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Assessment of Gamma Radiation ^{232}Th, ^{226}Ra and ^{40}K in Nassarawa, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author UR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors UR, IU and AZN managed the analyses of the study. Authors UR, HAA and HOA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study assessed gamma radiation from ^{232}Th, ^{226}Ra and ^{40}K. Twelve soil samples collected from the study area were analyzed using NaI (Tl) detector. Mean concentration for ^{40}K, ^{232}Th and ^{226}Ra were found to be 483.97±7.32 Bq/kg, 28.43±5.30 Bq/kgS and 66.84±2.02 Bq/kg respectively. Absorbed Dose Rate ranged from 44.85 nGy/h to 90.71 nGy/h with a mean of 73.68 nGy/h. Effective Dose Rate ranged from 0.055 to 0.111 msv/yr with a mean of 0.090 mSv/y. The Internal and External Hazard Indices ranged from 0.271 to 0.533 Bq/kg with the mean of 0.435 Bq/kg and 0.289 to 0.675 Bq/kg with the mean of 0.512 Bq/kg respectively. It can thus be concluded that the radiation dose of the study area is minimal and seems to have low exposure for the inhabitants in and around the contaminated areas. It is therefore recommended that regular radiation monitoring exercises should be conducted on the processing sites to prevent the inhabitants of the area from high radiation exposure due to direct inhalation of finely divided particulates and dust comprised of the above-mentioned radionuclides.

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Keywords: Soil; mining; columbite; radionuclide; health absorbed dose; effective dose; radium equivalent activity; external and internal hazard index and γ-ray spectrometry.

1. INTRODUCTION

The radiation hazards of uranium mining and milling were not appreciated in the early years, resulting in workers being exposed to high levels of radiation [1,2]. Inhalation of radon gas caused sharp increases in lung cancers among underground uranium miners employed in the 1940s and 1950s [3,4].

The human being is exposed outdoors to the natural radiation that originates predominantly from the upper 50 cm of the soil [5].

Only radioactivity with half-lives comparable with the age of the earth or their corresponding decay products existing in terrestrial material such as ^{232}Th, ^{226}Ra and ^{40}K are of great interest. Since these radionuclides are not uniformly distributed, the knowledge of their distribution in soil and sediments play an important role in radiation protection and measurement [6,7].

2. MATERIALS AND METHODS

2.1 Materials

In the course of the radiometric study, the following items or materials were used as shown in Table 1.

2.1.1 Study area

Four villages were chosen in Mararraba-Udege Area. The villages are Eyenu, OPanda, Okereku and Udegen-Mbeki abbreviated as M1, M2, M3 and M4 respectively. The villages M1, M2, M3 and M4 are located at 8º24'38.2"N and 7º52'59.2"E, 8º21'24.9"N and 7º54'29.6"E, 8º24'04.1"N and 7º52'10.6"E and 8º25'56.3"N and 7º53'49.3"E respectively. Columbite was mined in all the four villages as represented in Fig. 1 [8].

2.2 Methods

2.2.1 Samples collection

Four sample locations were visited from the study area to conduct the radiometry study. Three samples were collected from each sample area which makes a total of twelve samples. The samples were collected at a depth of 0.5 m from the surface of the soil. From each area, as stated earlier, three samples were collected as follows. Firstly from the mining spot, secondly from a distance of 100 m away from the mining spot, and thirdly, from the river area within the mining spot. The samples were sealed in a labelled polythene bags and enclose into one sack for easiest transportation from the mining or sample point to the house.

Meanwhile, when collecting the sample from the mining spot, Global Positioning System (GPS) was used to take the elevation and altitude of the area.

2.2.2 Sample preparation

The samples collected were brought to the laboratory and left open (if wet) for at least 24 hours to dry under ambient temperature. They were grounded using mortar and pestle and allowed to pass through a 5 mm-mesh sieve to remove the larger object and make it a fine powder. The samples are packed in a 7 cm by 6 cm cylindrical plastic container and each container accommodated 300 g of the sample. The containers were sealed to prevent the escape of radon and were carefully stored for at least 24 days to allow radium to attain equilibrium with the daughters.

2.2.3 Data analysis

Gamma spectrometry technique was used to analyze the samples; the radiological parameters such as Radium Equivalent Activity Ra_{eq}, Absorbed Dose Rate, Effective Dose Rate, External Hazard Index $H_{(ex)}$ and Internal Hazard Index $H_{(in)}$ were calculated ^{226}Ra, ^{232}Th and ^{40}K.

