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Geology and hydrochemistry characteristics of groundwater in Chikun and its environs, Kaduna, North Central - Nigeria

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ABSTRACT

The hydrogeology of Chikun and Environs in North Central Nigeria (Kakuri Sheet 144 NW) was studied using geological, GIS, and hydrogeological methods. Three main rock types—porphyritic granite, granitic gneiss, and mica schist—were identified in the area. Lineament studies revealed a predominant NE-SW direction. A groundwater configuration map based on hydraulic head measurements from 38 hand-dug wells indicated primary flow directions of SW, SE, NE in the dry season, and SW, SE, NW in the wet season. Hydraulic properties, including yield (15.552-88.128 m3/day), transmissivity (1.779 x 10-8.96 x 10-1 m2/day), and storativity (1.03 x 10-13.706 x 10-3), were analyzed using pumping test results to assess borehole performance. Geochemical data showed Total Dissolved Solids (TDS) ranged from 8 to 365 mg/l, Electrical Conductivity (EC) from 13 to 522 μ S/cm, temperature from 6 to 30.75°C, and pH from 5.26 to 6.80. Most major and minor element concentrations fell within WHO and NIS allowable ranges. While groundwater in the study area was generally deemed drinkable and suitable for various uses, certain locations, including Gwogofe, Damba 2, Gwagwada 3, Angwan Turai, Gudun Guya, and Angwan Alkali 2, exhibited slightly elevated concentrations of Pb and Cr. The groundwater potential was classified as low, with transmissivity coefficients falling within the class of T magnitude IV, according to Krasny's Classification. This suggests suitability for smaller withdrawals for local water supply (private consumption). Overall, the study concludes that the groundwater in Chikun and Environs is generally usable, though some areas require attention due to slightly elevated concentrations of specific elements.

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1 Introduction

Due to its necessity in every facet of existence, water is essential to human survival (Tiwari and Ranga 2012; Deshpande and Aher 2012; Ranjan 2012). Numerous government organizations in Nigeria, including the National Water Resources Institute (NWRI), Nigeria Hydrogeological Services Agency (NIHSA), Nigerian Integrated Water Resources Commission, and River Basin Development Authorities (RBDAs), have dug a number of boreholes equipped with hand pumps in order to supply drinkable water and enhance the standard of living for numerous rural communities. Nigeria is fortunate to have an abundance of groundwater resources.

An estimated 51.93 x 109 m3 of potential yearly groundwater resources exist, of which 67% are found in sedimentary basins (FMWRRD 1995). Nigeria's water resources are safeguarded by regulations such as the Nigeria Integrated Water **Resources Management Commission (NIWRMC** 2016), which effectively regulate the careless disposal of wastewater into open water bodies and the surrounding areas, which can contaminate aquifers by seeping into the subsurface. These effluents originate from a variety of sources, including industrial, agricultural, and domestic ones. Because of this, certain heavy metals, including as lead, copper, zinc, nickel, chromium, cadmium, and iron, have been discovered in quantities that are higher than significantly tolerable and permissible (Olayinka and Alo 2004; Esoka and Umaru 2006; Eniola et al. 2010). The four states of Lagos, Rivers, Kano, and Kaduna, which account for eighty percent (80%) of the nation's industries, have the worst water quality degradation. This has continued to be a threat to Nigeria's economic growth and public health (Ajibade 2004; Olayinka and Alo 2004; Adekunle et al. 2007; Adeyemi et al. 2008; Mustapha 2008; Adewolu et al. 2009). To offset the effects of borehole scarcity or non-availability or government-provided pipe-borne water, some people dig hand-dug wells to provide drinkable water, but this means that a sizable portion of Nigeria's population still lacks access to sufficient quantities and quality of water. The percentage of the population utilizing water from upgraded sources fell by 3% between 1990 and 2006, according to the 2008 report of the WHO/UNICEF JMP (Joint Monitoring Programme for water supply and sanitation) (WHO/UNICEF 2008). This study aims to advance our understanding of Nigeria's regional hydrogeology with regard to water quality.

Nigerian residential water quality has not received enough attention throughout the years with regard its physico-chemical to composition—that is, whether it is sufficient, moderate, or excessively high before consumption. This could result in the spread of illnesses like cholera, typhoid, etc. To identify areas with good water quality in compliance with WHO guidelines, the study area's water quality assessment becomes essential. Given that the research area is situated on the Kaduna River, downstream of the Kaduna Refinery and Petrochemical Company (KRPC) plant, this has become even more important. Crude oil must separate into distinct hydrocarbon groups in order for KRPC to refine it using the fractional distillation method. Crude oil is placed through a variety of treatment and dissociation procedures to remove unwanted components in order to increase the product's quality.

