GEOCHEMICAL CHARACTERISTICS OF GROUNDWATER RESOURCES IN PARTS OF OKITANKWO WATERSHED, SOUTHEASTERN, NIGERIA

BY

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CERTIFICATION

This is to certify that this work "**Geochemical Characteristics of Groundwater Resources in Parts of Okitankwo Watershed, Southeastern, Nigeria**" was carried out by **Iwuji, Callistus Chukwunenye** (**20134871338**)in partial fulfillment for the award of the degree of Master of Science (M.Sc) in Environmental Geology in Department of geology, Federal University of Technology of Owerri, Imo State, Nigeria.

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DEDICATION

This work is dedicated to God Almighty and all postgraduate students in the department of Geology.

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ABSTRACT

The geochemical characteristics of groundwater resources in parts of Okitankwo watershed, was carried out in order to evaluate its chemical composition and quality profile with respect to the environmental setting of the study area. A total of twelve groundwater samples were collected in grid, and analyzed for major cations and anions and trace elements like Fe and Pb. The major cation concentrations determined were in the order of $Na^{+}>Ca^{2+} > Mg^{2+}> K^{+}$ with mean values of 4.64, 3.44, 2.46 and 0.38Mg/L respectively and that of major anions concentrations of groundwater is of the order $HCO_3^{2-} > SO_4^{2-}>Cl^{-}$ with mean values of 19.07, 11.87 and 7.92 Mg/L respectively. Two major water types were identified based on characterization on Piper Trillnear digram. They are Ca^{2+}- Mg^{2+} (SO_4^{2-}) and Na (HCO_3^{2-}). Thus, this indicates diverse effects of bedrock lithologies ionic exchange processes, precipitation and weathering. However, the plot of Durov, Schoeller and Stiff diagram conform to the water chemistry of the study area. More so, the result of the geochemical analyses shows that the groundwater is generally acidic with pH values ranges from 4.32 to 6.4 with mean value of 5.37. The Sodium Adsorption Ratio (SAR) ranges from 0.06 to 0.81 with mean value of 0.48 indicating that the groundwater is suitable for agriculture. The result of the geochemical analyses also shows that the groundwater is fresh, soft and potable. But some of the groundwater resources may however be unsuitable for industrial use due to the concentration of Fe is above the permissible limit (0.2Mg/L) for industries and will require treatment.

Keywords: Geochemical Characteristics, Groundwater, Watershed, Chemical Composition, Resources, Hydrogeochemical, Physio-chemical, Water quality.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

Quality of water is of vital importance whether for industrial, agricultural or domestic purpose. The greatest water quality problem in developing countries is the prevalence of water-borne diseases. According to Davis and De Wist (1966), drinking water standards are based on two main criteria namely: the presence of objectionable taste, odour and colour; and the presence of substances with adverse physiological effects.There are many processes, which may be natural or artificial that generate pollutants or contaminants that may enter the ground water or surface water of an area. Some of these processes include physicochemical weathering, transportation of sediments as well as erosion and infiltration induced by precipitation (Onunkwo-Akunne and Uzoije, 2011). Other human activities such as agriculture, pit toilets, sewage disposal and garbage dumps also contribute to the pollution or contamination of the water systems in an area.

In addition to these human induced pollution problems, water supplies may also have natural quality problems that are related to local geology. Interaction between water and rock-forming minerals during groundwater circulation may lead to the build-up of harmful concentration of some trace elements (Spears, 1976). Some of these minerals/elements are highly soluble and therefore the total dissolved minerals in water plays a major role in determining its geochemical character and hence its suitability for domestic, industrial or agricultural purpose (Oteze, 1991). Other health effects may be caused by element deficiencies where rocks have low concentrations of essential elements. Water may also be unacceptable due to aesthetic problems such as bad odour or taste.

1.2 STATEMENT OF THE PROBLEM

The recent Government activities in the study area has brought about increase in socio-economic order such as population increase, pressure on the available facilities and new land use elements with their generated wastes. There is the need to examine the present status of the underground water resources of this area for effective development. Thus, it becomes necessary to carry out the groundwater quality assessment as a hydrogeochemical baseline for development programs.

1.3 AIM AND OBJECTIVES OF STUDY

Aim: To provide a more complete understanding of the hydro-geochemistry of Okitankwo Watershed.

Objectives;

i) To carry out chemical analysis of water samples in the Okitankwo watershed. In order to ascertain the potability of the groundwater resources with respect to WHO standard.

ii) To interpret the result of the laboratory analyses using Piper, Durov, Schoeller and Stiff diagramsdetermining the water types, patterns and by comparison with known standards e.g. W.H.O.

iii) To evaluate the physico-chemical quality of the groundwater system.

1.4 JUSTIFICATION OF STUDY

Due Government activities in the study area which has increases the socio-economic order in the area. Thus, it became necessary to evaluate the physico-chemical quality of groundwater resources of the study area as a hydro geochemical baseline for developmental programs.

1.5 SCOPE OF STUDY

This work involves the collection of Twelve (12) water samples in grid in the study area for the analyses of the physico-chemical parameters, interpretation and comparison with W.H.O. standard.

CHAPTER TWO

LITERATURE REVIEW

Onunkwo *et al*., (2013), worked on the Groundwater Quality Assessment of Nkwerre which is a part of the study area. According to him, the groundwater has high turbidity, high Fe, slightly acidic, soft, potable and suitable for industrial, agricultural and domestic purposes, but requires treatment to reduce Fe and turbidity. And also, the water type belongs to no dominant cation and anion type.

Other studies on different aspects of the hydrogeology of this area have been carried out by Etu-Efeotor, (1981); Offodille, (1981); Etu-Efeotor and Odigi, (1983); Egboka, (1983); Okonny, (1991); Ahiarakwem and Ejimadu, (2002); Ibeneme *et al*.,(2013). These studies covered both surface and sub-surface water resources of the area.

According to Ahiarakwem and Ejimadu(2002), the geochemical properties of the groundwater system of Orlu and environs of which the study area is a part of, is generally acidic with an average pH of 5.1. It has an average Ca^{2+} and Mg^{2+} concentrations of 2.97mg/l and 2.49mg/l respectively with an average hardness of 8.8mg/l indicating that it is relatively soft and has no laxative effect. The concentrations of total iron, manganese, sodium, chloride, nitrate, sulphate, bicarbonate, total dissolved solids(TDS)and heavy metals conformed to the WHO drinking water standard. It was found to be suitable for irrigation purposes because the SAR was found to range from 0.61 to 2.30 with an average of 1.09. A plot of the average constituents of the groundwater in a piper trilinear diagram showed that it was potable.

For surface water, it should be noted that its chemical quality depends on the origin of the water, rate of evapo-transpiration, the nature of the soils and rocks that are encountered along the course of the stream or rivers, the nature of the rocks underlying the stream bed, the length of the contact time with the soils and rocks, and the individual reaction rates between the water and the minerals in the soils and rocks (Lindskov and Kimball, 1984). The physical quality also depends on the nature of the soils and rocks along the flow path. Flow over muddy areas would increase the turbidity of surface water while flow over iron rich rocks would impart brown colouration on streams and rivers, and also high concentration of iron in the body can cause liver and lung problem (Offodile, 1987).

Finally, the local geology of an area influences its water quality. As water moves through surface and sub-surface rocks, it reacts with the minerals that make up the rocks. Hence water increases or decreases in mineral content as it moves along until a combined equilibrium of the dissolved substances is reached. It is therefore the dissolved materials in any water that determines its geochemical character and hence its acceptability for domestic, industrial and agricultural purposes (Oteze, 1991).

2.1 LOCATION OFSTUDY AREA

The study area which is Okitankwo Watershed is located in the Southeastern part of Nigeria. It lies within latitudes $5^o36'$N and $5^o47'$N and longitude $7^o05'$E and $7^o12'$E. The Topographic map of the study area is shown in Fig. 2.1.

The area is Accessible mainly by road and some other footpaths. It is bounded in the north by Ideato South, to the east by IsialaMbano, to the South by Mbaitoli and to the west by Isu Local Government areas.

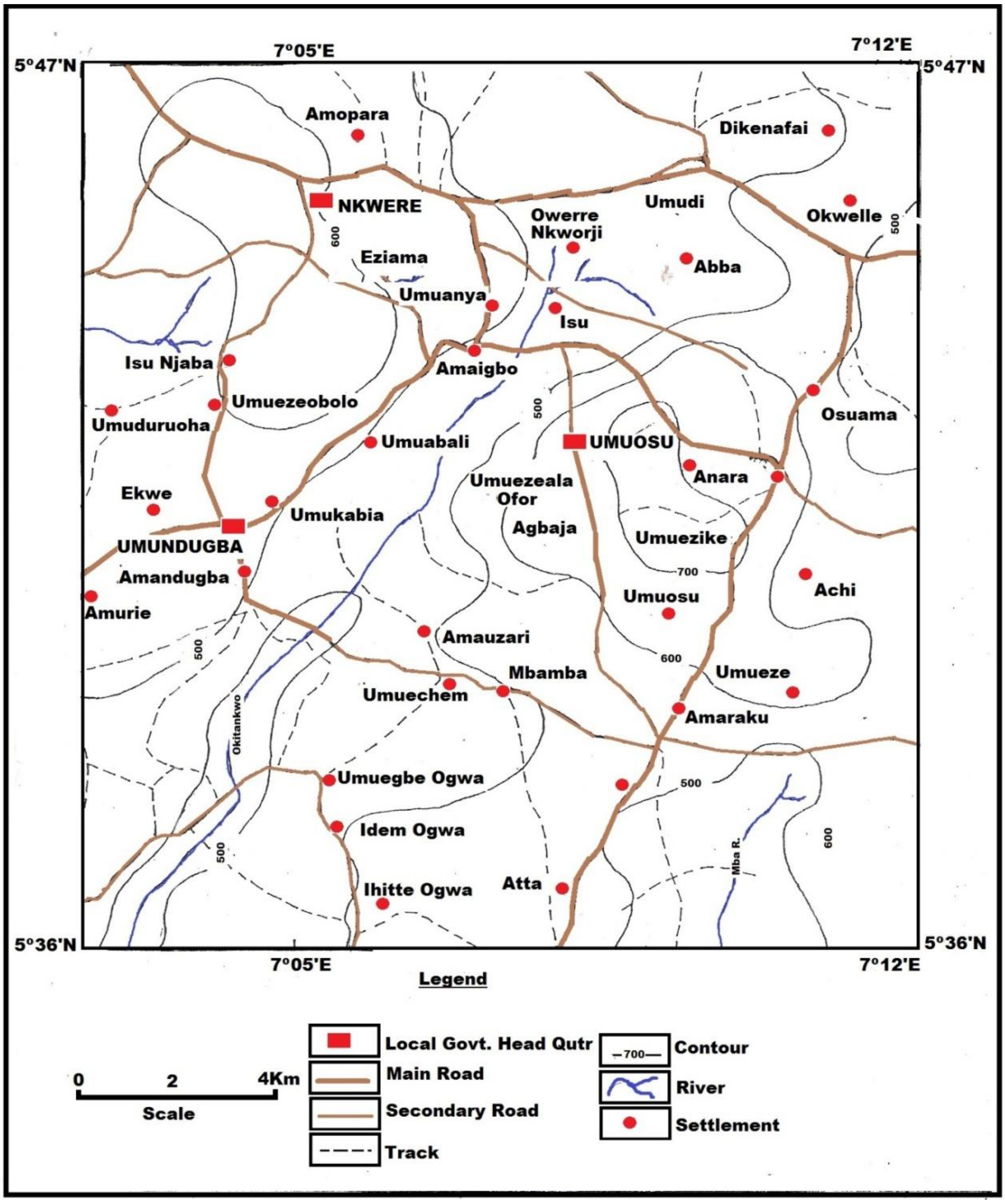


Fig.2.1.Topographic Map of the study area.

2.2 GEOLOGY AND HYDROGEOLOGY

Within the study area, it ispredominantly characterized by three major geologic formations with Ameki formation being the oldest. Ameki formation is overlain by Ogwashi-Asaba formation which in turn is overlain by the Benin Formation. The geology and hydrogeology of these units have been extensively studied by various authors (Kogbe, 1976; Reyment, 1965; Uma, 1989; Whiteman, 1982). The Benin formation comprises of a thick sequence of poorly consolidated to unconsolidated sandstones that are friable with sorting ranging from poorly to fairly sorted (Onyeagocha, 1980). Several grain sizes occur within the unit and the coarse and fine unit alternate along the vertical sequence. The thick sandy units are frequently separated by thin and discontinuous clay streaks and lenses. The clay beds are thin (less than 1 m) and sometimes occur as lamination lining the bedding plane of the unconsolidated sandstone beds. The formation starts as a thin edge at its contact with the Ogwashi/Asaba formation in the north of the area and thickens southwards (Avobovbo, 1978). The Ogwashi– Asaba formation is identified within the Palaeocene Anambra Basin (Afikpo geosynyncline) (Oboh – Ikuenobe *et al.*, 2005). The formation is characterized by alternation of clays, sands, grits and lignites

(Basseyand Eminue, 2012). The formation occurs mainly in Benin, Asaba, Onitsha and Orlu areas, Reyment (1965) suggested Oligocene–Miocene age for this formation, but palynological results by the work of Cherie et al. (1978) assigned a Middle Eocene age to the basal part.

Table 2.1: Stratigraphic succession of Rocks in Imo Southeastern, Nigeria (After Short and Stauble, 1967).

AGE	FORMATION	LITHOLOGY
Miocene-Recent	Benin-Formation	Sands with clay lenses
Oligocene-Miocene	Ogwashi Formation	Sands, Clay, Lignite
Eocene	Ameki Formation	Clayey Sandstone
Paleocene	Imo Shale	Sands, Laminated Clayey Shale

The Ogwashi–Asaba formation is a surface lateral equivalent of the Agbada Formation which occurs in the subsurface of the Niger Delta (Assez, 1989; Akpoborie *et al*., 2011). The Amaki formation of Eocene to Oligocene age consists of medium to coarse-grained white sandstone, which may contain pebbles, graygreen sandstone, bluish calcareous silt, with mottled clays and thin limestone. Considerable lateral variation in lithology has also been observed. The lower part of the formation consists of fine-coarse-grained lenses of sandstone with abundant calcarceous shales and thin shelly limestone. The Ameki formation overlies the impervious Imo shale group of Paleocene age, which is characterized by lateral and vertical variations in lithology (Akaninyene and Igboekwe, 2012). As shown in Fig. 2.2 and Table 2.1.

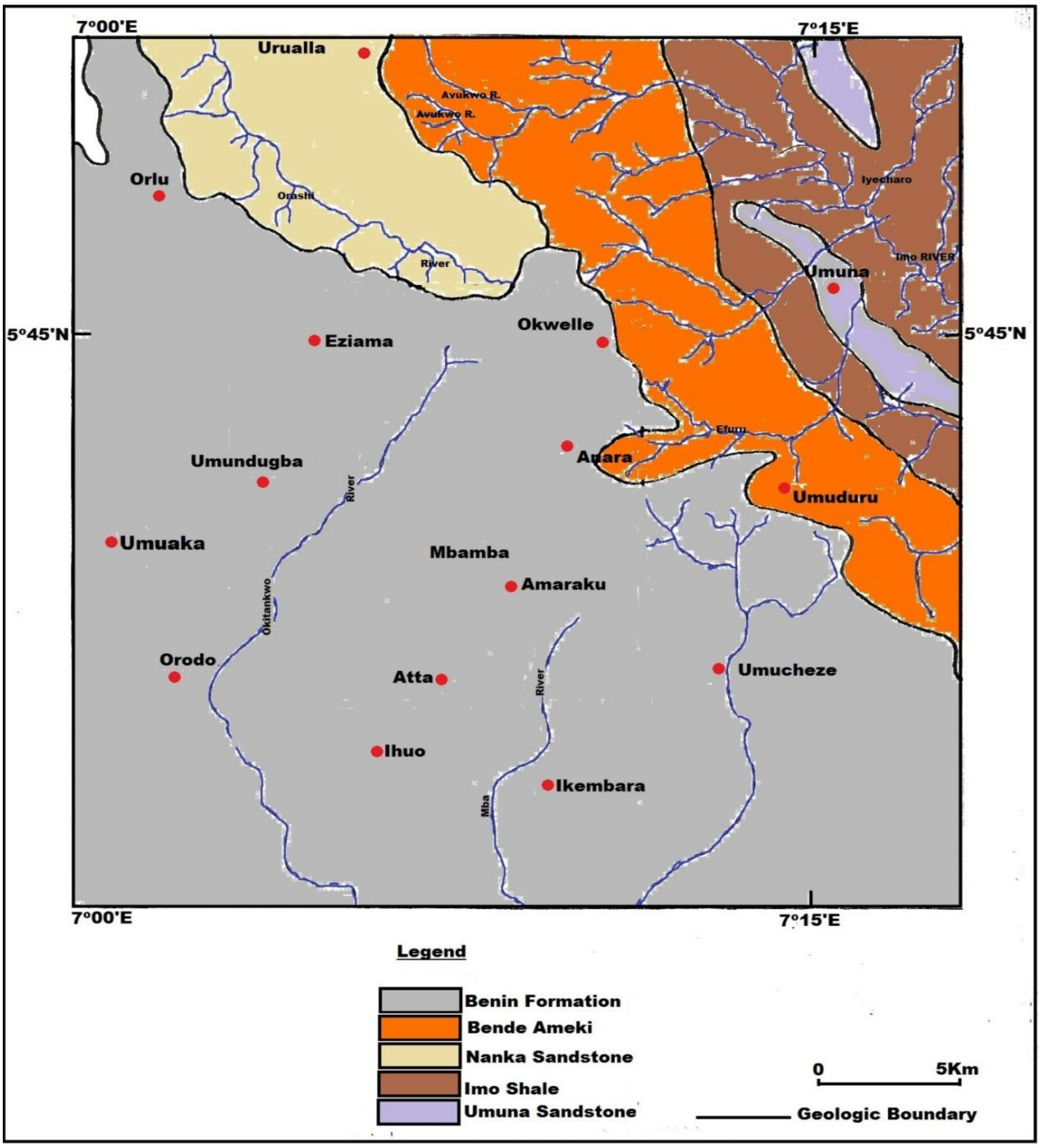


Fig.2.2. Geologic Map of the study area.

