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Geological and Hydrogeochemical Assessment of Groundwater Quality and Fluoride Concentration in Hong and Environs, North-East Nigeria

TERRANG ABIGAIL ABUBAKAR[1], EDWIN Y. MBIMBE[2], HENRY SIMON UMAR[3], ALKALI YAR'ADUA ABRAHAM[4], YAKUBU NANA[5]
[1, 2, 3, 4, 5]*Gombe State University*

Abstract-* This study investigates the geological and hydrogeological factors influencing groundwater quality in the Hong Local Government Area of Adamawa State, Nigeria, with a particular focus on fluorosis prevalence. The research aims to evaluate the relationship between geological formations, water quality parameters, and the occurrence of fluorosis in the study area. Field surveys and laboratory analyses were conducted to assess various physical and chemical parameters of groundwater, including pH, electrical conductivity, total dissolved solids, fluoride concentration, and major elemental composition. The results reveal a significant correlation between fluoride levels in groundwater and the presence of fine-grained granite, coarse-grained granite, and migmatite gneiss formations. Elevated fluoride concentrations were observed in areas with higher concentrations of these rock types, contributing to the prevalence of fluorosis among local residents. Additionally, the study provides insights into the distribution of other major elements and their potential implications for water quality and human health. The findings underscore the importance of understanding geological factors in assessing groundwater quality and highlight the need for effective management strategies to mitigate fluorosis and ensure access to safe drinking water in the study area.

I. INTRODUCTION

1.0 Background to the study

The importance of groundwater cannot be over emphasized as groundwater plays a crucial role in sustaining ecosystems and providing drinking water, making its importance very significant. According to Priscilla *et al*. (2019) groundwater plays a vital role as an important source of potable water in both rural and urban areas of Nigeria. It remains the largest available source of fresh water, thus it forms a very important part of the water supply chain. And as it stands there is a growing demand for groundwater in virtually all parts of Nigeria.

The study area which is in Hong Local Government Area of Adamawa state is a fast- growing town due to a lot of human activities being carried out in the area such as agriculture (crop farming and animal rearing), education and various business which has led to the high demand for potable water. Groundwater plays a vital role as an important source of potable water in the study area, this is due to the rapid growth in population and increasing industrial activities. The areas from which water samples were taken for the study depend on groundwater from sources like boreholes, wells, and stream channels for drinking and various other domestic activities.

The main purpose of this research is to investigate the quality of the groundwater from various sources in some communities at Hong Local Government Area of Adamawa State and determine whether or not it is suitable for drinking and other various domestic use in the study area with an emphasis on the concentration of fluoride. The results obtained from this study will be used to determine the concentration of fluoride in groundwater in the study area which can then be used to help in developing recommendations for improving the quality of groundwater in the study area and this information will be of immense value to policy makers, industries, health practitioners and can serve as a basis on which future studies can be carried out. This project work will also contribute to already established knowledge on the subject matter.

1.2 Location and Accessibility

The study area is located in some parts of Hong Local Government Area of Adamawa State, Nigeria. It is located between the Latitude 10°13’ N, 10°16’ N and Longitude 12°57’ E, 13°0’ E. It covers a very wide area which is around 25 km^2. The study area shares a boundary with other smaller communities in Hong Local Government Area such as Biri to the North,

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Shengwihi to the south, Manza'a to the west and Mubi to the east.

The study area can be accessed by road through the Gombi-Mubi major road.

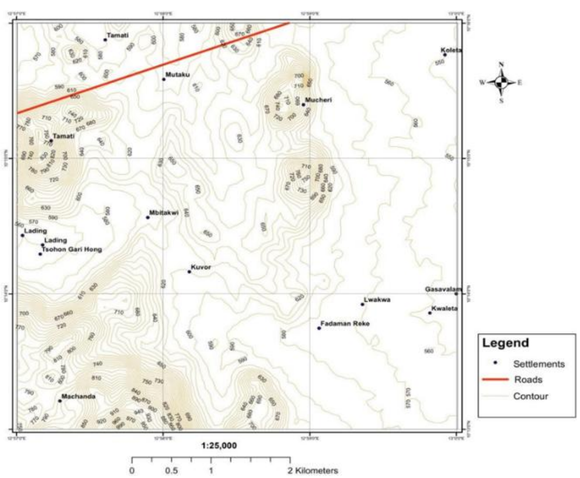

Fig 1.0 Topographic map of the study area

1.3 Aim and Objectives of the Project work

To carry out an investigation of the geology and groundwater quality of the study area with emphasis on fluoride concentration. The specific objectives of this work are:

- To produce geologic map
- To determine groundwater quality with specific emphasis on fluoride
- To relate the geology and fluoride distribution in the study area
- To produce geologic map of study area superimposed with fluoride distribution

1.4 Climate of the study area

Hong Local Government Area has two distinct seasons – rainy season and dry season. The rainy season starts from around the month of April up to around the month of November while the dry season picks up from around the ending of November to the month of April.

Temperatures are generally high (30°C to 42°C) throughout the year except between November and February when harmattan winds tends to reduce temperature to 16°C. However, minimum temperature can be as low as 12°C during the harmattan period. Relative humidity also varies seasonally in the study area, with low value of about 20% to 30% between January and March. Increasing in peak of 88% between April to August and September, and declining again in October (Okunlola, et al. 2014).

1.5 Vegetation of the study area

The area falls within the Sudan Savannah vegetation type which consists of shrubs, grasses and trees especially along the river channels (Dada, 2006).

Most of the trees found in the study area were mostly mango trees, baobab trees, and guava trees. Food crops such as cowpeas, cassava, groundnuts are the crops mostly cultivated on the farmlands. There are also shrubs scattered broadly around.

1.6 Topography of the study area

The relief of the study area is characterized by highlands ranging from heights of 800 meters to 1500 meter above sea level. There are also lots of valleys.

II. LITERATURE REVIEW

2.1 Previous work on the study area

The Benue Trough is the most important of all the Cretaceous Sedimentary Basins in Nigeria. At its north-eastern end is an area commonly known as the Upper Benue Trough, it bifurcates into an E-W trending Yola arm and N-E trending Gongola arm or Basin. The study area is within the Yola arm. (Benkhelil, J. 1989)

The early studies, of the upper Benue Trough and Southern Borno Basin was carried out by Falconer (1911); and Barber *et al* (1984); but was later elaborated on by Rayment (1965). Falconer (1911) classified the Basement Complex as older Granites of Pan-African Orogeny (600 ± 150 Ma) and also was the first person to use the term "Bima Sandstone" that occurred at the type locality, Bima Hill. Carter *et al* (1963) divided the Bima Sandstones into "upper, middle, and lower". The "Bima Sandstone" was formed at the base of sedimentary succession in the cores of great anticlines and directly overly the crystalline Basement.

