Characterization of Natural Radioactivity in Soil of Balad City and its Surroundings, Iraq

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Abstract
The main objective of this research is to study the natural radioactivity in soil samples collected fromBalad city and its surrounding area by measuring the concentrations of natural radionuclides for (^{238}U, ^{232}Th,^{40}K) and artificial nuclide^{137}Cs by using gamma ray spectroscopy withNaI(Tl) scintillation detector.The results show that the activity concentration for ^{238}U in soil ranged from 4.44 to 20.83 Bq/kg with an averages of 8.85 Bq/kg,the activity concentration for ^{232}Th in soil ranged from 1.26 to 68.54 Bq/kg with an averages of 27.43 Bq/kg, the activity concentration for ^{40}K ranged from 134.45Bq/kg to 680.67 Bq/kg with average 299.57 Bq/kg. The average level of specific activities of ^{238}U,^{232}Th and ^{40}K neutral nuclides in soil samples are below the recommended global limits 35, 30 and 400 Bq/kg respectively (UNSCEAR, 2000).The specific activity for artificial nuclide ^{137}Cs in soil sample recorded lowest value 0.23 Bq/kg and the highest value 4.03 Bq/kg with average 1.37 Bq/kg. The average level of specific activity of ^{137}Cs nuclide in soil samples are below the recommended global limits 14.8 Bq/kg (UNSCEAR, 2000). The radiological hazard indices were found to be within the recommended global International Commission on Radiological Protection recommended limits.

Keywords: *BaladCity, Gamma Ray Spectroscopy, Soil, Specific Activity, Radium Equivalent Activity, Hazard Index, Absorbed dose rates.*

INTRODUCTION

Natural radioactivity is widely spread in the earth's environment and is found in various geological formations such as earth's crust, rocks, soil, plants, water and air as the level of terrestrial sources of natural radioactivity varies according to the geological structure of the region, geographical location, radiochemical state and distribution of radionuclides on the earth (UNSCEAR, 2000) [1]. These radionuclides will be present in most environmental elements, they are found in air, water, vegetables, animals, soil, rocks, and the human body itself, in various quantities [2, 3].The earth radionuclides are one of the main sources of naturally occurring radioactive materials. Earth radionuclides are divided into three natural strings of radioactive (^{238}U,^{235}U, ^{232}Th and their decay progeny) andthe primordial radionuclide ^{40}K that usually remain for a long time because of their half-lives are more than a hundred million years [2].

Concentrations of natural radionuclides depend on the type of rock from which the soil originates. In general, radiation levels in volcanic rocks such as granite rocks higher than those in sedimentary rocks [4].

The international atomic energy agency (IAEA) defined NORM as "Radioactive Occurring RadioactiveMaterials" contain no significant amounts of radionuclide in compare with naturally occurring radionuclides" (IAEA, 2006) [5].The decay chain of uranium series is starting from radium (^{226}Ra), which is radiologically the most important. Therefore, the researcher often considers radium instead of uranium. The worldwide concentrations average of radium, thorium and potassium in the earth's crust are about 30, 35 and 400 Bq/kg respectively (UNSCEAR, 2000) [2].

The artificial radionuclides are the products of radioactive waste from nuclear weapons tests, accidents of nuclear reactors, nuclear plants, nuclear fuel, and plant waste. Which became necessary to measure it after the aftermath of the Chernobyl nuclear accident in 1986 [6].

The danger of these nuclides to humans is their natural liberation of alpha or beta particles, which are the main source of external exposure to humans. These radiation are transmitted to the body through absorption or inhalation, in addition to internal exposures. This means that humans are exposed to two types of internal and external radiation from these natural sources. Internal exposure occurs by inhalation or ingestion, as the exposure dose is mostly related to the decay chain(^{238}U and ^{232}Th plus ^{40}K) by ingestion through drinking and eating [4. 6].

The primary source of radiation from the crust weathering is the process of filtering or purifying earth radionuclides into the soil. The radioactivity in the air or in the soil is transmitted to agricultural crops via roots and leaves, while it is transmitted to animals through the consumption of these plants. [7]. The rate of absorption of natural radionuclides depends on the rate of human consumption of food and drink as well as on the concentrations of radionuclides [8,9].

The primary goal of the research was to measurement the specific activity of natural radiation in soiland to determine the (radium equivalents, internal and external hazard indicators, annual absorbed dose and hazard indicators for gamma rays) of radiation received from environmental sources to assess the health risks that may arise from it.This study was done for twenty soil samples collected from Balad city and its surroundings in Salah al-Din Governorate, Iraq.