Heavy metals like Fe, Pb, Cd, Cu, Cr, Mo, Zn, and Ni are used to blend petroleum (Oke 2007). Some of these metals are lost throughout the process and end up in effluents that are dumped into open water bodies and surrounding areas, where they leach into the subsurface and potentially damage aquifers. The creation of geological and hydrogeological maps of the study region, ascertaining the direction of groundwater flow during the wettest and driest periods of the year, and assessing the water quality of the study region for use in agriculture, industry, and residential areas are the particular goals of this research.

1. The study area

1.1. Location and Climate

The research region is situated between latitudes 100 15' and 100 30' N and longitudes 7000'-70 15' E in Kaduna State's Chikun Local Government region. It is located in Kakuri Sheet 144NW. It is reachable from the north via the Kaduna-Abuja route, from the south via the Buruku-Birnin Gwari-Lagos road, and from the west by the boundary with Niger State (Fig. 1). The area it occupies is approximately 733.86 km2. The research area has distinct wet and dry seasons and is located in the sub-equatorial and guinea climatic areas. It has a lengthy, roughly sixmonth-long wet season. April marks the start of the wet season, which finishes in October when the temperature spikes. October through April is the dry season, during which there is no precipitation (Fig. 2). 36°C is the typical temperature during the dry season.

In general, the region is located in northern Nigeria's Guinea Savannah zone (Du Preez and Barber 1965). Surface water systems react more quickly to changes in the weather than do groundwater systems. Because of this, evaluations and models of groundwater resources frequently rely on long-term average climate conditions (such as average yearly recharge), which may undervalue the significance of deviations from the norm. In terms of groundwater, droughts are the most well-known climatic disturbance (William 2001). In order to combat climate variability, water storage is essential. The utilization of groundwater storage to mitigate the effects of drought and the possibility of artificial recharge both become more crucial as surface water storage becomes scarcer. Droughts will have little to no impact on the long-term water storage in an aquifer system if there is significant groundwater storage. On the other hand, groundwater may be less available as a source of water to help during droughts in areas

long-term well withdrawals have where significantly decreased groundwater storage. The interactions between surface water and the land are among the most significant links between climate and groundwater. For instance, increased flows in streams, minimum levels in lakes, and the hydro period of wetlands can all be strongly impacted by groundwater development. Similarly, decreased head in response to increased pumping during droughts may cause compaction of aquifer materials, which may lead to land subsidence. The climate has numerous effects on groundwater quality as well.

Erroneous conclusions regarding temporal trends in groundwater quality might result from improper analysis of the absence of climate variability, especially if only a few numbers of samples have been taken. Changes in recharge in response to climate variability can alter pollutant transport. There are two different seasonal climates in the study area: the dry and wet seasons. It is a tropical continental climate. October to May is the wet season, and November to April is the dry season. According to Omosho et al. (2013), the mean annual rainfall varied from 1,016 mm to 1,524 mm. The weather patterns in Kaduna, Northern Guinea Nigeria's savanna vegetation zone is ideal for growing both income and subsistence crops year-round, while irrigation is frequently required to supplement dry season farming.

There are a few large trees mixed in among the prickly shrubs and sporadic trees that make up the vegetation. Because of the predominant soil moisture conditions along river courses, the vegetation there tends to be partially dense, luxuriant, and green, with thin but infrequently tall grasses. The annual bush burning and treecutting for firewood are two examples of anthropogenic activities that have drastically decreased the density of vegetation.



Fig. 1 Location and accessibility Map of the study area (Sheet 144 NW).



Fig. 1 Rainfall Depth in Kaduna state from 1991-2005 (After, Nigerian Meteorological Agency).

1.2. Geology, hydrogeology and Structures

The research area's geology is composed of three primary rock types: mica schist with small intrusives of quartz and pegmatite veins, granitic gneiss, and porphyritic granite. These rock types are typical of the schist belt of the Precambrian basement complex in northwest Nigeria. The rock units are arranged as follows: the mica schist is located in the center and toward the western portion of the study area; the granitic gneiss is located in the southeast; and the porphyritic granite terrain is located in the northwest of the map. Their field relationship is characterized by their distinct boundaries, which are unaffected by other minor outcrop exposures (Fig. 3).

In the research area, a number of granitic gneiss outcrops were mapped. The granitic gneiss is generally well foliated, with granophyric intergrowth texture on orthoclase feldspar, and ranges in texture from medium to coarse grain. The large occurrence of granitic gneiss has an approximate N-S trend. Porphyritic granite outcrops were seen in the research area's northern region. The porphyritic granite has coarse grains and a leucocratic texture. With an elevation of roughly 518 meters and an approximate NW trend that strikes 2800, it features noticeable joints as structures.

