Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr

Statistical Assessment of Radiation Exposure Risks of Farmers in Odo Oba, Southwestern Nigeria

Theophilus Aanuoluwa Adagunodo [a, *], Lukman Ayobami Sunmonu [b], Moruffdeen Adedapo Adabanija [c], Maxwell Omeje [a], Oluwole Akinwumi Odetunmibi [d], Victor Ijeh [b]

[a] Department of Physics, Covenant University, Ota, Ogun State, Nigeria
[b] Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
[c] Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
[d] Department of Mathematics, Covenant University, Ota, Ogun State, Nigeria
[*]Corresponding author: taadagunodo@yahoo.com; taadagunodo@gmail.com; theophilus.adagunodo@covenantuniversity.edu.ng; +2348067360352

http://dx.doi.org/10.19111/bulletinofmre.495321

ABSTRACT

The toxicity risks of being over exposed to ionizing radiation in the environments are of great concern to scientists. The distribution of radioactivity concentrations of thorium, uranium and potassium were studied in randomly selected soil samples from ten (10) farm locations in Odo Oba, southwestern Nigeria in order to determine the radiological risks of farmers' exposure to radionuclides. The radioactivity concentrations of thorium, potassium, and uranium varied from 11.37 to 101.91 Bq kg^{-1}, 788.76 to 1693.30 Bq kg^{-1}, and 12.35 to 50.64 Bq kg^{-1} respectively. The mean estimation of thorium and potassium are greater than the global average by factors of 1.5 and 2.7, while that of uranium fall below the global average. The estimation of radioactivity ratios showed that depletion of uranium and enrichment of thorium occur in the study area. The estimated radiological risks showed that the mean values of Dose Rate (DR), Annual Effective Dose (AED), Annual Gonadal Equivalent Dose (AGED), Excess Lifetime Cancer Risk (ELCR) and Gamma Radiation Hazard Index ($I_{\gamma r}$) are greater than the global average by the factors of 1.42, 1.43, 2.04, 1.24 and 1.36 respectively. However, the mean of External Radiation Hazard Index (H_{Ext}) fall below the global average. The descriptive analysis revealed that 92.3% of the analyzed variables showed positive skewness, while 69% showed positive kurtosis as well. However, multivariate analyses involving Pearson's correlation, Factor Analysis (FA), Hierarchical Cluster Analysis (HCA) were further used to explain the correlations among the data sets. It was affirmed from the multivariate analysis that the radiological hazards occur as a result of contributions from the three naturally occurring radionuclides (that is, thorium, uranium and potassium). The values obtained in this study revealed that the sampled locations are contaminated zones for farmers.

Keywords: Radiation exposure, Farmers' exposure risks, Inductively coupled plasma mass spectrometry, Radiological risks, Statistical assessment.

1. Introduction

All soils are radioactive as a result of primordial and/or cosmogenic radionuclides being present naturally. Radionuclides reach the soil through soil-borne photosynthesis and water absorption, as well as natural radioactive elements of potassium (^{40}K), uranium, thorium and their daughters. The former process occurs when the radioactive carbon (carbon-14) and radioactive hydrogen (tritium) are formed by the action of cosmic rays in the atmosphere which later fall to the surface of the earth. The later are present in the geological formations of many soils. Staying more than the required time in a natural radioactive contaminated area could be dangerous to human as the radionuclides inhaled can be greater than the allowable limit (ATSDR, 1990). Humans can be exposed to radioactive chemicals in the environment (breathing air, drinking, eating, or smoking substances with radioactive constituents), through the physical contact (such as skin), or coming too close to locations with high concentrations of radioactive chemicals, such as when there are industrial accidents or hazardous waste sites. Some of the factors that determine the toxicity

exposure to hazardous chemicals include: dose, pathway to the exposure, number of chemicals exposed to, and the individual features (for example, eating habits, sex, age, health status, family trait and life style) (ATSDR, 1990).

Nigerian farmers are often referred to as hand-hoe (peasant) farmers. This is due to the fact that mechanization rate in Nigeria is 0.27 hp/hectare, a lower standard to the recommended rate of 1.5 hp/hectare by FAO (2013). Apart from the method becoming obsolete globally, it could serve as a channel for being exposed to natural radioactive materials on a contaminated farm land ignorantly. Exposure to radionuclides in a naturally occurring radioactive contaminated zone needs to be avoided or access the land with protective wears. Long-term exposure to radium and uranium through inhalation has several effects as chronic lung diseases, anemia, acute leucopoenia, necrotizing periodontal disease, tumours in the bones, nasal and cranial nerves. Overexposure to thorium causes cancers of different kinds in human systems such as in lung, bone, pancreas, kidney, and liver. It can also cause hepatic and leukaemia (Ramasamy et al. 2009). Therefore, radionuclide's activity concentrations and the risks associated with farmer's exposure to these radioactive elements should be monitored.

Exposure to natural radioactivity is a function of the natural radioactive elements present in that area (UNSCEAR, 2000). Radioactivity of an area can be used to estimate the dose rates and the risks associated with over exposure to the natural radionuclides in a radioactive contaminated region (Alzubaidi et al. 2016).Thorium -232 and Uranium -238 decay series as well as potassium -40 are the natural radionuclides that are used for estimating the abundance of thorium, uranium and potassium in the subsurface. These natural elements contribute greatly to the dose received by humans. Radionuclides can be transferred to food chain through soil, rocks, and water bodies since they contain appreciable quantities of radioactive elements (Alzubaidi et al. 2016).

Knowledge of natural radioactivity present on farm land will guide in the assessment of possible risks associated with external exposure to radiation through inhalation. Hence, this study is aimed at evaluating the radiation exposure risks of farmers' in Odo Oba, Southwestern Nigeria.This study was borne out of the increasing economic activities mostly agriculture (farming and fishing) and cottage industries prompted by population growth. Odo Oba is the source of food crops to Ogbomoso and its environs. Agricultural practices are most eminence in the study area possibly due to the availability of water that Oba River provides. Among the researchers that have investigated on the radioactivity concentration emanating from subsurface and its risks include: Odunaike et al. (2008), Gbadebo and Amos (2010), Akinloye et al. (2012), Avwiri et al. (2012), Chandrasakaran et al. (2014), Qureshi et al. (2014), Rafique et al. (2014), Usikalu et al. (2014), (2017), Ademola et al. (2015), Ravisankar et al. (2015), Alzubaidi et al. (2016), Adagunodo et al. (2017b), Adagunodo et al. (2018a) and (2018b).

2. The Study Area and Its Geology

Odo Oba is located between the latitude 8° 2′ 46.7″ to 8° 2′ 58.5″ N and longitude 4° 8′ 00″ to 4° 9′ 15″ E (Fig. 1a). It is a settlement that is situated at the southwest of Ogbomoso, southwestern Nigeria. The average elevation of the study area is about 267 m. Materials being carried from several tributaries over the years are deposited around Oba river, a major river for irrigation in the study area (Fig. 1b), due to the planar surface of the study area. This has enhances the deposition of the Quaternary sediments in Odo Oba. The drainage pattern of Odo Oba is dendrite in nature. The climate of the study area is distinguished by averagely high temperature. Moderate-to-heavy rainfall is experienced in the study area between March and July annually, an average annual rainfall of 1,247mm. The Relative Humidity (RH) is at its peak at the early hours of the day, which decrease towards the post meridiem. The minimal and maximal RH is experienced from December – February and July – September annually. The continental air mass blows dry air (with little or no moisture) across the region during the dry season. In turn, the tropical air mass takes charge in the rainy season (Adagunodo et al. 2017b).

In Nigeria, four hydrogeological provinces have been reported in literature, these include: Volcanic-, Precambrian basement-, consolidated and unconsolidated sedimentary rocks. Odo Oba lies perfectly on the Precambrian basement

domain of SW Nigeria (Fig. 2), which composed of metamorphic and crystalline rocks of > 550 My (Sunmonu et al. 2012). This geological domain is constituted by gneiss, meta-sedimentary, and older granites (Jones and Hockey, 1964; Adagunodo and Sunmonu, 2012; Olafisoye et al. 2012; Sunmonu et al. 2012; Adagunodo et al. 2013a; 2013b; 2013c; Oladejo et al. 2013; Olafisoye et al. 2013; Adagunodo et al. 2017a; 2017b). The banded and granite gneisses are the dominant rock units in Odo Oba. The other rock units in the study area are quartzite, and sparsely distributed pegmatite (Adagunodo et al. 2017b; 2018c) (Fig. 2).