2.3 Radium Equivalent Activity (Ra_{eq})

According to AZU [9], can be calculated using the relation:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (1)$$

where A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively.

2.3.1 Absorbed dose rate

The absorbed dose rate at 1 meter above the ground (in nGy/hr) is calculated according to UNSCEAR [10] as:

$$D\ (nGy/hr) = 0.0417A_K + 0.462A_{Ra} + 0.604A_{Th} \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively.

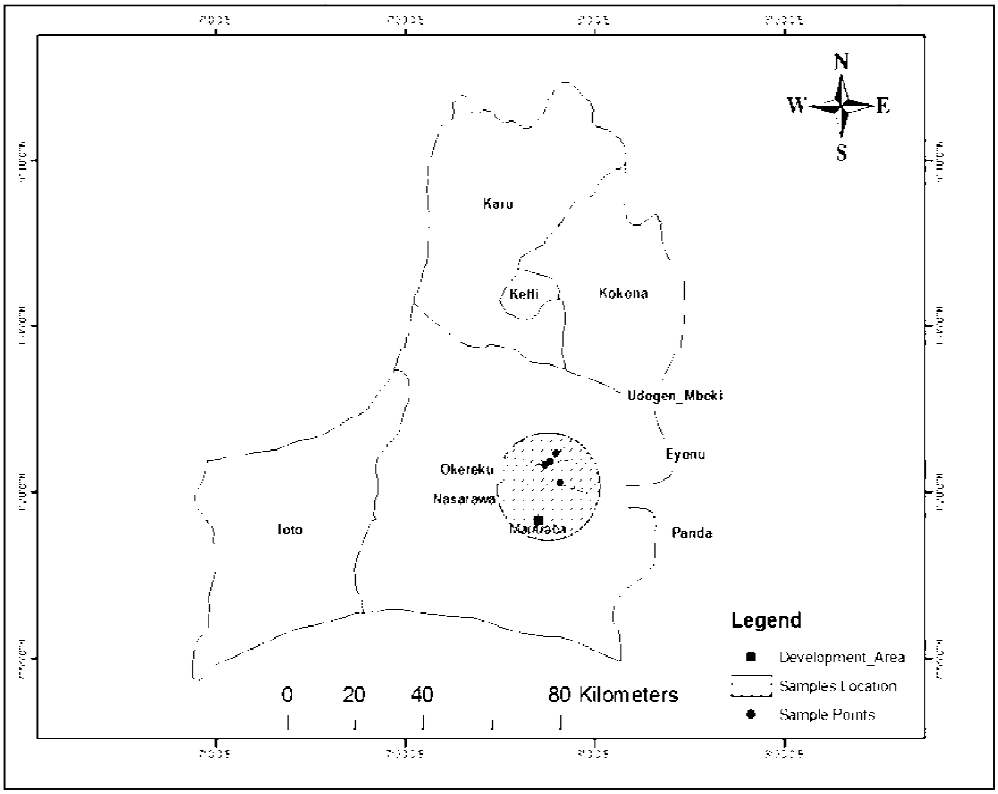

Fig. 1. Map of study area

Table 1. Materials and their specifications

Materials	Specifications
Global Positioning System (G.P.S)	This is a space-based satellite navigation system that provides location and time information in all weather, anywhere or near the earth. This was used to locate the mining sites.
Disposable Hand Glove	This is a shielding material used to protect the hands and fingers from contacting any radioactive source.
Masking Adhesive Tape	This was used to label the samples for easier identification.
Mortar and Pestle	This was used to ground the collected samples after being dried at 60ºC to 80ºC for 24 hours to maintain the radioactive equilibrium.
5 mm-Mesh Sieve	This was used to sieve the grounded samples to remove any larger particles in it and make it a powder.
Cylindrical Plastic Container	The sieved powder was packed into a cylindrical plastic container and the cover will be sealed with masking tape to prevent it from any external radiation.
Electronic Analytical Balance	The sealed containers were placed on the electronic analytical balance to measure its weight in grams.
Cutlass	This was used for clearing of the mining sites also for shallow digging.
Sealer	This was used to seal the sieved and labelled samples in their respective container to avoid leakage also to prevent the escape of gaseous ^{222}Rn from the sample.
Sodium Iodide-Thallium Gamma Spectroscopic System	This is an instrument set in the laboratory, which was used to analyze the soil samples. The Sodium Iodide-Thallium Gamma Spectroscopic System obtained from Centre for Energy Research and Training (CERT) located Ahmadu Bello University, Zaria in Kaduna State which is one of the popular Universities in Nigeria.