Hydrogeology

The lithologic units that occur in the area include mainly sand, sandstone, clay, ligniteof all the units; sands and sandstone constitute aquifers while the clay units are the aquitards. Thus, the hydrogeologic setting is that of alternating layers of aquifer and aquitards. The area thus is underlain by a multi-aquifer system which consists of an uppermost unconfined aquifer and the lower confined units.

2.3 PHYSIOGRAPHY

2.3.1 Drainage

The drainage pattern of the area consists of only one major river – the Okitankwo River that flows through Nkwerre and Nwangele Local Government Areas and has tributaries at Owerre-Nkworji and Umutakwo. This river is the major source of water supply for the surrounding communities.

Large quantities of sediments are supplied to this river through erosion, which suggests the source of its characteristic dirty colour.

2.3.2 Climate

The prevalent climatic condition of the study area has two distinct seasons that depend on the prevailing air masses. The air masses are the dry Northeast trade wind and moisture (wet) laden southwest maritime air mass. The rainy season is between the month of March and October while the dry season is between November and February.

The area has a mean annual rainfall of about 2000-2250mm while the mean annual temperature is between 26.5^{o}c and 27.3^{o}c (Atlas of Imo State, 1984). Relative humidity ranges between 70% - 80%. The maxima of relative humidity usually coincide with the peaks of the monthly rainfall in May/June and September/October. Relative humidity within the area is among the lowest value (60% - 85%) from November to March. At the hours of 05:00am and 07:00am relative humidity is maximum and lowest between 15:00 and 16:00 hours. Between 05:00 hours and 07:00 hours it is about 75% - 100% and decreases to between 70% and 80% during the time of maximum temperature. Evapo-transpiration ranges between 1350mm – 1450mm per year. Daily evapo-transpiration rates are higher during dry season ranging from 3.5mm in June/July and 4.2mm in February (Atlas map of Imo State, 1984).

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

1. Water sample
2. Plastic container
3. Co-ordinates of sample points and Elevation
4. Topographic Map of the study area.
5. Geologic Map of the study area.
6. GPS (Global positional system)
7. Litholog of some Boreholes.
8. Map maker(used in Digitalizing the map)
9. Rockware aqqa (used for contouring)

3.2 DESK STUDY

The desk study includes analyses and interpretation of data that are relevant to the study. Such data includes topographical maps, geologic maps, lithologic maps, water quality data, and published reports. The studied data gave vital information like geologic Formation of the area, hydrologic information, physiography of the area, and as well as drainage features. The lithology of the area was obtained from studies of four borehole data. The borehole information is as presented in Tables 3.1, 3.2, 3.3, and 3.4.

Table 3.1: Litho – log of Borehole at Umuezeobolo, Amaigbo

Depth (m)	Lithology	Description
0 – 20	🟫	Reddish- brown medium – coarse texture. laterite/lateritic sand.
20 – 40	⬜	Whitish and medium texture sand.
40 –50	⬛	Lignite.
50 - 60	⬛	Medium textured sand-lignite.
60 –70	🟩	Fine texturedsand/clay.
70 –80	🟩	Light grey fine – medium texture. Clay/sand.
80 –100	⬜	Whitish Medium textured Sand.
100 –120	🟩	Grey fine textured. Clay

Table 3.2: Litho – Log of Borehole at Umudugba.

Depth (m)	Lithology	Description
0 – 25	🟥	Reddish medium textured laterite/lateritic sand.
25 – 40	⬜	Whitish medium texturedSand.
40 – 50		Milky white fine textured Clay
50 – 65	⬜	Whitish medium textured Sand.
65 – 70	🟩	Grey fine textured Clay.
70 – 85		Milky white coloured with medium texture. Grit to touch. Sand.
85 – 90	🟨	Cream white fine – medium textured Claysand.
90 – 105	⬜	Whitish and medium textured Sand.

Table 3.3: Litho – log of Borehole at Nkwerre.

Depth(m)		Description
0 – 15	🟫	Brownish – red medium to coarse textured Lateritic sand/iron stone.
15 – 25	🟧	Light brownish medium to coarse textured Sand.
25 –30	🟩	Dark grey fine textured Clay/lignite.
30 – 35	🟩	Light grey Medium textured Sand.
35 – 40	⬛	Blackish fine textured Lignite/clay.
40 – 50	⬜	Dirty white medium textured Sand/sandstone.

Table 3.4: Litho – log of Borehole at Agbaja market in Nwangele, Imo State.

Depth (m)	Lithology	Description
0 – 20	🟫	Reddish- brown medium textured lateritic sand.
20 – 40	🟨	Yellowish medium textured sand.
40 – 45	⬛	Lignite.
45 – 50	🟩	Blackish-grey fine textured Clay/lignite.
50 – 65	⬜	Dirty white medium textured Sand
65 – 70	⬛	Lignite.
70 – 80	🟩	Grey fine texturedClayey shale.
80 – 100	⬜	Whitish medium textured sandy/clay

3.3 WATER SAMPLE COLLECTION

Water samples for analyses were collected carefully to ensure that the most representative sample is obtained. Water samples were collected as indicated in Fig. 3.1 at specified points on the map. This was to make sure that there was an even coverage of the area under study.

Clean containers (plastic bottles) were used for collecting the samples. The bottles were washed with soap solution, rinsed with tap water and 1:1 hydrochloric acid solution. This was allowed to stay in the bottle for six hours with the rotating of the bottle after every 30 minutes. The bottles were thereafter rinsed with distilled water and dried.

A total of twelve (12) water samples was collected, one (1) from Hand dug well in Umudi, one (1) from spring water at Umutakwo and ten (10) from Borehole at different locations as represented in Fig. 3.1. Samples were taken as closely as possible to the source of the supply to minimize the effect of contamination. While collecting from the borehole, the pump was allowed to run for some time to deliver water representative of the groundwater feeding the well and not the one in the well casing. Litholog of four boreholes in the study area were also collected.

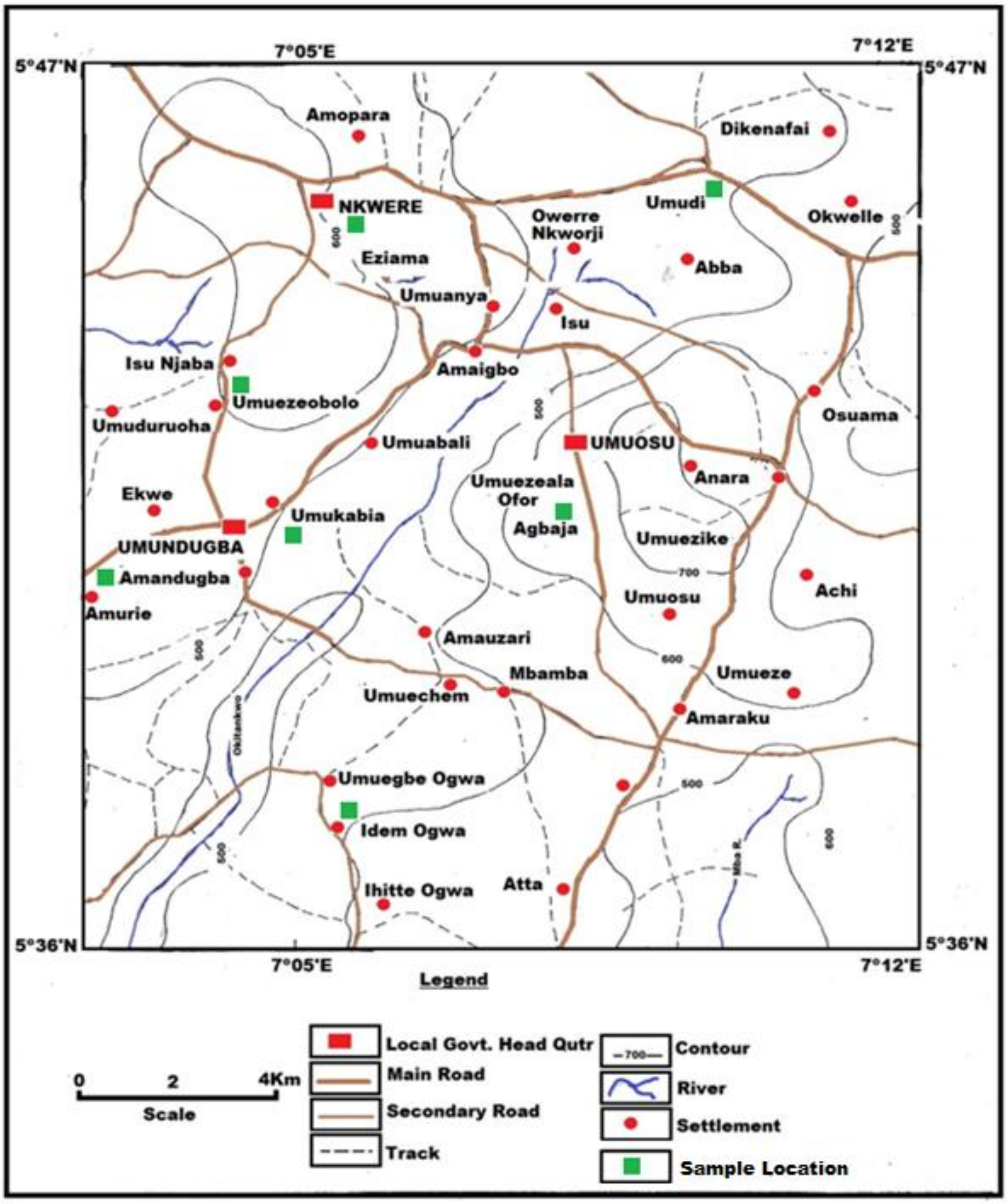


Fig.3.1.Topographic map of the study area showing sample location

3.4 METHODS OF SAMPLE ANALYSIS

The analysis of the water samples for chemical parameters and characteristics was carried out using three (3) major laboratory methods. They include:

i) Atomic Absorption Spectrometry method.
ii) Calorimetric/Photometric method.
iii) Titrimetric method.

3.4.1 Atomic Absorption Spectrometry Method

This method was used to carry out analysis using the UNICAM 919 Atomic Absorption Spectrophotometer, AAS. The parameters or elements that were detected using this method include lead (Pb), Calcium (Ca), Magnessium (Mg), Iron (Fe), Sodium (Na), and Potassium (K).

The standard for each element that was determined was aspirated into the nebulizer-burner assembly with the hollow cathode lamp of the desired element in place. Absorbance readings were obtained for the standards at the resonance wavelength of the element. The water samples were in turn aspirated into the nebulizer – burner assembly and using the appropriate hollow cathode lamp and the corresponding wavelength. The absorbance readings of the sample solutions for the analyses were also obtained.

The concentration of each element was obtained by extrapolation from the standard curve. The resonance wavelengths used for the different elements detected are as follows:

Lead (Pb) ……………………………………………….217nm

Sodium (Na) ……………………………………………589.0nm

Potassium (K) ………………………………………….766.5nm

Magnesium (Mg) ……………………………………...285.2nm

Calcium (Ca) …………………………………………..422.7nm

Iron (Fe) ……………………………………………………248.3nm

3.4.2 Colorimetric/Photometric Method

An HACH DREL/5 model spectrophotometer was used for this method of analysis. This spectrophotometer is designed for25ml sample volume. The parameters/elements that were detected using this method are: Sulphate ($SO^{2-}{}_{3}$), Nitrate (NO_3^-), and Total dissolved solid (TDS).

The HACH DREL/5 spectrophotometer has five (5) basic components that are integrated together. There is a stable source of radiant energy, a wavelength selector that allows a wavelength region, a sample cell holder, a radiant detector that convert radiant energy to usable signal and a signal processor (photo cell) with the analogue read-out.

The principle of operation of the spectrophotometer is based on the intensity of colour solution obtained by the appropriate chemical treatment of the sample. When a pre-treated sample is irradiated with a beam of radiant energy of specific wavelength through the light path, an amount of energy is absorbed which is seen as transmitted colour complement of the light absorbed. The detector converts the transmitted energy into usable signals. The signal is then processed by a signal processor (photocell) and shown in the analogue readout as mg/l of the element present in the sample.

For the colorimetric analysis to be correct, the instrument has to be set up in the following basic steps: (i) Installing the slide in meter scale. (ii) Selecting the wavelength. (iii) Selecting the normal or expanded range, and standardizing the instrument. The instrument can be standardized by the use of a standardizing solution which in most cases is a portion of the untreated sample. The only exception is in nitrate determination. The essence of this is to eliminate the effect of natural colour or turbidity in the sample.

3.4.3 Titrimetric Method

The parameters that are determined using the titrimetric method include: Chloride (CL), Bicarbonate (HCO_3), Total hardness. The two methods used in analyzing samples in titrimetric method are digital and burette titration.

The principle of operation involved the determination of the volume of a standard solution that will be required to react with the substance that is determined in sample. This is achieved by adding a suitable colour indicator to the buffered sample usually 50ml for burette titration and 100ml for digital titration.

In burette titration, titrating a sample with a suitable titrant to a colour or end point marks the end of the reaction. The adding of the buffer is to adjust the PH of the solution depending on the element to be determined.

The digital titration provides a precise digital readout with accuracy rating of ± 1%. The digit corresponding to sample concentration in mg/l appears in a counter window.

3.5 MODEL PLOTS FOR DATA ANALYSIS

3.5.1 Piper Diagram

This is a graphical representation of the chemistry of a water sample or samples (Piper, 1953). The cations and anions are shown by separate ternary plots. The apexes of the cation plot are calcium, magnesium and sodium plus potassiumCations. The apexes of the anion plot are sulfate, chloride and carbonate plus bicarbonate anions. Concentrations are expressed as %meq/L. The Piper diagram shows regional mixing trends. Its fields show localized well-defined regional and sub-regional mixing trends and important end-member compositions.

A piper plot is a way of visualizing the chemistry of a rock, soil, or water sample. It's comprises three pieces: a ternary diagram in the lower left representing the cations, a ternary diagram in the lower right representing the anions, and a diamond plot in the middle representing a combination of the two. To plot, take the normalized concentrations of each of your three cations for a sample and plot them on the lower left ternary diagram, using the colored axes as guides. Repeat for your anions on the lower right ternary diagram. Now, following a line parallel to the outer axis of each ternary diagram, project each point in the ternary diagrams upward until they intersect with one another in the diamond plot. This is where you draw the third point. These three points represent one sample. Repeat for your other samples or plot with the average concentration in percentage.

