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Uranium Concentration in Groundwater and Assessment of Radiation Doses Within Naraguta Sheet 168, North Central Nigeria

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Abstract
Water samples collected from 60 wells located within Naraguta Sheet 168 in North Central Nigeria were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) for uranium concentrations and other selected trace elements. This is aimed at assessing the radiation dose arising from intake of uranium through drinking water pathway for different age groups in the area. Results obtained show that uranium concentration in groundwater within the study area is generally within the acceptable reference level of 0.1mSv/y except in some places around Bukuru, Rayfield and Bishichi areas underlain mainly by the Jos-Bukuru Younger Granite Complex. The uranium values in groundwater within Naraguta Sheet 168 vary from 0.02-168.7 ppb, representing an activity concentration of 0.516-4.353 mBq/l. Radiation dose due to intake of uranium through drinking water pathway from the area is calculated to be 0.045-378.098 (μSv/y) among infants of 0-6 months, 0.051-432.112 (μSv/y) among infants of 7-12 months, 0.029-247.829 (μSv/y) among children between 1-3 years of age, and 0.026-216.056 (μSv/y) for children between 4-8 years. For 9-13 years old male children, it is 0.031-259.267 (μSv/y), while for the female children of the same age range, it is 0.031-259.267 (μSv/y). Male teenagers of between 14-18 years receives 0.042-351.250 (μSv/y) and female in the same age category receives 0.042-244.811 (μSv/y). Among the adult males older than 18 years, the radiation dose is 0.031-264.710 (μSv/y) and among females of 18 years and above, it is 0.023-193.021 (μSv/y). With effective dose due to uranium in water exceeding the reference level of 0.1mSv/y in some localities, it is therefore necessary to always carryout radiological investigations alongside analysis of major anions and cations present in the groundwater for safety reasons.
Keywords: Uranium. Activity Concentration. Dose Rates. Ingestion Dose Co-efficient. Naraguta Sheet 168. Jos-Bukuru Younger Granite Complex.

1. Introduction
Naraguta Sheet 168 is located in North Central Nigeria (Figure 1). It lies between Latitude 9^{0}30'N - 10^{0}00'N, and Longitude 8^{0}30'E - 9^{0}00'E, and covers an area of about 3025 km^{2}. It consists of many major settlements which are engaged in cassiterite and columbite mining activities. Uranium occurs in nearly all soils and rocks in small concentrations (Appleton 2007). Uranium is a naturally occurring radioactive element that is widely dispersed in the earth's crust at levels of approximately 2–4 ppm by weight (Stegnar & Benedik 2001). It is also detected everywhere in groundwater (Graham 1964; USEPA 2000). According to Maithani & Srinivasan (2011), granitic rocks contain higher uranium than the crustal average, thereby making them a potential source. Volcanic rocks are often found to be richer in uranium and thorium than their plutonic equivalents.

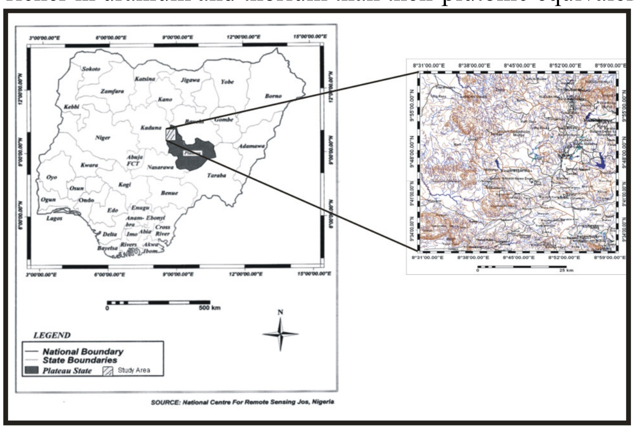

Figure 1. Location map of the study area.