2.3.2 Annual Effective Dose Equivalent (AEDE)

According to UNSCEAR [10,11,12]. AEDE is determined by the equations below.

AEDE (Outdoor) (mSv/y) = D (nGy/ h) × 8760h × 0.7 Sv/Gy× 0.2 × 10^{-6} (3)

And

AEDE (Indoor) (mSv/y) = D (nGy/h) ×8760h × 0.7 Sv/Gy× 0.8 × 10^{-6} (4)

2.3.3 External hazard index

According to Arena [13,14,15], the external and internal hazard index can be calculated using the equation:

$$H_{ex} = \frac{Ara}{370} + \frac{Ath}{259} + \frac{Ak}{4810} \quad (5)$$

2.3.4 Internal hazard index

$$H_{in} = \frac{Ara}{185} + \frac{Ath}{259} + \frac{Ak}{4810} \quad (6)$$

Where A_{ra}, A_{th} and A_k are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively.

3. RESULTS AND DISCUSSION

3.1 Results

This shows the experimental results obtained from the spectra of twelve soil samples under investigation. For the effective computation of the experimental data from Count Dose Rate (cpm) to Exposure Dose Rate (μSvhr^{-1}), Absorbed Dose Rate (nGyhr^{-1}), Annual Effective Dose Rate (mSvyr^{-1}), External Hazard Index (Bq/Kg) and Internal Hazard Index (Bq/Kg); Equation 1 to 6 was used and the results are presented in the Table 2.

Chats have been plotted to compare the activity concentrations of ^{40}K, ^{226}R and ^{232}Th as well as the radiological parameters with previous literature. In the charts, M1 represent Eyenu, M2 represent Opanda, M3 represent Okereku and M4 represent Udegen-Mbeki. The letters A represents mining spot, B represents 100 meters away from the mining spot, C represents the waterways within the mining spot.

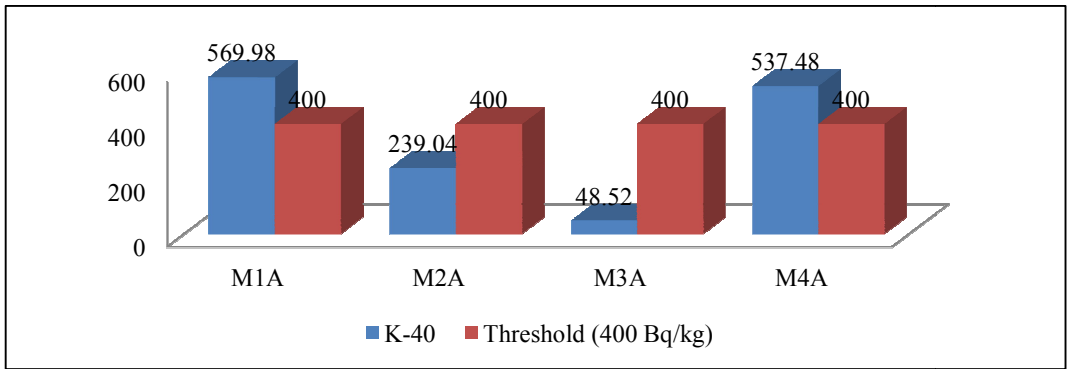

Fig. 2. Comparison of the spot's activity concentration for ^{40}K with threshold

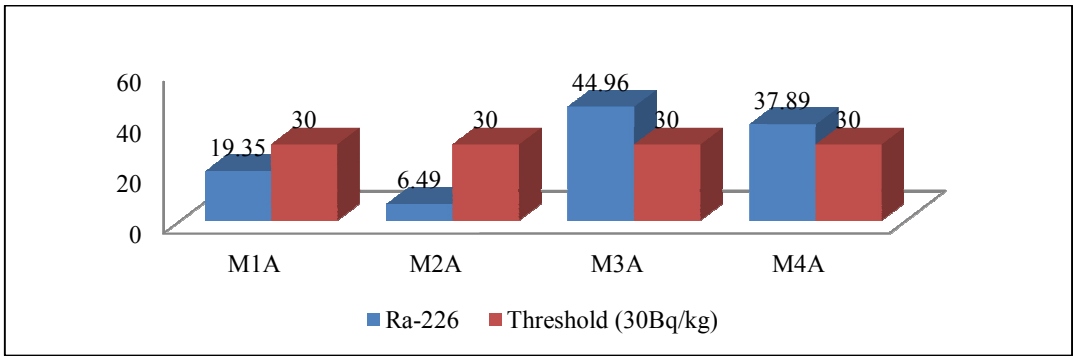

Fig. 3. Comparison of the spot's activity concentration for ^{226}Ra with threshold