Aplite dyke occurs inside the porphyritic granite towards the eastern part of the river Damba in the research region (Fig. 4). It looks to be a smaller unit with a younger age. One of the three mapped rock types is mica schist, which is found in Kulepe, northeast of Ndimana (Fig. 4). Its grain texture ranges from medium to coarse, and its color is light. Plate IVA shows a large outcrop with thin veins of quartz. The study area's mica schist is a well-developed medium-grade metamorphic rock with parallelism in minerals like quartz and mica. Both macroscopic and microscopic observations reveal that quartz, microcline, orthoclase, biotite, muscovite, plagioclase, and perthite are the predominant mineral compositions of these rocks.

These rocks have pegmatite vein, fractures, foliations, joints, and folds among their structural characteristics. The mica schist trends in the NNE - SSW direction with a dip angle of 400 in the 1100 ESE direction, the porphyritic granite strikes at an angle of 370 NE/2170 SW, and the granitic gneiss strikes at an angle of 600 NNE – 2400 SW with a dip of 600 in the 1400 ESE direction. The lineaments of the research region are made up of faults, valleys, rivers, streams, and ridges. The degree of anisotropy of groundwater flow in the fracture network is determined by the degree of lineament intersection; in situations with a high degree of connectivity, groundwater flow is smoother and more uniform (Mabee et al., 1994) (Figs. 5 and 6). The structural trend of the adjoining sheet (Sheet 144, Kakuri NE) of the study area displays a NE-SW trend (Fig. 6), which is validated by the presence of joints that were clearly visible and mapped on specific outcrops in the study area that showed a dominating NE-SW trend (Goki et al., 2011).



Fig. 3 Geological map of Kakuri, Sheet 144 NW (Study Area) with the Lineament map superimposed on it on a scale of 1:50,000.



Fig. 4 Water sampling Points and locations in the study area.



Fig. 5 Lineament map of the study area.



Fig. 6 Rose diagram of lineament in the study area.

Two water-bearing zones—the severely fractured zone and the somewhat weathered basement rock—were identified in the area using borehole lithologic logs. According to borehole data, the granitic gneiss gives an average of 48.216 m3/day, whereas the porphyritic granites have a greater output of 88.128 m3/day. These indicate that in the research location, the porphyritic granite offers a superior aquifer than the granitic gneiss. The research area's groundwater occurrence and flow originate from secondary porosities like joints, faults, and weathered zones (Chiton and Foster 1995; Foster et al. 2008; Srinivasa 2000; Wright and Burgess 1992).

The static water level recorded from manually drilled wells in October 2015 served as the basis for the water table map at the end of the wet season (Fig. 7). 6.8 m (22.3 ft) was the maximum depth to the water table, while 1.2 m (3.9 ft) was the lowest. The static water level in manually drilled wells observed in May 2015 served as the basis for the water table map (Fig. 8) at the height of the dry season.At 11 m (36.1 ft), the highest water level elevation was reached, and at 4.1 m (13.5 ft), the lowest.

The hydrogeological map of the research region shows the direction of groundwater flow, also known as groundwater movement, as represented by arrows drawn perpendicular to the contours of the groundwater table (equipotential lines). In the research area, groundwater flows primarily in the direction of the northeast as it moves from the contour of greater groundwater elevation to that of lower groundwater elevation (Fig. 7 and Fig. 8).

The study area's groundwater configuration map indicates that during the wet season, groundwater flows from high groundwater elevation contours of 617 m (2024 ft) in the Porphyritic granite province at the northeastern part of the study area around Gwogofe, Gudun Guya, Kadi, Kaboresha, and Kachere to an elevation of 457 m (1500 ft) around the granitic gneiss province at the southeast corner of the study area (Gajina, Godo, Kubusupe, and Gwagwada). The groundwater configuration map of the study area indicates that, with the exception of a few water wells near Chikun village that completely dried up, there was only a slight change in the flow direction during the dry season (May, 2016). This could have been caused by the dynamic nature of groundwater as well as the fact that some wells have their base flow below the well's depth (Figs. 7 and 8).



Fig. 7 Hydrogeological map of the study area showing groundwater table configuration and direction of groundwater flow, at Peak of wet Season (October, 2015 Hydrogeologic year).



Fig. 8 Hydrogeological map of the study area showing groundwater table configuration and direction of groundwater flow, at Peak of dry Season (May, 2016 Hydrogeologic year).

2. Materials and methods

3.1. Geological mapping

The various rock types and their boundaries were located through geological mapping, petrographic description of outcropping rocks, and rock sampling. In order to conduct geological mapping, the study location was located using the Global Positioning System (GPS). Next, the traverse method of mapping was used, which involved moving from one study location to another for a detailed mapping, taking photographs of the outcrops, measuring the strike and dip of the outcrop exposures, gathering representative samples, and, when describing the needed, rock samples' mineralogical composition, texture, and color with the help of a hand lens.

