) wells within the grids; sampling protocol was based on the various quarters in the community which resulted to five grids (Figure 1). In the case of borehole, samples were collected after 10 minutes of direct pumping from the aquifer, while a depth sampler with long rope attached to it was used in collecting groundwater sample from HD wells at a depth of 0.3 m below the surface of the water level in the well (Rajmohan and Elango, 2005). The samples were stored in a well-labeled pre-rinsed 75 cL plastic bottle and transported to the laboratory in ice cheeps cooler for analysis. The portion allotted for heavy metal (Pb), and cations parameters were preserved with 20% diluted Nitric Acid (HNO_3^-) to keep the pH under 2 (Efobo *et al.,* 2020; Olasumbo and Olufemi, 2020; Paternoster *et al.,* 2021). The addition of nitric acid was to ensure that all volatile parameters were kept under control. Similarly, samples for anion analysis were kept in the refrigerator at a controlled temperature of 4°C according to the method outlined in the handbook of the America Public Health Association (APHA, 1995).

Analysis of Groundwater Samples: In situ parameters like the pH, Electrical Conductivity (EC), and Total Dissolved Solids (TDS) were measured with RaeSung AZ86031 in-situ analyzer during sampling just before the addition of 20% diluted nitric acid for preservation of volatile parameters. The instruments were applied after calibration was performed in accordance with the manufacturer's specification (HACH, 1997; Paternoster et al., 2021). Other parameters measured include HCO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^- and Pb. Determination of Pb and SO_4^{2-} were performed analytically with the digital UV-spectrophotometer (Manivaskam, 2011), while HCO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and NO_3^- were achieved by titrimetric methods (APHA, 1995).

Evaluation of Hydrochemical Indices: Durov diagram was developed by using Aquachem 2004 software to determine the dominant ions in the groundwater system. The plot is vital in the interpretation and evaluation of the sources and characteristics of groundwater quality.

Irrigation Parameters: The assessment of water for irrigation application is subject to established fundamental indices like: Soluble Sodium Percentage (SSP) also refer to as Sodium Percentage (Na^+ %). It was calculated based on the method outlined in Singh *et al.* (2020); Paternoster et al. (2021); Todd and Mays, (2005). The calculation is expressed mathematically in equation 1.

$$SSP/Na\,\% = \frac{(Na^{+}+K^{+})}{(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})} \times 100 \quad (1)$$

Sodium Adsorption Ratio (SAR) is an essential parameter for irrigation water quality assessment. The mathematical expression is presented in equation 2 after Richards, (1954); Paternoster *et al.* (2021)

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \quad (2)$$

Magnesium Hazard (MH): In this study, the methods outlined in Szabolcs and Darab (1964) cited in Singh et al. (2020) was adopted; the mathematical expression is shown in equation 3.

$$MH = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} \times 100 \quad (3)$$

Permeability Index (PI) is one of the crucial indicators considered in irrigation water evaluation. In this study, the procedure outlined in Doneen (1964) as applied in Singh *et al.* (2020). The formula used is shown in equation 4.

$$PI = \frac{(Na^{+}+\sqrt{HCO_3^{-}})}{(Ca^{2+}+Mg^{2+}+Na^{+})} \times 100 \quad (4)$$

Chloroalkaline Index I (CAI I) was determined by equation 5 based on the work of Scholler (1977) cited in Singh et al. (2020)

$$CAI\ I = Cl^{-} - \frac{(Na^{+}+K^{+})}{Cl^{-}} \quad (5)$$

In addition, USSL salinity diagram, Wilcox permeability index were determined by the application of Grapher free software to assess irrigation quality in the study area.

Map Production and Groundwater Flow Direction: Sample location and groundwater flow maps were produced by using ArcGIS PRO and Suffer 15 software. The coordinate generated from field were used as the data set to generate the maps.

