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Estimation of Natural Radionuclides in Cattle from a Rearing-Field at Alabata, Abeokuta Ogun State, Southwestern, Nigeria

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Abstract

The natural radioactivity levels in granitic soils of some locations in Abeokuta were reported to be significantly higher than the world average. The grass (pennisetum purpureum) grown in such soils may be susceptible to high radioactivity levels through the plant root uptake of radionuclides from the soils. The ingestion of such grasses by livestock that human consume may result in enhanced internal radiation exposure. Therefore the aim of this study was to determine the radioactivity levels of ^{40}K, ^{226}Ra and ^{232}Th in grass, soils and dung; soil to grass radioactivity transfer and estimate the retained radionuclides in the cattle grazing in the area.

The results from the study showed the radioactivity levels in the soils are higher than the values earlier reported for Abeokuta and the world average values of 420 $Bqkg^{-1}$, 32 $Bqkg^{-1}$ and 40 $Bqkg^{-1}$ for ^{40}K, ^{226}Ra and ^{232}Th respectively.

1.0 Introduction

The presence of radioactivity everywhere in the human environments has been a phenomenon witnessed since the creation of the Earth. The foremost human radiation exposure originates from natural background sources that comprise terrestrial, extra-terrestrial sources as well as artificial (man-made) sources resulting from modern scientific and technological activities. The presence of natural radiations at the different horizon of the soils depends primarily on the geological formation in each region of the world [1, 2, 3]. The natural background radioactivity accounts for 96.1% of the total radiation dose to the world population while the man-made sources account for the remaining 3.9% [4].The earth crust typically contains naturally decay series isotopes (^{238}U and ^{232}Th) with their progenies and non-series radionuclide (^{40}K)that constitute the terrestrial (primordial) radionuclides. Out of the total natural background radiation dose that the world population receives about 85% is from terrestrial sources [5]and about 23% of the average annual dose to human from all radiation sources [6]. The radioactivity levels in any region are greatly dependent on the composition of each lithology of the area and the content of the rock from which the soil originates [7]. The presence of these naturally occurring radionnuclides in the soil poses serious challenges in the understanding and studying their activities (mobility, transfers, and translocation) in the environment, which is necessary for radiological assessments [8].

The natural radioactivity levels in the soil of some locations in Abeokuta were reported to be significantly higher than the world average [9].The radioactivity levels in grasses and vegetation grown in such soils may be enhanced through the plant-root uptake and as such, animals grazing on the grasses may have high retention of natural radionuclides in their flesh. The radionuclides in soil entered the plant through the plant-root uptake in the same manner non-radioactive elements enter the plant [10]. Animals that consume or ingest these contaminated plants are potentially dangerous for human consumption. Hence, effort should be made in carrying out radiological measurement in all the identifiable matrices in the area and it is therefore necessary to measure the activity concentrations of the natural radionuclides in the soil samples, the grasses and the dung so as to estimate the level of radioactivity retained in the cattle grazing in the study area that human consumed.

The area under investigation, Abeokuta shown in Figure1, lies in latitude 7.1^0 north of the Equator and longitude 3.2^0 east of the Greenwich Meridian with an elevation of approximately 150m above the sea level in the western and northern plains and the eastern and northern regions are characterized by deeply dissected hills rising to approximately 180m above the sea level [11]. Abeokuta enjoys tropical climate with distinct wet season that spans from March/April to October but a short break in August and dry season from November to February/March [12]

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The mass area of Abeokuta is underlain by basement complex of granitic rocks which are predominantly migmatites, biotitic-granite gneiss, porphyritic granites, with minor pegmatite and quartz vein [13]. Jone and Hockey [14] had earlier reported that the geology of the entire Abeokuta is a subset of the basement complex geology of western Nigeria. However the geology of Alabata where the samples were collected for the study comprises of varieties of gneisses which can be mapped as early phase granodiorite and quartz-diorite[15]. The gneiss granite rocks contain relatively high concentrations of uranium and thorium and their decay products [16, 17]. In addition, granite rock is known to contain high distribution of potassium up to about 3.5% [18, 19].

