EVALUATION OF DOSE RATE AND HAZARD FROM BACKGROUND RADIATION OF DIRE DAWA CITY, ETHIOPIA

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Abstract. Assessment of the level of radioactivity from radionuclides in soil is important for the assessment of the exposure to natural radiation. Sixteen samples from soil were collected from different sites of Dire Dawa city and the level of natural radioactivity was measured using gamma-ray spectrometry based on a high purity germanium (HPGe) detector. Radiation hazard indices were calculated to evaluate the radiological risk for the public and environment. The results show that the mean value of radium equivalent activity is 246.5±9.6 Bq·kg^{-1}, while the values of absorbed dose rate and annual effective dose equivalent are 73 nGy·h^{-1} and 89.72 mSv·y^{-1} respectively. The values of external and internal health hazard indices are 0.12 and 0.83 respectively which is less than the permitted values in all samples, while the values of gamma index is 0.59 is less than the permitted limit. In general, there are no harmful radiations effects posed to the population who lives in the study area; however, that exceed the internationally accepted values.

Key words: HPGe, absorbed dose, annual effective, hazard indices, gamma indices.

INTRODUCTION

Humans are continuously exposed to ionizing radiation from naturally occurring radioactive materials (NORM). Although the origin of these materials is the Earth's crust, they find their way into building materials, air, water, food, and the human body itself [16]. It depends on geological composition of the soil and rocks. Therefore, systematic and accurate measurements of the radioactivity level in soils are essential for understanding changes in the natural radiation background as a function of geographical location and time [10].

The environment is radioactive and human beings are exposed to radiation arising from cosmic rays, natural radionuclides in water, air, soil, plants artificial radioactivity from fallout in nuclear testing and medical applications. The gamma radiation from natural radionuclides and cosmic rays constitute the external exposure while those derived from inhalation and ingestion through foods and drinking water constitutes internal exposure to humans [12] estimated that 80% of doses contributions in the

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environment are derived from the natural radionuclides while the remaining 20% is from cosmic ray and nuclear processes. The natural radionuclides of concern in terrestrial environment are mainly potassium (^{40}K), uranium (^{238}U), thorium (^{226}Th) and the radioactive gas radon which is produced as these naturally occurring radioisotopes decay.

These three sources produce a part of the earth's natural background radiation. Due to the differing concentrations of each type of NORM in different parts of the world, this background radiation level varies across the world [22]. In most parts of the world it is at a safe level, with no ill effects on humans or nature. In some parts of the world, high concentrations of NORMs can have detrimental effects [18] and therefore it is of utmost importance to be able to determine levels of background radiation, and to distinguish between safe and unsafe levels as well as to determine causes of each type of radiation.

One of the major sources of natural radioactivity is soil. It produces hazard radiation which affects human beings who live around this area and transfer radionuclides into the environment. Therefore, soil natural radioactivity is taken as the main indicator for radiological contamination [17, 20].

In this work, the concentrations of natural radionuclides were measured in 16 soil samples from Dire Dawa city, Ethiopia using gamma-ray spectrometry shown in [2]. It was aimed to assess the radiological hazards due to external gamma ray exposure in the residence area by calculating the radium equivalent activity (Ra_{eq}), the absorbed gamma dose rate (D_R), the external hazard (H_{ex}), the internal hazard (H_{in}), the gamma radiation representative level index (I_γ) and the outdoor and indoor annual effective dose rate (*AEDE*).

MATERIALS AND METHODS

A total of sixteen soil samples were collected from different locations in the city of Dire Dawa as shown in [1]. Each sample was taken from a depth of 10–15 cm at the chosen point, and the Global Positioning System (GPS) was used for tracking the recorded data. The samples were mixed and sieved with 0.2 mm mesh, then dried in an oven at 110 ºC for 12 hours and crushed into fine powder by using a mortar. The samples weights collected from sample areas were between 400–700 g. It was packed in a 1 kg Marinelli beaker, which were sealed and left for at least 4 weeks to ensure radioactive equilibrium between radon and its decay products. The prepared soil samples filled in a Marinelli beaker were sealed with plastic tape to prevent the escape of airborne radionuclides.

The final sample preparation and all the gamma-ray measurements by using a gamma spectroscopy system that comprised of Genie 2000 software, a High Purity Germanium Detector (HPGe) and multichannel analyzer (MCA) was under counting the samples to determine the radioactivity. This will be performed in the radiation detection laboratory of Ethiopian Radiation Protection Authority.

