Evaluation of Chemical and Impacts of Radionuclides in Borehole Waters in Igbajo Town, Osun State, Nigeria

Fayemi O. S. [a*], Giwa A. A. [b], Aderanti A. E. [a], Adenekan A. I. [a] and Olorunniyi, A. G. [a]

[a] *Department of Science Laboratory Technology, Faculty of Applied Sciences, Igbajo Polytechnic, P.M.B. 303, Igbajo, Osun State, Nigeria.*
[b] *Department of Pure and Applied Chemistry, Faculty of Pure and Applied Science, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Oyo State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Water is a universal solvent on earth and sources such as wells, rivers, springs, boreholes, and other freshwater bodies typically serve as a pathway for contaminants to enter the ecosystem while also supplying water for domestic and drinking purposes. The activity concentrations of radionuclides in borehole water in Igbajo town were assessed using gamma-ray spectroscopy, so as to effectively determine the degree of radiological risk to the environment and its inhabitants, the outcomes were used to calculate all the radiological impact parameters. The activity concentrations obtained for ^{40}K, ^{238}U and ^{232}Th ranged from 7.25 ± 0.60 to 62.15 ± 4.48 Bq.L^{-1}; 3.08 ± 0.45 to 15.24 ± 3.07 Bq.L^{-1} and 1.08 ± 1.10 to 17.75 ± 1.59 Bq.L^{-1} and with average values of 23.12 ± 1.59 Bq.L^{-1}, 6.27 ± 2.01 Bq.L^{-1} and 7.01 ± 0.89 Bq.L^{-1} respectively. The Annual Effective Dose (AED) for

_____

*Corresponding author: E-mail: olalekan.fayemy@gmail.com;

ingested radionuclide in drinking water for an adult was1.4872 µSv.yr^{-1}. The Radium Equivalent Activity Index, Ra$_{eq}$ obtained was 34.9186 Bq.L^{-1}. The estimated hazard indices H$_{int}$ and H$_{ext}$ were 0.04876 and 0.06574 respectively. The Excess Lifetime Cancer Risk, ELCR (x10^{-6}) was 5205.15. With a lifetime expectancy of 70 years, this high value suggests that there is a high chance of developing cancer.The value of the Annual Gonadal Equivalent Dose, AGED in the water was 55.9175µSv.yr^{-1}. The estimated Gamma Index, I$_\gamma$ was0.1273 mSv.yr^{-1}. There is a significant health hazard to the environment and people living in the area owing to the radioactivity contents and radiological impact parameters. Hence, the need for urgent attention and means to prevent hazards which the overdose could cause.

1. INTRODUCTION

The contamination and pollution of nature are results of human activity. These ongoing activities have severely deteriorated the natural ecosystem and caused it to be vulnerable to natural radiation from the earth and space [1].

Due to the fact that borehole water quality differs from source to source, examination of the suitability of this water is crucial in Nigeria where drinking of borehole water has significantly increased. Different analytical techniques have been used in different nations to quantify the radioactivity levels in drinking water [2]. Naturally occurring ^{40}K,^{232}Th and ^{238}U series are the sources of radioactivity in geological materials, primarily soilandrocks [3].

Radiation levels are higher in igneous rocks (granite), and lower in sedimentary rocks.However, rare exceptions abounds, including phosphate and shales rocks that have comparatively high radioactive concentrations [4]. Depending on the dose ingested, radiation has consequences on people. High radiation doses have the potential to change human DNA, although low doses may not have any noticeable effects. Both random and predictable biological effects of radiation exposure exist [5]. A deterministic effect takes a dose threshold, and the severity of the effect is dose-related, as in the case of skin reddening, but stochastic effects do not require a dose threshold and are determined by the molecular mechanisms at play, as in the case of cancer or a hereditary defect.

Naturally Occurring Radioactive Material (NORM) refers to radioactive elements with a long half-life, such as uranium, thorium, and potassium, as well as any of their decay products, including radium and radon. These elements existed in the Earth's crust and atmosphere but are concentrated in particular places, such as deposits of extractable uranium ore. Industrial with NORM related issues include: oil and gas production; coal mining and combustion; mineral sands (rare earth minerals, titanium, and zirconium); metal mining and smelting; fertilizer (phosphate); recycling; building; and uranium mining and all related fuel cycle activities [6].

