RADIOACTIVITY AND CHEMISTRY OF GROUNDWATER FROM URANIUM MINERALIZED AREAS AROUND GURBRUNDE, NORTH-EASTERN NIGERIA

BY

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DEPARTMENT OF GEOLOGY

AHMADU BELLO UNIVERSITY

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2012

DECLARATION

I declare that the work in the dissertation entitled "Radioactivity and Chemistry of Groundwater from Uranium Mineralized areas around Gubrunde, North-eastern Nigeria" has been performed by me in the Department of Geology under the supervision of Prof. Idris Isa Funtua, Prof. Peter Zaborski, Dr. Solomon Ayodele Alagbe and Dr. Bala Bello Muhammad Dewu. The information derived from the literature has been duly acknowledged in the text and a list of reference provided. No part of this dissertation was previously presented for another degree or diploma at any University.

_____ _____

Abdullahi, Arabi Suleiman Signature Date

CERTIFICATION

This dissertation entitled "Radioactivity and Chemistry of Groundwater from uranium Mineralized Areas around Gubrunde, North-eastern Nigeria" by Abdullahi, Arabi Suleiman meets the regulations governing the award of degree of Ph.D. Applied Hydrogeology of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Uranium mineralization around Gubrunde, Kanawa, Zona and Dali in north-eastern Nigeria has been reported by previous workers. As a result of its chemical toxicity and/or ionizing radiation, consumption of groundwater with elevated uranium levels over a long period of time has the possibility of causing kidney and/or cancer problems. Thirty five groundwater samples were collected from dug wells within latitude 10°00'N to 10°30'N and longitude 11°30'E to 12°00'E. These samples were analyzed for mass/activity concentration of uranium, radium and thorium, concentration of major, minor and trace constituents in order to evaluate the risks associated with its use for different purposes. The results showed that uranium concentration ranges from 0.07 to 68.09µg/L (0.07 to 61.28pCi/L) with percentage relative standard deviation (%RSD) of 4.06%. A total of 5.7% of the samples analyzed had uranium concentrations exceeding the World Health Organization's maximum contaminant level of 30µg/L indicating a possibility that consumption of water from these areas over a long period of time might result in kidney and/or cancer problems. The presence of dissolved phosphate, slightly acidic and high iron values in the waters might have affected the migration of radionuclides from the rhyolite and undifferentiated granite and gneisses to water leading to low uranium levels in 84.3% of the samples. Values recorded for ^{226}Ra and ^{228}Ra range from 0.05 to 6.7pCi/L and 0.2 to 4.8pCi/L, respectively, which falls below the guideline of 20pCi/L. Thorium is not considered a threat as values recorded range from 0.02 to 1.10µg/L. Water types identified are Mg-HCO_3, Ca-HCO_3, Na-HCO_3, Mg-Cl and Ca-Cl types, with percentage distributions of 45.7%, 22.8%, 14.28%, 14.28% and 2.85%, respectively. As regards their suitability for irrigation, 82.7% of the samples were

categorized as good to excellent, 8.3% as permissible to good, 6% as doubtful to permissible, and 3% as unsuitable for irrigation.

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IST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ANL	Argonne National Laboratory
CERT	Center for Energy Research and Training
CPUT	Cape Peninsular University of Technology
EC	Electrical Conductivity
EDXRF	Electron Diffraction X-Ray Fluorescence
EPA	Environmental Protection Agency
EURACHEM	European Association of Chemical Measurement
FSN	Federal Survey of Nigeria
GUM	Guide to Expression of Uncertainty in Measurements
IAEA	International Atomic Energy Agency
IAH	International Association of Hydrgeologists
ICP-MS	Inductively Coupled plasma Mass Spectrometer
ICP-OES	Inductively Coupled Optical Emission Spectrometer
ICRP	International Commission on Radiological Protection
ICS	Instrument Calibration Standard
IEC	International Electrotechnical Commission
IPC	Instrument Performance Check
ISO	International Organization Standardization
LCS	Laboratory Control Sample
LET	Linear Energy Transfer
MCL	Maximum Contaminant Levels
NAA	Neutron Activation Analysis
NCRPM	National Council on Radiation Protection and Management

NIMET	Nigeria Metrological Agency
NIS	Nigerian Industrial Standard
NJDEOP	New Jersey Department of Environmental Protection
NMC	Nigeria Mining Corporation
NRC	National Resources Council
NUMCO	Nigeria Uranium Mining Company
PTDF	Petroleum Technology Development Fund
RBE	Relative Biological Effectiveness
REE	Rare Earth Element
RSC	Residual Sodium Carbonate
RSD	Relative Standard Deviation
SADA	Spatial Analysis and Decision Assistance
SAR	Sodium Adsorption Ratio
TDS	Total Dissolved Solids
TETFund	Tertiary Education Trust Fund
UCT	University of Cape Town
UNSCEAR	United Nations Scientific Committee on the Effect of Atomic Radiation
USSL	United States Salinity Laboratory
UWC	University of the Western Cape
VANR	Vermont Agency of Natural Resources
WHO	World Health Organization
WRP	Water Resources Programm

Chapter 1

INTRODUCTION

1.1 Background to the Study

Groundwater is most favored as a source of drinking water in Africa (International Atomic Energy Agency/Water Resources Program (IAEA/WRP, 2010). It is often thought to be cleaner and easier to treat compared to surface water and as a result, many wells have been either sunk or drilled. However, groundwater can be contaminated by anthropogenic activities while naturally it contains several chemical components, which can lead to different kinds of health problems. According to Karanth (1987) a groundwater source can potentially contain several naturally occurring chemical elements, many of which are not tested routinely as indices of water quality despite their known toxicity. Uranium and other radionuclides in water can lead to health problems if present in high concentrations. Examples of countries that have had problems with natural radioactivity in their water include Sweden, Finland, Norway, USA, Canada, India, Iran and Brazil (Argonne National Laboratory (ANL), 2007).

The Earth has two types of natural radioactivity namely primordial radionuclides that have survived since their creation (several billion years ago) and secondary radionuclides that are formed from the decay of primordial nuclides (Eisenbud and Gesell, 1997). Uranium is a primordial radionuclide with a half-life of 4.5 billion years. Uranium is the heaviest naturally occurring element and is found in an average concentration of 0.0003% (3mg/kg) in the earth crust. It is present at a concentration of about 3.0µg/L in seawater (Lal and Sess, 1968; Hess *et al*., 1985; Central Water Commission, 2000; Hakam *et al*., 2001; Bleise *et al*.,

2003; Guogang *et al*., 2005 and Nagarajan *et al*., 2009). Uranium isotopes during their disintegration course decay into other radioactive elements and eventually decay to stable lead isotopes (Fig. 1) and in the process emit beta and gamma radiation (Bleise et al., 2003).

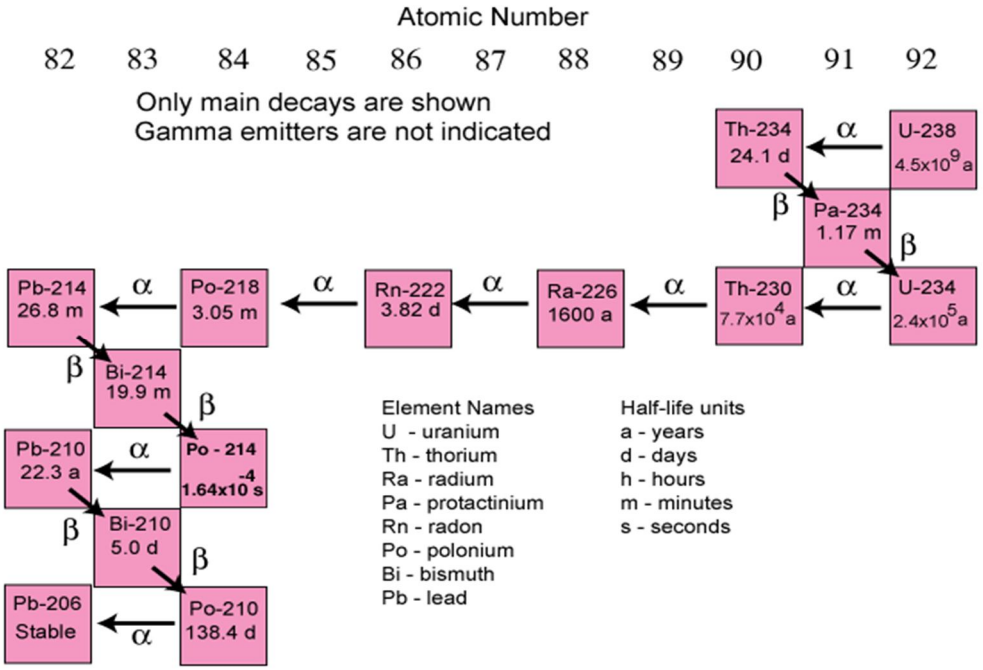


Figure 1: Uranium decay series

The decay products of ^{238}U (^{234}Th and ^{234}Pa) and ^{234}U (^{231}Th) are responsible for the presence of beta and gamma radiations in purified natural uranium (Bleise *et al*., 2003).

In the earth's crust, the average concentration of uranium is of the order of 2.7ppm (Siegel and Bryan, 2004). Uranium originates from magma and in some rocks, the uranium concentration is naturally higher than average amount due to the way rocks were formed and the types of minerals they contain (Keller, 1992). The major primary ores of uranium are uraninite and pitchblende whereas secondary uranium minerals, which were formed as a result of alteration and redistribution by groundwater, are mainly a mixture of uranium

oxides, other elements (Pb, Th, Cu, Ca, and P) and a certain content of water (Burns and Finch, 1999). Acid igneous rocks such as granite often have higher than average concentrations of uranium, of the order of 5 ppm (Akerblom and Lindgren, 1997). Other rock types that often have enhanced uranium concentrations include syenites, pegmatites, acid volcanic rocks and acid gneisses (Knutsson and Olofsson, 2002).

Despite a high content of uranium, some rock types are usually not considered problematic since water is not extracted from them because either they give no sustainable yields or the water cannot be used for drinking purposes due to contamination by other heavy metals that are even more toxic than uranium. Carbonaceous black shale is one example. A typical situation that is sometimes encountered is that wells are thought to have been drilled in low-uranium containing rock types, which in reality are supplied with water from another rock type deep below. The flow of groundwater to a drilled well in crystalline rock often follows fractures and fracture zones and other rock structures such as rock contacts (Olofsson *et al.,* 2001).

Radon is formed during the decay of radium, a progeny of uranium. During that process, the radon formed is propelled away from the site of decay and an alpha particle is recoiled in the opposite direction. Depending on its position and orientation in a mineral grain, the radon may either end up in the fracture carrying water or become buried deeper in the rock matrix (Fleischer, 1980). The fraction of radon atoms released into a pore as compared to the total radon produced from a radium-bearing grain is called the 'radon-emanating coefficient' (Edsfeldt, 1998). After emanation, other processes like diffusion and dispersion are responsible for the transport of the radon formed. Pre-requisites for uranium, radon and

radium to be transported in groundwater depend on the permeability of the bedrock. The flow of groundwater depends on potentials, which are often formed from groundwater recharge and topography. Groundwater flow is usually slow in fractures except in the vicinity where pumps are in operation (Olofsson *et al.,* 2001). Not all fractures are hydraulic conductors. Hydraulically significant fractures facilitate fluid flow and are connected to other hydraulically conductive fractures to form a network of fractures (National Resource Council, 1996).

Uranium, radium and radon are transported by different mechanisms in the groundwater. In rocks, uranium occurs in the +4 oxidation state and is immobile in that state at low temperatures and pressures. In an oxidizing environment (in which the groundwater in fracture contains an appreciable amount of dissolved oxygen), uranium is oxidized to the more mobile +6 state (UO_2^{+2}). Leached uranium goes into solution and is transported together with the groundwater. In the water, uranium (VI), as UO_2^{+2} ions, can also form complexes with commonly existing ions in groundwater such as OH^-, CO_3^{2-}, F^-, PO_4^{3-} and SO_4^{2-} (Chen and Yiacoumi, 2002), and may also be strongly complexed by dissolved humic substances (King *et al.,* 1982; Glaus *et al*, 2000). Uranium (VI) is also strongly bound by Fe oxides, at pH > 5 (Waite *et al*., 1994). Under reducing conditions when U (IV) predominates, sorption or co-precipitation of uranium with metal oxides in grain coatings becomes an important process (Schumann and Gundersen. 1996). The occurrence and distribution of ^{226}Ra in groundwater is principally controlled by its production from its immediate parent isotope, thorium (^{230}Th) as well as its removal from solution by adsorption or cation exchange processes (Herczeg *et al.,* 1998). According to Langmuir and Riese (1985), in natural waters Ra predominates as the free ion, Ra^{2+}, or as an uncharged complex

($RaSO_4$). Based on previous studies by Langmuir and Riese (1985), radium can easily be removed from solution by adsorption (on to for example. clays and rock silicates) or by co-precipitation with insoluble sulphates. It was also found that Ra appears to be stabilized in solution where high concentrations of Ca^{2+}, Mg^{2+} and Cl^- prevail. This is because these ions compete for adsorption sites.

As a result of the hydrogeochemical processes occurring in the subsurface, uranium and its decay products such as radium may be enriched on the surface of the fractures (Akerblom and Lindgren, 1997). This geochemical process significantly increases the radon emanation efficiency of the rocks (Schumann and Gundersen, 1996). Consequently, groundwater in uranium-rich crystalline rocks can have an elevated radon concentration in relation to the radon concentration of the surrounding rock types. Radon migration depends on a number of factors including emanation, diffusion and permeability of the rock.

As earlier stated, only a certain percentage of radon atoms emanated are released into the fracture and mobilized. The recoil distance is dependent on the density and composition of the material. The distance of ^{222}Rn is short and is of the order of 0.02-0.07 mm in mineral grains (Tanner, 1980). It is thus justified to assume that only a few millimetres layer of the rock near to the fracture surface can potentially contribute to increase the total ^{222}Rn concentration in the groundwater. This migration of radionuclides results in a disequilibrium of the water-rock system, implying that the activity of radionuclides in the groundwater is different from that in the surrounding matrix. The consequences of the geochemical reactions and the transport processes can result in high radon concentration in water and can render uranium and radium mobile and then transported.

The uranium concentration in groundwater sometimes depends on lithology, geomorphology and other geological conditions of an area (Schot and Van Der Wal, 1992; Bhatt and Saklani, 1996; Nisi *et al.* 2008). In groundwater, uranium occurs in dissolved and particulate form due to minerals such as uranite, pitchblende and carnalite or as secondary mineral in the form of complex oxides of silicates, phosphates, vanadates, lignite and monazite sands (Mahesh *et al*., 2001). Naturally, uranium occurs by mass of isotope proportions as 99.275% for ^{238}U, 0.72% for ^{235}U and 0.005% for ^{234}U. Therefore, theoretically, the radioactivity of ^{235}U or ^{234}U in water is negligible compared to ^{238}U (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1982). The behavior of the uranium and thorium decay series in groundwater has contributed to an understanding of the mechanisms of geochemical reactions and transport processes in rock-water systems. However, many uncertainties persist regarding the activities of these radio-elements in rock water systems, mainly due to the relative importance of nuclear alpha particle recoil and chemical processes, such as ion exchange, sorption and precipitation (Lyengar, 1990).

Radon exists as a gas and is a health hazard since exposure to the gas over a long period of time increases the risk of developing lung cancer (Darby *et al.,* 2005). Radon in water is a problem in that the gas easily degasses from the liquid and contributes to the total concentration in an indoor environment, implying that the main risk of contamination is via inhalation (Paulsen, 1991). Uranium on the other hand is more harmful due to its toxic nature rather than its radioactivity. Uranium has been identified as a nephrotoxin by the World Health Organization (WHO, 2011), implying it is a naturally produced chemical, which may cause kidney damage. Studies of human and laboratory animals have shown that uranium exposure leads to kidney problems (Zamora *et al.,* 1998: Kurttio *et al.,* 2002).

Groundwater can either be extracted from bedrock (by drilled wells) or from an overburden aquifer (by dug well). Private wells are often drilled or sunk to supply water to individual households that cannot be connected to a public water supply. Groundwater from overburden aquifers usually contains 5 to 50 Bq/L in soils with low uranium concentration and 10 to 100 Bq/L in soils with normal concentrations (Akerblom and Lindgren 1997). Radon is principally a problem in wells drilled in bedrocks that contain average or high concentrations of uranium. Uranium on the other hand can be a significant problem in both dug and drilled wells. This study therefore focuses on dug wells because it represents about 97% of sources of water used in the study area. It was also chosen because only one out of the three hand-pump boreholes in the study area was functional at the time of the study.

The surface runoff from agricultural fields is one of the main sources for nutrients and salinity in groundwater, and occurrence of nitrate and nitrite in the groundwater above the permissible limit is not conducive for drinking purpose (Lee *et al.,* 2003; Rajmohan and Elango, 2005). Nitrate results mostly from surface contamination caused by human activities. A condition called methemoglobinemia, also known as blue baby syndrome, results from the ingestion of high concentration of nitrate in its inorganic form. Nitrate contamination is strongly related to land use pattern and reported in several studies throughout the world (Kalkhoff *et al.,* 1992; Ator and Denis, 1997; Jeong, 2001; Elhatip *et al.,* 2003; Rajmohan *et al.*, 2009). Also, groundwater with low pH values can cause gastrointestinal disorder and this water cannot be used for drinking purposes (Laluraj and Gopinath, 2006). Total Dissolved Solids (TDS) values are also considered as an important parameter in determining the type/suitability of usage of water, and groundwater with high TDS values was not found to be suitable for both irrigation and drinking purposes (Freeze

and Cherry, 1979; Fetters, 1990). Rajmohan *et al.* (1997), Elampooranan *et al.*,(1999), Elango *et al.* (1998 ; 2003), Al-Bassam and Al-Rumikhani (2003), Sujatha and Rajeshwara (2003), Subramani *et al.* (2005), Jeevanandam *et al.* (2006) and Al-Futaisi *et al.* (2007) evaluated the suitability of groundwater from different places for irrigation using various parameters such as Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC),Wilcox, and US Salinity Laboratory (USSL) classifications methods.

1.2 Aim and Objectives of the Study

The aim of this study is to determine the natural radioactivity and chemistry of groundwater from an area with reported uranium mineralization in part of north-eastern Nigeria with the objectives of:

a. Determining radioactivity and chemistry of groundwater in the study area
b. Producing a groundwater radioactivity map for uranium and radium
c. Evaluating the risks associated with the use of groundwater from the area
d. Determining the salinity, Sodium Adsorption Ratio, Magnesium Hazard, Residual Sodium Carbonate and Exchangeable Sodium Ratio distribution in the study area.
e. Determining the levels of concentration of the major, minor and trace elements and compare with WHO, EPA and NIS guidelines.
f. Determining the dispersion pattern of the studied radionuclides in groundwater and its trends in and beyond the study area.

1.3 Scope of the Study

The scope of this study is limited to groundwater from hand dug wells in parts of Borno and Gombe State withing latitude 10°00'N to 10°30'N and longitude 11°30'E to 12°00'E

1.4 Justification of the Study

Uranium mineralization around Gubrunde, Kanawa, Zona, Dali in north-eastern Nigeria has been reported by Okujeni (1987), Okujeni *et al.* (1990), Funtua (1992) and Elegba *et al.* (1993). An uptake of uranium from soil and groundwater by plants (e.g. *Bosweilia dalzielli*) around the uranium occurrences has been reported by Okujeni (1987). Qualitative interpretation of the airborne radiometric map of the area showed a very prominent anomaly trending in a NE – SW direction (Labbo, 2009). High uranium amplitudes were observed along the anomaly with the highest value of 369 ppm around Gubrunde town. A magnetic discontinuity was identified on the total intensity aeromagnetic map and interpreted as faulting trending in a NE – SW direction. A 2-D magnetic model showed a depression in the basement which constitutes a graben and basement uplift that formed a horst suggesting the possibility that groundwater movement might be structurally controlled. The present study also delineated areas of high radiometric values associated with uranium amplitudes from aero-radiometric maps of the entire north–eastern region. The area was found to coincide with areas reported to host uranium mineralization.

The environmental transport of uranium is strongly influenced by its chemical form. It is generally one of the most mobile radioactive metals and can move down through soil in percolating water to underlying groundwater. Through groundwater and other media, uranium can concentrate in certain food crops and in terrestrial and aquatic organisms. The

U.S. Environmental Protection Agency (EPA) established a maximum contaminant level (MCL) for uranium in drinking water at 27pCi/L or 0.03mg/L (EPA, 2005) while the World Health Organization (WHO) put it at 30pCi/L (WHO, 2011). The chemical properties of uranium in drinking water are of greater concern than its radioactivity. Most ingested uranium is eliminated from the body. However, a small amount is absorbed and carried through the bloodstream. In addition to the risks of cancer and kidney problems caused by elevated uranium levels in drinking water (EPA, 2000), uranium has also been implicated in causing reproductive defects in laboratory animals and developmental defects in young animals (EPA, 2000).

Uranium enters well water from bedrock that contains uranium. The amount of uranium in bedrock and well water in its vicinity will vary greatly from place to place. It is therefore necessary to test well water in these places to determine if the water can be considered safe for drinking. The United States Environmental Protection Agency mandatory program in the context of its National Primary Drinking Water Regulation recommends gross alpha and beta radioactivity determination in groundwater as a first step in determining whether additional tests are advisable on groundwater while the Connecticut Department of Public Health, for example, recommends a uranium radioactivity test as its first step test before tests for other radionuclides can proceed. Therefore, there is a great deal of public concern about the level of radioactivity in groundwater even in areas that are not perceived as hosting uranium.

This study is the first of its kind to have been carried out in north-eastern Nigeria; therefore, the results would provide a baseline data for future groundwater radioactivity and chemistry study and serve as data for future comparison and tracking of groundwater quality changes.

1.5 *Location, Extent and Accessibility*

The study area (Figs. 2- 4) falls within the upper Benue Trough, and is bounded by latitudes 10^0 00'N and 10^0 30'N and longitudes 11^0 30'E and 12^0 00'E on sheet 153 (Wuyo) covering an area of about 3025km^2. All the areas sampled are connected with minor access roads through the major towns and villages either off the Gombe – Biu or Kwayakusar - Numan roads. Most of these roads are inaccessible during the rainy season.

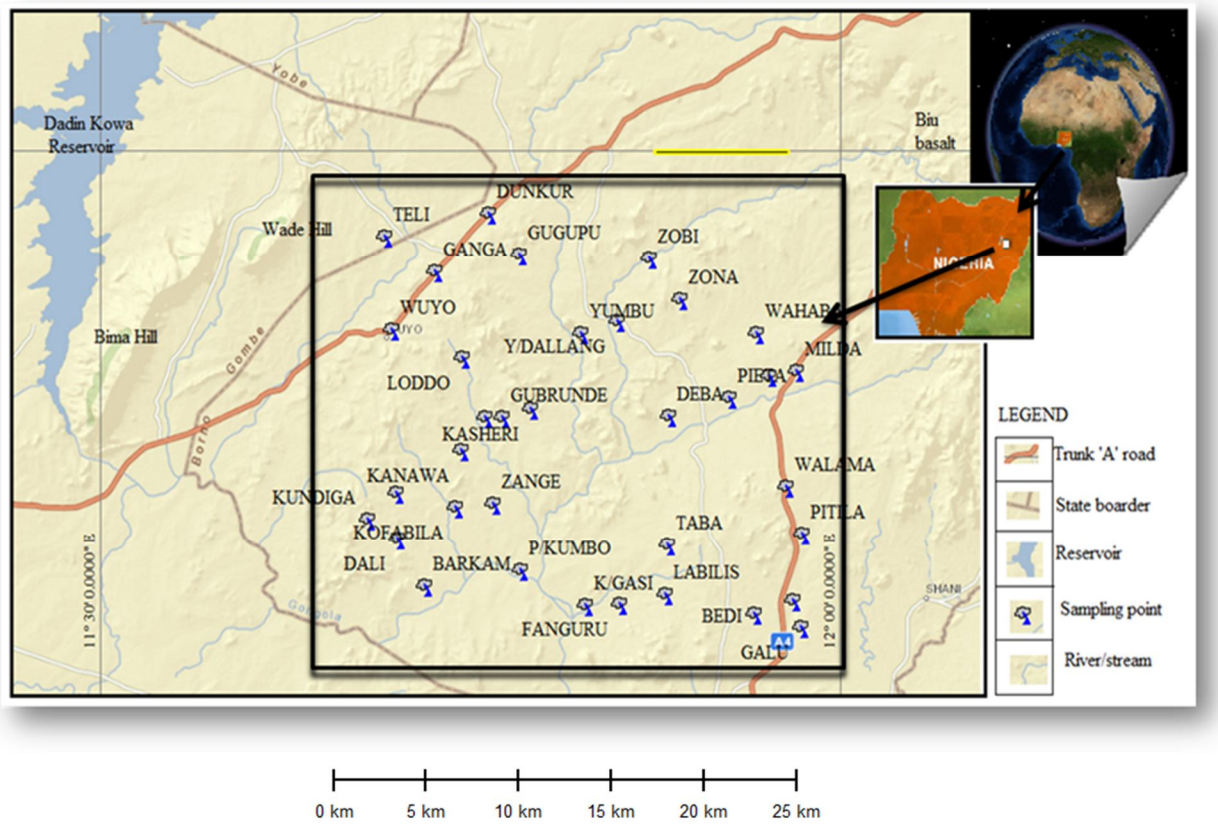


Figure 2: Location of sampled points within the study area (GlobalMapper 13)

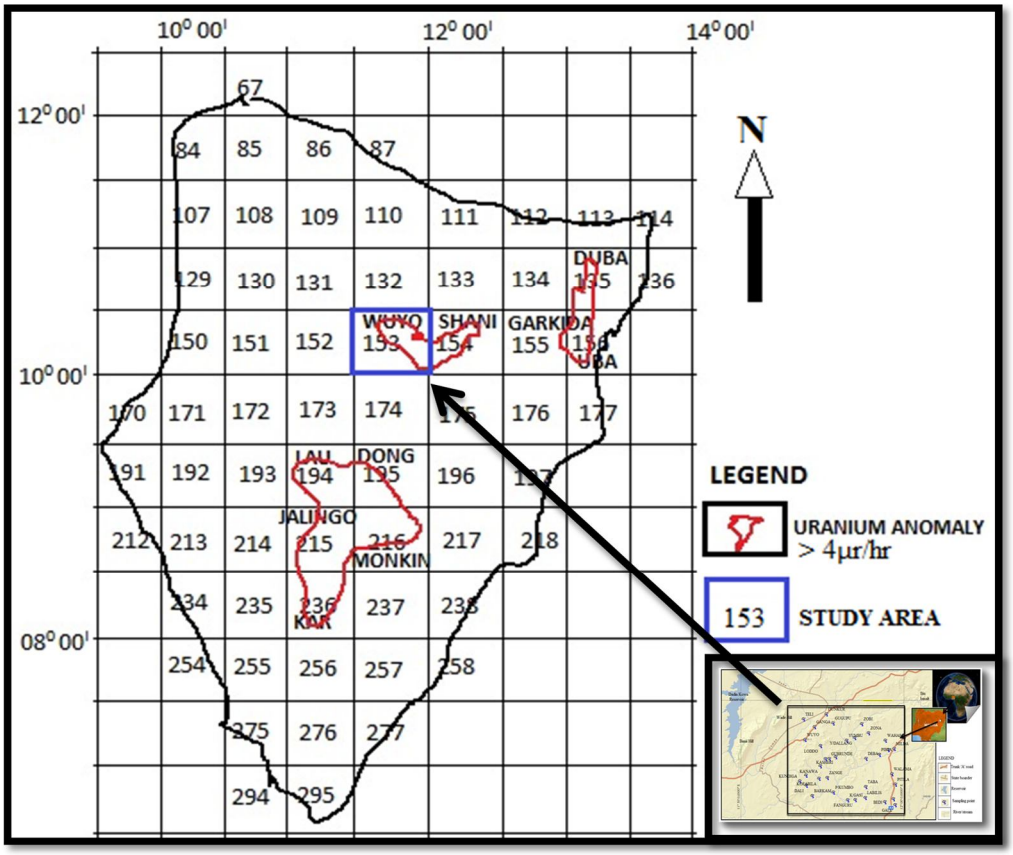


Figure 3: Outline of index map of Upper Benue showing the study area (Sheet 153) and areas with high uranium amplitudes (red color) (NGSA, 2004)

1.6 Relief and Drainage

The study area provides a great diversity of topographic forms. Rugged hills of granite and sandstone, volcanic plugs, sedimentary and volcanic plateaux and low, swampy plains are all present. The numerous geological units of the region are often clearly demarcated by topographic forms. The basement, the Cretaceous sandstones and the volcanic rocks form prominent hill features, but rarely exceed 310 masl. Granite, rhyolite and migmatite form isolated, rocky hills and low ranges of serrated outline. The northeast southwest trending rugged hills of the Bima Group around Wade in northwestern part of the study area form a prominent feature rising abruptly about 457 m above the plains of the River Gongola near

Kombo. Among the sedimentary rocks the most impressive hill features are formed by the Upper Bima sandstone group.

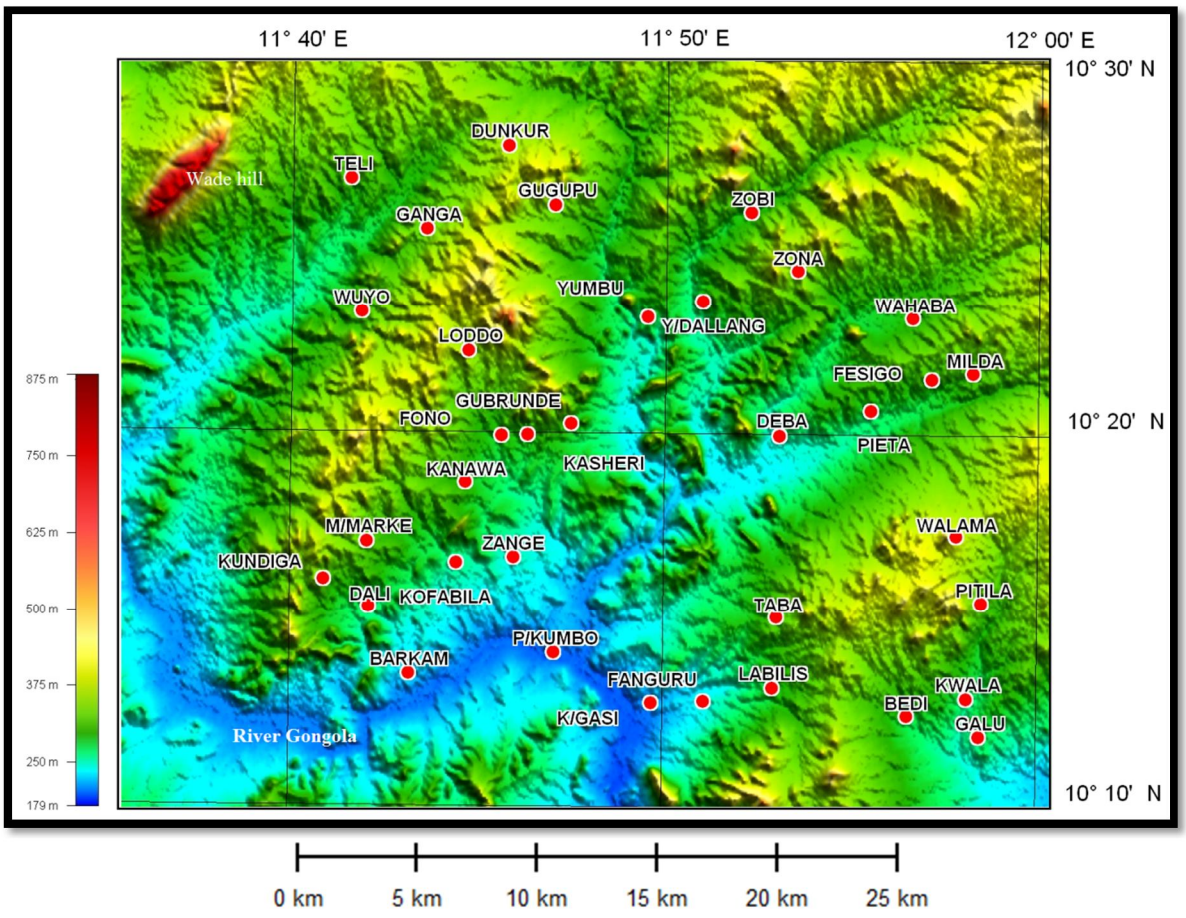


Fig. 4: Digital elevation model of the study area (GlobalMapper 13)

Cuestas are the commonest landforms in the area underlain by the Bima Group. The great cuestiform ranges of the Bima and Wade Hills dominate the landscape for hundreds of square kilometers and are famous historical landmarks in this part of the country. Numerous volcanic plugs and cones occur around Kasheri. The volcanic intrusions in the southern part of the region are the only hills in the extensive, low-lying plains of the Benue River (Carter *et al.,* 1963).