3.2. Hydrogeological mapping

Locating the water-bearing features in the research region, such as manually excavated wells, boreholes, streams, and rivers, was another step in the hydrogeological mapping process. Using metric tape, the hydraulic head in wells was measured during the dry and wet seasons of 2015–2016. The reading obtained from this measurement is then utilized to compute the groundwater configuration maps at the peak of the wet season as well as the peak of the dry season. Refer to Figures 7 and 8 for maps of hydrogeology.

3.3. Water Sample collection and preparation

Twenty (20) well water samples from various geologic units within the study area were gathered and tabulated (Fig. 4 and Table 1). Water samples were collected using screw-capped polyethylene bottles. Before being sampled, the bottles were carefully cleaned and rinsed with water. Samples were taken using a random sampling technique, and sensitive parameters including temperature, pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) were measured insitu (at the sample collection location) using thermometers, pH meters, TDS meters, and conductivity meters, respectively. The samples were carefully labeled with the name of the place; samples intended for

cation analysis were acidified, while samples intended for anion analysis were frozen before being sent to the lab for examination.

3.4. Lineament Extraction

This was carried out under geological and geophysical analysis utilizing the "Line: lineament extraction module" in the PCI Geomatica geographic information system (GIS). Lineaments are extracted from any single 8-bit image using PCI's lineament extraction technique in three stages: edge detection, thresholding, and curve extraction. A single image of landsat enhanced thematic mapper plus (ETM+) 2005-10-19, route 189/ Row 052, obtained on October 19, 2005, was obtained from the University of Maryland USA's Global Land Cover Facility (GLCF). Seven bands in the data are wavelength-sensitive. Visible (7,4,1), near-infrared (NIR) (3), and shortwave infrared (SWIR) (5) wavelengths are detected by six of these bands.

A single panchromatic and one thermal. The study's focus region was taken from the single scene and applied in this investigation. Since it contains the greatest information and is appropriate for lineament extraction, the first principal component picture (PC1) of the terrain sat 7 pan sharpened reflected bands in 8-bit grayscale and 30m spatial resolution was utilized. This was done on a layer-stacked image of the obtained landsat scene using the ENVI 4.5 software. Table 2 displays the parameter settings that were employed. The GIS environment ArcMap 10.1 was used to split compound lines into simple lines. The vertices of compound lines were torn apart. The goal was to obtain straight line endpoints with accuracy, which is required for trend/orientation analysis. Within the ArcMap 10.1 GIS environment, the line length and endpoints (X coordinate of line start (X1), Y coordinate of line start (Y1), X coordinate of line end (X2), and Y coordinate of line finish (Y2) were also computed (Fig. 5 and Fig. 6).

3.4. The laboratory work

Major cations, anions, and some heavy metal components were analyzed from the collected water samples. The following techniques were used to analyze the major ions: rapid sequential Atomic Absorption Spectrometry (AAS), version product AA240FS, was used to determine the lead (Pb), calcium (Ca), magnesium (Mg), chromium (Cr), iron (Fe), and potassium (K); flame photometry was used to analyze sodium (Na) and potassium (K). Sulfate (S04) was determined by the turbidimetric method using an H18200 multiparameter Bench Photometer; bicarbonate (HCO3) was determined by the silver nitrate titration method; nitrate (NO3) was determined by the chromotropic acid method using a high range test 'N' tube.

4. Results and Discussion

4.1. Hydrochemical characteristics

Table 1 displays the physicochemical findings from the groundwater analyses conducted during this investigation. The average water temperature was recorded at 22.00oC, with a range of 20.09 to 30.75oC. Comparing the total dissolved solids (TDS) value to the WHO (2011) and NIS (2007) acceptable limits, the TDS value ranged from 8.00 to 365 mg/l with an outstanding average of 70.00 mg/l. Talabi and Tijani (2012) state that the research area's relatively low TDS is indicative of a mildly mineralized groundwater system, a short residence time, and rock-water interaction. The samples' pH values ranged from 5.26 to 6.86, with an average of 6.00. Of them, 50% fell within the neutral range of 6.5 to 6.9, and 50% were slightly acidic (less than 6.4). Table 3 shows that the samples' pH values were good when compared to the NIS (2007) and WHO (2011) permissible limit. The area's groundwater system and soil may have been affected by the effluent, which could account for the mild acidity (Amadi et al 2014). With an average of 100.1 μ S/cm, the Electrical Conductivity (EC) ranged from 13.00 to 522.00 µS/cm. Groundwater samples had an average calcium value of 4.00 mg/L, ranging from 0.00 to 60.29 mg/L. Groundwater samples' total hardness (TH), measured as CaCO3, varied from 0.00 to 215.00 mg/L, with an average of 35.13 mg/L. Most samples (85%) of the sample falls within the soft water category and hard water, moderately hard water and extremely hard water