Weathering and decomposition of rocks facilitate the dissolution of uranium, while groundwater within the weathered regolith aquifer in acidic rock environments may contain significant amount of uranium. Groundwater may equally become contaminated with uranium as a result of human activities such as discharges from mines and mineral processing wastes, or leakages from nuclear facilities. Many international bodies such as the World Health Organization (WHO), International Commission on Radiological Protection (ICRP), and United State Environmental Protection Agency (USEPA) have recognized uranium as a potentially harmful constituent in drinking water and have proposed drinking water standard for uranium beyond which consumption of such water can affect the well being of the public. The WHO (2008) proposed a 15 µg/l as a safe limit for uranium in drinking water while ICRP (1993) recommended a value of 1.9 µg/l. The USEPA puts its safe limit at 30 µg/l. Some countries have also set a limit for uranium in their drinking water. For instance, Canada puts uranium limit in drinking water at 20 µg/l, (Michael 2010), while Nigeria through the Standards Organization of Nigeria (SON 2007) set its limit for drinking water quality for radionuclides (uranium inclusive) at 0.1 Bq/l which is approximately the activity concentration of 3.88 µg/l of uranium in water.

Many people in Nigeria tend to favour groundwater as a source of drinking water because it is generally believed that groundwater is pure and does not require any form of treatment before consumption. While analysis for major anions and cations present in water for drinking are carried out periodically, investigation on the radiological aspects of groundwater are hardly done despite the fact that groundwater can contain high concentration of several chemical components, many of which may be radioactive and therefore injurious to human health. This problem was pointed out by Reimann & Banks (2004). Consequently, this work is aimed at assessing radiation doses arising from intake of uranium through drinking water pathway for different age groups within Naraguta Sheet 168 in North Central Nigeria and its possible health effects on the inhabitants.

2. Geology of the study area

Naraguta Sheet 168 is underlain by three main rock groups. They include the Basement Complex rocks, the Younger Granite and the Basalts (Figure 2, modified after Kinnaird et al 1981). The basement rocks occur mostly around the northwestern part of the area while the Younger Granites occur essentially around the northeastern and south eastern parts. The basalts are mostly found in the south western and central parts. The basement rocks here are mainly migmatite and granite gneiss. According to Wright et al (1985), they have been subjected to multiple episodes of deformation such as the Eburnean Orogeny (2000±200Ma), Kibaran (1100±150Ma) and Pan-African (6000±1500Ma). These later culminated in the emplacement of the Older Granites. The Younger Granites here maintains a distinct topographic expression, forming a range of plateau which rises between 300-1100m above the surrounding basement rocks. Four (4) major lithological units of the Younger Granites are recognizable in this area. They include:

a). Hornblende-Pyroxene-Fayalite granite, which is greenish and porphyritic with phenocrysts of quartz and feldspars.

b). Hornblende-Biotite granite, which is characterized by the presence of mafic dots and needles of apatite. These granular rocks outcrop considerably in all the Younger Granite complexes.

c). Biotite granite, which is a granular rock and is very abundant. Here the quartz and biotite are generally clustered into rounded crystal aggregates.

d). Riebeckite granite, rhyolites, gabbros and dolerites which are less prominent.

The sequence of magmatic activities in the complexes can be divided into an early volcanic cycle and four later separate cycles, while the emplacement of the magmatic fluids that yielded the Younger Granites is believed to be controlled by deep seated Paleo-lineaments of the Precambrian Basement Complex (Rahaman 1984).

