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AN APPRAISAL OF THE CHEMICAL COMPOSITION OF THE GROUNDWATER IN MINNA METROPOLIS CENTRAL NIGERIA

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Abstract

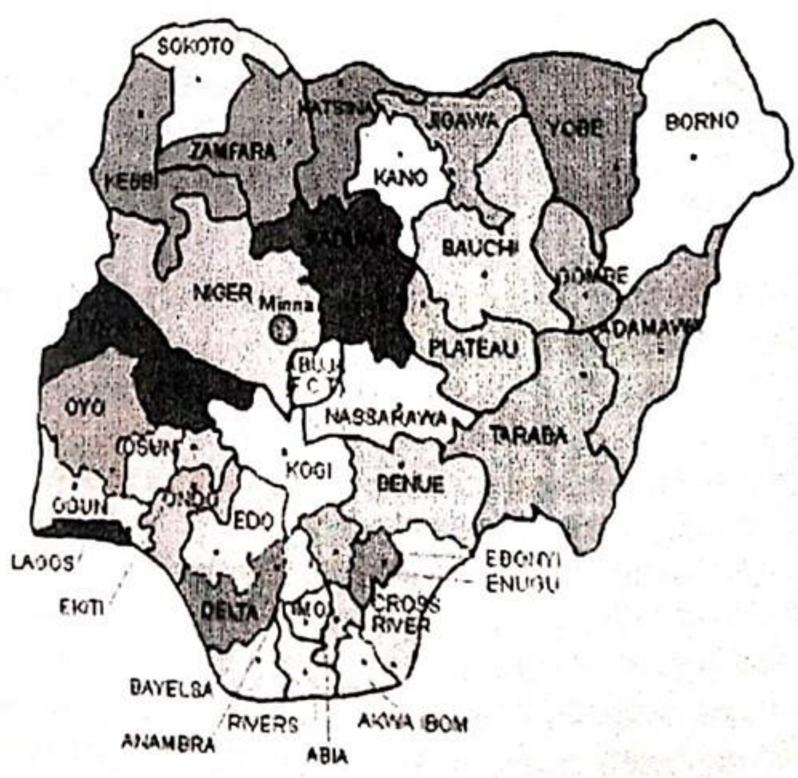
Groundwater in recent years has become the main source of water supply for domestic use in Minna metropolis following rapid expansion of the town and fledgling services provided by the state's public water service. Minna is the capital of Niger State and lies between latitudes 9°32' and 9°41' N and longitude 6°28' and 6°37' E covering an approximate surface area of 105km^2. The geology of Minna comprises mainly of rocks belonging to the PreCambrian Basement Complex system of Nigeria. The main rock types include granites, gneisses, migmatite and schist. Mapping of the area was conducted using a hand held GPS (Garmin Etrex Legend). The geology of the area was studied using the traverse method on a topographic map (Minna sheet 164) on a scale of 1:50,000. Water samples were obtained from various locations on a grid basis in glass and plastic bottles. Physical properties of the water were measured at the time of sampling. Water analysis was conducted in the laboratory to determine the chemical composition, instrumentation was by Atomic Absorption Spectrometry, Colourimetry and Titrimetry. Major, Minor and Trace Element composition of the water were determined. The cations with greatest concentration are Mg, Ca, and Na while the dominant anions are HCO_3, CO_3 and NO_3. Trace Elements with higher concentration are Mn, Cu, As, and Pb. The groundwater regime can generally be classified into two; a Calcium carbonate water and the other in which no cation or anion predominates. The results generally indicate that the groundwater is of good quality, however the water shows signs of gradual enrichment in Mn, As, and Pb.

Keywords: Groundwater, Trace Element, Chemical parameters, contamination.

Introduction

Groundwater is the source of water for wells, boreholes and springs. It occurs below the surface within cracks in bedrock or filling the spaces between particles of soil and rocks (Offodile, 2002). Approximately over half the population of Minna (>350,000, NPC 1991) rely on groundwater for drinking water and over 90% of those living in the environs obtain their water from groundwater through wells and boreholes. In its natural state, ground water is usually of excellent quality and can be used with no costly treatment or purification. However, ground water can also become contaminated or polluted as a result of natural or human factors

