NATURAL RADIATION AND RADIOACTIVITY IN SOIL AND GROUNDWATER OF JOS PLATEAU, NIGERIA

HABU TELA ABBA

UNIVERSITI TEKNOLOGI MALAYSIA

NATURAL RADIATION AND RADIOACTIVITY IN SOIL AND GROUNDWATER OF JOS PLATEAU, NIGERIA

HABU TELA ABBA

A thesis submitted in fulfilment of the

requirements for the award of the degree of

Doctor of Philosophy

Faculty of Science

Universiti Teknologi Malaysia

JANUARY 2018

I dedicate this research work to my family for their patient, understanding and perseverance during the period of my study

ACKNOWLEDGEMENT

I would like to thank Almighty Allah who granted me the health, strength and time to overcome life's difficulties and complete this work.

I would like to express my gratitude to my supervisor, Assoc. Prof. Wan Muhamad Saridan Wan Hassan for his trust in me which encouraged me to know the strength in myself and motivated me to work harder and achieve this success. Special thanks to my co–supervisor, Dr. Muneer Muhammad Aziz Saleh for his kind supervision, help and support. He gave me more understating of the experimental and theoretical aspects of my research. His incredible attention, physics explanations, advice, and guidance are highly appreciated. My appreciation also go to my external co–supervisor, Dr. Sadiq Abubakar Aliyu for endless support in course of this research. I would also like to thanks Engr. Saiful for his valuable technical support. My profound gratitude goes to Prof. Ahmad Termizi Ramli for nursing me as Ph.D candidate and his support from the beginning of this programme.

I would also extend my gratitude to Yobe State University (YSU) Damaturu and Tertiary Education Trust Fund (TED–FUND) for giving me the opportunity to achieve this feat, the Ministry of Science, Technology and Innovation Malaysia (MOSTI) for some financial support. Special regards goes to my academic colleagues at YSU, friends and relatives who have encourage me in one way or the other in the course of my research.

Above all, I would like to thank my beloved wife, Fatima Abdu Mainasara, for her encouragement to undertake the Ph.D journey without her love, support and patience I would have done nothing. Her company and help while we stay in Malaysia are unforgettable. I would also like to thank my sons; Muhammad Auwal, Abdullahi, and Muhammad Abba for dealing with a student father and even more stressed and busy than usual.

ABSTRACT

This study aimed to establish baseline data on the natural environmental gamma radiation and radioactivity levels as well as to evaluate the corresponding radiological health impacts for Jos plateau, Nigeria. It employed the use of portable NaI(Tl) survey meter and hyper pure germanium spectrometer to measure external gamma dose rate and to determine the specific activity concentration of terrestrial radionuclides, ^{226}Ra, ^{232}Th and ^{40}K in soil samples, respectively. External gamma dose rates were measured at 811 locations while activity concentration were determined for 102 soil samples. The mean value for the measured gamma dose rate was found to be approximately four times the world average value while the mean values for the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were found to distinctly exceed their corresponding world reference values for continental soil. Gamma dose rate and activity concentration of the terrestrial radionuclides for each geological formation and soil type of the area are presented. Statistical relationships between gamma dose rate with the different geological formations and soil types of the area are established. Younger granites geological formation and Haplic acrisols soil type were found to contribute the highest to the natural background radioactivity and ^{232}Th was found to be the highest contributor to the terrestrial gamma dose rate for the study area. Various groundwater samples were also measured for concentration of U and Th using inductive coupled plasma mass spectroscopy and the concentrations of U ranged from 1.4 to 35 μg L^{-1} with a mean value of 13.15 μg L^{-1} while for Th ranged from 0.10 to 11.1 μg L^{-1} with a mean value of 1.85 μg L^{-1}. Few groundwater samples were found to have values exceeding the recommended limit of U provided by WHO and USEPA for drinking water. Radiological health impact parameters namely radium equivalent, external hazard index, annual effective dose, collective dose and excess lifetime cancer risk due to soil radioactivity and annual ingestion dose as well as radiotoxicity risks due to ingestion of groundwater were also evaluated. It is found that, an individual leaving in this area is most likely to incur a radiological health related risks due to natural radiation. Isodose maps for gamma rates and the spatial distribution pattern of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K for the study area were produced using ArcGIS mapping software. The results revealed that Jos Plateau has above normal levels of natural background radiation. The data here presented will be useful for radio–geochemical investigation and as a reference data to asses possible changes in the environmental background radiation levels due to local and transnational releases of radioactive materials from artificial sources and also useful for preparing radiological map for Nigeria.

ABSTRAK

Kajian ini bertujuan untuk menentukan data pangkalan aras sinaran gama persekitaran tabii dan aras keradioaktifan serta menilai impak kesihatan radiologi bagi dataran Jos, Nigeria. Kajian telah menggunakan meter tinjau NaI(Tl) mudah alih dan spektrometer germanium hipertulen untuk mengukur kadar dos gama luaran dan menentukan kepekatan keaktifan radionuklid daratan ^{226}Ra, ^{232}Th dan ^{40}K dalam sampel tanah. Kadar dos gama luaran diukur di 811 lokasi manakala kepekatan keaktifan ditentukan bagi 102 sampel tanah. Nilai min kadar dos sinaran gama yang diukur didapati lebih kurang empat kali nilai purata dunia, manakala nilai min kepekatan keaktifan ^{226}Ra, ^{232}Th dan ^{40}K didapati melebihi nilai rujukan dunia yang sepadan bagi tanah benua. Kadar dos sinaran gama dan kepekatan keaktifan radionuklid daratan untuk setiap formasi geologi dan jenis tanah kawasan kajian dibentangkan. Hubungan statistik antara kadar dos gama dengan formasi geologi dan jenis tanah berbeza di kawasan itu ditentukan. Formasi geologi granit muda dan tanah jenis *haplic acrisols* didapati paling menyumbang kepada keradioaktifan latar belakang tabii dan ^{232}Th didapati paling menyumbang kepada kadar dos gama daratan bagi kawasan kajian. Pelbagai sampel air tanah diukur dengan spektroskopi jisim plasma berganding aruhan bagi mendapatkan kepekatan U dan Th, dan nilai kepekatan adalah dalam julat 1.4 hingga 35 μg L^{-1} dengan min 13.15 μg L^{-1} bagi U, manakala dalam julat 0.10 hingga 11.1 μg L^{-1} dengan min 1.85 μg L^{-1} bagi Th. Beberapa sampel air tanah didapati melebihi had U yang dicadangkan oleh WHO dan USEPA bagi air minuman. Parameter impak kesihatan radiologi iaitu kesetaraan radium, indeks hazad luaran, dos berkesan tahunan, dos kolektif dan risiko kanser masa hayat lebihan disebabkan oleh keradioaktifan tanah dan dos penelanan tahunan serta risiko radiotoksikan disebabkan peminuman air tanah juga dinilai. Didapati, individu yang tinggal dalam kawasan ini berkemungkinan besar mendapat risiko kesihatan radiologi disebabkan oleh sinaran tabii. Peta isodos untuk kadar dos gama dan corak taburan ruang kepekatan aktiviti ^{226}Ra, ^{232}Th dan ^{40}K untuk kawasan kajian dihasilkan melalui perisian pemetaan ArcGIS. Keputusan menunjukkan aras sinaran latar belakang tabii dataran Jos adalah lebih tinggi daripada aras normal. Data yang diperoleh berguna untuk kajian radiogeokimia dan sebagai data rujukan untuk menilai perubahan aras sinaran latar belakang persekitaran disebabkan oleh pelepasan tempatan dan transnasional bahan radioaktif dari sumber buatan dan berguna juga untuk penyediaan peta radiologi negara Nigeria.