2.0 Material and Methods

3.0 Sampling

The study area is a cattle rearing field in Alabata, Abeokuta Ogun State. The area was divided into twenty sub-areas for good sampling coverage. The coordinates of the sub-areas were logged with Nuvi 1310 GPS, manufactured by GARMIN and listed in Table1.Ateach sub-area, cattle dung, grasses and soil samples were collected at four different points. Each sample collected at the four different points were mixed thoroughly and packed in a polythene bag to form a sample representation. The samples were then taken to Radiation and Health Physics Laboratory of Ladoke Akintola University of Technology for preparation and spectrometry measurements

4.0 Soil Sample Preparation

In the laboratory, the soil samples were air dried until the mass of the samples reduced to a constant value. The oven dried soil samples were thoroughly crushed, and pulverized. The powdered soil samples were sieved with a 2mm sieve and 200gm each of the powdered soil samples was packed into a clean and radon-impermeable plastic container of uniform size and sealed for a period of about 30 days to allow for secular equilibrium to establish between ^{226}Ra and ^{228}Ra and their respective gaseous progenies prior to gamma spectroscopy.

5.0 Grass sample preparation

The grass samples were cut into small pieces and air dried to constant mass, ground to pass through a 2.0mm sieve, then homogenized and transferred into uncontaminated geometry sample containers of uniforms size (60 mm in height by 65 mm in diameters). The containers were then sealed for a period of about 28 days (4 weeks) to for allow secular equilibrium between ^{226}Ra and ^{228}Ra and their respective progenies prior to gamma spectroscopy [20]

6.0 Dung sample Preparation

The dung samples were air dried to a constant mass, pounded in a mortal and then sieved with a 2.0mm, homogenized and transferred into uncontaminated geometry sample containers of uniforms size (60mm in height by 65mm in diameters). The containers were then sealed for a period of about 28 days (4 weeks) to for allow secular equilibrium.

7.0 Radioactivity Determination

The samples were analyzed using a single crystal 5.0cm × 5.0cm NaI(Tl) detector, manufactured by Scintitech Instrument, USA, is coupled with a Hamamatsa (R1306NSV3068) photomultiplier tube and a Multichannel Analyzer, MCA (2100R:01) manufactured by Price gamma Technology, USA. It does not require any internal PC interface slot or special memory reservations. The MCA 2100R includes Quantum MCA software for qualitative analysis. The MCA 2100R performs an automatic adjustment of the detector bias and amplifier gain. All calibration functions were made through the software. The standard reference soil sample from Rocketdyne Laboratories, California, USA with activity concentrations traceable to a mixed standard gamma source (Ref. No. 48722-356) by Analytic Inc., Atlanta Georgia and the standard reference food sample from the International Atomic Energy Agency, IAEA traceable to source Ref No IAEA-152 were used for efficiency calibration of the detector used in the study.

The detector has an energy resolution (FWHM) of about 6.2% in 0.662MeV (^{137}Cs) which is considered enough to distinguish the gamma ray energies of interest in the present study. The activity concentration of ^{214}Bi determined from its 1.760MeV γ-ray peak was chosen to provide an estimate of ^{226}Ra (^{238}U) in the sample, while that of the daughter radionuclide ^{208}Tl, determined from its 2.615MeV γ-ray was chosen to estimate ^{232}Th. The ^{40}K radionuclide was determined by measuring the 1.460MeV γ-ray emitted during its decay. Each of the sample containers was placed on top of the detector and analysed for a period of 36000 seconds (10 hrs.) and the radioactivity levels in the samples were obtained with the aid of the Quantum MCA software. However, the activity concentrations in the samples may be determined using Equation (2.1) [21].