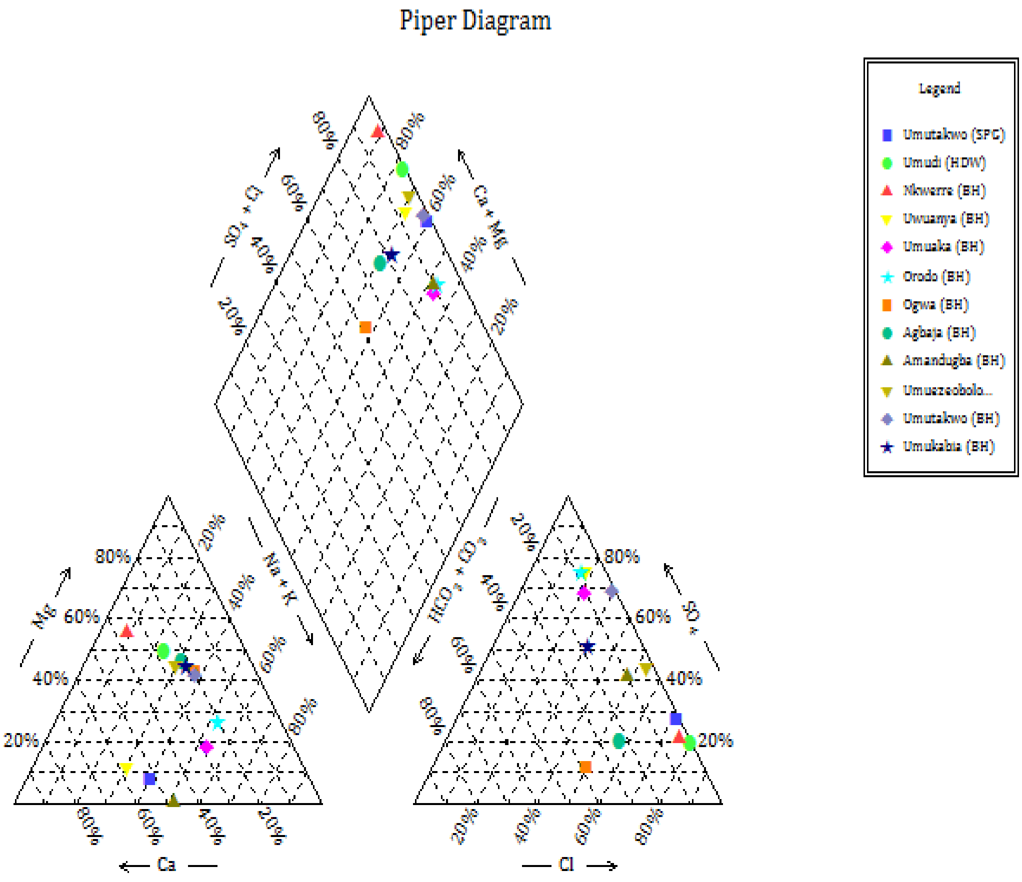


Fig. 3.2. Piper Trilinear Plot of the Studied Water Samples.

3.5.2Durov Diagram

The Durov diagram is a composite plot consisting of 2 ternary diagrams where the cations of interest are plotted against the anions of interest (data is normalized to 100%); sides form a binary plot of total cation vs. total anion concentrations (this plot can be contoured); expanded version includes TDS (mg/L) and pH data added to the sides of the binary plot to allow further comparisons. The plot makes use of more parameters in comparison to express the water chemistry by making use of Primary: Cations (i.e. Na + K, Ca and Mg) and Anions (i.e. Cl, HCO_3 and SO_4), and total cations vs. total anions only. The application/use of the durove is to graphically illustrate cation/anion concentrations, relative to TDS and pH.

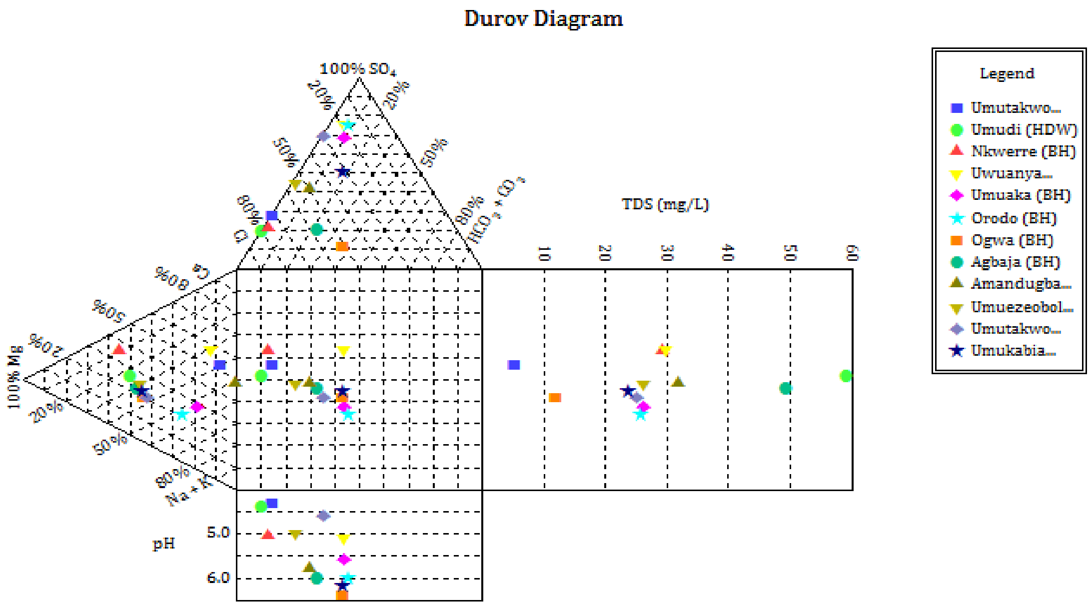


Fig. 3.3.Durov Diagram for Studied Water Samples.

3.5.3Schoeller Diagram

This is a semi-logarithmic diagram of the concentrations of the main ionic constituents in water (SO_4, HCO_3, Cl, Mg, Ca, Na/K) in equivalents per million per kg of solution (mEq/kg).The diagram gives absolute concentration, but the line also gives the ratio between two ions in the same sample (Schoeller, 1977). If a line joining two points representing ionic concentrations in a single sample is parallel to another line joining a second set of concentrations from another sample, the ratio of those ions in those samples are equal.

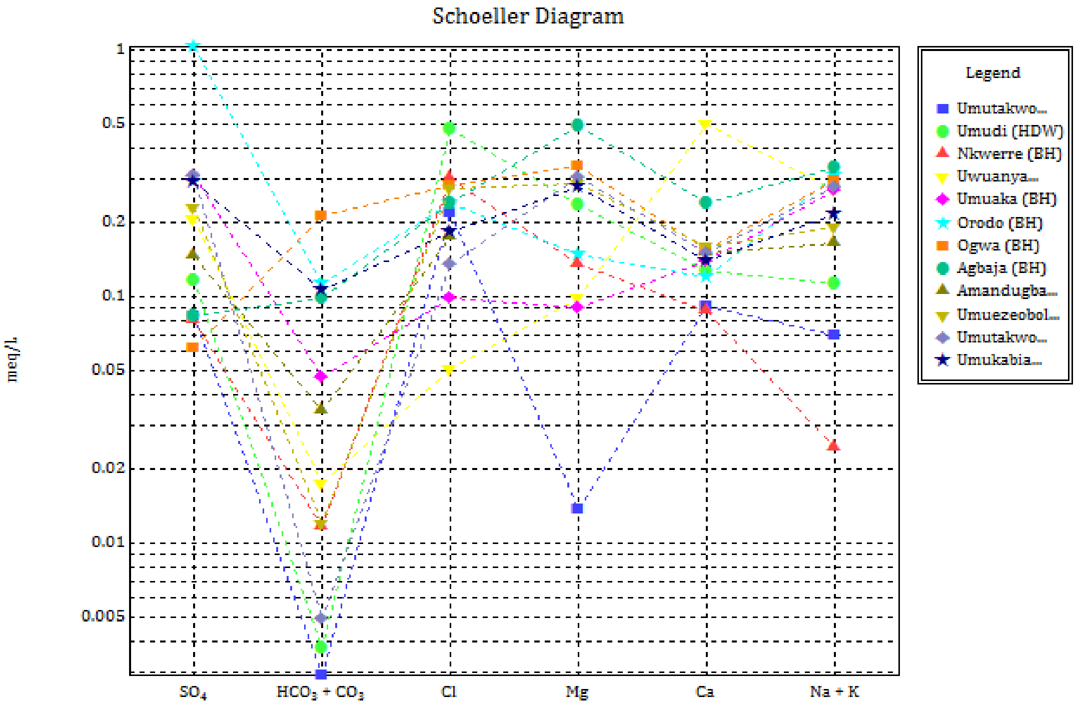
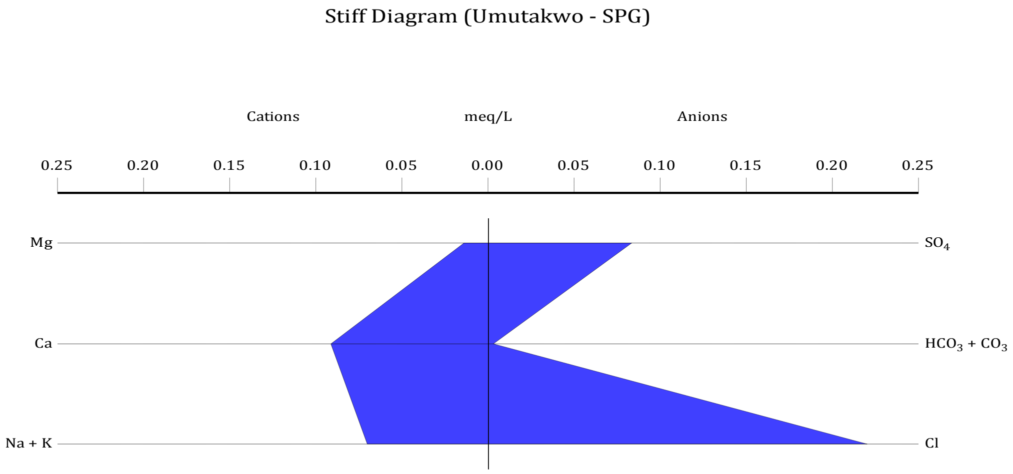


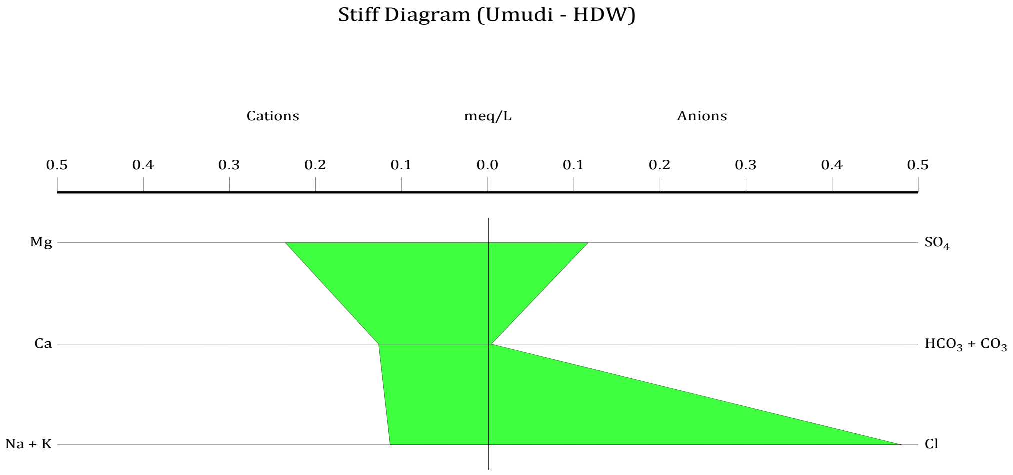
Fig. 3.4.Schoeller Diagram for Studied Water Samples.

3.5.4 Stiff Diagram

Stiff diagrams are graphical representation of water chemical analyses, whereby Cations are plotted in milliequivalent per liter on the left side of the zero axes, one to each horizontal axis, and anionsare plotted on the right side. Stiff patterns are useful in making a rapid visual comparison between water from different sources (Stiff, 1954).

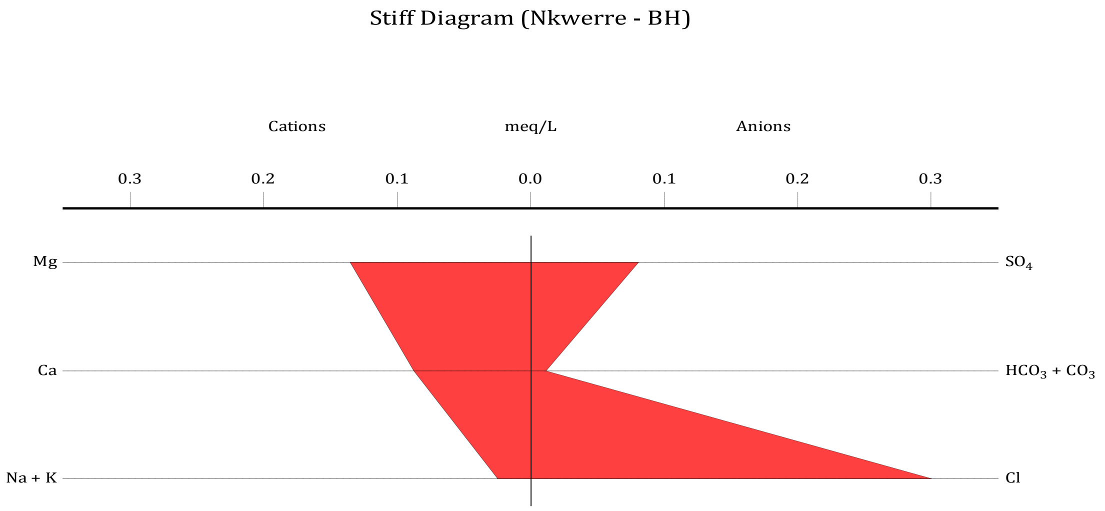


(a)Stiff Diagram for Water Sample Umutakwo-SPG

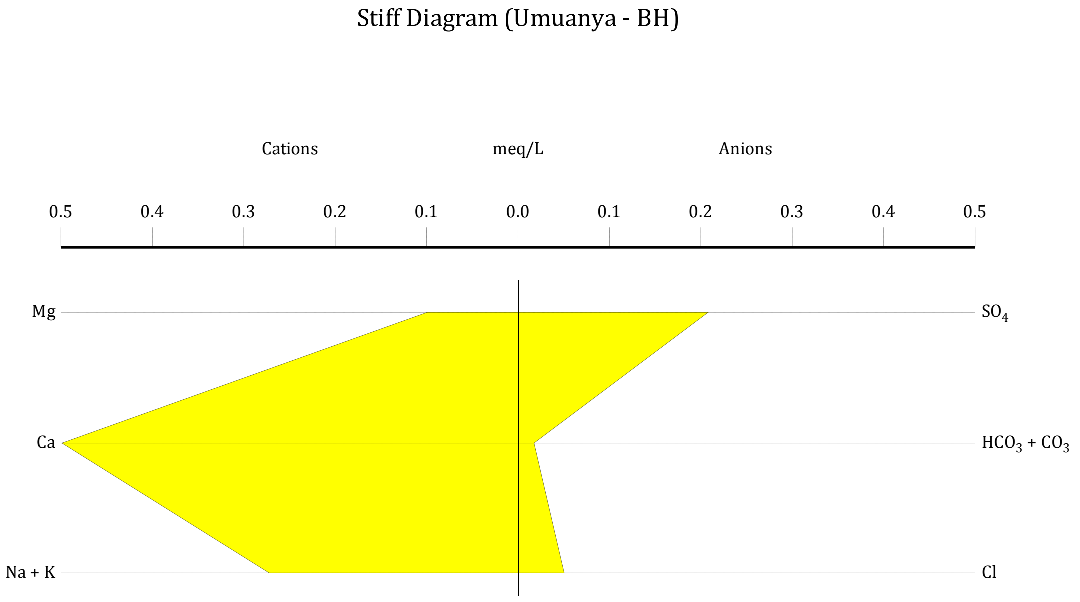


(b) Stiff Diagram for water Sample at Umudi-HDW

Fig. 3.5.Stiff Diagram for water Sample at Umudi-HDW and Umutakwo-SPG

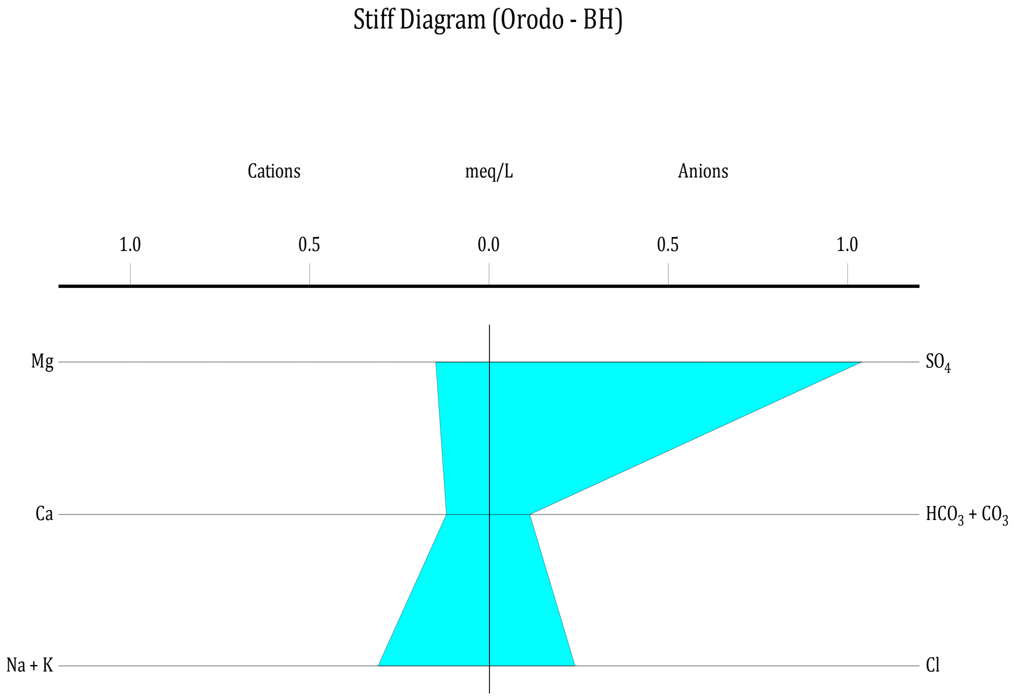


(a) Stiff Diagram for Water Sample at Nkwerre-BH.