Materials and Methods

A. The study area:

The city of Balad is located in the south of Salah Al-Din Governorate, Iraqas shown in Fig.1. The center of the judiciary is surrounded by large areas of agricultural land and is considered an important center of agricultural crops marketing with a high population density as well as production plants and diesel electric power generation stations. Soil samples were collected from different regions of the center of the district and its surrounding areas for the purpose of measuring the natural radioactivity.

Figure 1: Map of the investigated area of Balad city

B. Collecting and preparing soil samples:

The study included 20 soil sampleswere collected from different regions of Balad city and its surrounding areas (Balad, Al-Dhuluiya, Bani- Saad). Soil sample was carried out in the months, (April, Jun 2020) as shown in Table 1.

Table 1: Locations and Symbol of Soil Samples from different Regions in Balad City and its Surrounding areas.

SampleSymbol	Regions	Samples Code	Regions
D1	Al-Dhuluiya/airport-1	D11	Balad/sayedmoh.street
D2	Al-Dhuluiya/airport-2	D12	Balad Diesels
D3	Al-Dhuluiya/ block factory	D13	Bala/ industrial area
D4	Bishkan	D14	Balad/Al-jameya
D5	Kubayba	D15	Aziz balad intersection
D6	The project	D16	The wood bridge
D7	Al-meshraga	D17	The bridge check point
D8	Zanajha	D18	Almeeraj station
D9	Sheikh Nasser	D119	Ahbabtelalthahab
D10	Balad/the hospital	D20	The project pump

Soil samples were taken at depth (5cm) from twenty regions (Balad and its surrounding regions). The samples were dried through sunlight to get rid of moisture and cleaned from the doping grinds using special sieve (300 mm in diameter). One kilogram of each homogeneous sampleswere placed in a polyethylene marinelli beakers, closed tightly and left for a month In order to obtain the radiation balance between ^{226}Ra and ^{232}Th and their respective progenies [10].

C. Estimation of Natural and Artificial Radionuclides Activity

The spectrometer consist ofNaI (TI) scintillation detector (3"x 3") (CANBRA-USA), pre- amplifier, amplifier equipped with a voltage and a multi-channel analyzer analyzes. The Fill Width at Half Maximum (FWHM) for ^{60}Co in the peak 1.33 keV was 7%. . Spectral data from the detector was analyzed by using (GINE-2000) computer software. The detector was surrounded by a lead shield to reduce the background radiation.

One litter Marinelli beaker with mixed radionuclide standard source were used to carried out the energy and efficiency calibration of gamma spectrometer.

The radionuclides are described using the energy calibration method and then quantifying them using the relative method by comparison with standard sources.

The radiological background of the laboratory was measured before the beginning of the measurements by placing an empty plastic container on the detector and collecting the γ-ray spectrum for a period of (3600 s).

All samples were measured at a constant geometry and for a constant time. The photo peak regions of ^{40}Kwith energy 1460 keV,^{238}U(lead ^{214}Pb with energy 352 keVand ^{214}Bi with energy of 609 keV)then adopting the highest value, while^{232}Th,(^{228}Ac has takenwith energy of 911 keV) to measure it. Artificial radionuclide ^{137}Cs with energy 662 keV was interest to measure any trace of ^{137}Cs nuclide.

The net area under peaks in the energy spectrum was computed by subtracting counts due to higher peaks and other background sources from the peaks from the net area, the activity concentration was obtained using the following equation [11]:

$$A(Bq/kg)=\frac{C}{P(E\gamma)\times Eff\times Tc\times M} \quad \ldots\ldots\ldots..(1)$$

where A is the specific activity (Bq/kg), C the net gamma counting rate (counts per second),*Eff*the efficiency of the specific γ-ray, P(Eγ) the absolute transition probability of Gamma-decay, Tc the counting time (sec) and M the mass of the sample (kg).

D. RADIOLOGICAL PARAMETERS

Radium Equivalent Activity

The radium equivalent activity is one of the mostly used hazard indices in radiation protection assessment. It is used to account the radiation doses accruing from ^{226}Ra, ^{232}Th and ^{40}K. It is assumed 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma ray dose rate [12]. Radium equivalent activity can be calculated from the relation [13].

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad \ldots\ldots\ldots(2)$$

Where, A_{Ra}, $A_{Th}$and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K respectively in $Bqkg^{-1}$.