TABLE OF CONTENTS

LIST OF TABLES

TABLE NO. **TITLE** **PAGE**

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE

LIST OF ABBREVIATIONS

AED	–	Annual effective dose
ANOVA	–	Analysis of variance
ADC	–	Analog to digital converter
BEIR	–	Biological effect of ionizing radiation
DNA	–	Deoxyribonucleic acid
DL	–	Duration of life
EPC	–	Exposure point of concentration
FEPE	–	Full energy peak efficiency
FAO	–	Food and Agriculture Organisation
FWHM	–	Full width at half maximum
GIS	–	Geographical information system
GPS	–	Geographical positioning system
HQ	–	Hazard quotient
HPGe	–	High purity germanium
IAEA	–	International Atomic Energy Agency
ICP–MS	–	Inductive coupled plasma mass spectroscopy
ICRP	–	International Commission on Radiological Protection
ICRU	–	International Commission on Radiation Units and Measurements
LGA	–	Local government area
LADD	–	Lifetime average daily dose
MCA	–	Multichannel analyser
MDA	–	Minimum detectable activity

NGSA	–	Nigerian Geological Survey Agency
NPC	–	National Population Commission
NCRP	–	National Council on Radiation Protection and Measurements
PPM	–	Parts per million
QC	–	Quality control
RRA	–	Radiological risk assessment
R_fD	–	Reference dose
RF	–	Risk factor
RIO	–	Radiological impact assessment
R	–	Cancer risk
RL	–	Lifetime cancer risk
Ra_{eq}	–	Radium equilibrium
SC	–	Collective dose equivalent
SPSS	–	Statistical package for social science
TGRD	–	Terrestrial gamma radiation dose
UTM	–	Universiti Teknologi Malaysia
USEPA	–	United State Environmental Protection Agency
UNSCEAR	–	United Nation Scientific Committee on Effects of Atomic Radiation
UNESCO	–	United Nation Educational Scientific and Cultural Organization
WHO	–	World Health Organisation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Human and non–human population are continuously expose with or without their consent to background radiations due to natural and artificial sources (UNSCEAR, 2000; Kannan *et al.*, 2002). Environmental radioactivity are naturally derived from two sources. Firstly, the terrestrial sources from the decay series of primordial radionuclides ^{238}U and ^{232}Th and the non–decay series of ^{40}K; secondly is of extra–terrestrial origin from cosmic rays. The former are distributed in varying concentration in the earth crust which are significantly influenced by local geology, soil type, chemical processes and rainfall of a particular place; and appear at different levels in the rocks and soils of a particular region of the world (UNSCEAR, 2000).

Among the ^{238}U series, 98% of natural radiations are released by ^{226}Ra decay products, thus ^{226}Ra series is usually used instead of ^{238}U series. High activity of these radionuclides are associated with rocks that comprised intrusive materials (UNSCEAR, 2000). Uranium and thorium, because of their large ionic radial are found mainly in crystalline magmas which were formed lately. Therefore, they exist in granites and pegmatites in considerable amount (Ivanovich and Harmon, 1982).

In terms of natural radioactivity, it is obvious that, Silica–oversaturated rocks such as granitic rocks present higher radioactivity compared to sedimentary rocks such as limestone, gypsum and chalk; and low grade metamorphic rocks. This is due to substantial content of naturally occurring radioactive materials (NORMs) such as thorite, monazite, zircon, ilmenite and trace amounts of xenotime and rutile contained in granitic rocks (Aieta *et al.*, 1987; Zapecza and Szabo, 1986; UNSCEAR, 2008).

Gamma radiations emitted as a result of radioactivity of the naturally occurring radioactive elements such as ^{40}K and the primordial radionuclides series of ^{232}Th and ^{238}U in soil (often called terrestrial gamma background radiations) make the biggest contribution to the total natural background radiation dose (Yang *et al.*, 2005). A substantial amount of gamma radiation dose as high as 1 mSv due to natural radioactivity mainly comes from terrestrial sources (Jibiri, 2001). According to United Nations Scientific Committee on the Effects of Atomic Radiation Report (UNSCEAR, 2000), the greatest contribution to mankind's exposure comes from natural background radiation, and the global average annual effective dose is 2.4 mSv.

The specific levels of terrestrial gamma radiation (TGR) dose rates are related to content of radionuclides (^{238}U, ^{232}Th and ^{40}K) within the earth's crust or rocks from which soils of an area originate (Tzortzis and Tsertos, 2004). About 95% of external gamma radiation due to the primordial radionuclides incorporated in soil comes from the upper part (30 cm) of the soils (Klein and Hurlbut, 1993). In addition, soil is a good agent of radionuclides transfer to plant and animals (Jabbar *et al.*, 2010); therefore, soil is a good indicator of environmental radiological status.

The greatest number of natural radionuclides in the environment exist in water sources especially those from the decay series of ^{238}U and ^{232}Th. Some of these radionuclides such as ^{238}U, ^{226}Ra and ^{222}Rn are found in particulate and in dissolved form in groundwater as a result of rock–water interactions (Abdurabu *et al.*, 2016a).

The concentrations of ^{238}U and ^{232}Th in groundwater are also significantly related to the geomorphology, lithology and other geological factors of the region. Their existence is due to the presence of certain minerals such as uraninite, pitchblende, silicate, phosphate, validates, lignite and monazite sand in different rocks bearing aquifers (Maxwell *et al.*, 2015b). Therefore, the levels of radioactivity in groundwater depend on their concentrations in the aquifer host rocks, the physical processes that occur at the rock–water boundary and chemical reactions. These radioelements can leach out into groundwater, as the water moves through the fractures of the bedrocks. Salih *et al.* (2002), claimed that radioactivity level is high in groundwater for wells constructed in granitic region and some sedimentary rocks such as shale and phosphate; these rocks contain considerable amount of ^{238}U and ^{232}Th and their decay products. Activity concentration of ^{238}U in groundwater in the range of 20.55 to 273.82 $\mu g\ L^{-1}$ near granitic quarry area at Odeda area of Ogun state, Nigeria have been reported by Amakom and Jibiri (2010).

Exposure to excessive levels of gamma radiation from these radioisotopes pose a radiological health implication on the living organisms; especially internal irradiation of human lung tissue from the inhalation of radioactive gas radon and its decay products (Singh *et al.*, 2005). The interaction of gamma rays with body's critical cell (DNA) may alter or destroy the biochemical processes of the body which will leads to various diseases such as cancer, development of tumour cells and sometimes even lead to death (Fridovich, 1978). Therefore, the assessment of radiation levels from natural sources is of particular importance as natural radiation is the largest contributor to the external radiation dose of the world population (UNSCEAR, 1988).

1.2 Problem Statement

Despite the global interest in the measurement of natural background radiation and the extent of nuclear research and applications being carried out in

Nigeria, the level of natural radioactivity for most of its environments have not been established, and effort has not been made to carry out an extensive measurement program to cover the entire country (Jibiri, 2001). Thus, data on the natural environment radioactivity are still sparse and limited.

From a geological point of view, Jos Plateau is underlain by formations of igneous rocks namely basement complex, younger granites and volcanic rocks which are associated with substantial deposits of cassiterite (Tin Ore) and columbite (Falconer, 1921; Ibeanu, 2003). These valuable minerals are associated with substantial amount of naturally occurring radioactive materials (NORMs) such as xenotime, monazite and zircon; NORMs have high concentration of thorium and uranium which are the major sources of natural background radiations of an environment (Lee *et al.*, 2009). Radioactivity levels is reported to be high in groundwater for wells constructed in granitic region and some sedimentary rocks such as shale and phosphate (Salih *et al.*, 2002). A research work by Arogunjo *et al.* (2009) reported high concentration of uranium in groundwater in one of the communities (Bisitchi) of Jos Plateau. Consequently, the geology of the area constitute a major source of external exposure to radiation for the inhabitants of the area; thus, making the assessment of radiological impact and risks to the population are of major interest.

Most of previous studies on environmental radioactivity in Jos Plateau concentrate on the measurement of natural radionuclides in soil and water samples for specific locations and reported relatively higher radioactivity levels (Arogunjo *et al.*, 2009; Arogunjo, 2007; Amakom and Jibiri, 2010; Abdullahi *et al.*, 2013; Jibiri *et al.*, 2007a; Ademola, 2008; Jibiri *et al.*, 2009) compared to other parts of Nigeria (Jibiri *et al.*, 2014; Jibiri *et al.*, 2016; Bashir *et al.*, 2013). None of these studies consider the measurement of activity concentration of terrestrial radionuclides or background gamma dose rates (in–situ) based on geological settings and soil types of the area.