RESULTS AND DISCUSSIONS

Results were read in triplicate and presented in mean values (Table 2). The following; pH, EC, TDS, HCO_3-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^- and Pb were analyzed, while SAR, MH/MAR (%), CAI I, SSP/Na (%) and PI (%) were calculated for as fundamental irrigation assessment parameters. The pH of the groundwater ranges from 4.20 – 6.90. The values indicate that the groundwater is slightly acidic to moderately acidic. However, the pH recorded in School Environment (SE) and the Deputy Governor House (DGH) were within the recommended permissible range of (6.5-8.5) by WHO (2020). Broadly speaking, of the five grids in Figure (1), 18.18 % of the total groundwater assessed was fit for consumption, while 81.81% were not based on the pH values obtained in the study. The most acidic groundwater in the study area was recorded at Zion Environment (ZE) with a mean value of 4.20, whereas the most basic groundwater source were those recorded within the General Hospital (GHO) and School Environment (SE), with a corresponding value of 6.90 respectively. Electrical Conductivity (EC) and the TDS values in the study indicated that 36.36% and 50% of the groundwater are unfit for consumption, while 63.63% and 50%, respectively, are fit for consumption. These percentage values correspond to the EC range of 87 – 2982.67 µS/cm, with the lowest mean value recorded at Zion Church point in Zion Environment, whereas the highest mean value was recorded in Okerenkoko II. The values of TDS in the study ranged from 43.67 in the ZC borehole at the ZE grid to 1492.33 mg/L in the OK1 hand-dug well at OKII grid respectively. The upper limit of TDS recommended in drinking and irrigation water purposes respectively is 1000 mg/L; in the study area, 40% of the groundwater assessed was higher than the tolerable limit specified by regulatory organizations, whereas 60% of the recorded values were within and below the required limit (WHO, 2017; Omorogieva and Igberase, 2022). On the basis of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-), the results recorded in the study indicated that Na^+, K^+, Ca^{2+}, Mg^{2+}, have a range of Na^+ (0.8 – 16.27 mg/L); K^+ (0.18 – 1.67); Ca^{2+} (7.2 – 43.53 mg/L) and , Mg^{2+} (1.13 – 36.80 mg/L). The permissible limit for Mg^{2+} for water quality evaluation is 0.2 mg/L, while Ca^{2+} is 75 mg/L (WHO, 2017). Chloride (Cl^-) values ranged from 53.42 -478.47mg/L; these values indicate that 45% of the groundwater is fit for consumption while 55.55 was not. The results for Pb range from 0.05 – 0.64 mg/L. The highest value of 0.64mg/L was recorded at SE, while the lowest value of 0.05mg/L was recorded at the ZE borehole in the ZE grid. Conversely, DGH, OKII and OK1 had a value of 0.11mg/L respectively. These results compare to previous study in neighbouring communities shows a systematic increase from 0.001 to 0.64 in the current study (Tonjoh and Omorogieva, 2020).

Irrigation Parameters: For the purpose of irrigation application, Magnesium Hazards (MHs), Chloroalkaline Index (CAI I), Sodium Adsorption Ratio (SAR), Permeability Index (PI) and Sodium Percentage (Na^+ %) were calculated. The results obtained showed that SAR values ranges from 0.22-2.15 mg/L; the lowest mean value was recorded at OK1 well within OKII grid, and the highest mean value was noted in ZC borehole within the ZE grid. Similarly, MH values documented in the study ranges from 30 – 45mg/L. The lowest mean value was recorded at the ZC borehole within the ZE grid, whereas the highest value was recorded at ZE borehole within the ZE grid respectively. On the other hand, Na^+ %, sometimes refer to as Soluble Sodium Percentage (SSP) was also determined; the values recorded in study ranges from 3.44 – 16.26 mg/L with the lowest and highest mean values recorded in OK1 at OKII well and SE borehole within SE grid respectively. Other irrigation parameters measured include PI and CAI I; the lowest mean value of 28.13 mg/L and the highest mean value of 96.86 mg/L for PI were noted in ZC borehole within the ZE grid, and ZE borehole at the ZE grid respectively. For the CAI1, the values recorded ranges from 53.40 – 374.39 mg/L; the lowest mean value was recorded in the ZC borehole at the ZE grid, while the highest value was recorded in OK1 well at the OKII grid in the study area.