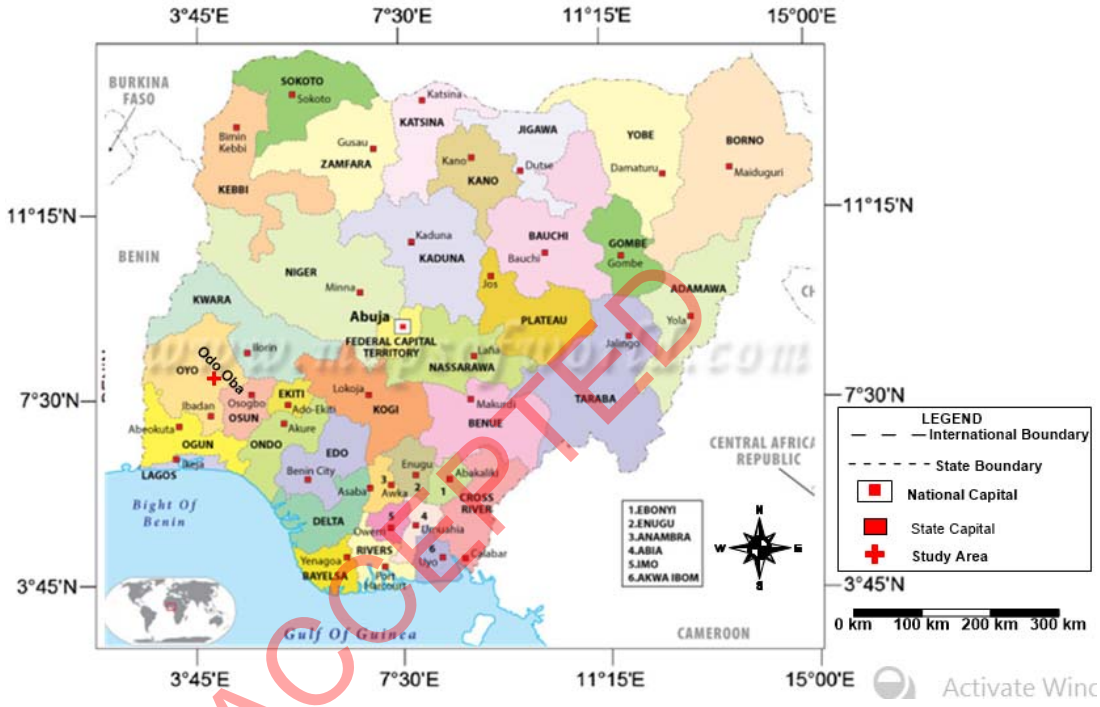

Fig. 1a. States and Capitals in Nigeria showing Odo Oba in Oyo state, Nigeria

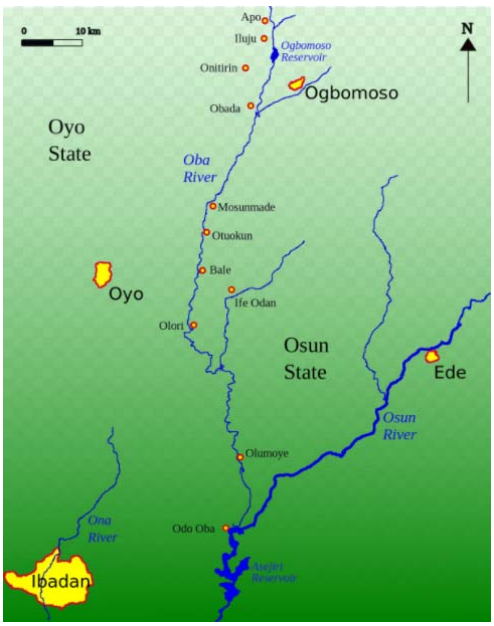

Fig. 1b. Rivers in south-west Nigeria showing Odo Oba (adapted from Rivers of Yorubaland, 2017).

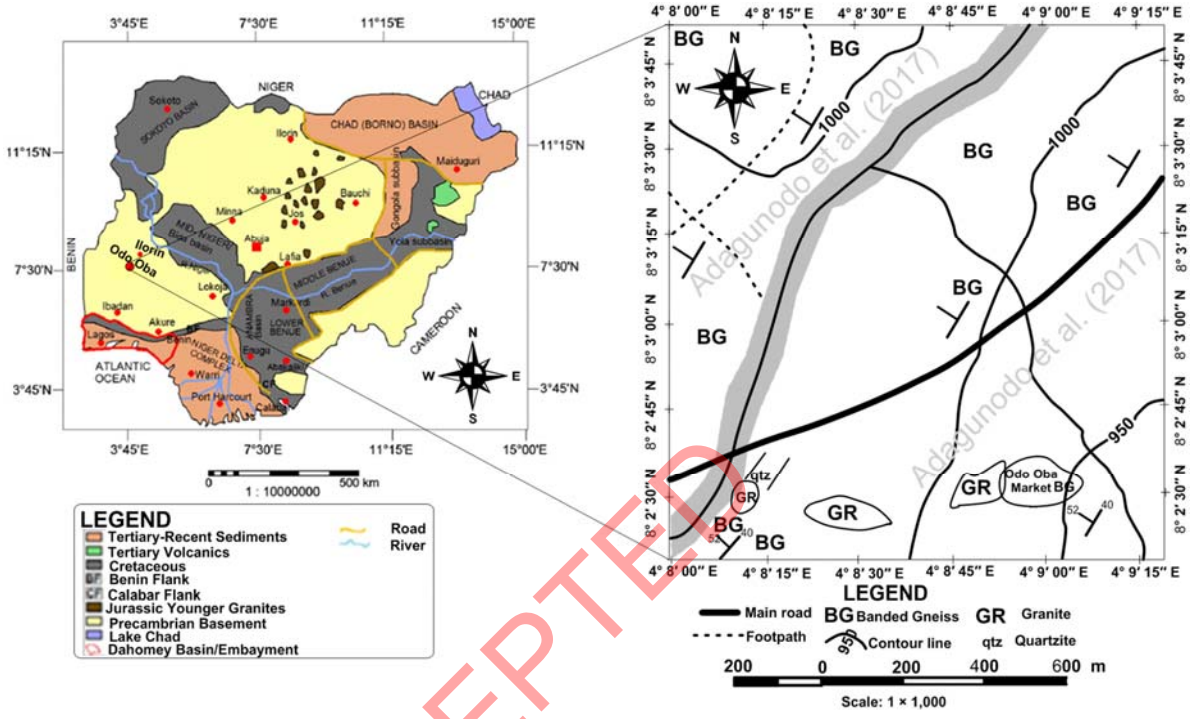

Fig. 2. Geological domains in Nigeria revealing Odo-Oba geology (modified from Obaje (2015) and Adagunodo et al. (2017b; 2018c)).

3. Materials and Methods

Topsoil samples (up to a depth of 25 cm) from ten (10) farm locations (S1 to S10) were randomly taken for the analysis (Fig. 3). This was carried out in order to investigate the toxicity risks of farmers' exposure to natural radioactivity in Odo Oba farm land. The results obtained are expected to reveal the radionuclide dispersions in the area and be used for further hazards' evaluation. In respect of this, the samples collected were dried under ambient temperature for number of weeks, and sieved by a 2 mm mesh to remove larger objects. Each sample was packed into a plastic sock and transported to Canada for Analysis. The analysis was carried out in ACME laboratories, Canada. AcmeLabs is one of the world-class geochemical and assaying laboratories to geoscientists. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to determine the concentrations of radionuclides (^{238}U and ^{232}Th) and potassium (^{40}K) in the samples. ICP-MS is one of the techniques used for radionuclide and elemental analysis either solid or liquid samples. The detection limit of ICP-MS for ^{238}U, ^{232}Th and ^{40}K are 0.05 ppm, 0.1 ppm and 0.01% respectively. The samples were dried at 110^{o}C in the oven to constant weight and further grounded to a powder. After grinding of each sample, high pressure compressor air with nozzle was used to blow the remnant from the grinder in order to avoid cross-contamination. The samples were digested and were transferred to Teflon beakers for evaporation using a hot plate. The residues were dissolved in 10% HNO_3 for fifteen minutes to ensure complete digestion, which was finally dissolved in 100 ml of HNO_3. The certified soil reference material (calibration standard) was digested with the same proportion of HNO_3 for quality control analysis. Prior to the ICP-MS analyses, standard solutions were prepared from SPEX Multi-element Plasma Standard in order to obtain the calibration curves for the analyses. Each sample was analyzed thrice to monitor the reproducibility of each result, which is in line with the standard procedures highlighted by Sahoo et al. (2001), (2011), and Bank et al. (2016). The concentrations of potassium, uranium and thorium in each soil sample were given in percent (%) and parts per million (ppm) respectively. Eqs. (1) to (3) were further used to covert respective concentration to Becquerel per kilogram (Bq kg^{-1}) in accordance with IAEA (1989) and Omeje et al.