(Deming, 2002, Ogunbajo, 2003).
Minna is the capital of Niger State, Fig.1 and lies between latitudes 9°32'N and 9°41'N and longitudes 6°28'E and 6°37'E, covering an approximate surface total area of 105km^2. The area is easily accessible through Abuja-Dikko-Lambata-Tegina, Lagos-Mokwa-Bida and Kaduna- SarkinPawa roads. It has an annual rainfall of about 2500mm with a distinct rainy and dry seasons experienced between April to October and between November to March respectively. It has a mean temperature of 27°C in the rainy season and 35°C at the peak of the dry season with a relative humidity of 87% in the rainy season and 35% in the dry season (Idris-Nda, 2000). The vegetation is typically that of the savannah grassland, comprising mainly of mangos, gmelinas, neem, cashew and mahogany, most of which have given way to urbanisation. The area is drained mainly by River Chanchaga, which is a tributary of River Kaduna, as well as other minor seasonal streams. In recent years Minna has witnessed a high increase in population as a result of influx of people into the town from neighbouring states in the country. The rapid expansion of the town coupled with the inability of the state water corporation to meet up with the demand for water has led to a large number of people resorting to the use of groundwater through the drilling of boreholes and hand dug wells. Fig.2 is the relief map of Minna showing the major areas and principal direction of groundwater flow. Urbanisation comes with its own environmental problems which includes pollution and stretching of the available water resources. It is for this reason that an assessment of the water quality and availability of Minna and environs was undertaken.



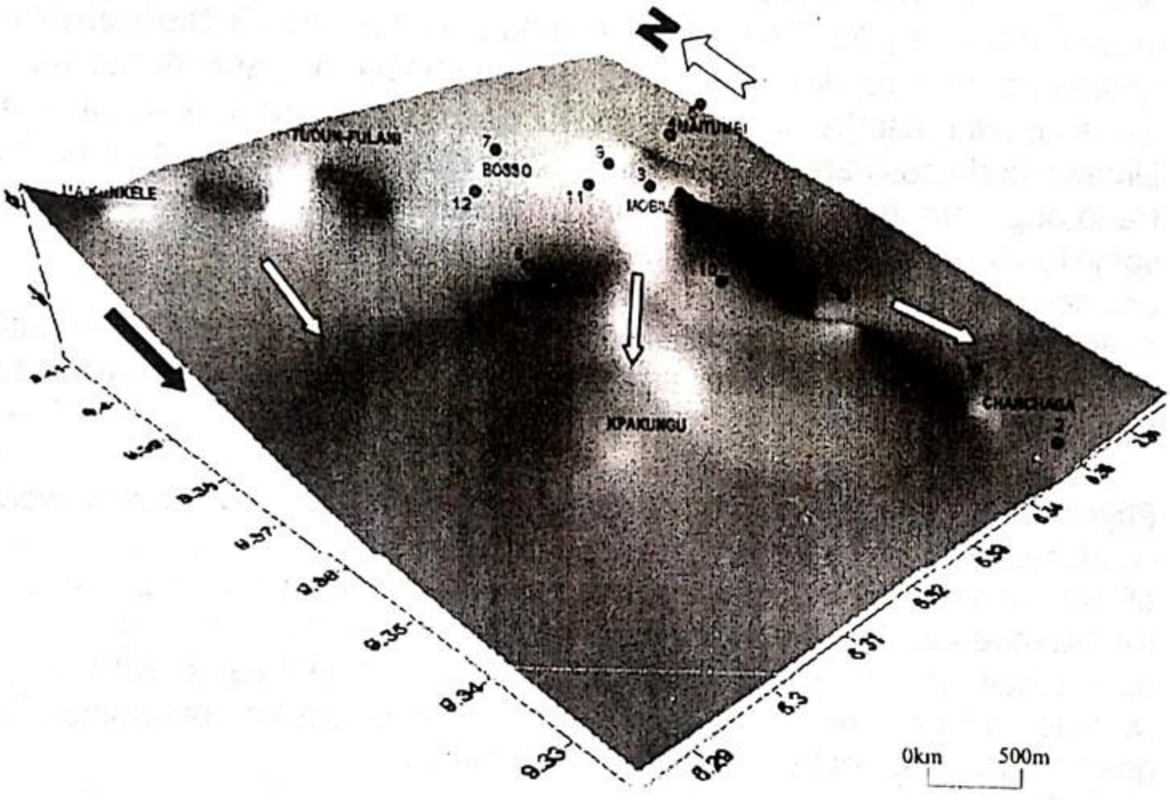


Fig. 2: Relief map of Minna metropolis showing direction of groundwater flow (arrows) and the sampled points.

Geology and Hydrogeology

The geology of the area comprises mainly of rocks belonging to the Precambrian basement complex system of Nigeria (Truswell and Cope, 1963). It is mainly underlain byOlder granites, migmatites, gneisses and schist. The granites range from coarse to fine grained biotite- muscovite granites while the schist are highly foliated with platy and elongated minerals that commonly include muscovite, biotite and amphiboles. The migmatites are the oldest rocks in the area and occur as high, extensive outcrops (Ajibade, 1976) and are composed mostly of quartz, feldspar and mica in varying proportions. Older Granite suite is widespread in the study area and occurs as elongated hills. The landscape especially in the Eastern to North-Eastern parts is represented by these hills forming the Minna Batholith.