Groundwater Flow: Groundwater flow map and the digital elevation model (DEM) indicating the topography and flow direction of the study area are shown in Figure2 and 3 respectively. The direction of flow is indicated with the arrows in Figure 2; this is in alignment with DEM in Figure 3 that depicts ground elevation of the study area.

When groundwater is over-extracted, a cone of depression is formed; in a situation where the rate of recharge is low compared to the rate of extraction, the possibility of saltwater infiltrating into the freshwater aquifer is inevitable (Fig, 4a and b); this becomes more realistic when the water table is high. During the dry season, the water table is low; consequently, the water contained in ERB becomes a source of recharge to the groundwater system. During the period in question, the groundwater will become enriched with dissolved ions enhance by tidal mixing coupled with other biogeochemical processes occurring on the surface derived water. Furthermore, the salinity will increase as a result of excessive evaporation due to intense sunshine during the dry season; these whole processes will facilitate saline seawater from the surface to intrude into freshwater aquifer in the subsurface (Barlow, 2003; Ghyben-Herzberg, 2018; Tonjoh and Omorogieva, 2020).

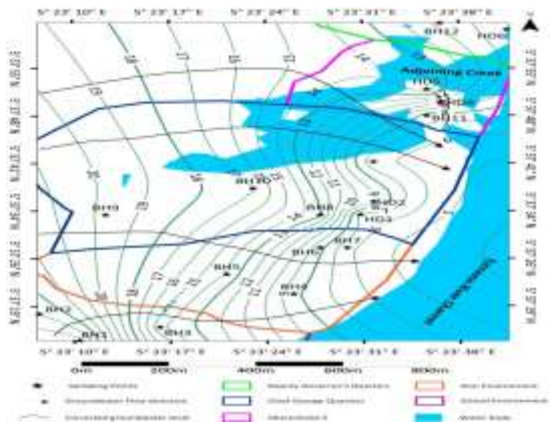

Fig. 2 Groundwater flow direction in the study area

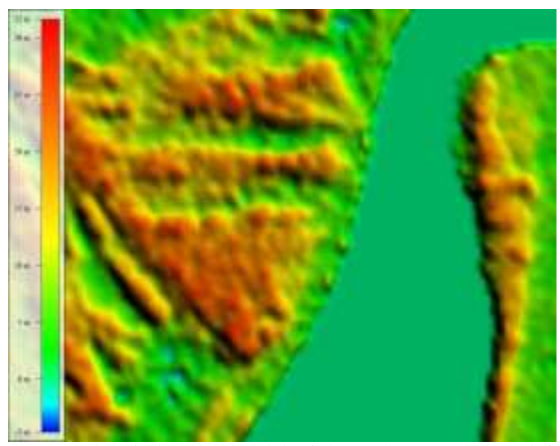

Fig. 3: Digital elevation model of the study area extracted from shuttle radar topography mission (SRTM). The red color indicates ground elevation (highest points)

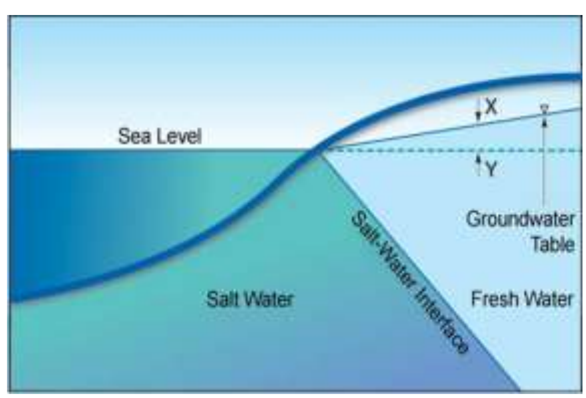

Fig. 4a: Salt-water interface in an unconfined coastal aquifer (Ghyben-Herzberg, 2018 in Tonjoh and Omorogieva, 2020)