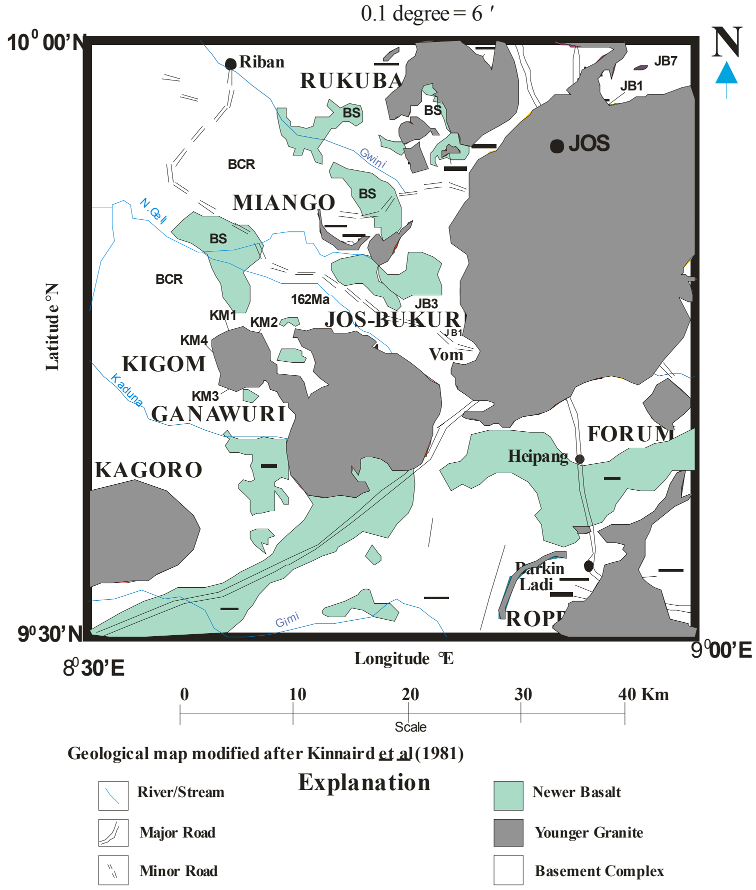

Figure 2. Simplified geological map of Naraguta Sheet 168.

The biotite granite has been recognized to be the host of primary tin mineralization associated with the Younger Granites. The granite is the source of alluvial deposits of cassiterite (tin oxide, SnO_2) and columbite (oxide of tantalum-niobium, iron and manganese, $(Fe,Mn)(Ta,Nb)_2O_6$), as well as radioactive mineral residues such as thorite ($ThSiO_4$), zircon ($ZiSiO_4$) and monazite (Ce,La,Yt)PO_4) amongst others.

The basalts here comprise the Older Basalts, the Lateritized Basalts and the Newer Basalts. The Older Basalts are represented by partly decomposed basaltic boulders, plugs and dome-like outcrops and still very well preserved in the Werram Valley southward of Jos extending to the Rukuba, Ganawuri and south of Ropp areas. The Lateritized Basalts represent the product of weathering of mainly the Older Basalt (Macleod et al. 1971). The Newer Basalt occurs extensively in the western and southern Jos Plateau as cones and lava flows characterised by steep sided central craters, rising a few metres above their surroundings, and are generally aligned in NNW-SSE direction (Macleod et al. 1971).

3. Methodology

A total of sixty (60) water samples were collected from wells in different locations in this area during the dry season when dilution is lowest (Figure 3). Their depths to static water level vary approximately from 5-20 metres. The water samples were acidified with few drops (0.2 ml) of concentrated nitric acid (HNO_3) to prevent adsorption, precipitation of ions in solution, as well as to avoid bacterial growth.

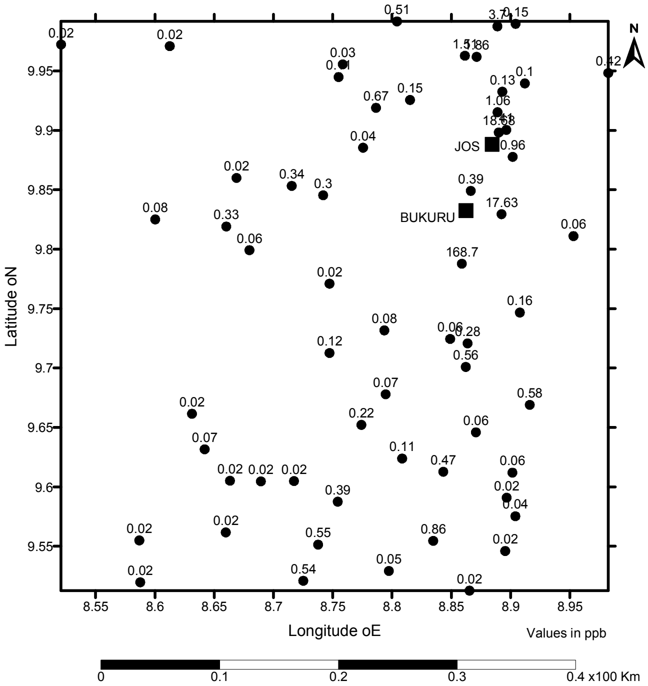

Figure 3. Sample Location and distribution of uranium in groundwater within Naraguta Sheet 168.

