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Research Article

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Radiological Safety Assessment of Quarry Processing Site in Keffi, Nigeria

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Abstract

Disposal of large quantities of certain minerals (mining) containing ^{40}K, ^{232}Th and ^{226}Ra and other radionuclides in the decay series of Th and U from the earth crust results in increase in the radionuclides concentrations. This research looks at the radiological safety assessment of quarry Processing Site in Keffi, Nigeria. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the five (5) different Soil samples, varied widely as 10.54±3.040 Bq/kg, 2.61±1.170 Bq/kg and 36.99 ± 7.490 Bq/kg respectively. Ungwan Tanko (UTN) has the highest activity concentration of 14.90 ± 2.30 Bq/kg for ^{226}Ra while Pyanku (PYK) has the highest activity concentration of 4.52 ± 0.32 Bq/kg for ^{232}Th. Activity concentration of ^{40}K was highest (57.32 ± 2.530 Bq/kg) in Ungwan Kwara (UKW). It was also observed that Yalwa (YLW) had the lowest activity concentration of 02.20 ± 1.31 Bq/kg for ^{226}Ra, while Ungwan Tanko (UTN) had the lowest activity concentration values of 1.03 ± 1.74 Bq/kg for ^{232}Th and Attab Fueling Station (AFS) had the lowest activity concentration values of 13.67 ± 15.73 Bq/kg for ^{40}K. Radium equivalent activity Raeq (Bq/kg), alpha index, internal hazard index, and total cancer risk 17.52 Bq/kg 0.055, 0.077 and 6.82 x 10^{-7} respectively. Based on the results presented, the present quarry processing sites in Keffi has less effect on ingestion rate of Soil and may poses no radiological risk to the population.

Keywords: Quarry, Radioactivity, Radiological Risk, Effective Dose, Cancer Risk

Introduction

Naturally occurring radioactive materials (NORMs) are known as all the radionuclides existing naturally in the environment, which happens to be the primordial radionuclides ^{40}K, ^{232}Th and ^{238}Ra, and their decay products exist in different amounts within the earth [1-4]. Mostly, the concentration of NORMs in all substances in the environment can be neglected, but disposal of large quantities of certain minerals (mining) containing ^{40}K, ^{232}Th and ^{226}Ra and other radionuclides in the decay series of Th and U from the earth crust results in increase in the radionuclides concentrations [4-9].

This research will look at the radiological safety assessment of quarry Processing Site in Keffi, Nigeria

Experimental

Soil samples collection and preparation

Samples of dry Soil were collected from five different processing site (Pyanku, Ungwan Kwara, Yalwa, Ungwan Tanko and Attab Filling Station) of Keffi, Nigeria. The samples were collected in a labelled polyethylene bag. Table 1 presents the samples information, in order to be sure that the samples represents all the quarry being mined within Keffi Nigeria, A total of five (5) composite samples were collected altogether [10-12]. The varieties of the Soil samples were obtained through random sampling based on availability were: Jan K'asa, Jan K'asa, Farin K'asa, Jan Laka and Bak'in Laka. Plate 1 presents the varieties of Soil samples from different quarry processing sites in Keffi, Nigeria. The collected samples were taken to the Centre for energy research and training, Ahmadu Bello University, Zaria for preparation and subsequent analysis. At the sample preparation laboratory, the samples were pulverised to fine powder, then sieve so as to obtain uniformly homogenous sample matrix and weighed using an electronic balance. In order to avoid contamination of the plastic containers, the plastic containers were washed with distilled water, then rinsed with dilute HCl and finally air dried. The plastic containers used for the sample, background and calibration had the same geometry as the detector surface area in order to ensure accuracy. The dimensions of the plastic containers were chosen in such a way that it suited the optimal soil mass of 350 g for analysis of bulk samples. Each empty container with its cover was weighed, then each of the pulverised samples was placed in each container, labelled and reweighed in order to deduce the mass of the sample [13-16]. The inner portion of the lid of the plastic container was then coated with Vaseline and the container sealed with the candle wax followed by sealing with the masking tape to avoid any possibility of the escape of radon. The containers were then kept for 28 days to avoid the escape of Rn-222 gas and for the sample to attain secular radioactive equilibrium between Ra-226 and its decay products in the uranium series, and Ra-228 and its decay products in the thorium series [17-19].