(2013) models. The activity concentrations' results from AcmeLabs (in % and ppm) and the converted results (in Bq kg^{-1}) are revealed in Table 1.

1% of ^{40}K = 313 Bq kg^{-1} (1)

1 ppm of ^{238}U = 12.35 Bq kg^{-1} (2)

1 ppm of ^{232}Th = 4.06 Bq kg^{-1} (3)

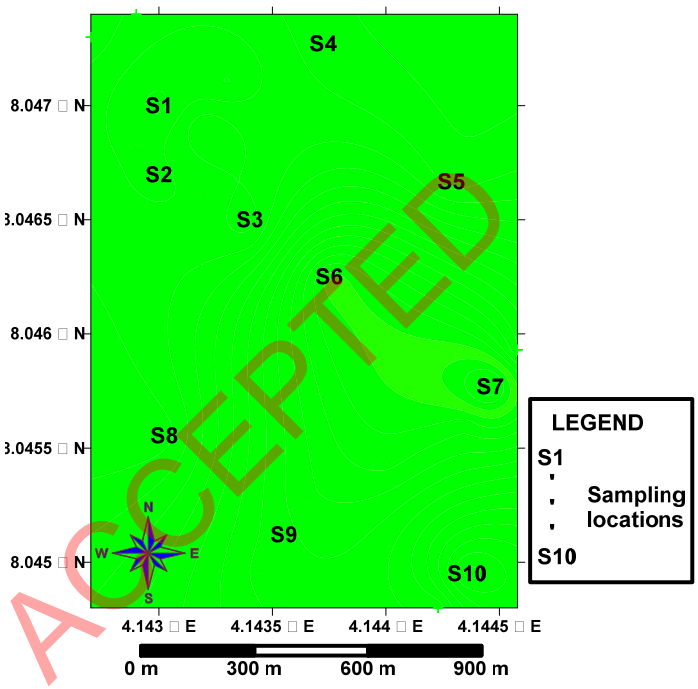

Fig. 3. Sampling locations in the study area.

Table 1. Concentrations of natural radioactivity in soil samples of Odo Oba

Samples	Uranium (ppm)	Thorium (ppm)	Potassium (%)	Uranium (Bq kg^{-1})	Thorium (Bq kg^{-1})	Potassium (Bq kg^{-1})
S1	2.60± 0.19	12.80 ± 3.00	2.69 ± 0.35	32.11 ± 2.35	51.97± 12.18	841.97± 109.55
S2	1.00 ± 0.43	2.80 ± 1.00	3.43 ± 0.92	12.35 ± 5.31	11.37± 4.06	1073.59± 287.96
S3	2.20 ± 0.11	9.90 ± 3.00	2.85 ± 0.13	27.17 ± 1.36	40.19± 12.18	892.05± 40.69
S4	1.50 ± 0.92	6.20 ± 2.00	2.52 ± 0.54	18.53± 11.36	25.17± 8.12	788.76± 169.02
S5	2.50 ± 0.21	9.00 ± 2.00	3.29 ± 0.73	30.88± 2.59	36.54± 8.12	1029.77± 228.49
S6	1.10 ± 0.09	3.70 ± 2.00	2.94 ± 0.21	13.59± 1.11	15.02± 8.12	920.22± 65.73
S7	2.10 ± 0.25	10.90 ± 3.00	5.41 ± 0.17	25.94± 3.09	44.25± 12.18	1693.33± 53.21

S8	3.70 ± 0.21	13.70 ± 1.00	3.70 ± 0.37	45.70± 2.59	55.62± 4.06	1158.10± 115.81
S9	4.10 ± 0.56	25.10± 1.00	3.67 ± 0.80	50.64± 6.92	101.91± 4.06	1148.71± 250.40
S10	3.00 ± 0.17	14.90 ± 1.00	4.71 ± 0.29	37.05± 2.10	60.49± 4.06	1174.23± 90.77

N.B: For S1, 2.60 is the mean of the uranium results for sample 1, while ± 0.19 is the standard deviation value.

4. Results and Discussion

4.1.Activities of ^{238}U, ^{232}Th and ^{40}K

The distributions of the activities of ^{238}U, ^{232}Th and ^{40}K in the ten (10) analyzed topsoil samples are presented in form of bar charts, as revealed in Figs. 4a to 4c. The activities range from 12.35± 5.31 (S2) to 50.64± 6.92 (S9) Bq kg^{-1} for ^{238}U with an average of 29.40 Bq kg^{-1}, 11.37± 4.06 (S2) to 101.91± 4.06 (S9) Bq kg^{-1} for ^{232}Th with an average of 44.25 Bq kg^{-1}, and 788.76± 169.02 (S4) to 1693.3± 53.21 (S7) Bq kg^{-1} for ^{40}K with an average of 1072.07 Bq kg^{-1} respectively. The obtained results of S8, S9 and S10 for ^{238}U are greater than the global average value of 35 Bq kg^{-1}(Sartandel et al., 2009; Chandrasekaran et al., 2014). Apart from S2, S4 and S6 that showed lower values than the global recommended value of 30 Bq kg^{-1} (Chandrasekaran et al., 2014), other samples possessed higher results than the global average for ^{232}Th. However, the results obtained for ^{40}K have higher values than the recommended limit of 400 Bq kg^{-1} as reported by Chandrasekaran et al. (2014). The activities of ^{238}U, ^{232}Th and ^{40}K are in the order ^{238}U $<^{232}Th$ $<^{40}K$ with only ^{238}U showed an average value below the world average value for radionuclides in soil samples of Odo Oba farm.

Thorium is a naturally occurring radioactive metal. This substance is almost present everywhere, at least in small amount. It is found in rocks, soil, surface water, groundwater, animals and plants. Most of the naturally occurring thorium exists as ^{232}Th (isotope). Apart from this natural isotope, there are more than ten (10) isotopes of thorium that can be produced artificially. Thorium does not easily dissolve in water or evaporate from soil or water into the air. The high values recorded for ^{232}Th might be attributed to the topographical settings of Odo Oba (Oba River Basin). From the literature (Adagunodo et al. 2017b), the transported materials by the river channels over the years are mixed with the soil structures of Odo Oba, because the study area possess a planar surface. Since the soil containing thorium can be washed into rivers and be transported to another plane (such as Odo Oba), this has justified the average value recorded for thorium which is greater than the global average by a factor of 1.5. Farmers working on this area can be exposed to thorium by inhaling contaminated dust. In addition, people eating food grown on this soil can be contaminated with thorium through transfer factor (ATSDR, 1990). Effects of being exposed to thorium through inhalation include cancers of different forms such as pancreas, lung and bone. It can even result into damage of the body systems or result into death. Other effects through ingestion include: liver diseases, and diseases in the blood stream (ATSDR, 2014). The presence of thorium in an environment can lead to further exposure to hazardous radioactive decay of thorium such as thoron and radium – isotopes of radon. It should be noted that exposure to thorium has not been linked with birth defects or sexual incapability from previous studies (ATSDR, 1990; 2014; Xing-an et al. 2014).

Potassium is essential in the body but exposure to potassium is worse than its inadequacy. The function of the kidney is to regulate the level of potassium in the body, but for many reasons, the potassium level can exceed the required limit. High concentration of potassium in the body is referred to as hyperkalemia. Effects of high concentration of potassium in the body systems include: nausea, stomach upset, diarrhea, weakness or tiredness, vomiting, tingling, intestinal gas, trouble in breathing, chest pain, listlessness, paralysis, mental confusion, dizziness, irregular heart rhythm or palpitation, low blood pressure, and possibly death (Beckerman, 2016; Wint and Cherney, 2017). The average value recorded for ^{40}K in Odo Oba is greater than the global average by the factor of 2.7.