GAMMA RAY DETECTION SYSTEM

The gamma-ray spectrometry analysis of the samples was carried out using an HPGe coaxial detector of crystal of 72.5 mm and a thickness 72.5 mm with the relative efficiency of 70 %. The HPGe-detector is coupled to a computer based multi-channel analyzer card system, which could determine the area under characteristic peak energy by using Genie 2000 software. For the measurement of low level radioactivity, a counting system having a well shielding arrangement is very essential. The shielding reduces the radiations from background.

The concentrations of various radionuclides of interest were determined in $Bq\cdot kg^{-1}$ using the count spectra. Gamma-ray photo peaks corresponding to 1.46 MeV (^{40}K), 1.76 MeV (^{214}Bi) and 2.614 MeV (^{208}Tl) were considered to correspond to the activities of ^{40}K, ^{238}U and ^{232}Th, respectively, in the samples. The detection limits of HPGe detector system for ^{40}K, ^{238}U and ^{232}Th is 8.50, 2.21 and 2.11 $Bq\cdot kg^{-1}$, respectively. Each sample and background data were counted for 86400 s.

BACKGROUND COUNT

To calculate the efficiency of the detector and the activity concentration of the soil samples, it is necessary to have an accurate background count rate. The detector is protected by a lead shield, but a certain amount of background radiation does manage to pass through and has an impact on the counts detected and since background variation varies in type and magnitude across the world, it is difficult to know exactly what to expect. By taking a long reading using no sample, it is possible to determine the background count rate at each energy, and by subtracting this information from readings used for efficiency and activity calculations we can achieve a more accurate result.

RADIOLOGICAL PARAMETERS

Radium equivalent activity (Ra_{eq})

Due to non-uniformity in the distribution of ^{226}Ra, ^{232}Th and ^{40}K in environmental sample, a common index of radiation, the radium equivalent activity (Ra_{eq}) was introduced to account cumulatively for the hazard associated with individual radionuclides [5, 22]. To assess the radiation hazard associated with the soil the Ra_{eq} was evaluated, where it is assumed that all the decay products of ^{226}Ra and ^{232}Th are in radioactive equilibrium with their precursors. Ra_{eq} is calculated according to the following formula [8, 13], the radium equivalent activity represents a weighted sum of activities of ^{238}U, ^{232}Th and ^{40}K. It is based on the fact that 370 $Bq\cdot kg^{-1}$ of ^{238}U, 259 $Bq\cdot kg^{-1}$ of ^{232}Th, and 4810 $Bq\cdot kg^{-1}$ of ^{40}K produce the same gamma radiation dose rate [9, 15]. Ra_{eq} is related to the external γ dose and internal dose due to radon and its daughters.

$$Ra_{eq} = A_{\mathrm{U}} + 1.43A_{\mathrm{Th}} + 0.077A_{\mathrm{K}} \quad (1)$$

where A_{U}, A_{Th}, and A_{K} are the specific activities of ^{238}U, ^{232}Th and ^{40}K in Bq·kg^{-1}, respectively. This formula is based on the estimation that 1 Bq·kg^{-1} of ^{238}U, 0.7 Bq· kg^{-1} of ^{232}Th and 13 Bq·kg^{-1} of ^{40}K produce the same gamma-ray dose rates. This index (Ra_{eq}) is related to both internal doses due to the radon and external gamma doses [8] and should have the highest value of 370 Bq·kg^{-1} for safe in soil.

EVALUATION OF RADIOLOGICAL HAZARD PARAMETERS

Absorbed dose rates

This refers to the amount of radiation energy absorbed or deposited per unit mass of the substance. It is a measure of the energy deposited in a medium by ionizing radiation per unit mass. It may be measured as joules per kilogram and represented by the equivalent S.I. unit, gray (Gy), or rad. The absorbed dose rate of gamma radiation is uniform near to the surface of ground of the naturally occurring radionuclides. The calculation is based on the guideline shown in [22]. The absorbed dose rate is calculated by the following expression provided by [19, 22].

$$D_R = 0.462A_{\mathrm{U}} + 0.604A_{\mathrm{Th}} + 0.0417A_{\mathrm{K}} \quad (2)$$

where A_{U} , A_{Th} and A_{K} are the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively and D_R is the absorbed dose rate in nGy·h^{-1}.

