RADIOMETRIC INTERPRETATION OF GEOLOGIC DATA AND ITS EFFECT ON GROUNDWATER IN ABUJA, NORTH-CENTRAL NIGERIA

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I dedicate this work

To my dear wife and family

Whose love, kindness, patience and prayers have brought me this far

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ABSTRACT

The purpose of this study is to evaluate the quality of groundwater in different locations for water consumption at Dei-Dei, Kubwa, Gosa and Lugbe area of Abuja, North-Central Nigeria. Vertical electric sounding and shuttle radar topography mission was used to determine the depth of groundwater bearing formation and map lineaments structures underlying the area. Boreholes with the geophysical log data were drilled and rock samples in each layer lithologically were collected for γ-ray analysis. The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K from the borehole rock samples were determined using high-purity germanium γ-detector. The activity concentration of radionuclides in Dei-Dei borehole has a mean value of 30.1 $\pm$ 2.9 Bq kg^{-1} for ^{238}U; 67.2 $\pm$ 5.2 Bq kg^{-1} for ^{232}Th, and 832.3 $\pm$ 105.0 Bq kg^{-1} for ^{40}K. Kubwa borehole has a mean value of 34.4 $\pm$ 3.2 Bq kg^{-1} for ^{238}U; 60.5 $\pm$ 5.4 Bq kg^{-1} for ^{232}Th and 573.1 $\pm$ 72.0 Bq kg^{-1} for ^{40}K. At Gosa borehole, ^{238}U has a mean value of 26.1 $\pm$ 2.5 Bq kg^{-1}, 62.8 $\pm$ 4.8 Bq kg^{-1} for ^{232}Th and 573.3 $\pm$ 73.0 Bq kg^{-1} for ^{40}K. At Lugbe borehole ^{238}U has a mean value of 20.0 $\pm$ 2.0 Bq kg^{-1}, 46.8 $\pm$ 4.9 Bq kg^{-1} for ^{232}Th and 915.2 $\pm$ 116.1 Bq kg^{-1}for ^{40}K . Significantly higher concentration of ^{238}U and ^{232}Th occurred in samples collected from Dei-Dei borehole was attributed to granitic intrusions produced by denudation and tectonism. Inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the concentrations of ^{238}U and toxic elements (i.e. Pb, Cr, Cd, Zn, Ni, As and Mg) in water samples collected from the boreholes and public water supply in the study area. The activity concentration of ^{238}U in groundwater-based drinking was noted higher at Lugbe borehole with a value of 2736 µBq L^{-1} when compared with other boreholes. In the study area, the inhabitants permanently used water from the boreholes for daily drinking and household requirements. The annual effective dose was estimated to be in the range from 1.46 x 10^{-5} to 9.03 x 10^{-5} mSv yr^{-1} for boreholes with the highest value noted in Lugbe borehole with a value of 9.03 x 10^{-5} mSv yr^{-1}. The group receives about 5.55 x 10^{-5} mSv of the annual collective effective dose in the study area due to ^{238}U in drinking water. The highest radiological risks for cancer mortality and morbidity were found to be low, with highest values of 1.03 $\times$ 10^{-7} and 1.57 $\times$ 10^{-7} obtained from Lugbe borehole. The chemical toxicity risk of ^{238}U in drinking water over a life time consumption has a mean value of 4.0 x 10^{-3} µg kg^{-1} day^{-1} with highest value of 6.0 x 10^{-3} µg kg^{-1} day^{-1} obtained from Dei-Dei and Lugbe boreholes. The elemental concentration of Pb was noted to be higher than the recommended permissible limit at Lugbe borehole and Public Nigeria Water Board with values of 0.014 and 0.012 mg L^{-1}, respectively. Other results obtained were below the recommended acceptable level by World Health Organization and United State Environmental Protection Agency. Results of the measurements could be of importance in radio-epidemiological assessment, diagnosis and prognosis of uranium induced cancer in the population of the inhabitants of Abuja.