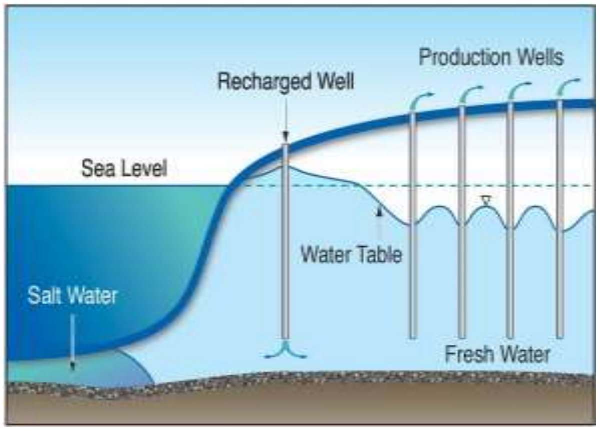

Fig. 4b Salt-water interface in an unconfined coastal aquifer (Ghyben-Herzberg, 2018 in Tonjoh and Omorogieva, 2020)

Coastal environment of Gbaramatu in Nigeria including Okerenkoko community, groundwater derived from the MSF is the only available source of water for irrigation and drinking purposes. The results obtained from the fundamentals of water quality assessment parameters for drinking and irrigation purposes in the study area indicates that the groundwater cannot serve the purpose of the study because of the saline nature and the presence of surface derived contaminants. Water laden with impurities can cause serious health problem and resistance to healthy plant growth. The situation can lead to food scarcity and water borne diseases which in turn may lead to low productivity and food scarcity. On the other hand, when contaminated water is adequately treated, and the right crops cultivated, the outcome will be transformational because arable land will be cultivated and there will be plenty of food supply and increase in human productivity.

Water with low or high pH can facilitate dissolution of minerals in high concentration. The concentration of these minerals in water for irrigation and drinking purpose can cause significant harm to the ecosystem when it's above the tolerable limits. The values of pH obtained in the study revealed that the groundwater in the study area is slightly to moderately acidic; the low pH values could be influenced by the high level of anthropogenic activities of gas flaring, crude oil theft, ocean vessel direct and incidental discharge in the surface water. When surface water intermingled with groundwater, the contaminants in the surface water are introduced into the groundwater system, vise a vise (Dehghani *et al.,* 2018; Tóth, 2020; Zhou *et al.,* 2020). Ideally, the recommended value of pH in potable water should not exceed the range of 6.5 – 8.5; this implies that groundwater in the study area in terms of pH value is not suitable for drinking purposes because over 50% of the groundwater exceeded the recommended limit (Soveri, 1992; WHO, 2003; WHO, 2017; WHO, 2021; SON, 2015). The EC and TDS results on the other hand show an appreciable level of acceptance for drinking and irrigation purposes but continue dissolution of materials in the groundwater system can cause unusual level of EC and TDS respectively. For the cations, Mg^{2+} in all the groundwater samples analyzed were noted to be above the threshold limit of 0.2mg/L recommended by WHO (2017) for potable water, although the Ca^{2+} in all the samples were within the acceptable limit of 75 mg/L. The values obtained for Mg^{2+} call for concern. The presence of Magnesium (Mg^{2+}) in water bodies could be traced to the dissolution of rock with high content of magnesium whereas Ca^{2+} may be mainly due to biogeochemical processes involving Calcium dissolution from shell organisms and carbonate rocks (Singh *et al.,* 2020). At a concentration greater than 0.1 mg/L, Magnesium can result in an undesirable taste in water supply scheme and also, a threat due to its ability to form coating material on fabrics and supply pipes. On health assessment, 0.4 mg/L of Mg^{2+} is acceptable compared to the general tolerability limit of 0.1 mg/L. The anomaly concentration of Mg^{2+} in groundwater system in the study area can be is attributed to the dissolution of Mg ions in the groundwater system. On the other hand, the anions values showed a similar trend when compare to the cations; it was observed that about 50% of the sampled groundwater was above 250 mg/L recommended for Cl^- and HCO_3^- in drinking water while about 82% of SO_4^{2-} recorded in the study exceeded 100 mg/L recommended in drinking water.