Annual effective dose rates

Exposure risk to any individual due to absorbed dose rate is estimated in term of the annual effective dose equivalent. The absorbed dose rate was converted into the annual effective dose equivalent by using a conversion factor of 0.7 Sv·Gy^{-1} recommended by the [22] and 0.2 for the outdoor occupancy factor by considering that the people on the average, spent ~ 20% of their time in outdoors. The effective dose outside the door due to natural activity in the soil was calculated by Eq. (3), as it was given by [4, 6].

$$AEDR_{\mathrm{outdoor}} = D_R(\mathrm{nGy \cdot h^{-1}}) \cdot 8760(\mathrm{h \cdot y^{-1}}) \cdot 0.2 \cdot 0.7(\mathrm{Sv \cdot Gy^{-1}}) \cdot 10^{-3} \quad (3)$$

The Eq. (3) can be simplified into:

$$AEDR_{\mathrm{outdoor}}(\mathrm{mSv \cdot y^{-1}}) = D_R(\mathrm{nGy \cdot h^{-1}}) \times 0.00123 \quad (4)$$

External (H_{ex}) and internal (H_{in}) hazard indices

Other additional criteria for assessing the radiological burden on a given population are the external hazard index (H_{ex}) and the internal hazard index (H_{in}).

The external hazard index (H_{ex}) is derived from the same expression of Ra_{eq} with the supposition that its maximum value corresponds to the upper limit of Ra_{eq}, 370 Bq·kg^{-1}. It represents the hazard incurred due to external exposure to radiation from ^{226}Ra, ^{232}Th and ^{40}K in the studied soil samples. As it was shown by [4], the indices that represent external and internal radiation hazards dose rates are given by Eq. (5). These indices limit the radiation dose which has an equivalent limit of 1 mSv·y^{-1}. The external hazard indexes based on a criterion have been introduced using a model proposed by [3, 11]. The external hazard index (H_{ex}) for the soil is given by

$$H_{\text{ex}} = \frac{A_{\text{U}}}{370\ \text{Bq}\cdot kg^{-1}} + \frac{A_{\text{Th}}}{259\ \text{Bq}\cdot kg^{-1}} + \frac{A_{\text{K}}}{4810\ \text{Bq}\cdot kg^{-1}} \tag{5}$$

where A_{U} , A_{Th} and A_{K} are the specific activities of ^{238}U, ^{232}Th and ^{40}K in Bq·kg^{-1}, respectively. This index value must be less than unity to the radiation hazard and which is safe for human being to live.

The internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and its short-lived progeny. To account for this threat the maximum permissible concentration for ^{226}Ra must be reduced to half of the normal limit (185 Bq·kg^{-1}) and it is given by the following Eq. (6) [15].

$$H_{\text{in}} = \frac{A_{\text{U}}}{185\ \text{Bq}\cdot\text{kg}^{-1}} + \frac{A_{\text{Th}}}{259\ \text{Bq}\cdot\text{kg}^{-1}} + \frac{\text{A}_{\text{K}}}{4810\ \text{Bq}\cdot\text{kg}^{-1}} \tag{6}$$

To have negligible hazardous effects of radon and its short-lived progeny to the respiratory organs, the values of H_{ex} and H_{in} must be less than unity for the radiation hazard to be negligible [22].

Excess life time cancer risk

Excess lifetime cancer risk (*ELCR*) is the probability of developing cancer over a lifetime at a given exposure level. A higher value of *ELCR* implies higher probability induction of cancer of the individual that was exposed. It can be calculated using Eq. (7) given by [21].

$$ELCR = AEDE \times DL \times RF \tag{7}$$

where $AEDE$ is annual effective dose equivalent, the duration of life (DL) is duration of life (estimated to be 70 years) and a risk factor (RF) is risk factor (Sv^{-1}).

For stochastic effects, the International Commission on Radiological Protection (ICRP) uses *RF* as 0.05 for the general public. *ELCR* is higher than the world permissible value of 0.29×10^{-3} [21].

Annual gonad equivalent dose

The annual gonadal equivalent dose (*AGED*) represents the dose received by those organs which include the reproductive organs (gonads), bone marrows, and bone cells. The gonads, the bone marrow and the bone surface cells are considered as organs of interest shown by [22] because of their sensitivity to radiation. An increase in *AGED* has been known to affect the bone marrow, causing destruction of the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal. It is calculated using the Eq. (8) given by [1].

$$AGED\left(\frac{\mathrm{mSv}}{\mathrm{y}}\right) = 3.09A_{\mathrm{Ra}} + 4.18A_{\mathrm{Th}} + 0.314A_{\mathrm{K}} \quad (8)$$

where A_{Ra}, A_{Th} and A_{K} are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K respectively in Bq·kg^{-1}. 3.09, 4.18 and 0.314 are the respective conversion factors that transform the specific activities of ^{226}Ra, ^{232}Th and ^{40}K into total dose received by the organs of interest.