$$C(Bq/kg) = \frac{C_n}{£_p I_¥ m_s} \qquad (2.1)$$

where C is the activity concentration of the radionuclide in the sample (Bqkg-1); Cn is the count rate under the photo peak, $£_p$ is the detector efficiency at the specific γ-ray energy, Iγ is the absolute transition probability of specific γ-ray and m_s is the mass (kg) of the sample. The operational capability of the measuring system without the influence of any sample is expressed as LLD in Equation (2.2) as

$$LLD = 1.96\left(\frac{\frac{B}{T} + SD_b^2}{k£.m}\right)^{1/2} \qquad (2.2)$$

whereB is the background radiation count, Tis the radioactivity counting time, SD_b is the estimated standard error of the net background count in the peak; *k* is the abundance of gamma emissions per radioactive decay; $£$ is the counting efficiency (cps/Bq) of the detector at energy E(keV) and m is the the mass of the sample. The lower limit of detection (LLD) obtained were 21.3Bqkg^{-1}, 9.1Bqkg^{-1} and4.9Bqkg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th respectively. The values that were lower than these values of detection limits in the present study were considered as below detection limit (BDL) of the detector. One-half of the detection limits, DL value was considered for calculating the mean activity concentration and other radiological assessments whenever the concentration of any radionuclide was below the detection level.

8.0 Result and Discussions

9.0 Activity Measurement in the Soil Samples

In the study, the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th radionuclides in the soil samples were observed higher than the corresponding results in grass samples. This affirmed the general assertion that only a fractional part of the radionuclides in the soil is transferable to the plant[22].As shown in Table 2,the radioactivity levels in the soil samples ranged from 364.7 to 1329.0 Bq/kg with a mean value of 829.1±260.6Bq/kg for ^{40}K; 19.9 to 94.1 with a mean value of 61.7±21.7Bq/kg for ^{238}U and 29.7 to 87.8Bq/kg with a mean value of 50.1±16.6Bq/kg for ^{232}Th. The results are significantly higher than 411±341 Bq/kg,184±205 Bq/kg and 65±29 Bq/kg for ^{40}K, ^{226}Ra and ^{232}Th respectively in Abeokuta and 446.2 Bq/kg,451 Bq kg^{-1} and163 Bq/kgfor^{40}K,^{226}Ra and ^{232}Th respectively in Jos as reported by Jibiri [23].The soil samples in the present study ^{40}K and ^{238}U exhibited high activity concentrations, and low ^{232}Th concentration when compared with the results reported for the soil samples from University of Ibadan [24].The ranges of soil radioactivity in the present study are higher than the range of values 7.05 to 99.15 Bq/kgfor ^{40}K; 1.61 to 50.90 Bq/kg for^{226}Ra and 1.23 to 32.15 Bq/kg ^{232}Th reported for surface of Kitchener drain of the River Nile Delta, Egypt [25].

The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the study were higher than the results in other literatures including some other locations from Abeokuta that had earlier been reported as higher than the world average values (35.0 Bq/kgfor ^{238}U, 28.0 Bq/kg for ^{232}Th and 410.0 Bq/kgfor^{40}K[26]. The results in the study were about double the world average values and this is attributed to the basement complex nature and the granitic rock outcrops which weathered and formed the soils of the study area.