ABSTRAK

Tujuan kajian ini adalah untuk menilai kualiti air bawah tanah di kedudukan berbeza sebagai sumber air bagi kegunaan di kawasan Dei-Dei, Kubwa, Gosa dan Lugbe di Abuja, Utara-Tengah Nigeria. Pembunyian elektrik menegak dan misi topografi radar olak-alik digunakan bagi menentukaan kedalaman pembentukan takungan air bawah tanah dan struktur garisan peta di bawah permukaan kawasan tersebut. Lubang gerek dengan data log geofizik digerudi dan sampel batuan pada setiap lapisan litoligik diambil untuk analisis sinar-γ. Kepekatan keaktifan ^{238}U, ^{232}Th dan ^{40}K daripada sampel batuan lubang gerek ditentukan dengan mengunakan pengesan sinar-γ germanium berketulenan tinggi. Kepekatan keaktifan radionuklid di lubang gerek Dei-Dei mempunyai nilai min 30.1 $\pm$ 2.9 Bq kg^{-1} bagi ^{238}U; 67.2 $\pm$ 5.2 Bq kg^{-1} bagi ^{232}Th, dan 832.3 $\pm$ 105.0 Bq kg^{-1} bagi ^{40}K. Lubang gerek Kubwa mempunyai nilai min 34.4 $\pm$ 3.2 Bq kg^{-1} bagi ^{238}U; 60.5 $\pm$ 5.4 Bq kg^{-1} bagi ^{232}Th dan 573.1 $\pm$ 72.0 Bq kg^{-1} bagi ^{40}K. Lubang gerek Gosa mempunyai nilai min 26.1 $\pm$ 2.5 Bq kg^{-1} bagi ^{238}U , 62.8 $\pm$ 4.8 Bq kg^{-1} bagi ^{232}Th dan 573.3 $\pm$ 73.0 Bq kg^{-1} bagi ^{40}K. Lubang gerek Lugbe mempunyai nilai min 20.0 $\pm$ 2.0 Bq kg^{-1} bagi ^{238}U, 46.8 $\pm$ 4.9 Bq kg^{-1} bagi ^{232}Th dan 915.2 $\pm$ 116.1 Bq kg^{-1} bagi ^{40}K. Kepekatan tinggi yang ketara bagi ^{238}U dan ^{232}Th didapati pada sampel yang diambil dari lubang gerek Dei-Dei adalah disebabkan penerjahan granitik yang dihasilkan oleh penggondolan dan tektonisme. Spektrometer jisim plasma gandingan teraruh (ICP-MS) digunakan untuk menentukan kepekatan ^{238}U dan unsur toksik (Pb, Cr, Cd, Zn, Ni, As dan Mg) dalam sampel air yang diambil dari lubang gerek yang sama dan pembekal air awam di kawasan kajian. Kepekatan keaktifan ^{238}U dalam air bawah tanah yang diminum didapati tinggi di lubang gerek Lugbe dengan nilai 2736 μBq L^{-1} jika dibandingkan dengan lubang gerek yang lain. Di kawasan kajian, penghuni menggunakan air dari lubang gerek secara tetap sebagai minuman harian dan keperluan isi rumah. Dos berkesan tahunan telah dianggarkan dalam julat antara 1.46 x 10^{-5} hingga 9.03 x 10^{-5} mSv tahun^{-1} bagi lubang gerek dengan nilai tertinggi didapati pada lubang gerek Lugbe dengan nilai 9.03 x 10^{-5} mSv tahun^{-1}. Kumpulan tersebut menerima dos berkesan terkumpul kira-kira 5.55 x 10^{-5} mSv di kawasan kajian akibat kandungan ^{238}U dalam air minuman. Risiko radiologi tertinggi bagi mortaliti kanser dan morbiditi kanser didapati rendah dengan nilai tertinggi masing-masing ialah 1.03 $\times$ 10^{-7} and 1.57 $\times$ 10^{-7} yang didapati dari lubang gerek Lugbe. Risiko toksik kimia dari ^{238}U dalam air minuman bagi penggunaan seumur hidup mempunyai nilai min 4.0 x 10^{-3} μg kg^{-1} hari^{-1} dengan nilai tertinggi 6.0 x 10^{-3} μg kg^{-1} hari^{-1} yang diperoleh dari lubang gerek Dei-Dei and Lugbe. Kepekatan unsur Pb didapati lebih tinggi daripada had yang dibenarkan yang disyorkan, masing-masing didapati di lubang gerek Lugbe dan bekalan air awam dengan nilai masing-masing adalah 0.014 dan 0.01 mg L^{-1}. Hasil lain yang didapati adalah di bawah nilai aras yang diterima yang disyorkan oleh Organisasi Kesihatan Sedunia dan Agensi Perlindungan Alam Sekitar Amerika Syarikat. Hasil pengukuran adalah sangat penting dalam penilaian radio-epidemiologi, diagnosis dan prognosis kanser akibat uranium bagi penduduk Abuja.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AB	-	Distance from point A to B of the current electrode spacing
AT	-	Average time
BW	-	Body weight
CNSC	-	Canadian nuclear safety commission
Cpm	-	Count per minute
DC	-	Direct current
ED	-	Exposure duration
EF	-	Exposure frequency
EPA	-	Environmental protection agency
EPC	-	Exposure point concentration
GM	-	Geiger muller
GPS	-	Geographical positioning system
HPGe	-	High purity germanium
IAEA	-	International atomic energy agency
ICRP	-	International commission on radiological protection
ICP-MS	-	Inductively coupled plasma mass spectrometry
IR	-	Ingestion rate
LADD	-	Life average daily dose
LFI	-	Limited field investigation
NAA	-	Neutron activation analysis
NASA	-	National aeronautics and space administration
ND	-	Not detected
NE	-	North east
NNE	-	North north east
NOR	-	Natural occurring radionuclide
NORM	-	Natural occurring radioactive material