Table 2. Evaluated results for the radiological hazard parameters

Sample codes	k-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	Ra_{eq} (Bq/kg)	G.A.D. (nGy/h)	E.D.R. (mSv/yr)	H_{in} (Bq/kg)	H_{ex} (Bq/kg)
M1 A	0569.98±9.95	19.35±2.32	79.93±1.03	177.54	80.99	0.099	0.479	0.532
M1 B	0536.39±8.55	24.91±0.12	67.50±0.11	162.74	74.65	0.091	0.439	0.507
M1 C	0530.48±9.49	33.60±7.18	63.06±1.37	164.62	75.73	0.093	0.445	0.535
M2 A	0239.04±5.60	06.49±1.28	52.79±1.77	100.39	44.85	0.055	0.271	0.289
M2 B	0268.27±4.51	20.63±5.33	42.65±5.25	102.27	46.47	0.057	0.276	0.332
M2 C	0646.19±5.91	35.46±10.78	78.45±4.11	197.40	90.71	0.111	0.533	0.629
M3 A	0048.52±3.58	44.96±3.71	73.32±0.46	153.54	67.08	0.082	0.415	0.536
M3 B	0570.30±6.53	33.60±6.61	65.34±4.79	170.95	78.70	0.097	0.462	0.552
M3 C	1026.13±7.62	18.31±0.48	62.71±1.61	189.00	89.13	0.109	0.505	0.554
M4 A	0537.48±11.2	37.89±7.88	71.38±2.28	181.35	83.03	0.102	0.489	0.592
M4 B	283.83±8.40	54.58±8.23	83.12±0.46	195.30	87.27	0.107	0.527	0.675
M4 C	551.01±6.53	11.36±9.62	61.80±1.03	142.16	65.55	0.080	0.384	0.415
Range	48.52±3.58-1026.13±7.62	6.49±1.28-54.58±8.23	42.65±5.25-83.12±0.46	100.39-197.40	44.85-90.71	0.055-0.111	0.271-0.533	0.289-0.675
Mean	483.97±7.32	28.43±5.30	66.84±2.02	161.44	73.68	0.090	0.435	0.512

Where M1 represent Eyenu, M2 represents Opanda, M3 represent Okereku and M4 represent Udegen-Mbeki. The letters A, B and C represents mining spot, 100 meters away from the mining spot and river area within the mining spot, respectively

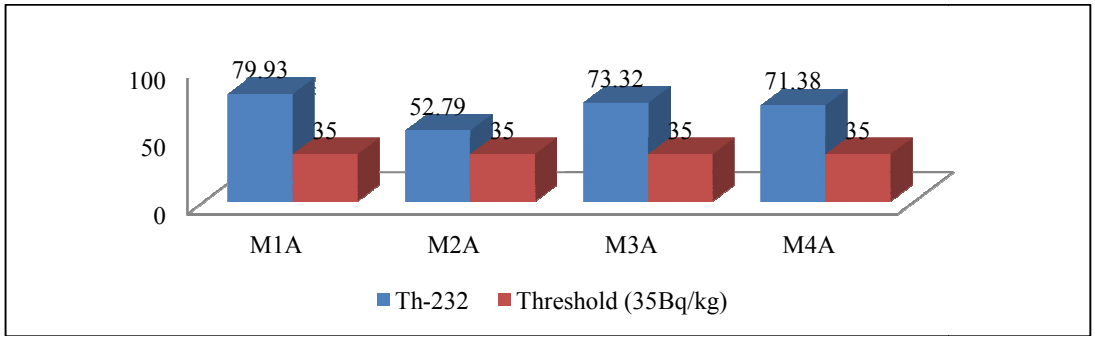

Fig. 4. Comparison of the spot's activity concentration for ^{232}Th with threshold