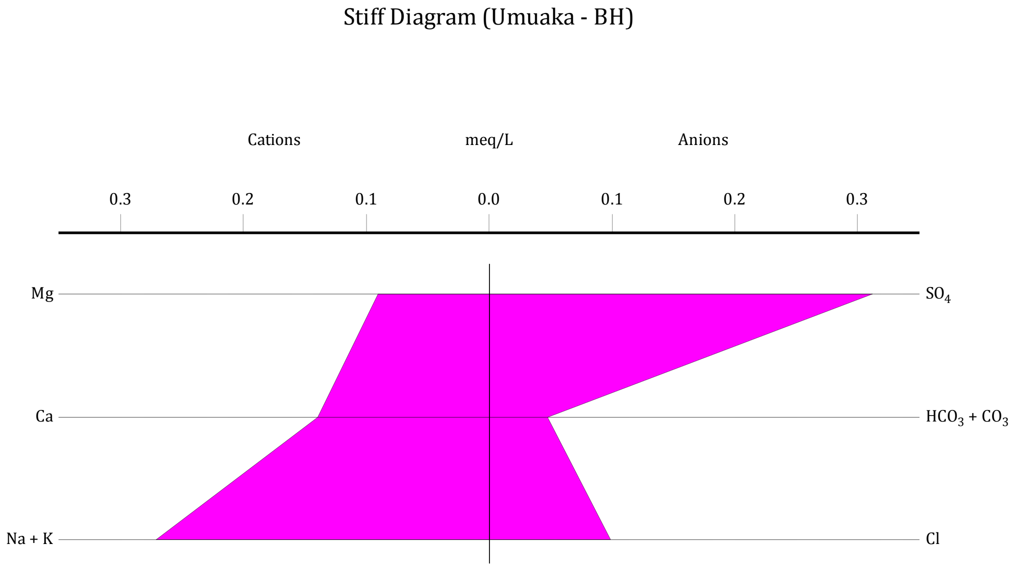


(b) Stiff Diagram for Water Sample at Umuanya-BH

Fig.3.6. Stiff Diagram for Water Sample at Nkwerre-BH and Umuanya-BH

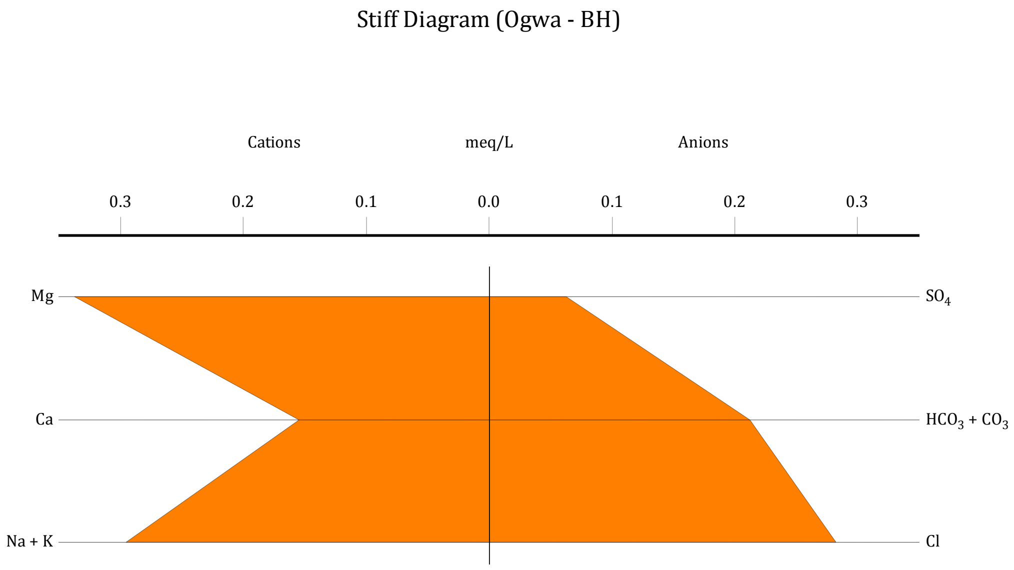


(a) Stiff Diagram for Water Sample at Orodo BH

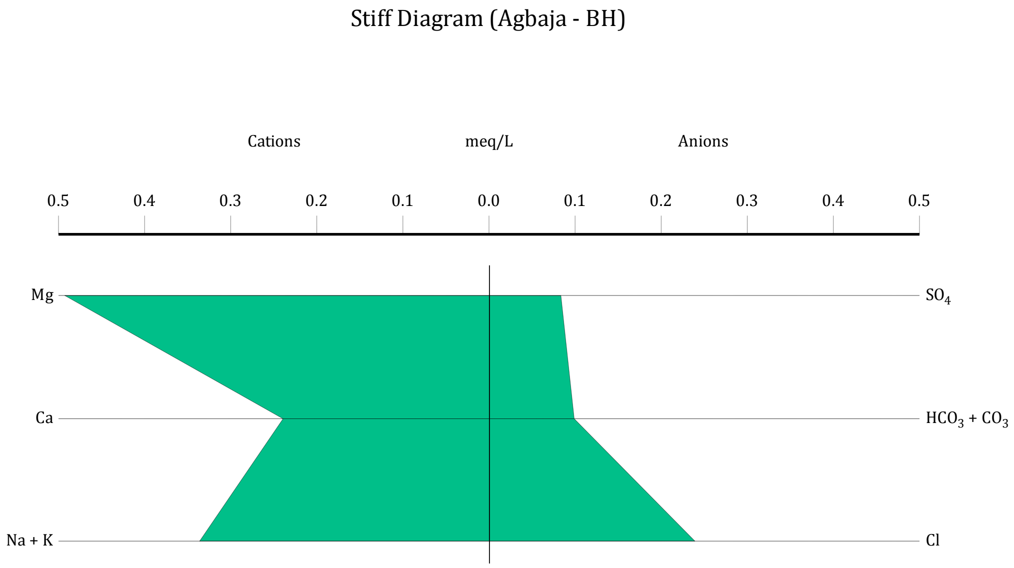


(b) Stiff Diagram for water sample Umuaka-BH

Fig: 3.7. Stiff Diagram for Water Sample at Orodo BH and Umuaka-BH

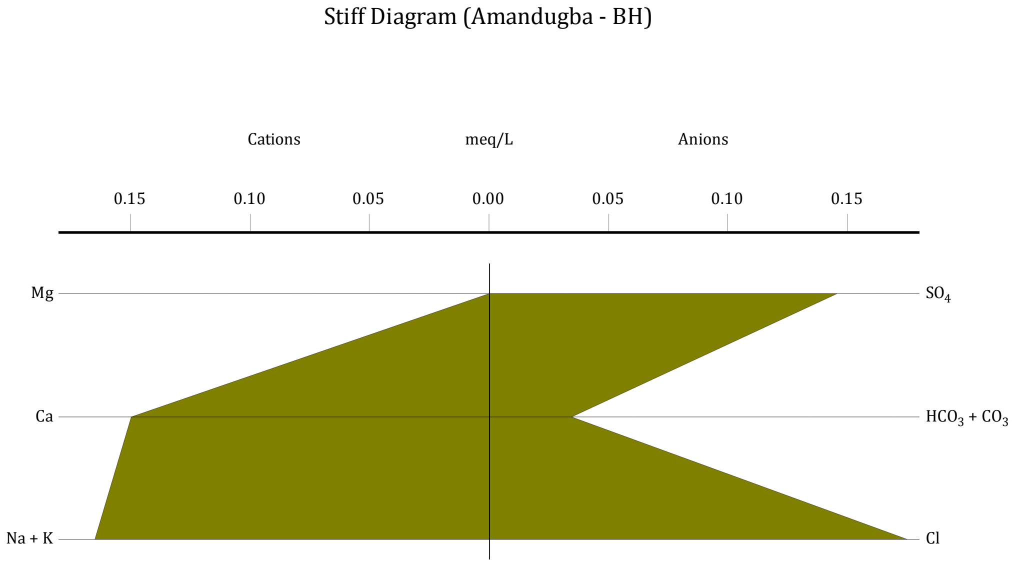


(a) Stiff Diagram for Water Sample at Ogwa-BH

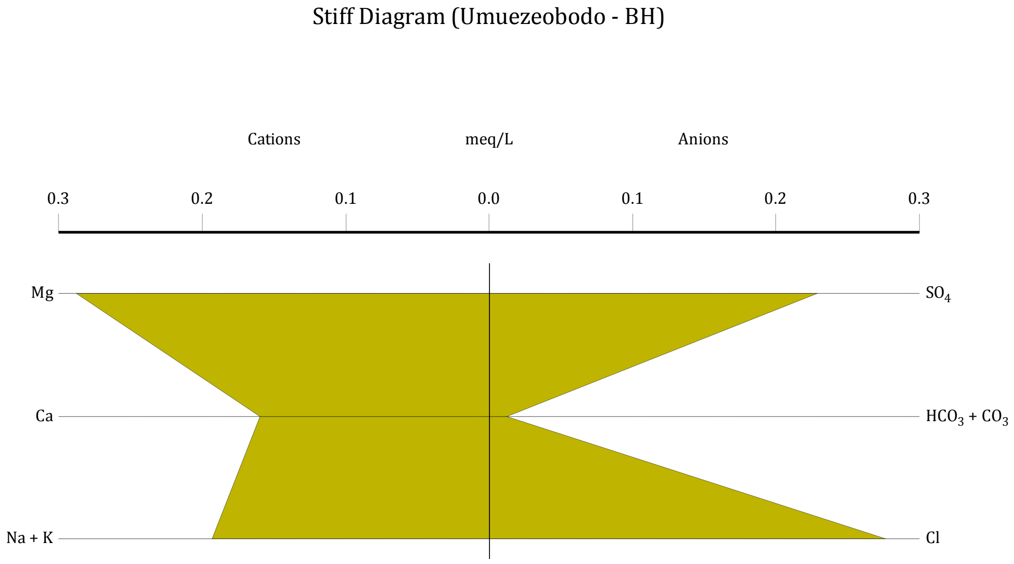


(b) Stiff Diagram for Water Sample at Agbaja-BH

Fig.3.8. Stiff Diagram for Water Sample at Ogwa-BH and Agbaja-BH

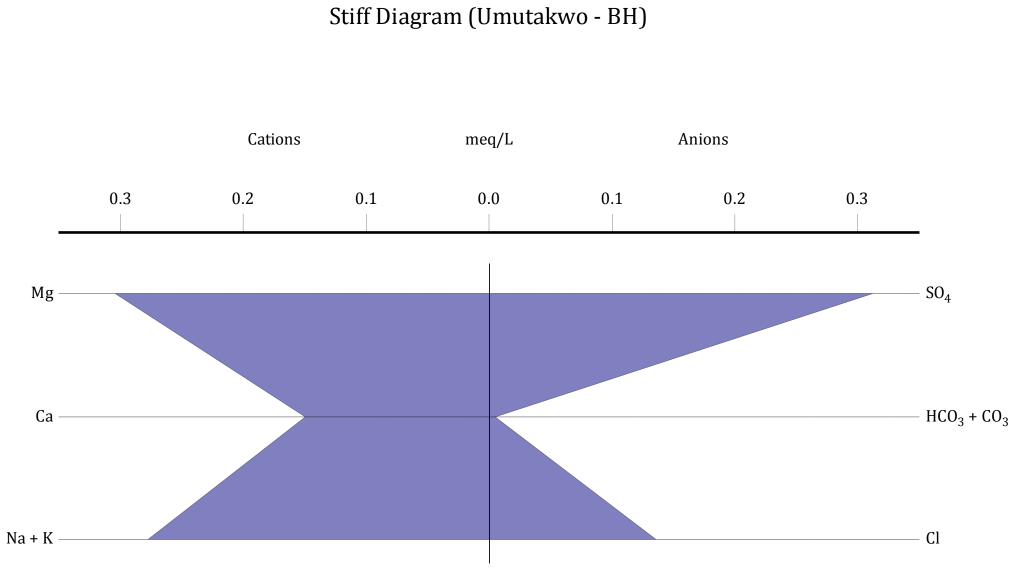


(a) Stiff Diagram for Water Sample at Amandugba-BH

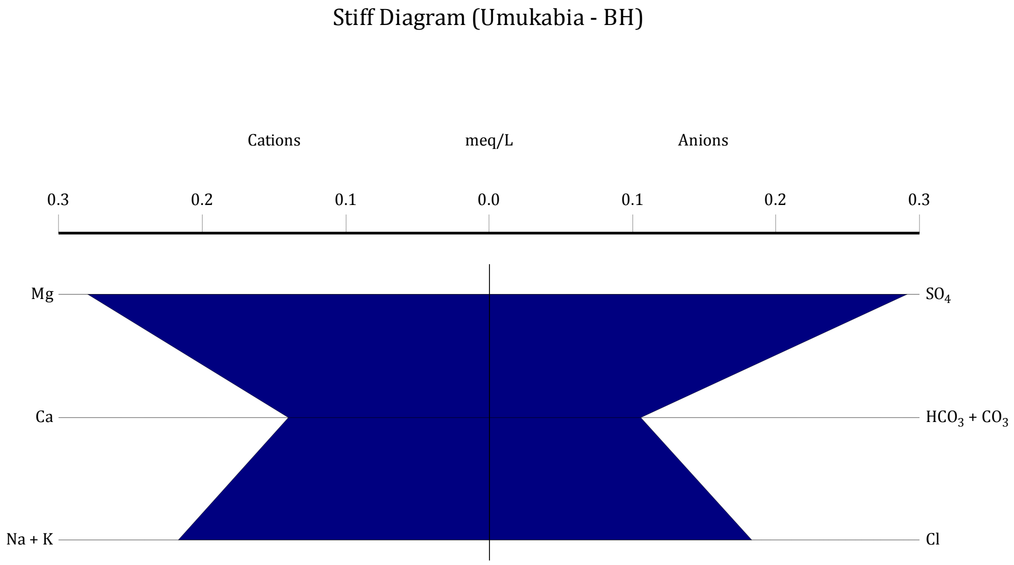


(a) Stiff Diagram for Water Sample at Umuezeobolo-BH

Fig. 3.9. Stiff Diagram for Water Sample at Amandugba-BH and Umuezeobolo-BH



(a) Stiff Diagram for Water Sample at Umutakwo-BH



(b) Stiff Diagram for Water Sample at Umukabia-BH

Fig. 3.10. Stiff Diagram for Water Sample at Umutakwo-BH and Umukabia-BH

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS PRESENTATION

The result of the geochemical analysis is shown in Table 4.1.

The average values of the major anions and cations in milliequivalent per litre were used to prepare a Piper plot. The average concentrations were converted to meq/l using the formula in (Table 4.2)

Table 4.1: RESULT OFTHEGEOCHEMICAL ANALYSIS OF WATER SAMPLE FROM THE STUDY AREA

SAMPLE & LOCATION	Pb (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Na (mg/l)	K (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	CL^- (mg/l)	HCO_3 (mg/l)	PH	TDS (mg/l)	Total Hardness As $CaCO_3$S(mg/l)
SPG H_2O at Umutakwo	ND	1.83	0.167	ND	1.50	0.20	4.0	0.012	7.81	20.25	4.32	5.4	5.00
HDW H_2O at Umudi	ND	2.54	2.856	0.250	2.375	0.40	5.6	0.100	17.04	22.25	4.39	59.3	13.50
BH H_2O at Nkwerre	ND	1.756	1.644	ND	0.50	0.10	3.87	ND	10.65	15.39	5.06	29.4	8.50
BH H_2O at Uwuanya	ND	10.0	1.20	0.280	5.9	0.6	10.0	9.4	1.80	21.0	5.1	30.0	15.0
BH H_2O at Umuaka	ND	2.8	1.10	0.19	6.0	0.4	15.0	Trace	3.5	20.0	5.6	26.4	3.0
BH H_2O at Orodo	ND	2.4	1.8	0.10	6.8	0.5	50.0	5.07	8.5	23.0	6.0	25.9	5.0
BH H_2O at Ogwa	ND	3.1	4.1	0.04	6.5	0.5	3.0	1.10	10.0	25.0	6.4	12.0	25
BH H_2O at Agbaja	ND	4.8	6.0	0.18	7.5	0.4	4.0	2.30	8.5	20.0	6.0	49.5	11
BH H_2O at Amandugba	ND	3.0	ND	1.81	3.5	0.5	7.0	Trace	6.2	10	5.8	31.9	3.5
BH H_2O at Umuezeobolo	ND	3.2	3.5	0.81	4.2	0.4	11.0	Trace	9.8	18	5.0	26.4	7.0
BH H_2O at Umutakwo	ND	3.0	3.7	0.16	6.2	0.3	15.0	ND	4.8	18	4.6	25.3	7.1
BH H_2O at Umukabia	ND	2.8	3.4	0.15	4.8	0.3	14.0	Trace	6.5	16.0	6.2	23.7	7.0
Average		3.44	2.46	0.33	4.64	0.38	11.87	1.50	7.92	19.07	5.37	28.77	9.22
WHO(2006)	0.05	200	150	0.3	500	50	400	40-70	500	500	6.5-9	1500	<150

ND= Not Detected, BH= Borehole, SPG = Spring, HDW = Hand dug well.