Groundwater is water that occurs below the water table within the saturated parts of the rock. It occurs mostly in structural units known as aquifers. An aquifer is any geological material that can store and transmit water in sufficient quantities to be considered economical. The aquifers in hard rocks are represented by the weathered portions of the rock and also by fracturing that occur within the bedrock. The former is the source of water for wells while the latter is the source of water for boreholes. The weathered portions of the rock in the area extends up to 9m in some areas like Shango, Chanchaga, Maitumbi, and Maikunkele , while the shallower depths of weathering occurs around the G.R.A, Dutsen Kura, Limawa and Bosso areas with the weathered regolith commonly less than 5m. Hand dug wells are the common source of water of the inhabitants of the area, some few individuals have boreholes in their homes and offices while government and some donor agencies like UNICEF, JICA and the EEC/MIDDLE BELT Program drilled some communal boreholes within the town and environs. Government also drilled over 100 handpump operated boreholes spread across the town to ease the drastic water problem the town faced in 2009.

Physico – Chemical analysis of the water from these boreholes were not conducted at the time of there construction. Most often than not chemical analysis of water is seldom conducted and even when it is done, most parameters tested for are so few as to make the whole exercise futile. Most problems that may arise as a result of groundwater contamination are often treated without proper records and as a resultlong term effects of a particular contaminant in the groundwater may not be immediately identifiable.

Just like most urban settlements in Nigeria, sanitary conditions are very poor, with pit latrines being the commonest method of waste disposal, while solid waste is dumped in open dumps, drainagesand streams, these have a high potential of contaminating surface and groundwater sources.

Methodology

Mapping of the area was conducted using the Garmin GPS (Etrex Legend), this was used to determine the coordinates and altitudes of the various areas in the town, and the information obtained was used to draw the contour and relief maps of the area using "Surfer 8" software. The geology was determined using the traverse method by the use of compass/clinometer and hammer using the topographical map that was obtained from the initial mapping of the area, on a scale of 1:25,000, as the base map. Twenty five water samples were obtained from various locations in plastic and glass bottles for cations and anions respectively, and taken to RUWATSAN and National Water Quality laboratories for analysis. Physical parameters of conductivity and pH were determined using a portable field kit (Yokogawa) digital conductivity and pH meters while the temperature was obtained using a thermometer.

Groundwater analyses were carried out in the laboratory to determine the cation, anions and trace elements in the water. The methods used for the analysis were the Atomic Absorption Spectrometry (AAS) for cations such as sodium ($Na+$), calcium ($Ca2+$), magnesium (Mg^{2+}), iron (K^{+}) and heavy metals (Mn, Pb, As and Cr), Ultraviolet Spectrometry was used for the anions of sulphate (SO_4^{-2}), nitrate (NO_3^{-}), phosphate (PO_4^{-}), carbonate (CO_3) and bicarbonate (HCO_3) while the Titrimetry method was used for chloride (Cl^{-}) concentration.

The laboratory results were analysed using various analytical methods. Physical parameters like Temperature, Conductivity, and pH as well as the heavy metals were interpreted using bar and pie charts, the water was classified using the Piper Trilinear diagram, while the various waters in the area were compared using Stiff Plot.

Results and Analysis

Temperature, Conductivity and pH

The temperature of the water has a range of 27°C to 30°C with a mean of 28 °C; conductivity has a range of between 19.0 to 358 μS/cm with a mean of 209.35μS/cm while the pH has a range of 6.1 to 8.5 with a mean of 6.4