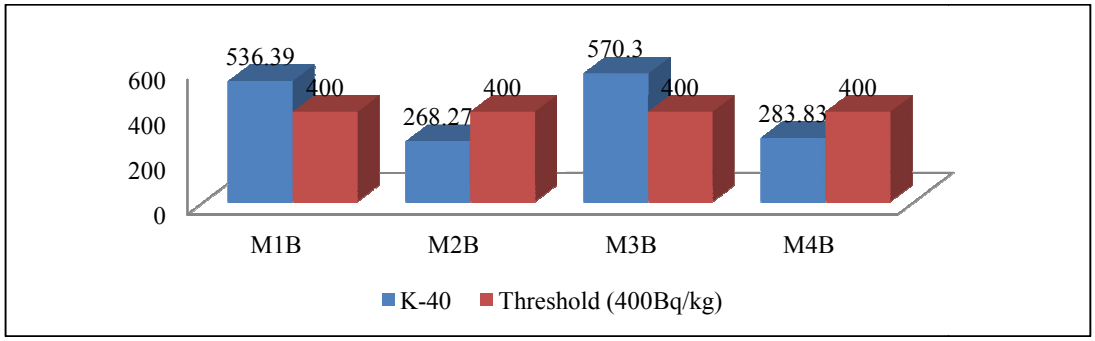

Fig. 5. Comparison of the hundred metre's activity concentration for ^{40}K with threshold

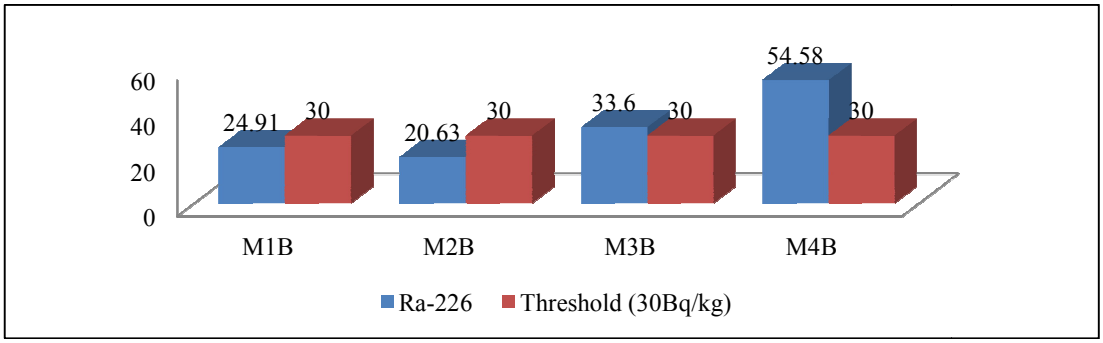

Fig. 6. Comparison of the hundred metre's activity concentration for ^{226}Ra with threshold

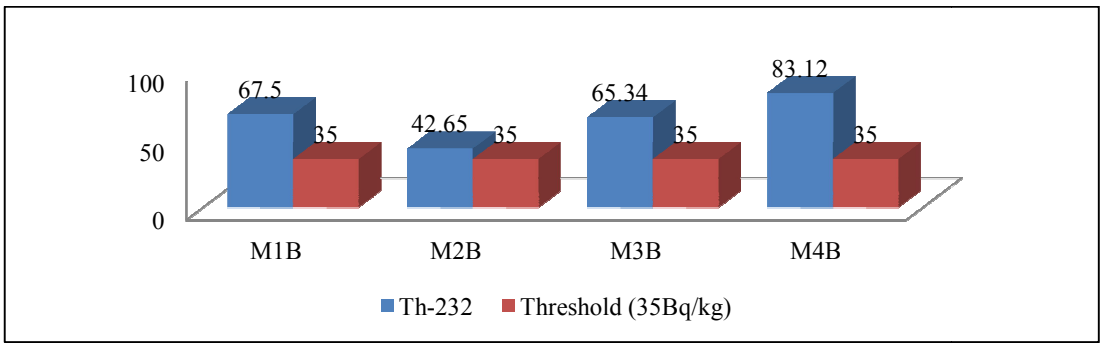

Fig. 7. Comparison of the hundred metre's activity concentration for ^{232}Th with threshold