NRC	-	Nuclear regulatory commission
MCA	-	Multi-channel analyzer
MNA	-	Malaysian nuclear agency
MDA	-	Minimum detectable activity
MINT	-	Malaysian institute of nuclear technology research
PPM	-	Parts per million
PPB	-	Parts per billion
PSI	-	Pound per square inch
QF	-	Quality factor
RAD	-	Radiation absorbed dose
REM	-	Roentgen equivalent man
REV	-	Representative elementary volume
RFD	-	Reference dose
SL	-	Site layer
SRTM	-	Shuttle radar topography mission
SRTM-DEM	-	Shuttle radar topographic mission-digital elevation model
SSW	-	South south west
STUK	-	Säteilyturvakeskus strålsäkerhetscentralen (radiation and nuclear safety authority Finland)
SW	-	South West
TP	-	Technical procedure
UNFPA	-	United nations population fund
UNICEF	-	United nations internationl Children’s emergency fund
UNSCEAR	-	United nations scientific committee on the effect of atomic radiation
U(IV)	-	Uranous
USSGS	-	US geological survey
VES	-	Vertical electrical sounding
X-SAR	-	X-band synthetic aperture radar
SI	-	International system of units
WHO	-	World health organisation
WSW-ENE	-	West South West- East North East
XRF	-	X-ray fluorescence

LIST OF SYMBOLES

Al_2O_3	-	Aluminium oxide
As	-	Arsenic
A_{samp}	-	The specific activity concentration of sample
A_{std}	-	The specific activity concentration of the standard sample
BqL^{-1}	-	Becquerel per litre
CaO	-	Calcium oxide
$CaCO_2$	-	Calcium carbonates (calcite)
Cd	-	Cadmium
Co	-	Cobalt
CO_3^{2-}	-	Carbonate
Cr	-	Chromium
C_{samp}	-	Concentration of sample
C^{std}	-	Concentration of the standard sample
E_{BE}	-	Binding energy
E_e	-	Kinetic energy
Eh	-	Oxidation potential
Eγ	-	Gamma energy
F	-	Fluoride
Fe_2O_3	-	Iron oxide
K	-	Potassium
KCl	-	Potassium chloride
K_2O	-	Potasium oxide
m	-	Sample mean
M	-	Molecular weight
Mg	-	Magnesium