The concentration of Lead (Pb) in the groundwater system was relatively high. Primarily, Pb occurrence in groundwater is attributed to natural processes, and the concentration is usually very low (below the detectable limit). However, anthropogenic activities resulting from industrial inputs, crude oil spills, gas flaring, and plumbing materials are a major sources (Pazand *et al.,* 2018). Excess Pb in the human system can lead to myriad health challenges, ranging from low intelligent quotient (IQ), particularly in children under age 5, to reproductive dysfunction to being carcinogenic (Adimalla *et al.,* 2020; Omorogieva *et al.,* 2022a). The occurrence of relatively high concentration of Pb in the groundwater system is traceable to the incessant gas flaring, artisanal crude oil refinery and industrial activities. This is because the result obtained from the various well assessed shows that 100% of the mean values recorded were higher than the recommended 0.01mg/L intervention by national and world water regulatory bodies (Omorogieva and Igberase, 2021; WHO, 2017; SON, 2015), a record that calls for urgent intervention.

Irrigation Parameters: Magnesium Hazard (MH), Chloroalkaline Index (CAI I), Sodium Adsorption Ratio (SAR), Sodium Percentage (Na %) and permeability index were calculated accordingly; these parameters are key in evaluating the suitability of water for irrigation purposes (Nagaraju *et al.,* 2006). In natural water, Mg^{2+} and Ca^{2+} maintain equilibrium; however, if the value of Mg^{2+} is more than 50 mg/L in water, such water cannot be used for irrigation purposes. This is because high value of magnesium in water can influence the value of pH in the system. Consequently, the rate of water infiltration in soil will be impeded because of the increase in alkalinity; this occurrence can obstruct the growth and yield of crops. The MH values measured in the study shows that the groundwater in the area can be apply for irrigation purpose. The outcome of the result may be due to the period of sampling being the peak of wet season where the groundwater has been diluted (Khodapanah *et al.,* 2006). According to Biswa *et al.* (2002), SAR within the range of 0-10 is rated excellent, 11-18 is classified as good, whereas values >18 are rated unsuitable for irrigation. Most of the groundwater sampled in the study falls within the permissible limit of < 18 mg/L. The United State Salinity Limit (USSL) diagram was employed to aid the interpretation of the results recorded in the study (Fig. 4).