Uranium series disequilibrium techniques were first applied by Rosholt et al., [7] and subsequently by Titayeva et al., [8]. Two facts form the basis of these applications. Firstly, ^{234}U and ^{238}U are often under secular equilibrium in rocks. Second, natural levels of ^{238}U differs within a very wide range [101 to 103 mBq/l] [9]. These elements work together to provide the foundation of a very effective geochemical instrument. Some daughter radionuclides exhibit preferential leaching and this can result from a variety of physical effects. For duration comparable to their individual half-lives, the initial disequilibrium of other long-lived radionuclides continues. According to geochemical theory, radium and uranium are soluble species, with natural activity concentrations typically higher than 1 mBq.L^{-1}. [10].

The purpose of this study is to assess the radioactivity and evaluate the risk parameters for the samples of water collected from Igbajo town, to ascertain the level to which the inhabitants are disposed to radiation hazards.

2. MATERIALS AND METHODS

2.1 The Study Area

It is situated in Igbajo town, Boluwaduro Local Government, Osun State, South-west Nigeria on latitude 7º54'24"N and longitude 4º48'44"E.

The community comprises range of mountains and adjacent basins and its environs are

strategically defensible due to surrounding rockytopography with stalwart outcrops. The major tectonic actions range to hornblende-granite-biotite, muscovite-granite-tourmaline-gneiss, gneiss,biotite-gneiss-granite, variably migmatized gneisses and pegmatite intrusions. The dominant rock is quartz schist and quartz and variably biotite-garnet-schist gneiss and biotite-garnet-schist [11].

2.2 Sampling

A collection protocol was established and was strictly adhered to. These include a collection procedure, using suitable bottles and application of acid for preservation so as to minimize the influence of adsorption.

A total of six (6) samples were collected each with 2L-sized plastic bottles, which was washed and rinsed with dilute hydrochloric acid (0.1M HCl). The samples collected were acidified with 1M hydrochloric acid to attain a pH < 2 so as to prevent adsorption of the radionuclide on the walls of the container [12]. The samples were then transported to the laboratory where instrumental analysis of the samples were done.

2.3 Measurement and Analysis

The procedure involved using a thallium activated Canberra vertical high purity 3" x 3" Sodium Iodide [NaI(Tl)] detector connected to ORTEC 456 amplifier. The detector was protected by about 15cm thick lead on the four sides and 10cm thick at the top. About 2.0KeV resolution and 33% efficiency at 1.33 MeV was accomplished in the system with 27000scounting time. For calibration, the usual sources recommended by the International Atomic Energy Agency (IAEA) were employed [13]. From the counting spectra, the activity concentrations of ^{40}K, ^{238}U and ^{232}Thweredetermined using computer program. Various peaks were taken into account. prior to arriving at the calculation of each activity levels, in comparison to 1460 KeV (40K) for 40K, 1764.5 KeV (Bi-214) for 238U, and 2614.5 KeV (Ti-208) for 232Th.

The activity concentration (C) of the radionuclide can be evaluated after subtracting decay correction [14].

$$C_a = C_n / \varepsilon P_\gamma M_s t_c \qquad (i)$$

Where

C_a = Activity concentration of radionuclide (Bq.L^{-1})
C_n= net counts of radionuclide in the samples
ε = absolute counting efficiency of the detector system
P_γ= gamma ray emission probability (gamma ray yield)
M_s = the mass of the sample (kg)
t_c = total counting time

2.3.1 Radiological hazard parameters

Absorbed Dose Rate (D): The rate, D (nGy/h) with respect to activity concentration of ^{238}U, ^{232}Th and ^{40}K is calculated using [15].

$$D = 0.462C_U + 0.604C_{Th} + 0.0417C_K \qquad (ii)$$

Annual Effective Dose (AED): The annual effective dose due to ^{40}K, ^{238}U, and ^{232}Th ingestion was calculated using [16,17].

$$AED = \sum (C_A \times AI \times IDF) \qquad (iii)$$

Where,

AED = Annual effective dose (mSvyr^{-1}),
C_A= Activity concentration of the radionuclides (BqL^{-1})
AI = Average person's intake of water per year (730Lyr^{-1} for adult)
DF =Dose conversion factors (ingestion dose coefficient);
DF for adults for ^{40}K, ^{238}U, and ^{232}Th is 6.2 $\times$ 10^{-9}, 2.3 $\times$ 10^{-7}, and 4.5 $\times$ 10^{-8}Sv.Bq^{-1} for respectively.