Table 1: Soil samples information.

S/N	Sample Code	Collected from	Soil Local Name	Quarry Mined from
1	PYK	Pyanku	Jan K'asa	Toto
2	UKW	Ungwan Kwara	Jan K'asa	Kokona
3	YLW	Yalwa	Farin K'asa	Karu
4	UTN	Ungwan Tanko	Jan Laka	Keffi
5	AFS	Attab Filling Station	Bak'in Laka	Nasarawa

Soil samples analysis

In order to measure the concentration of the naturally occurring radioactive materials in the Soil samples collected. The procedures reported elsewhere [20-23] were adopted. NaI (Tl) gamma ray spectrometry system situated at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria was used. The detector assembly consisted of a 7.62 × 7.62 cm NaI (Tl) detector housed in a 10 cm thick lead-shielded, cadmium-lined assembly with copper sheets for the reduction of background radiation. The assembly was coupled to a computer-based Multichannel Analyser (MCA) card system MAESTRO software used for the data acquisition and spectra analysis. The standards used were the IAEA supplied reference materials RGK-1, IAEA-448 and RGTh-1 for the quantitative analysis of the ^{40}K, ^{226}Ra and ^{232}Th respectively.

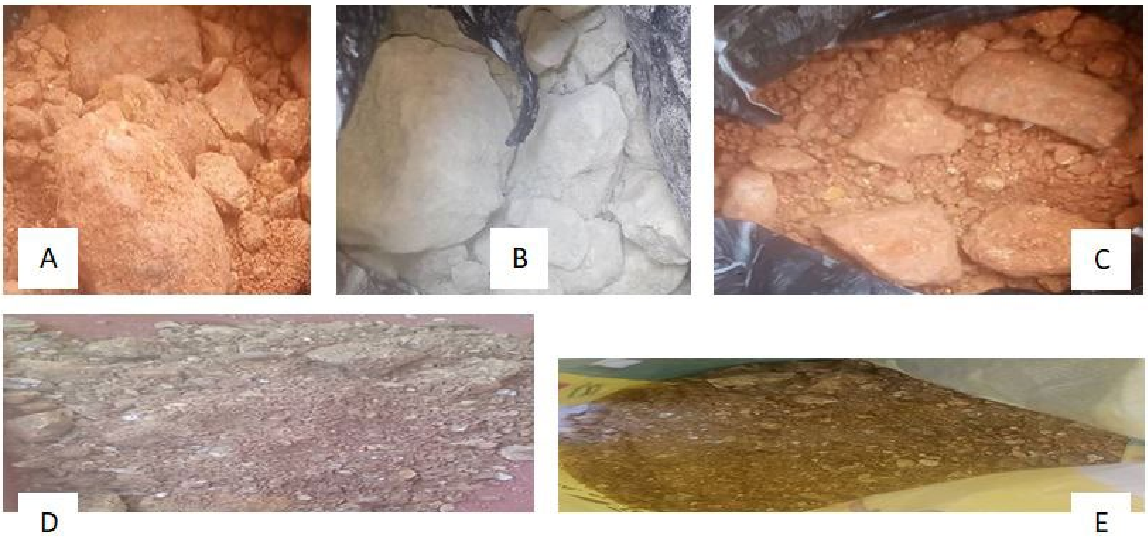

Plate 1: Varieties Soil Samples in Keffi, Nigeria.
Legend: A: Jan K'asa; B: Farin K'asa; C: Jan K'asa; Jan Laka: Bak'in K'asa.