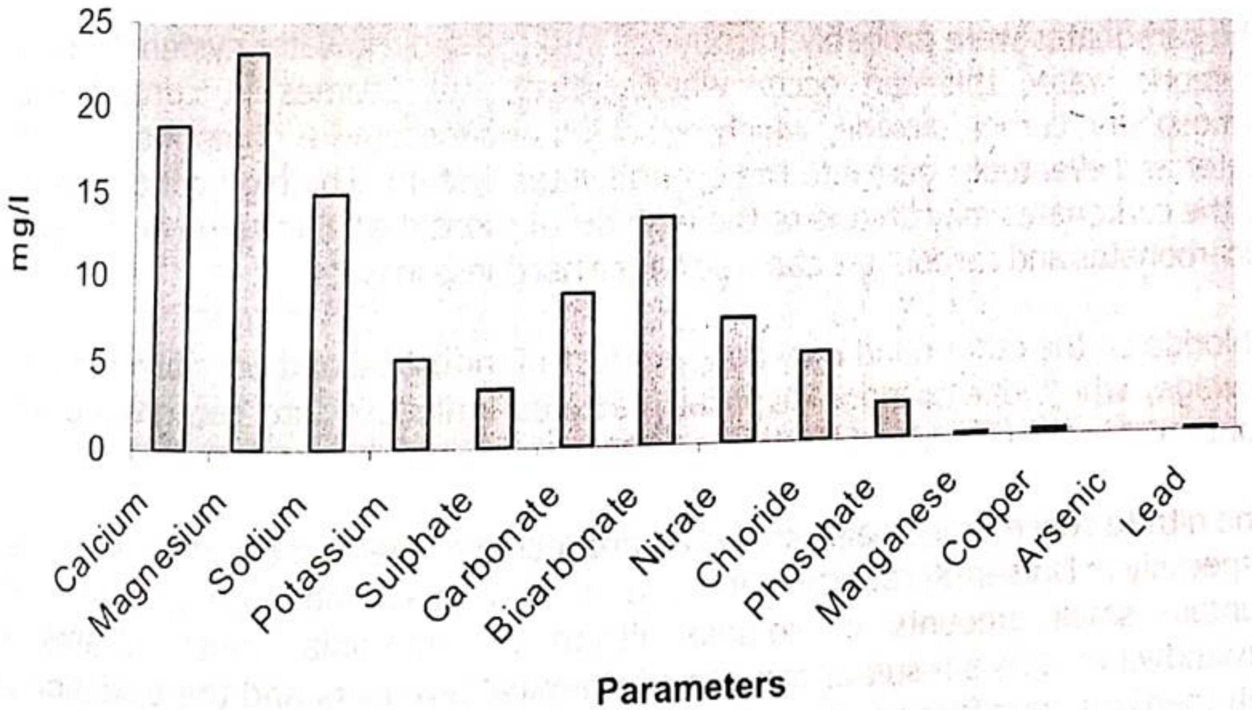


Figure 3: Concentration of the determined parameters

Cations

The cations that have the greatest concentration are magnesium, calcium and sodium. In the basement environment, the source of these metals is mainly the

weathering of apatite, wollastonite pyroxene, amphiboles and plagioclase feldspar.
The most common source of Magnesium in groundwater is through weathering of rocks rich in magnesium bearing minerals like olivine, biotite, hornblende, talc etc.

Calcium is abundant in the earth crust and extremely mobile in the hydrosphere. The high concentration of calcium in the area is also due to the weathering of minerals like apatite, wollastonite, fluorite and pyroxene group.

High concentration of magnesium and calcium leads to water hardness which is defined as the concentration of calcium and magnesium ions expressed in terms of calcium carbonate.

Anions

The dominant anions are the Bicarbonates, Carbonates and Nitrates.
Most Carbonates and Bicarbonates ions in groundwater are derived from the carbon dioxide in the atmosphere, in the soil and in solution of carbonate rocks, they also occur in igneous rocks. The high concentration of these ions in the groundwater in this area may be attributed to these sources.

The carbonates were probably introduced into the groundwater system through meteoric water, this can occur when precipitation comes in contact with atmospheric carbon dioxide, which dissolves and become a component of the water and eventually gets into the groundwater system. The high concentration of the carbonates may be due to the high pH of more than 8 in some areas. Both bicarbonates and carbonates can also cause hardness in water.

Chloride on the other hand may be a product of industrial and possibly domestic sewage, which due to poor disposal practices infiltrates into the ground and contaminate the groundwater (Fetter, 2002).

The nitrate concentration also shows an appreciable level in most of the samples, especially in Dutsen-Kura, Maitumbi, Shango and Bosso. Although igneous rocks contain small amounts of soluble nitrate or ammonia, most nitrates in groundwater is as a result of the use of chemical fertilisers and the oxidation of nitrogen compounds in sewage effluent (Back, 1960). The marked enrichment of nitrate in these areas could be due to poor disposal of municipal waste, siting of wells near sewage systems or probably fertilization of agricultural land. Nitrate is not adsorbed by soil particles, thus, making it a highly mobile ion and therefore moves with infiltrating water into aquifers. This ion shows moderate to low concentration at Chanchaga, FGC and Paida, while it is almost absent at F-Layout, and FUT Bosso campus.

Heavy metals

Heavy metals such as Arsenic, Lead, Copper, may be present in water as a result of industrial discharges, runoff from city streets, mining activities, leachate from landfills and a variety of other sources. These toxic chemicals are generally persistent in the environment and find their way into the groundwater system posing long term health risks to humans. The heavy metals analysed in the area that show any significant concentration are manganese, copper, arsenic and lead.