Table4.2: Average Concentration ofthe Constituents (Meq/L)

LOCATION/SAMPLE	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	$Cl^- + NO_3^-$	SO_4^{2-}	HCO_3^-	SAR
SPG WATER UMUTAKWO	0.09	0.014	0.07	0.22	0.08	0.33	0.29
HDW WATER UMUDI	0.13	0.24	0.11	0.48	0.12	0.36	0.24
BH WATER NKWERRE	0.09	0.14	0.02	0.30	0.08	0.25	0.06
BH WATER UMUANYA	0.5	0.10	0.28	0.20	0.21	0.34	0.47
BH WATER UMUAKA	0.14	0.09	0.27	0.10	0.31	0.33	0.77
BH WATER ORODO	0.12	0.15	0.31	0.32	1.04	0.38	0.81
BH WATER OGWA	0.16	0.34	0.30	0.30	0.06	0.41	0.57
BH WATER AGBAJA	0.24	0.50	0.34	0.28	0.08	0.33	0.50
BH WATER AMANDUGBA	0.15	-	0.16	0.17	0.15	0.16	0.60
BH WATER UMUEZEOBOLO	0.16	0.30	0.19	0.28	0.23	0.30	0.38
BH WATER UMUTAKWO	0.15	0.31	0.28	0.14	0.31	0.30	0.60
BH WATER UMUKABIA	0.14	0.28	0.22	0.18	0.30	0.26	0.46
TOTAL	2.07	2.46	2.56	2.97	2.67	3.75	5.75
AVERAGE	0.17	0.21	0.20	0.25	0.22	0.31	0.48
% EPM	29	36	34	32	28	40	

$$Meg/L = \frac{Mg/L}{Equivalentmass}$$

4.1.1 Spatial Variation Maps of the Parameters Analyzed In the Study Area

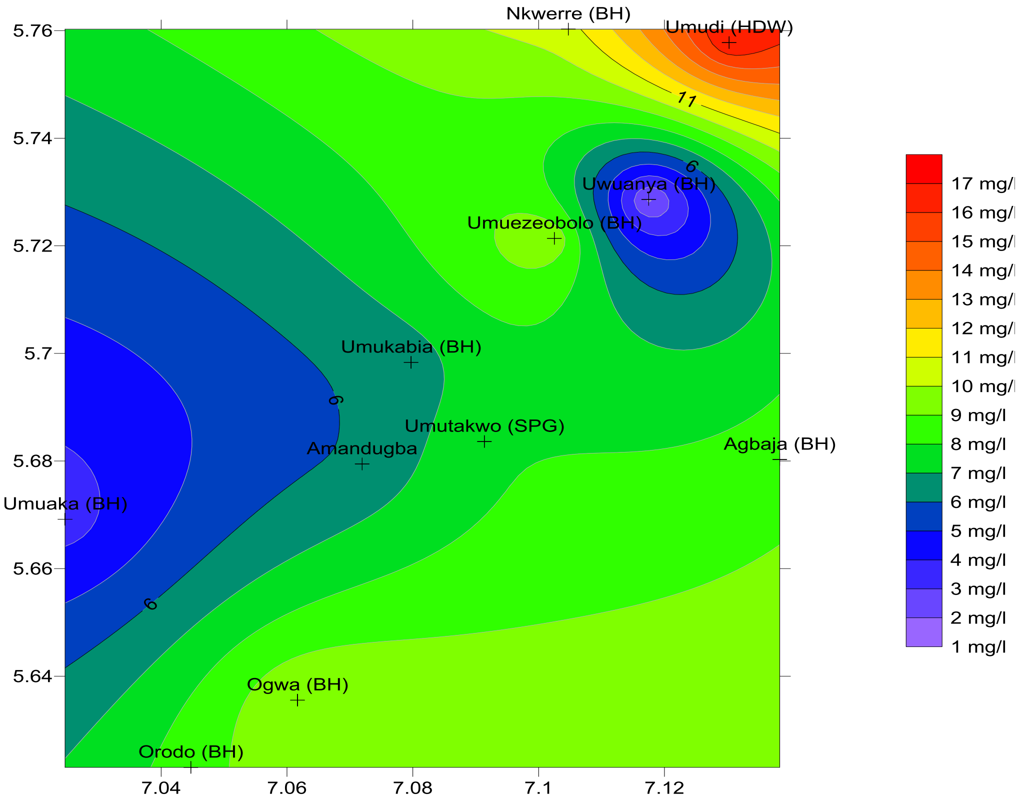
Elevations and co-ordinates of sample points collected used for plotting spatial variation maps of the parameters are presented in Table 4.3

Figs.4.1 to 4.11shows the variation mapsof individual distribution of the concentration of the parameters analyzed. They also display the direction of decrease or increase of the parameters. For example, chloride concentration is lowest (1-6mg/l) towards the west and the north-east (Fig. 4.1). Figure 4.3 shows that bicarbonate concentration is highest (22-25mg/l) in the southern area and part of the extreme west of the study area. In the case of Magnesium, the concentration is highest (4.2 – 5.8mg/l) in the southeastern area while the least values of 0.2-1.8mg/l occur in the western/northern zones. TDS concentration is highest (40 -60mg/l) in the northeast/east, and least in the central/southern area (4-24mg/l).

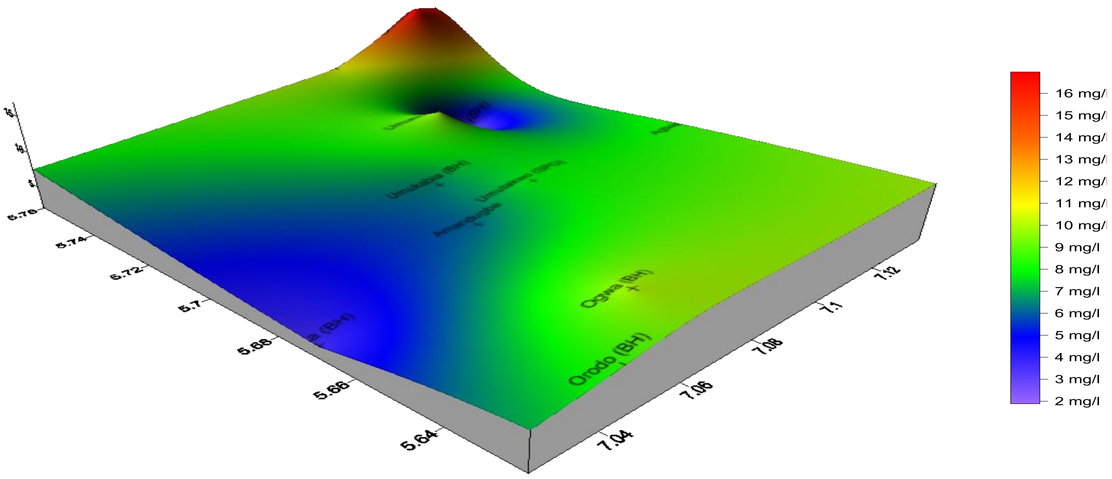
The variations in concentrations of the ions can possibly be accounted for using Chebotarev Sequence of groundwater geochemical evolution as well as anion/cation exchange processes.

Table 4.3: Elevations and Co-Ordinates of Points of Sample Collection

LOCATION	ELEVATION (m)	LATITUDES	LONGITUDES
UMUDI	167	5^{0}45’28”	7^{0}7’49”
NKWERRE	170	5^{0}45’37”	7^{0}6’17”
UMUANYA	160	5^{0}43’43”	7^{0}7’3”
UMUAKA	126	5^{0}40’9”	7^{0}1’29”
ORODO	135	5^{0}37’23”	7^{0}2’41”
OGWA	117	5^{0}38’8”	7^{0}3’42”
AGBAJA	196	5^{0}40’49”	7^{0}8’18”
AMANDUGBA	157	5^{0}40’46”	7^{0}4’19”
UMUEZEOBOLO	187	5^{0}43’17”	7^{0}6’9”
UMUTAKWO (SPG)	130	5^{0}41’1”	7^{0}5’29”
UMUTAKWO OBODO	133	5^{0}4’18”	7^{0}5’23”
UMUKABIA	156	5^{0}41’54”	7^{0}4’47”

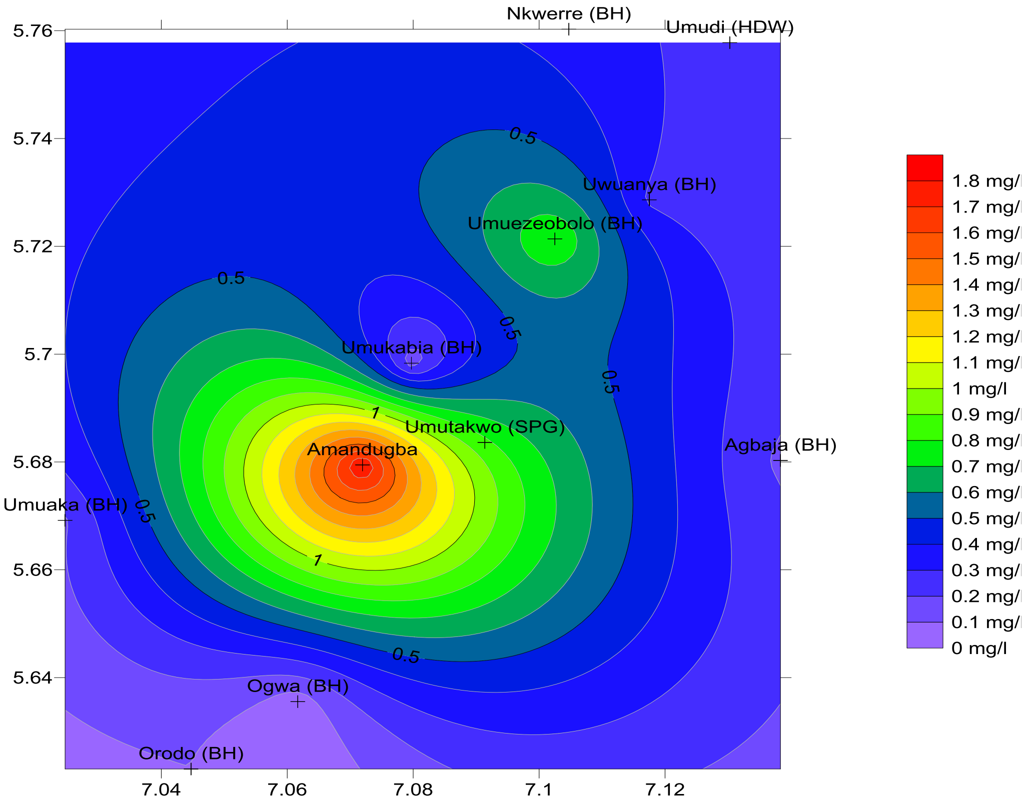


(a)Plain View

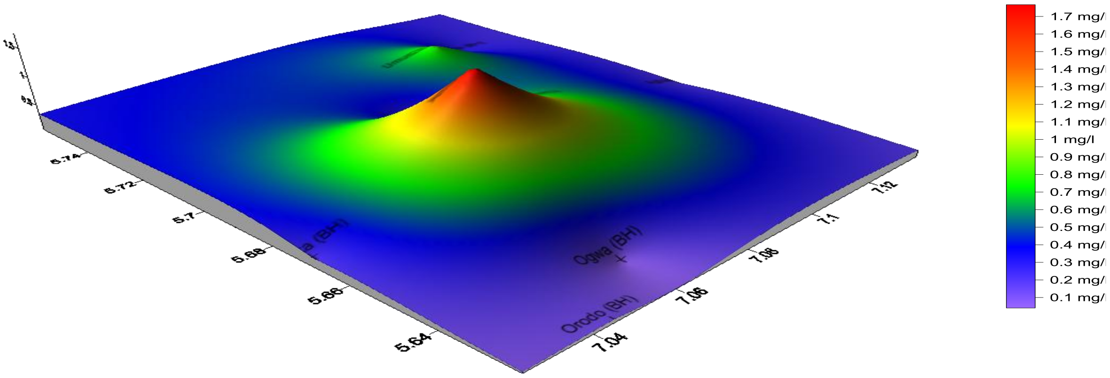


(b)3-D View

Fig. 4.1 Spatial variation Map of Chloride Concentration in the Study area.

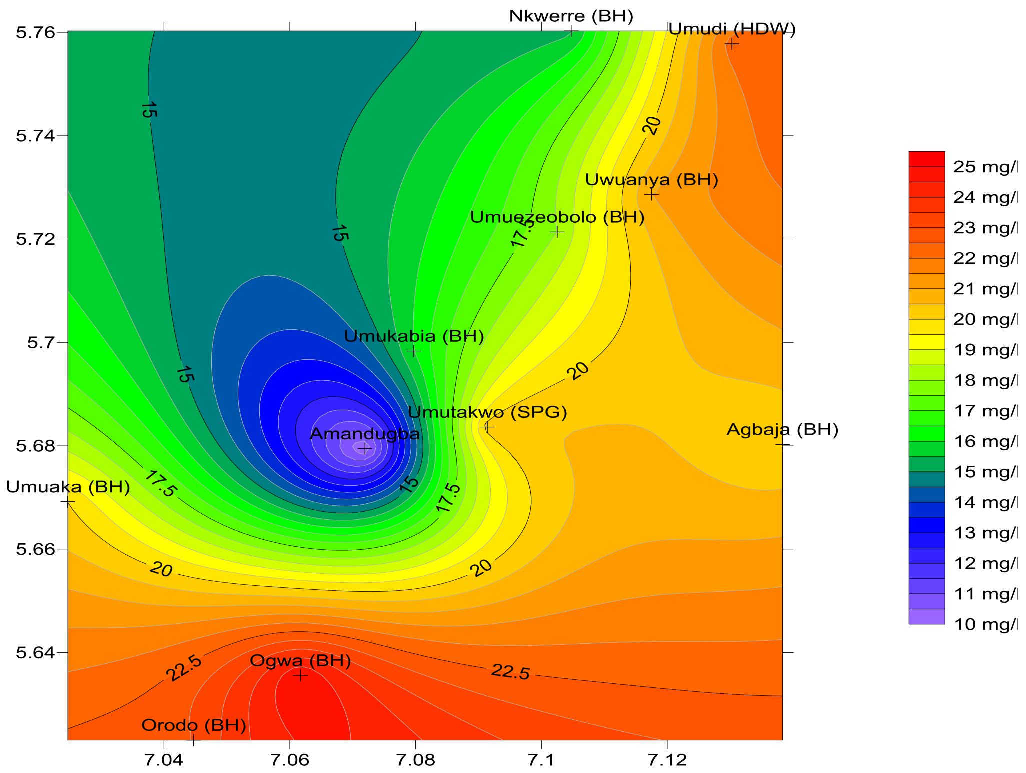


(a)Plain View

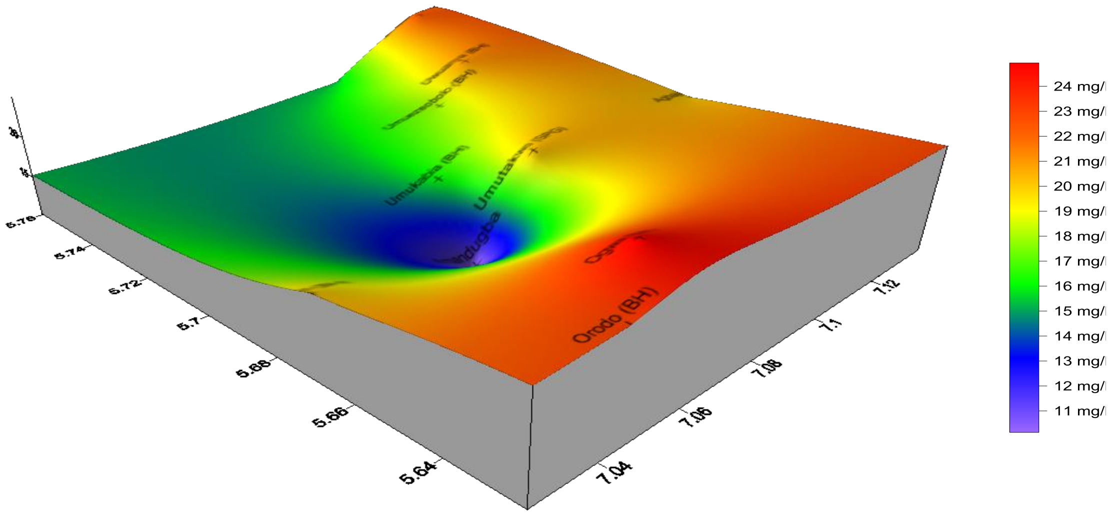


(b)3-D view

Fig. 4.2.Spatial Variation Map of Iron concentration in the study area.