Gamma index

Gamma index I_{γ} was calculated using Eq. (9), this is used to estimate the I_{γ} radiation hazard associated with the natural radionuclide in specific investigated samples. Values of $I_{\gamma} \leq 1$ Bq·kg^{-1} correspond to an annual effective dose of less than or equal to 1 mSv [7, 16].

$$I_{\gamma} = \frac{A_{\mathrm{U}}}{300} + \frac{A_{\mathrm{Th}}}{200} + \frac{A_{\mathrm{K}}}{3000} \quad (9)$$

where A_{U} , A_{Th} and A_{K} are the ^{238}U, ^{232}Th and ^{40}K specific activities (Bq·kg^{-1}) in the soil samples, respectively.

RESULTS AND DISCUSSION

One of the main objectives of the radioactivity measurement in an environmental sample is not simply to determine the activity concentrations of ^{238}U, ^{232}Th and ^{40}K, but also to estimate the radiation exposure dose and to assess the biological effects on humans. The assessment of radiological risk can be considered in various terms. In this study eight related quantities were deduced, these being: (i) the absorbed dose rate (D_R) in air at 1 meter above the ground surface; (ii) the annual effective dose equivalent from outdoor terrestrial gamma radiation; (iii) the radium equivalent activity (Ra_{eq}); and (iv) the external hazard index (H_{ex}); (v) the internal hazard index (H_{in}), (vi) radioactivity level index I_{γ}, (vii) Annual gonad equivalent dose and (viii) excess lifetime cancer risk from the activity concentration of ^{238}U, ^{232}Th and ^{40}K respectively help to assess the possible health effects of the radionuclides on people living in the study area, are presented in Table 1. Moreover, these radiological parameters can be calculated from the measured activity concentrations of three main primordial radionuclides in soil samples, using the relations described in the methodology section. The values of these radiological hazard parameters as deduced in the current work are listed in Table 1.

It was inferred that for all the soil samples analyzed, the Ra_{eq} value was well within and less than the permissible limits of 370 Bq·kg^{-1} [22]. The results indicate that in city, the site with maximum indoor radiations is found at S6. The results obtained for Ra_{eq} varied from 31.66 to 227.51 Bq·kg^{-1} with a mean value of 158.11 Bq·kg^{-1}. The mean value was lower than the safe precautionary limit of 370 Bq·kg^{-1} set by [14].

Radiologically, all the obtained values of the gamma dose rate (*DR*) were higher than the internationally recommended value 55 nGy·h^{-1} [5] except site S4, S7 and S16. The absorbed dose rate ranged from 14.52 nGy·h^{-1} to 103.37 nGy·h^{-1} with the mean value of 73.16 nGy·h^{-1}. The result shows that the peak value of the dose rate is greater than the world average values given by [7]. Similarly, the estimated mean annual effective dose rate of 0.08 mSv·y^{-1} was recorded for the studied samples which were also lower than the mean worldwide outdoor effective dose of in most of the sample areas; however, in one of the sample areas the recorded value agrees with [22].

The internal hazard indices ranged from 0.1 to 0.7 with a mean value of 0.47 and external hazard indices ranged from 0.09 to 0.61 with the mean value of 0.042. All the values are below unity as recommended limit [7] and less than [22]. The external hazard indices were found in the city greater than the results shown by [8] similarly, the mean internal hazard indices were found in this study greater than the mean results shown by [20] in both cases the measurement shows less than the unity. Therefore, these areas do not pose significant radiological health risk to the inhabitants due to exposure to ionizing radiation from the natural radionuclides in the soil.

The seventh column of Table 1 shows the gamma index. The values range from 0.12 to 0.83 with an average of 0.59 mSv. Values of $I_\gamma \leq 1$ correspond to an annual effective dose of less than 1 mSv. The results revealed that the area of the study is below the limit.