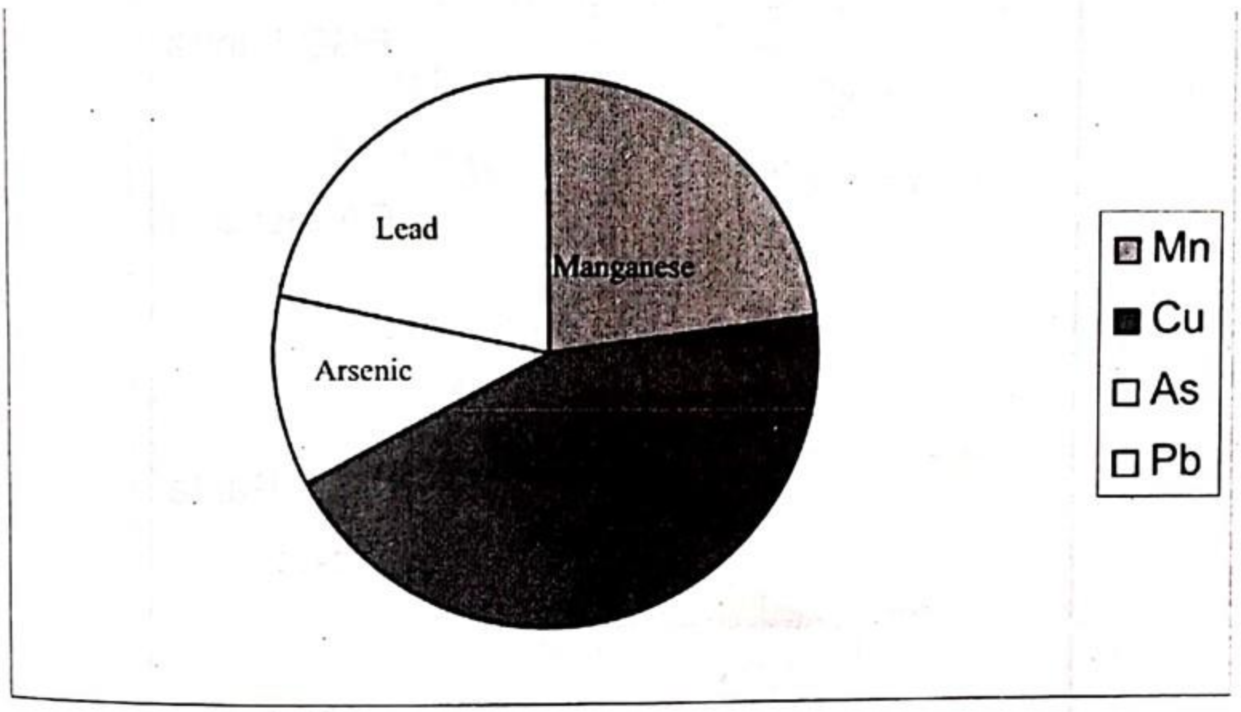
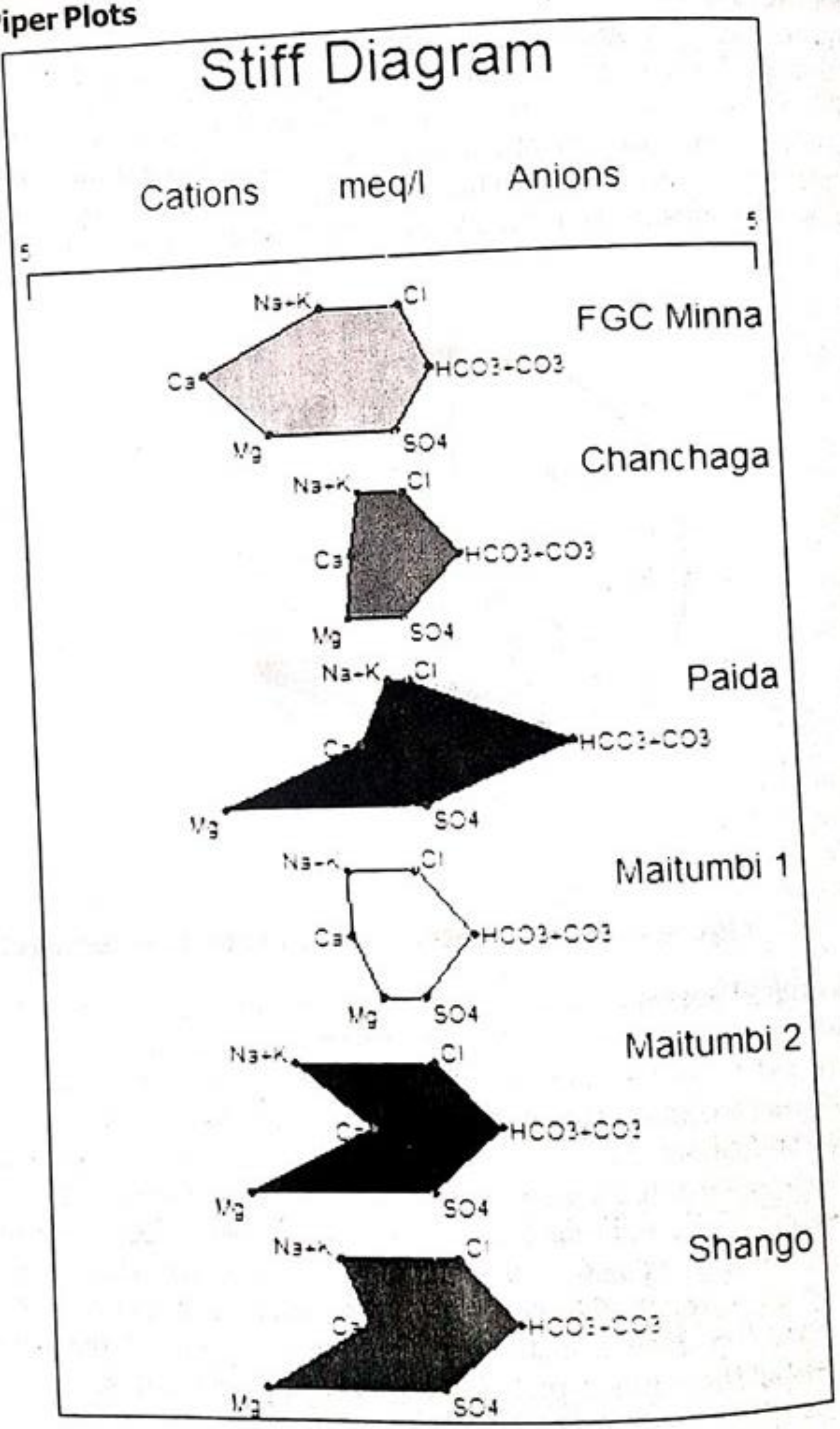