The major drainage system in the study area is the River Gongola and its tributaries. The River Gongola, and the River benue are the two major hydrographical systems that traverse northeastern Nigeria. The Benue and its tributaries and the Gongola, River drain over 90% of the region.

1.7 Climate and Vegetation

The study area is characterized by scattered shrubs and trees typical of the Sahel savannah vegetation. Trees around include gum Arabic whose leaves rarely escape the picking of grazing animals.

The area experiences two seasons, the rainy and dry seasons. The rainy season in most cases lasts for six to seven months (from late April to early October) with mean annual rainfall of about 967.82mm measured at Gombe Meteorological Station, while the dry season lasts five to six months (early October to early April) during which a dry dust laden harmattan wind blows from the northeast (Nigeria Meteorological Agency [NIMET] 2007).

The temperature is relatively uniform throughout the year except for the diurnal nature. The mean monthly air temperature ranges from around 25°C in January to 32°C in April which is the hottest month just before the setting in of the rains. The coolest months in the study area are December and January where the average daily temperature may fall to 24.70°C and 25.29°C respectively (Nigeria Meteorological Agency (NIMET), 2007).

1.8 Land Use

The land use in the study area is mostly for agriculture and animal husbandry. Almost every piece of appropriate land is cultivated during the rainy season because farming is the primary occupation of inhabitants of the area. Major crops are cultivated on farmlands further away from homes while vegetables are cultivated in backyards and in some cases even in open spaces inside homes. Movement of animals is restricted during the rainy season because most of the crops cultivated can be eaten by animals but during dry season most animals feed on the remains of cultivated plants late in the dry season when animals can only scavenge for shrubs and leaves. Dry season farming is also practiced along river channels where tomatoes and other vegetables are cultivated on banks of rivers and on lands that are still marshy even during this period. The planting of sugarcane is also done during dry season along river channels and on marshy lands where shallow wells are dug. In some cases, shallow tube wells are drilled for watering of the cultivated plants.

Chapter 2

LITERATURE REVIEW

2.1 Geology and Hydrogeology of the Study Area

2.1.1 Review of the Regional Geology

The Cretaceous and Tertiary sedimentary formations in the study area were first described by Falconer (1911). Carter *et al.* (1963) mapped the Federal Survey of Nigeria 1:250,000 Sheets Nos.85, 153 and 194 (Potiskum, Gombe and Lau). Guiraud (1989) published geological maps of part of Upper Benue valley covering Sheets 153 and parts of Sheets152 and 154 at a scale of 1:50,000.

The Precambrian basement, Meocene volcanics, Cretaceous, Tertiary and Quaternary sediments, and Neogen volcanics outcrop in the upper part. The oldest rocks comprise the remnants of an ancient sedimentary series which have been transformed into anatectic migmatites and granites. Sedimentation was followed by an orogenic cycle during which the Older Granites were emplaced. The "Older Granites" are distinguished by three phases; basic and intermediate plutonic rocks; fine-grained granites; and syntectonic granites. Small, irregular bodies of gabbro and quartz-diorite and small discordant bodies of fine-grained granite represent the earliest intrusions of the Older Granites (Carter *et al.,* 1963). Granitization on an extensive scale followed where a diverse and widespread series of syntectonic granites were emplaced. Granitization profoundly modified the earlier rocks and large tracts of syntectonic migmatites and hybrid rocks were formed. The end of the Older Granite orogeny was marked by the intrusion of granitic dykes and after a considerable interval, an episode of high level magmatic activity commenced. The Older Granites

represents a cycle of granitic evolution in which anatexis and all stages of granitization and magmatic activity are displayed. The rocks vary considerably in structure, texture and mineralogy and show diverse contact relationships with the metasediments.

Four divisions of the granites and porphyries are recognized; the Kwaba Hill granites not far from Shelleng (Funtua, 1992), the Jamboram Hill porphyry; the Bongna Hills volcanics; and felsic dykes. The age of Burashika Group is not clear; these rocks intrude the Older Granites and are overlain by the Early Cretaceous Bima Group (Grant *et al*., 1972). The Burashika Group might be related to the "Younger Granites" for which a Jurassic age is indicated as they contain distinctive rock types often characterized by tin mineralization and the presence of riebeckite and amphibole-fayalite-granites which were emplaced in the basement by ring fracturing and cauldron subsidence (Jacobson *et al*., 1958).

The basement is overlain by a great thickness of continental sands and clays, the Bima Group which is overlained by transitional and marine deposits of the Yolde and Pindiga formations, respectively. The Bima Group comprises Early Cretaceous continental clastics, dominantly marine Late Cretaceous succession (Zaborski, 1998). Continental conditions were re-established in the Maestrichtian and resulted in the deposition of the upper part of the Gombe Sandstone. A period of folding followed and a further continental succession, the Kerri-Kerri Formation, uncomformably overlies the Gombe Sandstone. The Kerri – Kerri Formation is assigned to the Paleocene.

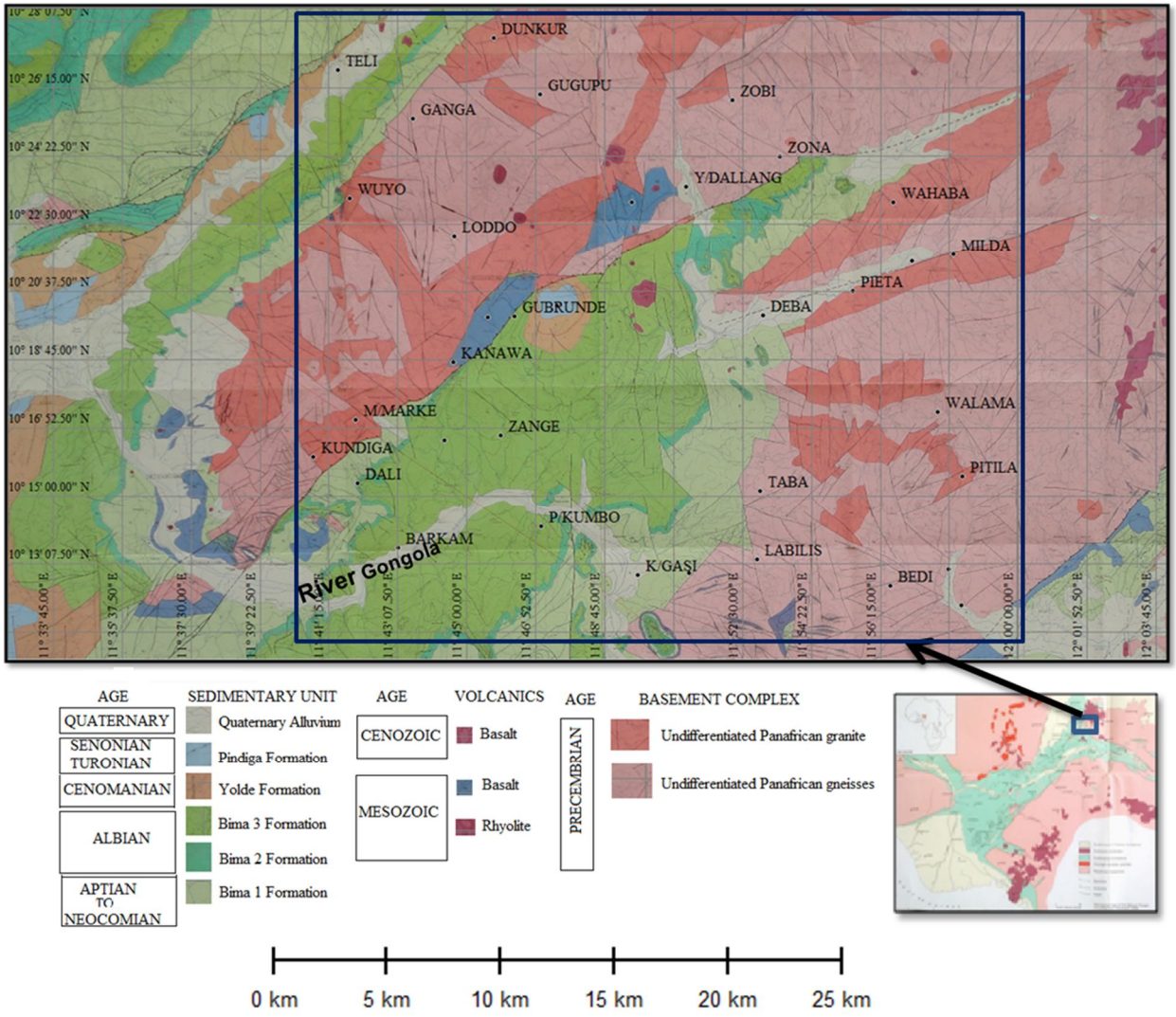


Figure 5: Location of the study area superimposed on Geological map of the study area (Guiraud, 1989) inset is geologic map of Benue trough showing location of the area.

2.1.2 Geology of Uranium Mineralization in the Study Area

The geology of the study area (Figure 5, see also Appendix II for enlarged map) comprises the Precambrian basement, the Late Jurassic to Early Cretaceous volcanics, the Bima Group, the Yolde Formation, the Pindiga Formation, and the Neogene to Quaternary basalts. Uranium mineralization in the Gubrunde horst occurs within the Bima Group at Zona and Dali (Funtua, 1992).

The Gubrunde horst is bounded by the Neogene basalt of the Biu Plateau and the sedimentary sequences of Bryel and Zange to the north and north-west, respectively. The horst itself is comprises crystalline basement rock. Migmatite, gneissic complex, granitic complex of mafic to intermediate plutonic rocks (diorite and granodiorite) as well as fine-grained granite and syntectonic porphyritic and equigranular granite form the main rock types.

According to Ojo (1988), the Gubrunde horst was subjected to metamorphism, granitization, feldspathization and tectonism which according to Carter *et al.* (1963), Burke and Durotoye (1970) and Ojo (1984) resulted in the intrusion of volcanic rocks. Also associated with the basement rocks are volcanic rocks such as rhyolites in veins and fracture zones.

According to Funtua, (1992) uranium mineralization occur in three main areas at Kanawa, Gubrunde and Adada but numerous thorium and uranium anomalies has been detected within the Gubrunde horst.

At Kanawa, the granite has been intruded in places by rhyolites, pegmatite and aplite bodies (Funtua, 1992). Uranium mineralization occurs along a north-south trending sheared zone near Kanawa village extending for more than 4 km (Funtua, 1992). The uranium ores are located at the contact of sheared rhyolite bodies and the granites (Funtua, 1988) are zoned with a central volcanic breccia and re-silicified volcanic fragments, sorrounded by altered, laminated and silicified volcanic fragments (Funtua, 1992). Also, according to Funtua et al. (1997), the radon emanation fraction of rhyolite and granite uranium ore samples from N. E. Nigeria (essentially phospho-uranylite and meta-autunite) and the variation of recorded γ-ray activity with particle size indicate emanation fractions of 0.22 for the phospho-uranylite

ore and 0.31 for the meta-autunite ore. According to Okujeni *et al*. (1990), the ore minerals are phosphor-uranylite, meta-autinite and kasolite with traces of galena and chalcopyrite. The results of geochemical and gamma spectrometric analysis of ores and host rock from the Kanawa uranium occurrence obtained by Okujeni and Funtua, (1994) show an enhancement of U, Mn, P_2O_5, Fe_2O_3, CaO, ^{210}Pb, ^{226}Ra and ^{234}Th in the ore zones.

At Gubrunde, uranium is also associated with siliceous breccias and rhyolite veins emplaced between the granite basement and the volcano-sedimentary formations of the Gubrunde complex (Funtua *et al.,* 1997).

According to Suh *et al.* (2000), the only significant uranium occurrence around the study area is the Zone uranium anomaly. (see map of structure and geology of Zona occurrence in Appendix III).

2.1.3 Hydrogeology

Shortage of both surface and groundwater at some places within the study area is partly caused by the high rate of evaporation during the dry season and by variations in permeability of the rocks. Groundwater is the predominant source of potable water supply in this region. The Gongola River has perennial surface flows and its importance as a source of water has attracted settlements near its bank. Springs are of subsidiary importance as most dry up before the end of the dry season. Springs around the margins of the Biu and Longuda plateaux and at Baure along the Gombe-Dadin-Kowa road however, provide supplies to certain villages.

Groundwater in the Crystalline Basement and the Basalts: Groundwater in the crystalline basement rocks and plateau basalts is localized in pockets and patches of weathered rocks and fractures. Wells usually encounter water at shallow depths but yields are often low and subject to seasonal fluctuations. Boreholes are usually sited near river channels and where overburden is thickest. On the basalt-capped plateaux the weathered zone near some of the larger streams is up to 9 m thick and yields moderate amounts of water, usually two to three liters per second. The basalts are usually jointed which permits the circulation and storage of groundwater which issues as small springs along the margins of Biu and Longuda plateaux (Carter *et al.,* 1963).

Groundwater in Sedimentary Rocks: Groundwater occurrences are generally good in the study area, but depend on location and depth to aquifers because of the lithology and structure of the underlying sedimentary rocks. Gently inclined, impermeable fine-grained horizons found within the aquifers of the Yolde Formation give rise to artesian conditions.

The Bima Group in some places around Wade- Shinga axis provide good water supply at both watertable and confined conditions at many locations because they consists of porous and permeable rocks.

The Yolde Formation outcrops on the gently – sloping plain, immediately east of Gombe town giving rise to a gentle slope towards the Gombe Hills. The formation is saturated at shallow depth.

The Pindiga Formation consists essentially of impermeable shale that produces very little water in boreholes, sand layers occur within the Deba Fulani member and form pressured and patched aquifers (Arabi, 2006).

According to the general information available and the result of hydrogeological reconnaissance (Arabi, 2006), (Offodile, 2002), the stratigraphic succession of the study area could be defined from the hydrogeological point of view as follows (from oldest to youngest).

(a) Bima Formation: This contains aquifers of variable yield under both watertable and confined conditions or as layer of porous and permeable sandstone confined at top and bottom by thin layers of clay and in others as consolidated sand where water can only be got in fractures.

(b) Yolde Formation: This occurs in some places as aquicludes within the clayey layers but with scattered water bearing horizons mostly within the sandstone and limestone aquifers in its lower part.

(c) Pindiga Formation: This formation is mostly made of thick clays and shales

(d) Recent deposits; generally permeable but do not provide sufficient ground water supply because they are mostly not thick enough, are mainly dry for most of the year except along river channels.

2.2 Radioactivity

Naturally occurring radioactive substances are frequently found in groundwater in low concentrations. They are present at least to some extent in almost all rocks and soils (Fig. 6). Radioactivity in drinking water is not a new phenomenon, having been present to some

extent since the earth was formed. Radionuclide testing of public drinking water systems has been required in developed countries since the 1970's; however, uranium testing has not been required in developing countries until recently. Concentrations of uranium, thorium, radium and other radionuclides in drinking water above the US Environmental Protection Agency's (EPA's) Maximum Contaminant Level (MCL) over a long period is believed to cause kidney damage and to increase one's lifetime risk of developing certain types of cancer.

Geologically, high levels of uranium, thorium and radium in drinking water are most likely to be found in uranium mineralized provinces and neighboring regions. It is also possible for radium and radon in water to be found in this area.

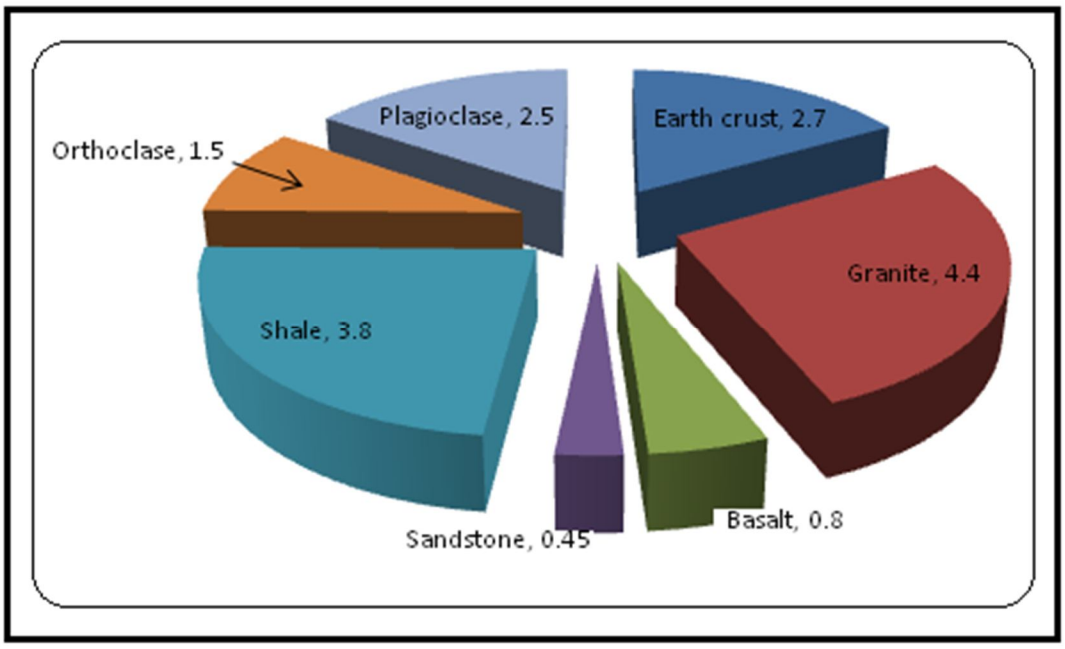


Figure 6: Concentrations of Uranium in Rocks and Minerals (Wanty and Nordstroms, 1993)

2.2.1 Ionizing Radiation

Ionizing radiation is energy that is carried by any of several types of particles and rays (electromagnetic radiation) given off by radioactive materials, X-ray machines, and nuclear reactions. This energy can knock electrons out of atoms in materials with which they interact, thus creating ions. Non-ionizing radiation, such as that emitted by a laser, is different because it does not create ions when it interacts with matter but dissipates energy generally in the form of heat. The three main types of ionizing radiation are alpha particles, beta particles, and gamma rays.

An alpha particle consists of two protons and two neutrons and is identical to the nucleus of a helium atom. Because of its relatively large mass and charge, an alpha particle produces ions in a localized area. An alpha particle loses some of its energy each time it produces an ion (its positive charge pulls electrons away from atoms in its path), finally acquiring two electrons from an atom at the end of its path to become a complete helium atom. An alpha particle has a short range (several centimeters) in air and cannot penetrate the outer layer of skin.

Beta particles are smaller and more penetrating than alpha particles, but their range in tissue is also quite limited. Beta particles can be either negative (negatron) or positive (positron). Negatrons are identical to electrons and originate in the nucleus of an atom that undergoes radioactive decay by changing a neutron into a proton. The only difference between a negative beta particle (negatron) and an electron is the ancestry. A beta particle originates in the nucleus whereas an electron is external to the nucleus. Unless otherwise specified, the term “beta particle” generally refers to a negatron. A positron is emitted from an atom that

decays by changing a proton into a neutron. When its energy is spent, a negatron attaches itself to an atom and becomes an ordinary electron, while a positron collides with an ambient electron and the two particles annihilate each other, producing two gamma rays. When a negatron passes close to the nucleus of an atom, the strong attractive Coulomb force causes the beta particle to deviate sharply and lose energy at a rate proportional to the square of the acceleration; this energy manifests itself as photons termed Bremsstrahlung.

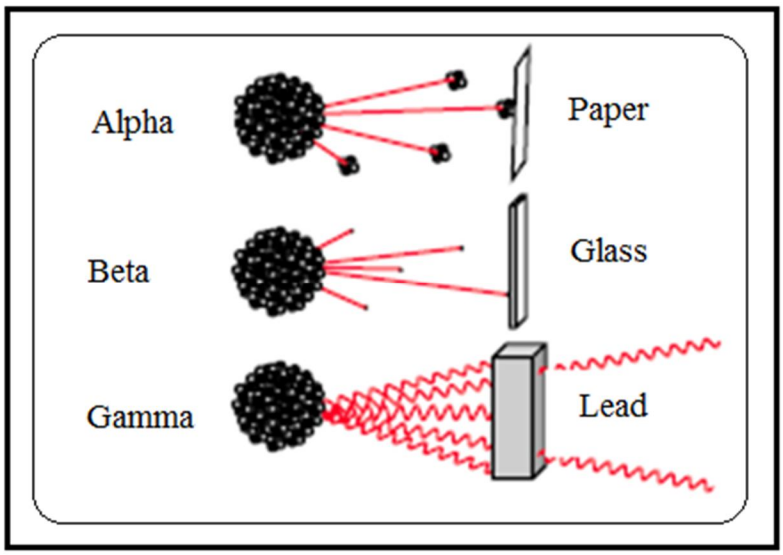


Figure 7: Penetrating capacities of the three types of ionizing radiation

The amount of beta energy converted into photons is directly proportional to the energy of the beta particle. This effect is only significant for high-energy beta particles generally passing through very dense materials such as lead, i.e., those with higher atomic numbers and so more protons in the nucleus.

Gamma rays are electromagnetic radiation given off by an atom as a means of releasing excess energy. They are bundles (quanta) of energy that have no charge or mass and can travel long distances through air (up to several hundred meters), body tissue, and other

materials. A gamma ray can pass through a body without hitting anything, or it may hit an atom and give that atom all or part of its energy. This normally knocks an electron out of the atom, ionizing it. This electron then uses the energy it receives from the gamma ray to create additional ions by knocking electrons out of other atoms. Because a gamma ray is pure energy, it no longer exists once it loses all its energy. The capability of a gamma ray to do damage is a function of its energy, where the distance between ionizing events is large on the scale of the nucleus of a cell. Additional forms of ionizing radiation beyond the three types shown in Fig. 7 include neutrons, protons, neutrinos, muons, pions, heavy charged particles, X-rays and others (Argonne National Laboratory, 2007).

2.2.2 Sources of Ionizing Radiation

All organisms are being exposed to ionizing radiation from natural sources all the time. Sources and distribution of average radiation exposure for the World population has been evaluated by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) as given in Figure 8, (UNSCEAR, 2000). Radiation doses are typically given in units of rem – an acronym for Roentgen equivalent man – or millirem (mrem), which is one one-thousandth of a Rem. This unit was developed to allow for the consistent reporting of hazards associated with the various types and energies of radiation on the human body. The rem is the product of the absorbed dose in rads (i.e., the amount of energy imparted to tissue by the radiation, where 1rad equals 0.01 joules/kg) and factors for the relative biological effectiveness (RBE) of the radiation. The RBE is directly related to the linear energy transfer (LET) or distance over which the radiation energy is imparted to the absorbing medium and is accounted for by a quality factor. For example, alpha particles are 20 times more hazardous than beta particles for the same energy deposition and hence have

a quality factor of 20, whereas the quality factor for beta particles is one. The International Commission on Radiological Protection (ICRP) has developed a methodology for reporting the effective dose equivalent. This is the product of the dose (in rem or mrem) to individual tissues and the tissue-specific weighting factors (fractional values less than one) that indicate the relative risk of cancer induction or hereditary defects from irradiation of that tissue, summed over all relevant tissues. By use of the effective dose equivalent, it is possible to compare the relative radiation hazards from various types of radiation that impact different organs of the body. Most of the total dose received by individuals in the United States for example comes from natural sources; 55% comes from radon gas decay products, 8% from cosmic radiation, 8% from terrestrial radiation, and 11% from internal sources such as potassium-40. The rest comes from man-made sources that include medical X-rays (11%), nuclear medicine (4%), consumer products (3%), radioactive fallout, and nuclear power plants (<1%). Sources and distribution of average radiation exposure for the World population is presented in Figure 8. These percentages are representative, and not all people are exposed to the same sources to the same degree. The National Council on Radiation Protection and Measurements (NCRP) estimates an average radiation dose of 360 mrem/yr from natural and man-made sources, with about 300 mrem/yr from natural sources and 60 mrem/yr from man-made sources (mostly from medical procedures).

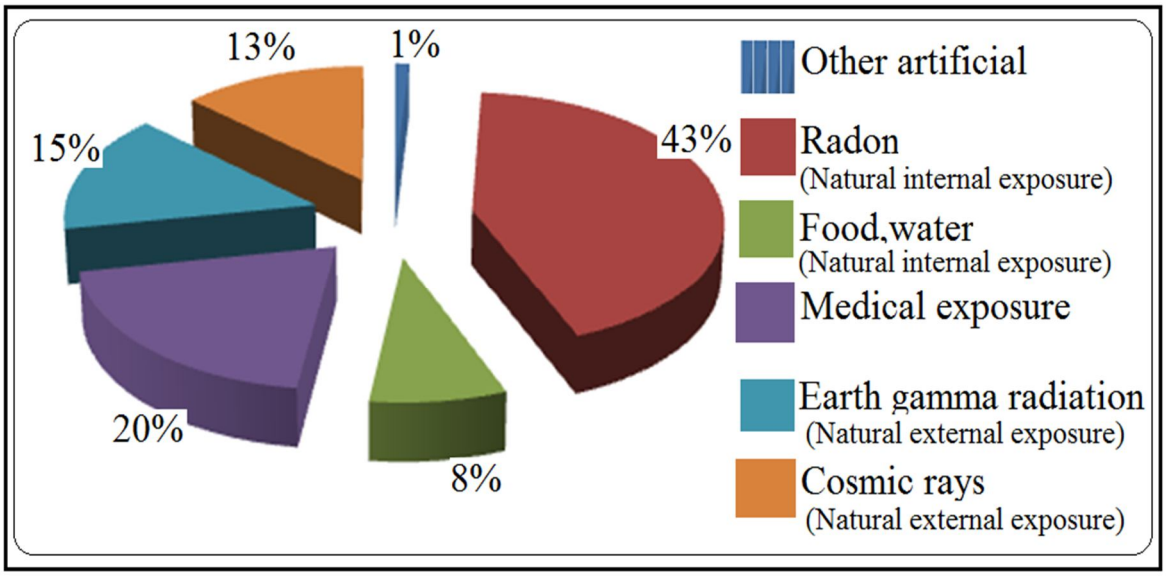


Figure 8: Sources and distribution of average radiation exposure for the World population (United Nations Scientific Committee on the Effect of Atomic Radiation, 2000)

2.2.3 Applications of Ionizing Radiation

Some radioactive materials and other sources of ionizing radiations are not very harmful, they are widely used to detect and treat diseases in both human and veterinary medicine. Medical and dental X-rays are used to detect problems such as broken bones and dental cavities. Sealed radiation sources are used to deliver very high, localized radiation doses to treat certain types of cancers. Ionizing radiation also has a number of industrial and commercial uses. Radioactive sources are used in consumer products' quality checks such as smoke detectors and also to sterilize food products to improve their shelf life. Ionizing radiation is also used to test materials, inspect welds, generate heat and electricity for space travel, determine soil moisture content, and track the movement of various elements in the environment and human body (through the use of radioactive tracers).

2.2.4 Health Effects of Ionizing Radiation

High doses of ionizing radiation can lead to skin burns, hair loss, birth defects, illness, cancer and even death, depending on the dose and the period of time over which it is received. High doses such as from a serious accident involving nuclear materials can result in damage to the blood-forming organs, gastrointestinal tract, and central nervous system. Very high doses (e.g., on the order of 500rem (500,000mrem) or more) can cause death in many (but not all) individuals, depending on the degree of medical intervention. The main health concern associated with radiation exposure is the induction of various cancers. Other effects may include genetic mutations (although none have been observed in humans) and teratogenic effects such as mental retardation. The U.S. Environmental Protection Agency (EPA) has indicated that for radioactively contaminated sites, the risk from cancer is limiting and should be used as the sole basis for assessing radiation-related human health risks. The EPA noted that on average; about 50% of all cancers that can be induced by radiation (they can also be caused by other agents) are fatal, ranging from about 10% for thyroid cancer to 100% for liver cancer. Other EPA estimates for specific isotopes indicate the average may be higher, 60 to 70% or more.

2.2.5 Radionuclides in the Body

Radioactive materials can enter the body by inhalation, ingestion, or dermal absorption. In addition, gamma radiation external to the body can penetrate the skin and produce a dose in various tissues. Inhalation is the primary exposure mode for gaseous radionuclides (such as radon), and particulates near the source of an airborne release. A fractional amount of inhaled radionuclides is transferred from the lungs to the blood, where it is distributed to other organs. The extent of absorption is strongly dependent on the radionuclide and its

chemical form. Ingestion is the primary uptake mode for radionuclides in soil, water, and food, including those naturally occurring (such as radium and uranium in soil and groundwater) and man-made (such as plutonium from radioactive fallout). A fractional amount of ingested radionuclides is absorbed from the gastrointestinal tract into the blood while the rest is cleared from the body through normal biological processes via urine and faeces. As with inhalation, the extent of uptake depends on the radionuclide and its chemical form. The skin is generally an effective barrier against absorption of radionuclides, so dermal absorption is a very minor route of exposure. An exception to this is dermal absorption of tritiated water, i.e., water containing some amount of tritium (hydrogen-3) in place of a normal hydrogen atom in the water molecule, which is absorbed through the skin in the same manner as ordinary water (Argonne National Laboratory, 2007).

Radiological Risk Coefficients for Uranium: Table 1 provides selected risk coefficients for inhalation and ingestion of uranium. Recommended default absorption types were used for inhalation, and dietary values were used for ingestion. These values include contributions from short-lived uranium decay products. Risks are for lifetime cancer mortality per unit intake (pCi), averaged over all ages and both genders (10-9 is a billionth, and 10-12 is a trillionth).

Table 1: Risk coefficient for lifetime cancer mortality for inhalation/ingestion of uranium

	Lifetime Cancer Mortality Risk	
Isotope	**Inhalation** (pCi/L)	**Ingestion** (pCi/L)
Uranium-234	1.1×10^{-8}	6.1×10^{-11}
Uranium-235	9.5×10^{-9}	6.2×10^{-11}
Uranium-238	8.8×10^{-9}	7.5×10^{-11}

Radiological Risk Coefficients of Radium in the Body: Table 2 below provides selected risk coefficients for inhalation and absorption of radium. Recommended default absorption types were used for inhalation, and dietary values were used for ingestion. These values include the contributions from the short-lived radium decay products. Risks are for lifetime cancer mortality per unit intake (pCi), averaged over all ages and both genders (10-9 is a billionth).

Table 2: Risk coefficient for lifetime cancer mortality for inhalation/ingestion of Radium

	Lifetime Cancer Mortality Risk	
Isotope	**Inhalation** (pCi/L)	**Ingestion** (pCi/L)
Radium-226	2.4×10^{-8}	2.9×10^{-9}
Radium-228	9.0×10^{-8}	1.3×10^{-9}

Radiological Risk Coefficients of Thorium in the Body: Table 3 below provides selected risk coefficients for inhalation and ingestion of thorium. Recommended default absorption types were used for inhalation, and dietary values were used for ingestion. These values include the contributions from the short-lived thorium decay products. Risks are for lifetime cancer mortality per unit intake (picocurie, pCi), averaged over all ages and both genders (10-9 is a billionth, and 10-12 is a trillionth).