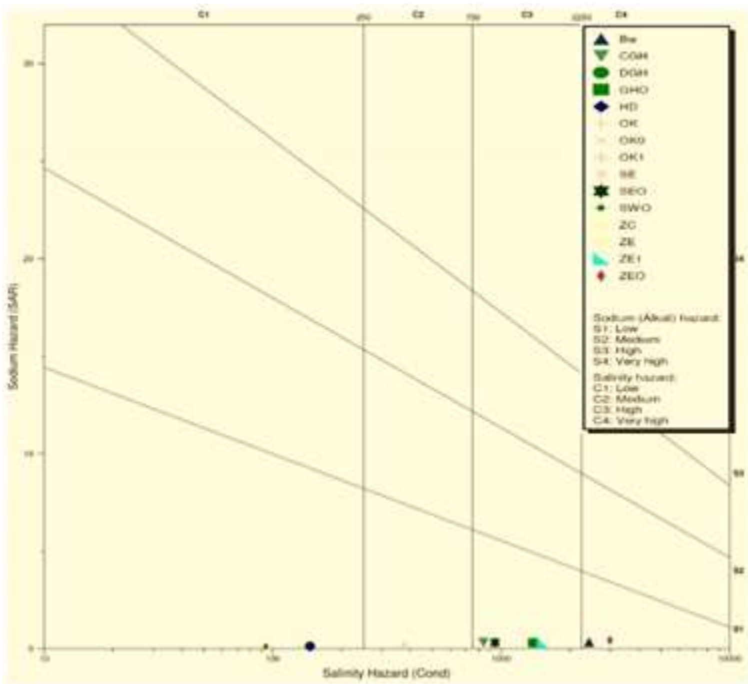

Fig. 4 USSL salinity diagram indicating the level of salinity

The diagram revealed that the salinity of the assessed groundwater ranges from moderate to very high salinity based on the classification. The implication is that Na^{+} in the groundwater might be possibly replaced with Mg^{2+} and Ca^{2+}; this may repel the infiltration of water into the soil due to impermeability resulting from the cation exchange. The stunted growth and undeserving yield of crops noticed in the area could be as a result of the high salinity and possibly cation exchange capacity. Durov diagram in Figure 5 further confirmed the assertion. In Figure 5, the Durov diagram revealed that Mg^{2+} and Ca^{2+} were the dominant ions, and their presence indicate ion mixing and a gentle dissolution from a polluted source.

Soluble Sodium Percentage SSP (Na^{+} %) in the study showed that the groundwater type is slightly salty but fell within suitable water for irrigation purposes, and the result is similar to that of Singh et al. (2020). Permeability Index (PI) was calculated based on the values of Ca^{2+}, Mg^{2+}, Na^{+} and HCO_3^{-} dissolution in the groundwater system under investigation. The results of PI obtained in the study reflect an appreciable level of ratio 1:9 acceptance for irrigation purpose. In other words, 10% of the groundwater indicates non acceptability for irrigation whereas 90% of the values recorded are acceptable for irrigation application. Li *et al.* (2021); Nagaraju et al. (2006) categorized PI into three categories. Category I and II fell within the value range of > 75% and 25 – 75%, respectively, while category III fell within < 25% values. Those in categories I and II are classified as excellent water for irrigation, whereas those in category III are regarded as unsuitable for the same purpose.

Table 2. Results of the physicochemical and hydrochemical parameters measured in mean values (n=10)

Code	pH	EC (µS/cm)	TDS	Pb	HCO_3^-	SO_4^{2-} mg/L	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	NO_3^-	SAR	MH/MAR %	CAI I	SSP/Na %	PI
CGH	5.77	358.00	178.33	0.33	109.13	0.87	8.53	0.59	26.67	17.87	372.53	2.53	1.81	40.12	372.51	16.99	35.76
DGH	6.63	145.67	73.00	0.11	42.9	0.18	1.70	0.18	7.20	3.67	88.80	0.87	0.73	33.76	88.78	14.75	65.63
GHO	6.90	1383.55	1032	0.37	104.07	0.99	9.67	1.01	36.27	22.47	302.20	5.08	1.78	38.25	302.16	15.38	29.05
OKII	6.63	145.67	1243.67	0.11	42.9	0.18	1.70	0.18	7.20	3.67	88.80	0.87	0.73	33.76	88.78	14.75	65.63
OK0	6.63	145.67	73.00	0.55	42.9	0.26	1.70	0.18	7.20	3.67	88.80	0.87	0.73	33.76	88.78	14.75	65.63
OK1	4.47	2982.67	1492.33	0.11	177.63	0.56	1.40	1.37	42.27	35.53	374.40	6.90	0.22	45.67	374.39	3.44	18.60
SE	6.90	375.33	187.33	0.64	32.77	0.13	3.47	0.24	9.80	6.24	118.47	1.75	1.23	38.90	118.44	18.78	47.10
SE0	6.10	939.00	469.00	0.07	61.00	0.13	8.00	0.57	22.40	15.40	212.70	4.12	1.84	40.74	212.66	18.48	34.52
ZC	5.23	87.00	43.67	0.17	12.37	0.09	0.80	0.04	2.53	1.13	53.42	0.49	0.59	30.87	53.40	18.67	28.13
ZE	4.20	2592.67	1286.67	0.05	140.30	1.25	13.25	1.27	40.80	35.13	318.37	6.63	2.15	46.27	318.32	16.05	96.86