constitute 5% of the sample accordingly (Ayuba et al 2019). Higher total hardness (hard to extremely hard water) values are found in the southeast of the study area (locations Gwagwada1, Gwagwada2, and Gwagwada 3). This is probably due in part to the lithological characteristics of the aquifer matrix, which is primarily made up of weathering products of the nearby granitic gneiss. These rocks are rich in calcium and magnesium, which when dissolved, produce high concentrations of these elements that raise the overall hardness of the groundwater (El-Ahamdi and El-Fiky 2009). This is partially because contaminants drift in the direction of the southeast, which coincides with the flow direction of the groundwater in the area, and groundwater flows in a NW-SE direction. The concentrations of the major cations were generally low: Hg > Mg2+ = Ca2+ = Na+ > K+ > Cr> Pb > Fe2+, with average values of 4.63 mg/L, 4.00 mg/L, 4.00 mg/L, 3.00 mg/L, 0.124 mg/L, 0.078 mg/L, and 0.00 mg/L, respectively; the anions were arranged in the following order: HCO3- > Cl- > NO33- > SO42- order, with average values of 42.10 mg/L, 29.75 mg/L, 13.30 mg/L, and 2.84 mg/L (Table 4). The findings demonstrated that all anions and cations had values below the maximum allowable limits for drinking water suggested by WHO (2011) and NIS (2007).

To ascertain if groundwater in the research area is suitable for use in agriculture, industry, and home settings, its chemical composition has been evaluated. The three rock units' major element compositions fall within acceptable bounds. With the exception of lead (Pb) and carbon (Cr), which are found to be rather high following interlaboratory comparison, the results also show low levels of heavy metals (Table 5). The heavy metals used to blend petroleum and improve the quality of the crude oil product may be the cause of the high Pb and Cr values. Some of these metals were lost during this process and became part of the petrochemical and refinery effluents that were disposed of in soil, water bodies, and surrounding areas, where they leached into the subsurface and may have contaminated aquifers. These results concur with the Amadi et al. (2012)

report, which found heavy metal pollution in the soil and groundwater. The groundwater of the studied area does not seem to contain many anions, with the probable exception of a well 2, Angwan Alkali where nitrate near concentrations as high as 35 mg/l were discovered, suggesting potential pollution. The high level of nitrate content may be attributed to the presence of a tiny grazing field/reserve at close proximity to the groundwater well in question and also to the indiscriminate application of fertilizer by the farmers in the vicinity (Uma 1993). Other reasons responsible for excessive nitrate concentrations in the area include soil leaching and nitrogenous organic waste (Ozoko 2004), poor well completion (Edet and Okereke 2005), incorrect waste disposal (Alagbe 2006). According to the Eduvie (1999) report, the total dissolved solids in the study area show low total mineralization. For home and industrial uses, the majority of the study area's groundwater's chemical characteristics fall within NIS (2007) and WHO (2011) acceptable limits (Table 5). With the exception of the Pb and Cr level, which appears to be significantly above the allowable limit, the area's groundwater is potable and appropriate for both home and industrial purposes based on its chemical properties (Table 4).

Groundwater quality for drinking purposes

Based on the water type classification of Vasanthavigar et al. (2010) and Ayuba et al. (2019), the computed WQI values were used to rate the groundwater quality for drinking purposes in the study region (Table 6, 7 and 8). Table 8 presents the values of the groundwater samples obtained from Chikun 1, Angwan Alkali 1 and Angwan Alkali 2. Of these, 15.0% represent "good water," 45.0% represent "poor water," 35.0% represent "very poor water," and 5.0% represent "water unsuitable for drinking purposes" (Gwogofe, Damba 2, Gwagwada 2, Gudunguya, Kudo, Gajina 3 and SabonKauWia). The vast majority of the water samples fall within the categories of "poor water" and "very poor water."

This could be due to the heavy metals used to blend petroleum and improve the quality of the crude oil product; some of these metals were lost during this process and ended up as part of the petrochemical and refinery effluents that were disposed of in soil, water, and surrounding areas, leaching into the subsurface. There may also have been an agricultural impact that contaminated the aquifers. Chromate (Cr) and lead (Pb) were used as pollution markers for the water quality index test. The research area's low groundwater quality is indicated by the observed high Pb and Cr levels, which match the same WQI. 85% of the study area's northeastern region, which is mostly home to industrial and agricultural operations, has water of poor quality. In places in the northwest portion of the research region, where basement rock predominates because of the Kaduna Refinery and Petrochemical Company, bedrock dissolution, and residential and industrial activity, poor water quality is seen.