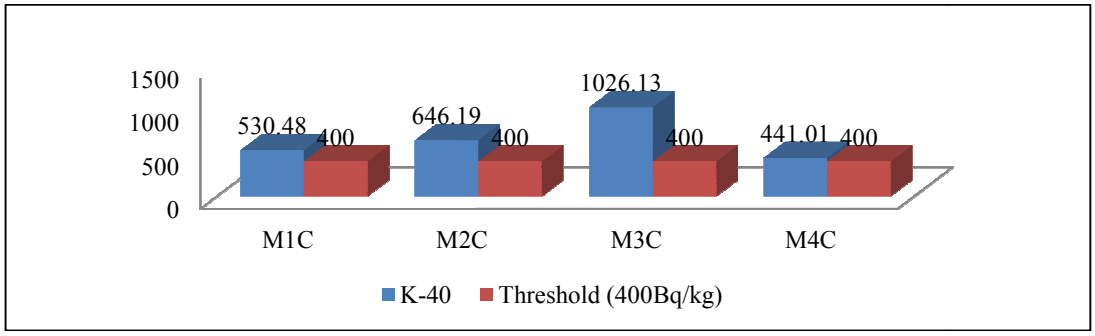

Fig. 8. Comparison of the water way's activity concentration for ^{40}K with Threshold

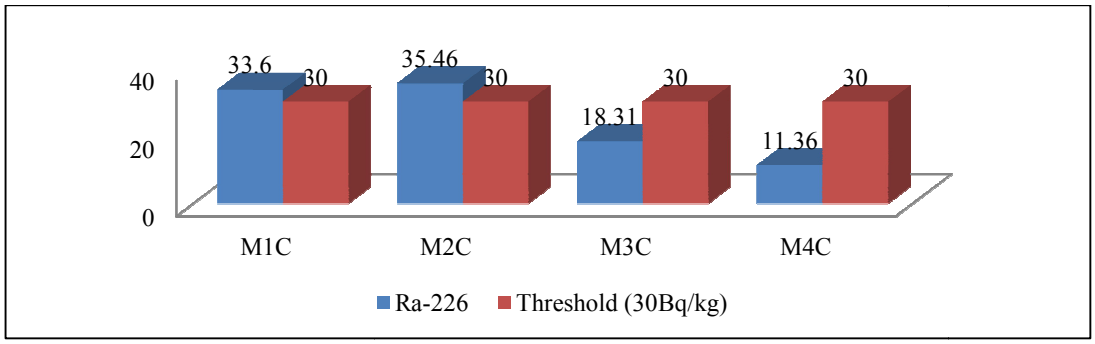

Fig. 9. Comparison of the water way's activity concentration for ^{226}Ra with threshold

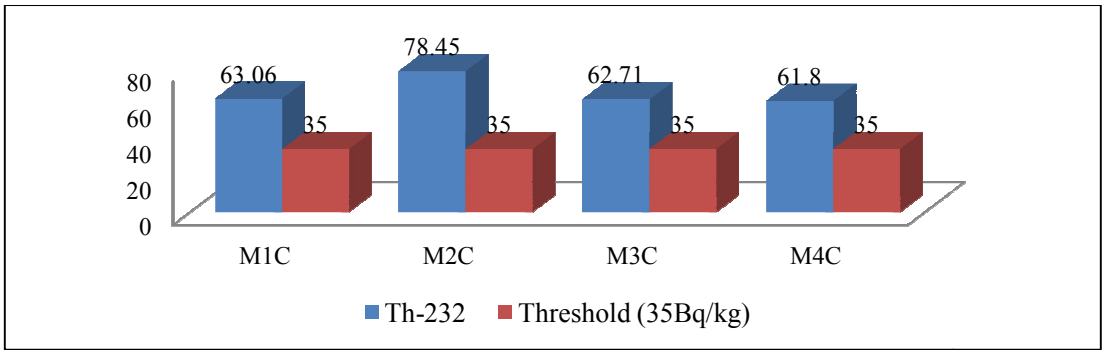

Fig. 10. Comparison of the water way's activity concentration for ^{232}Th with threshold

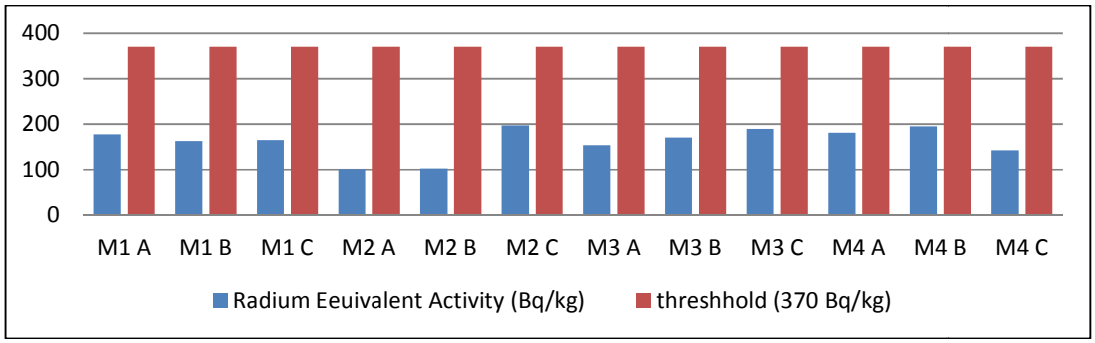

Fig. 11. Comparison of the radium equivalent activity for all locations with threshold