The system was set at an energy range of 0 to 3000 keV, which accommodated the energy range interested in the present study. Each sample was counted for 28,800 s (8 hours) in the set geometry. The activity concentration of ^{226}Ra was determined by the gamma line of its daughter ^{214}Bi (1760 KeV), ^{232}Th activity concentration was determined by the gamma line of its daughter ^{208}Tl (2614 KeV) while the activity concentration of ^{40}K was determined from its 1460 KeV gamma line. Energy calibration was carried out using a point source whereas the efficiency calibration was done using a 500 mL multi-nuclide standard solution of: ^{60}Co (1173 and1332 keV), ^{241}Am (59.54 keV), ^{137}Cs (661.62 keV). The net number of counts under each photo peak of interest was then background subtracted using the time correct spectrum taken using the blank container. The activity concentration was calculated using Equation 1 [24-26].

$$Activity\ (Ra, Th, K) = \frac{count\ rate\ (cpm) Ra, Th, K}{background\ count\ rate\ (cpm) Ra, Th, K}$$

Assessment of radiation hazards associated with the Soil samples

Radium equivalent activity (Raeq)

To compute the activity levels of ^{226}Ra, ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards associated with them, a common radiological index called Radium equivalent activity was used. This parameter was calculated using Equation 2 [27-30] based on the assumption that 10 Bq/kg of ^{226}Ra, 7 Bq/kg of ^{232}Th and 130 Bq/kg of ^{40}K produce equal gamma dose.

$$Ra_{eq} = C_{Ra} + 1.43 C_{Th} + 0.077 C_K$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively.

Annual effective dose from ingestion of Soil

From the activity concentration of 226Ra, 232Th and 40K in the Soil samples, the annual effective dose due to the ingestion of Soil in humans was estimated using Equation 3 [31,32]

$$E = 10^{-3}(4.50 \times 10^{-8} C_{Ra} + 2.30 \times 10^{-7} C_{Th} + 6.20 \times 10^{-9} C_K)M$$

Where, M is the annual average quantity of Soil ingested per person in Nigeria which was adopted as 9.13 kg/capita/year [30]. C is the specific activity concentration of radionuclides in Soil determined in this work, and 4.50×10^{-8}, 2.30×10^{-7} and 6.20×10^{-9} refers to the effective dose coefficients measured for the radionuclides (Sv/Bq) for different age groups for the ingestion of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K respectively and 10^{-3} is the factor that convert from µSv to mSv [31-32].

Internal and alpha hazard indices

Internal hazard and alpha hazard indices (H_{in} and I_α) were used to estimate the internal hazards that could arise from the ingestion of Soil, these indices were computed using Equation 4 and 5 respectively [31,32]. For radiation protection purposes, the value of internal and alpha hazard indices must not exceed the limit of unity. The maximum value of H_{in} and I_α equal to unity corresponds to the upper limit of radium equivalent activity 370 Bq.kg^{-1}.

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810}$$

$$I_\alpha = \frac{A_{Ra}}{200(Bq/kg)}$$

Cancer and hereditary risks

The cancer and hereditary risks due to low doses without threshold dose known as stochastic effects were estimated using Equation 6 and 7 respectively based on ICRP, 2007 cancer risk assessment methodology. The lifetime risks (70 years) of fatal cancer were based on the hypothesis of linearity of dose and effect without any threshold. The nominal risk coefficients for low doses as adopted from ICRP based on data for cancer incidence weighted for lethality and life impairment were 5.5×10^{-2} and 0.2×10^{-2} for cancer and hereditary risks, respectively, these values were derived by [32].

Fatality cancer risk = total AED (Sv) × cancer nominal risk factor

Hereditary risk =total AED (Sv) × hereditary nominal risk factor

Results and Conclusion

Table 2: Specific activity of the NORMs in the analysed samples.

Sample Code	Ra-226(Bq/kg)	Th-232(Bq/kg)	K-40(Bq/kg)
PYK	12.70 ± 6.05	4.52 ± 0.32	54.45 ± 1.310
UKW	13.51 ± 3.82	2.521± 1.71	57.32 ± 2.530
YLW	02.20 ± 1.31	2.04 ± 0.42	23.20 ± 16.45
UTN	14.90 ± 2.30	1.03 ± 1.74	36.30 ± 1.450
AFS	11.38 ± 1.73	2.93 ± 1.67	13.67 ± 15.73
Mean	10.94±3.040	2.61±1.170	36.99 ± 7.490
Where PYK = Pyanku; UKW = Ungwan Kwara: YLW = Yalwa: UTN = Ungwan Tanko: AFS = Attab Fueling Station.			