Radium Equivalent Activity Index (Ra$_{eq}$): It represents the weighted sum of activities concentration of ^{40}K, ^{238}U and ^{232}Th. It is usually calculated to estimate the radiological risksrelated with the three radionuclides. It is assumed that 1Bq.Kg^{-1} of ^{238}U, 0.7Bq.Kg^{-1} of ^{232}Th and 13Bq.Kg^{-1} of ^{40}K produce the same gamma-ray dose. It can be defined empirically using [18] as:

$$Ra_{eq} = C_U + 1.43C_{Th} + 0.077C_K \qquad (iv)$$

Where

C_U, C_{Th} and C_K are the radioactivity concentration of ^{40}K, ^{238}U and ^{232}Th respectively.

Excess Lifetime Cancer Risk (ELCR): The ELCR was assessed using equation (v) below.

$$ELCR = AED \times DL \times RF \qquad (v)$$

Where

AED = Annual Effective Dose
DL = Average Duration of Life (70 years)
RF = Risk Factor, for stochastic effects, ICRP uses 0.05 for public

Radiation Hazard Indices: Both the external radiation hazard index (H_{ext}) and the internal radiation hazard index (H_{int}) were estimated using [14].

$$H_{ext} = \frac{1}{370} C_U + \frac{1}{259} C_{Th} + \frac{1}{4810} C_K \qquad (via)$$

$$H_{int} = \frac{1}{185} C_U + \frac{1}{259} C_{Th} + \frac{1}{4810} C_K \qquad (vib)$$

Where

C_U, C_{Th} and C_K are the radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th respectively.

The values of both the H_{ext} and H_{int} should be below unity for the radiation risk to be negligible.Internal exposure to radon is very dangerous thus lead to respiratory diseases like lung cancer, asthma etc.

Gamma Index ($I_γ$): It is used for the estimation of gamma radiation hazard related with the natural radionuclide in specific samples.It can be calculated using:

$$I_γ = \frac{1}{150} C_U + \frac{1}{100} C_{Th} + \frac{1}{1500} C_K \qquad (vii)$$

$$I_γ \leq 1$$

Where

C_U, C_{Th} and C_K are the radioactivity concentrations of ^{238}U, ^{232}Th and ^{40}K in water samples.

An increase in $I_γ$ greater than 1 often results to radiation risk which may result to the modification of human cells thereby causing cancer.

Value of $I_γ$ = 1 corresponds to an annual effective dose of less than or equal to 1 mSv.

Value of $I_γ$ = 0.5 corresponds to annual effective dose less or equal to 0.3 mSv [14].

Annual Gonadal Equivalent Dose (AGED): The gonads, bone cells and bone marrow are centre of interest by UNSCEAR [3] because of their sensitivity to radiation. As the AGED increases, the bone marrows are affected, causing damage of the red blood cells and are then substituted with white blood cells. This results in a blood cancer known as leukemia.

AGED can be evaluated using:

$$AGED \ (μSv.yr^{-1}) = 3.09C_U + 4.18C_{Th} + 0.314C_K \qquad (viii)$$

Where

C_U, C_{Th} and C_K are the radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K in water samples.

2.3.2 Chemical toxicity risk

The chemical toxicity risk was calculated using the lifetime average daily dose (LADD) of uranium through drinking water intake, and related it with the reference dose (RFD) of 0.6 $μg.kg^{-1}.day^{-1}$ (Ye-shin et al., [19] produced a hazard quotient usingas standards for uranium in several foreign organizations.

$$Hazard \ quotient = \frac{LADD}{RFD} \qquad (ix)$$

$$Ingestion \ LADD \ of \ drinking \ water = \frac{EPC \times IR \times EF \times ED}{AT \times BW} \qquad (x)$$

Where

LADD = Lifetime Average Daily Dose ($μg.kg^{-1}.day^{-1}$)
EPC = Exposure Point Concentration ($μg.L^{-1}$); IR = Water Ingestion Rate ($L.day^{-1}$)
EF = Exposure Frequency ($days.year^{-1}$); ED = Total Exposure Duration (years)
AT = Average Time (days); BW = Body Weight (kg)

Using IR = $2L.day^{-1}$; EF = 350 days; ED = 45.5 years; AT = 16,607.5 (from 45.5 x 365); BW = 70kg (standard man)

Conversion: 1 $Bq.L^{-1}$ = 27.0 $pCi.L^{-1}$; 1$μg.L^{-1}$=1$pCi.L^{-1}$/0.67 (xi)