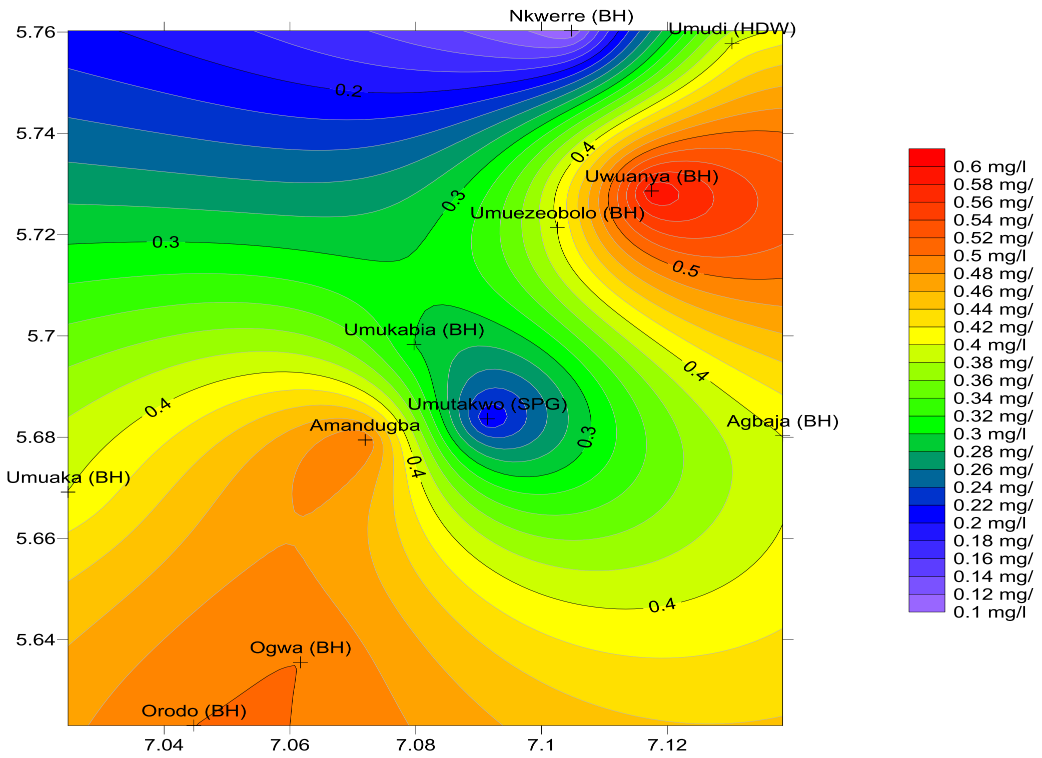


(a)Plain View

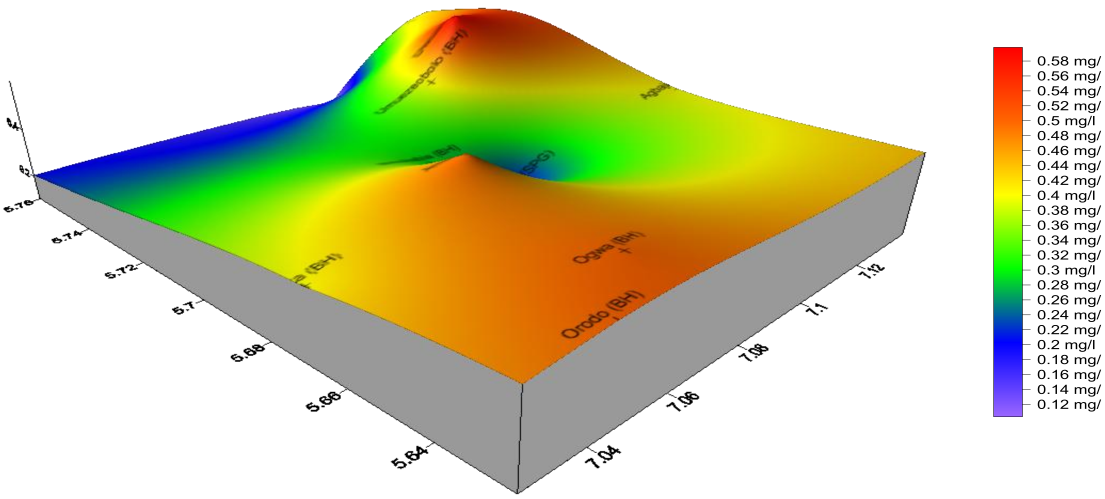


(b)3-D View

Fig. 4.3.Spatial Variation Map of Bicarbonate Concentration in the study area.

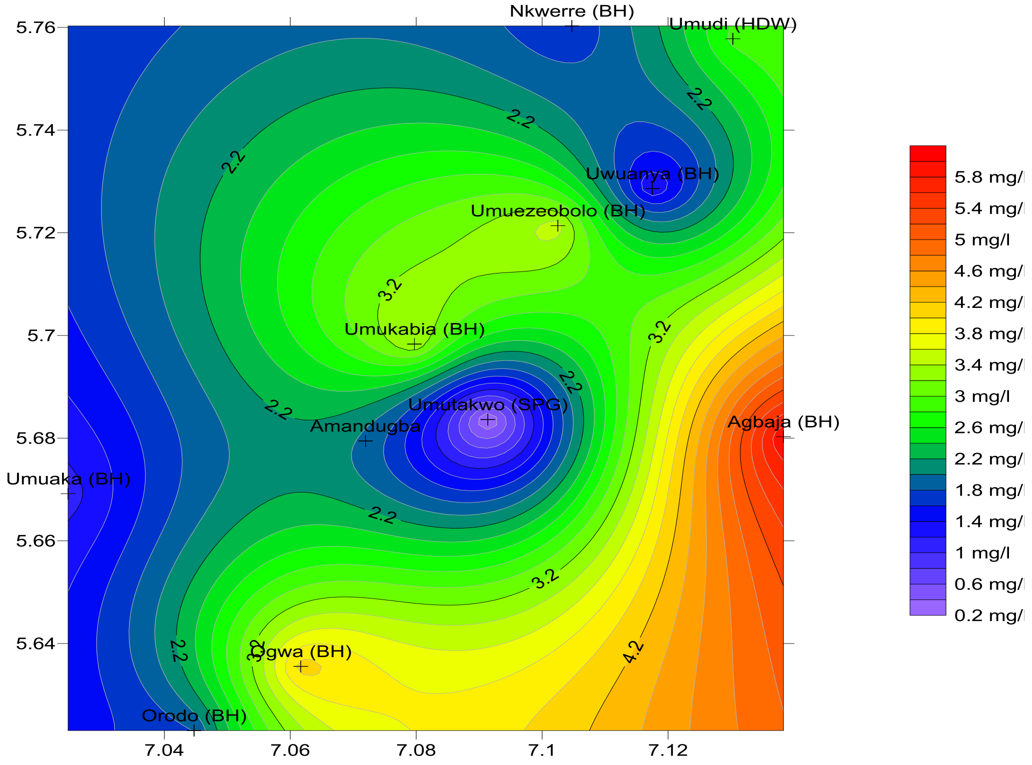


(a)Plain View

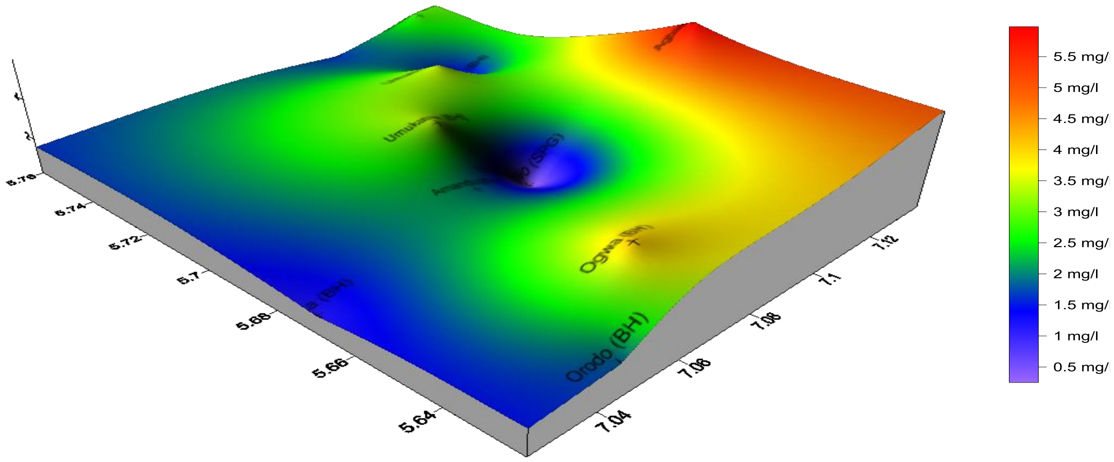


(b)3-D View

Fig. 4.4.Spatial Variation Map of Potassium Concentration in the study area.

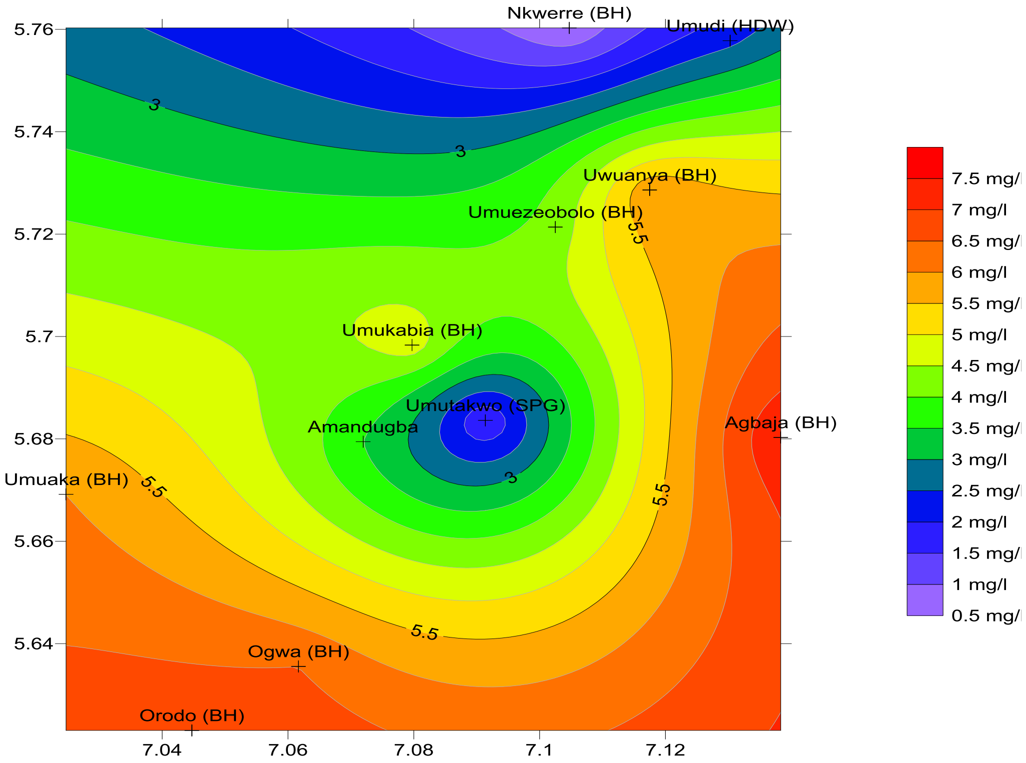


(a)Plain View

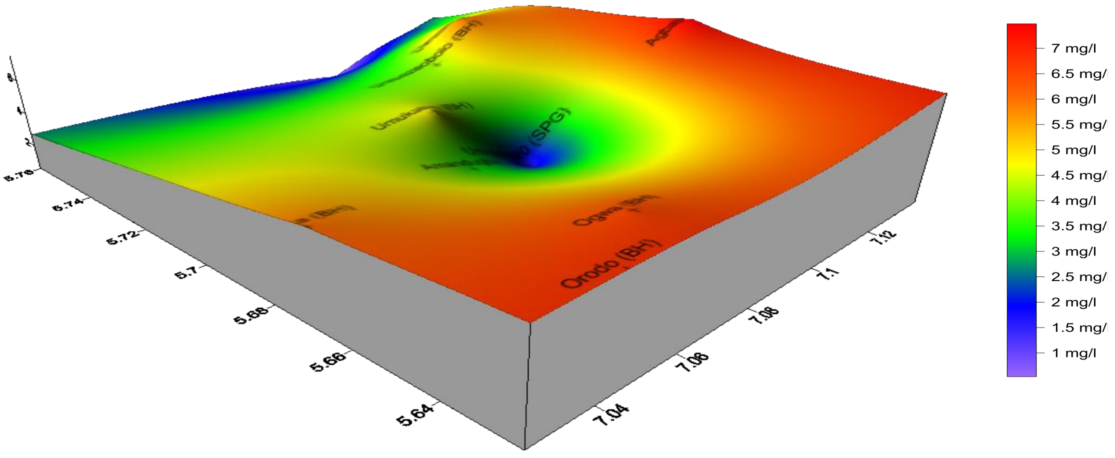


(a)3-D View

Fig. 4.5. Spatial Variation Map of Magnesium Concentration in study area.

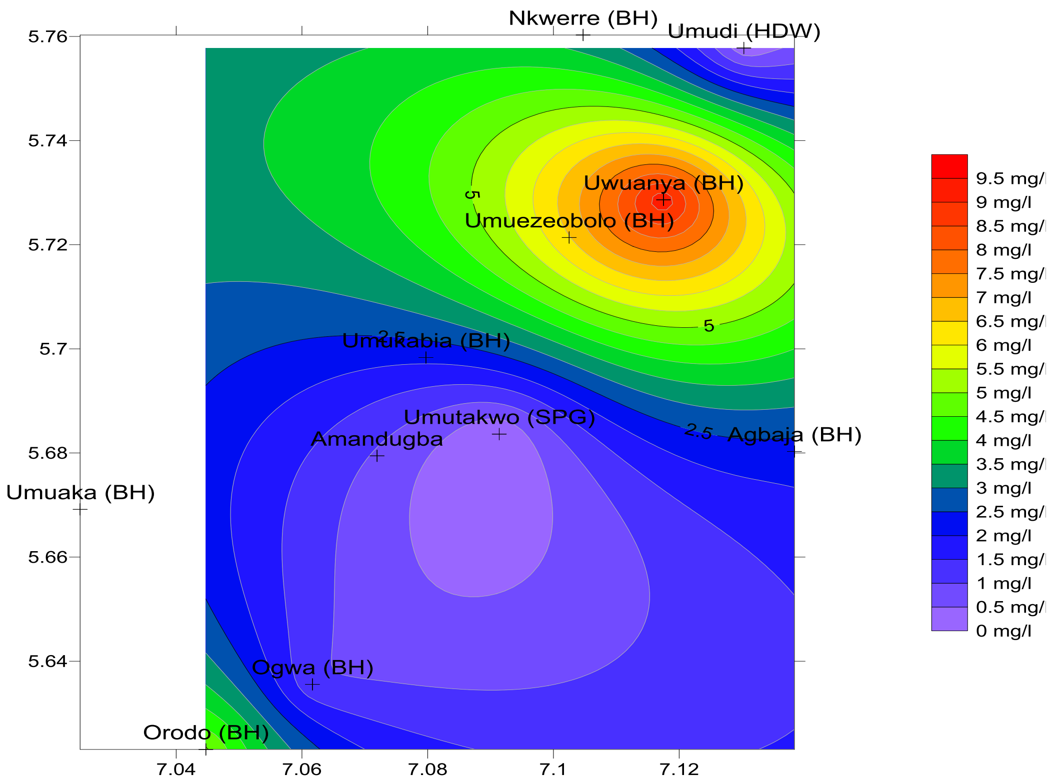


(a)Plain View

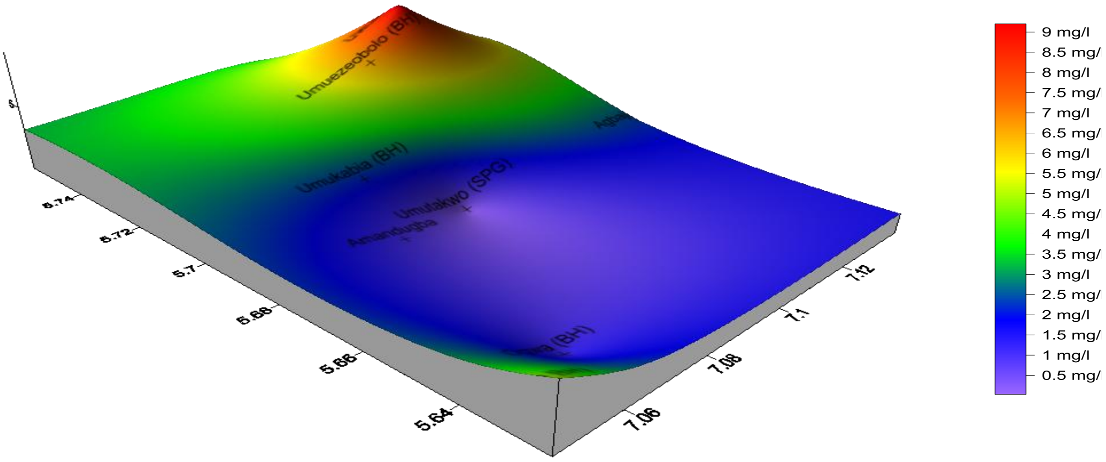


(a)3-D View

Fig. 4.6. Spatial Variation Map of Sodium Concentration in the studyarea.