The ratios of the radioactivity concentrations were estimated and presented in Table 2. The ratios of ^{238}U to ^{40}K ranged from 0.012 (S2) to 0.044 (S9), the ratios of ^{232}Th to ^{40}K ranged from 0.011 (S2) to 0.089 (S9), the ratios of ^{238}U to ^{232}Th ranged from 0.497 (S9) to 1.086 (S2), while that of ^{232}Th to ^{238}U ranged from 0.921 (S2) to 2.012 (S9). The mean

of each of the ratio as presented in Table 2 is compared with global average as reported by UNSCEAR (1988) and Qureshi et al. (2014). From the mean of all the estimated activities' ratios, only $^{238}U/^{232}Th$ is greater than the global average by the factor of 2.8, others fall below the global average limit. From Table 2, it was revealed that the radioactive level of thorium is greater than that of uranium, hence 90% of $^{238}U/^{232}Th$ results are less than 1 while $^{232}Th/^{238}U$ results are greater than 1. The ratios of thorium to potassium and uranium to potassium are less than 1, because concentrations of potassium are higher than thorium, and uranium concentrations are far less when compared with potassium concentrations. Based on the ratios, there is depletion in uranium and enrichment in thorium concentration in Odo Oba farm (Tzortzis and Tsertos, 2004).

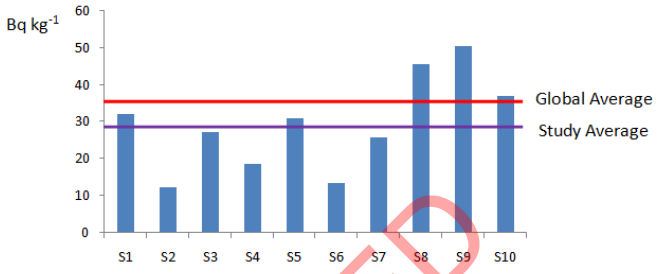

Fig. 4a. Activity concentration of ^{238}U

Fig. 4b. Activity concentration of ^{232}Th

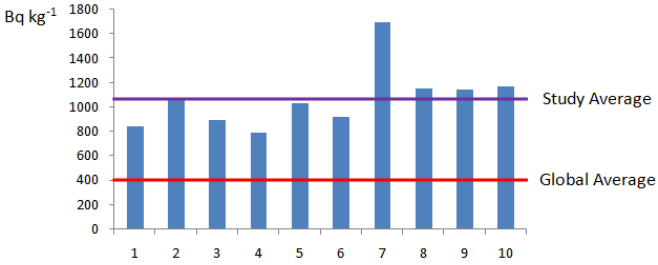

Fig. 4c. Activity concentration of ^{40}K

Table 2. Radioactivity ratios in Odo Oba

Samples	$^{238}U/^{40}K$	$^{232}Th/^{40}K$	$^{238}U/^{232}Th$	$^{232}Th/^{238}U$
1	0.038	0.062	0.618	1.618
2	0.012	0.011	1.086	0.921
3	0.030	0.045	0.676	1.479
4	0.023	0.032	0.736	1.358
5	0.030	0.035	0.845	1.183
6	0.015	0.016	0.905	1.105
7	0.015	0.026	0.586	1.706

8	0.039	0.048	0.822	1.217
9	0.044	0.089	0.497	2.012
10	0.032	0.052	0.612	1.633
Average	0.028	0.042	0.738	1.423
World Average	0.067[+]	0.067[+]	0.260[+]	3.500[+]

[+] represents UNSCEAR (1988)

4.2. Dose rates (DR) and annual effective doses (AED)

The absorbed Dose Rates (DR) ascribed to gamma radiation emanating from subsurface (that is, dose rates from outdoor contributions) as a result of activity concentration of ^{238}U, ^{232}Th and ^{40}K at one meter above the topsoil were estimated in accordance with UNSCEAR (1993) guidelines, assuming that other naturally-occurring radionuclides' (^{87}Rb, ^{147}Sm, ^{235}U, ^{90}Sr, ^{138}La, ^{137}Cs, ^{87}Rb and ^{178}Lu) contributions to the doses from the environmental background are frivolous (Qureshi et al. 2014; Ravisankar et al. 2016). The conversion factors used to estimate the absorbed dose rates in the dry weight of each sample corresponds to 0.436, 0.599 and 0.0417 (nGy h^{-1} Bq^{-1} kg^{-1}) for ^{238}U, ^{232}Th and ^{40}K respectively (Qureshi et al. 2014). However, the absorbed dose rates are estimated using Eq. (4) as given by UNSCEAR (2000).

$$DR = 0.436\ C_U + 0.599\ C_{Th} + 0.0417\ C_K \quad (4)$$

where C_U, C_{Th} and C_K are the activities of ^{238}U, ^{232}Th and ^{40}K respectively. The estimated dose rates in Odo Oba farm range from 53.3 (S6) to 131.0 (S9) nGy hr^{-1} (Fig. 5a). The average outdoor dose rate in Odo Oba is higher than the global average of 59 nGy hr^{-1} (UNSCEAR, 2000) by the factor of 1.4

The outdoor Annual Effective Dose (AED) is estimated based on Eq. (5) as given by UNSCEAR (2000) and Qureshi et al. (2014).

$$AED = 8760\ hr\ y^{-1} \times 0.7\ Sv\ Gy^{-1} \times 10^{-6} \times 0.2 \quad (5)$$

From Eq. (5), the outdoor occupancy factor is given as 20% (with an assumption that farmers spend 20% of a day on the field) of hours in 365 days that makes a year. However, the conversion factor that converts external absorbed doses to outdoor annual effective doses is given as 0.7 Sv Gy^{-1}.

In this study, the outdoor annual effective doses range from 0.06 (S2, S4 and S6) to 0.16 (S9) mSv $year^{-1}$ with an average 0.1 mSv $year^{-1}$(Fig. 5b). This value is higher than the global average of 0.07 mSv $year^{-1}$ (UNSCEAR, 2000; Qureshi et al., 2014) by factor of 1.4.

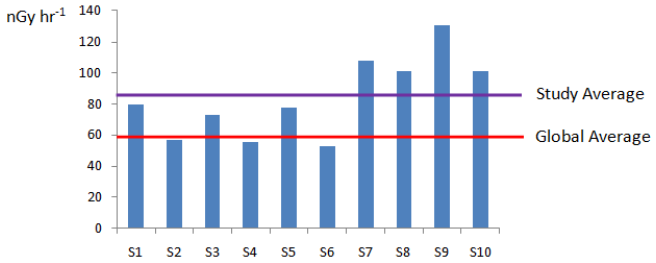

Fig. 5a. The absorbed dose roses distributions on Odo Oba farm

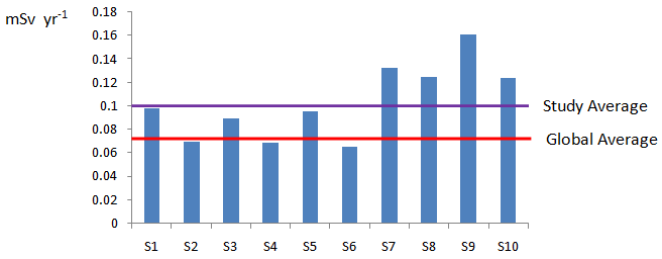

Fig. 5b. The annual effective dose distributions on Odo Oba farm

4.3. Annual gonadal equivalent dose (AGED)

The gonad, bone marrow and the bone surface cells are essential in terms of assessment of level of exposure of human organs to natural occurring radionuclides (UNSCEAR, 1988). It is crucial to include AGED as parts of our assessment to farmers' exposure to natural radionuclides on Odo Oba farm, because farm activities require longer time to execute. As a result of this, AGED emanating from the farm land needs to be estimated. Therefore, the AGED due to activity concentrations of ^{238}U, ^{232}Th and ^{40}K was estimated based on Eq. (6) as given by Mamont-Ciesla et al. (1982).

$$AGED\ (\mu Sv\ y^{-1}) = 3.09\ C_U + 4.18\ C_{Th} + 0.314\ C_K \quad (6)$$

This parameter (that is, AGED) has been used by some authors as part of the radioactivity risk assessment in an environment (Avwiri et al. 2012; Chandrasekara et al. 2014; Ravisankar et al. 2016). The AGED of Odo Oba is presented in Fig. 6. The values range from 393.7 (S6) to 943.2 (S9) μSv y^{-1}. As it is revealed from Fig. 6, the mean value in this present study (612.4 μSv y^{-1}) exceed the global average of 300 μSv y^{-1} by the factor of 2. This result is considered to be hazardous to the farmers in Odo Oba.