Studies on the lithostratigraphy of the upper Benue Trough has been carried out by Allix and Popoff *et al* (1983) here described the upper Benue Trough

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beginning with the continental classic Bima Group of lower Cretaceous, the transitional environment – Pindiga Formation and Gombe Formation, which are all late Cretaceous. Studies on the sedimentology and structural framework of the sedimentary Formation was done by Carter *et al* (1963). This forms the basis for all the later works. They undertook a regional study of the area covered by the Geological Survey of Nigeria 1:250,000 series map sheets 25 (Potiskum), 36 (Gombe) and 47 (Lau).

However, more detailed work has been done on the upper Benue Trough because it has almost been entirely remapped recently through the work of Allix (1983); Benkhelil (1985, 1986, 1988); Popoff (1988); Guirand (1990, and 1993) and Zaborski *et al* (1997). The upper Member of the Bima Sandstone is entirely continental throughout the upper Benue Trough consists of sandy deposits containing ubiquitous cross bedding and diversity of soft- sediment sedimentary structures (Samaila et.al, 2005, 2006).

Yolde Formation lies conformably on the Bima Formation. This formation is Cenomanian in age and it represents the beginning of marine incursion into this part of the Benue Trough. The Yolde Formation was deposited under a transitional/coastal marine environment.

The Yolde Formation is overlain by the following formation – Dukkul, Jessu, Sekuliye, Numanha and Lamja which were deposited during the Cenomanian-Turonian and indicate the period of full marine incursion in the Upper Benue Trough.

2.2 GEOLOGY OF THE STUDY AREA

Hong Local Government Area study lies within the Adamawa Massif which is towards the northeastern sector of the Basement complex of the Upper Benue Trough in Nigeria. Within the Adamawa Massif is characterized by high grade metamorphic rocks, pervasive migmatization and extensive granite plutonism (Ferre et al., 1996).

Most of the migmatization has been dated at 580 ± 10 Ma. This area is bounded by the Tertiary - Quaternary Chad Basin northwards, the Yola arm of the Cretaceous Benue Basin southward and the Gongola Basin westwards. The area experienced Tertiary magmatism between 7 to 1 Ma (Grant et a1, 1972), during which volcanic and sub-volcanic rocks were emplaced. These volcanic and sub-volcanic rocks are extensions of the Cameroun volcanic line into Nigeria (Fitton, 1980; Fitton and Dunlop, 1985). Earlier during the Mesozoic, transitional alkaline basalts were emplaced in Shani area 146 Ma: 7.3 < age. < 127 Ma: (Popoff et al., 1982, and Baudin, 1986). Bassey (2006) reported that the gneisses and migmatites are the older rocks within the Adamawa Massif occupying mainly low-lying areas, or existing as residual hills. The gneisses are generally strongly foliated and banded, and in some places are commonly dissected by quartzofeldspatic dykes and veins which impart them with migmatitic characteristics. Good examples of these are found in Mubi. The gneisses have been subjected to series of folding, shearing and faulting and are extensively intruded by granitic rocks of the Pan African orogeny (600±150 Ma). The granites consist of fine to coarse grained or porphyritic varieties with well-developed euhedral crystals. A variety exists as granite gneiss which has well defined foliation. Outcrops of the granite gneiss are found at Dumne, Song, Uba and Mubi. Granites in the area have experienced extensive faulting and shearing and are commonly intruded also by pegmatite.

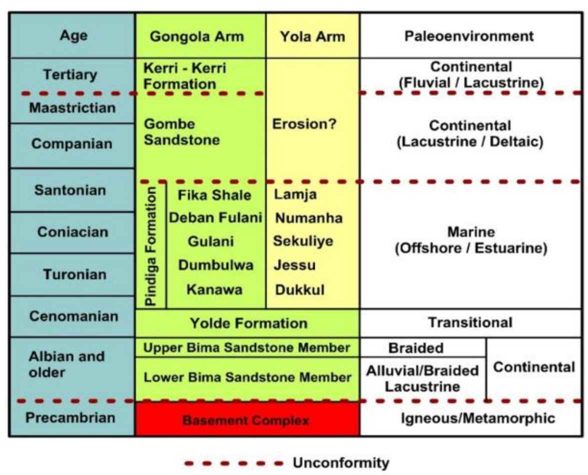

Figure 2.0: Stratigraphic successions of the Upper Benue Trough

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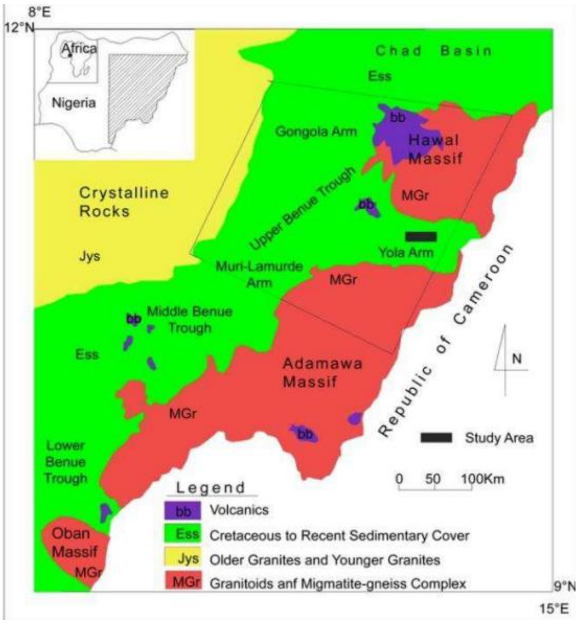

Figure 2.1: Geologic map of Adamawa Massif (Umar, 2022)

III. METHODOLOGY

3.1 Desk Study

Prior to setting out to the study area for fieldwork, desk study was carried out to review and consult various related literatures on the Geology, Hydrology and hydrogeology of the study area.

3.2 Reconnaissance study

A letter of introduction was submitted to the head of the community where the study area is located after which a reconnaissance survey was then carried out to get a more physical preliminary overview of the study area.

While on the reconnaissance survey, elevations of the area were observed during as well as stream channels, accessible routes, rock formations available, road networks vegetation and how the temperature was from the time of starting the survey to the end.