Table 1

Hazard indices obtained in this study for the city of Dire Dawa, Ethiopia, radium equivalent activity (Ra_{eq}), the absorbed gamma dose rate (D_R), the external (H_{ex}) and internal (H_{in}) hazard index, the radioactivity level index (I_γ), and the annual effective dose annual equivalent (*AEDR*) for the investigated soil

Sample code	Ra_{eq} **(Bq·kg^{-1})**	D_R **(nGy·h^{-1})**	$AEDR$ **(mSv·y^{-1})**	H_{ex}	H_{in}	I_γ **(Bq·kg^{-1})**	$AGED$ **(μSv·y^{-1})**	$ELCER$ **(10^{-3})**
S1	222.20	102.26	0.12	0.60	0.66	0.83	726.37	0.43
S2	178.59	85.86	0.10	0.48	0.56	0.67	597.37	0.35
S3	117.89	55.72	0.06	0.32	0.37	0.45	398.12	0.23
S4	31.66	14.52	0.01	0.09	0.10	0.12	102.35	0.62
S5	203.18	93.28	0.11	0.55	0.61	0.75	661.42	0.40
S6	227.51	103.37	0.12	0.61	0.70	0.83	729.00	0.44
S7	76.03	35.45	0.04	0.21	0.25	0.28	251.14	0.15
S8	127.83	59.98	0.07	0.34	0.40	0.48	427.24	0.26
S9	152.04	68.66	0.08	0.41	0.45	0.56	483.76	0.29
S10	209.12	99.87	0.12	0.56	0.63	0.80	718.10	0.43

Table 1 (continued)

S11	156.93	78.06	0.09	0.42	0.49	0.62	567.80	0.34
S12	193.84	93.76	0.11	0.53	0.60	0.75	676.13	0.40
S13	126.84	62.48	0.07	0.34	0.37	0.50	451.44	0.27
S14	216.05	98.48	0.12	0.58	0.66	0.79	695.37	0.42
S15	184.62	86.05	0.10	0.50	0.08	0.70	614.66	0.37
S16	105.39	50.99	0.06	0.39	0.43	0.41	251.95	0.22
Min	31.66	14.52	0.01	0.09	0.10	0.12	102.35	0.15
Max	227.51	103.37	0.12	0.61	0.70	0.83	729.00	0.62
Ave	158.11	73.16	0.08	0.42	0.47	0.59	415.67	0.38
SD	56.79	26.13	0.03	0.15	0.19	0.21	194.23	0.11
World average	≤ 370	55	0.48	≤ 1	≤ 1	≤ 1	300	0.29

For stochastic effects, ICRP uses *RF* as 0.05 for the general public. *ELCR* was calculated and the results vary from 0.15×10^{-3} to 0.62×10^{-3} with an average value of 0.38×10^{-3}. *ELCR* is higher than the world permissible value of 0.29×10^{-3} [21].

The result revealed that in most of the sample areas the *AGED* value is higher than the internationally accepted value of 300 $\mu Sv \cdot y^{-1}$. The mean value varies from 102.35 to 726.00 with the mean value of 415.65 $\mu Sv \cdot y^{-1}$. This shows that the area is sensitive for background radiation produced by the radionuclides might affect the bone marrow of the residence.

CONCLUSIONS AND RECOMMENDATIONS

This study has presented the natural background radiation levels in Dire Dawa city for the first time. The radiological dose as absorbed gamma-ray dose rate, the radium equivalent activity, the external and internal hazard index, the radioactivity level index and the annual effective dose equivalent from ^{238}U, ^{232}Th and ^{40}K were shown within the limit of internationally recommended values. To determine the radiological risk gamma radiation representative level index and external hazard index were evaluated. Part of the investigated locations (S1, S6, S10, and S14) exceeded the internationally accepted threshold values. The obtained results show that the average values of dose rate, effective dose, and annual gonadal dose are higher than the worldwide average. Since the external hazard index is less than unity, no significant radiological hazard has been found for the residents of the study area.