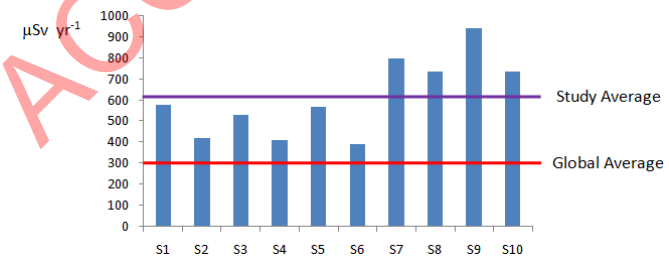

Fig. 6. Distributions of annual gonadal equivalent doses on Odo Oba farm

4.4. External and gamma radiation hazard indices

The two indices employed in this present assessment for farmers' exposure to gamma radiation are external radiation hazard index (H_{Ext}) and gamma radiation hazard index ($I_{\gamma r}$). The external radiation hazard index (H_{Ext}) in Odo Oba is estimated based on the model from Krieger (1981), Ibrahiem, (1999), UNSCEAR (2000), and Ravisankar et al. (2016). This equation is presented in Eq. (7).

$$H_{Ext} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (7)$$

The conversion factor of each of the three concentrations (^{238}U, ^{232}Th and ^{40}K) is based on the assumption that 370, 259 and 4810 (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K produce the same gamma radiation dose rate (OECD, 1979; Akinloye et al. 2012; Qureshi et al. 2014; Ravisankar et al. 2016).The estimated external radiation hazard index in Odo Oba varies from 0.3 (S2, S4 and S6) to 0.9 (S9). The estimated average value of H_{Ext}in Odo Oba is 0.6 (Fig. 7). This clearly

showed that contributions from H_{Ext} are insignificant and pose no threat or radiological risks to the farmers since it is less than unity.

Gamma radiation hazard index ($I_{\gamma r}$) is one of the indices used to measure the safety of humans when they are exposed to γ-radiation emanating from subsurface (EC, 1999; UNSCEAR, 2000). The $I_{\gamma r}$used in this study is presented in Eq. (8) as given by OECD (1979), Alam et al. (1999) and Uosif et al. (2014).

$$I_{\gamma r} = 0.0067\, C_U + 0.01\, C_{Th} + 0.00067\, C_K \leq 1 \quad (8)$$

where C_U, C_{Th} and C_K have the same definitions as in Eq. (4), (6) and (7) respectively.

The estimated $I_{\gamma r}$ fluctuate from 0.8 (S6) to 2.1 (S9). The average $I_{\gamma r}$ in Odo Oba is 1.4. This is greater than the global average as presented in Eq. (8). From the ten samples analyzed, 30% fluctuate below unity while 70% vividly exceed the acceptable limit (Fig. 7). The implication of $I_{\gamma r}$ results is that the radiation emitted from the study area is toxic to man's health as reported by Palomo et al. (2010) and Uosif et al. (2014).

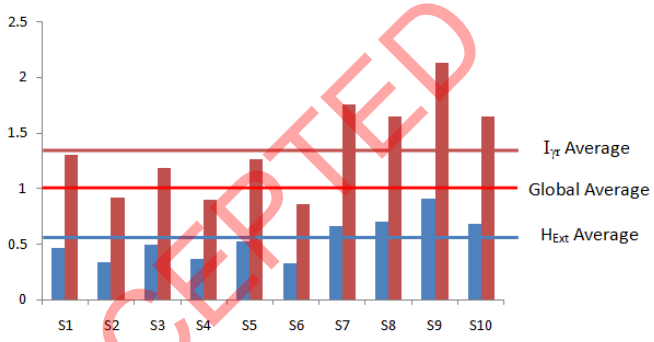

Fig. 7. Distributions of external and gamma radiation hazard indices in Odo Oba

4.5. Excess lifetime cancer risk

Excess Lifetime Cancer Risk (ELCR) is estimated from Eq. (9) as given by Eq. (9).

$$\text{ELCR} = \text{Annual Effective Dose} \times 70 \times 0.05 \quad (9)$$

ELCR depends greatly on the results of annual effective dose and other two constants. The first constant (70) is referred to as duration of life which is given as 70 years while the second constant (0.05) is the risk factor which is given as 0.05 S_v^{-1} (ICRP-60, 1990; Taskin et al., 2009; Chandrasekaran et al. 2014; Qureshi et al. 2014; Ravisankar et al. 2016). For stochastic effect, 0.05 was ascribed to the public (ICRP-60, 1990). ELCR is another risk from radiological hazards. It measures the possibility of having cancer if someone is overexposed to cancer-causing environment. The estimated range of cancer risk in Odo Oba is 0.23×10^{-3} (S6) to 0.56×10^{-3} (S9) with a mean of 0.36×10^{-3}. This value is higher than the global average of 0.29×10^{-3}(Ravisankar et al. 2007; UNSCEAR, 2000) by the factor of 1.2 (Fig. 8).Virtually, only three locations (S2, S4 and S6) (that is, 30% of the total samples) depict lower values than the global average, others depict a higher degree than the recommended limit which varied in factors from 1.1 to 1.9.

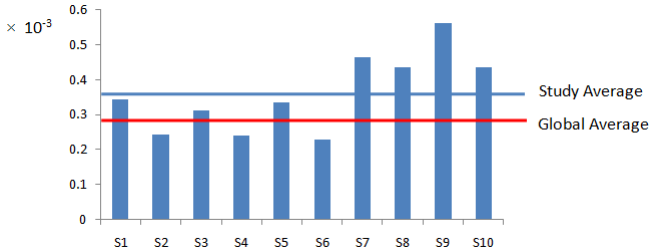

Fig. 8. Excess lifetime cancer risk in Odo Oba

4.6. Statistical analyses of all the data sets

The descriptive analysis and multivariate statistics were employed under this section in order to examine the relationship between the variables used in this study. This approach has been found useful from the literature in the recent times (Chandrasekaran et al. 2014; Isinkaye and Emelue 2015; Raghu et al. 2017). Variations of the mean, standard deviation, skewness, kurtosis, and the global average of all the variables are presented in Table 3.

Skewness and kurtosis are parts of data characterization in statistical analysis. The skewness defines the symmetric or asymmetric distributions of data sets. For a normal distribution, skewness is always zero, and nearly equals zero for symmetric data. The skewness with negative value signifies that the data is skewed left and vice versa. The kurtosis measures the 'tailedness' of a normal distribution, whether it is heavy-tailed or light-tailed. Data sets with high kurtosis showed that there are outliers (that is, heavy tails) and vice versa. These two parameters have been used to discuss the variability of data sets by Adagunodo et al. (2017b), (2018a) and (2018c). The skewness and kurtosis were estimated by Eqs. (10) and (11) respectively. Potassium-40 possesses highest values of mean and standard deviation of 1072.07 and 258.28, with the ELCR showing the least mean and standard deviation value of 0.36 × 10^{-3} and 0.11 × 10^{-3} respectively. Only ^{238}U / ^{40}K showed negative skewness, four (4) variables (^{232}Th, ^{40}K, ^{232}Th / ^{40}K and ^{238}U / ^{232}Th) showed positive kurtosis while 69% of the total variables showed negative kurtosis.

$$\text{Skewness} = \frac{\sqrt{N(N-1)}}{N-2}\frac{\sum_{i=1}^{N}\left(Y_i-\bar{Y}\right)^3/N}{s^3} \tag{10}$$

where N is the number of data points or population number, Y is the individual data, $\bar{Y}$ is the mean, s is the standard deviation, and i is the integer.

$$\text{Kurtosis} = \sum_{i=1}^{N}\frac{\left(Y_i-\bar{Y}\right)^4/N}{s^4} - 3 \tag{11}$$

The multivariate analyses employed are Pearson's correlation, factor analysis, and cluster analysis. The multivariate analysis has been found useful in explanation of correlation among varying data sets without losing much information (Ashley and Lloyd, 1978; Jackson, 1991; Chandrasekaran et al. 2014; Adagunodo et al. 2017). This approach is efficient in data compression without losing its original information, and helpful to draw relationships between or among variables (Chandrasekaran et al. 2014).