Table 3: Risk coefficient for lifetime cancer mortality for inhalation/ingestion of Thorium

	Lifetime Cancer Mortality Risk	
Isotope	**Inhalation** (pCi/L)	**Ingestion** (pCi/L)
Thorium-229	2.2×10^{-7}	4.7×10^{-10}
Thorium-230	2.7×10^{-8}	8.0×10^{-11}
Thorium-232	4.1×10^{-8}	9.1×10^{-11}

2.3 Natural Decay Series of Uranium and Thorium

Uranium, radium, and thorium occur in three natural decay series, from uranium-238, uranium-235, and thorium-232 parents, respectively. In nature, the radionuclides in these three series are approximately in a state of secular equilibrium, in which the activities of all radionuclides within each series are nearly equal. Two conditions are necessary for secular equilibrium. Firstly, the parent radionuclide must have a half-life much longer than that of any other radionuclide in the series. Secondly, a sufficiently long period of time must have elapsed, for example ten half-lives of the decay product having the longest half-life, to allow for in-growth of the decay products. Under secular equilibrium, the activity of the parent radionuclide undergoes no appreciable changes during many half-lives of its decay products. The radionuclides of the uranium-238, thorium-232, and uranium-235 decay series are shown in Figures 9, 10 and 11 along with the major mode of radioactive decay for each element. Radioactive decay occurs when an unstable (radioactive) isotope transforms to a more stable isotope, generally by emitting a subatomic particle such as an alpha or beta particle. Radionuclides that give rise to alpha and beta particles are shown in Figures. 9 - 10, as well as those that emit gamma radiation (Argonne National Laboratory, 2007).

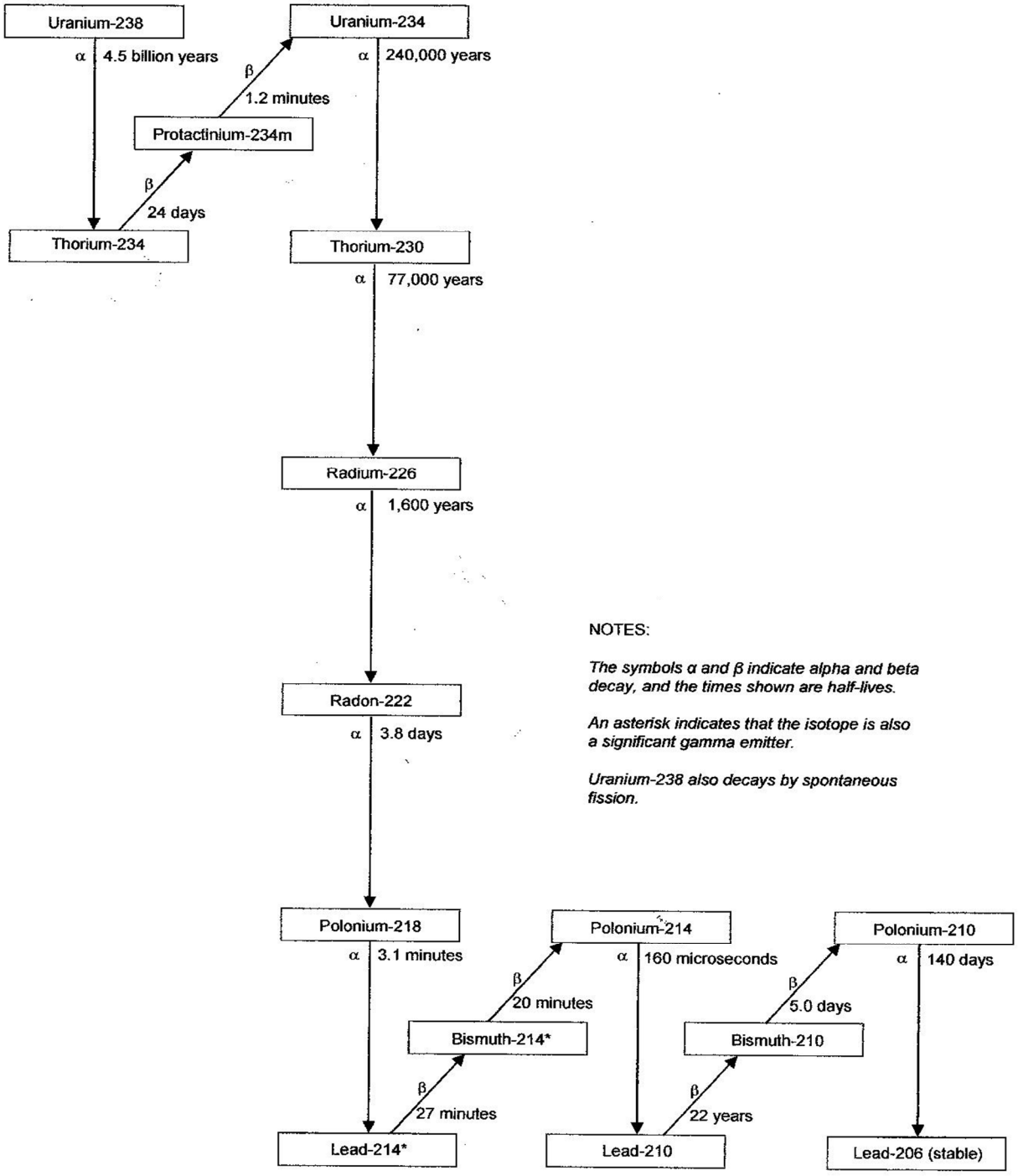


Figure 9: Natural Uranium-238 Decay Series (Argonne National Laboratory, 2007)

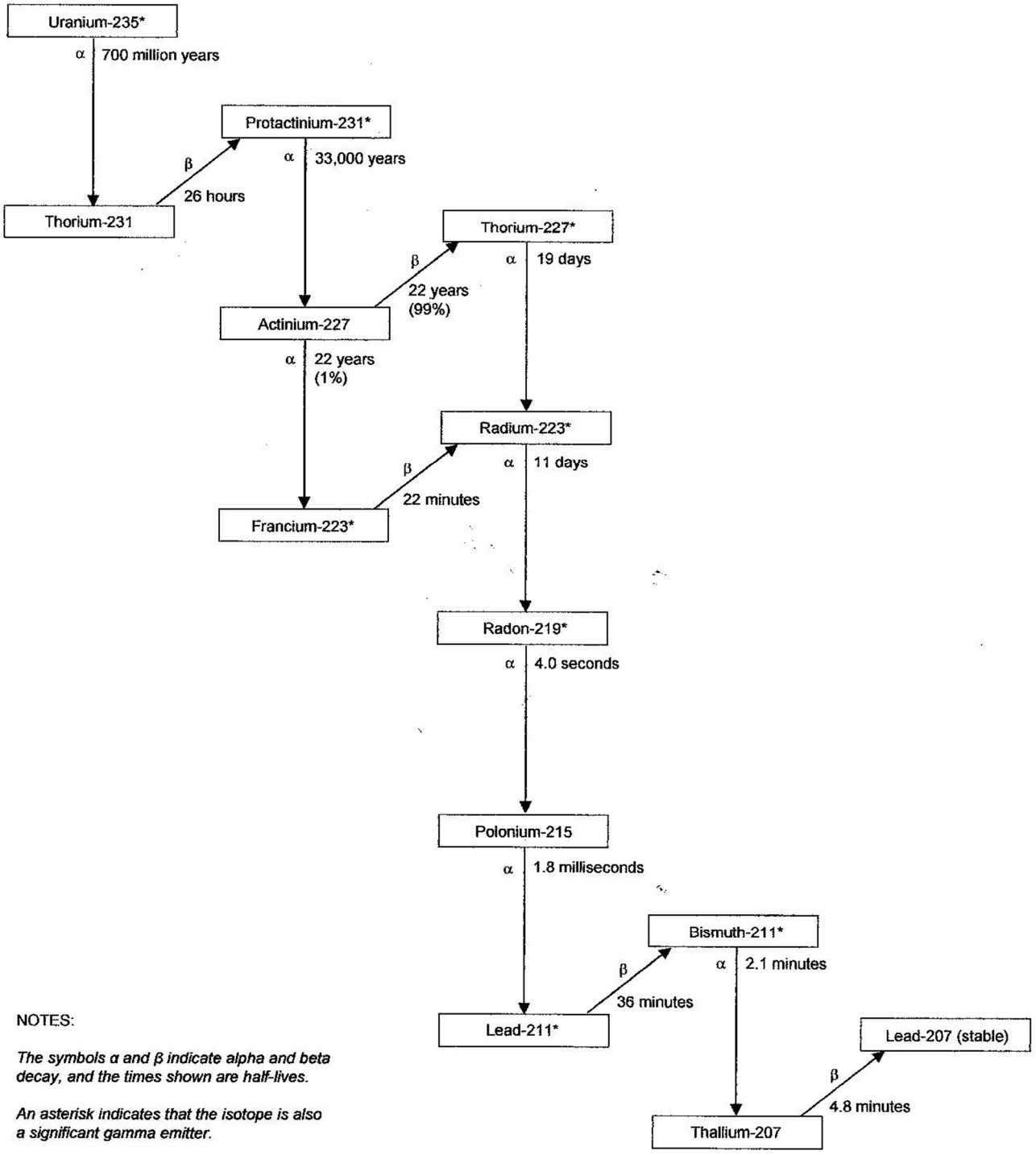


Figure 10: Natural Uranium-235 Decay Series (Argonne National Laboratory, 2007)

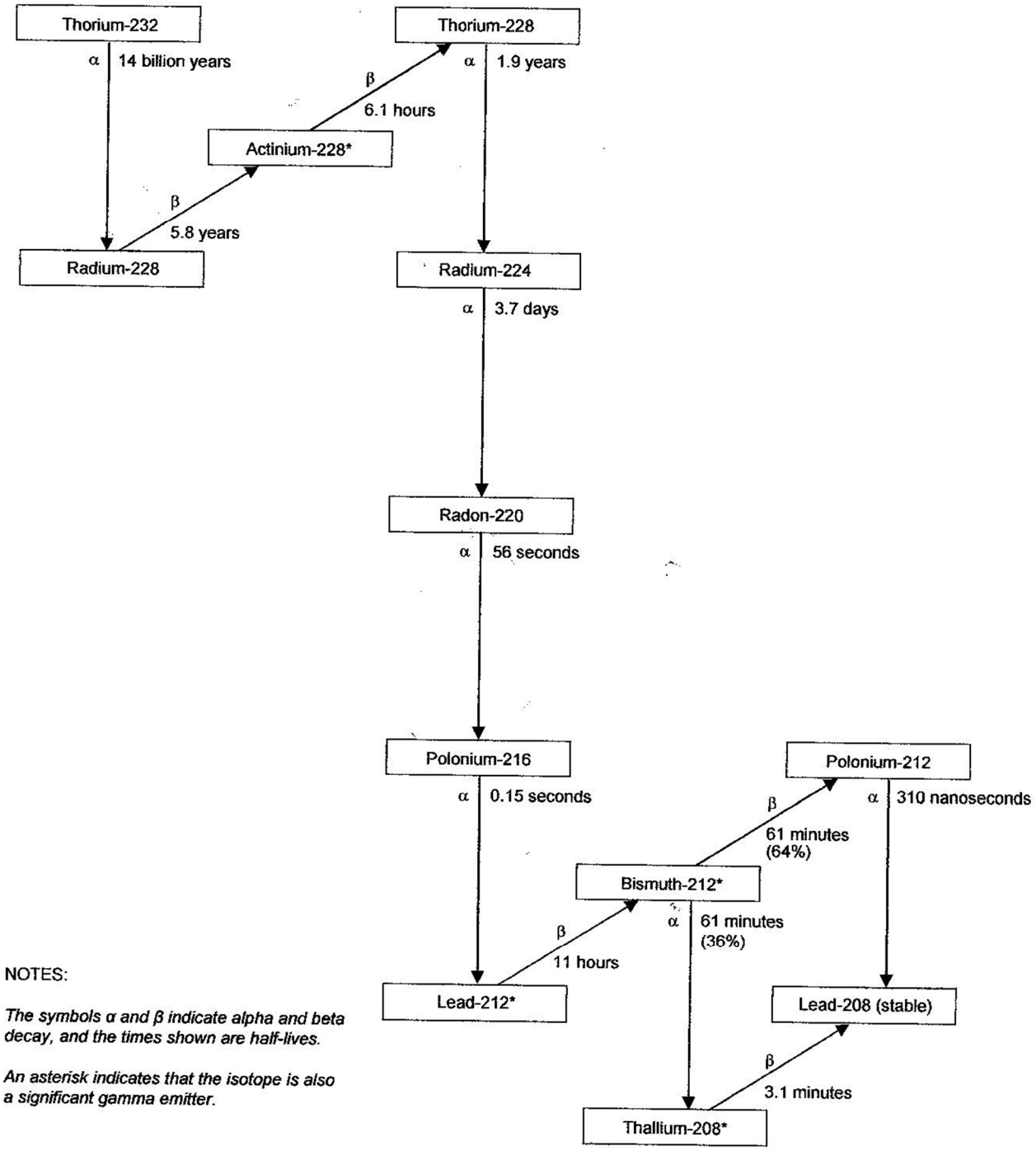


Figure 11: Natural Thorium-232 Decay Series (Argonne National Laboratory, 2007)

Gamma radiation is not a mode of radioactive decay (such as alpha and beta decay). Rather, it is a mechanism by which excess energy is emitted from certain radionuclides, i.e., as highly energetic electromagnetic radiation emitted from the nucleus of the atom. For simplicity, only significant gamma emissions associated with the major decay modes are shown in Figures 9, 10 and 11; that is, radionuclides listed are those for which the radiation dose associated with gamma rays may pose a health concern. The gamma component is not shown for those radionuclides whose gamma emissions do not generally represent a concern. Of the two conditions noted above for secular equilibrium, the first is generally met for the uranium-238, thorium-232 and uranium-235 decay series in naturally occurring ores. While the second condition may not be met for all ores or other deposits of uranium and thorium (given the extremely long half-lives for the radionuclides involved and the geological changes that occur over similar time scales) (Argonne National Laboratory, 2007). It is reasonable to assume secular equilibrium for naturally occurring ores to estimate the concentrations of the various daughter radionuclides that accompany the parent. The state of secular equilibrium in natural uranium and thorium ores is significantly altered when they are processed to extract specific radionuclides.

After processing, radionuclides with half-lives less than one year will re-establish equilibrium conditions with their longer-lived parent radionuclides within several years. For this reason, at processing sites what was once a single, long decay series (for example the series for uranium-238) may be present as several smaller decay series headed by the longer-lived decay products of the original series (that is, headed by uranium-238, uranium-234, thorium-230, radium-226, and lead-210 in the case of uranium-238). Each of these sub-series can be considered to represent a new, separate decay series. Understanding the

physical and chemical processes associated with materials containing uranium, thorium, and radium is important when addressing associated radiological risks.

In fact sheets for uranium, radium, and thorium developed by Environmental Science Division, Argonne National Laboratory, the contributions of radionuclides having half-lives less than one year were included in the risk coefficients. (Each fact sheet identifies which radionuclides are included in these coefficients.) In some situations, it may be necessary to add the radiological risk identified for a given radionuclide to that of its parent radionuclide to properly represent the total risk. For example, the radiological risk for thorium-232 is comprised of the risk for thorium-232 plus the risk for radium-228. Decay series information should be used together with the information in these fact sheets to ensure that the radiological risks associated with uranium, radium, and thorium are properly estimated and represented.

2.4 Radioactivity and its Measurement

Radioactive substances are those that are unstable in nature. Naturally occurring uranium, thorium, radium, and radon emit radiation to reach a more stable condition. This process is called radioactive decay. By measuring the type of radiation emitted, the specific energy level or levels of radiation and the rate of decay, scientists are able to identify a radioactive substance and determine how much of it is present. The unit typically used to describe the concentration of radioactivity present in drinking water is the picocurie per liter (pCi/L) which is equivalent to one trillionth of a curie. Uranium is also expressed as micrograms per liter (μg/L), a mass per unit volume measurement. A microgram is one millionth of a gram.

2.4.1 Procedure for Radionuclides Testing in Groundwater

From the geology of the study area, the likely source of radioactivity in drinking water is uranium, radon, or both. A gross alpha test is the first step in determining the type and level of radioactivity in drinking water. This test serves as a preliminary screening and determines whether additional testing is advisable. The gross alpha guideline in literature (15 pCi/L) is calculated by first measuring gross alpha activity and then subtracting the uranium and radon contributions from this value, if the gross alpha test result is above 15 pCi/L, then further testing for uranium, radium, and radon is recommended. Since there likelihood that all of these radionuclides are found in the area of the study, with uranium and radon being the most prevalent, the additional tests are necessary in order to ensure the correct treatment device is installed. Each requires a different kind of treatment system. The recommended value for uranium is 30µg/L. There is currently no recommended value for radon in drinking water, but the EPA has proposed a level of 4000pCi/L as an alternate MCL, assuming the community water system contributes to mitigating radon in air problems throughout the United State. The EPA proposed that no action was needed for community water systems if the level of radon in water was 300pCi/L or below.

2.5 Guidelines for Radionuclides in Drinking Water

A nuclide is a general term applicable to all atomic forms of an element. Nuclides are characterized by the number of protons and neutrons in the nucleus, as well as by the amount of energy contained within the atom. A radionuclide is an unstable form of a nuclide. They may occur naturally, but can also be artificially produced. Most drinking water sources have very low levels of radioactive contaminants ("radionuclides"), most of which are naturally occurring, although contamination of drinking water sources from

human-made nuclear materials can also occur [(New Jersey Department of Environmental protection (NJDEO, 2004), Cothern, C. R., (1987)]. Most radioactive contaminants are at levels that are low enough to not be considered a public health concern. At higher levels, long-term exposure to radionuclides in drinking water may cause cancer. In addition, exposure to uranium in drinking water may cause toxic effects to the kidney. To protect public health, reputable Organizations such as the World Health organization (WHO), United State Environmental Protection Agency (USEPA) and other National bodies such as Nigeria Industrial Standards (NIS) has established drinking water guidelines for several types of radioactive contaminants; combined radium 226/228 (20 pCi/L); beta emitters (4 mrems); gross alpha recommended value (15 pCi/L); and uranium (30 μg/L). The EPA's regulation trend for radioactive contaminants in drinking water from 1976 to 200 is listed in Table 4.

Table 4: Example of radionuclides regulatory changes over time

Provision	**1976 rule (current)**	**1991 proposal**	**2000 final rule**
Affected systems	CWS	CWS+NTNC	CSW
MCLG, all radionuclides	No MCLG	MCLG of zero	MCLG of zero
Radium MCL	Combine $^{226}Ra+^{228}Ra$ of 5pCi/L	Ra-226 (20pCi/L) Ra-228 (20pCi/L)	Maintain current MCL based on the newly established risk level associated with the 1991 proposed MCL
Uranium MCL	Not regulated	20μg/L or 30pCi/L	30μg/L

Source: EPA (2000)

2.6 Previous Works on Groundwater Radioactivity and Chemistry

The measurements of risks associated with natural radioactivity in drinking water have been adopted as a routine activity in many countries all over the World. These measurements were aimed at checking the compliance of individual water bodies to set guideline.

In Nigeria, compliance checking on drinking water has not received the required attention either from the government or private wells. Such measurements are mostly found only in academic publications while in developed and some developing countries, guideline (Maximum Contaminant Limits) for major, minor, trace and individual radionuclides have been set and public compliance is enforced and strictly monitored. In Nigeria, in 2007 the Nigeria Industrial Standard (NIS) has set limits for some water constituents but much still has to be done. For example, other countries like the United State have set limits for individual radionuclides in water, the NIS only assigned 0.1Bq/L as MCL for all radionuclides which is about 2.7pCi/L (below EPA and WHO's MCL of Uranium alone).

Whereas no work has been carried out from the study area on radioactivity despite the known occurrence of uranium mineralization in the area, Garba (2008) conducted a study of the natural radioactivity of groundwater in the Precambrian rocks around Zaria, Nigeria. His results showed levels of ^{226}Ra activity to range from 0.03 to 0.02Bq/L while ^{228}Ra ranged from 0.5 to 0.9Bq/L indicating that both isotopes of radium are below the WHO guideline of 0.1 and 1.0Bq/L.

Onoja (2004; 2011) also carried out radioactivity studies of well-water from the Zaria area and found that the alpha activity in the studied water ranged from 0.58 to 43.19Bq/m^3. Dewu (2007) carried out radon measurements in Ahmadu Bello University, Zaria's water supply

and found that radon concentration is low which was exhibited by a low radioactivity count. In southwestern Nigeria, Amakom and Jibiri (2010) carried out a chemical and radiological risk assessment of uranium in borehole and well water in the Odeda area of Ogun State their study revealed that uranium levels in the studied samples ranged from 20.17±0.79 – 267.8±9.09 µg/L with an average of 156.7µg/L. Also from Ogbomosholand in southwestern Nigeria, Awodugba (2008) conducted an assessment of radionuclide concentrations in groundwater and reported that the average concentration of uranium in the studied samples was 17.73±5.04µg/L and the average value for thorium was 11.00±2.58µg/L.

In Sweden, Isam *et al.* (2002) conducted a study of the uranium and thorium series in drinking water. They discovered a poor correlation between aquifer geology and bedrock radioactivity. They found that concentrations of ^{238}U, ^{226}Ra, ^{228}Ra, ^{222}Rn and ^{210}Po in groundwater samples were in the ranges of <0.027 – 5.3, <0.016 – 4.9, <0.014 – 1.24, 5 – 8105 and <0.05 – 0.947Bq/L. They also discovered that the average contribution from inhalation of ^{222}Rn in air to the total effective dose was 58±22%, 73±18% and 77±16% for the age categories one year old, 10 years old and adults, respectively. In Finland, Laina (1994) conducted a study titled ^{238}U series radionuclides as a source of increased radioactivity in groundwater originating from Finnish crystalline bedrock". The results of this study recorded an average and maximum concentrations of ^{222}Rn in drilled wells of 93 Bq/L and 77500 Bq/L, respectively, but those in wells dug within the overburden and springs were only 76Bq/L and 3500Bq/L. The highest concentrations of ^{222}Rn and total uranium (maximum 12400 µg/L) were recorded in southern Finland in uraniferous granite areas. The study also found out that of the long-lived radionuclides present in water, ^{210}Pb and U (total) make the highest contribution to the effective dose.

Binesh and Arabshahi, (2011) studied radon and radium concentrations in 120 samples of spring and river water from northwest Mashhad, Iran. The average values of radon and radium concentrations in the studied area were found to be 30.2±5.1 and 18.4±2.2 Bq m^{-3}, respectively. The dose rate due to radon, radium and their progenies received by the population in the studied location was found to be between 0.1-0.5 mSv/y. The arithmetic and geometric mean concentrations are 0.2±0.05 and 0.2 mSv/y, respectively. They concluded that these results showed no significant radiological risk for the inhabitants of the studied regions.

Skeppstrom and Olofsson, (2007) studied uranium and radon in groundwater in Sweden. They found a high uranium concentration of 445 µg/L (WHO limit is 15 µg/L) in a private well in Stockholm County. They discovered that the heterogeneous condition of the subsurface, with respect to geochemistry, groundwater flow, geology and fracture pattern makes the development of a risk prediction model that can be applied at a general scale complex.

Babu *et al.* (2008) carried out a study aimed at estimating uranium in groundwater trapped in granite and gneiss in the region of Kolar, South India,. They collected water samples and analyzed them using inductively coupled plasma mass spectrometric techniques. A significant finding was the very high levels of uranium in groundwater compared to similar assays reported in other nearby districts. Also, the levels were considerable when compared to groundwater levels of uranium reported by other workers. On the basis of the study, they inferred that the origin of uranium was from the granite and there was a trend of diffusion observed along the flow-path of water in the region.

Many groundwater chemical studies have been done in and around the study area. Obiefuna and Sheriff (2011) conducted a study to assess the chemical quality of shallow groundwater in the Pindiga - Gombe area for irrigation and domestic purposes. They measured electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), permeability index (PI), Kellys ratio (KR), and residual sodium bicarbonate (RSBC) and compared them with regulated limits. The values of total dissolved solids (<166 mg/L), electrical conductivity (<0.249ds/m), soluble sodium percentage (2.6 to 38.4%), permeability index (0.19 to 7.4%), magnesium adsorption ratio (37.3 to 66.5%), Residual Sodium Carbonate (0.35 to 3.02meq/L) and Sodium Adsorption Ratio (0 to 0.035) were found to be within the safe limits and thus the water was found to be largely suitable for irrigation purposes. The study concluded that the groundwater will neither cause salinity hazards nor have an adverse effects on the soil properties of the area and that the measured parameters also fall within the recommended limits and are suitable for domestic purposes.

Arabi *et al.* (2010) carried out a hydro-chemical study of groundwater from the northeastern parts of Gombe State, north-eastern Nigeria. Twenty groundwater samples were analyzed for the purpose of evaluating thier quality for culinary and agricultural uses. Three water types were identified, CaCl, Ca - HCO_3 and NaCl. Total carbonate ranged from 27.4 - 239.3 mg/L and salinity hazard ranged from low to medium. The low salinity type of water identified has no detrimental effects on crops while for medium salinity waters, detrimental effects were expected on crops that are sensitive to salinity. Dissolved solids ranged from <200 and 200 - 500 mg/L respectively, while sodium absorption ratio (SAR), exchangeable sodium ratio (ESR) and magnesium hazard (MH) ranged from 0.83 - 4.13, 0.29 - 3.968 and 0.086 - 82 respectively. They concluded that the variation in the chemical composition of

groundwater in the study area may be due to leaching of terrestrial salts mostly within the Gombe Sandstone to the west of the study area, extensive use of fertilizers and ion exchange between soil minerals and water. The study further showed that the examined groundwater quality is suitable for domestic and agricultural uses except in some locations underlain the Gombe Sandstone where detrimental effect were expected on crops that are sensitive to salinity.

Anudu *et al.,* (2011) conducted hydrochemical analysis and evaluation of water quality in Anguwan Jeba and its environs in Nasarawa State, Nigeria to the south-west of the study area. A total of eight hand-dug wells, four hand-pump boreholes, one stream and two rivers were sampled and analyzed for cations and anions. Physical parameters such as temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured in the field. They concluded that all the analyzed parameters were within the WHO guidelines for drinking water and therefore are considered to be suitable for domestic, livestock and irrigation purposes.

State agencies responsible for supply of safe drinking water in the study area have at one time or the other conducted quality control tests on water supplied either from boreholes or treatment plants but such tests were limited to physico-chemical parameters. Radioactivity and other radionuclide related tests are rarely or never conducted. Tekwa *et al.* (2006) conducted an assessment of water quality and usage around Mubi, north of the Ghumchi mineralization; this study was limited to electrical conductivity (EC), sodium absorption ratio (SAR) and major ions. Nur and Kujir (2006) conducted a geo-electrical study of the northeastern part of Adamawa State to the east of the study area. The study was restricted to

the hydraulic and physical properties of the groundwater. Parts of Gombe State and its environs (the south-western part of the Gubrunde horst) was studied by Arabi (2006) based on the same parameters used by Nur and Kujir (2006).

A stream sediment survey was conducted by Ojo (1988) in the middle Gongola Basin, which identified structurally associated element patterns which he associated with Cu-Zn mineralization along the northern flank of the Gubrunde horst, notably the area east of Wuyo, which contains significant Cu and Zn anomalies.

Studies that showed anomalous contents of Pb, Zn, Cu, Ag and Co in soil and in bark and leaf of samples of some trees growing in and around the uranium mineralized areas include Orientation biogeochemical survey of some mineral occurrences in the area covered by Sheet 153 (Funtua, 1985), soil surveys of the Zona, Kanawa and Dali occurrences (Ogunmokuwa, 1985) and biogeochemical investigation using bark and leaves of some savannah trees (Okujeni, 1987). Further work by Okujeni (1987), Okujeni and Funtua (1994), Okunjeni *et al.* (1990), Funtua (1992) and Lancelot and Maurin (1985) all indicated uranium mineralization and the uptake of the above elements and uranium by *Bosweilia dalzielli* soils around the uranium occurrences.

The Nigerian Mining Corporation (NMC) explored for uranium in the Gubrunde horst and adjacent areas before the formation of the Nigerian Uranium Mining Company (NUMCO) in 1978 which then took over the activities of uranium exploration. Three major prospective areas were identified. These included the Gubrunde horst in Borno State, the Monkin in Taraba State and the Ghumchi in Adamawa State, all in Precambrian basement terrain. These works involved interpretation of aero-radiometric maps, photogeological

interpretation on a scale of 1:40,000, regional geological mapping, ground radiometric surveys and detailed geological mapping of selected areas. Percussion drilling was carried out on the Kanawa mineralization in the Gubrunde horst while both percussion and diamond drilling were performed at Mika and Ghumchi.

Later exploration was in the zones of discordance between the basement and Cretaceous sediments in a search for discordant-type deposits as discontinuities can favor concentration of uranium similar to occurrences in northern Australia and Canada [Nigeria Uranium Mining Company (NUMCO), 1981]. The role played by fault zones in the crystalline basement is usually fundamental in pre-concentration and trapping of uranium at the zone of discordance. Maurin (1985) undertook a structural study of the Ghumchi mineralization and also carried out U-Pb and Pb-Pb dating of the Ghumchi and Mika mineralization.

Funtua (1988) studied the geology and genesis of the Kanawa mineralization. Other reports on the Kanawa mineralization were presented in Funtua (1992), who analyzed 300 rock samples from the Mika mineralization for 25 elements using Neutron Activation Analysis, and X-ray fluorescence techniques. He identified two distinct element associations in the ore zone and host rocks; Ti_2 O- MgO-CaO-K_2O-Co-Sr-Rb-Zr and Fe_2O_3-P_2O_5-Cu-Zn-Mo-Pb-U. The first association reflects the mineralogy of the host rock that includes Fe_2O_3, P_2O_5, Cu, Zn, Mo, Pb, and U in the altered granites and rhyolites. The second association was a product of remobilization of the former and reflects the mineralogy of the ores.

Ogunleye (1991) carried out detailed study of the geology and geochemistry of the Zona uranium mineralization and a beneficiation study of the Kanawa uranium ore. The study confirmed the occurrence of uranium mineralization around Zona.

Elegba *et al.* (1993) analyzed 36 samples for 38 elements from a low-grade uranium occurrence from the Gubrunde horst using NAA, DNAA, EDXRF and AAS techniques. Their results showed three element groupings: (i) Rare Earth Elements (LREE) which are capable of serving as pathfinder elements for uranium; (ii) Rare Earth Elements (HREE) which indicate altered/mineralized rocks; and (iii) the bulk of the elements with little or no significant enrichment which they described as refractory minerals.

Chapter 3

MATERIALS AND METHODS

3.1 Study Methods

The methods adopted in this work were in three types: field methods, laboratory and evaluation methods. The methods employed during sampling campaign on the field are referred to as the field methods, these comprise recordings- coordinates of sampling points, locating a sampling point within a grid, measurements, e.g. static water level in wells, and in-situ determinations, e.g. conductivity, Total Dissolved Solids (TDS), pH and temperature. The laboratory methods included the determination of radioactivity, concentration of major, minor and trace constituents in water samples while evaluation methods includes results evaluation using software such as Suffer9® for contouring, AQ-QA spread sheet for water analysis and evaluation and development of sampling grids using Spatial Analysis and Decision Assistance (SADA) software.

3.1.1 Field Work

The field work was carried out during the peak of the dry season because this was assumed to be the time when concentration and activity of the radionuclides, is highest and dilution as a result of precipitation is lowest. Also, at this time of the year, most streams and rivers have dried up, so that groundwater is most saturated with not only the radionuclides but every other constituent. The sampling was undertaken in stages that included the purging of wells, sample collection and preservation and *insitu* measurements as described in Michael *et al*. (1985).

Purging of Wells: The purging of wells involved pumping water out of well using a "Cole-Parmer" Model 7571-05 portable environmental sampler (Plate I). This equipment is designed in such a way that it provides the user with an opportunity to purge a well and collect a representative sample from any well without any form of contamination because it uses a self-priming effect which creates a suction pressure with the tube that conveys the water out of the well.