The Gamma Absorbed Dose Rate

The gamma absorbed dose rate is used to measure the radiation exposure to human body in order to assessment the quantity of radiological hazards due to the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil. The absorbed dose rate Dγ($nGyh^{-1}$) at 1m above the surface of the earth was calculated using the specific activities (A_U, $A_{Th}$and A_K) of ^{238}U, ^{232}Th, ^{40}K respectively and the conversion factors (for ^{238}U= 0.462 nGy/h, ^{232}Th = 0.604 nGy/h and ^{40}K = 0.0417 nGy/h [14]. The absorbed dose was calculated using the expression:

$$D\gamma\ (nGy / h) = 0.92A_U + 1.1A_{Th} + 0.08A_K \quad \ldots\ldots\ldots(3)$$

The Annual Effective Dose Equivalent

The effective annual equivalent dose (AEDE)in units (mSv/y) can be defined as a radiation coefficient that is used to measure the health effects of the absorbed dose as it is measured in units of (mSv/year). To estimate the annual effective dose, a conversion factor (0.7Sv / Gy) is used, which represents the conversion factor from the dose absorbed in the air to the effective dose, as well as the use of the outdoor occupancy factor of value (0.2) and the internal occupancy factor of value (0.8) Using the following equations [15].

$$AEDE_{in}\ (mSv/y) = D \times 8760 \times 0.7 \times 0.2 \times 10^{-6} \quad \ldots\ldots\ldots(4)$$

$$AEDE_{out}\ (mSv/y) = D \times 8760 \times 0.7 \times 0.8 \times 10^{-6} \ldots\ldots\ldots(5)$$

Where D is the absorbed dose rate measured in units (nGy/h) and 8760 represents the number of hours per year.

According to UNSCEAR measurements, the average global value of the annual effective dose (460µSv/y) [2].As for the average global values, it is (0.41mSv/y), including the internal dose (0.34mSv/y) and the external(0.07mSv/y) [16].

Radiation Hazard Index (H)

It is a coefficient used to find out the risks of internal and external radiation, as the indicators of external risk are what the body is exposed to from radiationsource outside the body, as the average radiation dose absorbed by the body depends on the distance between the radioactive source and the body, the size of the radioactive source, and the amount of radioactive energy of the radioactive source[2]. As for the internal risk indicators that appear as a result of the entry of radioactive materials into the body as a result of inhalation, absorption or ingestion of foodstuffs containing radioactive material in high concentrations even if the quantities are small, its risk is greater [17]. The interior of the two equations: -

$$H_{in} = A_U/185 + A_{Th}/259 + A_K/4810 \quad \ldots\ldots\ldots(6)$$

$$H_{ex} = A_U/370 + A_{Th}/259 + A_K/4810 \quad \ldots\ldots\ldots(7)$$

Representative Gamma Index

The gamma index is used to estimate the level of γ-ray hazard associated with the natural radionuclides in specific investigated samples [11] .

$$I\gamma = (1/150)A_{Ra} + (1/100)A_{Th} + (1/1500)A_K \quad \ldots\ldots\ldots(8)$$

RESULTS AND DISCUSSION

A. Specific Activity

The results ofnatural and artificial radionuclides specific activity in soil samples of Balad city are shown inTable. 2.

The results of specific activity for ^{238}U in soil sample recorded lowest value 4.44 Bq/kg in D20 (The project pump) and the highest value 20.83Bq/kg in D1 (Al-Dhuluiya/airport-1) with average 8.85 Bq/kg. The average level of specific activity of ^{238}U nuclide in soil samples are below the recommended global limits 35Bq/kg (UNSCEAR, 2000).

The specific activity for ^{232}Th in soil sample recorded lowest value 1.26Bq/kg in D20 (The project pump) and the highest value 68.54 Bq/kg in D2 (Al-Dhuluiya/airport-2) with average 30.55Bq/kg. The average level of specific activity of ^{232}Th nuclide in soil samples are haer than the recommended global limits 30 Bq/kg (UNSCEAR, 2000).

The specific activity for ^{232}Th in soil for locations (D2,D4,D5, D6, D10, D14 and D18) are higher the recommended global limits 30 Bq/kg (UNSCEAR, 2000).

The specific activity for ^{40}K in soil sample recorded lowest value 134.45Bq/kg in D15 (Aziz balad intersection) and the highest value 680.67 Bq/kg in D18 (Almeeraj station) with average 299.57 Bq/kg. The average level of specific activity of ^{40}K nuclide in soil samples are below the recommended global limits 400Bq/kg (UNSCEAR, 2000).