A bivariation statistics involving correlation matrix was carried out and presented in Table 4, with a view to determining the nature of relationships that exist between the thirteen (13) variables analyzed in ten (10) samples used in this study. A very strong positive correlation exists between ^{232}Th and ^{238}U. This is because the two elements undergo their decay series simultaneously (Tanaskovi et al. 2012). The correlation between ^{40}K and ^{232}Th as well as ^{40}K and ^{238}U are very weak. This might be associated with the different decay series between the two parameters, since ^{40}K has

no progeny like ^{238}U and ^{232}The. Generally, very strong positive correlations exist between ^{238}U and the radiological indices as well as radioelements' ratios except ^{238}U / ^{232}Th that showed very strong negative correlation. The correlations between ^{232}Th and the radiological indices, ^{232}Th and radioelements' ratios resemble the type of correlations with uranium-238 and its radiological indices. A very strong positive correlation exist between the radiological indices, while negative correlations exist between ^{40}K and radioelements' ratios except ^{232}Th / ^{238}U that showed very strong positive correlation. The correlation has further confirmed that radiological indices exist due to radionuclides' activities. The approach of correlation analysis has justified that uranium depletion with thorium and potassium enrichments exist in the study area.

Table 3. Descriptive statistics for the analyzes datasets (N = 10)

Variable	Mean	SD	Skewness	Kurtosis	Global mean as presented in this study
^{238}U	29.40	12.74	0.28	-0.70	35.0 Bq kg^{-1}
^{232}Th	44.25	26.15	1.01	1.81	30.0 Bq kg^{-1}
^{40}K	1072.07	258.23	1.59	3.51	400.0 Bq kg^{-1}
DR	84.03	25.90	0.45	-0.71	59 mGy hr^{-1}
AED	0.10	0.03	0.45	-0.71	0.07 mSv yr^{-1}
AGED	612.44	185.03	0.44	-0.82	300 µSv yr^{-1}
ELCR	0.36×10^{-3}	0.11×10^{-3}	0.45	-0.71	0.29×10^{-3}
^{238}U / ^{40}K	0.03	0.01	-0.17	-1.30	0.067
^{232}Th / ^{40}K	0.04	0.02	0.73	0.77	0.067
^{238}U / ^{232}Th	0.74	0.18	0.67	0.08	0.260
^{232}Th / ^{238}U	1.42	0.33	0.24	-0.41	3.5
H_{Ext}	0.55	0.19	0.44	-0.32	1.0
$I_{\gamma r}$	1.36	0.42	0.46	-0.67	1.0

Table 4. Pearson's correlation matrix among the analyzed parameters in Odo Oba farm

Variables	^{238}U	^{232}Th	^{40}K	DR	AED	AGED	ELCR	^{238}U / ^{40}K	^{232}Th / ^{40}K	^{238}U / ^{232}Th	^{232}Th / ^{238}U	H_{Ext}	$I_{\gamma r}$
^{238}U	1.00												
^{232}Th	0.93	1.00											
^{40}K	0.23	0.27	1.00										
DR	0.87	0.91	0.63	1.00									
AED	0.87	0.91	0.63	1.00	1.00								
AGED	0.86	0.91	0.64	1.00	1.00	1.00							
ELCR	0.87	0.91	0.63	1.00	1.00	1.00	1.00						
^{238}U / ^{40}K	0.90	0.82	-0.19	0.61	0.61	0.60	0.61	1.00					
^{232}Th / ^{40}K	0.88	0.94	-0.05	0.73	0.73	0.72	0.73	0.92	1.00				
^{238}U / ^{232}Th	-0.63	-0.79	-0.26	-0.72	-0.72	-0.71	-0.72	-0.59	-0.76	1.00			
^{232}Th / ^{238}U	0.64	0.84	0.32	0.78	0.78	0.78	0.78	0.56	0.80	-0.97	1.00		
H_{Ext}	0.93	0.95	0.51	0.99	0.99	0.99	0.99	0.72	0.81	-0.73	0.78	1.00	
$I_{\gamma r}$	0.87	0.92	0.62	1.00	1.00	1.00	1.00	0.62	0.74	-0.72	0.79	0.99	1.00

The Factor Analysis (FA) was also performed on the variables in order to establish relationship among the parameters (Rodrigues-Barroso et al. 2009; Ramasamy et al. 2011; Chandrasekaran et al. 2014). The FA is carried out on the Pearson's correlation matrix data sets. The extraction method for the factor was achieved through Principal Component Analysis (PCA), which was further rotated by varimax. The communalities of the thirteen (13) variables were presented in Table 5. Based on Kaiser's rule with eigen values ≥ 1 (Kaiser, 1960), the initial eigen value of the variables is 1 with the extraction varying from 0.675 (the extraction of ^{238}U / ^{232}Th) to 0.995 (the extraction of DR, AED, AGED, ELCR and $I_{\gamma r}$). Two components were produced from the component matrix based on PCA extraction method (Table 6). Component 1 accounted for 51.30% of the total variance, which constitute high levels of variables such as H_{Ext}, AED, ELCR, DR, AGED, ^{232}Th, ^{238}U, ^{232}Th / ^{40}K, ^{232}Th / ^{238}U, ^{238}U / ^{40}K, ^{238}U / ^{232}Th and ^{40}K with high positive loading varying from 0.741 to 0.991. AED, DR and ^{40}K showed the same loading of 0.977 while AGED and ELCR also showed the loading of 0.972. Concentration of ^{238}U is the most significant factor to the contributions of component 1. Component 2 accounted for 42.15% of the total variance, which constitute high positive loading of 0.881 for $I_{\gamma r}$. The results of the two components revealed that exposure to radiological hazards in the study area are chiefly from ^{40}K, ^{238}U and ^{232}Th respectively. The plot of eigen value against the component number is presented in Fig. 9. However, the graphical representation of the two components is presented in Fig. 10. The plot of the two components revealed that ^{238}U / ^{232}Th and ^{40}K reside in the same community (quadrant 1) with AED, DR, AGED, ^{232}Th / ^{238}U and $I_{\gamma r}$; while H_{Ext}, ELCR, ^{232}Th / ^{40}K, ^{238}U / ^{40}K and ^{238}U / ^{232}Th reside in the fourth quadrant respectively.

Table 5. Communality of the variables

Variables	Initial	Extraction
^{238}U	1.000	0.895
^{232}Th	1.000	0.982
^{40}K	1.000	0.990
DR	1.000	0.995
AED	1.000	0.995
AGED	1.000	0.995
ELCR	1.000	0.995
^{238}U / ^{40}K	1.000	0.927
^{232}Th / ^{40}K	1.000	0.985
^{238}U / ^{232}Th	1.000	0.675
^{232}Th / ^{238}U	1.000	0.734
H_{Ext}	1.000	0.986
$I_{\gamma r}$	1.000	0.995

Extraction method: PCA

Table 6. Component matrix of the variables

Variables	Component	
	1	2
^{238}U	0.991	0.065
^{232}Th	0.978	0.196
^{40}K	0.977	0.201
DR	0.977	0.201
AED	0.977	0.201
AGED	0.972	0.224
ELCR	0.972	-0.194
^{238}U / ^{40}K	0.919	-0.225
^{232}Th / ^{40}K	0.855	-0.504

^{238}U / ^{232}Th	0.853	-0.083
^{232}Th / ^{238}U	0.809	0.144
H_{Ext}	0.741	-0.615
$I_{\gamma r}$	0.462	0.881
% of variance explained	51.30%	42.15%