Table 2 presents the activity concentration of the naturally occurring radioactive materials in five (5) different analyzed Soil samples. ^{232}Th had the lowest activity concentration in each sample compared to ^{226}Ra and ^{40}K, while ^{40}K had the highest activity concentration in all the samples analysed as expected since Potassium is an important nutrient for man and is naturally available in abundance. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the five (5) different Soil samples, varied widely and had an average ± error values of 10.54±3.040 Bq/kg, 2.61±1.170 Bq/kg and 36.99 ± 7.490 Bq/kg respectively. Ungwan Tanko (UTN) was found to have the highest activity concentration of 14.90 ± 2.30 Bq/kg for ^{226}Ra while Pyanku (PYK) was found to have the highest activity concentration of 4.52 ± 0.32 Bq/kg for ^{232}Th. Activity concentration of ^{40}K was found to be highest (57.32 ± 2.530 Bq/kg) in Ungwan Kwara (UKW). It was also observed that Yalwa (YLW) had the lowest activity concentration values of 02.20 ± 1.31 Bq/kg for ^{226}Ra, while Ungwan Tanko (UTN) had the lowest activity concentration values of 1.03 ± 1.74 Bq/kg for ^{232}Th and Attab Fueling Station (AFS) had the lowest activity concentration values of 13.67 ± 15.73 Bq/kg for ^{40}K.

Result Analysis

Table 3: Radiological implications of the consumption of the Soil samples.

Sample Code	Raeq (Bq/kg)	I_α	H_{in}	AED x 10^{-8} (mSv/yr)	FC x 10^{-7}	HR x 10^{-8}	TR x 10^{-7}
PYK	23.36	0.064	0.097	1.77	9.72	3.54	10.1
UKW	21.53	0.068	0.095	1.40	7.68	2.79	8.00
YLW	06.90	0.011	0.025	0.65	3.56	1.30	3.69
UTN	19.17	0.075	0.092	1.02	5.61	2.04	5.81
AFS	16.62	0.057	0.076	1.15	6.32	2.30	6.55
Mean	17.52	0.055	0.077	1.20	6.58	2.39	6.82

Where Ra_{eq} = Radium Equivalent Activity; Iα = Alpha Index; H_{in} = Internal Hazard Index; CF = Fatality Cancer; HR = Hereditary Risk; TR = Total Risk.

The radiological parameters associated with the consumption of naturally occurring radioactive materials in Soil samples are presented in Table 3. Considering the annual average quantity of Soil ingested per person in Nigeria as 14 kg/year [32], the average annual effective dose due to the ingestion of Soil in humans was estimated at 1.20 x 10^{-8} mSv/yr which was far (approximately 1000 times) lower than the world average annual committed effective dose of 1.0 mSv/y for ingestion of natural radionuclides provided in [32]. At the present average Soil ingestion rate of 9.13 kg/year in Nigeria [32], the annual effective dose is far below the acceptable limit reported by [32]. Consequently, it is important to predict the threshold ingestion rate above which the average annual effective dose will exceed the acceptable threshold of 1.0 mSv/y.

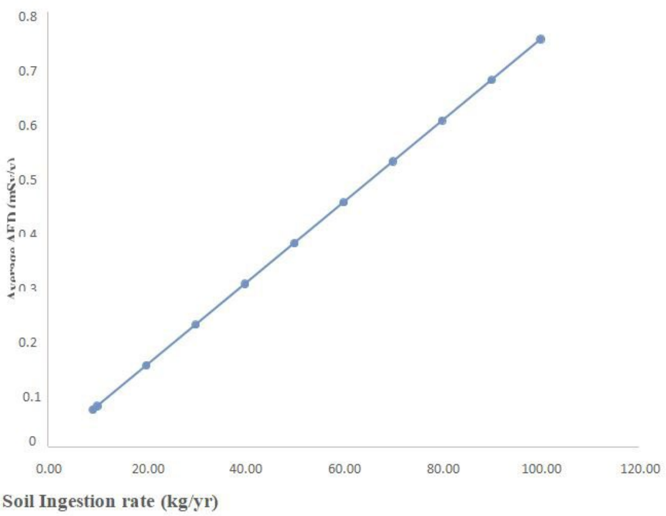

Figure 1: Annual effective dose (AED) due to Soil Ingestion.