Figure 4: Heavy metal concentration (Percentage).

The heavy metal analysis reveals that copper concentration is higher than those of manganese, arsenic and lead. Manganese and lead have an almost sub equal proportion (Fig 4) with arsenic having the lowest concentration. Generally the values obtained are above the limits set by the World Health Organisation (WHO, 2012). The sources of these metals can be both geologic and anthropogenic. Manganese may have been dissolved from the rocks and soils in the area as a result of deoxygination of groundwater by organic effluents. Lead may also enter groundwater through its dissolution from rocks, but it is typically introduced into the environment through automobile exhausts, lead pipes and possibly paints. Naturally occurring arsenic is the most common source of the element in groundwater, but the use of insecticides may have augmented this.

Stiff and Piper Plots



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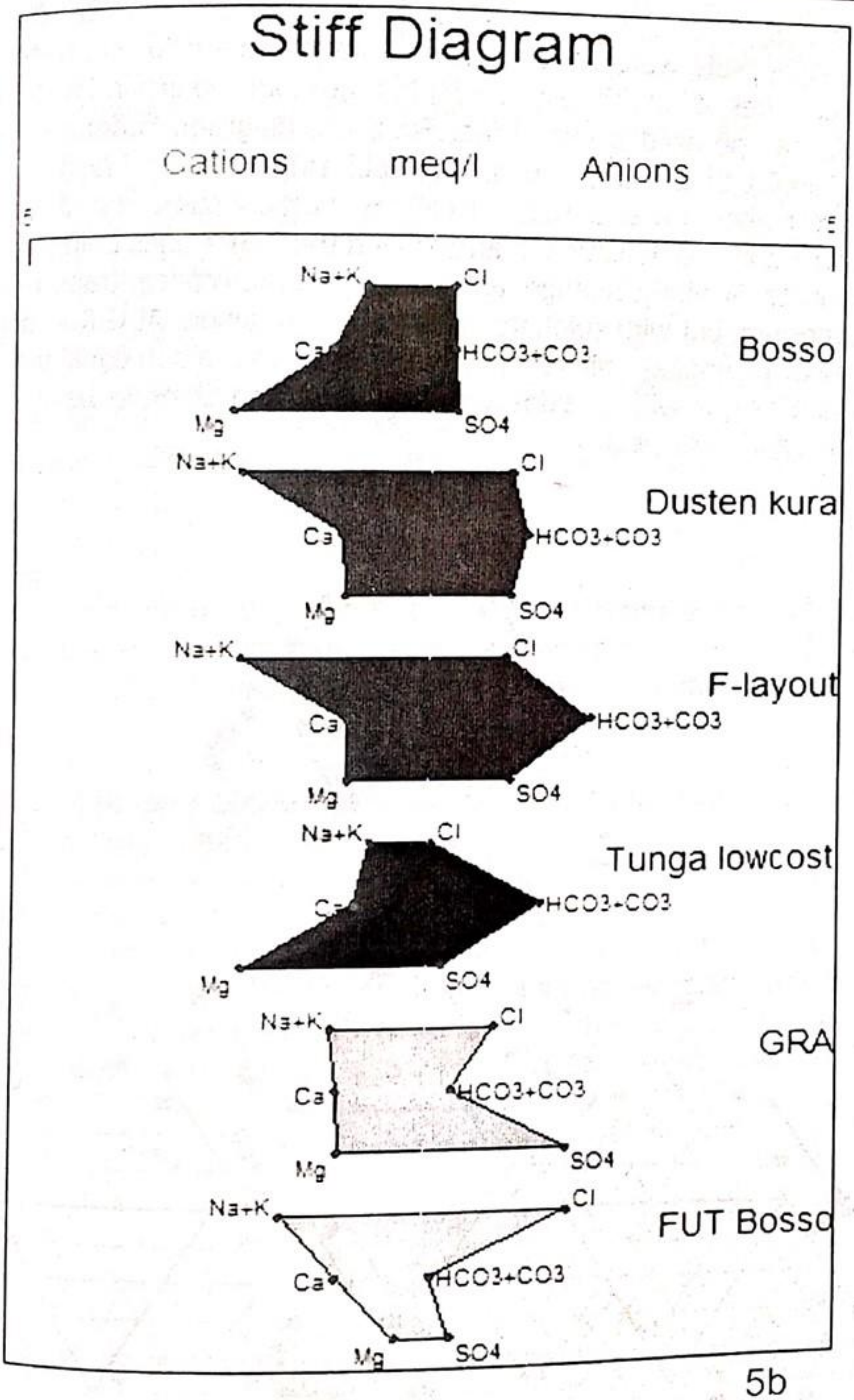