Mg	-	Magnesium
MgO	-	Magnesium oxide
MnO	-	Manganese oxide
n^-	-	n-doped material
N	-	Number of atoms
Na_2O	-	Sodium oxide
Ni	-	Nickel
N_{samp}	-	Net count of photopeak area of sample collected
N_{std}	-	Net counts of photopeak area of the standard sample
P^+	-	P-doped material
P_2O_5	-	Phosphorus oxide
pH	-	Potential hydrogen
Pb	-	Lead
$Pb(OH)^+$	-	Lead hydroxide
$Pb(OH)_2$	-	Lead (II) hydroxide
P0	-	Polonium
R	-	Lifetime cancer risk
R	-	Roentgen
SiO_2	-	Silicon oxide
SO_4	-	Tetraoxosulphate (VI)
T_d	-	Decay time
Th	-	Thorium
TiO_2	-	Titanium oxide
u	-	Atomic mass unit
U	-	Uranium
U_2^{2+}	-	Uranyl
U_3O_8	-	Uranium trioxide
U^{4+}	-	Uranous
UO_2	-	Uraninite
W_{samp}	-	The weight of the sample collected
W_{std}	-	The weight of the standard sample
Zn	-	zinc
$ZnSO_4$	-	Zinc sulphate

U	-	Potential,in volt.
m	-	Mass of the element
r	-	Risk coefficient
α	-	Alpha particle
β	-	Beta particle
γ	-	Gamma radiation
ε	-	Efficiency
θ	-	Volumetric water content
λ	-	Disintegration constant
μ	-	Micron
$\mu g\ L^{-1}$	-	Micron gram per litre
ρ	-	Resistivity of the medium
δ_{est}	-	Standard deviation
δ_{SE}	-	Standard error
1D	-	One dimensional
2D	-	Two dimensional
^{204}Pb	-	Lead-204
^{206}Pb	-	Lead-206
^{207}Pb	-	Lead-207
^{208}Pb	-	Lead-208
^{208}Tl	-	Thallium-208
^{210}Pb	-	Lead-210
^{210}Po	-	Polonium- 210
^{211}Pb	-	Lead-211
^{212}Po	-	Polonium- 212
^{214}Bi	-	Bismuth- 214
^{220}Rn	-	Radon- 220
^{222}Rn	-	Radon- 222
^{223}Ra	-	Radium-223
^{224}Ra	-	Radium-224
^{226}Ra	-	Radium -226
^{228}Ac	-	Actinium-228
^{228}Ra	-	Radium-228

^{233}Pa	-	Protactinium- 233
^{234}U	-	Uranium- 234
^{235}U	-	Uranium- 235
^{236}U	-	Uranium-236
^{238}U	-	Uranium -238
pH	-	Neptunium- 239
^{40}K	-	Potassium- 40

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Ionizing radiation in natural environment was discovered in 1899 and it is said to originate from radioactivity in environmental materials like rivers, ground waters, soils and rocks (Lowder, 1990). The natural radionuclides, ^{238}U, ^{232}Th and ^{40}K are present in the earth crust (Evans, 1969). Humans are usually exposed to some natural background radiations which are the naturally occurring radioactive material (NORM) (U.S. EPA, 1993). The presence of these (NORM) in soil, rocks, water, and air, alongside the cosmic radiation result in continuous and unavoidable internal and external radiation exposures of humans (UNSCEAR, 2000). The NORM in the earth and water of an environment mainly occur as progeny of ^{238}U, ^{235}U and ^{232}Th isotopes which are distributed by natural geological and geochemical processes in addition to potassium ^{40}K and small quantities of fission-product residues such as ^{137}Cs from atmospheric weapon tests (Trimble, 1968). In many countries, extensive work has been carried out to evaluate the risks associated with NORM (NRC,1999; UNSCEAR, 2000). Thus, it has been established that the specific levels of terrestrial environmental radiation are related to the geological composition of each lithologically separated area, and to the content of ^{238}U, ^{232}Th and ^{40}K in the rock from which soils originate in each area (Abd El-mageed *et al.,* 2011; Maxwell *et al*., 2013a; Tzortzis and Tsertos, 2004; UNSCEAR, 2000; Xinwei and Xiaolon, 2008).