Figure 1 presents the average annual effective dose as a function of ingestion rates. From the figure it could be observed that for ingestion rates between 0 and 40 kg/yr, the AED is within the acceptable limit, therefore the threshold ingestion rate is 40 kg/yr and any value slightly higher than the threshold values is prone to significant radiological health risk.

Comparison of Results

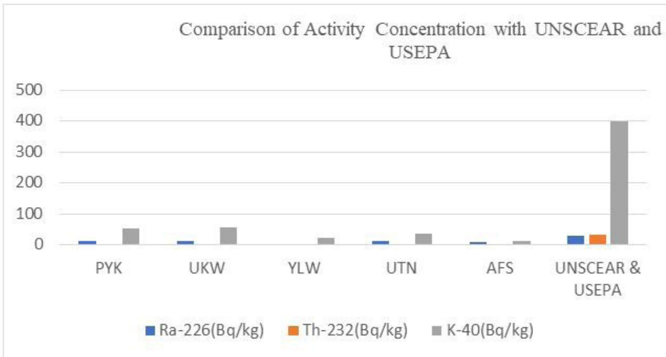

Figure 2: Comparison of Activity Concentration with UNSCEAR and USEPA

In order to safeguard the members of pubic from the radiological hazards associated with the Soil ingestion, radium equivalent activity Raeq (Bq/kg), alpha index, internal hazard index, and total cancer risk were estimated and found to be 17.52 Bq/kg 0.055, 0.077 and 6.82 x 10^{-7} respectively. UNSCEAR stipulated that; radium equivalent activity should not exceed 370 Bq/kg, internal hazard index and alpha index should not exceed the limit of unity, annual effective dose due to ingestion of naturally occurring radioactive materials in Soil should not exceed 1.0 mSv/y [32], hence the values obtained in this work were within the acceptable limits. Similarly, USEPA stated that the maximum acceptable total cancer risk should not exceed 1 ×10^4, since all the cancer risks obtained in this work were by far (approximately 100 times) less than the acceptable threshold, it implies that the ingestion of Soil is not associated with any radiological risk of concern. The fatality cancer risk for almost all the samples were found to be approximately 30 to 40 times the hereditary cancer risks. Of all the samples analysed.

Conclusion

At the present average Soil ingestion rate of 14.4 kg/y in Nigeria, the average annual effective dose due to the ingestion of Soil in humans was approximately 1000 times lower than the world average annual committed effective dose of 1.0 mSv/y for ingestion of natural radionuclides provided in UNSCEAR 2000 report. It was established that for ingestion rates between 0 and 40 kg/y, the AED is within the acceptable limit, therefore the threshold ingestion rate is 40 kg/y and any value slightly higher than the threshold values will be associated with a significant radiological health risk. The radium equivalent activity (Raeq), internal hazard index and alpha index were far lower than their UNSCEAR acceptable thresholds of 370 Bq/kg and 1 respectively. Furthermore, the total cancer risk due to fatality and hereditary effects that may arise from Soil ingestion was approximately 100 times less than the USEPA acceptable threshold of 1×10^4. Therefore, the present quarry processing sites in Keffi has less effect on ingestion rate of Soil and may poses no radiological risk to the population.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