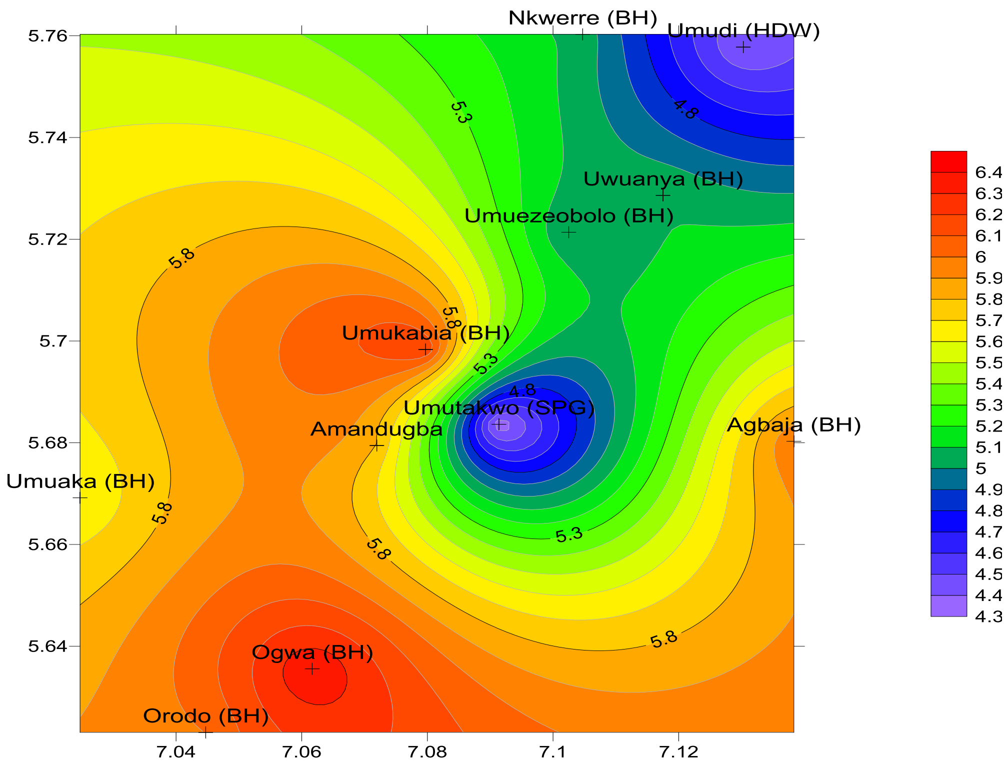


(a)Plain View

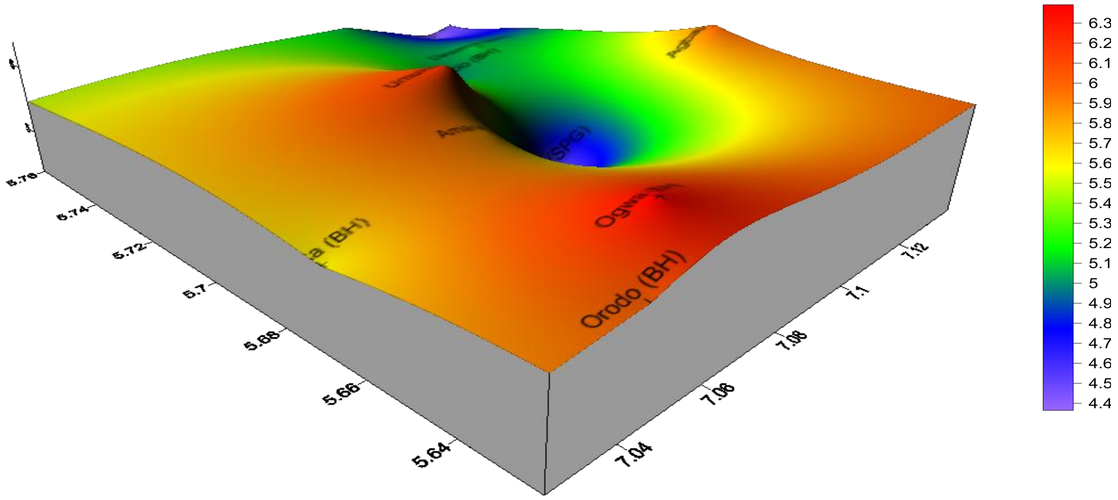


(b)3-D View

Fig. 4.7. Spatial Variation Map of Nitrate Concentration in the study area.

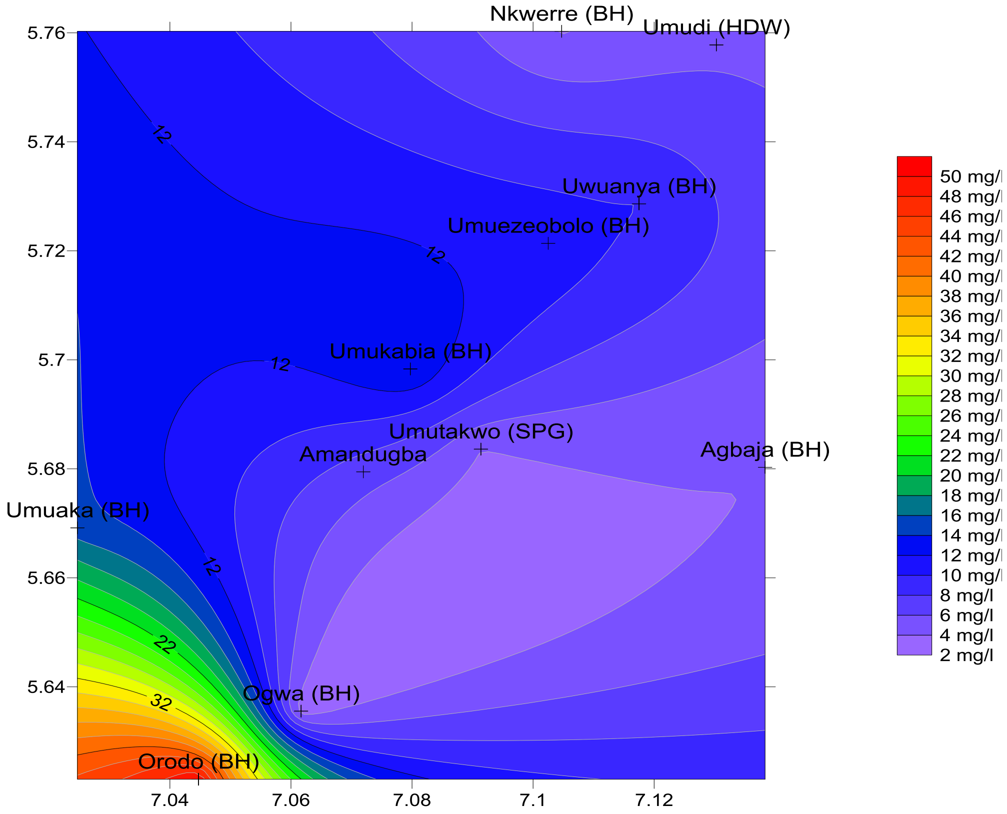


(a)Plain View

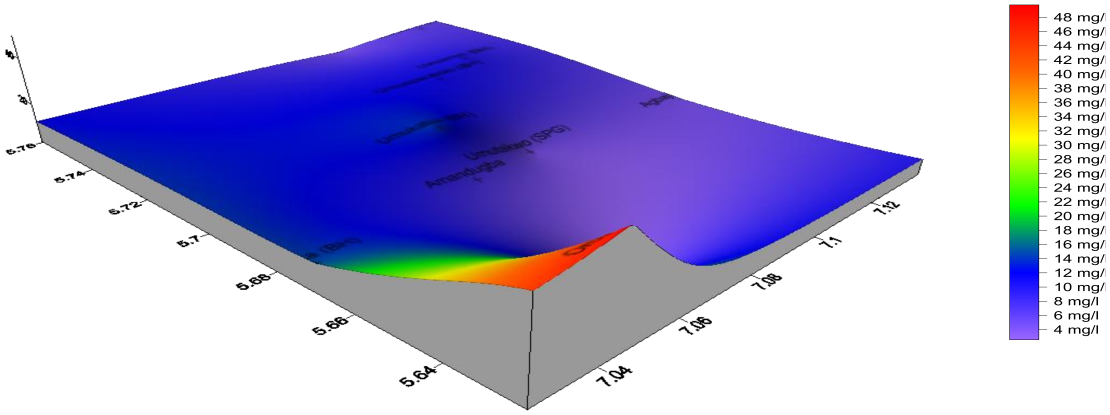


(b)3-D View

Fig. 4.8.Spatial Variation of PH in the study area.

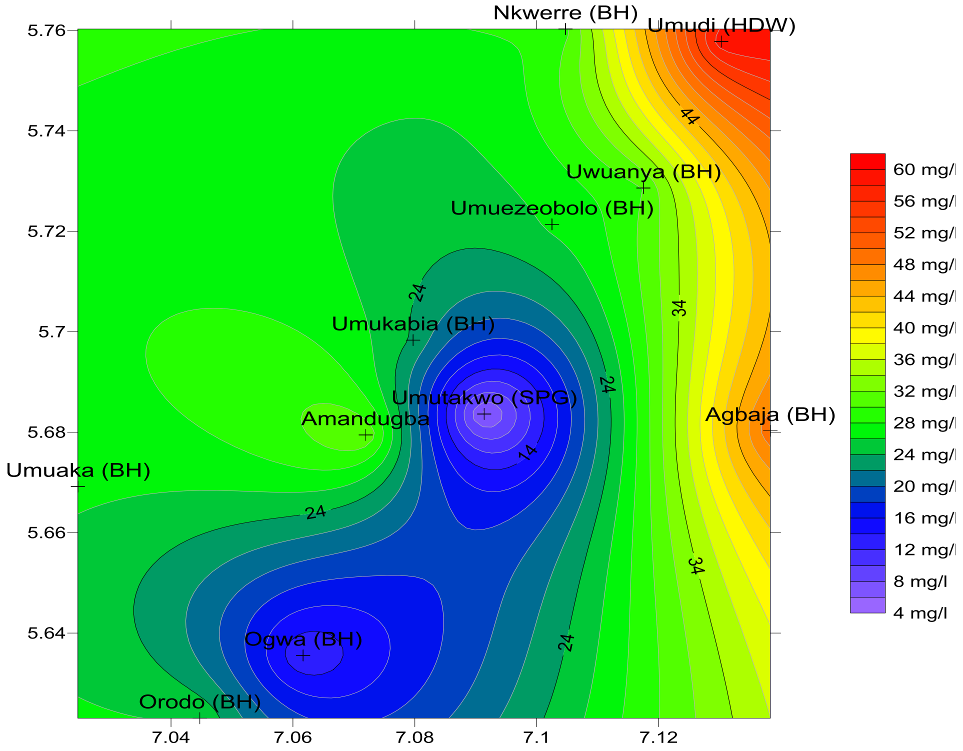


(a)Plain View

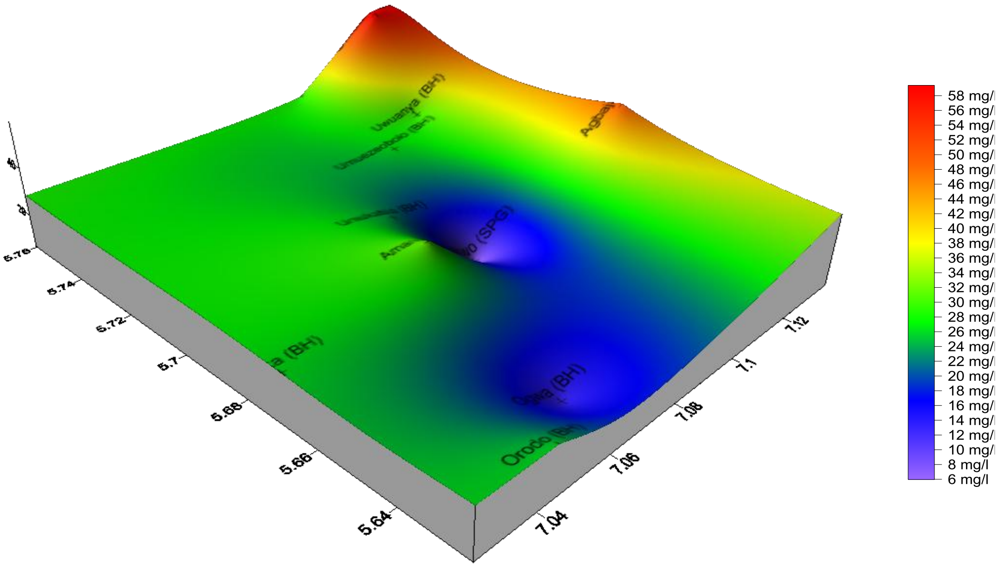


(b)3-D View

Fig. 4.9. Spatial Variation Map of Sulphate Concentration in the study area.

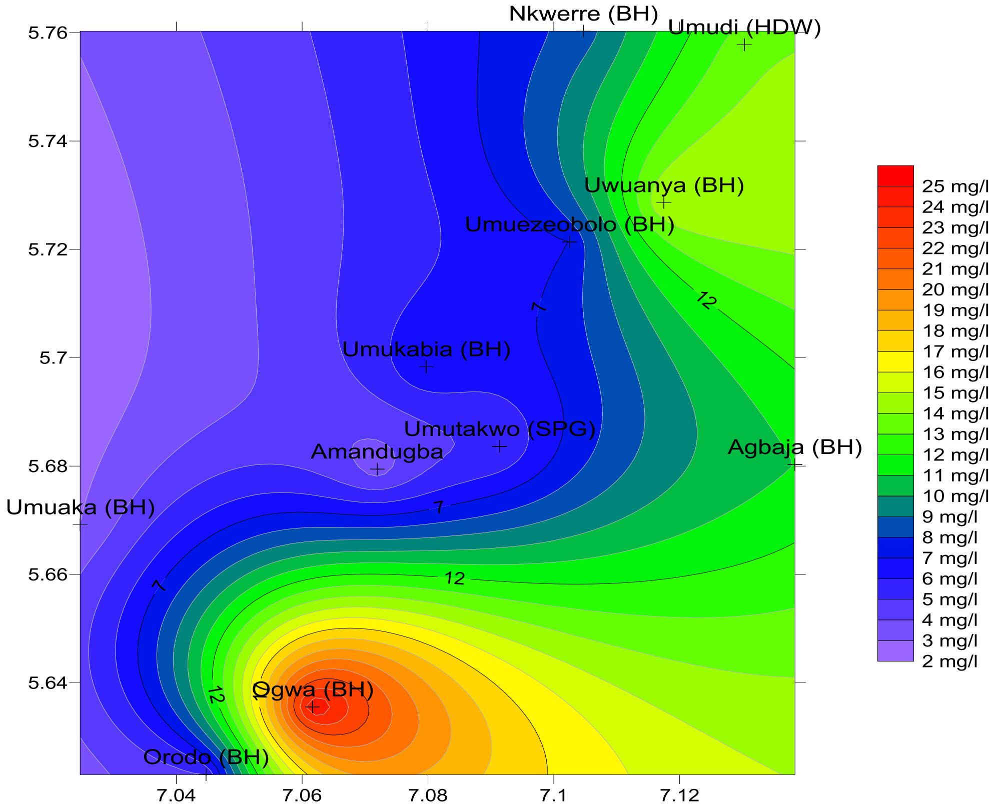


(a)Plain View

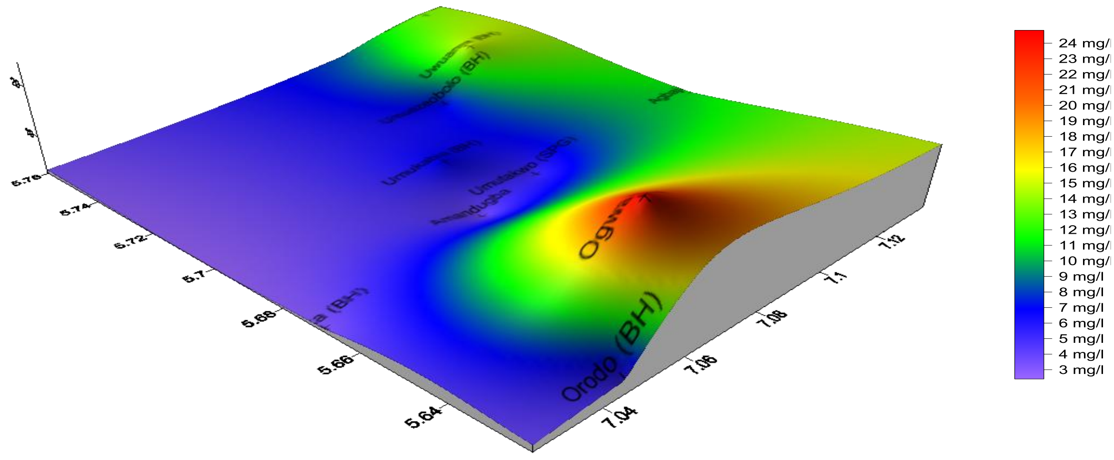


(b)3-D View

Fig. 4.10.Spatial Variation Map of TDS concentration in the study area.