Extraction method: PCA

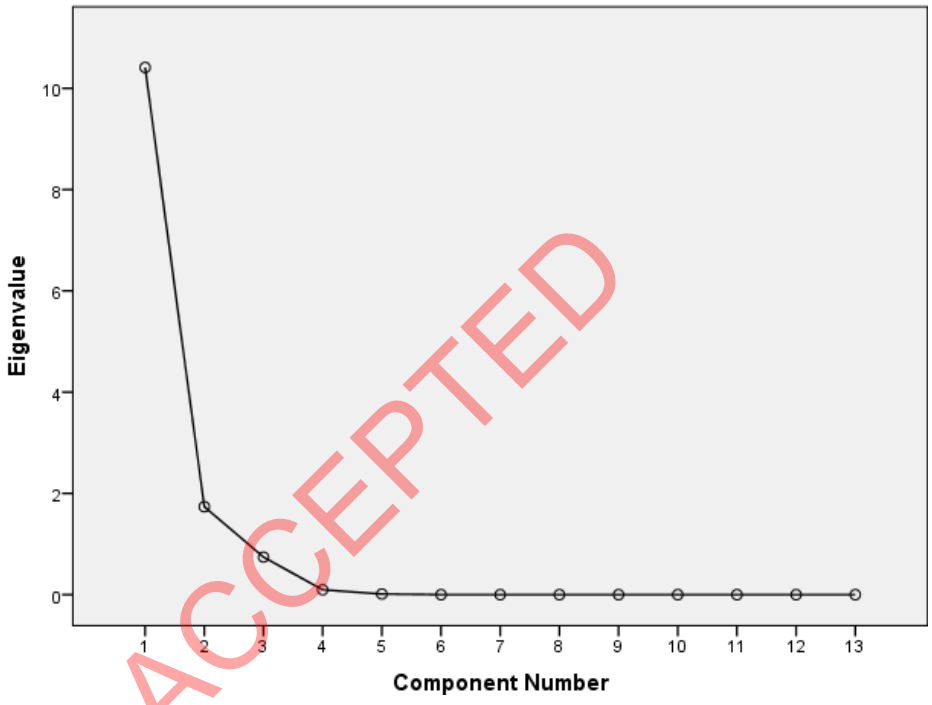

Fig. 9. The scree plot of the eigen values against the component number

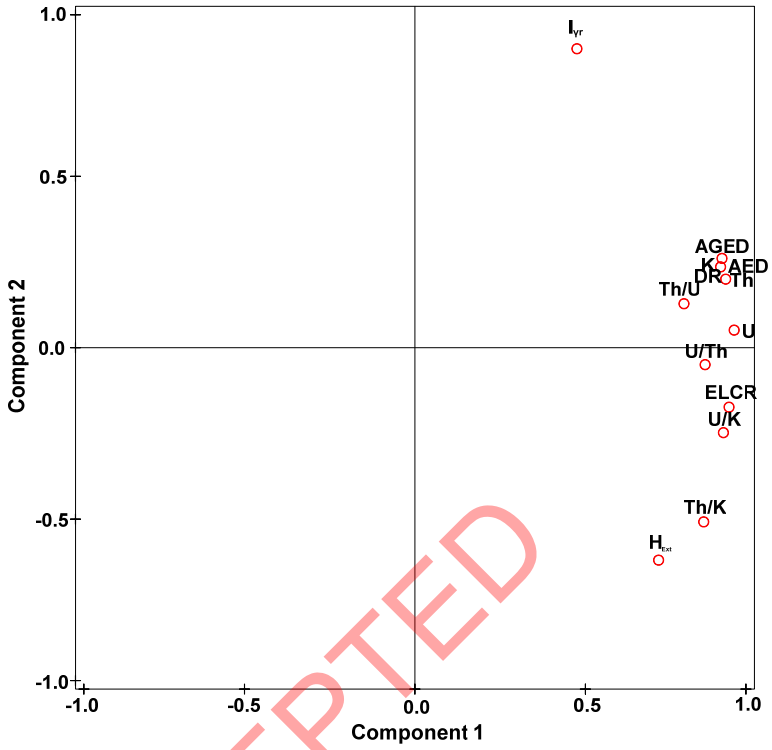

Fig. 10. Graphical representation of component 1 and component 2.

A multivariate statistical technique known as Hierarchical Cluster Analysis (HCA) was adopted to classify the thirteen (13) variables of all the ten (10) occupied stations in this study into categories based on their similarities and to produce dendrogram (Fig. 11). A dendrogram is a tree-structured graph that enables one to view the output of calculations from HCA (Fatoba et al. 2017). The output of HCA is usually represented as the distance between the clustered columns or rows based on the description of each measured parameter. The distance or order in dendrogram is estimated based on Eq. (12).

$$\frac{D_{Link}}{D_{Max}} \times 100 \tag{12}$$

where D_{Link} is the quotient between the linkage distances for certain case, D_{Max} is the maximal linkage distance. The constant in the equation (that is, 100) is used to standardize the linkage distance (Wunderlin et al. 2001; Fatoba et al. 2017). The linkage distance among the variables was estimated using squared Euclidean distance, and the Ward's method was employed for the clustering technique. The most similar variables appear as the first group, while the incongruous variables are far from each other on the dendrogram (Ramasamy et al. 2011; Chandrasekaran et al. 2014). In another words, the distance between any two variables within the clusters are referred to as similarity. Two variables with no distance between them signify 100% similarity, while variables that are disparate are said to possess 0% similarity.

The closest clusters produced are ^{238}U / ^{232}Th – ^{40}K, H_{Ext} – (AED, ELCR, DR), and (AGED, ^{232}Th) – ^{232}Th / ^{40}K, with potassium and thorium being the major natural radionuclide contributors within these clusters. The next clusters produced are ^{238}U / ^{232}Th – ^{238}U / ^{40}K, $I_{\gamma r}$ – ^{238}U, and H_{Ext} – (AGED, ^{40}K), with uranium and thorium being the natural radionuclides in these clusters. From Fig.12, five parameters (AED, ELCR, DR, AGED and ^{232}Th) were categorized as two variables. The first category combined three variables which are AED, ELCR and DR, while two variables (AGED and ^{232}Th) were the second set of combined variables. These are as a result of their loading on component

matrix (Table 5) which share loadings 0.977 and 0.972 respectively. In the larger clusters, three (3) clusters were present based on the observation from the top. Cluster-I is made up of nine (9) variables. These are ^{238}U / ^{232}Th, ^{40}K, ^{238}U / ^{40}K, $I_{\gamma r}$, ^{238}U, H_{Ext}, (AED, ELCR, DR), (AGED, ^{232}Th) and ^{232}Th / ^{40}K. Cluster-II comprised two variables, which are ^{40}K and ^{238}U. However, only one variable was observed in Cluster-III, which is ^{232}Th / ^{238}U. The dendrogram was able to show from Cluster-I that the radiological hazards occur as a result of contributions from the three naturally occurring radionuclides (that is, thorium, uranium and potassium).

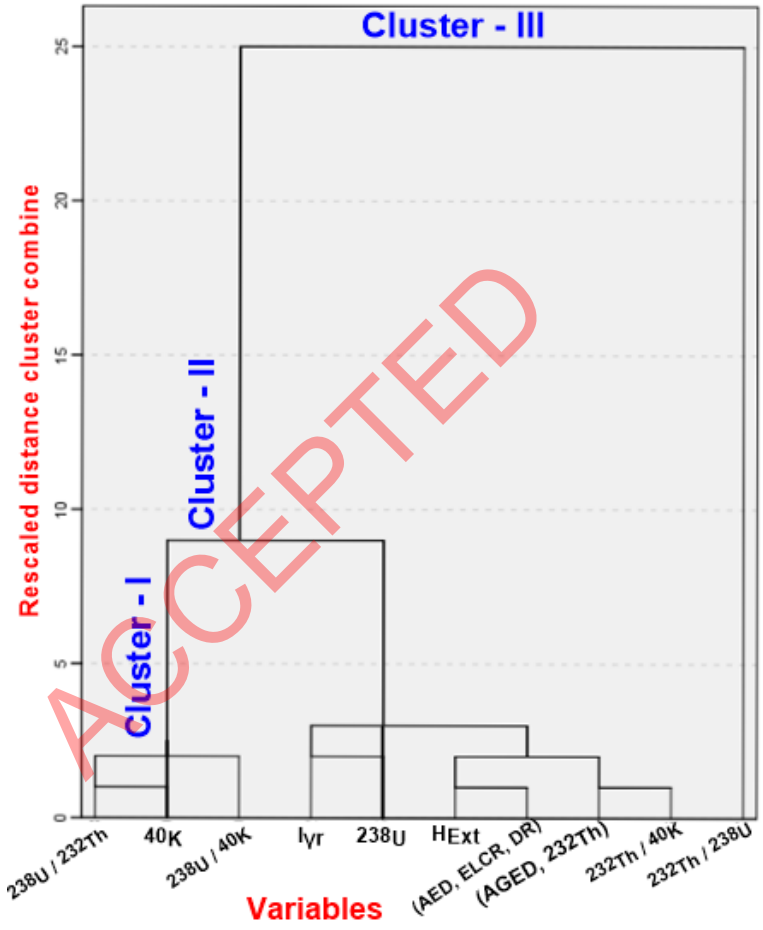

Fig.11. Dendrogram of the HCA of radioactivity concentrations and radiological risks.