Therefore, in an effort to address this issue, this study aimed to determine the natural gamma dose rates and radioactivity levels due to terrestrial radionuclides in soils and groundwater based geological formations and soil types of Jos Plateau and to evaluate the associated health risks.

1.3 Objectives of the study

The main objective of this study is to establish baseline data on natural gamma radiation and radioactivity levels and to evaluate the corresponding radiological health impacts for Jos Plateau. The specific objectives are as follows:

1) To measure natural gamma radiation dose rates in–situ based on geological formations and soil types of Jos Plateau.

2) To determine the specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples collected based on geological formations and soil types of the area.

3) To determine the mass concentrations of uranium (U) and thorium (Th) in various groundwater samples of the area.

4) To assess the radiological health risks associated with the gamma radiation and the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K.

5) To produce isodose map for gamma dose rates and spatial distribution of ^{226}Ra, ^{232}Th and ^{40}K based on activity concentrations.

1.4 Significance of the study

Baseline data on the background radiation forms the basic requirement for any environment that may be prone to radioactive contamination (Jibiri and Bankole, 2006). Therefore, the present study will provide basic information on the exposure rate due to background gamma radiation and the radioactivity levels of terrestrial radionuclides in soils and groundwater based on the geological formations and soil types of the area. Therefore, the data obtained could be useful for future radio–geochemical investigations in the area especially the search for rare earth elements and location of potassium alterations.

The results of this work will also form a scientific baseline data on the levels of natural radioactivity in the area for monitoring and evaluation for any future radiological contaminations in the environment due to local accidental releases or those of international scale. Such data can also be used to assess the radiological health effects of natural radiation in the environment and can be used to confirm, and to plan decisions regarding possible radiation related health problems in the area.

1.5 Scope of the research

The study covers nine local government areas within Jos Plateau bounded by latitudes of 8° 30’ – 10° 24’ on the North and longitudes of 9° 20’ – 9° 30’ on the East having a total land area of 15,038 km^2.

To achieve the stated objectives, the research work focused on measurement of natural gamma radiation levels of Jos Plateau to provide scientific reference data on the environmental natural background radiations.

A portable hand held survey meter (Model 19)(Ludlum Measurement, 1993) which uses NaI(Tl) as a detector was used to measure external gamma radiation dose rates (in–situ) across the geological formations and soil types of the area. Activity concentrations of terrestrial radionuclides ^{226}Ra, ^{232}Th and ^{40}K were determined using gamma spectroscopy technique.

Inductive Coupled Plasma Mass Spectroscopy (ICP–MS) analytical technique was used to determine the mass concentration of U and Th in groundwater samples collected from various sources across the geological formations of the area.

A statistical analysis using Statistical Packed for Social Science (SPSS) software such as frequency histogram and box plot were used to display and to compare the distribution of the data on gamma dose rates and a statistical comparison methods of paired sample t–test and Analysis of Variance (ANOVA) were used to compare means of gamma dose rates and activity concentration of ^{238}U, ^{232}Th and ^{40}K among the geological formations and soil types of the area.

Radiological human health risks and chemical toxicity risks due to exposure to external gamma radiation, radioactivity in soil and ingestion of groundwater were evaluated to assess the level of risks for the inhabitants of the area. Spatial distribution maps of ^{226}Ra ^{232}Th, ^{40}K based on activity concentrations and isodose map for gamma radiation dose rates were produced inform of digital plots using Geographical Information System (ArcGIS) mapping software.

1.6 Thesis outline

This thesis comprises of five chapters arranged chronologically. The first chapter gives the background of the research work, statement of the problem, aim and objectives of the study, significance of the study, scope of the research and outline of thesis organisation.

In chapter two, relevant literature review is presented on the topic. These include the concept of natural environmental radioactivity and radiations, sources of natural radiation (terrestrial and cosmic sources), radioactivity in different environmental media such as rocks, soils and groundwater. The chapter also reviews the radiological studies in different parts of the world and within Nigeria. Review on radiation related health risks is also presented in this chapter.

Chapter three describes the study area and the methodology used to achieve the stated objectives. These includes field measurement of gamma dose rates, soil and water samples collection, samples preparation, gamma spectroscopy technique and Inductive Coupled Plasma Mass Spectroscopy (ICP–MS) analytical method. Radiological and chemical toxicity health hazard parameters evaluation and different statistical analyses on the data obtained are also presented in this chapter.

Chapter four focuses on the data analysis and discussion of the results obtained. Chapter five presents the research conclusion and recommendations.

REFERENCES

Abdullahi, M., Mohammed, S. and Iheakanwa, I. (2013). Measurement of natural radioactivity in soil along the Bank of River Kaduna–Nigeria. *Department of Applied Sciences of Science and Technology Kaduuna polytechnic, Kaduna, Nigeria*.

Abdurabu, W. A., Ramli, A. T., Saleh, M. A. and Heryansyah, A. (2016a). The activity concentrations of 222 Rn and corresponding health risk in groundwater samples from basement and sandstone Aquifer; the correlation to Physicochemical Parameters. *Radiation Physics and Chemistry,* 127**,** 34–41.

Abdurabu, W. A., Saleh, M. A., Ramli, A. T. and Heryansyah, A. (2016b). Occurrence of natural radioactivity and corresponding health Risk in groundwater with an elevated radiation Background in Juban District, Yemen. *Environmental Earth Sciences,* 75(20)**,** 1360.

Ademola, A. K., Bello, A. K. and Adejumobi, A. C. (2014). Determination of natural radioactivity and hazard in soil samples in and around gold mining area in Itagunmodi, South–Western, Nigeria. *Journal of Radiation Research and Applied Sciences,* 7(3)**,** 249–255.

Ademola, J. (2008). Exposure to high background radiation level in the tin mining area of Jos Plateau, Nigeria. *Journal of Radiological Protection,* 28(1)**,** 93.

Agu, B. N. (1965). Observation of radioactive fallout in Nigeria up to 1961. *Nature, 205, 649–651.*

Ahmad, N., Jaafar, M. S., Bakhash, M. and Rahim, M. (2015). An Overview on measurements of natural radioactivity in Malaysia. *Journal of Radiation Research and Applied Sciences,* 8(1)**,** 136–141.

Ahmed, N. K. and El–Arabi, A. G. M. (2005). Natural radioactivity in farm soil and phosphate fertilizer and its environmental implications in Qena Governorate, Upper Egypt. *Journal of Environmental Radioactivity,* 84(1)**,** 51–64.

Aieta, E. M., Singley, J. E., Trussell, A. R., Thorbjarnarson, K. W. and Mcguire, M. J. (1987). Radionuclides in drinking water: An Overview. *Journal of American Water Works Association***,** 79(4),144–152.

Ajayi, I. and Kuforiji, O. (2001). Natural radioactivity measurements in rock samples of Ondo and Ekiti States in Nigeria. *Radiation Measurements,* 33(1)**,** 13–16.

Ajayi, I., Oresegun, M. and Babalola, I. (1996). Absorbed dose rates in air due to U, Th and K in soils in parts of South–Western Nigeria. *Nigerian Journal of Physics*, 8**,** 38–40.

Akkaya, G., Kaynak, G., Kahraman, A. and Gurler, O. (2012). The Investigation of radionuclide distributions in soil samples collected from Bursa, Turkey. *Radiation Protection Dosimetry,* 152(4)**,** 376–383.

Al–Hamarneh, I. F. and Awadallah, M. I. (2009). Soil radioactivity levels and radiation hazard assessment in the highlands of Northern Jordan. *Radiation Measurements,* 44(1)**,** 102–110.

Al–Jundi, J. (2002). Population doses from terrestrial gamma exposure in areas near to old phosphate mine, Russaifa, Jordan. *Radiation Measurements,* 35(1)**,** 23–28.