Analysis of uranium and other elements was carried out at the ACME Laboratory Vancouver, Canada using ICP - MS to determine trace to ultra - trace concentrations of elements in the samples and by ICP - ES for higher concentrations. Further details on the applicable analytical procedures are as specified by Xiandeng and Bradley (2000). The radiation doses due to intake of uranium through the drinking water pathway were then calculated according to the guidelines provided by the Radiological Protection Institute of Ireland in collaboration with the United States Environmental Protection Agency. According to Dowdall et al. (2013), radiation dose due to uranium is given by:-

$$D(Sv/y)=TAC(Bq/l) \times IDC(Sv/Bq) \times IWPY(L) \quad (1)$$

Where D represents dose due to uranium (Sv/y), TAC is total activity concentration (Bq/l), IDC is ingestion dose co-efficient (Sv/Bq), and IWPY is the intake of water per year (L).

The water intake component for different age groups in the equation is as shown in Table 2. The values were obtained from data published by the International Commission on Radiological Protection (ICRP 1996). Also shown in Table 2 are the average value of ingestion dose co-efficient assigned to these age groups, based on the effective dose coefficients for ingestion of radionuclides for members of the public, as published by the International Commission on Radiological Protection (ICRP 2013).

4. Results and Discussion

Uranium concentration, ingestion dose co-efficient and dose due to uranium in water samples for various age groups are shown in Table 1 and Table 2.

Table 1. Sample locations, concentration and activity of uranium in the water samples

S/No	SAMPLE 1D	LAT (◦N)	LON (◦E)	U (ppb)	U (mBq/l	S/No	SAMPLE 1D	LAT (◦N)	LON (◦E)	U (ppb)	U (mBq/l
1	OIS 1	9.61	8.72	0.02	0.52	31	OIS 45	9.59	8.90	0.02	0.52
2	OIS 2	9.66	8.63	0.02	0.52	32	OIS 46	9.61	8.90	0.06	1.55
3	OIS 6	9.63	8.61	0.07	1.81	33	OIS 47	9.65	8.87	0.06	1.55
4	OIS 8	9.61	8.66	0.02	0.52	34	OIS 48	9.70	8.86	0.56	14.45
5	OIS 9	9.61	8.69	0.02	0.52	35	OIS 50	9.90	8.89	18.68	481.94
6	OIS 10	9.56	8.59	0.02	0.52	36	OIS 51	9.93	8.82	0.15	3.87
7	OIS 11	9.52	8.59	0.02	0.52	37	OIS 52	9.96	8.76	0.03	0.77
8	OIS 12	9.56	8.66	0.02	0.52	38	OIS 53	9.92	8.79	0.67	17.29
9	OIS 16	9.72	8.85	0.06	1.55	39	OIS 54	9.89	8.78	0.04	1.03
10	OIS 17	9.65	8.77	0.22	5.68	40	OIS 55	9.85	8.72	0.34	8.77
11	OIS 18	9.68	8.80	0.07	1.81	41	OIS 56	9.86	8.67	0.02	0.52
12	OIS 19	9.72	8.86	0.28	7.22	42	OIS 57	9.97	8.61	0.02	0.52
13	OIS 20	9.92	8.89	1.06	27.35	43	OIS 58	9.97	8.52	0.02	0.52
14	OIS 21	9.93	8.89	0.13	3.35	44	OIS 59	9.82	8.66	0.33	8.51
15	OIS 22	9.94	8.91	0.10	2.58	45	OIS 60	9.85	8.74	0.30	7.74
16	OIS 23	9.95	8.98	0.42	10.84	46	OIS 61	9.80	8.68	0.06	1.55
17	OIS 24	9.99	8.90	0.15	3.87	47	OIS 64	9.83	8.60	0.08	2.06
18	OIS 25	9.96	8.87	1.86	47.99	48	OIS 65	9.77	8.75	0.02	0.52
19	OIS 26	9.96	8.86	1.51	38.96	49	OIS 66	9.71	8.75	0.12	3.10
20	OIS 27	9.99	8.89	3.70	95.46	50	OIS 67	9.73	8.79	0.08	2.06
21	OIS 28	9.99	8.80	0.51	13.16	51	OIS 69	9.79	8.86	168.70	4352.46
22	OIS 30	9.90	8.90	41.00	1057.80	52	OIS 71	9.62	8.81	0.11	2.84
23	OIS 31	9.88	8.90	0.96	24.77	53	OIS 72	9.59	8.75	0.39	10.06
24	OIS 33	9.85	8.87	0.39	10.06	54	OIS 73	9.55	8.74	0.55	14.19
25	OIS 34	9.83	8.89	17.63	454.85	55	OIS 74	9.56	8.84	0.86	22.19
26	OIS 36	9.81	8.95	0.06	1.55	56	OIS 75	9.53	8.80	0.05	1.29
27	OIS 38	9.95	8.76	0.11	2.84	57	OIS 76	9.61	8.84	0.47	12.13
28	OIS 39	9.75	8.91	0.16	4.13	58	OIS 77	9.67	8.92	0.58	14.96
29	OIS 43	9.55	8.90	0.02	0.52	59	OIS 78	9.51	8.87	0.02	0.52
30	OIS 44	9.58	8.90	0.04	1.03	60	OIS 79	9.52	8.73	0.54	13.93