Plate I: A portable environmental sampler used in purging and collecting sample from wells

Sample Collection: The various sources of the groundwater samples included: springs, where more direct samples are obtainable; and from wells, which produce the most direct sampling of the groundwater. Stringent procedures (which include use of environment sampler) were adopted in order to avoid contamination and changes in parameters that may occur during sample collection.

After purging each well, samples were collected in 5 litre low density plastic containers (Plate II). Two samples at each sampling point were collected, one acidified for cation

analysis and the other not acidified for anion and ICP-MS analysis. Both samples were stored in a refrigerator prior to analysis.



Plate II: Water samples in five litre low density plastic container

In-Situ Measurements: Before a sample was collected, a collection protocol was established which was strictly followed. This involved establishing a collection procedure, obtaining appropriate containers, and utilizing the appropriate methods of preservation in order to reduce the effect of adsorption or biodegradation. Measurements carried out *insitu* included conductivity, TDS, pH and temperature. Others were static water level in wells, coordinates of sampled locations and elevation at sampling points. Conductivity, temperature and Total Dissolved Solids (TDS) were determined using a "HACH" Sension 5 Model conductivity meter (size 7x15cm) while pH was measured with "HACH" Sension1 model pH meter (Plate III). Both conductivity and pH meters were calibrated with buffer standards before measurements were carried out.



Plate III: Conductivity (left) and a pH (right) meter used for in-situ measurements during field work

A total of 35 samples were collected during the field campaign. Most of the samples were collected from open wells because open wells are found in almost all the sampling areas, but most of the areas do not have boreholes and in some cases where they are found, they are not functional.

3.1.2 Laboratory Work

Laboratory work comprised sample preparation, instrument calibration and analysis at the department of Geology, University of Cape Town, South Africa as detailed below.

Sample Preparation: The first step in sample preparation in the laboratory included filtering of water samples through a 0.45 µm filter. Samples reserved for Atomic Absorption Spectrophotometry, ICP-MS and ICP-OES were filtered to avoid the blockage of aspiration lines (tiny tubes through which samples are sent into the analytical device).

Sample preparation for alpha spectroscopy included pre-concentration and reduction of sample volume by evaporation, followed by chemical separation (in order to separate uranium from other actinides that may alter uranium identification as a result of peak mis-identification) precipitation of uranium from the solution using cerium fluoride (CeF_3),

separation of uranium using a UTEVA column and deposition of uranium on filter paper for counting (detail in Eichrom, 2005).

Additional sample preparations for AAS involved placing the sample in a container for aspiration and in some cases dilution of sample with distilled water where concentrations in the sample were higher than a range that can be accommodated.

Instrument Calibration: All instruments (ICP-MS, ICP-OES, Alpha spectrometer, multi-analyte photometer and Atomic Absorption Spectrometer) utilized in this work were calibrated with standard reference materials using standard calibration procedures before measurements (determination of activity concentration, major, minor and trace elements in water samples) were carried out.

Analysis of Samples: The analyses of major, minor and trace elements were carried out using an Atomic Absorption Spectrometer [‘Spectra AA10’ model (Plate IV)], and an Inductively Coupled Plasma Optical Emission Spectrometer [‘Quantima’ model (Plate V)], while analysis of isotopes of uranium, radium, thorium, lead and copper were carried out using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) [“Variant Model” (Plate VI)] and Alpha Spectrometer, [“Ortec” model].

The AAS technique makes use of absorption spectrometry to assess the concentration of an analyte in a sample. The electrons of the atoms in the atomizer can be promoted to a higher orbit for an instant by absorbing a set quantity of energy (i.e. light of a given wavelength). This amount of energy (or wavelength) is specific to a particular electron transition in a

particular element, and in general, each wavelength corresponds to only one element. This gives the technique its outstanding advantage, which is elemental selectivity.



Plate IV: Atomic Absorption Spectrometer, 'Spectra AA10' model

As the quantity of energy (the power) put into the flame is known, and the quantity remaining at the other side (at the detector) can be measured, it is possible to calculate how many of these transitions took place, and thus get a signal that is proportional to the concentration of the element being measured.

ICP-OES is generally very effective in the analysis of samples with high total dissolved solids, which are more suited to a radially viewed system. This can include analysis of trace elements in water, silicate and phosphate rocks or the analysis of rare earth elements which requires not only high sensitivity but also high spectral resolution. The ICP-OES is able to analyze slurry and concentrated dissolved solids without dilution or digestion to enhance

productivity. Organic samples can be directly aspirated without oxygen accessories. With over 32,000 wavelengths for selection and 4 ppm resolution, it also enables analysis of complex matrices.



Plate V: Inductively Coupled Plasma Optical Emission Spectrometer, 'Quantima' model.

For ICP-MS, which was used to determine trace elements in isotopic forms, sample preparation is a relatively simple and quick process. The main component in the sample preparation is an internal standard, which also serves as the diluent. This internal standard consists primarily of deionized water, with nitric or hydrochloric acid, and Indium and/or gallium. To analyze a sample, only 5 ml of the internal standard is added to a test tube along with 10–500 µL of the sample. This mixture is vortexed for several seconds or until well mixed and is then loaded onto the auto-sampler tray. The ICP-MS allows determination of elements with atomic masses ranging from 7 to 250. This range encompasses Li to U. A typical ICP-MS can detect concentrations in the region of ng/L to 10 or 100mg/L or around

8 orders of magnitude of concentration units. Unlike AAS, which can only measure a single element at a time ICP-MS has the capability to scan all elements simultaneously.



Plate VI: Inductively Coupled Plasma Mass Spectrometer "VARIAN" model

3.1.3 Evaluation of Results

Results of field and laboratory tests were evaluated using software that utilizes test results to produce a figure that depicts and display a more meaningful visual picture from which major observations and deductions can be made. Software used for evaluation of test results included the RockWare Aq.QA spread sheet for water analysis [version 1.1.1(1.1.5.1)], Spartial Analysis and Decision Assistance software (SADA), Sufer9® contouring software, MapSource® waypoint software and Aquachem® water analysis software. This software can present results in graphical and tabular forms.

Of all graphical methods of presenting data, contouring is the most important to the hydrogeologist, because maps are generally used to accurately depict features such as

boundaries of geological or hydrogeological bodies; which can be formations, boreholes or drainages.

3.1.4 Uncertainty in the Measured Data

An uncertainty is a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurement itself (EURACHEM, 2000). The uncertainty applied to test methods in this study is within the ISO/IEC 17025-1999 Standard General requirements for the Competence of Testing and Calibration (ISO/IEC, 1999). It is based on the general rules outlined in the Guide to Expression of Uncertainty in Measurement (GUM). Components that contribute to analytical measurement uncertainty include sampling, handling, transport, storage, preparation and testing (ISO/IEC 17025-1999) (GUM, 1993).

To check for uncertainty during sampling, some samples were duplicated (replicates). These samples were taken from the same population and carried through all stages of *insitu* and laboratory measurements/testing.

In the laboratory, Instrument Calibration Standards (ICS) was used to calibrate the various analytical equipment used. ICS is a reference material used to standardize an analytical instrument. Analyses of the ICS were later carried out to verify initial and continuing calibration, this is called Instrument Performance Check (IPC). The IPC is used to quantify the instrumental testing repeatability varience and bias. At some stage of the analysis, a clean matrix reference material with an established analyte concentration derived from a source independent of the instrument calibration standard [Laboratory Control Sample (LCS)] was carried through the entire sample preparation and testing procedure in order to

quantify the variance and bias of the chemical preparation and instrument testing stages without matrix interference. Samples replicated for uncertainty determination for instruments used in the field are labeled with asterisk (*) in Table 5 for data obtained from the field as average deviation in percentage of a particular parameter recorded for all samples. This was found to be about 2% while for analytical results; it is given as percentage Relative Standard Deviation (%RSD) (as shown in Tables 5 and 6).

Chapter 4

RESULTS AND DISCUSSIONS

The results of this study are presented and discussed in two categories, results from measurements made in the field and those from laboratory measurements.

4.1 Results from Field Measurements

The data obtained from field measurements for conductivity, total dissolved solids, elevation and water levels are given in Table 5. The values recorded ranged between 65.9 – 3840 µs/cm, 46.2 – 2260 mg/L, 216 – 372 m and 0.1 – 26 m, respectively. The plot of conductivity against TDS gave expectedly a linear graph (Fig. 12).

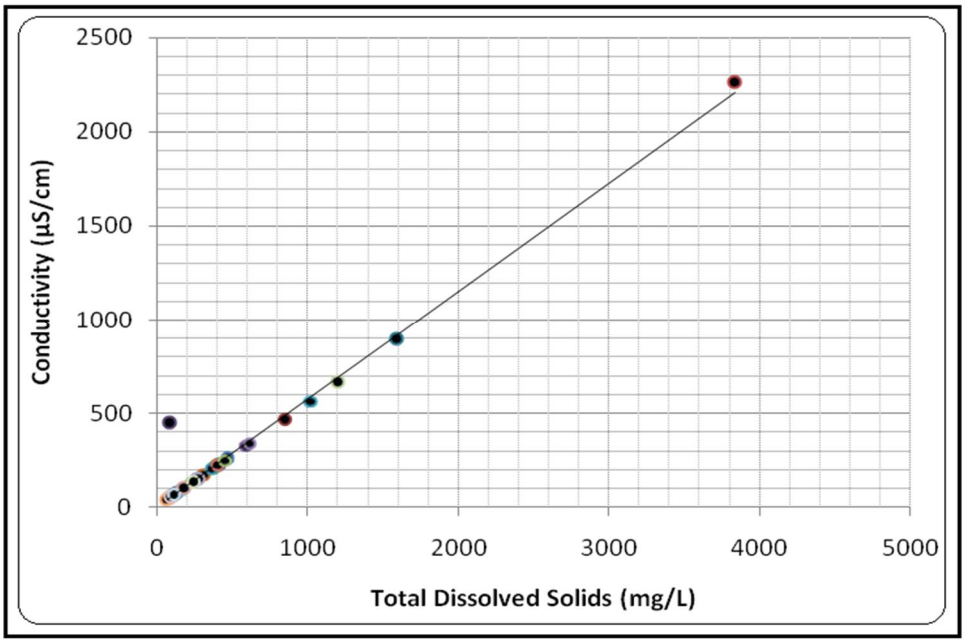


Figure 12: A plot of conductivity and Total Dissolved Solids for studied samples as measured in-situ.

Table 5: Results of measurements made in-situ

S/N	LOCATION NAME	LATITUDE	LONGITUDE	ELEV (m) asl	S.W.L (m) bgs	pH	COND (µs/cm)	TEMP (°C)	TDS (mg/l)
1	ZANGE	10°16'.4	11°45'.6	255	8.1	6.0	102.8	30.6	560
2	Y/DALLAN	10°23'.3	11°50'.6	286	5.2	7.2	1593	30.8	893
3	MILDA	10°21.4	11°58'.2	304	1.1	6.8	416	30.2	223
4	PIETA	10°20.4	11°55'.3	279	4	7.9	852	29.7	464
5	DEBA	10°19.6	11°53'.0	263	12.1	6.8	387	31.2	208
6	ZONA	10°24'.2	11°53'.3	337	2.1	6.1	85.7	30.9	445.2
7	Y/DALLAN	10°23'.3	11°50'.6	286	5.2	7.2	1593	30.8	893
8	YUMBU	10°23'.1	11°49'.3	273	0.7	7.2	312	30.7	166.7
9	ZOBI	10°25'.5	11°52'.2	288	0.3	7.7	123.1	35	65.1
10	DUNKUR	10°27'.4	11°45'.4	355	8.3	6.7	104.2	30	55.3
11	GANGA	10°25'.2	11°43'.3	323	10	6.4	401	30.6	216
12	WUYO	10°23'.1	11°41'.5	304	26	7.1	596	31	323
13	TELI	10°26'.4	11°41'.3	299	10	6.4	370	29.7	198.5
14	LODDO	10°22'.1	11°44'.4	342	1.3	6.3	87.6	29.5	46.2
15	GUBRUND	10°19'.6	11°46'.2	301	3	6.4	474	31.1	255
16	KASHERI	10°20'.1	11°47'.3	303	8.3	7.1	3840	31	2260
17	FONO	10°19'.5	11°45'.4	315	1.5	7.1	236	32.2	125.6
18	KANAWA	10°18'.4	11°44'.4	293	0.1	6.6	133	30	70.4
19	ZANGE	10°16'.4	11°45'.6	255	8.1	6.1	1022	30.8	559
20	P/KUMBO	10°14'.1	11°47'.0	216	4.6	7.2	89.1	25	47
21	KOFABILA	10°16'.3	11°44'.2	261	7	7	269	30	143.8
22	M/MARKE	10°17'.1	11°42'.0	313	2.5	7.3	407	28.2	219
23	DALI	10°15'.2	11°42'.0	262	9	7.5	454	28	244
24	KUNDIGA	10°16'.0	11°40'.5	346	7	7.4	622	28.4	336
25	BARKAM	10°13'.3	11°43'.1	271	8.7	7.3	174	29	92
26	GUGUPU	10°26'.0	11°47'.0	338	2.1	5.6	65.9	30	34.6
27	FESIGO	10°21'.3	11°57'.1	290	0.7	6.2	106	29.4	56
28	WAHABA	10°23'.1	11°56'.4	316	2	6.5	182	27.6	96.8
29	WALAMA	10°17'.2	11°57'.5	372	11	7	1206	29.1	663
30	PITILA	10°15'.3	11°58'.3	318	6	7.1	278	29.1	148.5
31	KWALA	10°12'.6	11°58'.7	266	3	7.4	106.3	31.5	56.1
32	GALU	10°11'.6	11°58'.3	279	4	7.4	106.1	31	57
33	LABILIS	10°13'.1	11°52'.5	284	0.3	6.1	98.3	31	51.9
34	TABA	10°15'.1	11°53'.0	391	4	6	98.1	31.5	50.7
35	FANGURU	10°12'.5	11°51'.0	248	8.1	6.8	246	29.9	131.4
36	K/GASI	10°12'.5	11°49'.4	218	7	6.5	119.4	32.2	63.2
37	BEDI	10°12'.3	11°56'.3	219	6	6.5	118.7	32	63

LAT=latitude, LONG=longitude, ELE=elevation, SWL=Static Water Level, , COND= conductivity, TEMP=temperature and TDS=Total Dissolved Solids

The superimposition of elevations of sampled points on the digital elevation model of the study area showed a close match which is also an indication of true measurement of elevation (Fig. 13).

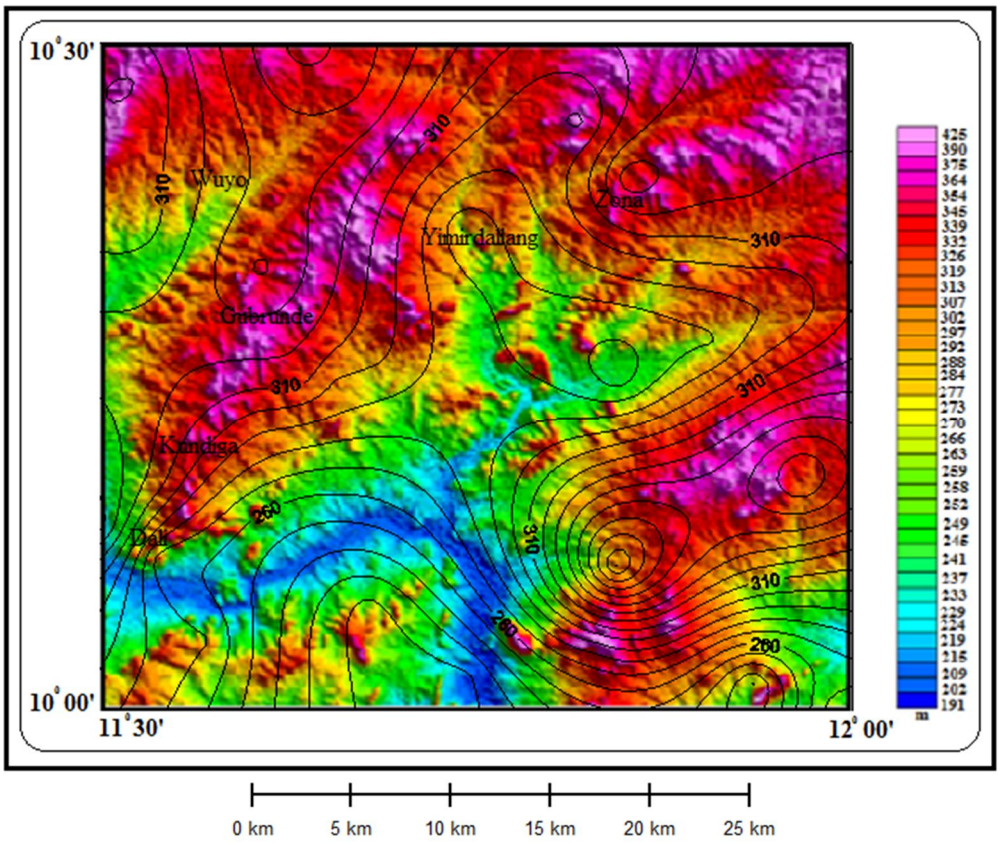


Figure 13: Superimposed elevation contour over digital elevation model of the study area

The superimposed water Table contour on digital elevation model of the study area shows that watertable is shallower in the northeastern part of the study area and is deepest in the in the northwestern part around Wuyo (Figs. 14, see enlarged in appedix). This also probably suggest that subsurface groundwater flow could be northeast-southwesterly in the northeastern part of the study area.

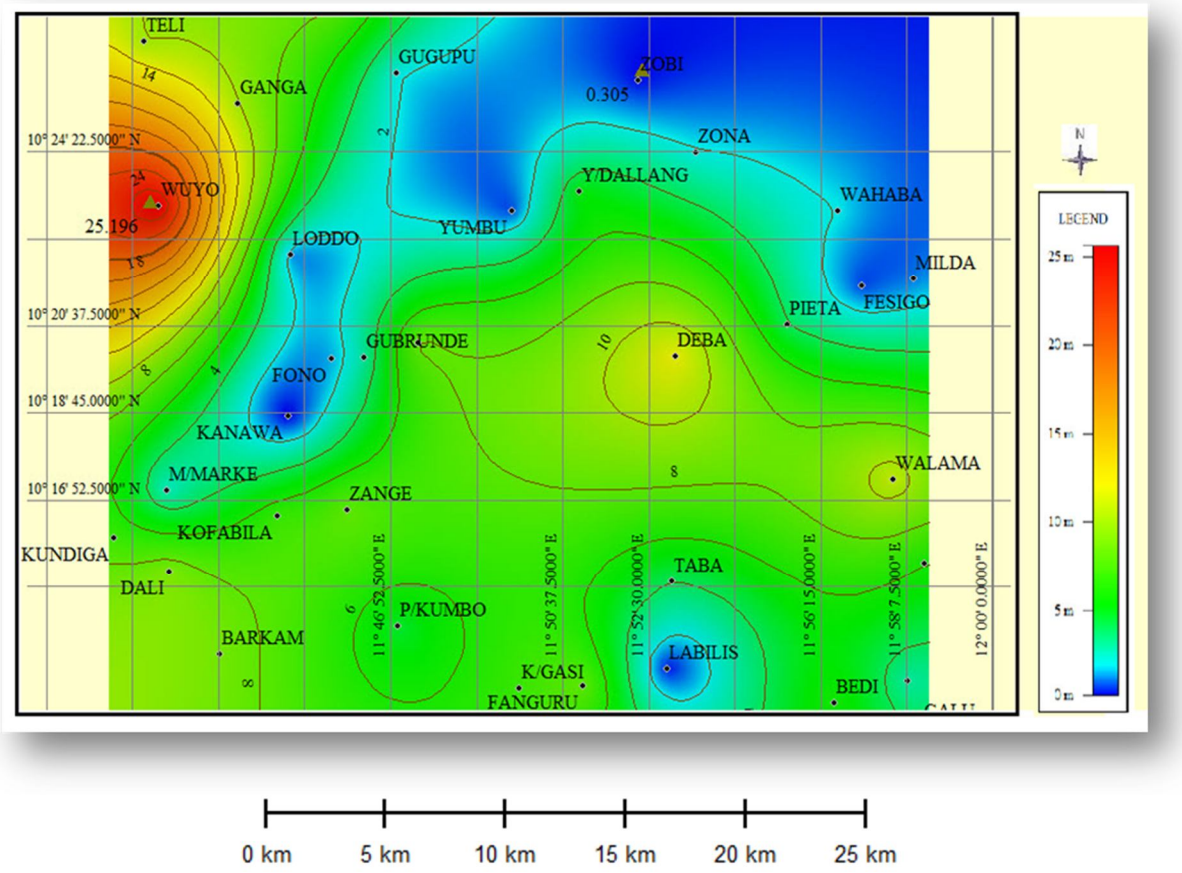


Fig. 14: Water Table contour on location map of the sampled area

4.2 Results from Laboratory Measurements

The results of laboratory measurements are classified into groundwater radioactivity measurements and groundwater chemistry.

4.2.1 Groundwater Radioactivity Measurements

The results of radionuclide measurements in groundwater samples are presented in Table 6. The results recorded showed that values recorded for U, ^{226}Ra, ^{228}Ra and ^{232}Th ranged from 0.07 – 61.25 µg/L, 0.05±0.0014 – 6.7±0.18 pCi/L, 0.1±0.003 – 4.8±0.12 pCi/L and 0.01±0.001 – 1.1±0.021 µg/L, respectively.

Table 6: Results of analysis of radionuclides in the studied water samples

S/N	LATITUDE	LONGITUDE	LOCATION NAME	^{234}U (µg/L	^{238}U (µg/L)	$^{234}U/^{238}U$	U (µg/L)	^{226}Ra (pCi/L)	^{228}Ra (pCi//L)	Ra (pCi//L)	^{232}Th (µg/L)	^{208}Pb (µg/L)
1	10°16'.4	11°45'.6	MILDA	0.39±0.008	0.32±0.007	1.20	0.71	1.8±0.0486	1±0.025	2.8	0.11±0.013	0.66±0.051
2	10°23'.3	11°50'.6	PIETA	5.84±0.112	4.17±0.08	1.40	10.00	4.3±0.116	2.9±0.073	7.2	0.08±0.002	0.55±0.011
3	10°21.4	11°58'.2	DEBA	0.22±0.004	0.21±0.004	1.02	0.43	0.9±0.0243	0.3±0.008	1.2	0.07±0.001	0.09±0.002
4	10°20.4	11°55'.3	ZONA	0.18±0.003	0.12±0.002	1.50	0.30	0.7±0.0189	0.3±0.008	1	0.63±0.012	0.45±0.001
5	10°19.6	11°53'.0	Y/DALLAN	18.34±0.350	16.37±0.313	1.12	34.71	6.7±0.1809	4.2±0.105	10.9	0.04±0.001	< d.l.
6	10°24'.2	11°53'.3	YUMBU	0.63±0.012	0.42±0.008	1.50	1.05	1.5±0.0405	1.2±0.03	2.7	0.05±0.001	7.99±0.153
7	10°23'.3	11°50'.6	ZOBI	0.13±0.003	0.11±0.002	1.20	0.25	0.6±0.0162	0.1±0.003	0.7	0.02±0.001	0.44±0.008
8	10°23'.1	11°49'.3	DUNKUR	0.03±0.006	0.03±0.006	1.06	0.07	0.3±0.0081	<dl	0.3	0.03±0.001	0.11±0.002
9	10°25'.5	11°52'.2	GANGA	1.83±0.035	1.02±0.020	1.80	2.85	1.7±0.0459	1±0.025	2.7	0.02±0.001	0.67±0.013
10	10°27'.4	11°45'.4	WUYO	5.65±-.108	4.71±0.090	1.20	10.37	0.12 ±0.0.2	3.7±0.093	8.3	0.02±0.001	< d.l.
11	10°25'.2	11°43'.3	TELI	1.58±0.030	0.99±0.019	1.60	2.56	1±0.027	0.7±0.018	1.7	0.71±0.014	0.99±0.019
12	10°23'.1	11°41'.5	LODDO	0.43±0.008	0.36±0.007	1.20	0.79	1±0.027	0.2±0.005	1.2	0.3±0.006	0.66±0.013
13	10°26'.4	11°41'.3	GUBRUND	1.34±0.256	1.03±0.020	1.30	2.37	1.5±0.0405	0.7±0.018	2.2	0.15±0.003	0.55±0.011
14	10°22'.1	11°44'.4	KASHERI	1.7±0.033	1.55±0.030	1.10	3.25	2±0.054	1±0.025	3	0.11±0.002	0.17±0.003
15	10°19'.6	11°46'.2	FONO	0.31±0.006	0.22±0.004	1.40	0.53	2.1±0.0567	1.6±0.04	3.7	1.1±0.021	0.65±0.013
16	10°20'.1	11°47'.3	KANAWA	0.1±0.002	0.08±0.002	1.20	0.18	0.9±0.0243	1±0.025	1.9	0.05±0.001	0.011±0.011
17	10°19'.5	11°45'.4	ZANGE	0.05±0.001	0.04±0.001	1.20	0.08	0.2±0.0054	<dl	0.2	0.02±0.001	0.88±0.017
18	10°18'.4	11°44'.4	P/KUMBO	0.05±0.001	0.04±0.001	1.25	0.08	0.1±0.0027	<dl	0.1	0.01±0.001	< d.l.

Cont… Table 6: Results of analysis of radionuclides in the studied water samples

S/N	LATITUDE	LONGITUDE	LOCATION NAME	^{234}U (µg/L)	^{238}U (µg/L)	$^{234}U/^{238}U$	U (µg/L)	^{226}Ra (pCi/L)	^{228}Ra (pCi//L)	Ra (pCi//L)	^{232}Th (µg/L)	^{208}Pb (µg/L)
19	10°16'.4	11°45'.6	KOFABILA	0.04±0.001	0.03±0.001	1.60	0.07	0.05±0.0014	<dl	0.05	< d.l.	< d.l.
20	10°14'.1	11°47'.0	M/MARKE	5.09±0.100	2.42±0.046	2.10	7.51	3±0.081	2.7±0.068	5.7	0.02±0.001	< d.l.
21	10°16'.3	11°44'.2	DALI	1.82±0.035	1.52±0.030	1.20	3.34	2.1±0.0567	2±0.05	4.1	< d.l.	1.91±
22	10°17'.1	11°42'.0	KUNDIGA	34.62±0.661	26.63±0.509	1.30	61.25	7.3±0.1971	4.8±0.12	12.1	0.01±0.001	0.05±0.001
23	10°15'.2	11°42'.0	BARKAM	1.2±0.023	0.91±0.017	1.31	2.11	2±0.054	1±0.025	3	0.81±0.016	6.16±0.118
24	10°16'.0	11°40'.5	GUGUPU	0.68±0.013	0.21±0.004	3.20	0.89	1±0.027	0.5±0.013	1.5	0.22±0.004	0.78±0.015
25	10°21'.3	11°57'.1	FESIGO	0.26±0.005	0.17±0.003	1.50	0.43	0.9±0.0243	0.2±0.005	1.1	0.31±0.006	1.53±0.030
26	10°23'.1	11°56'.4	WAHABA	0.13±0.003	0.11±0.002	1.20	0.24	0.7±0.0189	<dl	0.7	0.07±0.001	0.56±0.011
27	10°17'.2	11°57'.5	WALAMA	6.01±0.115	5.41±0.103	1.11	11.42	4.2±0.1134	3.3±0.083	7.5	0.04±0.001	0.7±0.013
28	10°15'.3	11°58'.3	PITILA	1.61±0.031	1.34±0.026	1.20	2.94	1.6±0.0432	0.9±0.023	2.5	0.02±0.001	5.75±0.110
29	10°12'.6	11°58'.7	KWALA	<dl	< d.l.	< d.l.	<dl	<dl	<dl	<dl	< d.l.	0.61±
30	10°11'.6	11°58'.3	GALU	<dl	< d.l.	< d.l.	<dl	<dl	2.6±0.065	2.6	< d.l.	< d.l.
31	10°13'.1	11°52'.5	LABILIS	0.09±0.002	0.05±0.001	1.60	0.14	0.7±0.0189	<dl	0.7	0.28±0.005	0.14±0.003
32	10°15'.1	11°53'.0	TABA	0.17±0.003	0.14±0.003	1.20	0.31	<dl	<dl	<dl	0.47±0.009	0.65±0.012
33	10°12'.5	11°51'.0	FANGURU	0.14±0.003	0.14±0.003	1.02	0.28	0.7±0.0189	0.5±0.013	1.2	< d.l.	< d.l.
34	10°12'.5	11°49'.4	K/GASI	<dl	<d.l.	< d.l.	<dl	<dl	<dl	<dl	< d.l.	0.03±
35	10°12'.3	11°56'.3	BEDI	<dl	<d.l.	< d.l.	<dl	<dl	<dl	<dl	< d.l.	0.52±

4.2.2 Result of Major, Minor and Trace Constituents in Groundwater

The results of these analyses are presented in Table 8. The result recorded showed Ca^2, Mg^{2+}, Na^+ and K^+ values ranged from 3.1±0.26 - 1524±131.06 mg/L, 21±0.59 - 1375±38.5 mg/L, 14.8±1.23 – 349.7±29.03 mg/L and 16.9±1.07 – 266.4±16.78 mg/L, respectively. Values recorded for HCO_3^-, SO_4^{2-}, Cl^-, NO_3, CO_3^{2-} and PO_4^{2-} were 163.7±7.04 – 257.4±11 mg/L, 11.7±0.82 – 64.3±4.52 mg/L, 41.34±3.06 - 81±6 mg/L, 21±0.7 - 76±2.51 mg/L, 10.6±0.2 – 12.9±0.25 mg/L and 7±0.57 – 106.8±8.65, respectively. Values recorded for Fe, Mn, Zn, Ni and dissolved oxygen (DO) ranged from 0.7±0.01 – 17.5±0.32 mg/L, 1.1±0.003 - 2±0.006 mg/L, 0.4±0.0.03 – 12.6±1.07 mg/L, 0.1±0.01 – 6.3±0.43 mg/L and 5.6±0.21 – 7.7±0.27 mg/L, respectively (Table 8).

The distribution of natural radionuclides, major, minor and trace elements in groundwater is to some extent controlled by the rock types that constitute the aquifer. In fact, in many cases the relative concentrations of different radionuclides in a sample can be used to determine the aquifer material (Van Price, 1990). The concentration of uranium in the studied groundwater samples increases from the basalts, weathered basement into the Bima Sandstones (Fig. 15).

The concentration of uranium in groundwater from wells around north-eastern and southern part (around the axis of Gongola River in the study area and was very low. This probably indicates low uranium concentration as a result of recharging of the aquifer by the River in the south which reduces the uranium levels within the aquifer (Fig. 15). 82.9% of the samples showed uranium levels less than the EPA's MCL of 30µg/L (Fig. 15).