The specific activity for ^{40}K in soil for locations (D4, D18, D20) are higher the recommended global limits 400 Bq/kg (UNSCEAR, 2000).

The specific activity for artificial nuclide ^{137}Cs in soil sample recorded lowest value 0.23 Bq/kg in D9 (Sheikh Nasser) and the highest value 4.03 Bq/kg in D15 (Aziz balad intersection) with average 1.37Bq/kg. The average level of specific activity of ^{137}Cs nuclide in soil samples are below the recommended global limits 14.8 Bq/kg (UNSCEAR, 2000).

The minimum, maximum and average of specific activity of natural radionuclides in soil samples are shown in Fig. 2.

Table 2: Specific Activates of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs Radionuclides in Soil Samples of Balad City and its Surrounding Regions

Sample Symbol	^{238}U Bq/kg	^{232}Th Bq/kg	^{40}K Bq/kg	^{137}Cs Bq/kg
D_1	20.83	14.99	314	3.0
D_2	10.40	68.54	307.4	0.86
D_3	6.61	16.80	325.38	2.31
D_4	13.95	52.76	630.9	3.97
D_5	10.16	30.14	316.5	MDA
D_6	MDA*	39.3	156.7	2.17
D_7	6.96	17.12	237.2	2.14
D_8	4.8	25.96	258.2	1.21
D_9	MDA	12.89	282	0.23
D_{10}	14.69	35.98	232	0.34
D_{11}	15.66	19.69	190.3	1.67
D_{12}	13.21	17.25	289.38	1.86
D_{13}	10.77	28.63	304.13	0.39
D_{14}	11.67	41.89	149.63	0.29
D_{15}	6.57	28.01	134.45	4.03
D_{16}	14.06	12.8	376.22	0.93
D_{17}	6.69	29.66	161.12	1.48
D_{18}	MDA	40.10	680.67	0.61
D_{19}	5.48	14.87	295.22	MDA
D_{20}	4.44	1.26	520	MDA
Min.	4.44	1.26	134.45	0.23
Max.	20.83	68.54	680.67	4.03
Avg.	8.87	30.55	299.57	1.37
W.A	35	30	400	14.8

*MDA, Minimum Detection Activity is defined as the smallest amount of radionuclide that can be reliably identified and coded for a specific measurement.

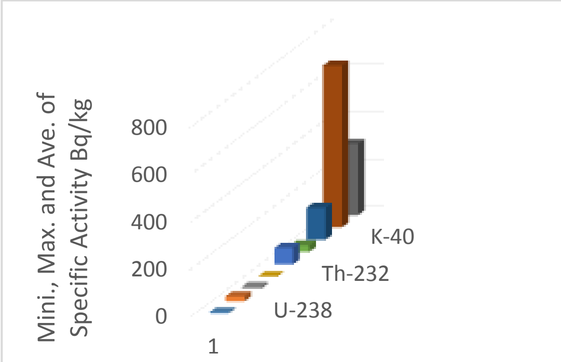

Figure 2: Minimum, Maximum and Average Specific Activity of Natural Radionuclides in Soil Sample for Balad City

B. Evaluation of Radiological Hazard Indices for Soil Sample

The risk factors for radium equivalent, gamma absorbed dose rate in air, internal and external risk coefficient, internal and external annual effective dose and risk factor for gamma rays were calculated as shown in Table 3.

The results for the radium equivalent Ra_{eq}recorded the highest value in the sample D2 (Al-Dhuluiya Airport) (110.56 Bq/kg) and the lowest value (9.88 Bq/kg) in the sample D20 (BaniSaad water project) with average50.17Bq/kg. The minimum, maximum and average of radium equivalent activity was shown in Fig.3.

The average level of radium equivalent was below the recommended global limits 370Bq/kg (UNSCEAR, 2000).

The results for the gamma absorbed doserate in air Dγ recorded 59.02 nGy/hin D2 (Dhuluiya Airport) and the lowest value 19.54nGy/h in D9 (Sheikh Nasser) with average 33.15nGy/h. The average of gamma absorbed dose in air is less than the global average value of 55nGy/y.

The results for annual effective dose equivalentout $AEDE_{out}$, show that the lowest value was 0.10mSv/y in D9 (Sheikh Nasser), the highest value 0.29 mSv/y in D2 (Dhuluiya Airport) with average 0.16mSv/yless than the global value of 1Bq/kg.