1. United Nations Scientific Committee on the Effects of Atomic Radiation. (1993). Sources and effects of ionizing radiation, united nations scientific committee on the effects of atomic radiation (UNSCEAR) 1993 report: report to the general assembly, with scientific annexes. United Nations.
2. U. Rilwan, I. Umar, A. Z. Ngari, H. A. Abdullahi and H. O. Aboh. (2019). Radiometric Evaluation Naturally Occurring Radionuclides in Some Ongoing Drilled Boreholes across Keffi Town of Nasarawa State, Nigeria. International Astronomy and Astrophysics Research Journal, 1(1), 1-9.
3. Rilwan, U., Umar, I., Abdullahi, H. A., Ngari, A. Z., & Aboh, H. O. (2019). Radiometric Evaluation of Naturally Occurring Radionuclides in Mining Sites across Mararraba-Udege of Nasarawa State, Nigeria. Physics Memoir-Journal of Theoretical & Applied Physics, 1(4), 161-170.
4. Rilwan, U., Umar, I., Ngari, A. Z., Abdullahi, H. A., & Aboh, H. O. (2019). Assessment of Gamma Radiation from 232Th, 226Ra and 40K in Nassarawa, Nigeria. Asian Journal of Research and Reviews in Physics, 2(4), 1-10.
5. Rilwan, U., Umar, I., Onuchukwu, G. C., Abdullahi, H. A., & Umar, M. (2020). Evaluation of Radiation Hazard Indices in Mining Sites of Nasarawa State, Nigeria. Asian Journal of Research and Reviews in Physics, 3(1), 8-16.
6. Rilwan, U., Maisalatee, A. U., & Jafar, M. (2021). Assessment of Indoor and Outdoor Radiation Exposure in Nasarawa General Hospital, Nasarawa State, Nigeria. Journal of Radiation and Nuclear Applications. An International Journal, 6(3), 245-249.
7. Rilwan, U., Hudu, A., Ubaidullah, A., Maisalatee, A. U., Bello, A. A., Ugwu, E. I., & Okara, G. O. (2021). Fertility Cancer and Hereditary Risks in Soil Sample of Nasarawa, Nasarawa State, Nigeria. Journal of Oncology Research, 3(2).
8. Ademoh, B. A., Rilwan, U., and Yusuf, M. (2022). Assessment on Radiation Hazard Indices from Selected Dumpsites in Lafia Metropolis, Nasarawa State, Nigeria. Journal of Oncology Research, 4(1), 20-26.
9. Rilwan, U., Galadima, O. O., Yahaya, I., & Rufai, A. M. (2022). Background Radiation Exposure in Keffi General Hospital, Keffi, Nasarawa State, Nigeria.
10. Galadima, O. O., Orji, C. E., Rilwan, U., Ojike, P. E., & Omita, E. (2022). Assessment of the Effects of Radiation Exposure to Human Sensitive Organs Due to Quarry Mining in Kokona, Nasarawa and Toto of Nasarawa State Nigeria.
11. Rilwan, U., Jafar, M., Musa, M., Idris, M. M., & Waida, J. (2022). Transfer of Natural Radionuclides from Soil to Plants in Nasarawa, Nasarawa State, Nigeria.
12. IAEA. (1989). Measurement of Radionuclides in Food and the Environment - A Guidebook International Atomic Energy Agency Technical Reports, 295, STI/DOC/10/295.
13. O. Adewale and T.I. Ojo (2015). Assessment of terrestrial naturally occurring radioactive Material in soil and mine tailings of Awo and Ede, Osun-State, Nigeria. Ife Journal of Sciences. 17(1), 199.
14. S. Tahir and A. Alaamer. (2009). Concentrations of Natural Radionuclides in Municipal Supply Drinking Water and Evaluation of Radiological Hazards. Environmental Forensics, 10(1), 1-6.
15. Tettey-Larbi, L., Darko, E. O., Schandorf, C., & Appiah, A. A. (2013). Natural radioactivity levels of some medicinal plants commonly used in Ghana. SpringerPlus, 2(1), 1-9.
16. Onuk, O. G., Orji, C. E., Rilwan, U., Ojike, P. E., & Omita, E. (2022). Cancer Implication of Background Radiation Exposure to Sensitive Organs in Keffi and Karu Local Government Areas of Nasarawa State, Nigeria. Acta Scientific Clinical Case Reports Volume, 3(6).
17. Unscear, S. (2000). Effects of Ionizing Radiation. United Nations, New York, 453-487.
18. Beretka, J., & Matthew, P. J. (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. Health physics, 48(1), 87-95.
19. Garba, N. N., Ramli, A. T., Saleh, M. A., & Gabdo, H. T. (2019). Natural radioactivity and associated radiation hazards in soil of Kelantan, Malaysia. Human and Ecological Risk Assessment: An International Journal, 25(7), 1707-1717.
20. E. Paul, F. Okibe, M. Abdullahi and J. Toryila. (2014). Mineral and Toxic Element Constituents of Dutsen Dan Libya (DDL). Journal of Basic and Applied Scientific Research, 4(4), 2090-4304.
21. Xinwei, L. A. U. L. W. A. U. X. J. A. U. L. Y. A. U. G. D., Lingqing, W., Xiaodan, J., Leipeng, Y., & Gelian, D. (2006). Specific activity and hazards of Archeozoic-Cambrian rock samples collected from the Weibei area of Shaanxi, China. Radiation protection dosimetry, 118(3), 352-359.
22. Scheibel, V., & Appoloni, C. R. (2007). Survey of natural radioactivity levels in Ilex paraguariensis (St. Hil.) by gamma-ray spectrometry. Brazilian Archives of Biology and Technology, 50, 901-904.
23. Jevremovic, M., Lazarevic, N., Pavlovic, S., & Orlic, M. (2011). Radionuclide concentrations in samples of medicinal herbs and effective dose from ingestion of 137Cs and natural radionuclides in herbal tea products from Serbian market. Isotopes in environmental and health studies, 47(1), 87-92.
24. Rilwan, U., Yahaya, I., Musa, M., Galadima, O. O., Waida, J., & Idris, M. M. (2022). Investigation of Radon-222 in Water from Loko Town in Nasarawa, Nasarawa State, Nigeria", J Oncology and Cancer Screening, 4 (2).
25. Balabanova, B., Stafilov, T., Šajn, R., & Bačeva, K. (2014). Comparison of response of moss, lichens and attic dust to geology and atmospheric pollution from copper mine. International journal of environmental science and technology,