Table 7: Results of analysis of major, minor and trace constituents in groundwater samples from the study area

				Location Name (ID)									
PARA	**UNIT**	**MDL**	**%RSD**	**Milda**	**Pieta**	**Deba**	**Zona**	**Y/Dallang**	**Yumbu**	**Zobi**	**Dunkur**	**Ganga**	**Wuyo**
TDS	mg/L	0		568	564	399	45.2	893	166.7	65.1	55.3	216	323
Conductivity	µs/cm	0.0		750	759	497	85.7	159.3	312	123.1	104.2	401	596
pH	pH	4		6.8	7.1	6.8	6.1	7.2	7.2	7.7	6.7	6.4	7.1
Temp	°C	1		30.2	29.7	31.2	30.9	30.8	30.7	35	30.1	30.6	31
Ca^{2+}	mg/L	0.5	8.6	44.2±3.80	32±2.75	24±2.06	50±4.3	385±33.1	150±12.9	124.6±10.72	1179±101.4	377.1±32.4	70.9±6.1
Mg^{2+}	mg/L	1.88	2.8	32.9±0.92	27.3±0.76	21±0.59	80±2.24	1375±38.5	73.2±2.05	954.3±26.72	340±9.50	283.1±7.91	113.±3.19
Na^{+}	mg/L	0.5	8.3	28.5±2.37	18.1±1.50	17±1.41	27±2.24	49.3±4.09	85.6±7.11	15.8±1.31	121.4±10.08	28.9±2.40	45±3.74
K^{+}	mg/L	0.5	6.3	36.4±2.29	74.8±4.71	49±3.09	95.7±6.03	104.8±6.60	107.2±6.75	186.5±11.75	308±19.40	106±6.68	89.4±5.6
HCO_3	mg/L	0.7	4.3	202.4±8.70	157.2±6.76	234.7±10.09	180.3±7.75	191.±8.222	179.2±7.71	270.1±11.61	181.3±7.80	257.4±11.0	187.9±8.1
SO_4^{2-}	mg/L	0.81	7	64.6±4.52	64.5±4.52	45±3.15	37±2.59	20.1±1.41	13.1±0.92	42.8±3.00	34.6±2,42	41.3±2.90	15.8±1.1
Cl	mg/L	3	7.4	72.9±5.40	81±6.00	52.9±3.92	45.83±3.4	43.68±3.24	46.6±3.45	47.19±3.50	45.83±3.40	44.46±3.30	46.8±3.47
CO_3^{2-}	mg/L	2	1.9	11±0.21	10.8±0.21	11±0.21	11.8±0.22	11.2±0.21	12±0.22	12.1±0.23	11.8±0.22	11.4±0.22	12±0.23
PO_4^{3-}	mg/L	4.5	8.1	26.6±2.16	107.6±8.72	12.6±1.02	0	19.6±1.59	0	23.8±1.93	371.7±30.11	13.4±1.09	0
Fe	mg/L	0.08	1.8	5.2±0.09	12.2±0.22	7.3±0.13	1.1±0.02	4.6±0.083	8.5±0.15	7.8±0.14	11.9±0.21	9.1±0.16	0.7±0.01
Mn	mg/L	1.4	0.3	0	0	0	0	1.1±0.003	0	0	0	0	0
Zn	mg/L	0.05	8.5	1.1±0.94	1.2±0.10	0.4±0.034	1.1±0.10	0.7±0.06	7±0.60	0.6±0.05	0.9±0.08	0.9±0.08	0.4±0.03
Ni	mg/L	0.05	6.8	0.1±0.01	0	0.2±0.014	0	0	0	0	0	0	0
NO_3	mg/L	7	3.3	25±0.83	34±1.12	65±2.14	76±2.51	75±2.48	65±2.15	77±2.54	65±2.15	56±1.85	21±0.70
DO	mg/L	2	3.7	7.73±0.27	6.7±0.25	6.5±0.24	6.6±0,244	5.9±0.23	6±0.22	6±0.22	7±0.26	7.4±0.27	5.8±0.22

Cont…Table 7: Results of analysis of major, minor and trace constituents in groundwater samples from the study area

				Location Name (ID)									
PARA	**UNIT**	**MDL**	**%RSD**	**Teli**	**Loddo**	**Gubrunde**	**Kasheri**	**Fono**	**Kanawa**	**Zange**	**Palakumbo**	**Kofabila**	**M/Marke**
TDS	mg/L	0		198.5	46.2	255	2260	125.6	70.4	559	47	143.8	219
Conductivity	µs/cm	0.0		370	87.6	474	3840	236	133	673	1022	89.1	269
pH	pH	4		6.4	6.3	6.4	7.1	7.1	6.6	6.1	7.2	7	7.3
Temp	°C	1		29.7	29.5	31.1	31	32.2	30	30.8	25	30	28.2
Ca	mg/L	0.5	8.6	234.6±20.18	440±37.84	241.9±20.80	35.8±3.08	36.1±3.11	901±77.49	1524±131.06	122.5±10.54	290.5±25.00	56.7±4.88
Mg	mg/L	1.88	2.8	232.±6.503	116±3.25	533.1±14.93	98.9±2.77	105±2.94	97.9±2.74	378.8±10.61	115.7±3.24	354.5±9.93	96.8±2.71
Na	mg/L	0.5	8.3	60.5±5.02	108.5±9.00	23.9±1.99	326.3±27.08	231.6±19.22	157.9±13.11	28.1±2.33	309.3±25.67	18.6±1.54	111.2±9.23
K	mg/L	0.5	6.3	101.3±6.38	266.4±16.78	112.1±7.06	104.6±6.59	98.8±6.22	114±7.18	165.5±`0.43	163.1±10.28	97.5±6.14	101.3±6.38
HCO_3	mg/L	0.7	4.3	210±9.03	167.1±7.19	220.1±9.46	183.8±7.90	189.4±8.14	183.3±7.89	250.3±10.76	194±8.34	163.7±7.04	180.3±7.75
SO_4^{2-}	mg/L	0.81	7	25.2±1.76	12.8±0.90	29.5±2.07	16.4±1.15	14.4±1.01	14.3±1.00	40.1±2.81	14.6±1.02	11.7±0.82	13.3±0.93
Cl	mg/L	3	7.4	44.85±3.32	42.9±3.18	43.88±3.25	44.85±3.32	48.75±3.61	46.8±3.47	43.29±3.21	50.12±3.71	42.9±3.18	46.8±3.47
CO_3^{2-}	mg/L	2	1.9	11.5±0.22	11±0.21	11.3±0.222	11.5±0.22	12.5±0.24	12±0.23	11.1±0.21	12.9±0.25	11±0.21	12±0.23
PO_4^{3-}	mg/L	4.5	8.1	12.6±1.02	169±13.69	15.4±1.25	0	327.7±26.54	0	23.8±1.93	0	25.2±2.04	103.5±8.38
Fe	mg/L	0.08	1.8	5.2±0.94	5.5±0.10	5.5±0.10	3.5±0.06	11.9±0.21	3.5±0.06	5.5±0.10	0.8±0.014	4.8±0.07	3.4±0.06
Mn	mg/L	1.4	0.3	0	0	0	0	0	0	0	0	0	0
Zn	mg/L	0.05	8.5	0.4±0.03	0.9±0.08	0.6±0.05	1.1±0.10	1.1±0.10	1.2±0.10	0.5±0.04	12.6±1.07	0.8±0.07	0.8±0.07
Ni	mg/L	0.05	6.8	0	0	0	0	0	0	6.3±0.43	0	0.4±0.03	0
NO_3	mg/L	7	3.3	35±1.16	67±2.21	72±2.38	66±2.18	65±2.15	63±2.08	56±1.85	55±1.81	66±2.18	65±2.15
DO	mg/L	2	3.7	6.7±0.25	6.5±0.24	6.5±0.24	6.6±0.24	6±0.22	6.1±0.23	6.4±0.12	6.0±0.90	6±0.22	5.6±0.21

Cont…Table 7: Results of analysis of major, minor and trace constituents in groundwater samples from the study area

				Location Name (ID)									
PARA	**UNIT**	**MDL**	**%RSD**	**Dali**	**Kundiga**	**Barkam**	**Gugupu**	**Fesigo**	**Wahaba**	**Walama**	**Pitila**	**Kwala**	**Galu**
TDS	mg/L	0		244	336	920	34.6	56	96.8	663	148.5	56.1	57
Conductivity	µs/cm	0		269	407	454	622	112	106	182	106	278	67
pH	pH	4		7.5	7.4	7.3	5.6	6.2	6.5	7	7.1	7.4	7.4
Temp	°C	1		28	28.4	29	30	29.4	27.6	29.1	29.1	31.5	31
Ca	mg/L	0.5	8.6	32.2±2.77	422±36.3	123.5±10.62	343±29.50	66.6±5.73	85.3±7.34	395±33.79	63±5.42	38.3±3.30	32±2.75
Mg	mg/L	1.88	2.8	72.6±2.03	110.3±3.09	72.1±2.02	99.7±2.80	578.4±16.20	102.4±2.87	337.4±9.45	115.5±3.23	340.6±9.54	101.±2.831
Na	mg/L	0.5	8.3	349.7±29.03	227.6±18.9	24.9±2.07	118.6±9.84	14.8±1.23	100±8.30	23.3±1.93	324.7±27	19.5±1.62	182.3±15.13
K	mg/L	0.5	6.3	138.1±8.70	17±1.07	138.1±8.70	106±6.68	98.8±6.22	115.2±7.23	163.1±10.28	186.3±11.74	114±7.18	112.1±7.06
HCO_3	mg/L	0.7	4.3	167.5±7.20	164.1±7.06	250±10.75	181.8±7.81	211.5±9.10	167.3±7.19	203.7±8.76	168±7.22	177.9±7.65	181.6±7.80
SO_4^{2-}	mg/L	0.81	7	13.7±0.96	13.4±0.94	40.4±2.83	11.9±0.83	28±2.0	11.7±0.82	18±1.26	12.3±0.86	13.5±1.0	12±0.84
Cl	mg/L	3	7.4	42.12±3.12	41.34±3.06	42.9±3.18	48.75±3.61	42.51±3.15	44.07±3.27	49.92±3.70	43.68±3.24	45.83±3.4	48.16±3.57
CO_3^{2-}	mg/L	2	1.9	10.8±0.21	10.6±0.20	11±0.21	12.5±0.24	10.9±0.21	11.3±0.22	12.8±0.24	11.2±0.21	11.8±0.22	12.4±0.24
PO_4^{3-}	mg/L	4.5	8.1	11.1±0.90	309.5±25.07	22.1±1.80	57.1±4.63	25.2±2.04	0	32.2±2.61	0	7±0.57	59.4±4.81
Fe	mg/L	0.08	1.8	11.9±0.21	12.6±0.23	4.9±0.09	10.4±0.19	12.9±0.23	10.8±0.19	4.3±0.07	13.4±0.24	5.2±0.09	12.6±0.22
Mn	mg/L	1.4	0.3	0	0	0	0	0	0	2±-0.006	0	0	0
Zn	mg/L	0.05	8.5	11.2±0.95	0.8±0.07	0.4±0.03	0.8±0.07	0.5±0.04	0.8±0.07	0.8±0.07	1.1±0.94	0.4±0.03	0.9±0.07
Ni	mg/L	0.05	6.8	0	0	1.3±0.09	0	2.8±0.19	0	0	0	0	0
NO_3	mg/L	7	3.3	76±2.51	56±1.85	50±1.65	65±2.15	60±2.0	60±2.0	76±2.51	72±2.38	70±2.31	65±2.15
DO	mg/L	2	3.7	6.2±0.23	7±0.26	7±0.26	6.5±0.24	6±0.22	6.2±0.23	5.8±0.22	6.1±0.23	6.4±0.24	6±0.22

Cont…Table 7: Results of analysis of major, minor and trace constituents in groundwater samples from the study area

PARA	UNIT	MDL	%RSD	Labilis	Taba	Fanguru	K/Gasi	Bedi	AVE
TDS	mg/L	0		51.9	50.7	131.4	63.2	63	291.2
Conductivity	µs/cm	0.0		106.1	98.3	246	119.4	118.7	0.8
pH	pH	4		6.1	6	6.8	6.5	6.5	6.8
Temp	°C	1		31	31.5	29.9	32.2	32	30.2
Ca	mg/L	0.5	8.6	3.1±0.26	75±6.45	282±24.25	72.5±6.24	31.2±2.68	239.6
Mg	mg/L	1.88	2.8	333.1±9.33	104.7±2.93	86.6±2.42	45.1±1.26	68.3±1.91	228.5
Na	mg/L	0.5	8.3	23.2±1.93	126±10.46	76.9±6.38	35.8±3.0	17.7±1.47	99.4
K	mg/L	0.5	6.3	104.6±6.59	114.7±7.23	119±7.50	37.6±2.37	16.9±1.07	116.1
HCO_3	mg/L	0.7	4.3	188.1±8.09	185.9±8.00	169±7.27	183.9±7.91	210±9.03	194.1
SO_4^{2-}	mg/L	0.81	7	16.5±1.16	14.8±1.04	11.7±0.82	34.5±2.42	35.6±2.50	24.6
Cl	mg/L	3	7.4	46.22±3.42	47.19±3.50	44.66±3.30	76.8±5,68	54.85±4.06	48.6
CO_3^{2-}	mg/L	2	1.9	11.9±0.23	12.1±0.23	11.5±0.22	12±0.23	11.5±0.22	11.6
PO_4^{3-}	mg/L	4.5	8.1	15.4±1.25	0	106.8±8.65	0	20.4±1.65	54.8
Fe	mg/L	0.08	1.8	10.1±0.18	12.2±0.22	10.5±0.19	17.5±0.32	9±0.16	7.9
Mn	mg/L	1.4	0.3	0	0	0	0	0	0.1
Zn	mg/L	0.05	8.5	1.2±0.10	0.9±0.08	1.2±0.10	11.2±0.95	0.8±0.07	1.9
Ni	mg/L	0.05	6.8	0.2±0.01	0	0	0	0	0.3
NO_3	mg/L	7	3.3	60±1.98	60±2.0	65±2.15	63±2.18	65±2.15	60.9
DO	mg/L	2	3.7	6.5±0.24	7±0.26	6.5±0.24	6±0.22	6.5±0.24	6.3

PARA = parameters, Temp = temperature, TDS = Total Dissolved Solids

The uranium levels recorded at Yimirdallang (YD07) and Kundiga (KD24) exceeded the EPA guideline. Groundwater from these areas might pose health hazards including cancer as a result of ionizing radiation from uranium in groundwater and kidney problems as a result of chemical toxicity of uranium isotopes. Uranium mineralization has been reported around Zona only three kilometers east of Yimirdallang town. The groundwater flow direction in the study area (Fig. 17) suggest that the uranium concentration in the studied water samples around Yimirdallang might originate from the source rocks of the mineralized areas around Zona and has moved with groundwater passing through the rock across Yimirdallang. The water table map (Fig. 14) suggests this possibility.

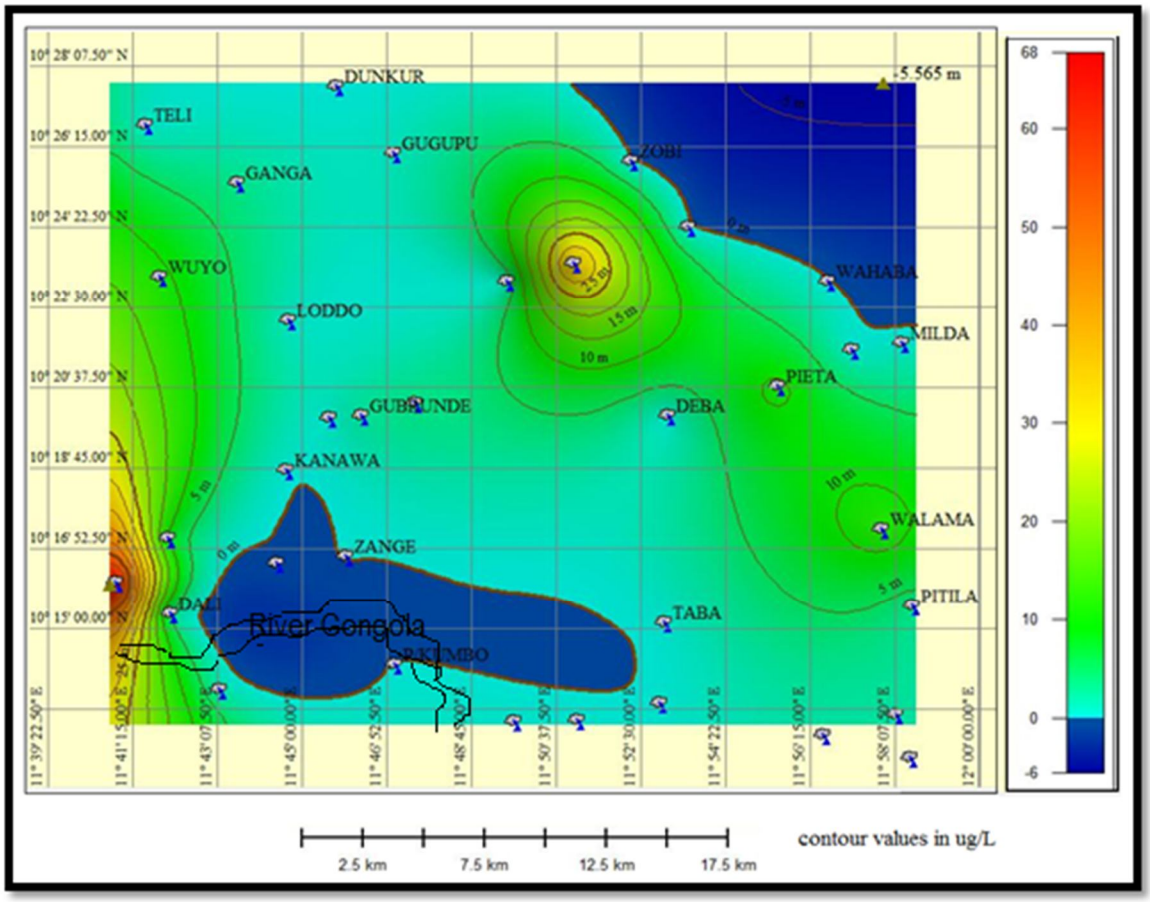


Fig. 15: Map of uranium concentration in groundwater showing locations that complied/exceeded the EPA's MCL of 30 µg/L

Also, it is possible that the high uranium concentration recorded at Kundiga might originate from mineralized areas around Dali and Zange which are less than three kilometers away and might have been dissolved in groundwater and swept through Kundiga (Fig. 15). Groundwater samples with elevated uranium concentration constitute only 5.7% of the samples studied. The Superimposing of uranium concentration contour on geologic map of the study area is presented in Figure 16 (see also Appendix II for enlarged map). The figure revealed that elevated uranium concentration was obtained in groundwater from the undifferentiated Precambrian gneisses, though these are not the localities reported to host uranium mineralization. Brindha *et al.* (2010) made a comparison between uranium

concentration and groundwater level in several wells in India. Their results indicated that the uranium concentration varies primarily due to recharge and discharge. Thus, as groundwater level increases the uranium concentration also increases. This according to them is so because the infiltrating rainfall recharge flushes the uranium from the unsaturated zone which results in an increase of uranium in groundwater along with the rise in water table (see also Emell and Moen, 2005).

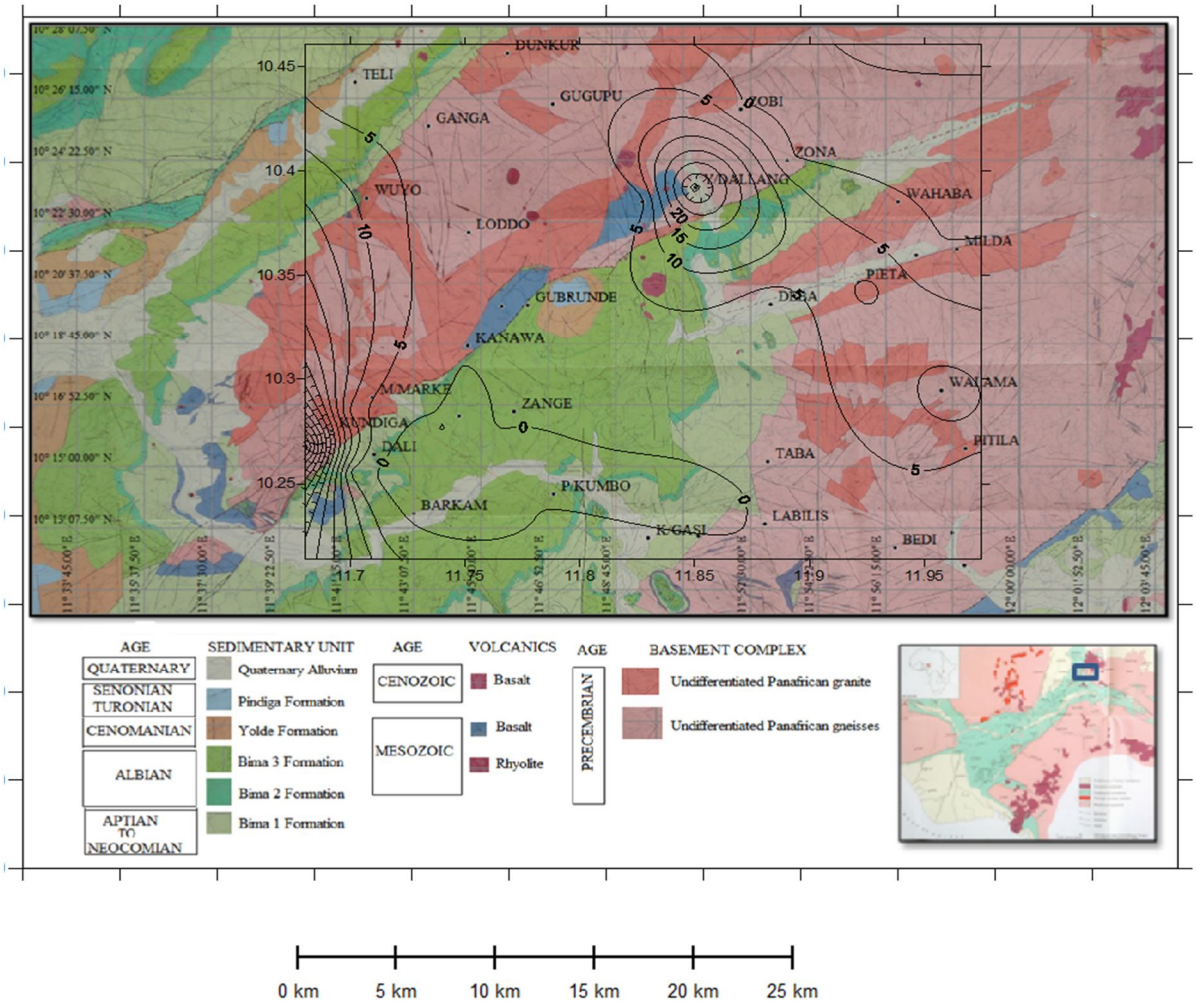


Figure 16: Superimposed contour of uranium concentration on geologic map (Guiraud, 1989) of the study area

In this study, this comparison was not made because of problems of logistics. Therefore, samples were collected only during the peak of dry season, thus, a direct comparison of

seasonal variation in uranium levels in groundwater was not possible. Higher uranium values were obtained in wells of average water level (6 to 13m).

Iron is such a good scavenger of uranium that, to concentrate uranium from a large water sample, a common analytical approach is to bubble an acidified samples with helium to remove the carbonate, add iron, and raise the pH to precipitate iron hydroxide and nearly 100% of the uranium. Concentrations of iron in water samples that had high uranium concentrations (Yimirdallang and Kundiga) are 4.6 and 12.6ppm, respectively. What is not known is how much of this iron contributed to the formation of hydroxide in the sample which might have helped in precipitating uranium from water thereby reducing its mobility and concentration in water and, probably, aiding in secondary uranium mineralization in the area. Groundwater flow in the area (Fig. 17) also indicates movement from mineralized area especially around Zona toward Yimirdallang where uranium concentration in water is greater than 30μg/L maximum contaminant limit. This indicates the possibility that groundwater might have acted as transporting medium for uranium in the area (see enlarged diagram of Figure 17 in appendix).

A graph of the relationship between uranium concentration and Fe and PO_4^{3-} contents and pH of the studied water samples is given in Figure 18. phosphate values > 100mg/l were recorded in five samples indicating the occurence of phosphate in rocks in the study area. High values of phosphate in the rocks and groundwater could enhance the formation of phosphate complexes of uranium which might reduce the chances of uranium entering solution and in this way reduce the uranium concentration/contribution to groundwater radioactivity. As reported by Fabiano and Borotto (2000) and Vermont Agency of Natural

Resources, (VANR, 2010), the presence of dissolved phosphate affects the migration of uranium to water, implying that the uranyl ions must be forming complexes with phosphate, a situation favoured by their near-neutral condition.

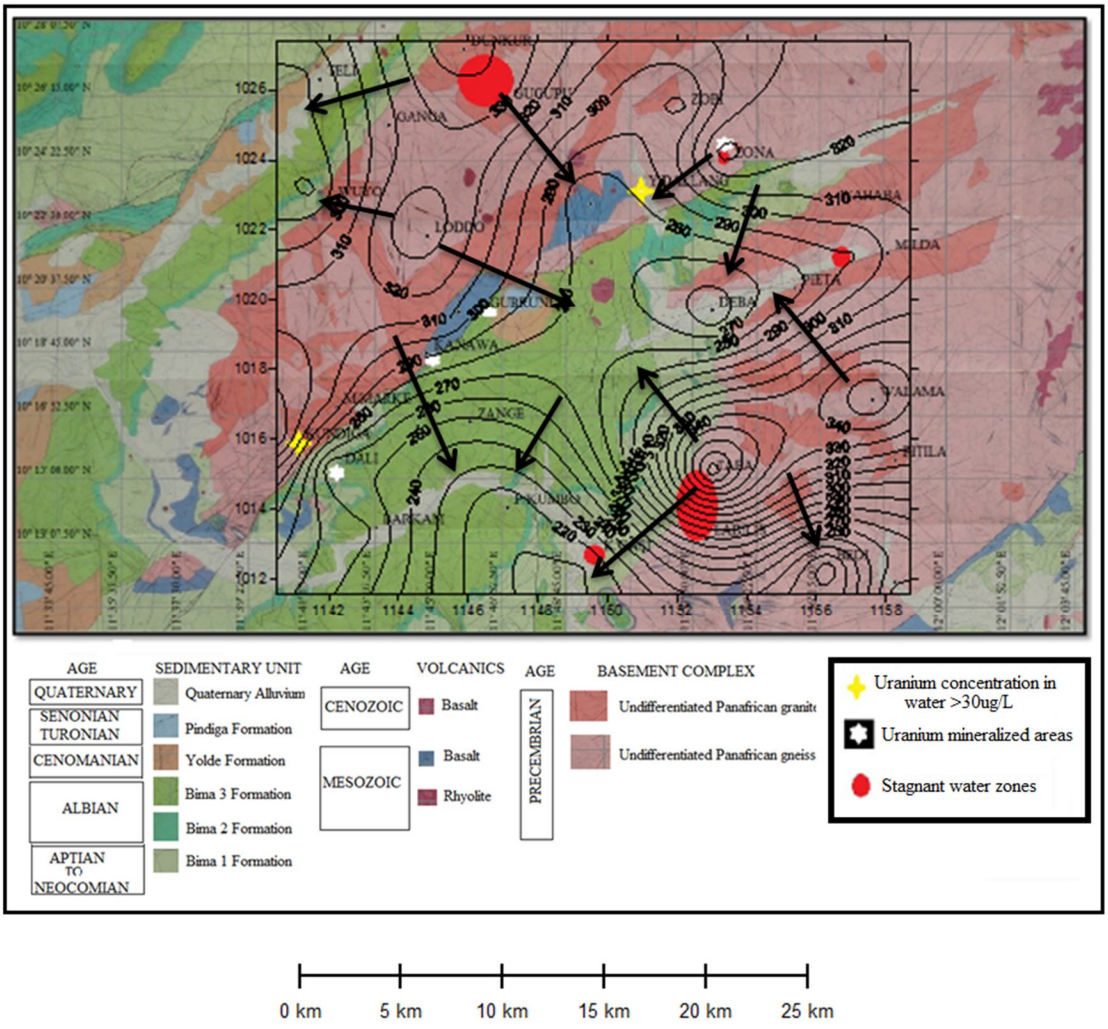
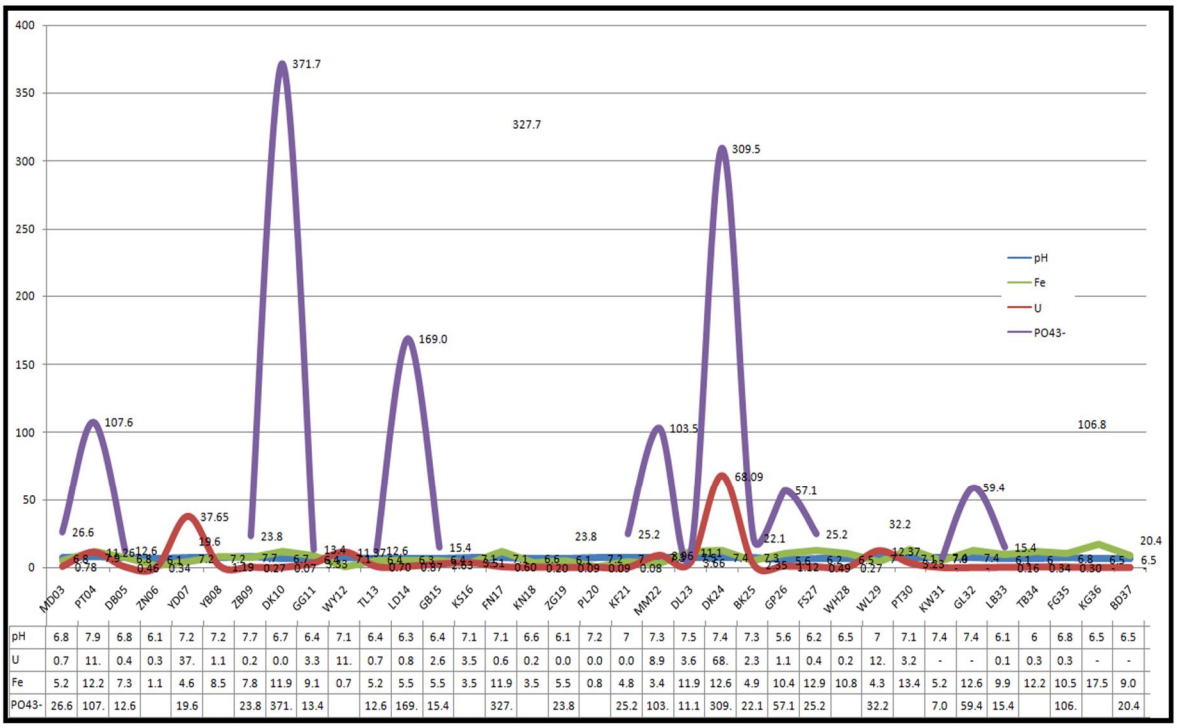


Figure 17: Map of configuration of water Table and direction of groundwater flow in the study area

Iron as a uranium scarvenger and the near acidic nature of the water have possibly aided in precipitating uranium from solution, leading to low uranium concentrations (within

acceptable limits) in about 96% of the studied samples. Results of uranium concentration in groundwater from other parts of Nigeria by Awodugba (2008), Amakum and Jibiri (2010) and Babu et al (2008) is given in Table 7 for comparison and deduction of background values.



pH	6.8	7.9	6.8	6.1	7.2	7.2	7.7	6.7	6.4	7.1	6.4	6.3	6.4	7.1	7.1	6.6	6.1	7.2	7	7.3	7.5	7.4	7.3	5.6	6.2	6.5	7	7.1	7.4	7.4	6.1	6	6.8	6.5	6.5
U	0.7	11.	0.4	0.3	37.	1.1	0.2	0.0	3.3	11.	0.7	0.8	2.6	3.5	0.6	0.2	0.0	0.0	0.0	8.9	3.6	68.	2.3	1.1	0.4	0.2	12.	3.2	-	-	0.1	0.3	0.3	-	-
Fe	5.2	12.2	7.3	1.1	4.6	8.5	7.8	11.9	9.1	0.7	5.2	5.5	5.5	3.5	11.9	3.5	5.5	0.8	4.8	3.4	11.9	12.6	4.9	10.4	12.9	10.8	4.3	13.4	5.2	12.6	9.9	12.2	10.5	17.5	9.0
PO43-	26.6	107.	12.6		19.6		23.8	371.	13.4		12.6	169.	15.4		327.		23.8		25.2	103.	11.1	309.	22.1	57.1	25.2		32.2		7.0	59.4	15.4		106.		20.4

Figure 18: Graph of U, Fe, PO_4^{3-} and pH values of the studied water samples

A comparison of uranium levels in groundwater in the study area and that elsewhere within and outside Nigeria showed that uranium levels in groundwater from the study area are higher than those from the basement area around Zaria as reported by Onoja (2011). For radium, the values from the study area are lower than those reported from the same area in Nigeria by Garba (2008) (Table 7).