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REFERENCES

1. AVWIRI, G.O, C.P. ONONUGBO, I.E. NWOKEOJI, Radiation hazard indices and excess lifetime cancer risk in soil, sediment and water around Mini-Okoro/Oginigba Creek, Port Harcourt, Rivers State, Nigeria, *Comprehensive Journal of Environment and Earth Sciences*, 2014, **12**(01), 38–50.
2. AYALEW, D., B. SITOTAW, E. MENGISTU, Assessment of natural radioactivity levels in the soil of Dire Dawa city, Ethiopia, *Romanian J. Biophys*., 2019, **29**(4), 113–122.
3. BASHIR, M., G.E. IBEANU, Y.I. ZAKARI, U. SADIQ, Assessment of Radiological Risk in Flooded Soil Samples of Kudenda State Nigeria, *International Journal of Engineering Science Invention*, 2013, **2**(10), 69–74.
4. BECK, H.L., The physics of environmental radiation fields. Natural radiation environment II, CONF-720805 P2, *Proceedings of the Second International Symposium on the Natural Radiation Environment*, New York, 1972.
5. BERETKA, J., P.J. MATHEW, Natural radioactivity of Australian building materials, industrial wastes and by-products, *Health Phys*., 1985, **48**, 87–95.
6. CHANG, B.U., S.M. KOH, Y.I. KIM, I.S. SEO, Y.Y. YOON, J.W. ROW, D.E. LEE, Nationwide survey on the natural radionuclides in industrial raw minerals, in South Korea, *Journal of Environmental Radioactivity*, 2008, **99**, 455–460.
7. EUROPEAN COMMISSION (EC), Radiological Protection Principles Concerning the Natural Radioactivity of Building Materials, Directorate General Environment, Nuclear Safety and Civil Protection, *Radiation Protection*, **112**, 1999.
8. EL-TAHER, A., Gamma spectroscopic analysis and associated radiation hazards of building materials used in Egypt, *Radiat. Prot. Dosim*., 2010, **138**(2), 166–173.
9. FARAI, I.P., J.A. ADEMOLA, Radium activity concentrations in concrete building blocks in eight cities in southwestern Nigeria, *J. Environ. Radioact*., 2005, **79**, 119–125.
10. KURNAZ, A., B. KÜÇÜKÖMEROGLU, R. KESER, N.T. OKUMUSOGLU, F. KORKMAZ, G. KARAHAN , U. CEVIK, Determination of radioactivity levels and hazards of soil and sediment samples in Firtina Valley (Rize, Turkey), *Applied Radiation and Isotopes*, 2017, **65**, 1281–1289.
11. KRIEGER, R., Radioactivity of construction materials, *Betonwerk Fertigteil Tech*., 1981, **47**, 468–473.
12. INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, International Atomic Energy Agency, Vienna, Austria, 2011, http://www-ns.iaea.org/standards/.
13. MALANCA, V., G. PESSINA, DALLARA, Radionuclide content of building materials and gamma-ray dose rates in dwellings of Rio-Grande Do-Norte Brazil, *Radiat. Prot. Dosim*., 1993, **48**(2), 199–203.
14. NEA-OECD, *Exposure to Radiation from Natural Radioactivity in Building Materials. Report by NEA Group of Experts. OECD*, Paris, 1979.
15. ONONUGBO, C.P., G.O. AVWIRI, G. TUTUMENI, Measurement of natural radioactivity and evaluation of radiation hazards in soil of abua/odual districts using multivariate statistical approach, *British Journal of Environmental Sciences*, 2016, **4**(1), 35–48.
16. RAGHU, Y., R. RAVISANKAR, A. CHANDRASEKARA, P. VIJAYAGOPAL, B. VENKATRAMAN, Assessment of natural radioactivity and radiological hazards in building materials used in the Tiruvannamalai District, Tamilnadu, India, using a statistical approach, *J. Taibah, Univ. Sci*., 2015, **4**(11), 523–533, http://dx.doi.org/10.1016/j.jtusci.2015.08.004.
17. RAHMAN, S., M. FAHEEM, Natural radioactivity measurements in Pakistan. An overview, *J. Radiol. Prot.*, 2008, **28**(4), 443–452.
18. SOHRABI, M., The state-of-the-art on worldwide studies in some environments with elevated naturally occurring radioactive materials, *Applied Radiation and Isotopes*, 1997, **49**(3), 169–188.
19. SOWOLE, O., Determination of radiological hazard associated with the use of Imayan river sediment as building material, *J. Appl. Sci. Environ. Manage*, 2015, **19**(1), 65–68.

20. TAQI, A.H., A.M. SHAKER, A.A. BATTAWY, Natural radioactivity assessment in soil samples from Kirkuk city of Iraq using HPGe detector, *International Journal of Radiation Research*, 2018, **16**(4), 455–463.
21. TASKIN, H., M. KARAVUS, P. AY, A. TOPUZOGLU, S. HIDIROGLU, G. KARAHAN, Radionuclide concentration in soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli, Turkey, *Journal of Environmental Radioactivity*, 2009, **100**, 49–53.
22. UNITED NATIONAL SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION SOURCES AND RISKS OF IONIZING RADIATION (UNSCEAR), *Report to the General Assembly with Annexes*, United Nations, New York, 2000.