The concentration of uranium in the water samples varies from 0.02 to 168.7ppb (corresponding to an activity concentration of 0.52-4.35 mBq/l) out of which about 93% are less than the 15 ppb (15 µg/l) provisional guideline value for uranium in drinking water, assuming that an adult consumes two (2) litres of drinking water per day (WHO 2004). However, some areas located within the Jos–Bukuru Younger Granite Complex in the north eastern part of the map have considerably higher values than 15 µg/l (Figure 4).

Table 2. Co-efficient and dose due to uranium in the water samples for various age groups in the study area.

Stage of Life	Infants	Infants	Children	Children	Children	Children	Teenagers	Teenagers	Adult	Adult
Age	0-6 Months	7-12 Months	1-3 Years	4-8 Years	9-13 Months	9-13 Years	14-18 Years	14-18 Years	>18 Years	>18 Years
Gender	Both	Both	Both	Both	Male	Female	Male	Female	Male	Female
Water Int. (L/d)	0.7	0.8	1.3	1.7	2.4	2.1	3.3	2.3	3.7	2.7
Ing. Dose Coeff. (Sv/Bq)	1.2E-07		1.2E-07	8.0E-08	6.8E-08		6.7E-08		4.5E-08	
Dose due to ^{238}U	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)	Dose (µSv/y)
	0.05 - 378.10	0.05 - 432.11	0.03 - 247.83	0.03 - 216.06	0.03 - 259.27	0.03 - 226.86	0.04 - 351.25	0.04 - 244.81	0.03 - 264.71	0.02 - 193.02

Correlation between well depths and the concentrations of uranium in the water samples gave a coefficient of determination (R^2) of 0.01. This suggests that uranium concentration in the water here is not dependent on the depths but rather on the local geology. Naturally, uranium concentrations in groundwater vary from place to place and from one country to another (Table 3). This is due to differences in degree of weathering, dissolution and precipitation reactions with uranium in rock and soil. Radiation dose due to ^{238}U here (Table 2) are generally higher among the younger people especially between the ages of 1-3 years as their ingestion dose coefficient are higher than those of older ages.

The presence of thorite ($ThSiO_4$), zircon ($ZiSiO_4$) and monazite ($(Ce,La,Yt)PO_4$) as a minor product of alluvial deposits of cassiterite (tin oxide, SnO_2) and columbite (oxide of tantalum-niobium, iron and manganese, $(Fe,Mn)(Ta,Nb)_20_6$) within the Jos-Bukuru Younger Granite Complex have increased radioactivity significantly around Bukuru, Rayfield and Bishichi areas. Solomon (2005) reported a radiation absorbed dose rates in air of 1.32–31.97 mSv/y within this area. High concentrations of uranium in water have been reported also in other parts of Nigeria. According to Arabi et al (2012), uranium concentration of 0.03-26.63 µg/l were found in the Wuyo area in North Eastern Nigeria, raising questions about the suitability of the water for drinking due to radiological concerns.