11(2), 517-528.
26. Moore, F., Kargar, S. and Rastmanesh, F. (2013). Heavy metal concentration of soils affected by Zn-smelter activities in the Qeshm Island, Iran. Journal of Sciences, Islamic Republic of Iran. 24(1), 339-346.
27. Ogunkunle, C. O., Fatoba, P. O., Awotoye, O. O., & Olorunmaiye, K. S. (2013). Root-shoot partitioning of copper, chromium and zinc in Lycopersicon esculentum and Amaranthus hybridus grown in cement-polluted soil. Environ. Exp. Biol, 11, 131-136.
28. Yan, X., Zhang, F., Zeng, C., Zhang, M., Devkota, L. P., & Yao, T. (2012). Relationship between heavy metal concentrations in soils and grasses of roadside farmland in Nepal. International journal of environmental research and public health, 9(9), 3209-3226.
29. Kouamé, I. K., Kouassi, L. K., Dibi, B., Adou, K. M., Rascanu, I. D., Romanescu, G., ... & Sandu, I. (2013). Potential groundwater pollution risks by heavy metals from agricultural soil in Songon area (Abidjan, Côte d'Ivoire). Journal of Environmental Protection, 2013.
30. Shamuyarira, K. K., & Gumbo, J. R. (2014). Assessment of heavy metals in municipal sewage sludge: a case study of Limpopo Province, South Africa. International journal of environmental research and public health, 11(3), 2569-2579.
31. Bi, X., Feng, X., Yang, Y., Qiu, G., Li, G., Li, F., ... & Jin, Z. (2006). Environmental contamination of heavy metals from zinc smelting areas in Hezhang County, western Guizhou, China. Environment international, 32(7), 883-890.
32. Tarradellas, J., Bitton, G. and Russel, D. (1996). Soil Ecotoxicology. (ed) CRC Lewis Publisher, New York.