3.3 Field materials used.

The following field equipment were used during the course of the field work:

- Field notebook (which was used for recording field data).
- Geological hammer
- Global Positioning system (GPS)
- Measuring tape (100m)
- Sample bag
- Permanent Marker
- Masking tape
- Sample bottles
- Nitric acid (HNO_3)
- Topographic map of the study area (1:50,000)
- Reflective jackets and Safety boots

3.4 Sampling of water on the field

A total of thirty (30) water samples were collected from various random locations in the study area, two from each sampling point. The water samples were collected in a one (1) liter plastic bottle from wells, boreholes, solar pump, and stream channels.

Before collecting each water sample from the source, the plastics bottles were rinsed with water from the water sources and held at the bottom to collect the water in order to avoid contamination. After collecting the sample, in the two plastics bottles, three drops of nitric acid is applied to one of the bottles of the samples and then the samples are labelled with a masking tape to indicate the location and GPS coordinates. After the samples have been taken, the GPS coordinate of the sampling point and its elevation are taken and recorded in the field notebook.

3.5 Sampling of rocks on the field

A total of twelve (12) rock samples were also collected from random points in the study area. The collected rock samples were broken with the Geological field hammer, their GPS coordinates collected and then the samples were labelled with a masking tape and permanent marker to indicate the locations before placing them in a sample bag.

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Plate 3.0: collection of samples from field

3.6. Laboratory analysis and determination of parameters of the samples
At the end of the field sampling, the water samples were sent to the Adamawa State Water Board at Adamawa state to be tested by a Water scientist for its physical/organoleptic, chemical/inorganic and micro-biological constituents. These parameters were determined using various methods/equipment at the laboratory.

While the rock samples were sent to the Petrology Lab at Gombe State University for analysis.

3.6.1 Determining pH
The pH of a substance refers to the measurement of the acidity and alkalinity of that substance.
This parameter was measured for the collected water samples, and the measurement was carried out using handheld pH meter EXACT instrument model CT60

3.6.2 Determining electrical conductivity (EC)
Electrical conductivity (EC) is a measure of how easily a substance such as water can conduct an electric current. It is determined in groundwater by the concentration of dissolved ions, and the higher the concentration of these in groundwater the higher the electrical conductivity. The Electrical Conductivity of the collected water samples was measured with a handheld conductivity meter EXACT instrument model CT3030.

3.6.3 Determining Temperature
The temperature was determined for the collected water samples and was measured using a handheld temperature meter EXACT instrument model CT6021.

3.6.4 Determining Total dissolved solids (TDS)
Total dissolved solids (TDS) was determined using handheld TDS meter EXACT instrument model CT3061.

3.6.5 Turbidity (NTU)
Nephelometric Turbidity Units (NTU) is a measure of the clarity of water otherwise known as turbidity, this mainly measures the level of suspended particles present in water. The turbidity of the collected water samples was determined by the use of handheld turbidity meter HACH model 2100Q.

3.6.6 Chemical/Inorganic Parameters
The following chemical parameters were tested for - Cations (Calcium - Ca^{2+}, Magnesium - Mg^{2+}, Potassium - K^{+}, Sodium - Na^{+}, Manganese - Mn^{2+}, Copper - Cu^{2+}, Zinc - Zn^{2+}, Iron - Fe^{2+}) and Anions (Carbonates - CO_3^{2-}, Bicarbonates - HCO_3^{-}, Sulphate - SO_4^{-}, Phosphate - PO_4^{3-}, Nitrate - NO_3^{-}, Fluoride - F^{-}, Chloride - Cl^{-}), Trace elements (Arsenic – As, Chromium – Cr^{6+}), Cyanide and Total Hardness (TH). Carbonates, bicarbonates and total hardness were determined by titration using HACH digital titrator model 16900. All the major cations and anions were done using HACH digital spectrophotometer model DR3900.

Also, Lead (Pb) Arsenic (As), Cyanide (Cn) and Chromium (Cr) were tested for.

3.6.7 Coliform Count
The coliform count of the collected water samples was determined by the use of a hand-lens. This often helps us determine if water has been contaminated or not.

S/N	Sample point	T°C	PH	EC π/oms cm⁻1	NTU mg/l	TDS mg/l	Co_3^{2-} mg/l	HCO_3^{2} mg/l	TH mg/l	Mg^{2+} mg/l	Ca^{2+} mg/l	K^{+} mg/l	Fe^{2+} mg/l	PO_4^{2-} mg/l	CL^{-} mg/l	SO_4^{2-} mg/l	Na^{+} mg/l	NO_3^{2-} mg/l	Mn^{2-} mg/l	Cu^{2+} mg/l	Zn mg/l	F mg/l	C.count Cfu/100mls
1	loc 1 NA	27.190	8.040	369.000	22.130	246.000	6.400	314.000	117.220	10.220	31.080	7.500	1.870	2.030	37.000	18.720	1.154	41.110	0.005	0.402	0.089	2.790	39.000
2	loc 2 NA	26.810	7.960	298.000	10.030	203.000	4.810	318.000	128.610	9.420	37.480	6.800	1.030	1.360	19.420	17.310	1.142	25.140	0.005	0.522	0.095	2.790	26.000
3	loc 3 NA	27.920	7.960	310.000	0.462	206.000	1.620	317.000	121.420	10.000	32.980	6.400	0.180	1.430	10.100	12.920	0.800	9.600	0.003	0.502	0.051	2.380	2.000
4	loc 4 NA	27.560	8.120	348.000	0.397	238.000	1.200	369.000	131.420	8.150	39.370	7.100	0.121	1.340	9.310	14.930	0.759	12.140	0.001	0.396	0.042	1.890	1.000
5	loc 5 NA	27.380	7.930	347.000	0.317	229.000	1.220	322.000	120.770	10.000	31.730	6.800	0.208	1.490	10.530	12.410	0.712	10.630	0.003	0.513	0.055	2.580	2.000
6	loc 6 NA	27.300	8.180	320.000	0.202	215.000	0.000	402.000	123.580	9.270	34.020	6.400	0.020	1.300	10.180	13.800	0.839	10.140	0.002	0.371	0.049	2.000	0.000
7	loc 7 NA	26.850	7.890	348.000	0.422	239.000	1.200	370.000	125.030	9.120	35.860	5.900	0.134	1.280	11.530	13.740	0.753	10.810	0.001	0.399	0.056	2.510	2.000
8	loc 8 NA	27.100	8.320	297.000	1.055	207.000	1.600	315.000	121.580	10.150	33.870	8.000	0.416	1.660	12.340	16.390	0.970	17.520	0.004	0.442	0.071	2.100	6.000
9	loc 9 NA	26.810	7.840	331.000	0.302	219.000	1.240	352.000	126.340	10.640	34.000	6.400	0.132	1.260	10.120	15.120	0.685	9.130	0.001	0.383	0.058	2.430	4.000
10	loc 10 NA	27.980	8.140	320.000	0.423	213.000	1.310	406.000	121.630	8.320	34.970	7.600	0.172	1.400	11.980	14.400	0.756	12.580	0.002	0.422	0.060	21.960	5.000
11	loc 11 NA	26.850	7.960	346.000	0.304	234.000	1.000	398.000	130.110	10.690	36.970	6.800	0.117	1.260	12.420	14.920	0.752	12.000	0.002	0.409	0.040	1.850	2.000
12	loc 12NA	27.000	7.960	297.000	0.269	196.000	1.390	294.000	118.020	9.420	33.470	7.400	0.166	1.360	11.170	13.000	1.000	1.010	0.002	0.410	0.047	2.380	4.000
13	loc 13 NA	27.310	8.120	367.000	0.114	248.000	0.000	387.000	110.180	8.610	31.960	7.100	0.102	1.410	12.100	14.020	8.830	9.090	0.000	0.394	0.042	2.400	0.000
14	loc 14 NA	27.090	8.210	364.000	0.363	245.000	1.120	371.000	127.160	8.980	39.170	6.700	0.136	1.320	10.420	13.920	8.891	11.510	0.001	0.491	0.052	2.000	2.000
15	loc 15 NA	26.920	8.190	356.000	4.018	241.000	2.840	401.000	117.660	9.100	33.810	7.300	0.840	1.970	18.150	16.830	1.107	20.140	0.002	0.516	0.930	2.590	10.000
MAX		27.92	8.32	369.00	22.13	248.00	6.40	406.00	131.42	10.69	39.37	8.00	1.87	2.03	37.00	18.72	8.891	41.11	0.005	0.522	0.93	21.96	39.00
MIN		26.810	7.840	297.000	0.202	196.000	0.000	314.000	110.180	8.150	31.080	5.900	0.020	1.260	9.310	12.410	0.71	1.010	0.001	0.371	0.042	1.850	0.000
AVG		27.365	8.080	333.000	11.166	222.000	3.200	360.000	131.420	9.420	35.225	6.950	0.945	1.645	23.155	15.565	4.802	21.060	0.003	0.371	0.486	11.905	19.500