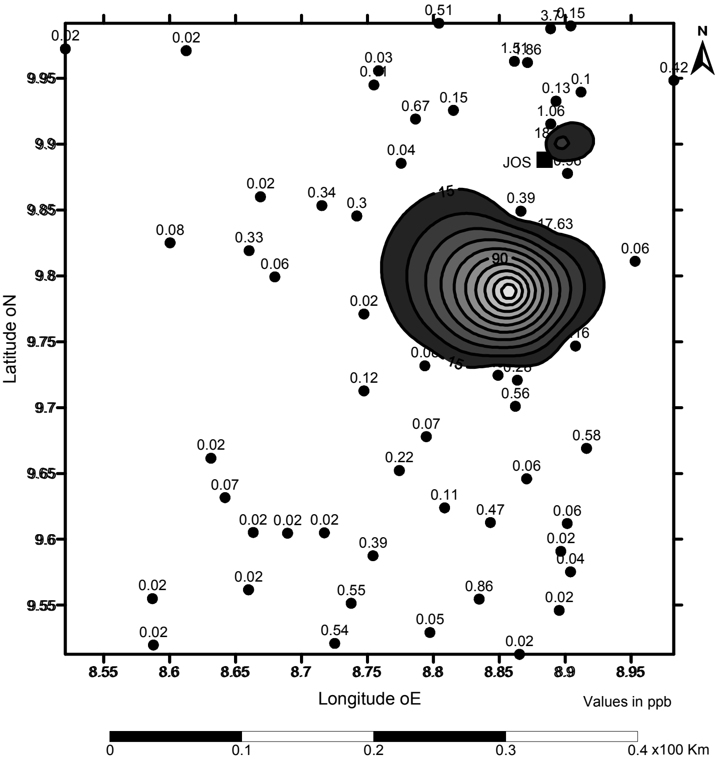

Figure 4. Naraguta Sheet 168 showing areas with uranium concentrations in excess of 15 ppm in groundwater (shaded black).

Table 3. Uranium concentrations in groundwater in some countries in relation to the study area

SNo	Country	^{238}U Concentration (µg/l)	Source
1	Argentina	0.02-1.48	Bomben et al. (1996)
2	China	0.004-28	UNSCEAR (2000)
3	Finland	0.02-6000	UNSCEAR, (2000)
4	France	0.18-37.2	UNSCEAR (2000)
5	German	0.02-24	UNSCEAR (2000)
6	Italy	0.02-5.2	UNSCEAR (2000)
7	Jordan,	0.04-1400	Smith et al, (2000)
8	Romania	0.02-1.48	UNSCEAR (2000)
9	Turkey	0.24-17.65	Kumru (1995)
10	United States	0.012-3.08	UNSCEAR (2000)
The study area (Naraguta Sheet 168)		***0.02 - 168.7***	

5. Conclusion

In most parts of Naraguta Sheet 168 in North Central Nigeria, uranium concentrations in groundwater are less than 15 ppb (15 µg/l) and radiation dose due to uranium are within the acceptable limit of 0.1mSv/yr. However, considerably higher values exist in some localities in the Bukuru, Rayfield and Bishichi areas underlain by biotite granites belonging to the Jos-Bukuru Younger Granite Complex.

The younger ages are generally more susceptible to radiation especially through the drinking water pathway as their ingestion dose coefficients are higher than those for older ages. For health reasons therefore, it is necessary to always carryout radiological investigations alongside analysis of major anions and cations present in the groundwater as most of the inhabitants depend on ground sources (wells and boreholes) for their daily water consumption.

References

Appleton, J.D., (2007). Radon: sources, health risks, and hazard mapping. AMBIO: AJ. Hum. Environ. 36, 85–89.

Arabi, S. A., Funtua, I. I., Dewu, B. B. M., Alagbe, S. A., Kwaya, M. Y., Garba, M. L., and Baloga, A. D. (2012). Activity concentration of uranium in groundwater from uranium mineralized areas and its neighborhood. Journal of Radioanalytical and Nuclear Chemistry.Springer.

Bomben, A.M, Equillor, H.E, and Oliveira, A.A. (1996). Ra226 and natural uranium in Argentina bottled mineral waters. Radiat. Prot. Dosim., 67: 221- 224.

Dowdall, A., Currivan, L. Hanley, O., Kelleher, K., Long, S., McCrory, A., McGinnity, P., McKittrick, L., McMahon, C., O'Colmain, M., Pollard, D., and Wong, J., (2013). Radioactivity levels in groundwater sources in Ireland. RPII 13/04. Dublin: Radiological Protection Institute of Ireland.