Table 8: Comparison of U, ^{226}Ra, ^{228}Ra and ^{232}Th values in groundwater from the study area with other reported value within and outside Nigeria

Worker	Radionuclide			
	U (µg/L)	^{226}Ra (pCi/L)	^{228}Ra (pCi/L)	^{232}Th (µg/L)
This work (NE, Nigera)	0.07±0.02 - 61.25±0.57 (*5.52)	0.05±0.002 - 7.3±0.19 (*1.87)	0.1±0.003 - 4.8±0.12 (*1.53)	0.01±0.001 - 1.1±0.021 (*0.206)
Garba (2010) (NW, Nigeria)		0.81 - 5.4 (*2.7)	13.5 - 5.14 (*2.43)	
Rose (2011) (NW, Nigeria)	0.00029 - 0.073 (*0.0297) ^{238}U			2.7E5 - 0.00973 (*0.0016)
Amakum and Jibiri(2010) (SW, Nigeria)	20.17±0.79 - 267.8±9.09 (*156.7)			
Awodugba (2008) (SW, Nigeria)	458.73±5.04 (*174)			297.00±2.58 (*117)
Babu et al (2008) (Kolar district, india)	0.69 - 54.69 (*15.77)			
Kris (1992) (Dakota, USA)	20 – 120 (*15.8)			

*Mean value

despite the occurence of uranium mineralization in northeastern part of nigeria, Awodugba (2008) and Amakum and Jibiri (2010) reported uranium and thorium levels in boreholes and wells from southwestern Nigeria to be much higher than those obtained both in this study and from Zaria (Table 7) implying greater effects from ionizing radiation and chemical toxicity after long term consumption of water from those parts of Nigeria. what is not know is whether the report value from southwestern parts of the country were correct or not.

The activity concentrations of radium in all the studied water samples fall below the EPA's MCL of 20pCi/L for both ^{226}Ra and ^{228}Ra (Figures 19, 20). This means that based on radium concentration levels, all the studied water sample are radium compliant.

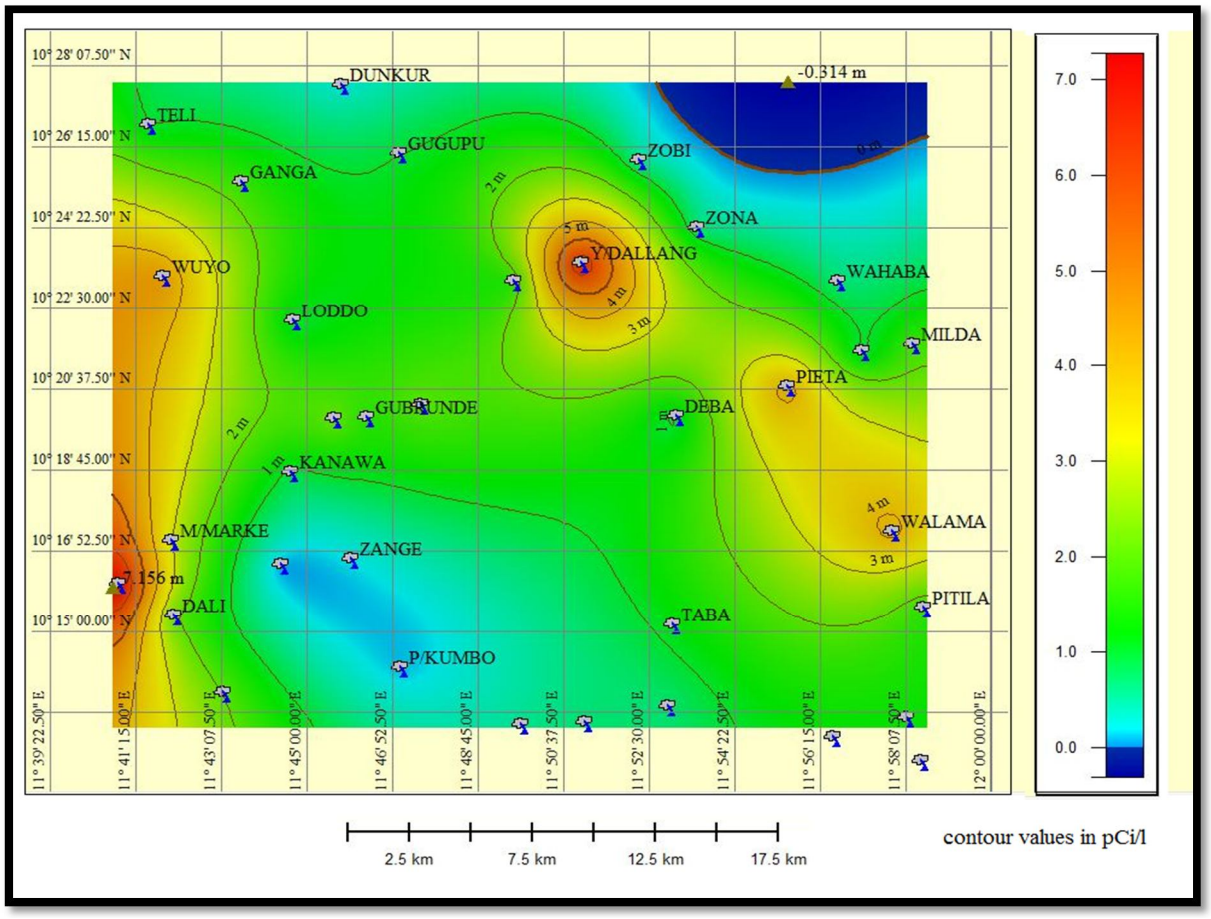


Figure 19: Map of ^{226}Ra activity concentration in groundwater of the study area

Thorium levels recorded in the studied groundwater samples ranged from below the detection limit to 1.1µg/L (Fig. 21). Thorium is not a regulated contaminant in the WHO, EPA and NIS guidelines and therefore, no health guidelines were proposed for it by these bodies.

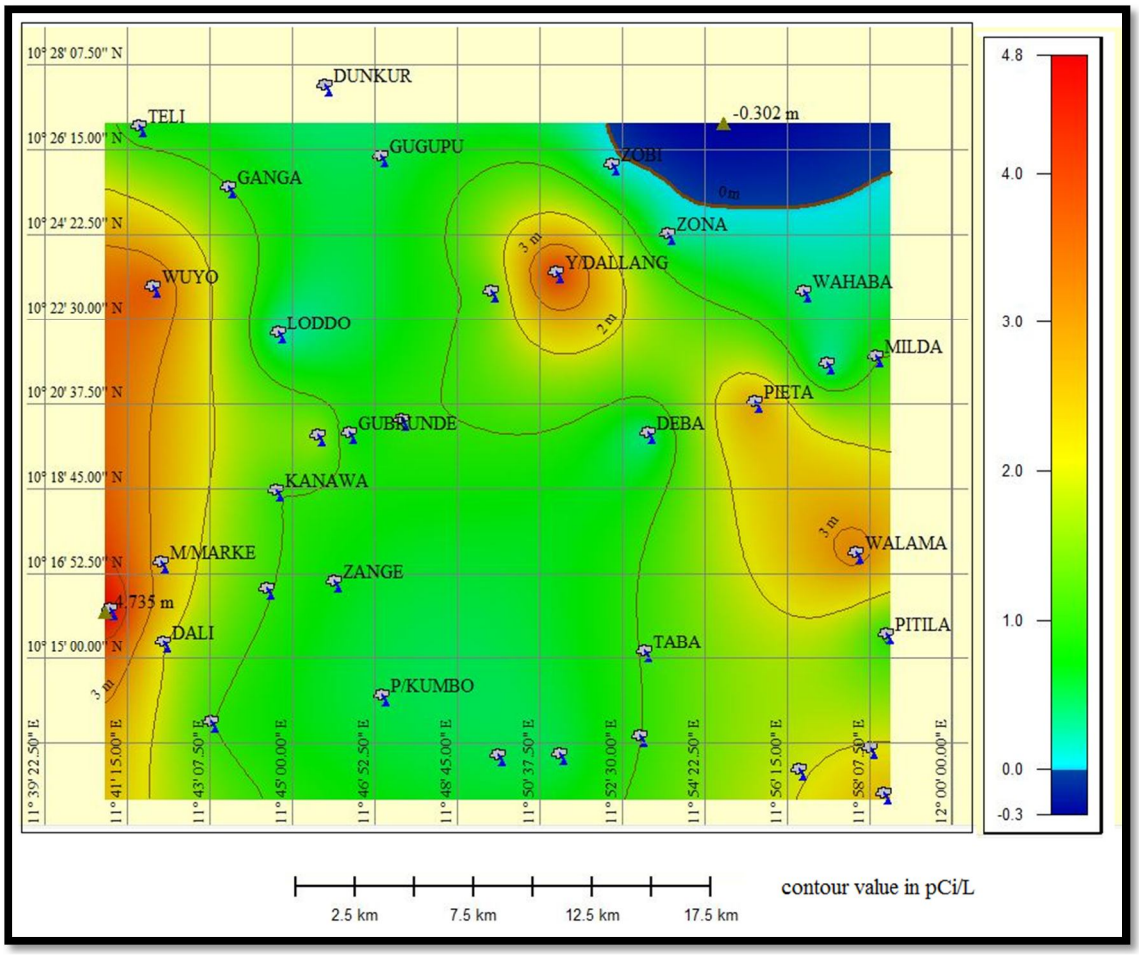


Figure 20: : Map of ^{228}Ra activity concentration in groundwater of the study area

The difference in concentrations of ^{226}Ra, ^{228}Ra and ^{232}Th in groundwater of the study area is that ^{232}Th and its daughter ^{228}Ra are in soluble in water, therefore this non solubility affect its concentration in water while ^{226}Ra which is a daughter to ^{238}U of which both are soluble contaminants that can dissolve and be transported along with groundwater flowing within the sub-surface.

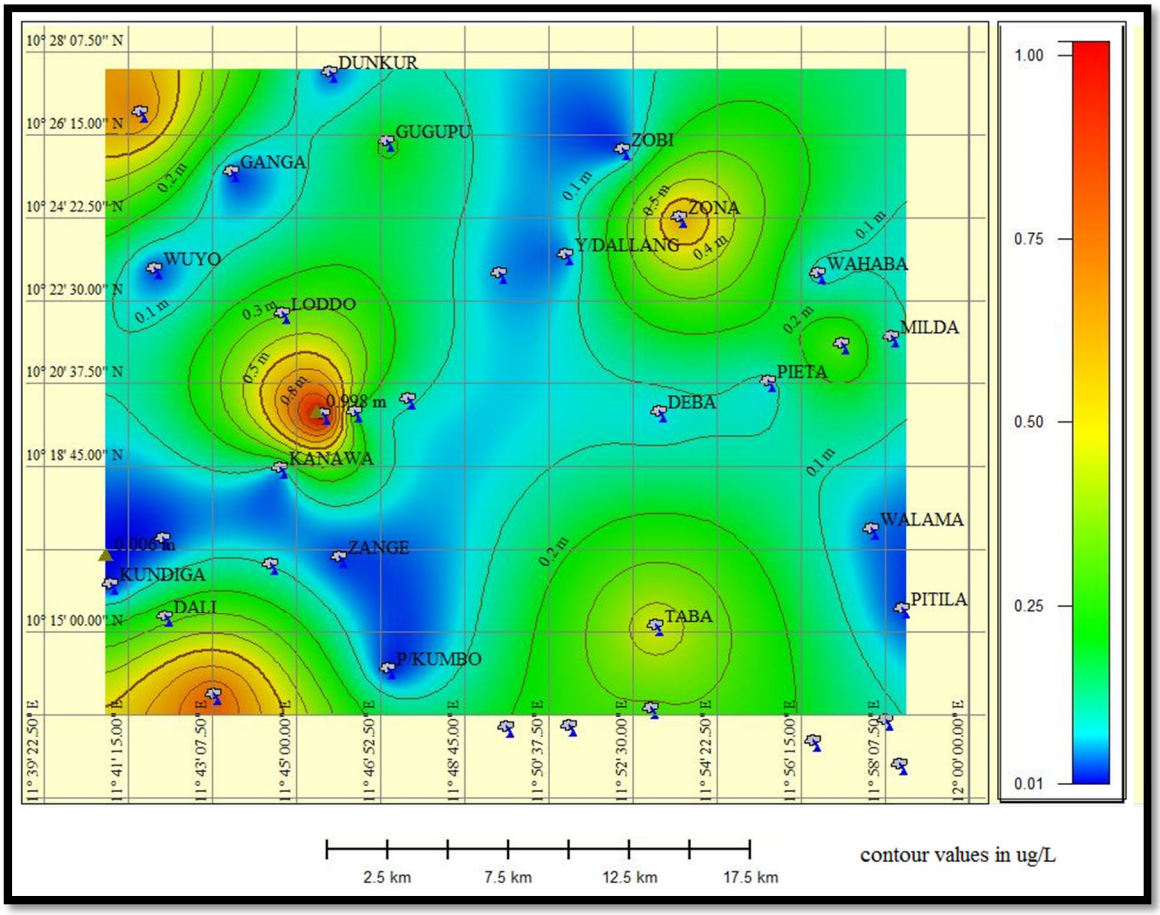


Figure 21: Map of ^{232}Th concentration in groundwater of the study area

4.2.3 Groundwater Chemistry of the Study Area

Water quality evaluation requires knowledge of the processes controlling natural groundwater composition obtained by a detailed hydrochemical evaluation of the groundwater samples. Basic concepts and numerical evaluation of chemical analyses are usually based on relationship between ions, forming the different types of waters. The way in which the data is graphically represented depends on the type and quality of the measured data. In this section, groundwater data is presented in tabular, graphical and contour forms.

According to Hem (1970), expression of the relationship among ions, or of one constituent to the total concentration in terms of mathematical ratios, is often helpful in establishing similarities among groundwaters. Therefore, grouping analyses represents a specific geological terrain, a single aquifer, or a water-bearing zone. The ratios calculated from results in Table 8 and presented in Table 9 in this work are: Cl/HCO_3, SO_4/Cl, (Cl-Na)/Cl, $(Na+Cl+SO_4)/(Ca+Mg+HCO_3)$, Ca/Mg, $(Na-Cl)/SO_4$, (Cl-Na)/Mg and $(Ca-Na)/(SO_4+HCO_3+NO_3)$.

The application of these ratios to hydrogeological evaluations, as proposed by Dundon (1977) is explained as follows:

a. *Chloride/Bicarbonate (Cl/HCO_3)*: This ratio indicates the distance from the source of recharge, i.e. the relative age of the water. The higher values are found in regions with higher TDS, whereas low ratios are usually associated with recharge areas.
b. *Sulphate/Chloride (SO_4/Cl):* Low sulphate-chloride ratios are usually indicative of a reducing environment, meaning that infiltration water passes through a bed containing organic matter. Generally, this ratio becomes smaller away from the recharge area. However, high values may occur as a result of gypsum dissolution (Hem, 1970).
c. *Chloride-Sodium/Chloride ((Cl-Na)/Cl):* This ratio is generally known as the Base Exchange Index. It means that the bivalent Ca^{+2} and Mg^{+2} ions are absorbed onto clay minerals, in exchange for Na^{+} ions. Negative ratios usually indicate base exchange. The Cl-Na/Cl ratio can also be correlated with the Schoeller diagram, meaning that negative ratio values indicate right-sloping line between Ca and Na, while on the other hand, ratios greater than one represent a left-sloping line between Cl and SO_4 (Hem, 1970).
d. *Sodium+Chloride+Sulphate/Calcium+Magnesium+Bicarbonate* ($(Na+Cl+SO_4)/(Ca+Mg+HCO_3)$): This ratio distinguishes between hydrochemical samples of

various compositions, meaning that different groups of water tend to have different ratios.

e. *Calcium/Magnesium (Ca/Mg):* This ratio is almost always less than one, except in limestone, dolomitic or igneous rock environments where these values can be higher, thus indicating probable recharge areas associated with these rock types.

f. *Sodium-Chloride/Sulphate ((Na-Cl)/SO_4):* If this ratio is less than one, the water can be classified as Na-SO_4 water, which means that the water may be relatively old. If, on the other hand, the ratio is greater than one, the water is classified as Na-HCO_3 water, meaning that the water displays characteristics of dynamic water.

g. *Calcium-Sodium/Magnesium ((Ca-Na)/Mg):* This ratio is best used in conjunction with the Cl/HCO_3 and (Na+Cl+SO_4)/(Ca+Mg+HCO_3) ratios in order to prevent a misleading interpretations. If the Cl-Na/Mg ratio is less than one, the analyzed water can be classified as a Mg-Cl water. Such waters are mostly unfit for any type of consumption and are often stagnant waters. If the ratio is greater than one, the water can be classified as a Ca-Cl water, which also suggest stagnant waters.

h. *Chloride-Sodium/Sulphate+Bicarbonate+Nitrate(SO_4+HCO_3+NO_3):* Similar to the (Na+Cl+SO_4)/(Ca+Mg+HCO_3) ratios, according to Hem, (1970), this varies for different groups of waters, thus distinguishing between different hydrochemical compositions.

Table 9: Relationship among ions in terms of mathematical ratio from the studied sample

HYDROCHEMICAL DATA RATIO	Sample ID																	
	Milda	**Pieta**	**Deba**	**Zona**	**YDalang**	**Yumbu**	**Zobi**	**Dunkur**	**Ganga**	**Wuyo**	**Teli**	**Loddo**	**Gubrunde**	**Kasheri**	**Fono**	**Kanawa**	**Zange**	**Palakumbo**
Cl/HCO_3	0.36	0.52	0.23	0.25	0.23	0.26	0.17	0.25	0.17	0.25	0.21	0.26	0.20	0.24	0.26	0.26	0.17	0.26
SO_4^{2-}/Cl	0.89	0.80	0.85	0.81	0.46	0.28	0.91	0.75	0.93	0.34	0.56	0.30	0.67	0.37	0.30	0.31	0.93	0.29
$(Cl-Na)/Cl$	0.61	0.78	0.68	0.41	-0.13	-0.84	0.67	-1.65	0.35	0.04	-0.35	-1.53	0.46	-6.28	-3.75	-2.37	0.35	-5.17
$(Na+Cl+SO_4)/(Ca+Mg+HCO_3)$	0.59	0.76	0.41	0.35	0.06	0.36	0.08	0.12	0.12	0.29	0.19	0.23	0.10	1.22	0.89	0.19	0.05	0.87
Ca/Mg	1.34	1.17	1.14	0.63	0.28	2.05	0.13	3.47	1.33	0.62	1.01	3.79	0.45	0.36	0.34	9.20	4.02	1.06
$(Na-Cl)/SO_4$	-0.69	-0.98	-0.80	-0.51	0.28	2.98	-0.73	2.18	-0.38	-0.11	0.62	5.13	-0.68	17.16	12.70	7.77	-0.38	17.75
$(Cl-Na)/Mg$	1.35	2.30	1.71	0.24	-0.00	-0.53	0.03	-0.22	0.05	0.02	-0.07	-0.57	0.04	-2.85	-1.74	-1.13	0.04	-2.24
$(Cl-Na)/(SO4+HCO_3+NO_3)$	0.14	0.24	0.11	0.07	-0.02	-0.17	0.09	-0.28	0.05	0.01	-0.05	-0.27	0.07	-1.23	-0.76	-0.45	0.05	-1.03

Cont…Table 9: Relationship among ions in terms of mathematical ratio from the studied sample

HYDROCHEMICAL DATA RATIO	Sample ID																
	Kofabila	M/Marke	Dali	kundiga	Barkam	Gugupu	Fesugo	Wahaba	Walama	Pitila	Kwala	Galu	Labilis	Taba	Fanguru	K/Gasi	Bedi
Cl/HCO_3	0.26	0.26	0.25	0.25	0.17	0.27	0.20	0.26	0.25	0.26	0.26	0.27	0.25	0.25	0.26	0.42	0.26
SO_4^{2-}/Cl	0.27	0.28	0.33	0.32	0.94	0.24	0.66	0.27	0.36	0.28	0.29	0.26	0.36	0.31	0.26	0.45	0.65
(Cl-Na)/Cl	0.57	-1.38	-7.30	-4.51	0.42	-1.43	0.65	-1.27	0.53	-6.43	0.57	-2.79	0.50	-1.67	-0.72	0.53	0.68
$(Na+Cl+SO_4)/(Ca+Mg+HCO_3)$	0.09	0.51	1.49	0.41	0.24	0.29	0.10	0.44	0.10	1.10	0.14	0.77	0.16	0.51	0.25	0.49	0.35
Ca/Mg	0.82	0.59	0.44	3.83	1.71	3.44	0.12	0.83	1.17	0.55	0.11	0.32	0.01	0.72	3.26	1.61	0.46
$(Na-Cl)/SO_4$	-2.08	4.84	22.45	13.90	-0.45	5.87	-0.99	4.78	-1.48	22.85	-1.95	10.82	-1.40	5.33	2.76	-1.19	-1.04
(Cl-Na)/Mg	0.07	-0.67	-4.24	-1.69	0.25	-0.70	0.05	-0.55	0.08	-2.43	0.08	-1.33	0.07	-0.75	-0.37	0.91	0.54
$(Cl-Na)/(SO4+HCO_3+NO_3)$	0.11	-0.29	-1.40	-0.85	0.06	-0.28	0.10	-0.23	0.09	-1.38	0.11	-0.56	0.09	-0.33	-0.15	0.16	0.13

4.2.4 Graphical Presentation of Hydrochemical Data

The way in which the data is presented graphically depends on the type and quality of the measured data. In general, there are five possibilities to portray hydrochemical data, and these are numerical, point wise, linear, diagrammatic and areal.

The dissolved solids in chemical analyses are generally in ionic form and are measured in mg/L. To represent the ions as equivalents, each ionic concentration is divided by its atomic weight to give concentration in meq/l.

The forms in which results are presented e.g. Piper, Durov, Schoeller and SAR diagrams are presented here and discussed below. All these diagrams are multivariate diagrams. They represent results of analyses of various water samples which permit direct comparison between the samples and also allow classifying them into different types.

Piper Diagram: Concentrations of ions in meq/l are represented on a trilinear diagram. The macro elements of any specific analysis were plotted on triangle and respective cation and anion positions are projected into a diamond shaped field, representing the total ion relationships.

Distinct groundwater quality types are displayed by their positions in certain subareas of the diamond shaped field (Piper, 1944). The diagram for the studied groundwater samples is shown in Figure 22.

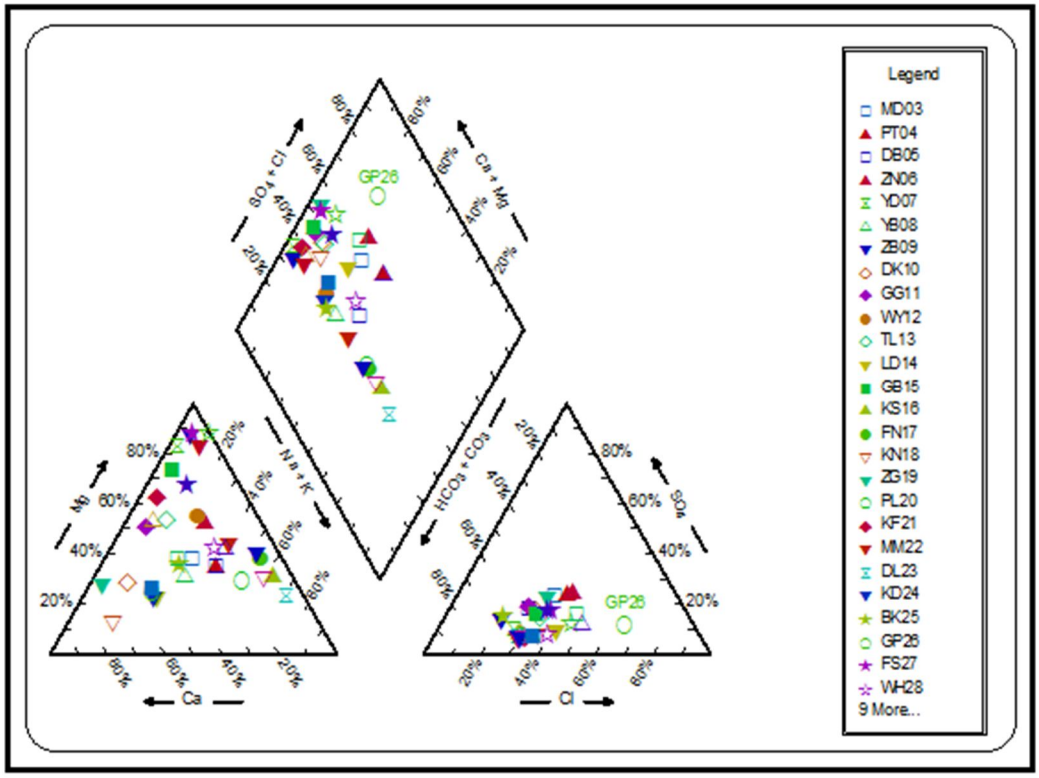


Figure 22: A plot of ions in the studied groundwater samples on Piper diagram.

Durov Diagram: This diagram was developed by Durov (1948) and can also be classified as a trilinear diagram. It is similar to the Piper diagram in that values of the major ions are plotted in separate triangles as shown in Figure 23. The intersection of lines, extended from the points in the triangles to a central enclosed square field, gives a point representing the total dissolved solids (TDS) and the pH values of the water sample, respectively. Lines are now further extrapolated into adjoining rectangular fields, where TDS and pH are plotted respectively.

The advantage of the Durov diagram over the Piper diagram lies in the representation of additional physical parameters of each analysis. According to Tredoux *et al.* (1987), the diagram however, has one disadvantage in that some samples although of different chemical

composition, can plot on the same spot in the adjacent square, which can be confusing. This does not often occur when using the Piper diagram. In general, the trilinear relationship diagrams depict the effect of mixing waters, due to the fact that the mixtures of different waters usually lie on a straight line or straight lines connecting the different components.

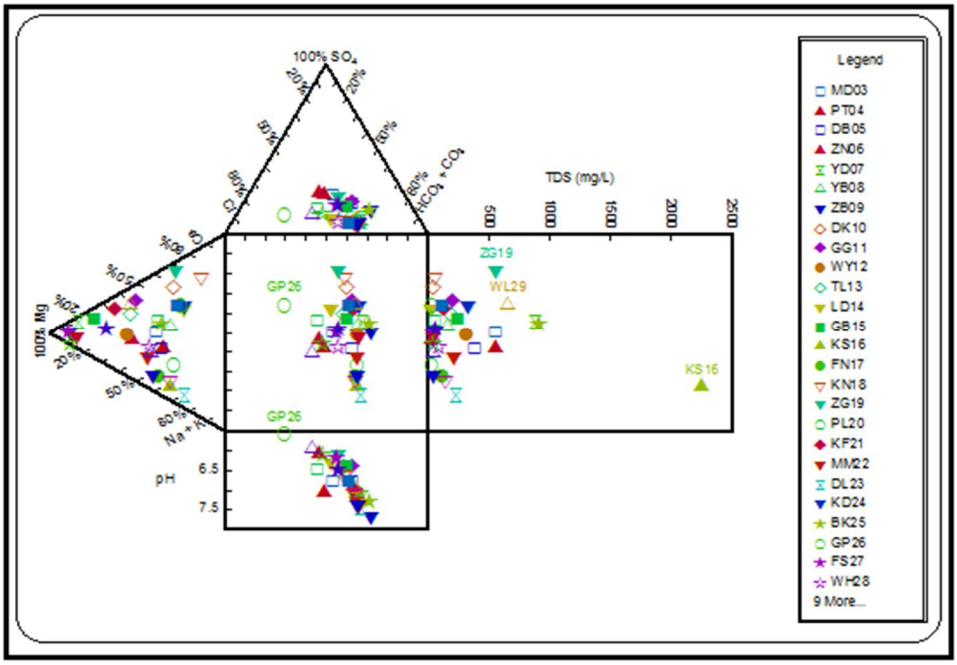


Figure 23: A plot of Durov diagram from results of physico-chemical parameters of the studied groundwater samples

Schoeller Diagram: This makes use of a vertical scale diagram. Ion concentrations in mg/l are plotted in the sequence Ca^{++}, Mg^{++}, Na^{+}, Cl^{-}, SO_4^{2-}, and HCO_3 on the vertical axes, using a logarithmic scale (Fig. 24). Points on different vertical axes, belonging to the same chemical analysis, are connected by straight lines. Thus, plotting the ion concentration of a number of chemical analyses on one diagram reveals different water classes. If the connecting lines between respective axes are parallel to one another, the ionic ratios are the same for different concentrations.

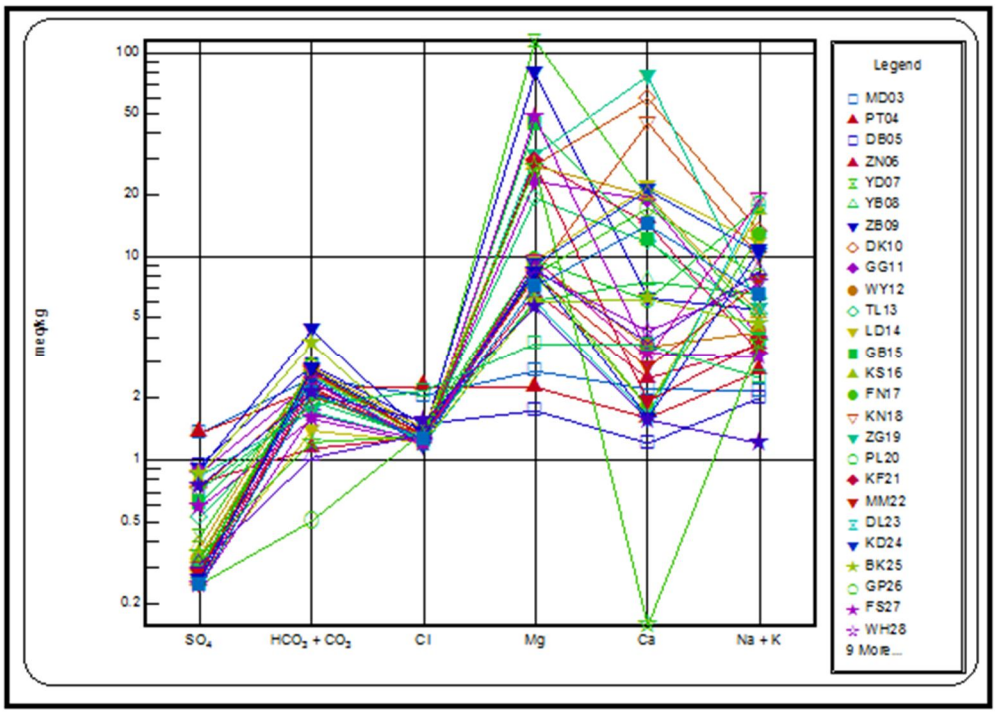


Figure 24: Schoeller diagram of results of major and minor elements in the studied water samples

One distinct advantage the Schoeller diagram has over the trilinear relationship diagram is that the actual ionic concentrations in mg/l are portrayed. Also, this diagram can easily be adjusted to accommodate other combinations of ions.

Sodium Adsorption Ratio (SAR) Diagram: This diagram (Figure 25) has been plotted for the studied water samples; it is appropriate for assessing the suitability of groundwater for irrigation. Groundwater under or near irrigated areas can be polluted by increasing salt accumulation due to the fact that large amounts of water with high salt concentrations due to evaporation losses are recycled. If the irrigation water has high sodium content, it can bring about a replacement of exchangeable cations, Ca^{2+} and Mg^{+2} in clays by sodium (Na^{+}). Soils becoming saturated with sodium lose their fertility as well as permeability. The ability of groundwater to exchange the Ca^{+2} and Mg^{+2} ions by Na^{+} ions is represented by a ratio,

generally known as the sodium adsorption ratio (SAR) represented by the following expression:

$$SAR = \frac{Na^{+}}{\frac{Ca^{++} + Mg^{++}}{2}} \quad \text{.....(1)}$$

SAR can also be expressed graphically, as shown in Fig. 25.