Note: SE (School Environment), ZE (Zion Environment), OK2 (Okerenkoko II), CGH (Chief George House) and DGH (Deputy Governors' House) and General Hospital (GHO).

Table 3. Correlation coefficient of the parameter measured

	pH	*EC*	*TDS*	*Pb*	*HCO_3^-*	*SO_4^{2-}*	*Na^+*	*K^+*	*Ca^{2+}*	*Mg^{2+}*	*Cl^-*	*NO_3^-*
pH	1											
EC	-0.717*	1										
TDS	-0.440	0.781**	1									
Pb	0.564	-0.381	-0.459	1								
HCO_3^-	-0.637*	0.899**	0.714*	-0.303	1							
SO_4^{2-}	-0.446	0.635*	0.509	-0.120	0.766**	1						
Na^+	-0.251	0.434	0.295	-0.139	0.482	0.803**	1					
K^+	-0.615	0.957**	0.759*	-0.313	0.956**	0.784**	0.593	1				
Ca^{2+}	-0.561	0.901**	0.702*	-0.275	0.950**	0.824**	0.672*	0.987**	1			
Mg^{2+}	-0.682	0.953**	0.725*	-0.337	0.963**	0.789**	0.617	0.991**	0.982**	1		
Cl^-	-0.512	0.748*	0.539	-0.190	0.927**	0.802**	0.643*	0.886**	0.940**	0.905**	1	
NO_3^-	-0.608	0.961**	0.739*	-0.337	0.902**	0.708*	0.613	0.983**	0.967**	0.976**	0.843**	1

**Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).*

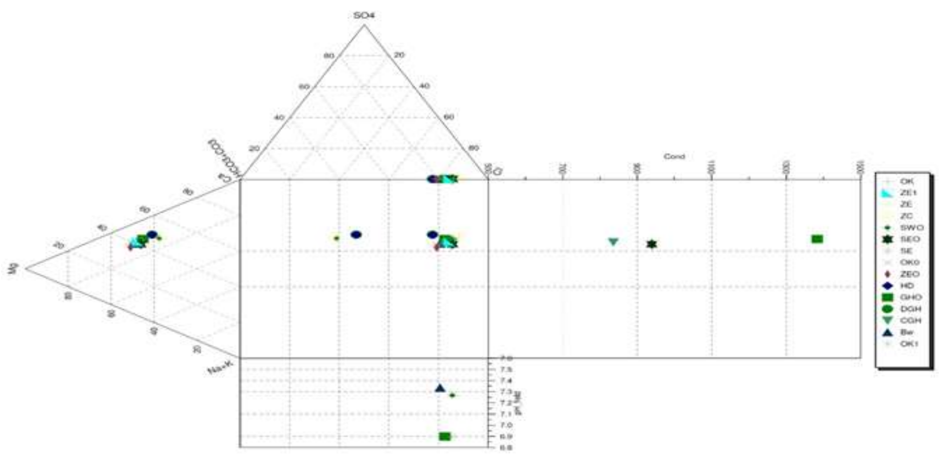

Fig. 5: Durov diagram indicating Mg^{2+} and Ca^{2+}as the dominant ion in the groundwater system

Chloroalkaline Index I (CAI I) is used to study the chemical composition of groundwater and its flow pattern. Scholler (1977) noted that positive value of CAI1 is an indication of direct ion exchange between Na^+ and K^+ from water and Mg^{2+} and Ca^{2+} with rock whereas negative values indicates a reversed order. In the study, CAI 1 values obtained indicated that 100% ion exchange took place between Na^+ and K^+ from water and Mg^{2+} and Ca^{2+} from rock. This implies that Mg^{2+} and Ca^{2+} in the groundwater are from dissolved underlying rock while Na^+ and K^+ are from dissolved substances in the groundwater system.