Aliyu, A. S. and Ramli, A. T. (2015). The world's high background natural radiation areas (HBNRAs) Revisited: A Broad Overview of the Dosimetric, Epidemiological and Radiobiological Issues. *Radiation Measurements,* 73**,** 51–59.

Almayahi, B., Tajuddin, A. and Jaafar, M. (2012). Effect of the natural radioactivity concentrations and 226 Ra/238 U disequilibrium on cancer diseases in Penang, Malaysia. *Radiation Physics and Chemistry,* 81(10)**,** 1547–1558.

Almeida, R. M., Lauria, D. C., Ferreira, A. and Sracek, O. (2004). Groundwater radon, radium and uranium concentrations in Regiao Dos Lagos, Rio De Janeiro State, Brazil. *Journal of Environmental Radioactivity,* 73(3)**,** 323–334.

Amadi, A., Okoye, N., Olasehinde, P., Okunlola, I., Alkali, Y., Ako, T. and Chukwu, J. (2012). Radiometric survey as a useful tool in geological mapping of western Nigeria. *Journal of Geography and Geology,* 4(1)**,** 242- 249.

Amakom, C. and Jibiri, N. (2010). Chemical and radiological risk assessment of uranium in borehole and well waters in the Odeda Area, Ogun State, Nigeria. *International Journal of Physical Sciences,* 5(7)**,** 1009–1014.

Antovic, N. M., Svrkota, N., Antovic, I., Svrkota, R. and Jancic, D. (2013). Radioactivity in Montenegro beach sands and assessment of the corresponding environmental risk. *Isotopes in Environmental and Health Studies,* 49(2)**,** 153–162.

Arogunjo, A. (2007). Terrestrial gamma radiation and the radiological implication in South Western Nigeria. *Journal of Applied Sciences,* 7(11)**,** 1534–537.

Arogunjo, A. M., Llriegl, V. H., Giussani, A., Leopold, K., Gerstmann, U., Veronese, I. and Oehb, U. (2009). Uranium and thorium in soils mineral sands water and food samples in a tin mining area in Nigeria with elevated activity. *Journal of Environmental Radioactivity***,** 232–240.

Aziz Saleh, M., Termizi Ramli, A., Alajerami, Y., Damoom, M. and Sadiq Aliyu, A. (2014). Assessment of health hazard due to natural radioactivity in Kluang district, Johor, Malaysia. *Isotopes in Environmental and Health Studies,* 50(1)**,** 103–113.

Babalola, I. (1984). Radiation measurement and assay of tailing from high natural radioactivity in Plateau State. *Nigerian Journal of Science,* 18**,** 98–101.

Badhan, K. and Mehra, R. (2012). Primordial radioactivity (238u, 232th and 40k) measurements for soils of Ludhiana district of Punjab, India. *Radiation Protection Dosimetry,* 152(1–3)**,** 29–32.

Banzi, F. P., Kifanga, L. D. and Bundala, F. M. (2000). Natural radioactivity and radiation exposure at the Minjingu Phosphate mine in Tanzania. *Journal of Radiological Protection,* 20(1)**,** 41.

Baranwal, V., Sharma, S., Sengupta, D., Sandilya, M., Bhaumik, B., Guin, R. and Saha, S. (2006). A new high background radiation area in the geothermal region of Eastern Ghats Mobile Belt (Egmb) of Orissa, India. *Radiation Measurements,* 41(5)**,** 602–610.

Bashir, M., Ibeanu, I., Zakari, Y. and Sadiq, U. (2013). Assessment of radiological risk in flooded soil samples of Kudenda, Kaduna State Nigeria. *International Journal of Engineering Science Invention,* 2(10) 69–74.

Baykara, O. and Doğru, M. (2009). Determination of terrestrial gamma, 238 U, 232 Th and 40 K in soil along fracture zones. *Radiation Measurements,* 44(1)**,** 116–121.

Baykara, O., Karatepe, Ş. and Doğru, M. (2011). Assessments of natural radioactivity and radiological hazards in construction materials used in Elazig, Turkey. *Radiation Measurements,* 46(1)**,** 153–158.

Bca, C. (2015). Baseline measurements of natural radioactivity in soil samples from the Federal University of Technology, Owerri, South–East, Nigeria *British Journal of Applied Science & Technology,* 5(2)142- 149.

Beck, H. L. (1972). The Physics of environmental radiation Fields. Natural radiation environment, Conference–720805 P2. *Proceedings of the Second International Symposium on the Natural Radiation Environment,* Canad*a.*

Beretka, J. and Mathew, P. (1985). Natural radioactivity of Australian building materials, industrial wastes and by–products. *Health Physics*, 48(1)**,** 87–95.

Borrelli, R. (1999). Characterization of radioactivity in the environment. . *M.Sc. thesis, Faculty of the Worcester Polytechnic Institute, Worcester, Massachusetts, USA.*

Buchanan, M., Macleod, W., Turner, D., Berridge, N. and Black, R. (1971). The geology of the Jos Plateau younger granite complexes. *Bulletin geology survey of Nigeria,* 2(32)**,** 67–106.

Clouvas, A., Xanthos, S., Antonopoulos–Domis, M. and Silva, J. (2000). Monte carlo calculation of dose rate conversion factors for external exposure to photon emitters in soil. *Health Physics,* 78(3)**,** 295–302.

Coker, J. O., Amidu, O., Makinde, V. and Adesodun, J. (2013). Application of radiometric surveys to delineate between sedimentary terrain and basement complex: A case study of Sagamu and Abeokuta, South Western Nigeria. *Journal of Natural Sciences Research,* 3(13)**,** 13–16.

Dinh Chau, N., Dulinski, M., Jodlowski, P., Nowak, J., Rozanski, K., Sleziak, M. and Wachniew, P. (2011). Natural radioactivity in groundwater–a Review. *Isotopes in Environmental and Health Studies,* 47(4)**,** 415–437.

Dioszegi, I., Salwen, C. and Vanier, P. (2014). Detection system for high–Resolution gamma radiation spectroscopy with neutron time–of–flight filtering. Google Patents, Washinton.

Dovlete, C. and Povinec, P. (2004). Quantification of uncertainty in gamma–spectrometric analysis of environmental samples. *Quantifying uncertainty in nuclear analytical measurements,* 103, Bangi.

Dragović, S., Janković–Mandić, L., Dragović, R., Đorđević, M., Đokić, M. and Kovačević, J. (2014). Lithogenic radionuclides in surface soils of Serbia: spatial distribution and relation to geological formations. *Journal of Geochemical Exploration,* 142**,** 4–10.

Edwerd, L. (1998). Radiation biophysics. *Academic Press, London. pp 27–47.*

Eisenbud, M. and Gesell, T. F. (1997). Environmental radioactivity from natural, industrial and military Sources. Academic Press, New York.

El–Arabi, A., Abbady, A. G. and Hussein, A. (2006). Gamma–ray measurements of natural radioactivity in sedimentary rocks from Egypt. *Nuclear Science and Techniques*, 17(2)**,** 123–128.

El–Bahi, S. M., El–Dine, N. W., Ahmed, F., Sroor, A. and Salaam, M. M. A. (2005). Natural radioactivity levels for selected kinds of Egyptian Sand. *Isotopes in Environmental Health Studies*, 41(2)**,** 161–168.

El–Mageed, A. A., El–Kamel, A., Abbady, A., Harb, S., Youssef, A. and Saleh, I. (2011). Assessment of natural and anthropogenic radioactivity levels in rocks and Soils in the environments of Juban Town in Yemen. *Radiation Physics and Chemistry*, 80(6)**,** 710–715.

El–Taher, A. and Al–Zahrani, J. (2014). Radioactivity measurements and radiation dose assessments in Soil of Al–Qassim Region, Saudi Arabia. *Journal of Environmental Physics*, 57, 726–735.