3. RESULTS AND DISCUSSION

Activity Concentrations of Radionuclides in the Samples: The radionuclides activity

concentrations in the water samples taken from the study areas are presented in Tables 1 below. The activity concentration of ^{40}K in the borehole water samples ranged from 7.25 ± 0.60 to 62.15 ± 4.48 Bq.L^{-1} with an average value of 23.12 ± 1.59 Bq.L^{-1} and that of ^{238}U ranged between 3.08 ± 0.45 and 15.24 ± 3.07 Bq.L^{-1} with an average value of 6.27 ± 2.01 Bq.L^{-1} while that of ^{232}Th in the samples ranged from 1.08 ± 1.10 to 17.75 ± 1.59 Bq.L^{-1} with an average of 7.01 ± 0.89 Bq.L^{-1}.

Hence, ODF sample had the lowest concentration of ^{40}K while ISA had the highest concentration. The highest and lowest activity concentration values of ^{238}U were found in ISA and ODF respectively. While the highest concentration of ^{232}Th was found in ODF, the lowest was found in ESW. These variations are attributed to the different sources of water samples. Thus, ^{40}K contributed the largest activity concentration while ^{238}U contributed the least activity in the samples.

Researcher's evaluation of potential radiological hazards to humans is made possible by knowledge regarding the distribution of these radionuclide activities found in natural materials. However, they will be utilized to calculate all radiological impact hazard parameters so that we can knowto what extent the local population are exposed.

*Radiological Hazard Parameter in Water: Absorbed Dose Rate (*D*):*The absorbed dose rate (nGy.h^{-1}) in the samples were evaluated with equation (ii), and the results presented in Table 2.The absorbed dose rate values ranged from 3.3727 to 18.2939 nGy.h^{-1} with an average value of 8.0922 nGy.h^{-1} for the study areas. From this study, the estimated average value was lesser than the world average value of 57 nGy.h^{-1}

UNSCEAR, [3]and hence, poses no severe health risk.

Annual Effective Dose (µSv.yr^{-1}): The annual effective dose resulting from the ingestion of water samples were calculated using equation (iii). The values ranged from 0.4194 to 3.1896µSv.yr^{-1} with an average value of 1.4872µSv.y^{-1} for the study areas.

It was eminent that the values assessed for all the water samples were lower than the world average value of 1000 µSv.yr^{-1} hence it is within the safe limit.

*Radium Equivalent activity Index (Ra$_{eq}$):*The Radium Equivalent Activity Index (Ra$_{eq}$) from water samples were estimated using equation (iv).The result ranged between 13.2435 to 87.4418 Bq.Kg^{-1} with an average value of 34.9186 Bq.Kg^{-1} for the study areas. The obtained average value was below the world average value of 370 Bq.Kg^{-1} and hence poses no significant health hazard [3].

Excess Lifetime Cancer Risk (ELCR): The excess life time cancer risk for the analyzed water samples were evaluated using equation (v). The ELCR ranged from 1467.95 x 10^{-6} to 11163.64 x10^{-6} with an average of 5205.15 x 10^{-6}. It is worthy of note that the obtained average value was greater than the world average value of 0.2 x 10^{-3} (200 x 10^{-6}) [3]. This suggests that there may be a significant risk of cancer associated with spending a 70 year average in this environment without associating with other environment for food and shelter.

The high value of the ELCR index for water samples is due to high AED caused by high activity concentration of ^{40}K radionuclide in the samples.

Table 1. Activity concentration of ^{40}K, ^{238}U and ^{232}Th in the borehole water samples

Water Samples	^{40}K (Bq.L^{-1})	^{238}U (Bq.L^{-1})	^{232}Th (Bq.L^{-1})
BAB	9.92±0.61	4.52±1.89	1.79±0.13
BAP	13.44±1.05	6.66±1.37	5.92±0.51
COM	29.70±1.81	3.09±1.03	1.17±0.75
ESW	16.24±0.98	5.01±4.23	1.08±1.10
ISA	62.15±4.48	15.24±3.07	14.34±1.26
ODF	7.25±0.60	3.08±0.45	17.75±1.59
MEAN±S.D.	23.12±1.59	6.27±2.01	7.01±0.89
WHO	10.00	10.00	1.00

BAB – Babalaje; BAP – Baptist; COM – Community; ESW – Essawe; ISA – Isao; ODF - Odofin