Uranium occurs as a trace element in the earth's crust and is typically present in the concentration of 1-10 ppm in granite and in clastic sediments of granitic origin and thorium is typically present in concentrations ranging between 3 and 30 ppm in crustal minerals. The average concentration of potassium in crustal rocks is approximately 2.5% with a range from 0.1% to 5% or more On the other hand, thorium occurs mostly in sediment (IAEA, 1989).

In 2006, limited field investigation (LFI) involving uranium in the subsurface at the Hanford Site's 300 Area in Washington, yielded unexpectedly high concentrations of uranium in groundwater samples collected at two of the four characterization boreholes (Williams *et al.*, 2007). The samples were obtained during drilling and came from stratigraphic intervals in the unconfined aquifer that is not monitored by the existing well network. The occurrences appeared to be restricted to an interval of relatively finer-grained sediment within the Ring old Formation. A subsequent investigation was carried out which involved drilling and characterization activities at four new locations near the initial discovery. This report presents the fresh information obtained since the LFI characterization report (Williams *et al.*, 2007) regarding uranium contamination beneath the 300 Area (Peterson *et al.*, 2008). It was estimated that approximately 650,000 m^3 of groundwater beneath the 300 area investigated are affected by uranium at concentrations that exceed the drinking water standard of 30 $\mu g\ L^{-1}$.

Naturally occurring radionuclides are manly from three different decay chains (^{235}U, ^{238}U and ^{232}Th). One of the longest-lived nuclides is ^{232}Th with a half-life of 1.405×10^{10} years. ^{236}U was the immediate parent of ^{232}Th with a life of 2.342×10^{7} years thus is not found in the environment anymore and ^{238}U refers to the second longest series. 99.2745% by weight of ^{238}U, 0.7200% of ^{235}U, and 0.0055% of ^{234}U are the estimated naturally occurring uranium (Pfennig *et al.*, 1998).

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in groundwater are connected to the activity concentrations of ^{238}U and ^{232}Th of aquifer bearing formation, and their decay products in subsurface rock formation. This occurs as a result of reactions between groundwater, soil and bedrock which release quantities of dissolved mineral components depending on the mineralogical and geochemical composition of the rock formation (IAEA, 1990; Langmuir, 1978). It also depends on the chemical composition of the water, degree of weathering of the subsurface rock formation, redox conditions and the residence time of groundwater in subsurface water bearing formation, (Durrance, 1986). ^{238}U and ^{232}Th decay series in soils, bedrocks and groundwater system is controlled by the chemical substances, radioactive decay and surrounding physical factors. As a result of these controlled processes, the radioactive elements either leach into the groundwater or to the surrounding, resulting into decay series of disequilibrium of nuclides (Durrance, 1986).

In Nigeria, NORM levels have been studied in surface soils in Ijero-Ekiti (Ajayi *et al*., 1995), in soil and water around Cement Company in Ewekoro (Jibiri et al., 1999) and in rocks found in Ekiti (Ajayi and Ajayi, 1999). Only insignificant levels of NORM were identified by (Ajayi *et al*., 1995). The health risks to human are real which is not defined in this geological condition. The activity concentration of these radionuclides is yet to be defined in the environment and no epidemiological studies to quantify the risk from all natural radionuclides in drinking water.

In this study, the main emphasis is to determine the risk areas in subsurface structures (lithology) and to examine activity levels of naturally occurring radionuclides in different raw water sources at Dei-Dei, Kubwa, Gosa, and Lugbe boreholes in order to evaluate the exposure to the inhabitants in the area. The study areas are bounded by latitudes 8^o 53`N - 9$^o$ 13`N and longitudes 7^o 00`E - 7$^o$ 30` E. The borehole points are in the coordinates lat: 9^o 6’52”N and long: 7^o 15’39”E (Dei-Dei), lat: 9^o 6’ 16.7” N and long: 7^o 16’ 26.0”E (Kubwa), lat: 8^o 56’ 45.6” N and long: 7^o 13’ 26.2” E (Gosa) and lat: 8^o 59’ 2.3” N and long: 7^o 23’ 7.8”E (Lugbe).