Correlation Analysis: Juxtaposing laboratory results with statistical analysis of correlation at two tailed $P < 0.05$ and 0.01, the parameters measured showed a moderate to strong relationship within and between the variables measured in the in the groundwater (Table 3). This implies that the variables in the groundwater system are possibly from the dissolution of minerals and the geology of the aquifer media as demonstrated in the Durov plot. Furthermore, the relationship between the pH and Pb (r^2=0.564) in the groundwater being investigated buttress the relatively high level of Pb which may be traceable to anthropogenic inputs. On the other hand, HCO_3^-, SO_4^2-, K^+, Ca^{2+}, Mg^{2+}, Cl^- and NO_3^- correlates positively between themselves and with EC indicating that parameters are from similar source, possibly from the dissolution of minerals in soil and sediments within the fresh groundwater system. On the other hand, the weak correlation between Na^+ and EC (r^2=0.434) may be due to intrusion of seawater into the freshwater aquifer because the composition of seawater indicates high percentage of N^+ whereas freshwater is richer in bicarbonate (HCO_3^-). This was further buttress by the positive strong correlation between the EC and HCO_3^- at r^2= 0.899. In other words, the N+ and HCO_3^- present in the groundwater are from dissimilar source of sea and freshwater interjecting.

Practical Application of the Study: The outcome of using poor water quality either for irrigation or drinking purposes could be very expensive to remediate and detrimental to biota within the ecosystem, and in some instances could lead to high mortality (Levallois and Villanueva, 2019). The study area has witness poor agricultural yield over the years and the issues relating to water borne diseases is a norm. Therefore, the outcome of the study will enable adequate recommendation to farmers on the right crops to cultivation in the vast arable fallow land, and information relating to water consumption, design of water scheme and treatment option. This will eventually translate to quality policy formulation by policy maker, and opinion leader for sustainable natural resources management. Furthermore, when the right information on water quality is provided to inhabitance in the study area, they will be able to adequately manage their water resources for drinking and irrigation purposes which will eventually translate to food security and quality health status of the locals in particular and other coastal communities of similar characteristics on a global scale. In addition, crops like the Sweet Potato as a common salt tolerance crop can be cultivated on the vas arable land laying fallow in the community. A similar example was reported in Spain on how saline water was applied for the purpose of irrigating Sweet Potato farm in Southern Spain. Salt tolerance agricultural practice can serve as an excellent alternative to the traditional agricultural practice especially in the coastal areas were saltwater in the Ocean mixes with freshwater derived from surface and groundwater systems; this form of agricultural practice can significantly improve the ever increasing food demand for the global population (Villanueva, 2021).

Conclusion: Okerenkoko groundwater cannot serve drinking purpose unless treated. On the other hand, groundwater in the study area can only support the cultivation of salt tolerance crops in its current state because of the high level of salinity. To ensure maximum benefits of the groundwater system in the study area, salinity tolerance crops such as sweet potato, grain-sorghum, sugar beet, cotton and carrot are suggested for cultivation while in the interim, a standard water-treatment tank should be built in the community to facilitate water treatment process before the distribution for public consumption. Furthermore, prolific aquifer layer devoid of external influence should be mapped for borehole sitting in the community; when this is achieved, the quest for quality freshwater for both irrigation and drinking purposes will become a thing of the past.

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