EPA (2000). National primary drinking water regulations; Radionuclides. Final rule. Federal Register 76708–76753, 7 December 2000. *US Environmental Protection Agency, Washinton.*

Esri, R. (2011). Arcgis Desktop: Release 10. *Environmental Systems Research Institute, Los Angeles.*

Faanu, A., Adukpo, O., Tettey–Larbi, L., Lawluvi, H., Kpeglo, D., Darko, E., Emi–Reynolds, G., Awudu, R., Kansaana, C. and Amoah, P. (2016). Natural Radioactivity levels in soils, rocks and water at a mining concession of Perseus gold mine and surrounding towns in central region of Ghana. *SpringerPlus*, 5:98.

Faanu, A., Darko, E. and Ephraim, J. (2011). Determination of natural radioactivity and hazard in soil and rock samples in a mining area in Ghana. *West African Journal of Applied Ecology*, 19(1), 249-255

Falconer, J. D. (1921). *The Geology of the Plateau Tin Fields.* Authority of the Nigerian government, Waterlow & Sons Limited, Kaduna.

Farai, I., Adewole, O., Isinkaye, M. and Jibiri, N. (2009). Radiological effects of some industrial wastes and by–Products generated in Lagos, Nigeria. *Jurnal Fizik Malaysia*, 30**,** 43–48.

Farai, I. and Sanni, A. (1992). A Survey of 222rn in groundwater in Nigeria. *Health Physics*, 62(1)**,** 96–98.

Faweya, E. (2007). Radiological dose implications of the natural radioactivity contents of sediment of rivers and streams in the Northern Part of Ibadan City. *Jurnal Fizik Malaysia,* 28(1 & 2)**,** 17–21.

Ford, R., Gerbier–Violleau, M. and Vázquez–Jáuregui, E. (2010). Measurement of the thorium–228 activity in solutions cavitated by ultrasonic sound. *Physics Letters A,* 374(5)**,** 701–703.

Freitas, A. and Alencar, A. (2004). Gamma dose rates and distribution of natural radionuclides in sand beaches—Ilha Grande, Southeastern Brazil. *Journal of Environmental Radioactivity,* 75(2)**,** 211–223.

Fridovich, I. (1978). The Biology of oxygen radicals. *Science,* 201, no. 4359**,** 875–880.

Friedlander, G. (1981). *Nuclear and Radiochemistry.* John Wiley & Sons, New York.

Garmin Corporation (2008). Gps 12xl Personal navigator, operator's manual & reference. Garmin Corporation, Washinton.

Genie, M. (2000). Spectroscopy software, customization tools manual. *V3.1–9233653F. Canberra Industries, Incoporated.* UK

Godoy, J. M. and Godoy, M. L. (2006). Natural radioactivity in Brazilian groundwater. *Journal of Environmental Radioactivity,* 85(1)**,** 71–83.

Grant, F. (1982). *Gamma ray Spectrometry for Geological Mapping and for Prospecting*. Mining Geophysics Workshops, 13,1–13.27.

Grupen, C. (2010). Units of Radiation Protection. *Introduction to Radiation Protection 6E***,** Florida.

Gür, F. and Yaprak, G. (2010). Natural radionuclide emission from coal–fired power plants in the Southwestern of Turkey and the population exposure to external radiation in their vicinity. *Journal of Environmental Science and Health Part A,* 45(14)**,** 1900–1908.

Gurgi, L. A. (2011). *Radiation from Oil Fields.* University of Surrey. UK.

Gyang, J. D. and Ashano, E. (2009). Effects of mining on water quality and the environment; A case study of parts of the Jos Plateau, North Central Nigeria. *Continental Journal of Environmental Sciences,* 11(1)**,** 631-639.

Hewson, G. (1996). Overview of radiation safety in the tin by–product (amang) industry of South East Asia. *Health Physics,* 71(2)**,** 225–234.

Hiemstra, P. H., Pebesma, E. J., Twenhöfel, C. J. and Heuvelink, G. B. (2009). Real–time automatic interpolation of ambient gamma dose rates from the Dutch radioactivity monitoring Network. *Computers & Geosciences,* 35(8)**,** 1711–1721.

Huang, Y.–J., Chen, C.–F., Huang, Y.–C., Yue, Q.–J., Zhong, C.–M. and Tan, C.–J. (2015). Natural radioactivity and radiological hazards assessment of bone–coal from a vanadium mine in central China. *Radiation Physics and Chemistry,* 107**,** 82–88.

Huikuri, P., Salonen, L. and Raff, O. (1998). Removal of natural radionuclides from drinking water by point of entry reverse osmosis. *Desalination,* 119(1)**,** 235–239.

Huy, N. Q., Hien, P. D., Luyen, T., Hoang, D., Hiep, H. T., Quang, N. H., Long, N. Q., Nhan, D. D., Binh, N. T. and Hai, P. S. (2012). Natural radioactivity and external dose assessment of surface soils in Vietnam. *Radiation Protection Dosimetry,* 151(3)**,** 522–531.

IAEA (1989a). Construction and use of calibration facilities for radiometric field equipment. *Technical Reports Series no.309. International Atomic Energy Agency, Vienna.*

IAEA (1989b). Measurement of radionuclides in food and the environment. *International Atomic Energy Agency, Vienna.*

IAEA (1990). Isotopes of noble gases as tracers in environmental studies. *IAEA (1990) 29 May–2 June, 1989, Vienna, Consultant's Group Report. In prep.*

IAEA (2007). Safety Glossary. Terminology used in nuclear safety and radiation protection. *International Atomic Energy Agency, Vienna*.

Ibeanu, I. G. E. (2003). Tin mining and processing in Nigeria: Cause for concern? *Journal of Environmental Radioactivity,* 64(1)**,** 59–66.

Ibrahiem, N. and Pimpl, M. (1994). Uranium concentrations in sediments of the Suez Canal. *Applied Radiation and Isotopes,* 45(9)**,** 919–921.

Ibrahim, U., Akpa, T. and Daniel, I. (2013). Assessment of radioactivity concentration in soil of some mining areas in Central Nasarawa State, Nigeria. *Science World Journal,* 8(2)**,** 7–12.

ICRP (1991). *ICRPPublication 60: 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Pergamon Press, Oxford*.

ICRP (1993). Protection against radon–222 at home and work,. *ICRP Publications 65,Annex ICRP23(2). Pergamon Press, Oxford, p. 46.*

ICRP (2000). "Protection of the public in situations of prolonged radiation exposure (Icrp Publication 82)," *International Commission on Radiological Protection (ICRP), Pergamon Press, Oxford.*

Isinkaye, M. and Emelue, H. (2015). Natural radioactivity measurements and evaluation of radiological hazards in sediment of Oguta Lake, South East Nigeria. *Journal of Radiation Research and Applied Sciences,* 8(3)**,** 459–469.

Isinkaye, M. O. (2013). Natural radioactivity levels and the radiological health implications of tailing enriched soil and sediment samples around two mining sites in Southwest Nigeria. *Radiation Protection and Environment,* 36(3)**,** 122-127.

Ivanovich, M. and Harmon, R. S. (1982). *Uranium Series Disequilibrium: Applications to Environmental Problems.* Oxford University Press, England.

Jabbar, A., Tufail, M., Arshed, W., Bhatti, A. S., Ahmad, S. S., Akhter, P. and Dilband, M. (2010). Transfer of radioactivity from soil to vegetation in Rechna Doab, Pakistan. *Isotopes in Environmental and Health Studies,* 46(4)**,** 495–505.

Jibiri, N. (2001). Assessment of health risk levels associated with terrestrial gamma radiation dose rates in Nigeria. *Environment International,* 27(1)**,** 21–26.

Jibiri, N., Alausa, S. and Farai, I. (2009). Assessment of external and internal doses due to farming in high background radiation areas in old tin mining localities in Jos–Plateau, Nigeria. *Radioprotection,* 44(02)**,** 139–151.

Jibiri, N. and Bankole, O. (2006). Soil radioactivity and radiation absorbed dose rates at roadsides in high–traffic density areas in Ibadan metropolis, Southwestern Nigeria. *Radiation Protection Dosimetry,* 118(4)**,** 453–458.