1.2 Problem Statement

In Nigeria, the case for conjunctive use of surface and groundwater supply, where available, to meet the ever increasing demand cannot be over-emphasized. However, relating the available resources to demand, the population finds it difficult to access quality water for consumption. Nigeria has been ranked the third in world's poorest countries in gaining access to water and sanitation according to World Health Organization report 2012. A report from (Godknows, 2012) noted that the World Health organization and UNICEF ranked Nigeria third behind China and India, in countries with largest population without adequate water and sanitation. The study area (Abuja) had a master plan in 1979 which projected population in the region to be 5.8 million people by 2026. The recent population of Abuja is 2, 759,829 at 2013 and the most recent is 3,028,807 at 2014 report (UNIFPA, 2014).

The Water Board has a designed capacity with the pre-plan which is not in phase with the city growth in the recent time. The increase in demand for water has led to compulsory alternative sources to defray the deficit. Majority of the public water supplies come from the borehole of reasonable depths. The water has been consumed without treatment and during drilling processes it cuts across so many rock formations. The radioelement exists in this rock formation like granite to some extent could contaminate the groundwater system through leaching and weathering processes. The natural radioactivity of ground water is derived primarily from radioactive rocks, soil and mineral with which the water has been in contact. There are three naturally radioactive elements: the uranium series, the thorium series and potassium-40.

The ground water is not considered acceptable to the public, organism and plantation if activity concentration value exceeds 1 Bq L^{-1} as recommended by IAEA and Annual effective dose exceeds 1 mSv y^{-1} as suggested by World Health Organisation (WHO, 2008). As a result, most of the public in the satellite towns and suburbs are not aware of the potential problems associated with aquifer bearing rocks constituting radioactive elements. In the same way, it leaches into the groundwater through chemical weathering and physical processes which is being consumed daily by the public. The study of these radionuclides in groundwater of the suburbs of Abuja has become important because many residents of the area embark on the development of private boreholes without the knowledge of the health risk associated with the naturally occurring radionuclides.

1.3 Research Objectives

The primary aim of this work is to gather new information on the occurrence of natural radioactivity in groundwater based drinking water and to reduce the radiation exposure to Abuja inhabitants. In order to achieve this aim, the objectives of this work are

1. To investigate the depth to aquifer bearing formation and the subsurface structures that controls the groundwater system using Vertical Electrical Sounding (VES) and Shuttle Radar Topography Mission (SRTM).

2. To determine the activity concentration of ^{238}U, ^{232}Th and ^{40}K in different layers of the subsurface lithology so as to infer the source rock that poses higher activity level.

3. To determine the corresponding geologic rock type that attributes such high level of natural radionuclides so as to set a baseline that will help geologists and hydrologists in groundwater resources on basement terrain areas how to drill hydrogeologically motivated boreholes in safer aquifer bearing formations for public consumption.

4. To investigate the occurrence of ^{238}U and toxic elements in groundwater and to obtain representative estimates of the effective dose to borehole users (private wells) in the study area.

1.4 Research Scope

The first part of the study was to determine the suitable sites for groundwater bearing formation (aquifer) at Dei-Dei, 70 m, Kubwa, 60 m, Gosa, 50 m and Lugbe, 40 m in Abuja, Northcentral Nigeria using Vertical Electrical Sounding (VES) integrated with 88 lineaments (fractures) extracted from Hill-shaded Shuttle Radar Topography Mission (SRTM) data.

Secondly, the comparison of activity concentrations of ^{238}U, ^{232}Th and ^{40}K in different layers of subsurface structures in the study area were determined such as to trace the source rock that constitute higher activity concentrations of ^{238}U, ^{232}Th and ^{40}K.

Thirdly, the rock layers with the highest activity level and geological type that contributed such high level of radionuclides in subsurface formation.