Table 3.0: Laboratory results from analysis

IV. RESULTS AND DISCUSSIONS

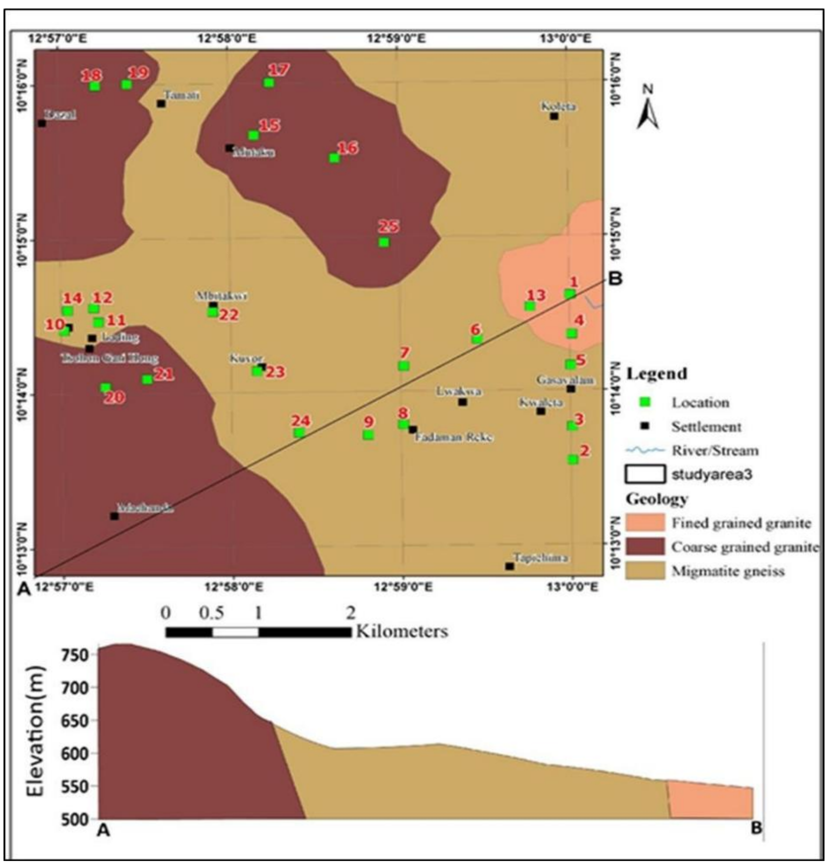

Figure 4.0: Geologic map of the study area

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4.1 THE STUDY AREA

The research in Hong local government area, Adamawa State examined the relationship between geological formations and groundwater quality, with a focus on fluorosis. We found that the presence of fine grained granite, coarse grained granite and migmatite gneiss significantly influence the fluoride levels in groundwater. Areas with higher concentrations of these rock types tends to have elevated fluoride levels in the groundwater contributing to the prevalence of fluorosis among local resident

4.2 RESULTS

A comprehensive study was conducted to evaluate the quality of groundwater in the Hong Local Government Area of Adamawa State. A total of 15 groundwater samples were meticulously collected and subjected to thorough analysis to assess various physical and chemical parameters.

The physical parameters investigated in this study included pH, Electrical Conductivity (EC) measured in µS/cm, Total Dissolved Solids (TDS) measured in mg/l, and temperature. Additionally, chemical parameters such as turbidity (NTU), Carbonates (CO_3^{2-}) measured in mg/l, and fluoride were also analyzed. Of particular concern was the presence of fluoride, given the observed cases of dental fluorosis in the area.

To visualize the results, a bar chart was constructed, depicting the concentration of each parameter against the corresponding borehole number. In cases where permissible limits were established, a thick red line was drawn to indicate the WHO (2011) guideline for safe drinking water. Parameters exceeding this limit are considered unsafe for consumption, while those below are deemed suitable for human consumption.

According to WHO (2011) standards, the permissible limit for fluoride in drinking water is 1.5 ppm. Concentrations exceeding this threshold are considered unsafe for consumption, while concentrations below are regarded as suitable for human consumption.

This study provides valuable insights into the quality of groundwater in the Hong Local Government Area, aiding in the formulation of strategies for the management and improvement of water resources to ensure the provision of safe and potable water to the community.