Jibiri, N. and Esen, N. (2011). Radionuclide contents and radiological risk to the population due to raw minerals and soil samples from the mining sites of quality ceramic and pottery industries in Akwa Ibom, Nigeria. *Radioprotection,* 46(1)**,** 75–87.

Jibiri, N., Farai, I. and Alausa, S. (2007a). Activity concentrations of 226ra, 228th, and 40k in different food crops from a high background radiation area in Bitsichi, Jos Plateau, Nigeria. *Radiation and Environmental Biophysics,* 46(1)**,** 53–59.

Jibiri, N., Farai, I. and Alausa, S. (2007b). Estimation of annual effective dose due to natural radioactive elements in ingestion of foodstuffs in tin mining area of Jos–Plateau, Nigeria. *Journal of Environmental Radioactivity,* 94(1)**,** 31–40.

Jibiri, N., Isinkaye, M., Bello, I. and Olaniyi, P. (2016). Dose assessments from the measured radioactivity in soil, rock, clay, sediment and food crop samples of an elevated radiation area in South–Western Nigeria. *Environmental Earth Sciences,* 75(2)**,** 107.

Jibiri, N., Isinkaye, M. and Momoh, H. (2014). Assessment of radiation exposure levels at Alaba E–Waste dumpsite in comparison with municipal waste dumpsites in Southwest Nigeria. *Journal of Radiation Research and Applied Sciences,* 7(4)**,** 536–541.

Joshua, E., Ademola, J., Akpanowo, M., Oyebanjo, O. and Olorode, D. (2009). Natural radionuclides and hazards of rock samples collected from Southeastern Nigeria. *Radiation Measurements,* 44(4)**,** 401–404.

Junaid, S. A. and Agina, S. E. (2014). Sanitary survey of drinking water quality in Plateau State, Nigeria.

Jwanbot, D., Izam, M., Nyam, G. and John, H. (2013). Radionuclides analysis of some soils and food crops in Barkin Ladi Lga, Plateau State–Nigeria. *Journal of Environment and Earth Science,* 3(3)**,** 79–86.

Kannan, V., Rajan, M., Iyengar, M. and Ramesh, R. (2002). Distribution of natural and anthropogenic radionuclides in soil and beach sand samples of Kalpakkam (India) Using Hyper Pure Germanium (Hpge) gamma ray spectrometry. *Applied Radiation and Isotopes,* 57(1)**,** 109–119.

Kebwaro, J., Rathore, I., Hashim, N. and Mustapha, A. (2011a). Radiometric assessment of natural radioactivity levels around Mrima Hill, Kenya. *International Journal of Physical Sciences,* 6(13)**,** 3105–3110.

Kebwaro, J. M., Rathore, I., Hashim, N. and Mustapha, A. (2011b). Radiometric assessment of natural radioactivity levels around Mrima Hill, Kenya.

Khan, K., Khalid, M. R., Jabbar, A. and Akhter, P. (2012). Appraisal of radioactivity and associated radiation hazards in sand samples of four rivers of Punjab Province, Pakistan. *Isotopes in Environmental and Health Studies,* 48(2)**,** 286–294.

Kim, Y.–S., Park, H.–S., Kim, J.–Y., Park, S.–K., Cho, B.–W., Sung, I.–H. and Shin, D.–C. (2004). Health risk assessment for uranium in Korean groundwater. *Journal of Environmental Radioactivity,* 77(1)**,** 77–85.

Klein, C. and Hurlbut, C. S. (1993). Manual of mineralogy. *(20th ed.). John Wiley & Sons, New York.*

Knoll, G. F. (2010). *Radiation Detection and Measurement.* John Wiley & Sons, New York.

Krull, I. S. (1991). *Trace Metal Analysis and Speciation.* Elsevier, Berlin.

Kundt, M. S., Martinez–Taibo, C., Muhlmann, M. C. and Furnari, J. C. (2009). Uranium in drinking water: Effects on mouse oocyte quality. *Health Physics,* 96(5)**,** 568–574.

Kurttio, P., Auvinen, A., Salonen, L., Saha, H., Pekkanen, J., Mäkeläinen, I., Väisänen, S. B., Penttilä, I. M. and Komulainen, H. (2002). Renal effects of uranium in drinking water. *Environmental Health Perspectives,* 110(4)**,** 337.

Langmuir, D. (1978). Uranium solution–mineral equilibria at low temperatures with applications to sedimentary ore deposits. *Geochimica et Cosmochimica Acta,* 42(6)**,** 547–569.

Langroo, M., Wise, K., Duggleby, J. and Kotler, L. (1991). A Nationwide survey of 222rn and gamma radiation levels in Australian homes. *Health Physics,* 61(6)**,** 753–761.

Lariviere, D., Packer, A. P., Marro, L., Li, C., Chen, J. and Cornett, R. J. (2007). Age dependence of natural uranium and thorium concentrations in bone. *Health Physics,* 92(2)**,** 119–126.

Lee, S. K., Wagiran, H., Ramli, A. T., Apriantoro, N. H. and Wood, A. K. (2009). Radiological monitoring: Terrestrial natural radionuclides in Kinta District, Perak, Malaysia. *Journal of Environmental Radioactivity,* 100(5)**,** 368–374.

Lehr, J. H. and Lehr, J. K. (2000). *Standard Handbook of Environmental Science, Health, and Technology.* McGraw Hill Professional, New York:

Leo, W. R. (1990). Techniques for nuclear and particle physics experiments. *Dr155.*

Ludlum Measurement (1993). Instruction Manual of Ludlum Model 19 Micro R Meter. Ludlum Measurements, Inc, Sweetwater, Texas.

M. Isam Salih, M., Bl Pettersson, H. and Lund, E. (2002). Uranium and thorium eeries radionuclides in drinking water from drilled bedrock wells: Correlation to geology and bedrock radioactivity and dose estimation. *Radiation Protection Dosimetry,* 102(3)**,** 249–258.

Macleod, W. N., Turner, D. C. and Wright, E. P. (1971). The Geology of Jos Plateau. *Bulletin Geological Survey of Nigeria. 32 Vol1., pp. 12–47 pp.*

Malczewski, D., Teper, L. and Dorda, J. (2004). Assessment of natural and anthropogenic radioactivity levels in rocks and soils in the environs of Swieradow Zdroj in Sudetes, Poland, by in situ gamma–ray spectrometry. *Journal of Environmental Radioactivity,* 73(3)**,** 233–245.

Mares, S. (1984). *Introduction to Applied Geophysics. S*pringer Science & Business

Media, Berlin, Germany.

Masok, F. B., Masiteng, P. L. and Jwanbot, D. (2015). Natural radioactivity concentrations and effective dose rate from Jostin mining dumpsites in Ray–field, Nigeria. *J. Environ. Earth Sci,* 5**,** 51–55.

Matheron, G. (1963). Principles of Geostatistics. *Economic Geology,* 58(8)**,** 1246–1266.

Maxwell, O., Wagiran, H., Ibrahim, N., Lee, S., Embong, Z. and Ugwuoke, P. (2015a). Natural radioactivity and geological influence on subsurface layers at Kubwa and Gosa Area of Abuja, Northcentral Nigeria. *Journal of Radioanalytical and Nuclear Chemistry,* 303(1)**,** 821–830.

Maxwell, O., Wagiran, H., Lee, S., Embong, Z. and Ugwuoke, P. (2015b). Radioactivity level and toxic elemental concentration in groundwater at Dei–Dei and Kubwa Areas of Abuja, North–Central Nigeria. *Radiation Physics and Chemistry,* 107**,** 23–30.

Megumi, K., Oka, T., Doi, M., Kimura, S., Tsujimoto, T., Ishiyama, T. and Katsurayama, K. (1988). Relationships between the concentrations of natural radionuclides and the mineral composition of the surface soil. *Radiation Protection Dosimetry,* 24(1–4)**,** 69–72.