While the results for annual effectivedose equivalent internal $AEDE_{in}$show that the lowest value was 0.16 mSv/y in D15 (Aziz balad intersection) and the highest value recorded 0.84mSv/y in D18 (Al Maraj

Station) with average 0.37mSv/y less than the global average value1Bq/kg.

The results for radiation hazard index out H_{out}show thatthe lowest value 0.11Bq/kg in D9 (Sheikh Nasser), while the highest value recorded 0.36Bq/kg in D2 (Dhuluiya Airport) with average 0.19Bq/kg. While the radiation hazard index internalH_{in}show that the lowest value was 0.11Bq/kg in D9 (Sheikh Nasser) and the highest value 0.38Bq/kgin D2 (Dhuluiya Airport) with average 0. 22Bq/kg less than the world average 1Bq/kg.

The results forgamma index Iγshow that the lowest value 0.04Bq/kg in the D20 (**The project pump**) and the highest value 0.77Bq/kg in the D2 (Dhuluiya Airport) with average 0.35Bq/kg less than the world average 1Bq/kg.

Table.3:Radium Equivalent, Outdoor and Indoor (Absorbed Dose Rates in Air, Annual Effective Dose Equivalents), (Internal and External) Hazard Index and Gamma Index in Soil Samples

Location	**Ra_{eq} (Bq.kg^{-1})**	**Dγ(nGy/h)**	**$AEDE_{in}$ (mSv/y)**	**$AEDE_{out}$(mSv/y)**	**H_{in}**	**H_{ex}**	**Iγ**
D1	44.46	31.77	0.39	0.16	0.24	0.18	0.33
D2	110.56	59.02	0.38	0.29	0.38	0.36	0.77
D3	32.91	26.77	0.40	0.13	0.17	0.15	0.25
D4	91.92	53.36	0.44	0.26	0.35	0.32	0.64
D5	55.48	36.10	0.39	0.18	0.24	0.21	0.40
D6	57.30	30.27	0.19	0.15	0.18	0.18	0.40
D7	33.10	23.45	0.29	0.12	0.15	0.13	0.23
D8	44.43	32.83	0.44	0.16	0.20	0.19	0.30
D9	20.41	19.54	0.35	0.10	0.11	0.11	0.15
D10	67.77	38.19	0.285	0.19	0.27	0.23	0.47
D11	45.15	27.06	0.23	0.13	0.20	0.16	0.31
D12	39.90	28.59	0.35	0.14	0.20	0.16	0.28
D13	53.89	34.95	0.37	0.17	0.23	0.20	0.39
D14	72.62	36.93	0.18	0.18	0.26	0.22	0.52
D15	47.57	25.56	0.16	0.13	0.17	0.15	0.33
D16	35.0	29.91	0.46	0.15	0.20	0.17	0.24
D17	50.23	27.72	0.20	0.14	0.18	0.17	0.37
D18	62.11	52.60	0.83	0.26	0.30	0.30	0.41
D19	28.81	23.82	0.36	0.12	0.15	0.13	0.19
D20	9.88	24.50	0.64	0.12	0.14	0.13	0.04
Min	9.88	19.55	0.16	0.10	0.11	0.11	0.04
Max	110.56	59.02	0.83	0.29	0.38	0.36	0.77
Avg.	50.17	33.15	0.367	0.16	0.22	0.19	0.35
W.A	370	55	1	1	1	1	1

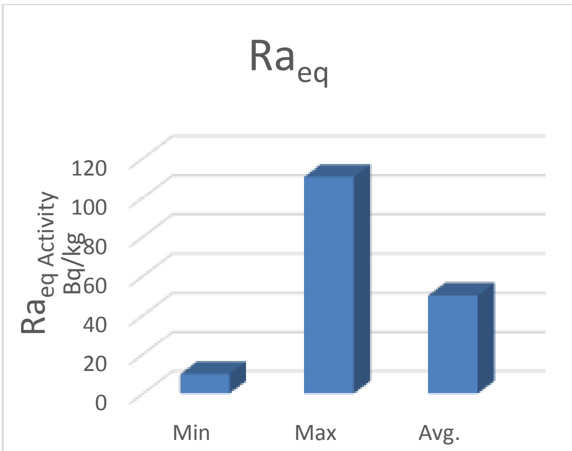

Figure 3: Radium Equivalent Activity

CONCLUSION

In the present study, the natural and artificial radionuclide ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs were measured. The natural radionuclides ^{232}Th and ^{40}K was found in all samples and also present in relatively somewhat higher concentration than world average but not significant.