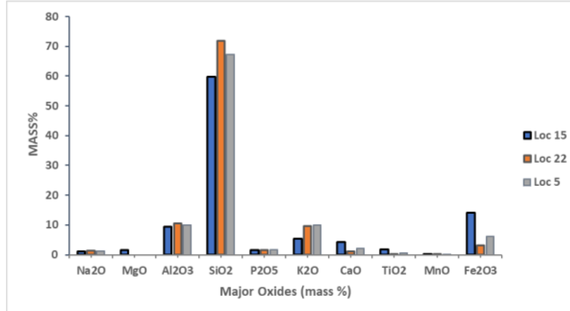

Figure 4.1: Bar chart of major oxides

The bar chart provides data on various elemental concentrations in water samples collected from different locations. Here's a summary of some key elements:

Sodium (Na): Present in all samples, ranging from 737 ppm to 740 ppm.

Chlorine (Cl): Concentrations vary between 363 ppm and 595 ppm.

Vanadium (V): Detected in some samples with concentrations up to 286 ppm.

Chromium (Cr): Found in trace amounts in some samples, with concentrations up to 97.433 ppm.

Nickel (Ni): Present in trace amounts, ranging from 3.37 ppm to 14.5 ppm.

Copper (Cu): Detected in all samples, with concentrations ranging from 0.727 ppm to 1.265 ppm.

Zinc (Zn): Present in all samples, with concentrations varying from 0.764 ppm to 1.1 ppm.

Arsenic (As): Present in some samples, but concentrations are not detected (ND) in others.

These elements are measured in parts per million (ppm) or micrograms per liter (µg/l) and provide insight into the chemical composition of the water samples. The concentrations of these elements are essential for assessing water quality and potential health risks associated with drinking or using the

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water. Additionally, they can help identify sources of contamination or natural mineralization in the sampled areas.

Sample point	T˚C	PH	EC π/oms cm^{-1}	NTU mg/l	TDS mg/l	Co_3^{2-} mg/l	HCO_3^{2} mg/l	TH mg/l	Mg^{2+} mg/l	Ca^{2+} mg/l
loc 1 NA	27.190	8.040	369.000	22.130	246.000	6.400	314.000	117.220	10.220	31.080
loc 2 NA	26.810	7.960	298.000	10.030	203.000	4.810	318.000	128.610	9.420	37.480
loc 3 NA	27.920	7.960	310.000	0.462	206.000	1.620	317.000	121.420	10.000	32.980
loc 4 NA	27.560	8.120	348.000	0.397	238.000	1.200	369.000	131.420	8.150	39.370
loc 5 NA	27.380	7.930	347.000	0.317	229.000	1.220	322.000	120.770	10.000	31.730
loc 6 NA	27.300	8.180	320.000	0.202	215.000	0.000	402.000	123.580	9.270	34.020
loc 7 NA	26.850	7.890	348.000	0.422	239.000	1.200	370.000	125.030	9.120	35.860
loc 8 NA	27.100	8.320	297.000	1.055	207.000	1.600	315.000	121.580	10.150	33.870
loc 9 NA	26.810	7.840	331.000	0.302	219.000	1.240	352.000	126.340	10.640	34.000
loc 10 NA	27.980	8.140	320.000	0.423	213.000	1.310	406.000	121.630	8.320	34.970
loc 11 NA	26.850	7.960	346.000	0.304	234.000	1.000	398.000	130.110	10.690	36.970
loc 12NA	27.000	7.960	297.000	0.269	196.000	1.390	294.000	118.020	9.420	33.470
loc 13 NA	27.310	8.120	367.000	0.114	248.000	0.000	387.000	110.180	8.610	31.960
loc 14 NA	27.090	8.210	364.000	0.363	245.000	1.120	371.000	127.160	8.980	39.170
loc 15 NA	26.920	8.190	356.000	4.018	241.000	2.840	401.000	117.660	9.100	33.810
MAX	27.92	8.32	369.00	22.13	248.00	6.40	406.00	131.42	10.69	39.37
MIN	26.810	7.840	297.000	0.202	196.000	0.000	314.000	110.180	8.150	31.080
AVG	27.365	8.080	333.000	11.166	222.000	3.200	360.000	131.420	9.420	35.225

K^{+} mg/l	Fe^{2+} mg/l	PO_4^{2-} mg/l	CL^{-} mg/l	SO_4^{2-} mg/l	Na^{+} mg/l	NO_3^{2-} mg/l	Mn^{2-} mg/l	Cu^{2+} mg/l	Zn mg/l	F mg/l	C.count Cfu/100mls

7.500	1.870	2.030	37.000	18.720	1.154	41.110	0.005	0.402	0.089	2.790	39.000
6.800	1.030	1.360	19.420	17.310	1.142	25.140	0.005	0.522	0.095	2.790	26.000
6.400	0.180	1.430	10.100	12.920	0.800	9.600	0.003	0.502	0.051	2.380	2.000
7.100	0.121	1.340	9.310	14.930	0.759	12.140	0.001	0.396	0.042	1.890	1.000
6.800	0.208	1.490	10.530	12.410	0.712	10.630	0.003	0.513	0.055	2.580	2.000
6.400	0.020	1.300	10.180	13.800	0.839	10.140	0.002	0.371	0.049	2.000	0.000
5.900	0.134	1.280	11.530	13.740	0.753	10.810	0.001	0.399	0.056	2.510	2.000
8.000	0.416	1.660	12.340	16.390	0.970	17.520	0.004	0.442	0.071	2.100	6.000
6.400	0.132	1.260	10.120	15.120	0.685	9.130	0.001	0.383	0.058	2.430	4.000
7.600	0.172	1.400	11.980	14.400	0.756	12.580	0.002	0.422	0.060	1.960	5.000
6.800	0.117	1.260	12.420	14.920	0.752	12.000	0.002	0.409	0.040	1.850	2.000
7.400	0.166	1.360	11.170	13.000	1.000	1.010	0.002	0.410	0.047	2.380	4.000
7.100	0.102	1.410	12.100	14.020	8.830	9.090	0.000	0.394	0.042	2.400	0.000
6.700	0.136	1.320	10.420	13.920	8.891	11.510	0.001	0.491	0.052	2.000	2.000
7.300	0.840	1.970	18.150	16.830	1.107	20.140	0.002	0.516	0.930	2.590	10.000
8.00	1.87	2.03	37.00	18.72	8.891	41.11	0.005	0. 522	0.93	21.96	39.00
5.900	0.020	1.260	9.310	12.410	0.71	1.010	0.001	0.371	0.042	1.850	0.000
6.950	0.945	1.645	23.155	15.565	4.802	21.060	0.003	0.371	0.486	11.905	19.500

Table 4.0: Result of laboratory analysis

4.3 DISCUSSION OF THE RESULTS

4.3.1 pH:

The pH values in the table range from 7.84 to 8.32 across different sampling locations. pH is a measure of the acidity or alkalinity of water on a scale of 0 to 14, where pH 7 is considered neutral, below 7 is acidic, and above 7 is alkaline. The pH of water is crucial for aquatic organisms and can influence chemical reactions, nutrient availability, and the effectiveness of water treatment processes. In the context of the provided data, the pH values fall within the acceptable range for drinking water (typically between 6.5 and 8.5), indicating that the sampled water sources are generally not overly acidic or alkaline.