Mehra, R., Singh, S., Singh, K. and Sonkawade, R. (2007). 226 Ra, 232 Th and 40 K Analysis in soil samples from some areas of Malwa region, Punjab, India using gamma ray spectrometry. *Environmental Monitoring and Assessment,* 134(1)**,** 333–342.

Nafaa, R. (2006). Gamma ray spectrometry practical information. *John Wiley & Sons,* Hoboken, New Jersey.

Narayana, Y., Radhakrishna, A., Somashekarappa, H., Karunakara, N., Balak, K., Balakrishna, K. and Siddappa, K. (1995). Distribution and enrichment of radionuclides in the newly discovered high background area in Ullal on the Southwest Coast of India. *Health Physics,* 69(2)**,** 178–186.

NCRP (1976). Environmental radiation measurements. *NCRP report no. 50. National Council on Radiation Protection and Measurements*, USA.

Ngachin, M., Garavaglia, M., Giovani, C., Nourreddine, A., Njock, M. K., Scruzzi, E. and Lagos, L. (2008). 226ra, 232th and 40k contents and Radon exhalation rate from materials used for construction and decoration in Cameroon. *Journal of Radiological Protection*, 28(3)**,** 369.

NGSA (1956). Geological Formations of Jos Plateau, Naraguta (Sheet 168): . *Prepared British Government's Dept. of Technical Co–operation Under the Special commonwealth African Assistance Plan. Bases Map prepared from D.C.S 30 by Director of Federal Survey, Nigeria, 1956.*

NPC (2006). *Provisional of 2006 Census Results*, National Population Commission, Abuja.

Oladapo, O, O, Oni, E.A., Olawoyin, A.A., Akerele, O.O., Tijani, S.A. (2012). Assessment of natural radionuclides level in wasteland soils around Olusosun dumpsite Lagos, Nigeria. *IOSR Journal of Applied Physics*, 2**,** 38–43.

Olise, F. S., Owoade, O. K., Olaniyi, H. B. and Obiajunwa, E. I. (2010). A complimentary tool in the determination of activity concentrations of naturally occurring radionuclides. *Journal of Environmental Radioactivity*, 101(11)**,** 910–914.

Olomo, J., Akinloye, M. and Balogun, F. (1994). Distribution of gamma–emitting natural radionuclides in soils and water around nuclear research establishments, Ile–Ife, Nigeria. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 353(1)**,** 553–557.

Omeje, M. and Wagiran, H. (2016). *Radiotoxicity risk of rocks and groundwater of Abuja, Northcentral Nigeria*. Lap Lambert Academic Publishing, Germany..

Oresegun, M. and Babalola, A. (1990). Occupational radiation exposure associated with milling of Th–U–Rich Sn Ore in Nigeria. *Health Physics*, 58(2)**,** 213.

Oresegun, M. and Babalola, I. (1993). The Environmental gamma radiation level of Jos, Nigeria. *Nigerian Journal of Science*, 27**,** 263–268.

Orloff, K. G., Mistry, K., Charp, P., Metcalf, S., Marino, R., Shelly, T., Melaro, E., Donohoe, A. M. and Jones, R. L. (2004). Human exposure to uranium in groundwater. *Environmental Research*, 94(3)**,** 319–326.

Oyebanjo, O., Joshua, E. and Jibiri, N. (2012). Natural radionuclides and hazards of sediment samples collected from Osun River in Southwestern Nigeria. *The Pacific Journal of Science and Technology,* 13(2)**,** p391.

Pe–Piper, G. and Piper, D. J. (2002). The igneous rocks of Greece. ISBN 978-3-443-11030-7, Gebruder Borntraeger, Berlin.

Quindos, L., Fernandez, P., Soto, J., Rodenas, C. and Gomez, J. (1994). Natural radioactivity in Spanish soils. *Health Physics,* 66(2)**,** 194–200.

Qureshi, A. A., Tariq, S., Din, K. U., Manzoor, S., Calligaris, C. and Waheed, A. (2014). Evaluation of excessive lifetime cancer risk due to natural radioactivity in the rivers sediments of Northern Pakistan. *Journal of Radiation Research and Applied Sciences,* 7(4)**,** 438–447.

Radhakrishna, A., Somashekarappa, H., Narayana, Y. and Siddappa, K. (1993). A new natural background radiation area on the Southwest Coast of India. *Health Physics,* 65(4)**,** 390–395.

Rafique, M., Rahman, S. U., Basharat, M., Aziz, W., Ahmad, I., Lone, K. A. and Ahmad, K. (2014). Evaluation of xcess lifetime cancer risk from gamma dose rates in Jhelum Valley. *Journal of Radiation Research and Applied Sciences,* 7(1)**,** 29–35.

Ramli, A. T., Hussein, A. W. M. and Lee, M. (2001). Geological influence on terrestrial gamma radiation dose rate in the Malaysian State of Johore. *Applied Radiation and Isotopes,* 54(2)**,** 327–333.

Ramli, A. T., Hussein, A. W. M. and Wood, A. K. (2005a). Environmental 238 U and 232 Th concentration measurements in an area of high level natural background radiation at Palong, Johor, Malaysia. *Journal of Environmental Radioactivity,* 80(3)**,** 287–304.

Ramli, A. T., Sahrone, S. and Wagiran, H. (2005b). Terrestrial gamma radiation dose Study to determine the baseline for environmental radiological health practices in Melaka State, Malaysia. *Journal of Radiological Protection,* 25(4)**,** 435.

Ravisankar, R., Chandramohan, J., Chandrasekaran, A., Jebakumar, J. P. P., Vijayalakshmi, I., Vijayagopal, P. and Venkatraman, B. (2015). Assessments of radioactivity concentration of natural radionuclides and radiological hazard Indices in sediment Samples from the East Coast of Tamilnadu, India with statistical approach. *Marine Pollution Bulletin,* 97(1)**,** 419–430.

Rogers, J. and Adams, J. (1969). Handbook of geochemistry. *Springer, Berlin, II/3, sections,* 90.

Saito, K. and Jacob, P. (1995). Gamma ray fields in the air due to sources in the ground. *Radiation Protection Dosimetry,* 58(1)**,** 29–45.

Sajo–Bohus, L., Gomez, J., Capote, T., Greaves, E., Herrera, O., Salazar, V. and Smith, A. (1997). Gross alpha Radioactivity of drinking water in Venezuela. *Journal of Environmental Radioactivity,* 35(3)**,** 305–312.

Saleh, M. A. (2014). Environmental radiology of Johor State, Malaysia. *Ph.D Thesis, Universiti Teknologi Malaysia, Skudai.*

Saleh, M. A., Ramli, A. T., Alajerami, Y. and Aliyu, A. S. (2013). Assessment of environmental 226 Ra, 232 Th and 40 K concentrations in the region of elevated radiation background in Segamat district, Johor, Malaysia. *Journal of Environmental Radioactivity,* 124**,** 130–140.

Saleh, M. A., Ramli, A. T., Alajerami, Y., Aliyu, A. S. and Basri, N. a. B. (2013a). Radiological study of Mersing district, Johor, Malaysia. *Radiation Physics and Chemistry,* 85**,** 107–117.

Saleh, M. A., Ramli, A. T., Alajerami, Y., Mhareb, M. H. A., Aliyu, A. S., Gabdo, H. T. and Garba, N. N. (2014). Assessment of radiological health implicat from ambient environment in the Muar District, Johor, Malaysia. *Radiation Physics and Chemistry,* 103**,** 243–252.

Saleh, M. A., Ramli, A. T., Alajeramie, Y., Suhairul, H., Aliyu, A. S. and Basri, N. A. (2013b). Terrestrial gamma radiation and its statistical relation with geological formation in the Mersing District, Johor, Malaysia. *Radiation Protection Dosimetry*.

Saleh, M. A., Ramli, A. T., Bin Hamzah, K., Alajerami, Y., Mhareb, M. H. A., Aliyu, A. S. and Hanifah, N. Z. H. B. A. (2015). Natural environmental radioactivity and the corresponding health risk in Johor Bahru district, Johor, Malaysia. *Journal of Radioanalytical and Nuclear Chemistry,* 303(3)**,** 1753–1761.