Table 2. Radiation hazard parameters for the water samples

Sample Code	D (nGy.h^{-1})	H_{int}	H_{ext}	Ra_{eq} (Bq.Kg^{-1})	I_{γ} (mSv.yr^{-1})	AGED (µSv.yr^{-1})	AED (µSv.yr^{-1}) Adults	ELCR (x 10^{-6})
BAB	3.5831	0.0212	0.0334	13.2435	0.0547	24.5639	0.4939	1728.72
BAP	7.2130	0.0436	0.0617	22.9405	0.1126	49.5452	1.2735	4457.53
COM	3.3727	0.0190	0.0274	33.6600	0.0521	23.7645	0.4324	1513.30
ESW	3.6441	0.0211	0.0346	19.0349	0.0550	25.0947	0.4194	1467.95
ISA	18.2939	0.1094	0.1507	87.4418	0.2864	126.5479	3.1896	11163.64
ODF	12.4463	0.0783	0.0867	33.1908	0.2029	85.9887	3.1142	10899.76
MEAN	8.0922	0.0488	0.0657	34.9186	0.1273	55.9175	1.4872	5205.15
UNSCEAR	57.00	1.00	1.00	370.00	1.00	300	1000.00	290.00

Table 3. The activity concentrations, mass concentrations and estimated lifetime average daily dose of uranium in the borehole (BH) water samples in the study area

Sample	^{238}U (Bq.L^{-1})	^{238}U (pCi.L^{-1})	^{238}U (µg.L^{-1})	LADD (µg.kg^{-1}.day^{-1})
BAB	4.52	122.04	182.16	4.99
BAP	6.66	179.82	268.40	7.35
COM	3.09	83.43	124.53	3.41
ESW	5.01	135.27	201.90	5.53
ISA	15.24	411.48	614.17	16.83
ODF	3.08	83.16	124.12	3.40

Radiation Hazard Indices: The radiation hazard indices in water samples, both the external and the internal were evaluated using equation (via) and (vib) respectively. The external radiation hazard index (H_{ext}) ranged between 0.0274 to 0.1507 with an average of 0.0657. While the internal radiation hazard index (H_{int}) ranged from 0.0190 to 0.1094 with an average of 0.0488 for the study. The two values were found to be lesser than the world average value of unity, therefore poses no significant health hazard [3].

Gamma Index (I_γ): The gamma indices for the samples were calculated using equation (vii). The average value estimated for the water samples was 0.1273 mSv.yr^{-1} for values ranging between 0.0521 and 0.2864. This value is within the safe limit of less than unity, the universal standard.

Annual Gonadal Equivalent Dose (AGED): The AGEDs of the water samples were calculated using equation (viii). The average value estimated was 55.9175 µSv.yr^{-1} for values ranging between 23.7645 and 126.5479. This value is within the safe limit of less than the universal standard.

The result presented in Table 3 showed that the exposure dose ranged from 3.40 – 16.83 µg.kg^{-1}.day^{-1}. The LADD value was observed highest in ISA sample. This might beas theresult of the depth of the water source and the geochemistry.

By comparing the lifetime average daily dose (LADD) obtained in this study and the reference dose (RFD) (0.6 µg.kg^{-1}.day^{-1}), the acceptable level, the chemical toxicity hazard because of the uranium in the water samples were all above the RFD. This suggests that there are health hazards associated with uranium in the water samples which are basically due to the chemical toxicity risk.

4. CONCLUSION

The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in borehole water samples in Igbajo town, Boluwaduro Local Government, Osun State, Nigeria have been examined and the possible radiotoxicity has been documented in this study. The average values of the activity concentrations of ^{40}K, ^{238}U and ^{232}Th exceeded the recommended value by the WHO but a slight difference in the value of ^{238}U.

Similarly, the activity concentrations were related to the mass concentrations of uranium in the samples and these were found to vary from 124.12 to 614.17 µg.L^{-1}. This indicates that the measured mass concentrations of uranium in the borehole water in the area were relatively high when compared with the recommended safe limits by some various international organizations. It was inferred that the human risk due to uranium content in water may likely be to the chemical toxicity of uranium as a heavy metal, however, this study represents a valuable radiometric data that are vital tools in radio-epidemiological assessment, diagnosis and prognosis of radionuclide-induced diseases to the population of the studied area.

5. RECOMMENNDATION

➢ Effective management of mining and milling activities should be practiced
➢ Promotion of organic fertilizer (green chemistry is safer and cheaper) instead of synthetic ones.
➢ Treatment of water should be encouraged and practiced
➢ Adequate socialization on the risk associated with radionuclides and ways to remediate it in the society should be encouraged

DISCLAIMER

This paper is an extended version of a preprint document of the same author.