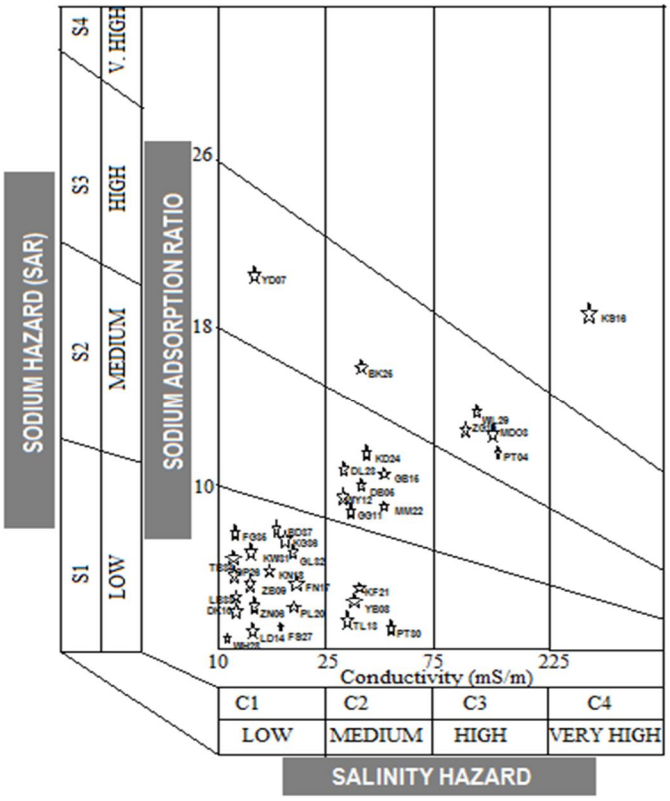


Figure 25: Classification of the studied water samples for irrigation based on Richards (1954) Salinity diagram

Classification of groundwater for irrigation purpose based on Wilcox (1955) is presented in Figure 26. The water is classified according to its electrical conductivity and the sodium adsorption ratio.

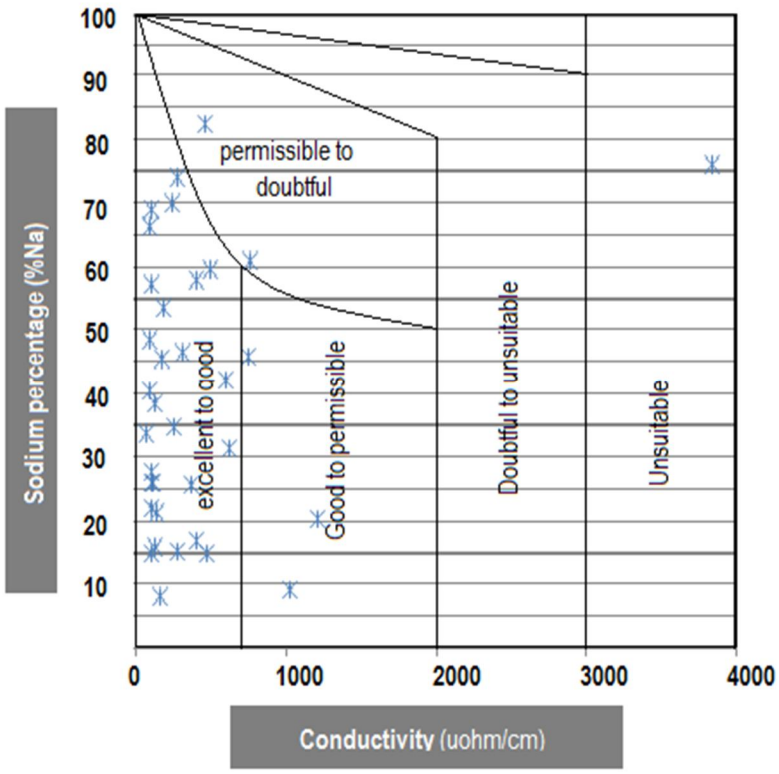


Figure 26: A plot of percentage Sodium and Electrical Conductivity (Based on Wilcox, 1955) for classification of studied groundwater samples for irrigation uses.

4.2.5 Maps Presentation of Data

Of all graphical methods of presenting data, maps and contours are the most important to the hydrogeologist as maps are generally used to accurately depict features, such as boundaries of geologic or hydrogeologic bodies whether formations, boreholes or drainages. Maps and contours constructed from field and analyzed data were constructed using the coordinates obtained during the sampling campaign. The coordinates in decimal degrees were transformed to x, y-coordinates and plotted.

4.2.6 Evaluation of Water Based on Major and Minor Elements

Groundwater evaluation was done by using the AqQA spreadsheet and five water types were identified. These are Mg-HCO_3, Ca-HCO_3, Na-HCO_3, Mg-Cl and Ca-Cl water types. The percentage distribution of these water types are 45.7%, 22.8%, 14.28%, 14.28% and 2.85%, respectively in the studied area. The chloride content of all the water samples are closely related while Mg, Ca and Na+K varied greatly among the different samples (Fig. 26). Based on Dundon, (1977), dynamic and stagnant water zones in the study area were delineated (Figure 28).

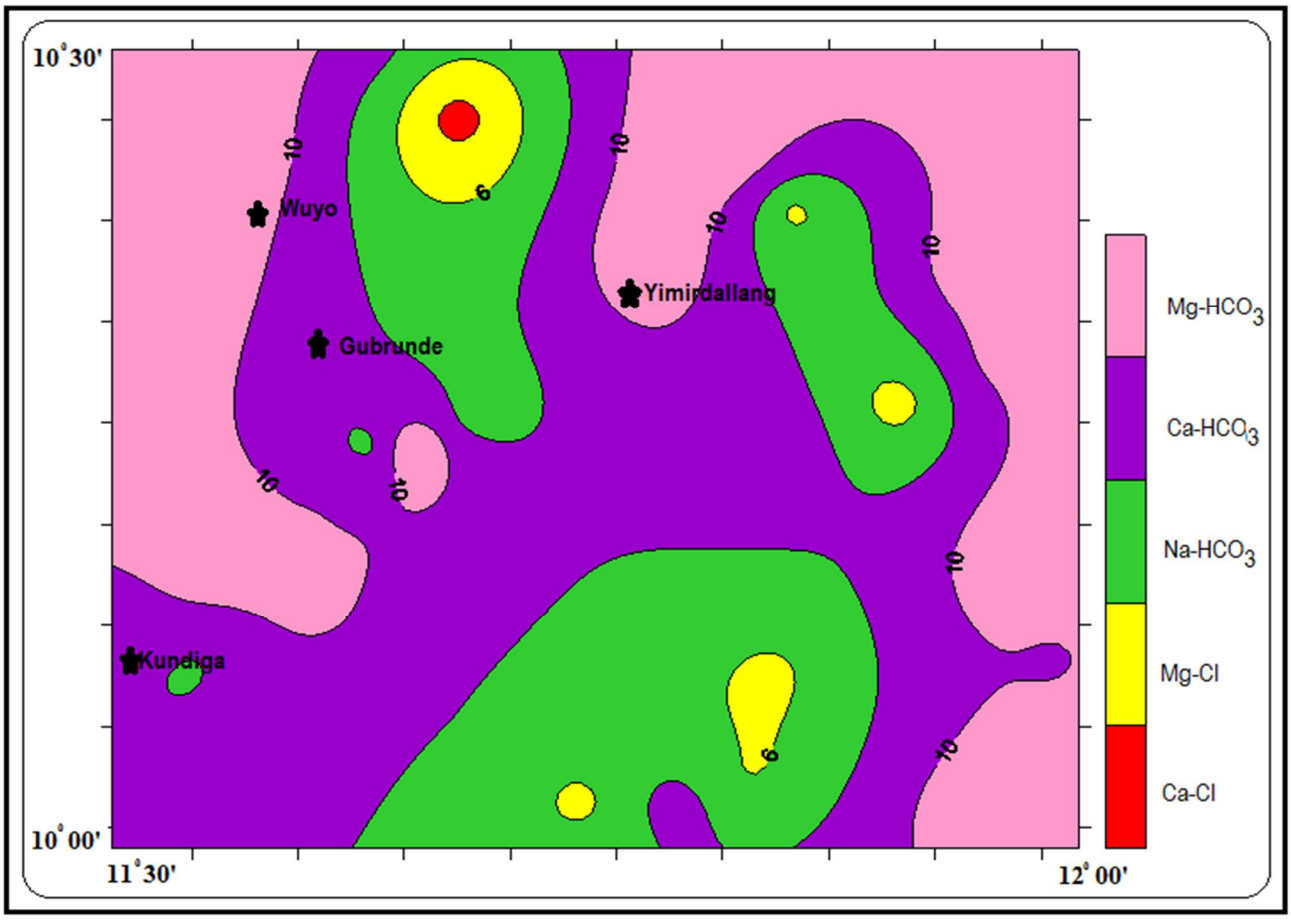


Figure 27: Water type map of the study area

There is no close comparison between the geology and the water types identified from the studied area. Almost all the water types are found in all the three geologic units. Ca-Cl and MgCl water type (stagnant water) were found to be closely related to the Undifferentiated Precambrian gneisses (red colored areas on figure 28) located around Gugupu and Zona in the north and northeastern part of the study area, respectively. In the east and southeastern part of the study area, stagnant water were found around Pieta, Taba, Labilis and K/Gasi, respectively (figure 28, see also appendix II for enlarged map).

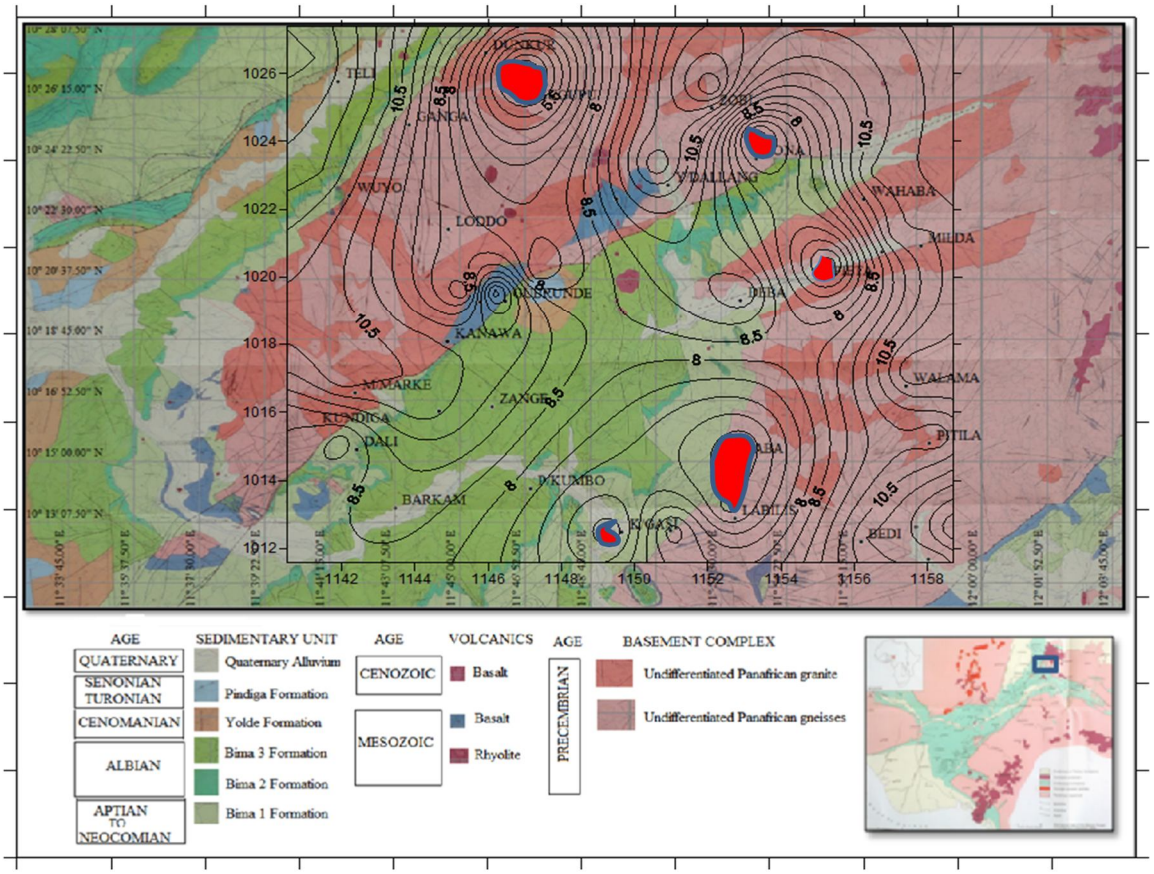


Figure 28: Water type contour superimposed on geologic map of the study area (red areas indicate stagnant water zones)

4.2.7 Evaluation of the Groundwater for Irrigation

The studied water samples have also been evaluated for use in irrigation and fish farming because water for each of these purposes is required to meet certain safety regulations that have been set by the World Health Organization (WHO) and agencies such as the US Environmental Protection Agency (EPA) and the Nigeria Industrial Standard (NIS).

The water quality evaluation in this study was done in order to determine their suitability for agricultural purposes. The suitability of groundwater for irrigation is contingent on the effects on the mineral constituents of the water on both the plants and the soil. It is known that, in particular, salts can be harmful to plants. They can limit growth of plants physically, by restricting the uptake of water through modification of osmotic processes. Also, salts may damage plant growth chemically by their toxic effects upon metabolic processes. Salinity, sodality and toxicity generally need to be considered for evaluation of the suitable quality of groundwater for irrigation (Lloyd and Heathcote, 1985; Todd, 1980; Sheinberg and Oster, 1976). Parameters such as Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), and salinity diagrams were used to assess the suitability of water for irrigation purposes. The results indicate that according to Wilcox (1955) classification of water for irrigation, 80.2% of the samples are classified as excellent for irrigation, 8.5% as good to permissible and permissible to doubtful, while 2-8% are unsuitable for irrigation. The water samples are grouped as detailed below.

Sodium Adsorption Ratio (SAR) and Salinity: Sodium Adsorption Ratio (SAR) is used to evaluate the suitability of water for irrigation. It estimates the degree to which sodium will

be adsorbed by the soil. High value of SAR means that sodium in the water may replace calcium and magnesium ions in the soil, potentially causing damage to the soil structure. Richards (1954) classified water for irrigation as low, medium, high and very high Sodium hazard based on SAR and Conductivity (Table 10 and Fig. 25).

Table 10: Groundwater groups based on sodium adsorption ratio (after Richards, 1954)

SAR	**EC** (mS/m)	**Class**	**Remark**
<100	<250	S1	Low sodium hazard
100 - 180	250 - 750	S2	Medium Sodium hazard
180 - 260	750 - 2250	S3	High sodium hazard
>260	2250 - 5000	S4	Very high sodium hazard

Seventeen (48.5%) of the groundwater samples were categorized as having low salinity and sodium hazard suggesting that the waters from the sources are very good for irrigation. It also indicates that the use of chemical fertilizers in this area did not affect the quality of water for irrigation activities. Twelve of the studied water samples, representing 34%, fall in the medium salinity waters group but based on Sodium Hazard (SH) were categorized as four (11%) were low sodium hazard, seven (20%) were medium sodium hazard; and one sample (3%) was high sodium hazard (Fig. 27). Waters with low and medium salinity or sodium hazard can be used for irrigation but medium salinity and sodium hazard water are best for coarse-textured soil with high permeability (Richards, 1954). About 85% of the studied water samples are suitable for irrigation while 15% might have adverse effects especially on crops without salt tolerance.

As classified by Wilcox (1955), sodium hazard is a function of both SAR and salinity and conductivity. Salinity hazard dividing points are 250, 750 and 2250 μohms, resulting in four

categories as shown in Table 11. Excess salt increases the osmotic pressure of the soil solution that can result in a physiological drought condition. Even though the field appears to have plenty of moisture, the plants wilt because insufficient water is absorbed by the roots to replace that lost from transpiration. The total soluble salt content of irrigation water is generally measured either by determining its electrical conductivity (EC), reported as μS/cm, or by determining the actual salt content in parts per million (ppm).

Table 11: Sodium and Salinity control values (after Wilcox, 1955; 1948)

	Salinity status	Sodium status
<250 μohms	Low salinity water	Low sodium water
250 -750 μohms	Medium salinity water	Medium sodium water
750 -2250 μohms	High salinity water	High sodium water
>2250 μohms	Very high salinity water	Very high sodium water

Based on Wilcox's classification of water for irrigation (Table 11 and Fig. 28), 29 samples (80.2%) were categorized as excellent to good, three samples (8.5%) as good to permissible, three (8.5%) as permissible to doubtful, and one (2.8%) as unsuitable for irrigation (Fig. 26).

Residual Sodium Carbonate (RSC): The Residual Sodium Carbonate (RSC) value considers the bicarbonate content of the water. A high concentration of bicarbonate leads to increases in the pH value of water that causes dissolution of the organic matter. The increase in RSC value also leads to precipitation of calcium and magnesium that can cause an increase in sodium content in the soil. The high concentration of bicarbonate ion in irrigation water increases its toxicity and affects the mineral nutrition of plants.

According to Eaton's classification, water with RSC greater than 2.5epm is considered unsuitable for irrigation. Water with RSC of 1.25 to 2.5 is considered as marginal and that

with values less than 1.25 is safe for irrigation purposes. All the water samples analyzed had RSC values of 0.0 which is less than 1.25 meaning that the water is suitable for irrigation purpose. According to this classification, all the samples fall under waters safe for irrigation.

Total Dissolved Solids (TDS): Wilcox's (1955) Classification of water according to TDS values is given in Table 12.

Table 12: Classification of irrigation water based on TDS (after Wilcox, 1955)

TDS (mg/L)	**Status**
200 – 1000	Best quality water
1000 - 3000	Water involving hazard
3000 – 7000	Used for irrigation only with leaching and perfect drainage

The TDS values recorded in the studied water samples range from 34.6 – 2260 mg/L. The highest TDS value recorded in the examined groundwater samples is 2260mg/L(in sample KS16) while the lowest value was 34.6mg/L (in sample GP26). Thirty one samples (97%) had TDS values of less than 1000mg/L which indicates that the water had best quality for irrigation purpose. Only one sample with TDS of 2260 mg/L requires soil with high leaching potential and perfect drainage for use in irrigation. According to Chebotarev (1955), waters with TDS of <1500mg/L are categorized as fresh water. This indicates that most of water samples are fresh water.

Magnesium Hazard (MH): Although calcium and magnesium ions are essential for plant growth, they may be associated with soil aggregation and friability. Generally, calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yield as the soil become more saline (Joshi *et al*., 2009). Water with calcium and magnesium concentrations higher than 200 mg/L cannot be used efficiently in

agriculture. The values of magnesium hazard in the studied water samples range from 29.1 to 99.4%, out of which two (5.73%) samples had magnesium hazards exceeding the 50% acceptable limit as described in Ayers and Westcott (1985). Therefore. these waters are considered unsuitable for irrigation based on magnesium hazard associated with them, a magnesium hazard exceeding 50% causes harmful effect to soil.

4.2.8 Evaluation of the Groundwater for Aquaculture

Recently in Nigeria, fish farming has experienced a boom. Water quality determines to a great extent the success or failure of a fish cultural operation (Piper *et al.,* 1982). Because water is an essential requirement for fish farming, it is only a properly trained aquaculturist who fully understands or takes into consideration the quality and quantity of water available for the purpose. Some aspects of water quality that have direct implication on fish farming have been evaluated; these include temperature, salinity, dissolved oxygen and hardness. As discussed below, most of these parameters were satisfied in the study area.

Temperature: Temperature recorded for the studied waters ranged from 25°C to 35^0C. All the temperatures recorded in the area studied are less than 32.2°C except in sample ZB09 where the temperature recorded was 35^0C. This indicates that, based on temperature and the species of fish grown in Nigeria (which are mostly catfish and tilapia), the water samples analyzed had tolerable temperatures for aquaculture. Sice these fish can survive under all the temperature ranges recorded.

Dissolved Oxygen (DO): In the studied waters, the concentration of dissolved oxygen recorded ranges from 5.6 to 7.73mg/L with a mean of 6.3mg/L (Table 8). This signifies that for aquacultural purposes, the studied water samples are suitable for fish farming. This is

especially so for warm-water fish whose dissolved oxygen requirements stand at 5mg/L or less, they being the type of fish mostly farmed in Nigeria.

A common generalization about oxygen requirements for aquaculture is that the minimum dissolved oxygen required for growth of warm-water and cold-water fish at their optimum temperature is > 5 mg/L and > 6 mg/L, respectively (Mbagwu and Adeniji, 1994). Thus, for a raceway or circular tank, oxygen concentration of the effluent water should be at least 5 mg/L. Oxygen is the first limiting factor for growth and well-being of Fish, fish require oxygen for respiration, which physiologists express as mg of oxygen consumed per kilogram of fish per hour (mg O_2/kg/h). The respiratory rate increases with increasing temperature, activity and following feeding, but decreases with increasing mean weight. Several important implications of these physiological facts for aquaculture are:

a. At a given temperature, smaller fish consume more oxygen per unit of body weight than larger fish; or put in another way, for the same total weight of fish in a tank, smaller fish require more oxygen than larger fish
b. Actively swimming fish consume more oxygen than resting fish. In raceways, high exchange rates will increase energy expenditures for swimming, and oxygen consumption.
c. Oxygen consumption of fish will increase after feeding; multiple feedings per day (3 or more) will result in less variation in greater oxygen demand than 1 to 2 feedings per day.

pH: The pH values recorded for the studied samples ranges from 5.7 to 7.2, this shows that except for one sample (GP26), all the water samples studied are within the 6.5 to 8.5 value for natural waters that are unaffected by pollution. The pH of water is an index of its hydrogen ion (H^+) activity of the water. The pH scale (range from 0 to 14) is logarithmic (base 10), an important fact to remember because a drop of 1 pH unit indicates a 10 fold increase in hydrogen ions (H^+) present in water. A pH value may fall anywhere on a scale from 0 (strongly acidic) to 14 (strongly basic or alkaline), with a value of 7 representing neutrality (10^{-7} moles/liter of H^+ ions).

4.2.9 Evaluation of Major, Minor and Trace elements

A summary and comparison of parameters in studied water samples with the WHO, EPA and NIS guidelines is given in Table 13.

Calcium: Eighteen (51.4%) of the studied samples had calcium content exceeding the 75 mg/L WHO recommended values. But based on the EC Scientific Committee for Food (1993) and US Committee on Dietary Reference Intake (1997), only 5.7% of the studied water samples had calcium values greater than 1000mg/L daily Dietary Reference Intake. According to Arthur (1995), sources of calcium in groundwater could be anorthite and some ferromagnesian minerals. Calcium is essential for the human body. Calcium is part of bones and teeth. In addition, it plays a role in neuromuscular excitability (decreases it), functioning of the myocardial system, heart and muscle contractility, intracellular information transmission and blood coagulability. There is no health guide recommendation for calcium in the EPA and NIS reference documents.

Table 13: Summary and comparison of studied parameters in studied water samples with WHO, EPA and NIS Guideline

PARAMETER	UNIT	EPA(2004)	NIS(2007)	WHO(2011)	THIS WORK		REMARK
					RANGE	MEAN	
Temperature	°C			-	25 - 35	30.21	Not regulated
Conductivity	µs/cm		1000	1,400	65.9 - 3840	419.88	11.4% > NIS, 5.7% > WHO
***Hardness(Total)**	mg/L		150	500	146 – 6621	1500	74.3% > WHO, 97.1% > NIS
***TDS**	mg/L	500	500	1,000	34.6 - 2260	291.20	17.14% > NIS,EPA
***pH**	pH	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	5.6 - 7.7	6.80	Within limit
Ca	mg/L			75	3.1 - 1524	239.56	5.7% > 1000mgpd intake
Mg	mg/L		0.2	50	21 - 1375	228.50	11.4% > 400mgpd intake
***Na**	mg/L		200	50	14.8 - 350	99.36	17.14% > NIS
***K**	mg/L			55	16.9 - 308	116.11	85.7% > WHO Sec.
HCO_3^-	mg/L			1,000	157 - 270	194.11	Within limit
***SO_4^{2-}**	mg/L	250	100	250	11.7 - 64.6	24.56	Within limit
***Cl**	mg/L	250	250	250	41.34 - 81	48.61	Within 250mg/L
NO_3	mg/L	10	50	50	29 - 65	44.34	85.7% > WHO, NIS
CO_3^{2-}	mg/L	120			10.6 - 12.8	11.59	Within limit
PO_4^{3-}	mg/L				0 - 371.7	54.82	
***Fe**	mg/L			0.3	0.7 - 17.5	7.88	All > WHO,NIS limit
***Mn**	mg/L	0.4	0.05	0.2	0 - 1.98	0.09	5.7% > WHO, EPA, NIS
Pb	mg/L	0.01	15	10	0.0 3 -7.99	0.034	Within limit
Zn	mg/L	0.1	5	3	0.37 - 12.6	1.92	14.3% greasy on boiling
Ni	mg/L	0.07		0.02	0 - 6.25	0.32	20% > WHO, NIS limit
^{226}Ra	pCi/L	20	20		0.1 - 6.7	1.87	Within limit
^{228}Ra	pCi/L	20	20	2.7pCi/L	0.1 - 4.8	1.50	Within limit
^{232}Th	µg/L				0.01 - 1.1	0.206	No Health Guideline
U	µg/L	30	30		0.07 - 61.25	5.52	5.7% > WHO, EPA limit

*Naturally occurring chemicals whose guideline values have not been established by WHO (values displayed are secondary or proposed guidelines)

Chloride: The chloride values recorded for the studied groundwater samples show that all the studied water samples had chloride values below the 250mg/L guideline set by the WHO, EPA and NIS. Sources of chloride in groundwater could be halite dissolution or reverse softening in the case of brine or sea water (Arthur, 1995). Chloride values above 250 mg/? might give a salty taste to water and beverages. Taste thresholds for the chloride anion depend on the associated cation and are in the range of 200–300mg/L for sodium, potassium and calcium chloride. Concentrations in excess of 250mg/L are increasingly likely to be detected by taste, but some consumers may become accustomed to low levels of chloride-induced taste. No primary health-based guideline value is proposed for chloride in drinking-water.

The EPA has identified 250mg/L as a concentration at which chloride can be expected to cause a salty taste in drinking water. The secondary level of 250mg/L is based on aesthetic concerns, and is only advisory in the US Federal Safe Drinking Water program.

Hardness: On the Piper diagram, most of the samples fall under waters with temporary hardness. Seventy three (97%) of the samples studied had hardness as greater than the WHO and NIS secondary guidelines. This means that these samples will require more soap than usual during washing or cleaning in homes. Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Public acceptability of the degree of hardness of water may vary considerably from one community to another, depending on local conditions.

The taste threshold for the calcium ion is in the range of 100–300 mg/L, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for

calcium. In some instances, consumers tolerate water hardness in excess of 500 mg/L. Depending on the interaction of other factors, such as pH and alkalinity, water with hardness above approximately 200 mg/L may cause scale deposition in treatment works, distribution systems and pipe work and tanks within buildings. On heating, hard waters form deposits of calcium carbonate scale. Soft water, with a hardness of less than 100mg/L, may, on the other hand, have a low buffering capacity and so be more corrosive for water pipes. No health-based guideline value is proposed for hardness in drinking water.

Iron (Fe): All the samples studied had iron concentrations exceeding the secondary limit of 1mg/L and 0.3mg/L set by WHO and NIS, respectively. Sources of iron in groundwater could be ferromagnesian minerals. Anaerobic groundwater may contain ferrous iron at concentrations of up to several mg/L without discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, giving an objectionable reddish-brown color to the water. Iron also promotes the growth of "iron bacteria" which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping. At levels above 0.3 mg/L, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 mg/L, although turbidity and color may develop. No primary health-based guideline value is proposed for iron by either the WHO (2008), EPA (2000) or NIS (2007).

Potassium: There is no health guide for potassium in the NIS and EPA Guide lines but the WHO (2004; 2008; 2011) has set a secondary health guide of 55mg/L. 85.7% of the present samples studied had potassium contents exceeding this level. Potassium occurs in various

minerals, from which it may be dissolved through weathering processes. Examples are feldspars (orthoclase and microcline), which are however not very significant for potassium compounds production, and chloride minerals such as carnalite and sylvite, which goes into solution. Some clay minerals contain potassium. It ends up in seawater through natural processes, where it mainly settles in sediments. Potassium is a dietary requirement human who take up about 1-6g/day at a requirement of 2-3.5g/day. The total potassium content in the human body is between 110 and 140 g and mainly depends upon muscle mass. The muscles contain most potassium (after red blood cells and brain tissue). Whereas its opponent sodium is present in intracellular fluids, potassium is mainly present within cells. It preserves osmotic pressure. The relation of potassium in cells to potassium in plasma is 27:1, and is regulated by means of sodium-potassium pumps. Vital functions of potassium include its role in nerve stimulus, muscle contractions, blood pressure regulation and protein dissolution. It protects the heart and arteries, and may even prevent cardiovascular disease. Potassium shortages are relatively rare, but may lead to depression, muscle weakness, heart rhythm disorder and confusion. Potassium loss may be a consequence of chronic diarrhea or kidney disease because the physical potassium balance is regulated by the kidneys. When kidneys operate insufficiently potassium intake must be limited to prevent greater losses.

Lead: Lead is a metal found in natural deposits. In the studied samples, lead source could be from natural decay of parent radionuclide (uranium). The World Health Organization (WHO) stated a legal limit of 50µg/L for lead in 1995, which is decreased to 10µg/L in 2010. For NIS, the value is the same as WHO while EPA MCL for lead is 15µg/L. Lead concentration in all the samples fall within the recommendations set by WHO, EPA and NIS. Lead is commonly used in household plumbing materials and water service lines. Lead

in drinking water can cause a variety of adverse health effects. In babies and children, exposure to lead in drinking water above the action level can result in delays in physical and mental development, along with slight deficits in attention span and learning abilities. In adults, it can cause increases in blood pressure. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Under normal conditions lead does not react with water. However, when lead comes in contact with moist air, reactivity with water increases. A small lead oxide (PbO) layer forms at the surface of the metal. When both oxygen and water are present, metallic lead is converted to lead hydroxide ($Pb(OH)_2$). A well-known example of a water soluble lead compound is lead sugar (lead (II) acetate), which derive its name from its sweet nature. Lead frequently binds to sulphur in sulphide form (S^{2-}), or to phosphorus in phosphate form (PO_4^{3-}). In these forms lead is extremely insoluble, and is present as immobile compounds in the environment.

Manganese: The WHO, EPA and NIS have set manganese in drinking water at 0.4mg/L, 0.05mg/L and 0.2mg/L, respectively. The two present samples in which manganese was detected had concentrations exceeding the WHO, EPA and NIS set guidelines, 0.2 mg/L, 0.4 mg/L and 0.05 mg/L, respectively.

At levels exceeding 0.1mg/L manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. Even at a concentration of 0.2 mg/L, manganese will often form a coating on pipes, which

may slough off as a black precipitate. The health-based guideline value for manganese is 4 times higher than this acceptability threshold of 0.1 mg/L

Magnesium: Four (11.43%) of the thirty five samples studied had magnesium values that exceeding the 400mgpd intake for adult as suggested by the EC Scientific Committee for Food (1993); Committee on Dietary Reference Intake (1997).

Magnesium is usually less abundant in waters than calcium, which is easy to understand since magnesium is found in the Earth's crust in much lower amounts compared to calcium (Farntisek, 2003). In underground and surface waters the weight concentration of Ca is usually several times higher compared to that of Mg, the Ca to Mg ratio reaching up to 10. Nevertheless, a common Ca to Mg ratio is about 4, which corresponds to a substance ratio of 2.4 (Pitter, 1999).

In low- and medium-mineralized underground and surface waters (as drinking waters are), calcium and magnesium are mainly present as simple ions (Ca^{2+} and Mg^{2+}) , the Ca levels varying from tens to hundreds of mg/l and the Mg concentrations varying from units to tens of mg/l.