Salih, M. I., Pettersson, H. and Lund, E. (2002). Uranium and thorium series radionuclides in drinking water from drilled bedrock wells: Correlation to geology and bedrock radioactivity and dose estimation. *Radiation Protection Dosimetry,* 102(3)**,** 249–258.

Sam, A. K. and Holm, E. (1995). The Natural radioactivity in phosphate deposits from Sudan. *Science of the Total Environment,* 162(2–3)**,** 173–178.

Samat, S. B., Green, S. and Beddoe, A. H. (1997). The activity of one gram of potassium. *Physics in Medicine and Biology,* 42(2)**,** 407.

Sanni, A. (1973). Seasonal variation of atmospheric radioactivity at Ibadan. *Tellus,* 25(1)**,** 80–85.

Sanni, A., James, D. and Schweikert, E. (1985). Radioactivity of the by–products of tin mining in Nigeria. *Nigeria Journal of Science,* 20**,** 115–120.

Sanusi, M., Ramli, A., Gabdo, H., Garba, N., Heryanshah, A., Wagiran, H. and Said, M. (2014). Isodose mapping of terrestrial gamma radiation dose rate of Selangor State, Kuala Lumpur and Putrajaya, Malaysia. *Journal of Environmental Radioactivity,* 135**,** 67–74.

Schoeneick, K. and Aku, I. M. (1998). Study of the degraded mine lands of Jos, Bukuru, Riyom, Barkin Ladi and Bokkos areas of Plateau State for development possibilities.

Sharma, S., Kumar, A., Mehra, R. and Mishra, R. (2017). Ingestion doses and hazard quotients due to intake of uranium in drinking water from Udhampur district of Jammu and Kashmir State, India. *Radioprotection,* 52(2)**,** 109–118.

Shaw, P. (2007). Natural radiation & Norm: Defining the challenge. *3rd International Conference on Natural Radiation & NORM. 2007, IBC Global Conferences, London.*

Singh, S., Rani, A. and Mahajan, R. K. (2005). 226 Ra, 232 Th and 40 K analysis in soil samples from some areas of Punjab and Himachal Pradesh, India using gamma ray spectrometry. *Radiation Measurements,* 39(4)**,** 431–439.

Skeppström, K. and Olofsson, B. (2007). Uranium and radon in groundwater. *European Water,* 17(18)**,** 51–62.

Sonneveld, B. G. J. S. (1979). "A Map of dominant soils of Nigeria". *European Digital Archive of Soil Maps. Retrieved from http://eusoils.jrc.ec.europa.eu/esdb_archive/EuDASM/Africa/lists/cng.htm*.

Sturchio, N., Banner, J., Binz, C., Heraty, L. and Musgrove, M. (2001). Radium geochemistry of ground waters in Paleozoic carbonate aquifers, midcontinent, USA. *Applied Geochemistry,* 16(1)**,** 109–122.

Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hidiroglu, S. and Karahan, G. (2009). Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *Journal of Environmental Radioactivity,* 100(1)**,** 49–53.

Tripathi, R., Sahoo, S., Jha, V., Khan, A. and Puranik, V. (2008). Assessment of environmental radioactivity at uranium mining, Processing and tailings management facility at Jaduguda, India. *Applied Radiation and Isotopes,* 66(11)**,** 1666–1670.

Tyler, A. N. (2008). In situ and airborne gamma–ray spectrometry. *Radioactivity in the Environment,* 11**,** 407–448.

Tzortzis, M., Svoukis, E. and Tsertos, H. (2004). A comprehensive study of natural gamma radioactivity levels and associated dose rates from surface soils in Cyprus. *Radiation Protection Dosimetry,* 109(3)**,** 217–224.

Tzortzis, M. and Tsertos, H. (2004). Determination of thorium, uranium and potassium elemental concentrations in surface soils in Cyprus. *Journal of Environmental Radioactivity,* 77(3)**,** 325–338.

Ugodulunwa, F., Ukpong, R., Ongbatabo, A. and Onazi, B. (2008). Radiation and other environmental hazards of mining: Focus on Jos Plateau mining region. *Journal of Engineering and Applied Sciences,* 4**,** 1–6.

UNSCEAR (1988). Sources, effects and risk of ionizing radiation:. *United Nations Scientific Committee on the Effect of Atomic Radiation, United Nations, New York.*

UNSCEAR (1993). Sources, effects and risks of ionising radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York.

UNSCEAR (2000). Sources and effects of ionizing radiation. Report to the General Assembly with scientific annexes, United Nations. *United Nations Scientific Committee on the Effects of Atomic Radiation*, New York.

UNSCEAR (2008). Sources and effects of ionizing radiation. *United Nations Scientific Committee on the Effects of Atomic Radiation, New York.*

UNSCEAR (2011). Sources, effects and risks of ionizing radiation. *United Nations Scientific Committee on the Effects of Atomic Radiation, New York.*

USEPA (2008). Groundwater and drinking water. *Environmental Protection Agency (EPA). US Drinking water Division.*

USEPA (1999). Compendium of methods for the determination of toxic organic compounds in ambient air. *United State Environmental Protection Agency (EPA), 600/4–89–017, June 1999.*

Vahabi Moghaddam, M. and Sadremomtaz, A. (2010). A comparative study of field gamma–ray spectrometry by Nai (Tl) and HPGe detectors in the South Caspian Region. *Caspian Journal of Environmental Sciences,* 8(2)**,** 203–210.

Vesterbacka, P. (2005). 238u–Series radionuclides in Finnish groundwater–based drinking water and effective doses.

Von Gunten, H. R. and Beneš, P. (1995). Speciation of radionuclides in the environment. *Radiochimica Acta,* 69(1)**,** 1–30.

WHO (2003). Guidelines for driking water quality health criteria and other supporting informations. *World Health Organisation (WHO). 2nd edition, vol.2; pp. 367–390*.

WHO (2006). Guidelines for drinking water quality health criteria and other supporting information 2nd edition, Vol. 2; , Pp. 367–370. *World Health Organization,* Geneva.

WHO (2008). Primary health care now more than ever. *The world health report 2008. World Health Organisation, Geneva.*

WHO (2011). Guidelines for drinking–Water quality 4th Ed., *World Health Organisation,* Geneva.

Wrenn, M. E., Durbin, P. W., Howard, B., Lipsztein, J., Rundo, J., Still, E. T. and Willis, D. I. (1985). Metabolism of ingested U and Ra. *Health Physics*, 48, 601–633.

Xhixha, G. (2012). Advanced Gamma–Ray Spectrometry for Environmental Radioactivity Monitoring. Università degli studi di Ferrara.

Yang, Y.–X., Wu, X.–M., Jiang, Z.–Y., Wang, W.–X., Lu, J.–G., Lin, J., Wang, L.–M. and Hsia, Y.–F. (2005). Radioactivity concentrations in soils of the Xiazhuang granite area, China. *Applied Radiation and Isotopes,* 63(2)**,** 255–259.

Zamora, M. L., Tracy, B., Zielinski, J., Meyerhof, D. and Moss, M. (1998). Chronic ingestion of uranium in drinking water: A study of kidney bioeffects in humans. *Toxicological Sciences,* 43(1)**,** 68–77.

Zapecza, O. S. and Szabo, Z. (1986). Natural radioactivity in groundwater—a review. *US Geological Survey National Water Summary***,** 50–57.

Zhao, L., Xu, C., Tuo, F., Zhang, J., Li, W., Zhang, Q., Zhou, Q., Zhang, J. and Su, X. (2011). Assessment of radionuclide level in topsoil samples for partial areas of Tibet, China. *Radiation Protection Dosimetry,* 148(3)**,** 380–386.

Zouridakis, N., Ochsenkühn, K. and Savidou, A. (2002). Determination of uranium and radon in potable water samples. *Journal of Environmental Radioactivity,* 61(2)**,** 225–232.