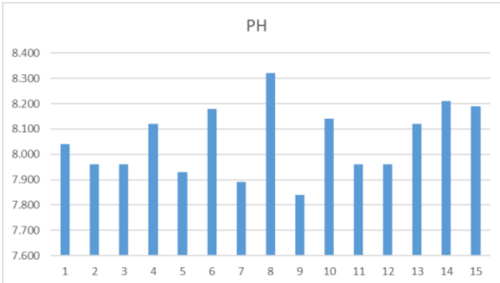

Figure4.2: Chart showing concentration of pH

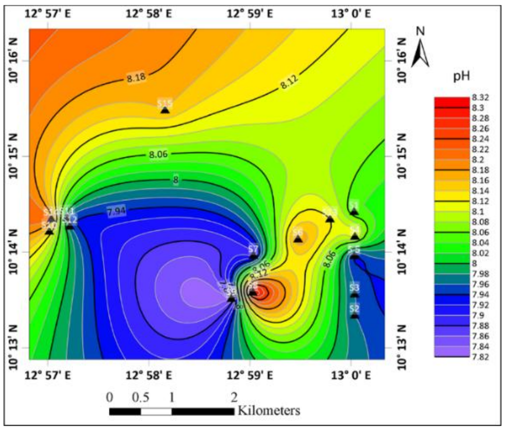

Fig 4.3: map of pH concentration of the water in the study area

4.3.2 Temperature:

The temperature values in the table range from 26.81°C to 27.98°C across different sampling locations. Water temperature plays a significant role in aquatic ecosystems, affecting the solubility of gases, metabolic rates of organisms, and overall ecosystem dynamics. In the context of drinking water quality, temperature influences consumer preferences and the growth of microorganisms. The temperatures recorded in the provided data are within the typical range for freshwater environments and are unlikely to pose any significant concerns for water quality or ecosystem health.

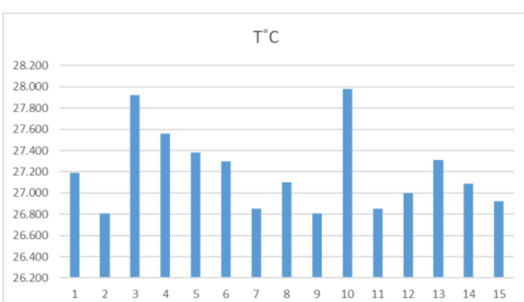

Figure 4.4: Chart showing temperature

4.3.3 Electrical Conductivity (EC):

The electrical conductivity (EC) values in the table range from 297.0 µS/cm to 369.0 µS/cm across different sampling locations. EC is a measure of water's ability to conduct electricity, primarily influenced by the concentration of dissolved ions. Higher EC values indicate greater ion concentrations, often associated with increased levels of Total Dissolved Solids (TDS). In the context of the provided data, the EC values suggest moderate to low ion concentrations in the sampled water sources, reflecting relatively good water quality with minimal contamination or salinity issues.

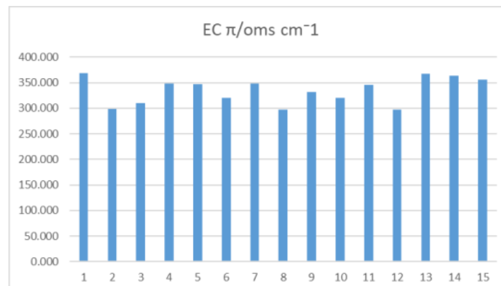

Figure 4.5: Chart showing the electrical conductivity of the study area

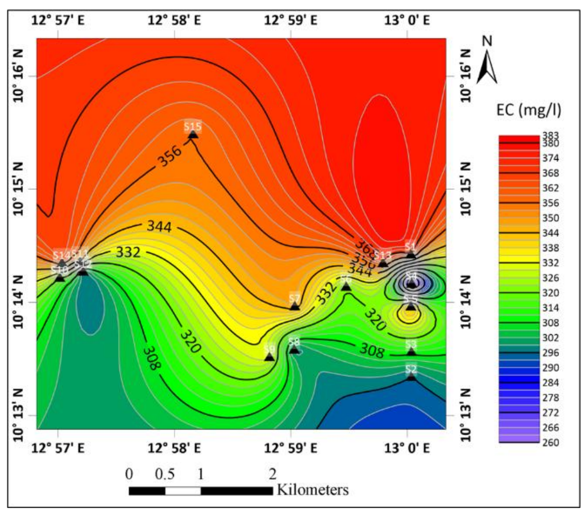

Fig 4.6: map of Electrical conductivity of the study area

4.3.4 Total Dissolved Solids (TDS):

The Total Dissolved Solids (TDS) values in the table range from 196 mg/L to 248 mg/L across different sampling locations. TDS represents the total concentration of dissolved inorganic and organic substances in water, including minerals, salts, metals,

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and other compounds. Elevated TDS levels can affect water taste, odor, and clarity, as well as pose potential health risks if certain contaminants are present. In the context of the provided data, the TDS values fall within the acceptable range for drinking water quality, indicating that the sampled water sources are generally suitable for consumption with minimal taste or health concerns.