Magnesium plays an important role as a cofactor and activator of more than 300 enzymatic reactions including glycolysis, metabolism, transport of elements such as Na, K and Ca through membranes, synthesis of proteins and nucleic acids, neuromuscular excitability and muscle contraction. It acts as a natural antagonist to calcium. Magnesium deficiency increases risk to humans of developing various pathological conditions such as vasoconstrictions, hypertension, cardiac arrhythmia, atherosclerotic vascular disease, and acute myocardial infarction, eclampsia in pregnant women, possibly diabetes mellitus of

type II and osteoporosis (Rude, 1998; Innerarity, 2000; Saris *et al.,* 2000). These relationships reported in multiple clinical and epidemiological studies have recently been increasingly supported by the results of experimental studies on animals (Sherer *et al.,* 2001). The recommended magnesium daily intake for an adult is about 300-400mg/L (EC Scientific Committee for Food, 1993; US Committee on Dietary Reference Intake, 1997).

Nickel: Nickel in groundwater could be due to the leaching of nickel from new nickel/chromium-plated materials use in fetching water from the wells. Low concentrations may also arise from stainless steel pipes and fittings in the case of tap water. Most of the samples studied (80%) had zero nickel contents, while about 20% had values in the range between 0.1mg/L (in sample MD01) and 6.3mg/L (in sample ZG19) with a mean of 0.3mg/L and %RSD of 6.8. The Nigerian guidelines for drinking water set 0.02mg/L as for nickel while the WHO (2011; 2008) is 0.07mg/L. All seven water samples that contained nickel could possibly cause carcinogenic health impacts as described in the NIS (2007). An increase of pH to control corrosion of other materials also reduces leaching of nickel.

Nitrate: The sources of nitrate as a contaminant in drinking water are runoff from fertilizer use leaking from septic tanks, sewage and erosion of natural deposits. Nitrate may be present as a consequence of tillage when there is no growth to take up nitrate released from decomposing plants, from the application of excess inorganic or organic fertilizer and in slurry from animal production. The WHO (2011) and NIS (2007) both set the MCL for nitrate at 50mg/L, while for the EPA (2000; 2005; 2010) it was 10mg/L. Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby

syndrome. Nitrate concentrations in the studied water samples ranged from 21mg/L (in sample MD03) to 77mg/L (in sample ZB09) with a mean of 60.9 and %RSD of 3.3. Some 85% of the studied samples had nitrate contents exceeding the WHO and NIS's MCL of 50mg/L while all the samples had nitrate levels exceeding the EPA's MCL of 10mg/L. The high nitrate concentration recorded in the sample might be due excessive use of chemical fertilizers in the area.

Sodium: Sources of sodium in the samples could be halite dissolution or natural softening or albite solution. Only 17.14% of the 35 samples studied had sodium contents greater than the NIS MCL of 200mg/L. The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution. At room temperature, the average taste threshold for sodium is about 200mg/L. No primary health-based guideline value has been set by the WHO and EPA, but the NIS has set a secondary MCL at 200mg/L.

Sulphate: Source of sulfate in groundwater could be pyrite oxidation or direct dissolution of gypsum or anhydrite. All the groundwater samples studied had sulfate contents below the secondary MCL set by all the regulatory bodies (WHO, EPA and NIS). The presence of sulfate in drinking-water can cause noticeable taste and very high levels might cause a laxative effect in unaccustomed consumers. Taste impairment varies with the nature of the associated cation; taste thresholds have been found to range from 250mg/L for sodium sulfate to 1000mg/L for calcium sulfate. It is generally considered that taste impairment is minimal at levels below 250mg/L. Only a secondary health-based guideline value has been derived for sulfate, this is set at 400mg/L, 250mg/L and 100mg/L by the WHO, EPA and NIS, respectively.

Total Dissolved Solids (TDS): About 17.14% of the 35 studied samples had TDS values exceeding the 500mg/L set by NIS (2007) and EPA (2000) while only one exceeded the 1000mg/L set by the WHO (2011; 2008). The palatability of water with a TDS level of less than 600mg/L is generally considered to be good. Drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000mg/L. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. As a secondary guideline, the EPA and NIS have set a value of 500mg/L value for TDS, while 1000mg/L was set by the WHO (2011; 2008).

Zinc: Although drinking-water seldom contains zinc at concentrations above 0.1mg/L (EPA , 2000), about 14.3% of the 35 groundwater samples studied had the tendency to developing greasy film on boiling because of the zinc levels (>0.1 mg/L) recorded in them. Zinc imparts an undesirable astringent taste to water at a taste threshold concentration of about 4 mg/L (as zinc sulfate). Water containing zinc at concentrations in excess of 3 to 5 mg/L may appear opalescent and develop a greasy film on boiling. Zinc levels in tap water can be high because of the zinc used in older galvanized plumbing materials. No health-based guideline value has been proposed for zinc in drinking-water but the WHO (2011; 2008) and EPA set a secondary guide for zinc in drinking water at 5 mg/L, while it was 3mg/L for the NIS.

Temperature: Cool water is generally more palatable than warm water, and temperature will impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature enhances the growth of microorganisms and may increase taste, odor, color and corrosion problems. It can also

result in high mortality (temperature shock) of fish (fingerlings) when moved between two different water bodied with considerable temperature variation.

In summary, the compliance of the studied parameters with WHO, EPA and NIS guidelines has been summarized and presented in Table 13 while a graphic presentation of some major, minor and physicochemical constituents in the studied samples is presented in Figure 29 which indicates that sample KS16, ZG19, YD07and Wl29 were more mineralized than the rest of the samples.

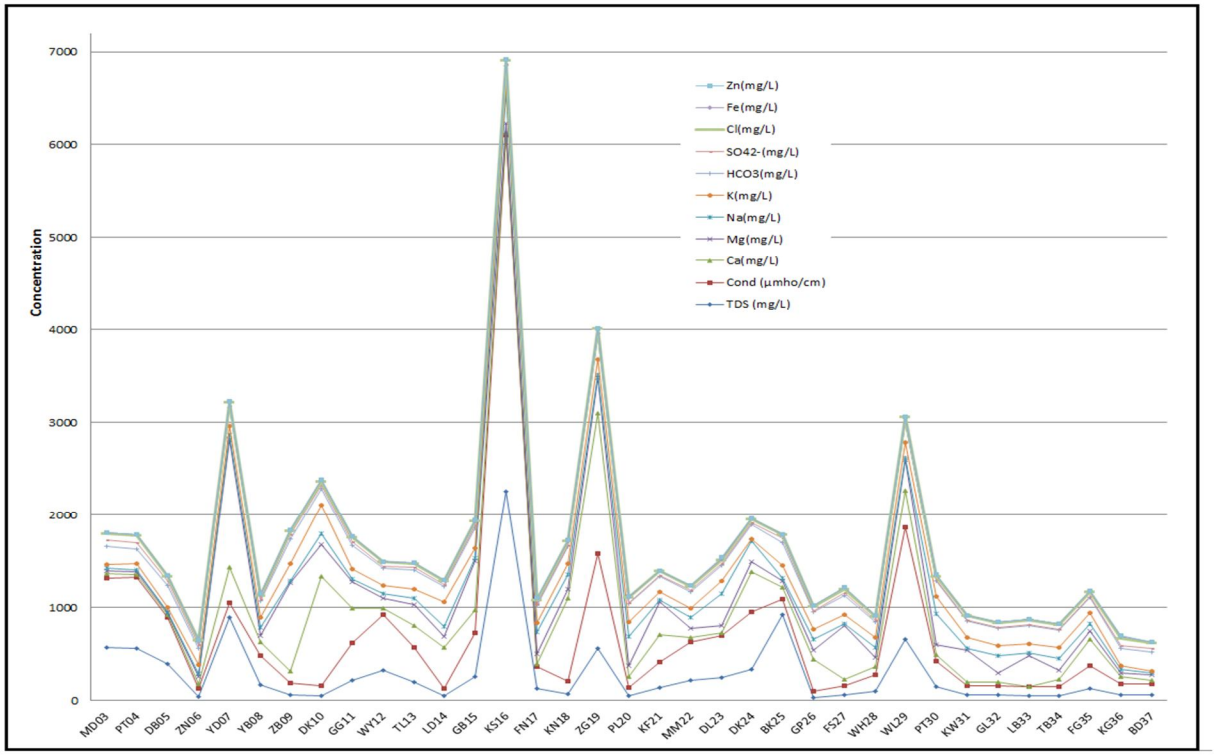


Figure 29: Graphic presentation of some major, minor and physicochemical constituents in groundwater of the study

Chapter 5

CONCLUSIONS, CONTRIBUTION TO KNOWLEDGE AND RECOMMENDATIONS

5.1 Conclusions

The parameters determined in this work have allowed the evaluation of groundwater from the study area for use in homes and other purposes. There are elevated levels of uranium in groundwater in some parts of the study area and this could be as a result of uranium mineralization in the study area. The extent to which groundwater has been tainted is limited within the mineralized zone but groundwater has possibly acted as a medium of transporting and enhancing some radionuclides (e.g. uranium) in aquifers away from that of its origin. The uranium concentrations above the EPA maximum contaminant limit (MCL) of 30mg/L were recorded at Yimirdallang and Kundiga might be related to mineralized zones around Zona and Kanawa-Dali transport to Yimirdallang and Kundiga in groundwater mobilizing the soluble uranium. This could be explained by water table map on which water levels increases toward these mineralized areas suggesting a flow in the opposite direction. The values recorded for radium and thorium concentrations were low. There was no equilibrium between the parent uranium and the radium daughter which may also be indicative of the non-solubility of thorium.

The evaluation of groundwater from the study area for agricultural purposes indicates that most of the studied samples are suitable for irrigation. The use of nitrate fertilizer might be the cause of high nitrate in groundwaters in the area. The high nitrate content has the potential to cause a health concern as regard drinking water.

5.2 Contributions to Knowledge

This work has contributed to knowledge in the following ways:

1. Delineating anomalous zones (zone with uranium amplitudse greater than 4routigens per hour) of radioactivity in the area using aero-spectrometric survey results.
2. Determining the status of the radionuclides U, Ra and Th in groundwater in the area and its implication for water quality by producing radioactivity maps which clearly demarcated radiologically contaminated areas as a result of these three radionuclides (U, ^{226}Ra, ^{228}Ra and ^{232}Th)
3. Determining the status of chemical and physical parameters that are of importance for categorizing the different waters for irrigation purpose.
4. Determining groundwater mobility of the study area, which clearly demarcated places where groundwater is stagnant.
5. Determining the compliance of other major, minor and traces constituents of groundwater with WHO, EPA and NIS guidelines.

5.3 Recommendations

This study has evaluated the concentration levels of uranium, radium, thorium as well as major, minor and trace constituents and their distribution in groundwater of the study area. Locations with elevated levels, agricultural and other health concerns have been clearly mapped out. For further studies on these parameters in the study area, a number of recommendations are given below.

1. Groundwater radioactivity of the adjacent FSN 1:50,000 Sheet 152 (Gombe) be carried out to ascertain the extent of radiological contamination by uranium in groundwater from sheet 153 (the studied sheet) around Kundiga into the adjacent Sheet 152 (Gombe).

2. This study was based on groundwater samples from dug wells, therefore concentration of radionuclides in water from deeper aquifers could not be ascertained. Therefore, it is recommended that in order to understand the radioactivity risks of deeper groundwaters, wells penetrating the deeper overburden, fractured and weathered part of the basement should be drilled.

3. It is recommended that a study similar to the present one be carried out on samples collected during the rainy season to ascertain the seasonal variation of these radionuclides, major, minor and trace constituents in the groundwaters of the study area.

4. There is a data gap concerning the radioactivity contribution by radon (Rn) from the studied groundwater samples, because radon was not determined. There is a need to determine radon levels in order to debetter understand the total alpha contribution in groundwater from the study area.

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APPENDIX I



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ICP-MS FACILITY SERVICE

Tuesday, 31st May, 2011

Dear Suleiman,

Please, find attached results of analysis of thirty seven water samples brought to us in a 120ml low density plastic bottles for ICP-MS. Note that "x" is the concentration and %RSD is the relative standard deviation in %. Due to very low intensities for some elements, some RSDs are a bit high.

Regards,

Christel

Christel TINGUELY

Chief Scientific Officer

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NUCLEAR SERVICES

Contact: ***Mr Y van Wyk***
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Pretoria
0001

Date: ***27 July 2011***
Report number: ***Final***
Pages:4
Our reference: ***RA-09179***
Your reference: ***PO-037857***

Analysis Report

Radioactivity analysis of water

Compiler: ***D Kotze***
Technical signatories: ***J Smit, S Seema, T Coetzee***

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

1. SERVICE

Analysis of 35 water samples, received 21 April 2011, for specified nuclides in the uranium and thorium decay series..

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	27/04/2011	J Smit
090631	Uranium by alpha spectrometry	WIN-145	23/05/2011	A Mamaila
090711	Thorium by alpha spectrometry	WIN-142	24/05/2011	T Motatle
090311	Radium by alpha spectrometry	WIN-145	24/05/2011	M Modiba

3. RESULTS

3.1 Results are attached as an appendix to this report.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.

4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

APPENDIX II

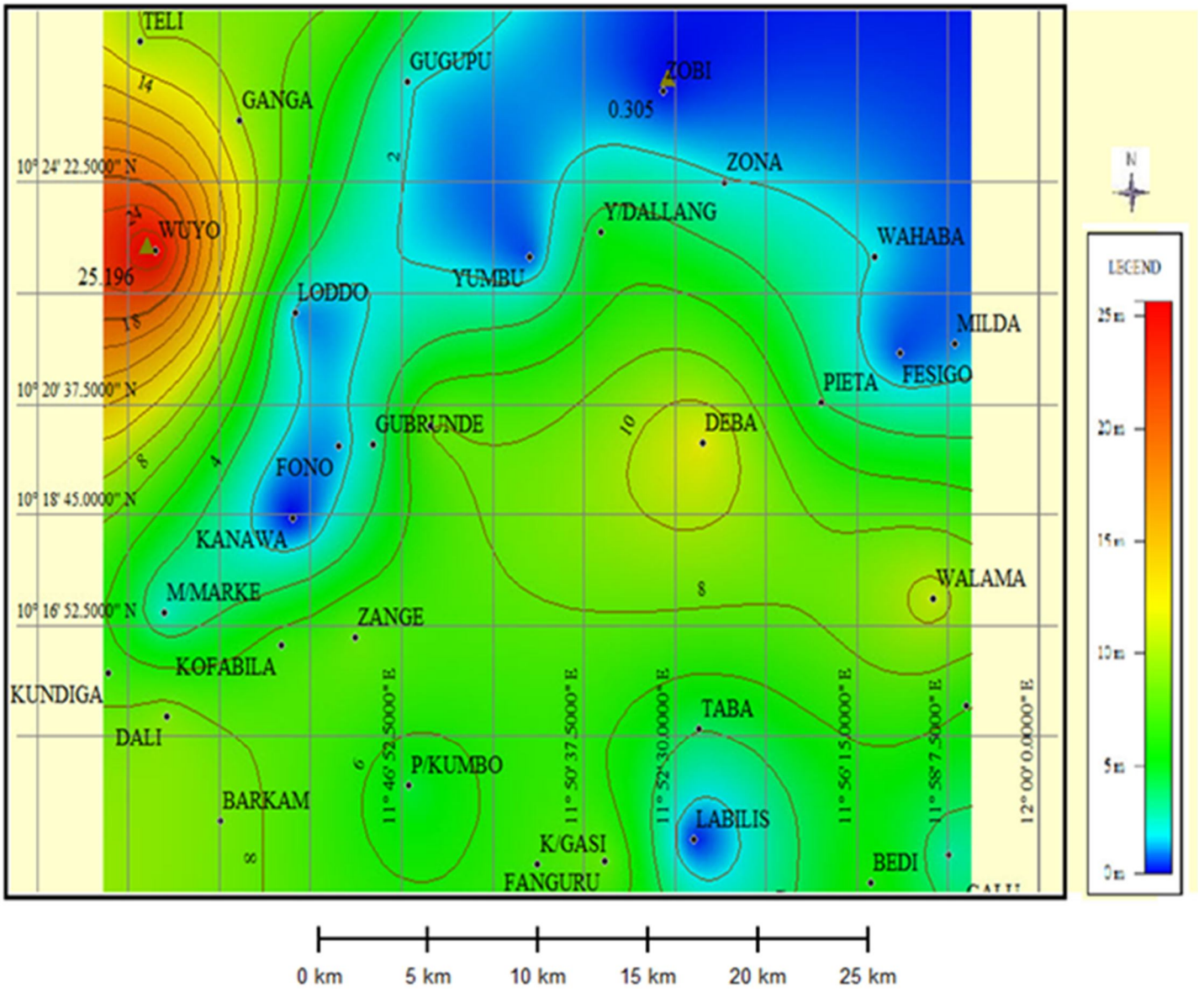


Fig. 14: Water Table contour on location map of the sampled area

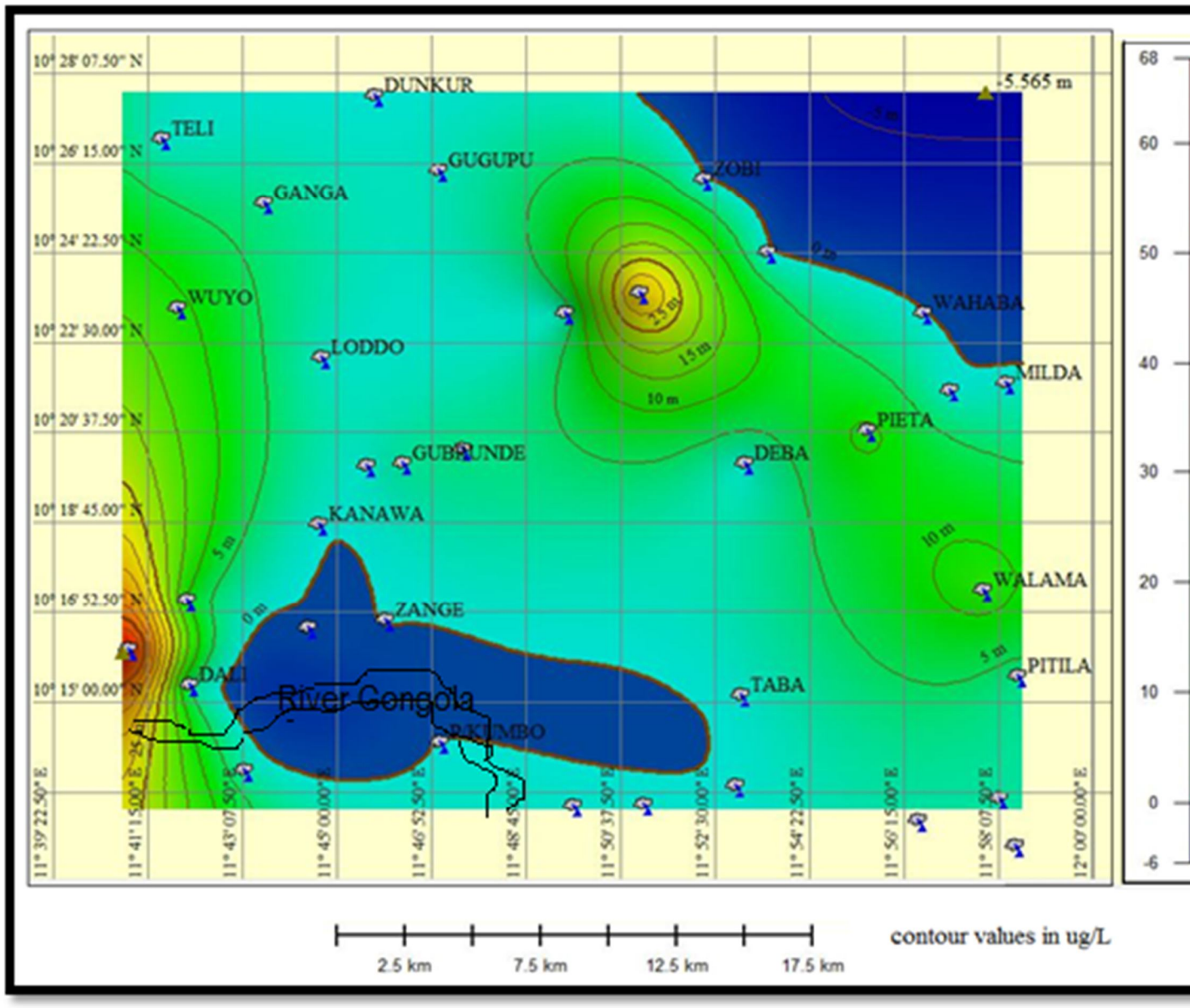


Fig. 15: Map of uranium concentration in groundwater showing locations that exceeded (red) the EPA's MCL of 30 µg/L

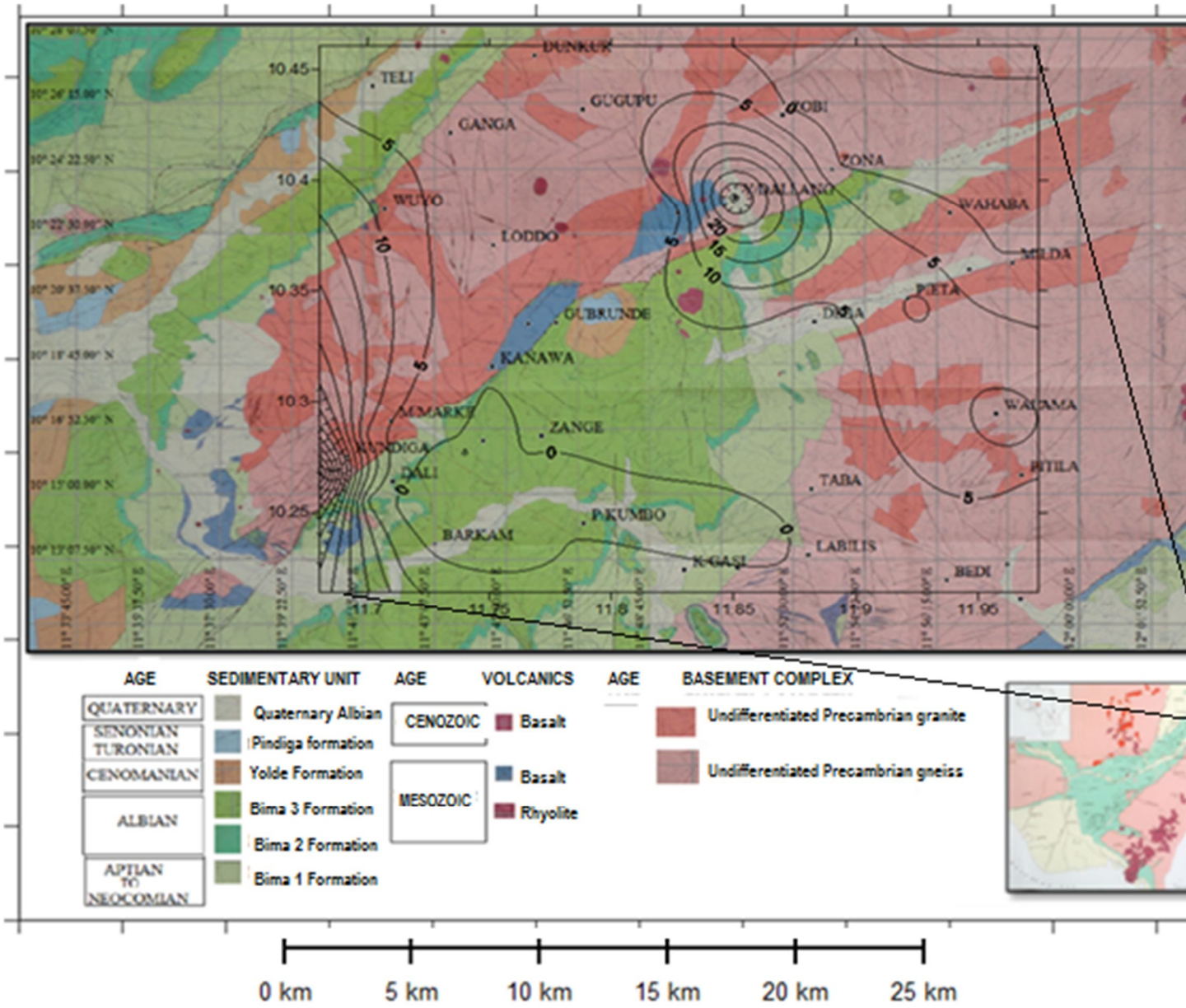


Figure 16: Superimposed contour of uranium concentration on geologic map (Guiraud, 1989) of the study area

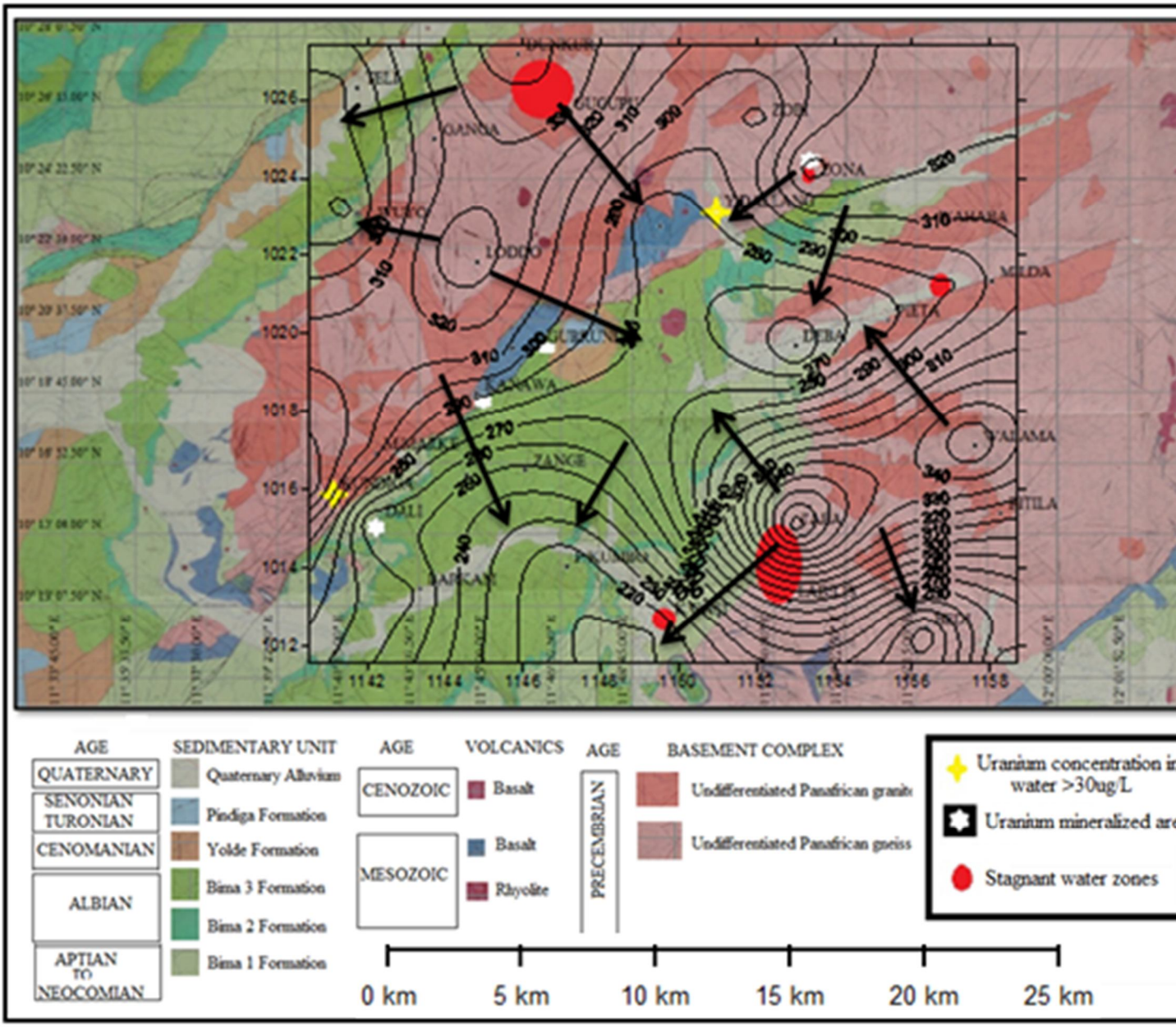


Figure 17: Map of configuration of water Table and direction of groundwater flow in the study area

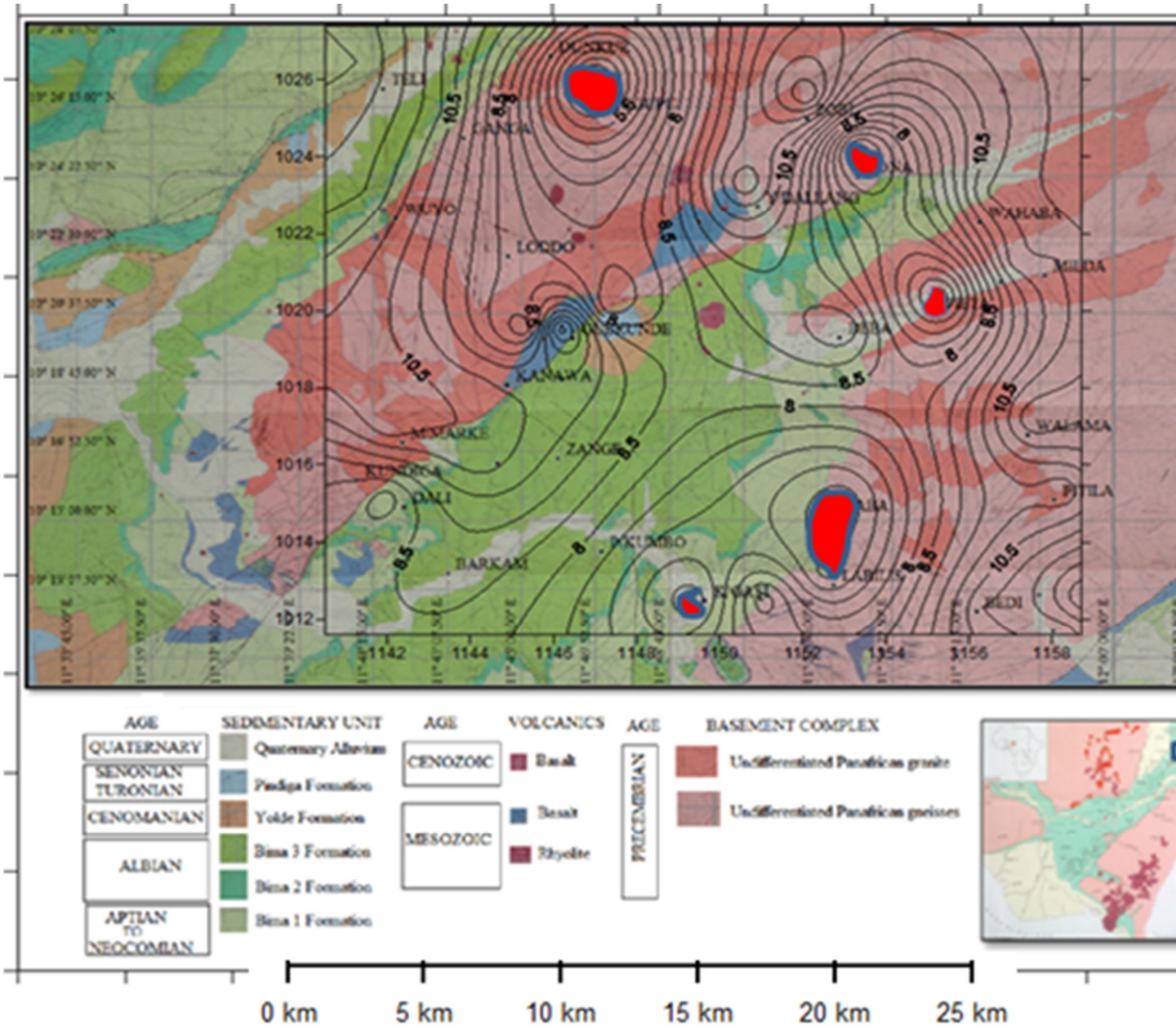


Figure 28: Water type contour superimposed on geologic map of the study area (red areas indicate less mobile water zones)