Groundwater quality for irrigation purposes

Schoeneich (2001) states that mineralization (predominant mega-ions, some trace elements, or some dissolved gasses) can be used to classify water chemically. According to this classification, all of the examined water samples exhibit mineralization less than 1 g/l (1000 mg/l), making them oligomineral waters, or simply fresh waters. Thirteen (14) of the water samples had conductivities less than 250 µS/cm, making them excellent for irrigation; the remaining six (6) have conductivities between 250 and 750 µS/cm, making them good for irrigation. The Wilcox plot (Fig. 9) illustrates whether water is suitable for irrigation. This graphic compares the salinity hazard (conductivity) to the sodium hazard and sodium adsorbtion ratio (SAR). The portions of the Wilcox plot are as follows: Conductance in µS/cm Low (0-249), Medium (250-749), High (750-2249), and Very High (2250-5000) are the C1–C4 ranges. The values are categorized as follows: S1 = Low, S2 = Medium, S3 = High, and S4 = Very High. The Wilcox plot (Fig.9) is a plot of sodium hazard (SAR) versus salinity hazard (Cond.), 14 out of the 20 water samples fall into C1-Low salinity hazard, 6 samples plotted into C2-Medium salinity hazard and the entire 20 samples plotted into the S1-Low sodium hazard class which means the water from the study area is excellent for irrigation purposes (Table 9 and

10). The Wilcox plot, Fig. 9, is relevant to this study since it shows that groundwater has a medium to high sodium content or a low calcium plus magnesium content if the SAR value is in

excess. This type of water can disperse soil colloids during irrigation, reducing the permeability and texture of the soil.



Fig. 9 Wilcox plot for classification of irrigation water in the study area (After Wilcox 1995).

Hydrochemical facies

Using the ion concentrations found from hydrochemical data, a Piper diagram of Piper (1944) was constructed to determine the types of groundwater and the percentage composition of various ions. The results are shown in Fig. 10. Plotting the main components (cations) and their corresponding anions on a triangle was done after the analysis. Plotting the cations and anions as single points in the left and right triangles, they were then projected into the diamond-shaped core region. Certain hydrochemical facies and water types are represented by these spots in the diamond-shaped area. Each type of water was represented by a single point that was acquired for each sample of water in the diamond-shaped area. The distribution of groundwater's hydrochemical faces across several geological units at the study sites was examined in this work (Tables 11 and 12). While 5.0% of each sample belongs to mixed Ca2+-K+-HCO3-(5.0%), Na+-Mg2+-HCO3-(5.0%), and Ca2+-Mg2+-K+-HCO3-(5.0%) water types, the majority of groundwater falls into Ca-Cl and Na-Cl types, which are classified into K+-HCO3--Cl-(5.0%), Ca2+-HCO3and Na+-HCO3-(25.0%). (30.0%),Minor representations are shown from mixed Ca2+-Mg2+-HCO3-(15.0%) and mixed Na+-Ca2+-HCO3-(10.0%) water types. According to the plot, strong acids (Cl and SO4) surpass weak acids (HCO3), and alkaline earths (Ca and Mg) surpass alkalis (Na and K) (Fig. 10 and Fig. 11). The variety of geology and geochemical processes in the studied area is correlated with the presence of several hydrochemical facies. Based on the Schoeller plot (Fig. 12), the main cation is in the Ca-Mg-Na order, whereas the anions are in the Cl-HCO3-SO4 order.



Fig. 10 Piper Trilinear Diagram of the relative Cation and Anion composition of groundwater samples of Kakuri NW (After Piper 1994).



Fig. 11 Groundwater Type of Kakuri NW, Superimposed on the Geological Map.



Fig. 12 Schoeller plot showing the dominant cations and anions in the study area.

5. Conclusion

The rocks of the basement complex, primarily mica schist, granitic gneiss, and porphyritic granite, underlie the study region, which is located within the crystalline hydrogeological province (Fig. 3). Based on fieldwork, it has been shown that the types of rocks that make up the aquifer and their degree of weathering and fracturing determine the groundwater potential. There are two main aquifer units in Kakuri sheet 144 NW: the highly weathered aquifer and the partially weathered aquifer.

The highly weathered aquifer is the main aquifer unit under investigation. Below the worn area is the broken basement aquifer. Because of its thickness, the fractured aquifer that exists beneath the study area is thought to be a source of groundwater. The amount and size of the aquifer's joints and fractures determine the groundwater system's permeability and storativity (Clark 1985). As a result, groundwater in the crystalline basement rocks is found in the fracture system of the unweathered rocks; the groundwater resources in these aquifers are typically constrained. On the other hand, some aquifers with fractures are very common, particularly if the cracks are widely connected and connected to the surface for replenishment. According to Du-Preez and Barber (1965), there are fractures in Northern Nigeria's crystalline basement that reach a maximum depth of 90 meters. According to Offodile (1992), the depth causes the distance between fractures to grow quickly. As a result, the frequency of fracture interception reduces with increasing drilling depth. With the exception of a few rivers like the Udawa and Chidu near Kaboresha, it is noticed that the majority of the rivers and streams in the study area fully dry up by the dry season. Its pattern, which is consistent throughout the year, is comparable to the contour lines of the ground, with the exception of the areas where basement rock outcrops are visible.