Finally, determination of activity concentrations of ^{238}U, ^{232}Th and ^{40}K in groundwater to estimate the exposure to the inhabitants of Abuja people who rely on groundwater based drinking water for consumption. Its purpose was to evaluate the suitability of different sites as locations for obtaining groundwater for consumption.

The scope of this work described in Figure 1.1 shows how radionuclides from the environment, soil, bedrock are being transferred to human through groundwater source from reasonable depths of varying rock formation to the aquiferous zone (groundwater host rock) below ground level. The exposure is by ingesting the water that comes from such formation with high dissolved uranium, thorium and potassium rich minerals due to water-rock interactions. The movements across the fractured zones through the recharging channels that supply the water to the aquifer are to be evaluated for the contamination level of the radionuclides to the inhabitants.

The scope of this study presented in a flowchart with structure of the study discussed in Figure 1.1 has two segments:

1. The first segment describes the occurance of radionuclides and the exposure to Abuja people.

2. The second part discussed the structure of the study to attain the purpose of this work.

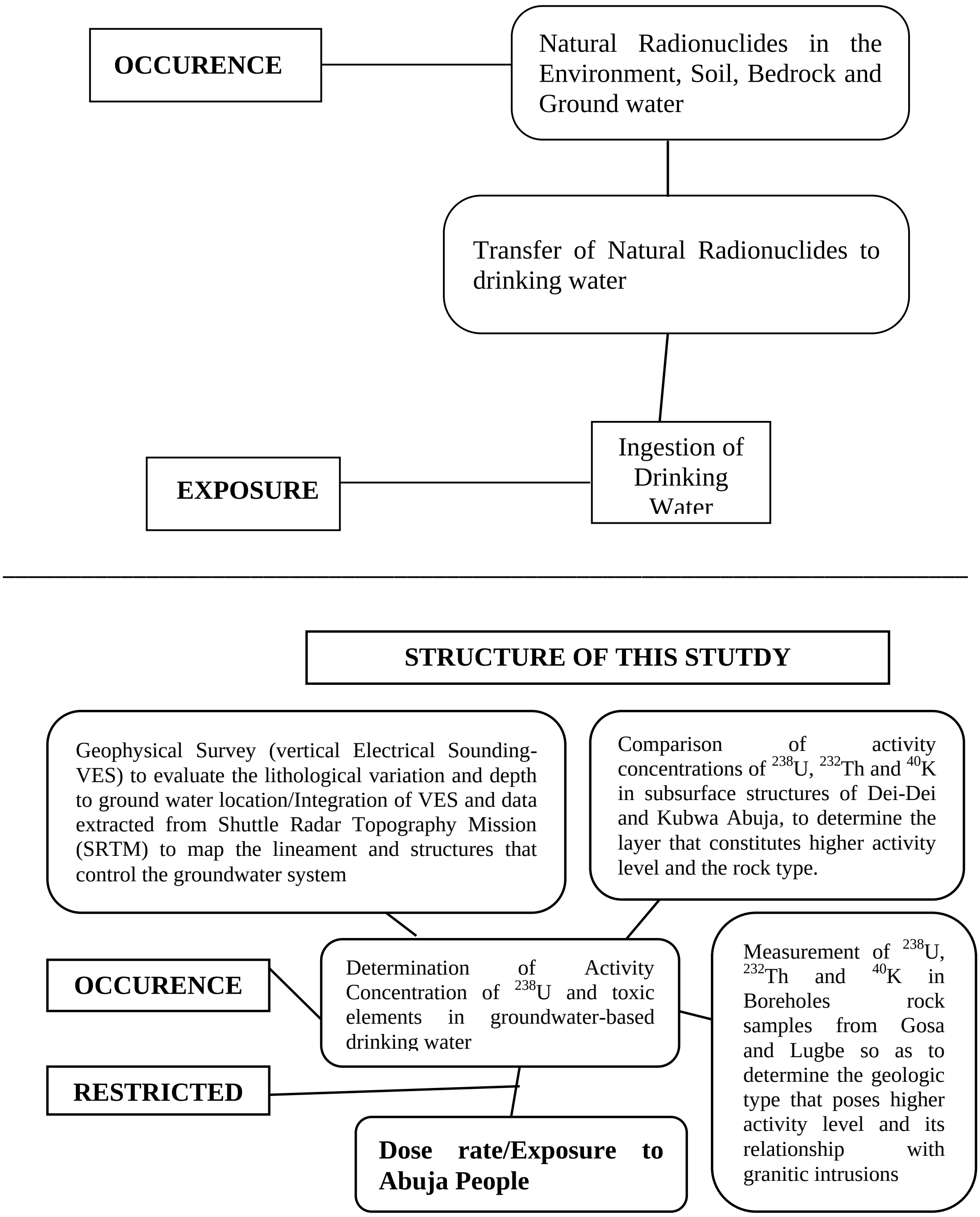

Figure 1.1 The flowchart of the Scope of work and the Structure of the study

1.5 Significance of the Study

1. The identification of radioactive source rock that constitute higher activity concentrations of ^{238}U, ^{232}Th and ^{40}K in subsurface layers will assist professionals in hydrogeology and water resources management: civil engineers, environmental engineers, geologists and hydrologists who are engaged in the investigation, management, and protection of groundwater resources on areas to drill boreholes for the safety of the inhabitants who rely on groundwater based drinking water for consumption.

2. It will identify the occurrence of radionuclides in groundwater and obtain representative estimate for the effective dose to the users of private wells in Abuja caused by ^{238}U, ^{232}Th and ^{40}K.

3. It will equally reveal the geologic conditions that will help to monitor the activity levels in groundwater by Geophysicists/Geochemists such as geologic rock units, weathering, chemical complexation and oxidations.

4. Importantly, to serve as guidance for the water resources management and effective utilization in Abuja.

5. Furthermore, this study contributes significant and general information on baseline to the people of Abuja on their groundwater consumption status.