Graham, E.R., (1964). Radioisotopes and soils. In: F.E. Bear (Ed.). Chemistry of the Soil, American Chemical Society, Monograph Series, Reinhold Publishing, New York, p. 445–473.

International Commission on Radiological Protection ICRP, (1993). Annals of the ICRP 23, 2. ICRP Publication 65, Pergamon Press, Oxford.

International Commission on Radiological Protection ICPR, (1996). Age dependent doses to members of the Public from intake of radionuclides: part 5. Compilation of ingestion and inhalation doe coefficient, Oxford : Pergamon Press, Annals of the ICRP 26(1). ICRP Publication 72.

International Commission on Radiological Protection ICRP, (2013). Compendium of Dose Coefficients based on ICRP Publication 60. Effective dose coefficients for ingestion of radionuclides for members of the public. Annals of the ICRP ICRP 42(4). ICRP Publication 119.

Kinnaird, J.A., Bowden, P., Bennett, J. N., Turner, D. C., Ike, E. C., Abba, S. I., Moyes, A. B., Badejoko, T. A., Weir, J., Martin, R. F. and Barriere, M. (1981). Geology of the Nigerian Anarogenic Ring Complexes. Jown Bartholomew & Sons Ltd. UK.

Kumru, M.N. (1915). Distribution of radionuclides in sediments and soils along the B¨uy¨uk Menderes River. Proceedings of the Pakistan Academy of Sciences, 32 (1/4), 51-56.

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.

Maithani, P.B., and Srinivasan, S. (2011). Felsic Volcanic Rocks, a Potential Source of Uranium - An Indian Overview. Energy Procedia 7, 163–168.

Michael, M. (2010). Uranium Anomalies in Shallow Groundwater Near Bonnyville, Alberta. Alberta Innovates – Technology Futures.pp94

Rahaman, M. A., Van Breemen, O., Bennet, J. N. and Bowden, P. (1984). Age migration of anarogenic ring complexes in Northern Nigeria. Journal Geological 92. pp 173-184.

Reimann, C., & Banks, D. (2004). Setting action levels for drinking water: Are we protecting our health or our economy (or our backs!)? Science of the Total Environment, 332, 13e21.

Smith, B, Powell A. E, Milodowski, A. E, Hards, V. L, Hutchins, M.G., Amro, A., Gedeon, R, Kilani, S, Scrivens, S.M, Galt, V. (2000). Identification, investigation and remediation of groundwater containing elevated levels of uranium-series radionuclides: a case study from the Eastern Mediterranean. In: Panayides L, Xenophotons, C., Malpas, J., (Eds.), Proceedings of the Third International Conference on the Geology of the Eastern Mediterranean, Nicosia, Cyprus. World Health Organization, Geneva (WHO/SDE/PHE/01.01).

Solomon, A. O. (2005). Natural radiation hazard mapping and distribution of dose equivalents within Naraguta Sheet 168, North Central Nigeria. African Journal of Natural Sciences, 8: 119-121.

Standards Organisation of Nigeria SON, (2007). Nigerian Standard for Drinking Water Quality. ICS 13.060.20.

Stegnar, P., Benedik, L., (2001). Depleted uranium in the environment—an issue of concern? Arch. Oncol. 9, 251–255.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR, (2000). Ionizing Radiation: "Sources and Effects on Ionizing Radiation," Report to the general assembly with scientific annex, United Nation, New York: 2000.

United States Environmental Protection Agency USEPA, (2000). "Standard for uranium in drinking water," 65 FR 76707.

World Heath Organization WHO, (2004). "Guidelines for Drinking Water Quality," Radiological aspects, Geneva: World Health Organization; 3, 1-494.

Wright, J. B., Hastings, D. A., Jones, W. B. and Williams, H. R. (1985). Geology and Min. Res. of West Africa.George Allen and Unwin, London. 187 pp.

Xiandeng and Bradley (2000). Inductively Coupled Plasma/Optical Emission Spectrometry. Encyclopedia of Analytical Chemistry. Meyers, R.A. (Ed.) pp. 9468–9485 John Wiley & Sons Ltd, Chichester.