Fig. 5 (a and b) Stiff plot of water from different parts of Minna (modified after Stiff, 1951).

Stiff and Piper plots were used to identify waters of similar character and for classification. Results of Stiff plot (Fig.5) indicate that the ground water in Minna metropolis can be divided into three. From the diagram, Federal Government College (Minna), Chanchaga, Paida, Maitumbi, Dutsen Kura, F-layout and Tunga areas have higher concentrations of cations, notably calcium and magnesium, with a corresponding depletion in anions with the major ones being bicarbonate and carbonate. Similarly, Shango, and Bosso show high concentrations of calcium and magnesium, but with sulphate being the major anion. At G.R.A. and Federal University of Technology, Minna Bosso campus there is a sub equal proportion of cations and anions with sodium and potassium and chloride being the major cations and anions respectively.

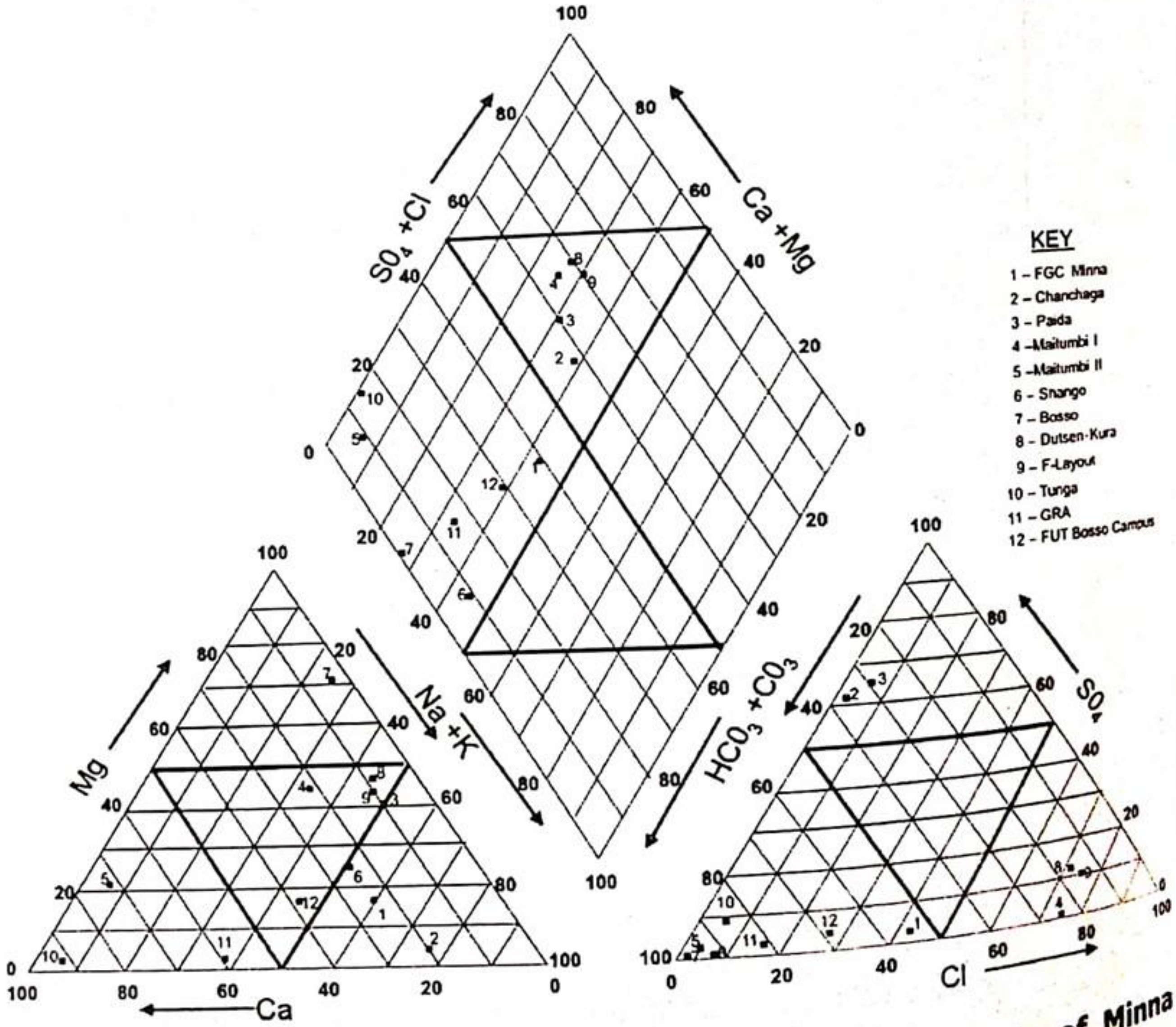

Fig. 6: Piper plot of groundwater from different parts of Minna (modified after Piper, 1944).

From hydrogeological point of view, groundwater is usually classified on the basis of the dominant ions present. The chemical composition of water is given as a percentage of equivalent per million (epm) of the anions and cations and is plotted (Fig.6), as a single point (Piper, 1944). On the basis of this, the water in Minna metropolis can generally be classified into two; a calcium carbonate water (secondary alkalinity) and a second one in which none of the cation-anion pairs exceed 50%, thus, indicating no dominant ion.

On the basis of location, the water in FGC, Maitumbi ,Shango, Bosso, Tunga , GRA and FUT Bosso campus have been classified as calcium carbonate water (secondary alkalinity). On the other hand, samples from Paida, Chanchaga, Dutsen-Kura and parts of Maitumbi have lower concentrations of both cations and anions.

Conclusion

The results of the analysis of physical and chemical parameters indicated that the pH, conductivity and temperatures have mean values of 5.24, 209.35μS/cm and 28.1°C respectively. These indicate that the physical parameters are low to moderate.