1. 6 Research Hypotheses:

H_1 = alternative hypothesis

- The layers with high metamorphosed granitic intrusion will report higher activity concentration of ^{238}U, ^{232}Th, and ^{40}K.
- The layers that are highly fractured and techtonized will be noted higher, which will be attributed to oxidation of uranium in aqueous phase.

H_o = null hypothesis

- Granitic intrusion has no effect on activity concentration of ^{238}U, ^{232}Th and ^{40}K.
- There will be no difference in Th/U ratio in different layers
- The ^{238}U and ^{232}Th activity does not increase with acidity of soil/rock
- Weathering and metamorphism do not modify the ^{238}U, ^{232}Th and ^{40}K to readily leach from pegimatite and granites and redeposit in sediment at large distance from the source rocks.
- Weathering does not have impact in decreasing the Th/U ratio.

1.7 Thesis Organization

This thesis consists of five chapters. Chapter 1 presents the introduction of the natural occurring radionuclides; problem statement; objectives of the study; scope of the study; significance of the study; Research hypothesis and development of conceptual model.

Chapter 2 involves a literature review of geophysical methods for groundwater investigation, radioactive study and radioactivity, natural occurring radionuclides in groundwater, natural occurring radionuclides in Nigeria, Groundwater flow concept, groundwater formation in Nigeria. Chapter 3 discusses the instrumentation for geophysical data acquisition and methods, groundwater flow model, methodology and calculations of elemental concentrations using comparison method for gamma spectrometry including HPGe detector and experimental procedures, methods and calculations for neutron activation analysis, geochemical characterization method using XRF, method of water analysis using inductively coupled plasma spectrometry (ICP-MS). Chapter 4 covers the results for geophysical interpretation, comparison of NAA and direct method (gamma ray spectrometry using HPGe detector), determination of elemental concentrations of ^{238}U, ^{232}Th and ^{40}K in (ppm) and Bq kg^{-1} in studied samples and interpretations, geochemical characterization and interpretation of the mineral contents in the rock sample obtained in the four boreholes in the study area, interpretation of ICP-MS results for both groundwater samples from the same four boreholes and Water Board from the study area . Chapter 5 summarized the conclusion of the research work and suggestions.

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