The findings of the water studies indicate that, with the exception of Pb and NO3 at a well in Angwan Alkali, the chemical quality of the groundwater in the studied regions is within the allowable limit set by WHO (2011) and NSDWQ (2007) of the investigated components. According to the results of the Atomic Adsorbtion Spectrometry, the amount of calcium (Ca) in places like Chikun 2, Angwan Alkali1, Angwan Alkali 2, Gajina 2, Gajina 3, and Dakwachi is below detectable limits. Nonetheless, data on the study area's water quality indicates that the water is fresh and has no mineralization. TDS values range from 9 mg/l to 365 mg/l, the highest being the lowest. Since the pH of the groundwater in the research region ranges from 6.86 to 5.26 on average, with a moderate acidity, it is suitable for both home and industrial purposes. The groundwater is classified as low to medium salinity hazard (C1–C2) and low sodium hazard (S1) based on electrical conductivity.

The research area's groundwater samples are generally regarded as excellent for irrigation purposes. Ca2+HCO3-Cl- (30.0%), K+HCO3-Cl-(5.0%), Na+ HCO3-Cl- (25.0%), mixed CaMg HCO3-Cl- (15.0%), mixed CaMg KHCO3-Cl- (5.0%), mixed NaMg HCO3-Cl- (5.0%), NaCa HCO3 (10.0%), and mixed CaKHCO3-Cl- (5.0%) were the water types assigned to the groundwater samples. The variety of geology and geochemical processes in the studied area is correlated with the presence of several hydrochemical facies. Therefore, we advise that: (i) factors causing higher concentrations of lead and chromium in some areas of the study area be managed; (ii) Krasny's classification of the study area's groundwater potential indicates that it has low groundwater potential; therefore, strategies for managing the situation sustainably for future use should be put in place; (iii) routine groundwater microbial concentration analysis should be conducted; and finally, (iv) surface water inform of overhead tanks should be built to improve rural water supply in the study area overall.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Adekunle I M, Adetunji M T, Gbadebo A M, Banjoko O B (2007) Assessment of Groundwater Quality in a Typical Rural Settlement in Southwest Nigeria, International Journal of Environmental Research and Public Health. 4(4): 307-318
- Adewolu M A, Akintola S L, Jimoh A A, Owodehinde F G, Whenu O O and Fakoya K A (2009) Environmental Threats to the Development of Aquaculture in Lagos State, Nigeria, European Journal of Scientific Research. 34(3): 337-347.
- Adeyemi D, Ukpo G, Anyakora C, Unyimadu J P (2008) Organochlorine Pesticide Residues in Fish Samples from Lagos Lagoon, Nigeria, American Journal of Environmental Sciences. 4(6): 649-653.
- Ajibade L T (2004) Assessment of water quality near river Asa, Ilorin, Nigeria, The environmentalist. 24(1): 11-18.
- Alagbe S A (2006) Preliminary evaluation of hydrochemistry of the Kalambaina Formation, Sokoto Basin, Nigeria, Environmental Geology.51: 39-45
- Amadi A N, Yisa J, Ogbonnaya I C, Dan-Hassan M A, Jacob J O, Alkali Y B (2012) Quality evaluation of River Chanchaga using Metal Pollution Index and Principal Component Analysis, Journal of Geography and Geology. 4(2): 13–21.
- Bates R L, Jackson J A (1980) Glossary of Geology, 2nd edition. American Geological Institute. p 749.
- Chilton P J, Foster S S D (1995) Hydrogeological Characterization and water-supply potential of basement aquifers in tropical Africa, Hydrogeology Journal, 3: 36-49.
- Clark L M (1985) Groundwater Abstraction from the Basement complex Areas of Africa, Quarterly Journal of Engineering Geology London. 18: 25-34.