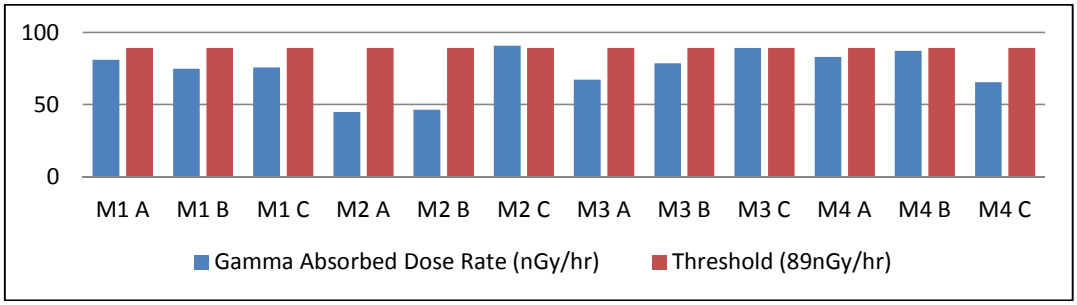

Fig. 12. Comparison of the gamma absorbed dose rate for all locations with threshold

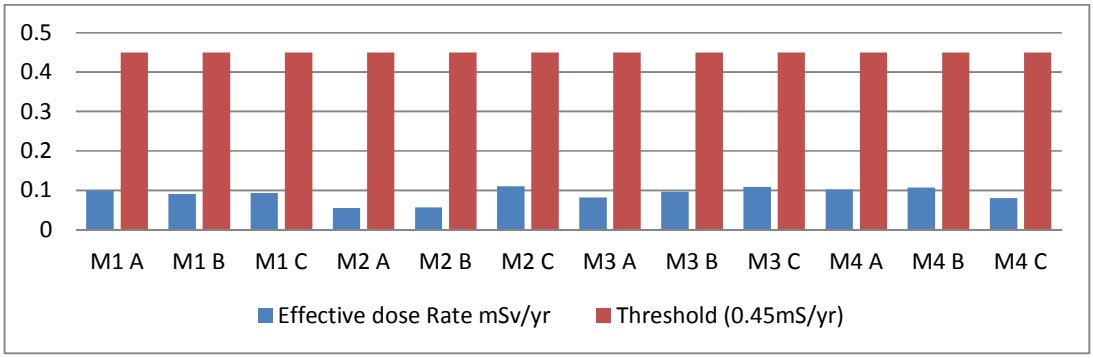

Fig. 13. Comparison of the effective dose rate for all locations with threshold

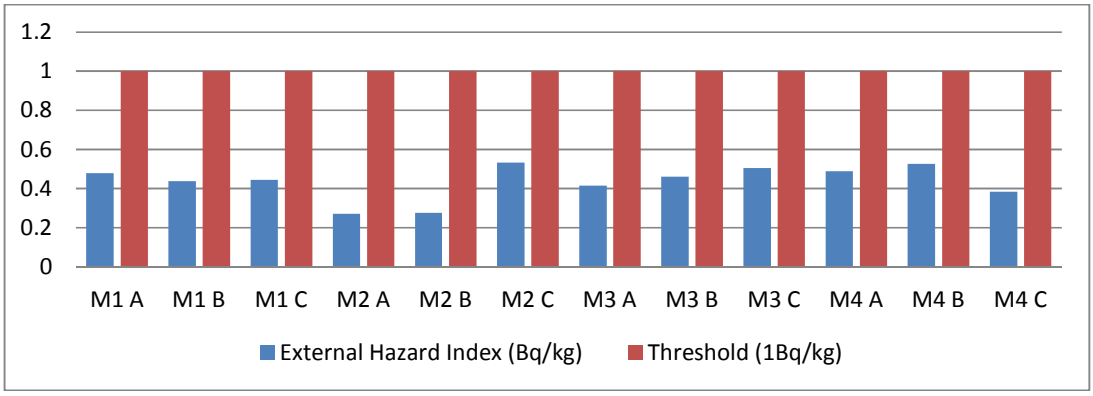

Fig. 14. Comparison of the external hazard index for all locations with threshold