10.0 Activity Measurement in the Grass Samples

As presented in Table 3,the activity concentrations measured in the grass varied from 210.2 to 370.6 Bq/kg with a mean value of 291.8±58.3 for ^{40}K; 10.4 to 13.1Bq/kg with a mean value of 11.7±0.8 for ^{238}U; and 4.5 to 12.2 Bq/kg with a mean value of 9.3±2.0Bq/kg for ^{232}Th. It is observed that the activity concentration of ^{40}K is the highest in the grass; this is attributed to the resulting residual potassium from the potassium fertilizers that farmers in the area of the study might have applied to their various farms at one time or the other. The results in the present study are higher than the values in some literatures. The activity concentrations inKuca vegetable from Jos north-central zone of Nigeria were 80.6Bqkg^{-1}for ^{40}K and 10.4Bqkg^{-1} for ^{226}Ra [10]. In Niger Delta (Ughelli and its environs) the activity concentrations in spear grass, were 1.7±4.3 Bqkg^{-1} and 69.3±9.4 Bqkg^{-1} for^{232}Th and ^{40}K respectively [27].It was also observed that the radioactivity levels in the grass from the study are higher than the values reported in some research studies. The activity concentrations in Ugwu (Telifairia) vegetable from Ondo South western Nigeria were 721.6Bqkg^{-1} and 28.94Bqkg^{-1}for ^{40}K and ^{232}Th respectively [28]. In Ibadan, the natural radioactivity concentrations due to^{238}U and ^{232}Th in elephant grass were found to be25.7±5.5 Bq kg^{-1}and 33.4±3.9 Bq kg^{-1}[23]. The ^{40}K and ^{238}U concentrations in the study were low compare to the values of 302 Bqkg^{-1}, 42 Bqkg^{-1} for ^{40}K, ^{226}Ra reported for Vernonia vegetables in Cameron [29].

11.0 Activity concentration in the Cattle Dung Samples

The natural radioactivity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the dung samples are presented in Table 3. The difference between the values of activity concentrations in the grass and the dung samples shown in Table 4are the assumed activity

concentration values of the radionuclides retained in the flesh of the cattle from the study area. The radioactivity levels in water from the area underlain with basement complex like the study area are very low [30]and therefore the activity concentrations in the water consumed by the cattle are regarded insignificant. As shown in the Table 4, the mean values of the radionuclides retained in the cattle flesh were 73.1 ±48.7 $Bqkg^{-1}$;1.2±0.8$Bqkg^{-1}$and 1.1±0.5$Bqkg^{-1}$for ^{40}K, ^{226}Ra and ^{232}Th respectively.

12.0 Soil to Grass Transfer Factors

Migration and accumulation of contaminants including radionuclides from soil to plant system is an assessment models commonly used in a soil-plant activity concentration ratio, referred to as transfer factor (TF).Factors such as soil characteristics, climatic conditions, type of plants, physic-chemical form of the radionuclides and the interfering element can all influence the transfer factor (TF) values [31].Various studies on natural radionuclides transfer or pathway mechanism to plant and human have been reported in the literatures [32, 33]. According to [33], the transfer factor (TF) is given by:

$$TF = \frac{A_F}{A_S} \qquad (2.3)$$

where A_F is the activity concentration of radionuclides in edible parts of food crop and A_S is the activity concentration of radionuclides in soil.

Using Equation (2.3), the transfer factor TFs for ^{40}K, ^{226}Ra and ^{232}Th were determined and the results were presented in Table 5.The mean values of the transfer factors TFs were 0.38±0.14, 0.23±0.13 and 0.20±0.08 for^{40}K, ^{226}Ra and ^{232}Th respectively. The values were higher than the range of values in other literatures [34], reported that soil-to-maize (shoot) transfer factor as 0.0074 and soil-to-maize (root) as 0.081 for ^{226}Ra; 0.0061 soil-to-maize shoot as 0.00045 and soil-to-maize (root) as 0.0061 for ^{232}Th.The TFs values for^{232}Th in the grass samples were smaller than the values obtained for ^{226}Ra. This is attributed to high solubility characteristics of ^{226}Ra compared to ^{232}Th and this observation was in agreement with the reports from [34, 35].

13.0 Conclusion

The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in the samples collected at cattle rearing field area of Alabata in Abeokuta were measured. The mean radioactivity distribution in all the samples is shown in Fig.2. The mean activity concentration of ^{40}K, ^{226}Ra and ^{232}Th were higher than the values in other literatures and about doubled the world average values. The soil samples exhibited highest radioactivity levels followed by the grass samples and the least was measured in the dung samples. It could be concluded that only a fractional amount of the radionuclides was transferred from the soil to the grass consumed by the cattle. The difference between the radionuclide contents in the grass and the dung is assumed the estimated radionuclide retained in the flesh of the cattle.