The preprint document is available in this link: https://assets.researchsquare.com/files/rs-3616921/v1/d18d40fe-dc57-4a52-b52b-203a31cf43d1.pdf?c=1700117829
[As per journal policy, preprint article can be published as a journal article, provided it is not published in any other journal]

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Edori OS, Kpee F. Physicochemical and heavy metal assessment of water samples from boreholes near some abattoirs in Port Harcourt, Rivers State, Nigeria. American Chemical Science Journal .2016;14(3):1-8.
2. El Arabi AM, Ahmed NK, Salahel Din K. Natural radionuclides and dose estimation in natural water resources from Elba Protective Area, Egypt. Radiat. Prot. Dosim .2006;121:284-292.
3. United Nations Scientific Committee on the Effect of Atomic Radiation, (UNSCEAR) Sources, effect and risks of Ionizing Radiation, Report to the General Assembly with Scientific Annexes B: Exposures from Natural Radiation Sources. New York, United Nations; 2000.
4. Uosif MA. Gamma-ray spectroscopic analysis of selected samples from Nile river sediments in upper Egypt. Radiat Prot. Dosimetry. 2007;123:215-220.
5. Hall EJR. Radiobiology for the Radiologist.Printed by Lippincott Williams & Wilkins, 530 Walnut Street Philadelphia, PA 19106, USA; 2000.
6. Cooper MB. Naturally Occurring Radioactive Materials (NORM) in Australian Industries.Review of Current Inventories and Future Generation. 2005;ERS-006
7. Rosholt JN, Shields WR, Garner EL. Isotopic fractionation of uranium related to roll features in sandstone, Shirley Basin, Wyoming. Economic Geology. 1964; 59(4):570–585.
   DOI:10.2113/gsecongeo.59.4.570
8. Titayeva NA, Orlova AV, Karpushina TI, Nikulin VI. Behavior of uranium and thorium isotopes in crystalline rocks and surface waters in a cold wet climate.Geochemistry International. 1973; 1146:7-8.
9. Osmond JK, Cowart JB. Groundwater. In: Ivanovich M, Harmon R (eds) Uranium-series disequilibrium, applications to earth, marine and environmental sciences, 2nd edition. Oxford Science Publications, Oxford. 1992;290-323
10. José Luis Mas, Manuel García-León, Rafael García-Tenorio and Juan Pedro Bolívar. Radionuclide Concentrations in Water, Radionuclide Concentrations in Food and the Environment. New York: CRC press – Taylor & Francis Group. 2007;59-112
11. Bello R, Oladunjoye M, Ajayi T. Preliminary Geophysical Investigation of Igbajo Archaeological site, Southwestern Nigeria.IARJSET. 2019;6(4):9-21
12. Australia and New Zealand Standards (AS/NZS) (1998). Water quality – sampling guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples (AS/NZS 5667–1).
13. International Atomic Energy Agency, IAEA Method for Developing Arrangements for Response to a Nuclear or Radiological Emergency: Updating IAEA-TECDOC-953, EPR-Method IAEA, Vienna; 2003.
14. Avwri GO, Ononugbo CP, Nwokeoji IE. Radiation hazard indices and excess lifetime cancer risk in soil, sediment and water around mini-okoro/oginigba creek, Portharourt, Rivers state, Nigeria. Comprehensive Journal of Environment and Earth Sciences; 2014;3(1):38-50.
15. Orosun MM, Lawal TO, andAkinyose FC. Natural radionuclide concentrations and radiological impact assessment of soil and water in Tanke-Ilorin, Nigeria. Zimbabwe Journal of Science & Technology. 2016; 11:158–172.
16. Meltem D, Gursel K. Natural radioactivity of various surface waters, Turkey. Desalination. 2010;261:126–130.
17. US-EPA. United State Environmental Protection Agency. National Primary drinking water regulations for radionuclides, Unites state government printing office (EPA/570/9- 91/700). 1991.
18. Issa SAM, Uosif MAM, Elsaman R. Gamma radioactivity measurements in Nile River sediment samples.Turkish Journal of Engineering and Environmental Science. 2013;37:109-122.

19. Ye-shin K, Hoa-sung P, Jin-yong K, Sun-ku P, Byong-wook C, Ig-hwan S, Dong-Chun S. Health risk assessment for uranium in Korean groundwater. Journal of Environmental Radioactivity. 2004 ;77-85.

_____

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/109769