Chemical analysis gave generally low values, except for isolated enrichment of nitrate, carbonate, bicarbonate and the trace elements. Trace element concentrations have been found to be above the limits set by the World Health Organisation (WHO).

However the results have indicated that the ground water in Minna metropolis is generally of good quality and may not have suffered adverse degradation by human activities. The high concentration of Arsenic in Paida and Maitumbi areas is however worrisome, this may become a health hazard to the inhabitants in the future.

Table of Concentrations (mg/l)

location	Temp °C	Cond. µS/cm	pH	Ca	SO_4	Mg	CO_3	Na	HCO_3	NO_3	Fe	K	Mn	Cu	As	PO_4	Cl	Total Hardness as $CaCO_3$
FGC Minna	30.2	59.2	7	52.2	1.00	20.9	5.35	20.55	325	0.05	1.15	2.2	0.7	1.3	ND	0.35	5.0	216
Chanchaga	29.5	220	6.1	13.4	3.5	8.99	3.35	11.5	50	9.42	1.25	1.4	0.6	0.12	ND	0.2	3.0	70
Paida	27	240	10.2	13	9.25	31	1.22	4.25	132.8	6.2	0.38	2.75	0.08	1.03	0.29	17.5	0.63	110
Maitumbi north	28	158	8.5	18	3.25	6.0	0.85	16.5	44.8	4.2	0.12	7.75	0.05	0.14	0.61	2.0	0.46	85
Maitumbi south	29	130	8.2	147	2.84	29.5	1.35	40.15	58.3	0.06	0.14	4.35	0.04	0.01	0.05	0.03	5.2	93
Shango	30	227	6.9	180	4.0	28	2.35	28.65	62.54	44	0.01	0.22	0.3	0.2	0.01	1.6	12	49.4
Bosso	25	233	8.8	24	15	29.1	1.45	18.39	14.23	35.2	0.11	0.07	0.1	0.35	0.01	1.7	9.0	160
Dutsen Kura	27	198	7.2	21.66	48.04	12.75	30.01	39.1	11.5	35	0.01	23	0.11	0.21	0.01	1.4	35.46	126
F-Layout	28	200	6.8	20.04	48	12.16	30	39.1	61.1	20	0.01	23	0.05	0.04	0.01	1.2	33.5	145
TungaLowcost	30	240	7.3	17.99	8.66	27.13	12.19	28.8	61	11.5	1.66	12.65	0.65	0.35	0.01	2.33	30	205
G.R.A.	27	158	6.5	21.66	28	12.75	0.74	25	18	13.5	1.34	3.3	0.03	0.28	0.01	1.4	25	212
FUT Bosso	30	220	7.2	20.88	17	3.88	0.64	39	4.72	1.18	1.05	1.1	0.05	0.11	0.01	1.5	30	198
MEAN	28.39	190.27	7.56	45.82	15.71	18.51	7.46	25.92	70.33	15.03	0.60	6.82	0.23	0.35	0.10	2.60	15.77	139.12
WHO Standard			6.5-8.5	75	250	50		200		50	0.3		0.105	2.0	0.01		200	

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