Table 1: Coordinates and elevation at the sub-areas

Sub-areas	Latitude	Longitude	Elevation
1	07^0 13' 48.2"	003^0 25' 22.4"	124m
2	07 13' 51.9"	003^0 25' 18.1"	123m
3	$07^0$13' 53.7"	003^0 25' 19.4"	126m
4	$07^0$13' 55.3"	003^0 25' 20.3"	125m
5	$07^0$13' 57.2"	003^0 25' 21.4"	125m
6	$07^0$13' 58.9"	003^0 25' 21.8"	124m
7	$07^0$13' 50.9"	003^0 25' 14.1"	125m
8	07^0 13' 51.2"	003^0 25' 12.4"	127m
9	07^0 13' 52.4"	003^0 25' 12.6"	127m
10	07^0 13' 53.7"	003^0 25' 13.4"	132m
11	07^0 13' 55.7"	003^0 25' 11.3"	135m
12	$07^0$13' 54.6"	003^0 25' 08.7"	136m
13	$07^0$13' 52.5"	003^0 25' 09.5"	137m
14	$07^0$13' 49.5"	003^0 25' 14.6"	123m
15	$07^0$13' 46.7"	003^0 25' 13.4"	120m
16	$07^0$13' 45.3"	003^0 25' 11.9"	120m
17	$07^0$13' 43.2"	003^0 25' 09.3"	120m
18	$07^0$13' 42.8"	003^0 25' 06.7"	120m
19	07^0 13' 41.0"	003^0 25' 00.9"	118m
20	$07^0$13' 40.5"	003^0 25' 00.5"	118m

Table 2: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the grass and soil samples from the study area

	Grass			**Soil**		
Sub-areas	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)
1	370.6±35.3	12.4±07.7	12.2±5.6	1302.0±10.2	56.7±5.6	49.3±5.6
2	267.3±39.7	10.9±01.7	10.5±4.6	713.4±11.4	32.7±8.41	56.3±4.81
3	325.6±18.3	11.4±03.1	10.4±5.6	1329.0±51.4	43.1±15.5	60.7±11.5
4	212.1±09.7	12.0±02.0	8.5±5.2	764.3±44.2	71.9±1.41	29.9±2.92
5	215.3±24.2	10.4±09.1	4.5±1.6	979.5±19.2	85.2±7.1	51.4±3.74
6	365.1±21.0	12.6±04.2	7.2±2.5	789.0±74.3	20.9±5.41	32.2±9.7
7	341.2±16.0	10.8±03.1	7.0±1.9	889.6±18.2	48.3±20.41	46.4±11.4
8	210.2±17.3	12.9±09.7	5.5±2.1	628.5±22.4	71.8±9.31	64.1±9.41
9	242.5±11.1	12.5±04.4	11.2±5.6	749.7±11.4	60.0±6.46	68.9±7.0
10	325.4± 9.0	11.2±01.5	12.2±5.0	987.3±16.2	19.9±11.41	46.4±5.43
11	289.3±11.4	11.8±05.1	10.1±3.7	624.7±41.3	81.1±10.0	37.9±4.12
12	367.0±11.2	10.9±02.7	8.9±1.9	876.8±61.2	54.1±11.34	77.7±3.41
13	215.2±45.1	11.1±09.4	10±7.0	548.5±22.2	94.1±21.43	87.8±7.54
14	221.7±32.8	12.0±03.7	9.2±5.6	596.8±11.4	78.3±11.0	25.3±11.6
15	342.4±41.1	11.1±06.4	9.2±4.3	654.3±11.4	52.2±14.1	38.9±6.4
16	315.3±12.4	11.2±01.6	10.4±3.6	1243.6±31.9	87.4±6.41	41.3±15.3
17	339.8±33.8	11.4±04.3	8.9±5.4	687.5±11.1	68.6±4.41	63.8±9.21
18	315.4±11.1	13.1±01.7	10.1±1.9	364.7 ± 17.6	50.9±11.41	46.8±7.25
19	234.7±32.8	11.2±06.6	9.1±5.9	744.5±16.3	88.4±19.43	29.7±3.41
20	318.4±9.7	12.3±09.4	10.1±2.6	1108.1±31.1	69.1±9.81	47.1±11.33
Mean±σ	291.8±58.3	11.7±0.8	9.3±2.0	829.1±260.6	61.7±21.7	50.1±16.6