- Deshpande S M, Aher K R (2012) Evaluation of Groundwater Quality and its Suitability for Drinking and Agriculture use in Parts of Vaijapur, District Aurangabad, MS, India, Research Journal of Chemical Sciences, 2(1): 25-31.
- Du Preez J W, Barber W (1965) The distribution and chemical quality of Groundwater in Northern Nigeria, G.S.N.Bulletin 36: 12-20.
- Edet A E, Okereke C S (2005) Hydrogeological and hydrochemical character of the regolith aquifer, northern Obudu Plateau, southern Nigeria, Hydrogeology Journal. 13(2): 391-415.
- Eduvie M O, Mogekwu E A, Adamu E A (1999) Aquifer Assessment and Borehole Characteristics in parts of Kaduna, Water resources journal of Nigerian association of hydrogeologists. 10: 38-45.
- Eniola E B, Chukwu L O, Olaide B S (2010) Hydro-Chemistry, Macro-Invertebrate Fauna and Fish Production of Acdja Fishing Sites in A Tropical Lagoonal Ecosystem, Journal of American Science. 6(1): 10-17.
- Essoka P A, Umaru J M (2006) Industrial effluent and water pollution in Kakuri area, Kaduna South, Nigeria, .Journal of Industrial pollution and control. 22(1): 122-129.
- FMWRRD (1995) The Study on the National Water Resources Master plan.Japan International Cooperation (JICA) and Federal Ministry of Water Resources and Rural Development, Federal Republic of Nigeria, Abuja.
- Foster S S D, Tuinhof A, Garduno H (2008) Groundwater in Subsahara Africa – A Strategic Overview of development issues. In Adelana, S.M.A. & MacDonald, A.M.(eds) Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology. 13, CRC Press/Balkenia, Leiden, the Netherlands.
- Goki N G, Amadi A N, Olasehinde P I, Dada S S, Ikpokonte E A, Adekeye J I D (2011) Appraising the Structural Geology of Kakuri sheet 144: Implications for the tectonic evolution of the Basement

Complex, J. Eng. Technol. Res. 3(2): 26-36.

- Mabee S B, Hardcastle K C, Wise D U (1994) A Method of Collecting and Analyzing Lineament for Regional scale Fracturedbedrock Aquifer studies. Groundwater. 32(6): 884-894.
- Mahre M Y, Akan J C, Moses E A, Ogugbuaja V O (2007) Pollution Indicators in River Kaduna, Kaduna State, Nigeria, Academic Journals Incorporated. 2(4): 304-311.
- Mustapha M K (2008) Assessment of the water Quality of Oyun Reservoir, Offa, Nigeria, Using Selected Physico-Chemical Parameters, Turkish Journal of Fisheries and Aquatic Sciences. 8: 309-319.
- NIS (2007) Nigerian Industrial Standard. Nigerian Industrial Standard for drinking water quality, physical/organoleptic parameters. p.554.
- Offodile M E (1992) "An approach to groundwater study and development in Nigeria", p.8-14, 18-19, 224, 233.
- Olayinka K O, Alo B I (2004) Studies on industrial pollution in Nigeria: the effects of textile effluents on the quality of groundwater in some parts of Lagos.-Nigeria, Journal of Health and Biomedical Sciences. 3(1): 44-50.

Omotosho J B, Agele S O, Balogun I A, Adefisan E A (2013) Climate Variability, Cropclimate modeling and Water Ecophysiology research: implications for plant's capacities for stress acclimation, yield production and food security.

- Ozoko D C (2004) Geochemical and microbial studies of the natural water systems in Agila, Benue State, Nigeria, Water Resources. 13: 60-65.
- Piper A M (1994) A graphic procedure in the geochemical interpretation of water analysis transactions, American

Geophysical Union.Washington D.C. 914-920.

- Ranjan R (2012) Water Quality Monitoring of Groundwater Resources around Sugar Factory, Near East-West Champaran Border, Bihar, India, Research Journal of Chemical Science. 2(7): 79-81
- Schoeller H (1965) Qualitative Evaluation of Groundwater Resources. In: Methods and techniques of groundwater investigation and development, Water Resources Series UNESCO. 33: 45- 55.
- Schoeneich K (2001) Water Resources Management.Unpublished Lecture Notes, Ahmadu Bello University,Zaria.
- Srinivasa R Y, Reddy T V K, Nayudu P T (2000) Groundwater targeting in a hard rockterrian using fracture pattern modeling, Niva River Basin, Andr. Pradesh, India, Hydrogeology Journal. 8(5): 494-502.
- Tiwari M, Ranga M M (2012) Assessment of Diurnal Variation of Physico Chemical Status of Khanpura Lake, Ajmer, India, Research Journal of Chemical Sciences. 2(7): 69-71.
- Uma K O (1993) Nitrates in shallow (regolith) aquifers around Sokoto Town, Nigeria, Environmental Geology. 21: 70-76.
- WHO/UNICEF (2008) Joint Monitoring Programme for Water Supply and Sanitation (JMP) report.
- Wilcox L V (1995) Classification and use of irrigation waters.US Department of Agriculture Washington DC, p. 19.
- William M A (2001) Chief, Office of Groundwater, U.S. Geological Survey, 411 National Centre, Reston, VA 20192. 39(2): p.60.

World health organization (WHO) (2011) Guidelines for drinking water quality, fourth edition.

Wright E P, Burgess W G (1992) The hydrogeology of crystalline basement aquifers in Africa. Geological Society, London. Special Publications. p.66.