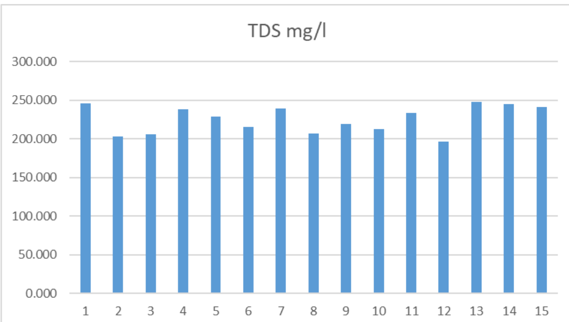

Figure 4.7: Chart showing the total dissolved solids of the study area

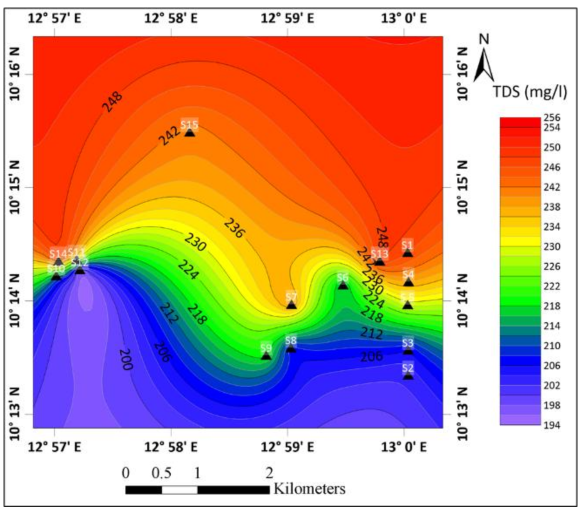

Fig 4.8: map of TDS Concentration of the study area

4.3.5 Fluoride (F):

Fluoride is essential for human health, with small amounts in water (around 1.0 mg/l) benefiting dental health, especially in reducing dental caries in children. However, excessive intake can lead to dental and skeletal fluorosis, along with metabolic changes affecting various soft tissues, including the thyroid, reproductive organs, brain, liver, and kidneys. These effects can include hypothyroidism, reproductive issues, and cognitive impairment.

Fluorosis is typically associated with higher fluoride intake through drinking water, often found in regions with elevated fluoride levels in groundwater, particularly those with volcanic rocks. Regulatory standards vary, with the WHO setting a permissible limit of 1.0 mg/l, while the USPHS adjusts based on climatic conditions. Some experts suggest even lower limits, such as 0.6 mg/l under tropical conditions.

Assessing fluoride exposure involves various methods, with urinary fluoride concentration considered the most reliable indicator. Studies have shown direct correlations between fluoride levels in drinking water and bodily sources like urine and hair. Dental fluorosis and bodily fluoride content are directly linked to fluoride levels in drinking water and dietary intake. The study utilized the ion selective electrode method to determine fluoride levels in drinking water samples from 15 different locations in Hong Local Government Area, Adamawa State.

In essence, fluoride has both beneficial and detrimental effects on human health, with regulation and monitoring of fluoride levels in drinking water crucial for maintaining optimal health outcomes. (Sandeep, Jaspreet, Amit, Poonam , & Rajbir, 2021)

4.3.6 Fluoride in groundwater

Fluoride's principal source in groundwater is geogenic contamination, the source which is mostly unclear. Groundwater pollution from geogenic sources is primarily determined by the geological context of the location (Araya et al., 2022). Fluoride concentration varies by rock type. Fluoride is an abundant trace element found in both igneous and sedimentary rocks. Fluoride may be found in a lot of minerals, some of which are fluorite, cryolite, apatite, topaz, biotite, epidote etc (Vithanage and Bhattachaya 2015, Yadav et al.,2021). The compositions of quartz, felsic, gneissic, syenite, granite and alkaline volcanic rocks contain the highest amount of fluoride. High fluoride content in groundwater can be attributed to either natural means via chemical weathering and rock dissolution processes or anthropogenic interference through the application of fluoride rich fertilizer (saxema and Ahmed,2002; Columbus *et al,* 2003; Nwankwoala *et al*.,2014).

The fluoride concentration in water is positively associated with ions such as chloride and phosphate.

Other sources of fluoride in groundwater in the study area are industries of fertilizers, block, textile and dye, and plastic which release polluted water as waste products after manufacturing.

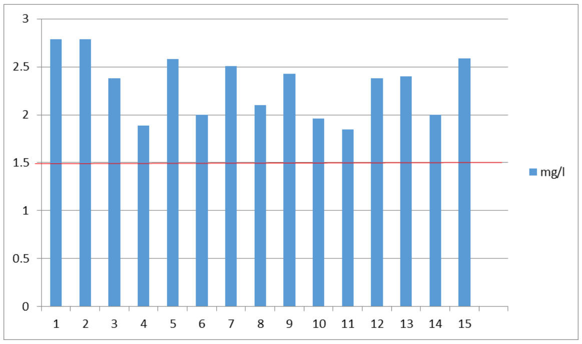

Figure 4.9: chart showing Fluoride concentration of the study area

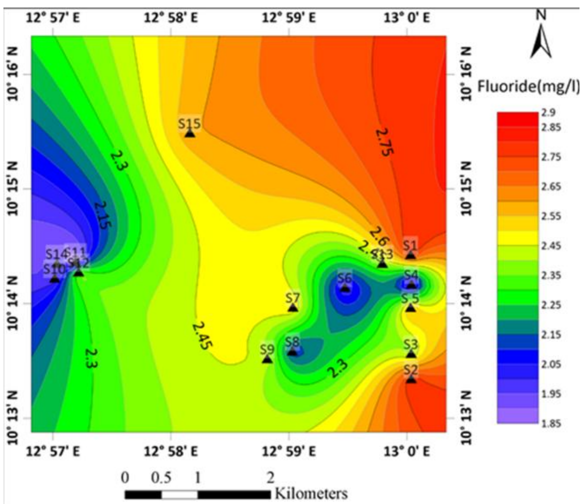

Figure 5.0: Fluoride distribution map of study area

The fluoride (F) concentration values in the table 4.0 range from 1.85 mg/L to 2.79 mg/L across different sampling locations. Fluoride is a naturally occurring mineral that can benefit dental health at optimal levels but may cause health problems if present in excess. The concentration of fluoride in the study area from different sample sources (streams, wells, and boreholes) in Hong local government were above the WHO standard limit of 1.5mg/L. Figure 4.6 shows a clear view of the standard limit set by WHO. This indicates that the fluoride levels in the study area exceed the recommended limit set by the World Health Organization (WHO), which could potentially lead to health concerns. Table 4.1 shows the comparison of the result with the WHO standard.