Table 3: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the dung and grass samples

Sub-areas	**Dung** ^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)	**Grass** ^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)
1	189.9±12.6	11.4±3.2	11.0±2.1	370.6±22.2	12.4±0.3	12.2±1.6
2	112.6±10.5	8.7±2.5	9.7±1.7	267.3±26.3	10.9±1.1	10.5±2.4
3	231.1±17.2	10.3±2.8	9.1±1.9	325.6±54.1	11.4±1.5	10.4±2.1
4	157.7±12.6	11.3±1.7	7.8±2.2	212.1±44.5	12.0±0.5	8.5±2.2
5	180.1±22.2	9.2±1.2	4.0±1.7	215.3±38.7	10.4±1.3	4.5±1.9
6	225.5±34.2	10.3±1.6	6.8±1.6	365.15±33.3	12.6±0.4	7.2±2.3
7	241.5±19.6	9.6±3.2	6.0±1.2	341.2±46.5	10.8±0.7	7.0±1.2
8	139.3±32.7	11.9±1.3	4.9±2.2	210.2±53.9	12.9±1.1	5.5±0.1
9	210.1±12.6	11.6±1.3	10.9±1.9	242.5±34.5	12.5±0.5	11.2±2.2
10	312.4±28.5	10.0±3.2	10.4±1.7	325.4±28.5	11.2±0.3	12.2±1.1
11	244.3±46.5	8.9±2.2	9.0±1.6	289.3±34.2	11.8±1.3	10.1±1.1
12	301.1±26.3	10.5±2.3	6.8±3.1	367.0±52.5	10.9±1.5	8.9±0.2
13	118.4±12.6	10.4±3.4	8.0±1.4	215.2±46.2	11.1±2.0	10.0±1.8
14	128.5±17.8	11.1±2.1	8.6±1.6	221.7±12.6	12.0±1.3	9.2±2.3
15	325.2±32.5	8.2±1.2	8.2±1.2	342.4±33.3	11.0±0.9	9.2±1.5
16	221.1±20.1	10.7±1.7	10.4±1.8	315.3±34.2	11.2±0.1	10.4±3.1
17	332.5±33.3	10.7±2.9	8.0±2.1	339.9±26.3	11.4±0.2	8.9±2.1
18	250.2±52.5	11.7±2.2	8.2±2.2	315.4±34.4	13.1±0.8	10.1±1.2
19	224.7±19.5	10.7±1.3	7.9±2.3	234.7±34.1	11.2±0.7	9.1±2.1
20	226.3±42.9	12.2±2.8	9.1±1.6	318.45±33.3	12.3±0.1	10.1±2.3
Mean ±σ	218.6±66.0	10.5±1.1	8.3±1.9	291.8±58.3	11.7±0.8	9.3±2.0

Table 4: Estimated activity concentrations of ^{40}K, ^{238}U and ^{232}Th retained in the cattle

Sub-areas	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)
1	180.7	1.0	1.2
2	154.7	2.2	0.8
3	94.5	1.2	1.3
4	54.4	0.7	0.7
5	35.2	1.3	0.5
6	139.6	2.3	0.5
7	99.7	1.2	1.0
8	70.9	0.9	0.6
9	32.5	0.9	0.3
10	13.1	1.2	1.8
11	45.0	2.9	1.1
12	65.9	0.5	2.2
13	96.9	0.8	2.0
14	93.2	0.9	0.7
15	17.2	2.9	1.0
16	94.2	0.5	1.0
17	7.4	0.7	1.0
18	65.3	1.4	1.9
19	9.9	0.5	1.2
20	92.1	0.1	1.0
Mean ±σ	73.1±48.7	1.2±0.8	1.1±0.5