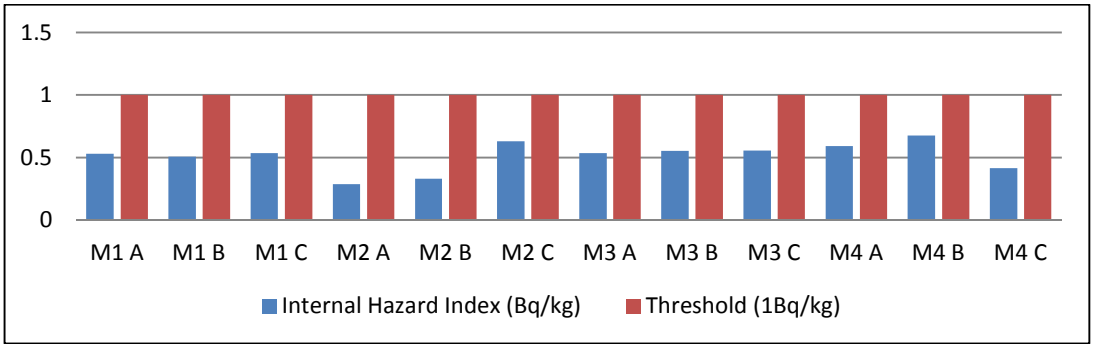

Fig. 15. Comparison of the internal hazard index for all locations with threshold

3.2 Discussion

Twelve soil samples from the study area have been analyzed. The activity of ^{40}K, ^{226}Ra, ^{232}Th, as well as parameters like Radium equivalent activity (Ra_{eq}), Absorbed Dose Rate, Effective Dose Rate, External Hazard Index and Internal Hazard Index are presented in Table 2. From Fig. 2, we can see that the concentration of ^{40}K in M2 A and M3 A are lower than the average standard, which 400 Bq/kg is recommended by regulatory bodies. While that of M1 A and M4 A is higher. From Fig. 3, we can see that the concentration of ^{226}Ra for M1 A and M2 A are lower than the average standard, which 30Bq/kg is recommended by regulatory bodies. While that of M3A and M4A are higher. From Fig. 4, we can see that the concentrations of ^{232}Th for all the locations plotted are higher than the average standard, which 35Bq/kg is recommended by regulatory bodies. From Fig. 5, we can see that the concentration of ^{40}K in M2 B and M4 B are lower than the average standard, which 400Bq/kg is recommended by regulatory bodies. While that of M1 B and M3 B is higher. From Fig. 6, we can see that the concentration of ^{226}Ra for M1 B and M2 B are lower than the average standard, which 30 Bq/kg is recommended by regulatory bodies. While that of M3 B and M4 B is higher. From Fig. 7, we can see that the concentration of ^{232}Th for all the locations plotted is higher than the average standard, which is 35 Bq/kg recommended by the regulatory bodies. From Fig. 8, we can see that the concentrations of ^{40}K for all the locations plotted are higher than the average standard, which 400Bq/kg is recommended by regulatory bodies. From Fig. 9, we can see that the concentration of ^{226}Ra for M3 C and M4 C are lower than the average standard, which 30Bq/kg is recommended by regulatory bodies. While that of M1 C and M2 C is higher. From Fig. 10, we can see that the concentrations of ^{232}Th for all the locations plotted are higher than the average standard, which 35 Bq/kg is recommended by regulatory bodies. From Fig. 11, it is observed that the values of Ra_{eq} in twelve samples were less than the acceptable safe limit of 370 Bq/kg recommended by regulatory bodies. From Fig. 12, except for two samples, all of the remaining values for the gamma absorbed dose rate is higher than the world average of 89 nG/h recommended by regulatory bodies. From Fig. 13, the values are found to be lower than the average standard of 0.45 $mSvyr^{-1}$ recommended by regulatory bodies. From Fig. 14, these values are found to be lower than the world standard of 1 $mSvyr^{-1}$ as recommended by regulatory bodies. From Fig. 15, these values are found to be lower than the world standard of 1 $mSvyr^{-1}$ as recommended by regulatory bodies.

4. CONCLUSION

In the course of this radiometric study, it was discovered that some places are subjected to high activity concentration and gamma absorbed dose rate. These areas with high level of radiation need regulatory control. The level of radiation in those areas is sufficiently high and can cause radiological hazard to the public of the area. Therefore, further investigation is needed to safeguard the areas with low-level radiation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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