The average of specific activity of natural and artificial radionuclides were below the recommended global limits reported by UNSCEAR (2000).

The radium equivalent activity, absorbed dose rate in Air, annual effective dose equivalents, (internal and external) hazard index and gamma index in soil samples are below the world average reported by UNSCEAR (2000).

REFERENCE

[1] IAEA., "*Terminology Used in Nuclear Safety and Radiation Protection*", in IAEA Safety Glossary, Vienna, 2007.

[2] UNSCEAR, United Nations Scientific Committee on the Effects of Radiations. Sources and Effects of Ionization Radiations. Report to the General Assembly, Sources (UNSCEAR, 2000).

[3] IAEA., "*Communications on Nuclear Radiation Transport and Waste Safety*", Practical Handbook, Vienna, 1999.

[4] Fisenne I., Perry P., Decker K., Keller H., "*The Daily Intake of $^{234,235,238}U$, $^{228,230,\ 232}Th$ and $^{226,228}Ra$ by New York City Residents*", Health Physics, 53, 357- 363, 1987.

[5] IAEA,"*Terminolog used In Nuclear, Radiation Waste and Transport Safety*". Version 2.0., Booklet in Safety Glossary. Vienna, 2006.

[6] Shiraishi K., Tagami K., Muramastu Y., Yamamoto M., "*Contributions of 18 Food Categories to Intakes of ^{232}Th and ^{238}U in Japan*", Health Physics, 78, 28-36. 2000.

[7] Radwan M., Salama A., "*Market Basket Survey for Some Heavy Metals in Egyptian Fruits and Vegetables*", Food and Chemical Toxicology, 44(8), 1273-1278, 2006.

[8] United State Environmental Protection Agency Radiation Protection Program- Uranium, (2015).

[9] Adeniji, A.E., O.O. Alatise and A.C. Nwanya, "*Radionuclide Concentrations in Some Fruit Juices Produced and Consumed in Lagos*", Nigeria. American. Journal of Environmental Protection, 2(2), 37-41, 2013.

[10] H. Papaefthymiou, G. Papatheodorou, A. Moustakli, D. Christodoulou and M. Geraga, *"Natural Radionuclides and ^{137}Cs Distributions and Their Relationship with Sedimentological Processes in PatrasHarbour*"*Greece Journal of Environmental Radioactivity*, Vol. 94, No. 2, pp. 55-74, 2007.

[11] LaithNajam, Hazim Louis Mansour, Nada F. Tawfiq, MahmoodSalimKarim, "*Measurement of Radioactivity in Soil Samples for Selected Regions in Thi-Qar Governorate-Iraq*", J. Rad. Nucl. Appl. 1, No. 1, pp. 25-30, 2016.

[12] Kohshi C, Takao I, Hideo V., "*Terrestial Gamma Radiation in Koshi Protectorate"*, Japan. Journal of Health Science, 47 (4): 362-372, 2001.

[13] Beretka J, Matthew PJ, "*Natural Radioactivity of Australian Building Materials, Industrial Wand by-Products"*, Health Physics, 48: 89-95, 1985.

[14] S. Turhan and L. Gunduz, "*Determination of Specific Activity of ^{226}Ra, ^{232}Th and ^{40}K for Assessment of Radiation Hazards from Turkish Pumice Samples*", Journal of Radiological Protection, Vol. 99, No. 2, pp. 332-342, 2008.

[15] Mehra, R., Singh, S.,and Singh, K.,"*Analysis of ^{226}Ra, ^{232}Th and ^{40}K in Soil Samples for the Assessment of the Average Effective Dose*", Indian Journal of Physics,vol. 83,No. 7, pp. 1031-1037, (2009).

[16] UNSCEAR, United Nations Scientific Committee on the Effects of Radiations. Sources and Effects of Ionization Radiations. Report to the General Assembly, Sources (UNSCEAR,1988).

[17] Diab HM, Nouh SA, Hamdy A, El-Fiki SA,*"Evaluation of natural radioactivity in a cultivated area around a fertilizer factory*", J NuclRadiatPhys 3(1), pp. 53-62 (2008).

[18] Sule, A.A., Iseh, A.J., Gyobe, A.M., Tyom, A.I., "*RADIOLOGICAL ANALYSIS OF SOIL IN ZAKI-BIAM, UKUM LGA, BENUE – NIGERIA*" SSRG International Journal of Applied Physics 7.1 (2020)