(a)Plain View



(b)3-D View

Fig. 4.11. Spatial Variation Map of Total Hardness as $CaCO_3$ concentration in the study area.

4.2 DISCUSSION

The groundwater resource of the study area is generalized to be acidic, as indicated by the average pH of 5.37. This is as a result of the presence of lignite in the study area. This may affect the groundwater due to the fact that part of the Carbon from it can react with dissolved oxygen to form Carbon dioxide.

$C + O = CO_2$

The Carbon dioxide (CO_2) formed can also react with water to form carbonic acid; $CO_2 + H_2O = H_2CO_3$, hence increasing the acidity of the groundwater in the study area. The pH range shows the absence of carbonates in solution. Carbonates usually occur in solution at pH of about 8.2 and above (Oteze, 1991). Other geochemical results considered in the evaluation of water quality for domestic use reveal that parameters such as nitrates, sulphate TDS are generally within the permissible limits. Thus, conforming to the World Health Organization (WHO) 2006 limits.

The average concentrations of Ca^{2+} and Mg^{2+} are 3.44mg/l and 2.46mg/l respectively and average hardness as $CaCO_3$ (9.22mg/l) indicate that the groundwater is soft and has no laxative effect. Lack of laxative effects of the groundwater is also confirmed by the average concentrations of sulphate and total dissolved solids, 11.87mg/l and28.77mg/l respectively. However, when the sum of magnesium and sulphate contents of drinking water exceed 100mg/l, most people who use it experience a laxative effect (Oteze, 1991).

The average concentration of iron is 0.33mg/l which is little above the recommended limit of 0.3mg/l by WHO (2006). The possible source of iron in the area may be the iron clay minerals associated with the lignite series. However, groundwater with high iron concentration poses problems of aesthetics rather than health.

According to Hem (1970), when the total hardness as $CaCO_3$ in water is less than 60mg/l (Table 4.5), it is classified as soft. Carroll, (1962) classified water with TDS less than 1000mg/l as fresh see Table 4.6. It can be deduced that the water resources of the area is acidic, soft and fresh.

Table 4.4: Water Class Based on Total Hardness as $CaCO_3$ (After Hem, 1970).

Hardness as $CaCO_3$ (mg/l)	Water Class
0 – 60	Soft
61 – 120	Moderately Hard
121 – 180	Hard
180	Very Hard

Table 4.5: Water Class Based on TDS (After Carrol, 1962)

TDS (mg/l)	Water Class
0 -1000	Fresh
1000 – 10,000	Brackish Saline
10,000 and above	Brine

The evaluation of water for household purposes is considered in terms of Nitrate, pH, Total dissolved solids (TDS), sulphate and Iron. From Table 4.1, the concentration of nitrate vary from 0.00mg/l to 9.4mg/l with an average of 1.50mg/l. TDS vary from 5.4mg/l to 59.3mg/l with an average of 28.77mg/l while the sulphate concentration values were generally low with values ranging from

4mg/l to 50mg/l with an average value of 11.87mg/l. The concentrations of iron vary from 0.00mg/l to 1.81mg/l with an average of 0.33mg/l. The average PH value is 5.37. Thus all the parameters conform to the WHO (2006) standard for safe drinking water.

The piper diagram shows close chemical relationship at the sampling points in terms of composition and origin. From the major anion ternary part of the plot, the water type based on cations and anions concentration for various sampled locations are categorized into fields thus: In the cations field, Umutakwo (SPC) and Uwuanya BH location are categorized as calcium dominant water type, Nkwere BH as magnesium water type and umuaka, Orodo and Amandugba as sodium-potassium water type. All others fell into the field of no dominant water type which implies that all three ions likely occur at equilibrium concentration. In the anions ternary, Ogwa, Agbaja, Umudi, Nkwere, Umutakwo (SPC), and Umuezeobolo indicate Chloride chemistry while Umuaka, Umukabia, Orodo, Uwuanya and Umutakwo boreholes are of Sulphate type.

The diamond plot summarizes as follows: Boreholes in Umuaka, Amandugba, and Orodohave Sodium Chloride water chemistry, while those in Nkwere, Umudi, Umuezeobolo, Uwuanya, Umutakwo (SPC), Agbaja, Umukabia and Ogwa chemistry are of Calcium-Magnesium sulphate water type. Boreholes in Ogwa, Umukabia and Agbaja have mixed Calcium-Magnesium-Chloride Sulphate water type. This implies that boreholes water in such areas may not be very portable as they are likely to be associated with permanents hardness resulting from sulphate salts of magnesium and calcium. Although, water from boreholes in Ogwa, Umukabia and Agbaja may not be as hard as those in earlier mentioned areas. Umuaka, Orodo and Amandugba fall into the category of Sodium-Chloride water type.

However, the water resources of the studied area were found to have two dominant hydrochemical facies according to the Trillinear diagram (Fig. 3.2). They are grouped as Ca^{2+}- Mg^{2+} (SO_4^{2-}) and Na (HCO_3^{2-}) water types. According to Lohnert (1973) and Onyekuru *et. al.*, (2010) the appreciable amount of the later facies is an indication of Cation exchange water.

The Schoeller plot in Fig. 3.4shows the relative tendency of major cations and anions in terms of their dominance in solution for all the sampled locations. This may be used to infer properly the chemistry described by the various fields on the Piper and Durov plots.

Durov chart in Fig. 3.3 also show close chemical relationship of constituents at the sampling points comparing TDS and pH along with the primary earlier stated major cations and anions. This is used to describe the water quality based on combination of TDS and pH to have a better view of ion exchange processes in its chemistry. The Durov diagram is used to show the hydro-chemical processes occurring within the different hydrogeological systems. Result above specifies ionic exchange and dominance of simple dissolution also known as linear mixing. Umutakwo (SPC), Umudi, Nkwere and Umuezeobolo hydrogeological systems have gone through ion exchange processes while those of Uwuanya, Umuaka, Orodo, Ogwa, Agbaja etc. reveal simple dissolution processes or mixing.

Stiff diagram in Fig. 3.5 to 3.10 shows that the shapes are not similar and may indicate different genetic water sources with respect to the study area geology. It also indicates in correspondence with Schoeller diagrams the dominant major cations and anions in the water composition.

In terms of the agricultural usage of the water, the SAR values computed for all the samples vary from 0.06 to 0.81 with an average of 0.48 (Table 4.2). According to Mandel and Shiftan (1981) groundwater containing SAR values from 0 – 10 can be applicable on all agricultural soils, while groundwater having SAR range of 18 – 26 may produce harmful effect. SAR range of 26 – 100 is unsuitable for irrigation purposes. The SAR can be determined with the formula:

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

Where Na^{+}, Ca^{2+} and Mg^{2+} concentrations are in miliequivalent per litre.

The average SAR concentration (0.48) indicates that the groundwater resources of the study area are excellent for irrigation purposes and are applicable to all types of soil.

Table 4.6: Water Class Based on SAR (After: ETU- EFEOTOR, 1981).

SAR	WATER CLASS
0 – 10	Excellent
10 – 18	Good
18 – 26	Fair
>26	Poor

For industries, water to be used should be odourless, colourless, and free from suspended matter and micro-organisms and low iron content (Ishaku and Matazu, 2001). From the results in Table 4. 1, the total hardness values range from 3.0mg/l to 15mg/l meaning that the groundwater resources of the study area can be said to be relatively soft. These values are also within the range of America Water Works Association (1971) standards of water quality tolerance for industries. Iron concentration was detected in ten (10) out of twelve (12) samples. Their concentrations vary from 0.00mg/l to 1.83mg/l with a mean of 0.33mg/l. Waters containing more than 0.2mg/l of iron are objectionable for most industries (Todd, 1980). Based on the above standard, some water samples reveal high iron concentration and therefore, may not be suitable for some industries.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The results of the geochemical analysis carried out on the groundwater samples indicate that the groundwater resources of the study area are generally acidic, soft and fresh. The chemical analysis result also indicate that the groundwater resources of the study area is chemically potable and suitable for agricultural purposes as the various ionic concentrations and parameters are within the maximum acceptable limits as specified by the World Health Organization (WHO, 2006). However, the water requires treatment before it can be used in industries, except for the groundwater sources where iron was not detected.

5.2 RECOMMENDATIONS

The groundwater of the study area should be treated to take care of the high iron concentration using oxidation filters based on a chemical oxidation process, especially sample sources where iron was detected. Also, the pH of the groundwater resources of the study area should be treated using neutralizing filter containing calcium carbonate ($CaCO_3$) or magnesium oxide (MgO) before consumption. Finally, it is recommended that the community living in the study area should on their own protect the groundwater system from man-made pollution and contamination.

5.3 CONTRIBUTION TO KNOWLEGDE

From the geochemical analyses carried out, it was discovered that the main source of pollution and contamination in the groundwater system in the study area is from the local geology.However, from the evaluation of the physic chemical parameters, a hydro geochemical baseline data provided for future development.

REFERENCES

Ahiarakwem, C. A. And Ejimadu, O.G. (2002).Geochemical properties of Groundwater in Orlu Area of Imo State, Southeastern Nigeria.Journal of Nigerian Association of Hydrogeologists. Pp. 19-22.

Akaninyene, O.A, Igboekwe, M.U (2012). Preliminary Lithologic Deductions for Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria, using Vertical Electrical Sounding Method. Arch. Phy. Res. 3(4):292-302.

Akpoborie, N.A, Nfor A.A., Etobro, I., Odagwe, S. (2011). Aspects of the Geology and groundwater conditions of Asaba, Nigeria. Arch. Appl. Sci. Res. 3(2):537-550.

American Water Works Association, (1971).Water quality and treatment. McGraw-Hill, New York, 654p.

Assez, L.O. (1989). In: Kogbe (ed). Geology of Nigeria. Rockview Publ., Jos, pp. 311-334.

Atlas map of Imo State of Nigeria, (1984).Prepared by C and G Co. Italy.Pp.5-15

Avobovbo, A.A (1978). Tertiary Lithostratigraphy of Niger Delta. Bull. Am. Assoc. Pet. Geol. 62:295-306.

Bassey, C., Eminue, O. (2012). Petrographic and stratigraphic analyses of Palaeogene Ogwashi-Asaba formation, Anambra Basin, Nigeria NAFTA 63(7-8):247-254.

Carroll, D. (1962). Rainwater as a Chemical Agent for Geological process: A review. U.S. Geological Survey Water Supply paper pp. 336-338 .

Cherie, R., Onyike, M.S. and Sowumi, M.A. (1978). Some new Eocene pollen of the Ogwashi – Asaba formation, Southeastern Nigeria. Rev. Esp. micropateont. 10:285-322.

Davis, S. N. and R. J. M. De Wiest (1966).Hydrogeology. John Wiley and Sons, New York, Vol. 643.

Egboka, B. C. E. (1983). Analysis of the Groundwater Resources of Nsukka Area and Environs, Anambra State. Nigerian Journal of Mining and Geology 1,20(1 & 2) Pp. 1-16.

Etu – Efeotor, J. O. (1981). Preliminary Hydrogeochemical Investigation of sub-surface waters in parts of Niger Delta. Journal of Mining and Geology 18 (1) Pp. 103 – 105.

Etu – Efeotor, J. O. and Odigi, M. I. (1983).Water supply problems in the Eastern Niger Delta, Nigeria. Journal of Mining and Geology 20 (1 & 2) Pp. 183 – 193

Hem, J. D. (1970).Study and Interpretation of Chemical Characteristics of natural water.Water supply papers published by U.S. Geological Survey, Washington DC. Nos. 1473 Pp. 254 – 255.

Ibeneme, S. I., Ukiwe L.N., Selemo, A.O., Okereke, C. N., Nwagbara, J. O., Obioha, Y. E., Essien A.G., Ubechu, B. O., Chinemelu E.S., Ewelike, E. A. and Okechi, R. N.(2013). Hydrogeochemical Study of Surface Water Resources of Orlu, Southeastern Nigeria. *Journal of Water Resources, Environmental and Engineering*, vol.5 (12), pp. 670-675.

Ishaku, J. M. and Matazu, H. I. (2001). Evalution of Water Resources of Numan area, Northeastern Nigeria. *Journal of Mining and Geology*. Vol. 37(2), pp195-202.

Kogbe, C. G. (1976). Geology of Nigeria. Rockview Nigeria Limited, Publishers.

Lindskov, K. L. and Kmball, B. A. (1984).Quantity and Quality of Stream-flow in Southern Uinta Basin, Utah and Colorado. U.S Geological Survey.

Lohnert, E.P. (1973). Austauschwaesser In H Schneider (Hrsg) Die Grunwasserchliessung, VulkanV erlag Essen 2nd Edition, pp. 138-144.

Mandel, S. and Shiftan, Z.L. (1981).Ground Water Resources Investigation and Development. Academic Press Inc.

Oboh-Ikuenobe, F.E., Obi, C.G. and Jaramillo, C. A. (2005). Lithofacies, Palynofacies, and Sequence Straigraphy of Paleogene strata in Southeastern Nigeria. *J. Afr. Earth Sci.* 41:79-101.

Offodile, M. E. (1981). The problems Resourcesof Water Resources Management in Nigeria. Presidential Keynote address to Jos Chapter of NMGS (unpublished).

Offodile, M.E. (1987) water resources management and the Nigerian groundwater system. Proceedings of delegate conference of the Nigeria academy of science pp23 – 35

Okonny, I. P. (1991).Imo Tectonic River.*Journal of Mining and Geology,* Vol. 27, NO.2 Pp. 33- 41.

Onunkwo-A, A and Uzoije, A. P. (2011) Exploratory survey of geochemical aspects of underground water in Ehime Mbano Area SE, Nigeria World Rural Observations, 3(2) PP 2 9 – 37.

Onunkwo-A.A, Uzoije A.P, Onyekuru, S.O, Agumanu, A. E, and Chinaemelu, E. S. (2013).Ground Water Quality Assessment of Newly Created Local Governments in Nigeria – A Case of Nkwerre, Local Government, Imo State. IOSR *Journal of Environmental Science, Toxicology And Food Technology*. Volume 5, Issue 3, PP 93-99.

Onyeagocha, A.C. (1980). Petrography and Depositional Environments of the Benin Formation *.J. Min. Geol.* 17 (2):147-150.

Onyekuru, S.O., Nwankwor, G.I. and Akaolisa, C.Z. (2010). Chemical Characteristics of Groundwater Systems in the Southern Anambra Basin, Nigeria. *J. Appl. Sci. Res.* 6(12):2164-2172.

Oteze, G. E., (1991). Potability of Groundwater from Rima Group Aquifers in Sokoto Basin, Nigeria. *Journal of Min. Geol.* 27(1), 17-23.

Piper, A. M. (1953). A Graphic Procedure in the Geochemical Interpretation of water Analysis. Washington D.C, US. Geol. Surv. ISBN ASIN: B0007H2Z36.

Reyment, R. A. (1965). Aspects of the Geology of Nigeria. Ibadan University Press Publisher.

Schoeller, H. (1977).Geochemistry of ground waters, In Groundwater Studies and International Research and Practice, UNESCO, Paris6.

Short, K.C. and Stauble, A. J. (1967). Outline Geology of Niger Delta. American Association of Petroleum Geology Bulletin, 51, 761-779.

Spears, D.A.(1976).“Information on Groundwater Composition Obtain from a Laboratory Study of Sediment- Water Interaction”. *Q.J. Engng. Geol.* 9:25-36.

Stiff, H.A.(1951) The interpretation of chemical water analysis by means of patterns: *Journal of Petroleum Technology,* v. 3. no. 10, p. 15-17.

Todd, D. K. (1980).Groundwater Hydrology 2nd ed. John Wiley and Sons Inc. New York.

Uma, K.O. (1989). Appraisal of the groundwater resources of the Imo River Basin, Nigeria .*J. Min. Geol.* 25(1&2):305-315.

WHO, (2006).Drinking Water Guidelines. Geneva 2006.

Whiteman, A. (1982). Nigeria, its petroleum Geology, Resources and Potentials. 2. Graham and Trotman Publ., London, pp. 234-241.