4.4 COMPARISON OF RESULT WITH WHO STANDRARD

NON ACIDIC SAMPLE	FLOURIDE	(WHO) STANDARD	REMARK
sample 1	2.79mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 5	2.58mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 12	2.38mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 3	2.38mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 4	1.89mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 14	2.00mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 15	2.59mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 10	1.96mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 6	2.00mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 11	1.85mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 2	2.79mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 13	2.40mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 7	2.51mg/l	1.0mg/l - 1.5mg/l	not acceptable
sample 8	2.10mg/l	1.0mg/l - 1.5mg/l	not acceptable

sample 9	2.43mg/l	1.0mg/l - 1.5mg/l	not acceptable

Table 5.1: comparing fluoride concentration with WHO standard

All the samples taken from the study area fall above the acceptable permissible limits when compared with the standard permissible limits this means that the study area has a very high concentration of fluoride.

The accumulation of fluoride more than the permissible limit leads to hazardous health issues in infants, children and adults. Fluoride may be harmful to humans depending on the overall concentration of fluoride consumed overtime. A deficiency in fluoride cause dental caris and weakening of the bones (when concentration is less than 0.5mg/l). Whereas, a concentration that is greater than 1.5mg/l leads to fluorosis.

4.4.1 Effect of fluoride on human

Fluoride, when consumed in excess of optimal levels, can have detrimental effects on human health, particularly in the form of dental and skeletal fluorosis. Dental fluorosis is a condition characterized by alterations in the appearance of tooth enamel, ranging from mild discoloration to severe pitting and enamel hypoplasia. It primarily affects developing teeth, especially during the period of enamel formation in childhood (Featherstone & D, 1999). Skeletal fluorosis, on the other hand, is characterized by changes in bone density and structure due to the accumulation of fluoride over time. It can manifest as joint stiffness, pain, and skeletal deformities, with symptoms varying in severity depending on the duration and intensity of fluoride exposure ((WHO), 1994).

Numerous epidemiological studies have highlighted the global burden of fluorosis, particularly in regions with high fluoride concentrations in drinking water. A study by (Susheela AK, 1999) estimated that approximately 200 million people worldwide are affected by fluorosis, with India and China being among the most severely impacted countries. In India, an estimated 62 million individuals, including 6 million children, suffer from serious health problems due to consumption of fluoride-contaminated water (Susheela AK, Endemic fluorosis in India, 1999). Similarly, endemic fluorosis has been reported in 29 provinces of China, municipalities, and autonomous regions, with dental and skeletal fluorosis being predominant (Wang X, 2016).

The adverse effects of fluoride on dental health have been extensively documented in the literature. Fluoride, when present in drinking water at concentrations above optimal levels, can lead to dental fluorosis, especially during the critical period of tooth development in childhood. A meta-analysis by (Clarkson JJ, 2000) found that dental fluorosis prevalence ranged from 12% to 33% in populations exposed to drinking water fluoride concentrations between 0.9 and 1.2 mg/litre. The susceptibility to dental fluorosis is highest during the mineralization of the secondary upper central incisor teeth, typically occurring at around 22-26 months of age (Dean HT, 1938).

Furthermore, the geographical variation in fluorosis prevalence has been attributed to factors such as climate and water consumption habits. In temperate areas with lower fluoride levels in drinking water, dental fluorosis typically does not occur at concentrations below 1.5 to 2 mg/litre (Council, 2006). However, in warmer regions where water consumption is higher, dental fluorosis can occur at lower fluoride concentrations (Griffin SO, 2007).

4.4.2 Mitigation technologies of removing fluoride from water

Several mitigation technologies are available for reducing fluoride concentration in groundwater, particularly in areas where it is high. Reverse osmosis (RO) is a widely used technology that involves forcing water through a semi-permeable membrane to selectively remove fluoride ions. Ion exchange is another effective method where resin beads are used to exchange fluoride ions with other ions, effectively reducing fluoride levels in high-fluoride groundwater areas.

Activated alumina, a highly porous material, is also effective in adsorbing fluoride ions from water, making it suitable for areas with high fluoride concentrations. Electrodialysis reversal (EDR) is a membrane-based technology that selectively removes fluoride ions by applying an electric field across ion-selective membranes, making it effective in reducing fluoride levels in high-fluoride groundwater areas

Bone char filters, derived from carbon-rich animal bones, offer an effective and environmentally friendly solution for fluoride removal through adsorption. These filters are particularly suitable for small-scale applications and rural areas with limited access to other treatment technologies

These technologies provide effective solutions for mitigating fluoride contamination in groundwater, particularly in regions where fluoride levels are high, offering various options depending on the specific needs and constraints of the affected communities.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

This study aimed to evaluate the relationship between geological formations and groundwater quality, with a focus on fluorosis, in the Hong Local Government Area of Adamawa State. The research utilized a combination of desk study, reconnaissance survey, fieldwork, laboratory analysis, and data interpretation to achieve its objectives.

The desk study involved reviewing relevant literature on geology, hydrology, and hydrogeology to establish a foundational understanding of the study area. Subsequently, a reconnaissance survey provided a preliminary physical overview, identifying key features such as geological formations and water sources.

Fieldwork involved the collection of water and rock samples from various locations within the study area. Water samples were analyzed for physical and chemical parameters, while rock samples underwent petrological analysis. Laboratory tests were conducted to determine parameters such as pH, electrical conductivity, total dissolved solids, fluoride concentration, and major oxide composition.

The results revealed significant correlations between geological formations, particularly fine-grained granite, coarse-grained granite, and migmatite gneiss, and fluoride levels in groundwater. The presence of these rock types contributed to elevated fluoride concentrations in water sources, posing a risk of fluorosis to local residents.

5.2 CONCLUSION

In conclusion, this study has provided valuable insights into the relationship between geological formations and groundwater quality, particularly concerning fluorosis, in Hong Local Government Area of Adamawa State. Through a comprehensive approach encompassing desk study, reconnaissance survey, fieldwork, and laboratory analysis, the research has shed light on the significant influence of geological factors, such as fine-grained granite, coarse-grained granite, and migmatite gneiss, on fluoride levels in groundwater. The findings indicate a prevalent issue of elevated fluoride concentrations in water sources within the study area, posing potential health risks to the local population. These conclusions emphasizes the urgent need for intervention measures to mitigate fluoride contamination and ensure access to safe drinking water for the community.

5.3 RECOMMENDATIONS

In light of the conclusions drawn from this study, the following recommendations are proposed:

Implementation of comprehensive water quality monitoring programs to regularly assess fluoride levels in groundwater.

Adoption of mitigation measures to reduce fluoride concentrations in affected water sources, including the installation of appropriate treatment facilities.

Public awareness campaigns to educate local residents about the risks of fluorosis and promote alternative sources of safe drinking water.

Further research to investigate the geological processes contributing to fluoride contamination and explore additional mitigation strategies.

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