Table 5:Transfer ratio of ^{40}K, ^{238}U and ^{232}Th of the soil to grass samples

Sub-areas	TF(^{40}K)	TF(^{238}U)	TF(^{232}Th)
1	0.28	0.22	0.25
2	0.37	0.33	0.19
3	0.25	0.26	0.17
4	0.28	0.17	0.28
5	0.22	0.12	0.09
6	0.46	0.60	0.22
7	0.38	0.22	0.15
8	0.33	0.18	0.09
9	0.32	0.21	0.16
10	0.33	0.56	0.26
11	0.46	0.15	0.27
12	0.42	0.20	0.12
13	0.39	0.12	0.11
14	0.37	0.15	0.36
15	0.52	0.21	0.24
16	0.25	0.13	0.25
17	0.49	0.17	0.14
18	0.86	0.26	0.22
19	0.32	0.13	0.31
20	0.29	0.18	0.22
Mean ±σ	0.38±0.14	0.23±0.13	0.20±0.08

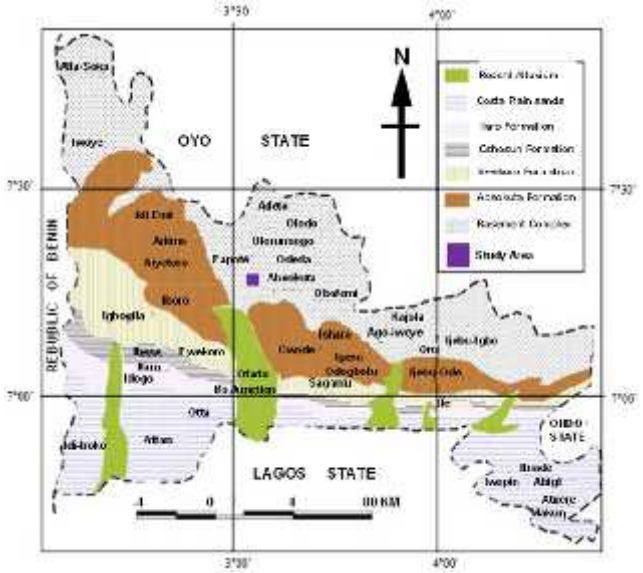

Figure 1: Geological map of Ogun State showing the study area [36]

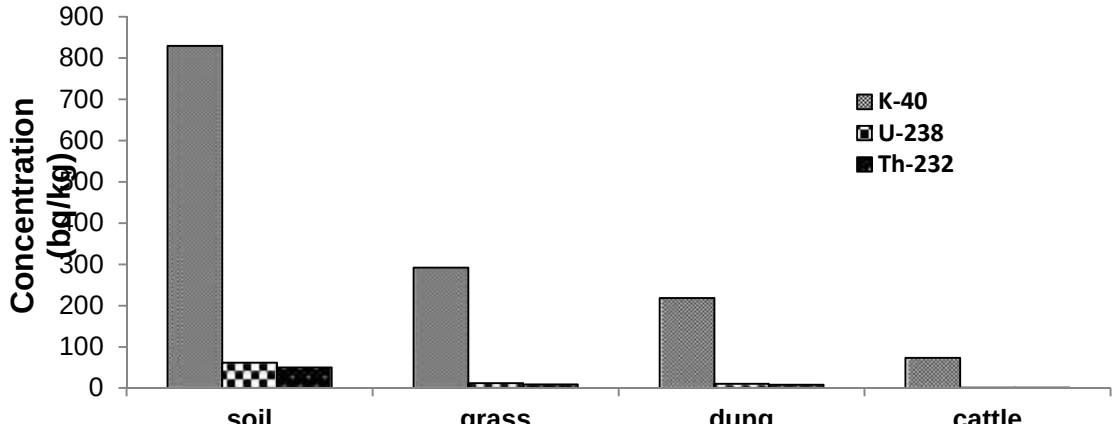

Fig. 2: Mean distribution of radionuclides in all the samples

14.0 References

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