5. Conclusion

The concentrations of thorium, uranium and potassium in the ten randomly selected topsoil samples from Odo Oba were determined using ICP-MS from ACME laboratories, Canada. The risks (DR, AED, AGED, ELCR, H_{Ext} and $I_{\gamma r}$) and radioelements' ratios were estimated from the naturally occurring radionuclides in the study area. The mean concentrations of thorium and potassium are greater than the global average of 30 and 400 Bq kg^{-1} while uranium fall below the global average of 35 Bq kg^{-1}. In comparison with the results of other studies from Nigeria and other parts of the world (as presented in Table 7), it was revealed that this present study is in agreement with their outcome, except for few cases where the results were below the global average (such as Akinloye et al. (2012), Avwiri et al. (2012) and Isola et al. (2015)). The high concentrations of thorium in the study area are associated with the nature of the terrain, as the thorium enriched materials carried from afar are deposited around Odo Oba over years. Farmers working on Odo Oba can be exposed to thorium by inhaling contaminated dust. The crops grown on the farm land can be contaminated and be transferred to humans by consumption. The estimation of radioactivity ratios showed that

depletion of uranium and enrichment of thorium occur in the study area. The estimated radiological risks showed that the mean values of DR, AED, AGED, ELCR and $I_{\gamma r}$ are greater than the global average by the factors of 1.42, 1.43, 2.04, 1.24 and 1.36 respectively. However, the mean of H_{Ext}< 1 fall below the global average. The farmers are advised to take safety measures whenever on the farm land in order to prevent themselves from being overexposed to natural radionuclides. However, further studies are recommended in Odo Oba and its environment in order to have a comprehensive report on the radiation level of the environment.

Table 7. Comparison of the results of radioactivity concentrations in this study with other works

Authority	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Location
Present study	29.40	44.25	1072.07	SW, Nigeria
Isola et al. (2015)	23.39	19.37	165.14	SW, Nigeria
Akinloye et al. (2012)	25.55	11.60	191.78	SW, Nigeria
Adagunodo et al. (2018a)	38.17	65.11	93.90	SW, Nigeria
Adagunodo et al. (2018b)	46.67	71.76	108.73	SW, Nigeria
Avwiri et al. (2012) site 1	13.71	10.45	57.17	SE, Nigeria
Avwiri et al. (2012) site 2	11.49	8.83	59.77	SE, Nigeria
Isinkaye and Emelue (2015)	47.89	55.37	1023.00	SE, Nigeria
Chandrasekaran et al. (2014)	19.16	48.56	1146.88	India
Ravisankar et al. (2016)	9.19	45.60	295.11	India
Raghu et al. (2017)	116.10	43.51	300.07	India
Turhan (2009) site 1	39.30	49.60	569.50	Turkey
Turhan (2009) site 2	82.00	94.80	463.60	Turkey

Acknowledgement

The handling Editor of this article and the reviewers are highly appreciated for their contributions.

References

Adagunodo, T.A., Sunmonu, L.A. 2012. Groundmagnetic Survey to Investigate on the Fault Pattern of Industrial Estate Ogbomoso, Southwestern Nigeria. Advances in Applied Science Research 3(5), 3142–3149.

Adagunodo, T.A., Adeniji, A.A., Erinle, A.V., Akinwumi, S.A., Adewoyin, O.O., Joel, E.S.,Kayode,O.T. 2017a. Geophysical Investigation into the Integrity of a Reclaimed Open Dumsite for Civil Engineering Purpose.Interciencia Journal 42(11), 324 – 339.

Adagunodo, T.A., George, A.I., Ojoawo, I.A., Ojesanmi, K., Ravisankar, R. 2018*a*. Radioactivity and Radiological Hazards from a Kaolin Mining Field in Ifonyintedo, Nigeria. MethodsX, 5C: 362 – 374. https://doi.org/10.1016/j.mex.2018.04.009.

Adagunodo, T.A., Hammed, O.S., Usikalu, M.R., Ayara, W.A., Ravisankar, R. 2018*b*. Data on the Radiometric Survey over a Kaolinitic Terrain in Dahomey Basin, Nigeria. Data in Brief 18C, 814 – 822. https://doi.org/10.1016/j.dib.2018.03.088.

Adagunodo, T.A., Sunmonu, L.A., Adabanija, M.A., Suleiman, E.A., Odetunmibi, O.A. 2017*b*. Geoexploration of Radioelement's Datasets in a flood plain of Crystalline Bedrock. Data in Brief 15, 809 – 820. https://doi.org/10.1016/j.dib.2017.10.046.

Adagunodo T.A., Sunmonu L.A., Emetere M.E. 2018*c*. Heavy Metals' Data in Soils for Agricultural Activities. Data in Brief, 18C: 1847 – 1855. https://doi.org/10.1016/j.dib.2018.04.115.

Adagunodo, T.A., Sunmonu, L.A., Ojoawo, A., Oladejo, O.P., Olafisoye, E.R. 2013a. The Hydro Geophysical Investigation of Oyo State Industrial Estate Ogbomosho, Southwestern Nigeria Using Vertical Electrical Soundings. Research Journal of Applied Sciences, Engineering and Technology 5(5), 1816–1829.

Adagunodo, T.A., Sunmonu, L.A., Oladejo, O.P., Ojoawo, I.A. 2013b. Vertical Electrical Sounding to Determine Fracture Distribution at Adumasun Area, Oniye, Southwestern Nigeria. IOSR Journal of Applied Geology and Geophysics 1(3), 10–22.

Adagunodo, T.A., Sunmonu, L.A., Oladejo, O.P., Olafisoye, E.R. 2013c. Groundmagnetic Investigation into the Cause of the Subsidence in the Abandoned Local Government Secretariat, Ogbomoso, Nigeria. ARPN Journal of Earth Sciences 2(3), 101–109.

Ademola, A.K., Olaoye, M.A., Abodunrin, P.O. 2015. Radiological Safety Assessment and Determination of Heavy Metals in Soil Samples from some Waste Dumpsites in Lagos and Ogun State, South-western, Nigeria. Journal of Radiation Research and Applied Sciences 8, 148 – 153.

Agency for Toxic Substances and Disease Registry (ATSDR) 1990. Public Health Statement Thorium. Summary Chapter from the Toxicological Profile for Thorium, Series of Public Health Statements about Hazardous Substances and their Health Effects, CAS#: 7440 – 29 – 1.

Agency for Toxic Substances and Disease Registry (ATSDR) 2014. Toxic Substances Portal –Thorium. Atlanta GA: Centers for Disease Control and Prevention. Retrieved on October 18, 2017.

Akinloye, M.K., Isola, G.A., Oladapo, O.O. 2012. Investigation of Natural Gamma Radioactivity levels and Associated Dose Rates from Surface Soils in Ore Metropolis, Ondo State, Nigeria. Environment and Natural Resources Research 2(1), 140 – 145.

Alam, M.N., Chowdhury, M.I., Kamal, M., Ghose, S., Ismal, M.N. 1999. The 226Ra, 232Th and 40K Activities in Beach Sand Minerals and Beach Soils of Cox's Bazar, Bangladesh. Journal of Environmental Radioactivity 46(2), 243 – 250.

Alzubaidi, Ghazwa, Hamid, Fauziah B.S., Rahman, I. Abdul 2016. Assessment of Natural Radioactivity Levels and Radiation Hazards in Agricultural and Virgin Soil in the State of Kedah, North of Malaysia. The Scientific World Journal Article ID 6178103, 1 – 9. Dx.doi.org/10.1155/2016/6178103

Ashley, R.P., Lloyd, J.W. 1978. An example of the use of factor analysis and cluster analysis in groundwater chemistry interpretation. J. Hydrol. 39, 335 – 364.

Avwiri, G.O., Osimobi, J.C., Agbalagba, E.O. 2012. Evaluation of Radiation Hazard Indices and Excess Lifetime Cancer Risk due to Natural Radioactivity in Soil Profile of Udi and Ezeagu Local Government areas of Enugu State, Nigeria. Comprehensive Journal of Environmental and Earth Sciences 1(1), 1 – 10.

Bank, T., Roth, E., Tinker, P., Granite, E. 2016. Analysis of Rare Earth Elements in Geologic Samples using Inductively Coupled Plasma Mass Spectrometry. US DOE Topical Report – DOE/NETL – 2016/1794.

Beckerman, J. 2016. Potassium and your Hearth. WebMD Medical Reference, WebMD, LLC. Reviewed on October 6, 2016, Retrieved on October 18, 2017. https://www.webmd.com/heart-disease/potassium-and-your-heart.

Chandrasankaran, A., Ravisankar, R., Senthilkumar, G., Thillaivelavan, K., Dhinakaran, B., Vijayagopal, P., Bramha, S.N., Venkatraman, B. 2014. Spatial Distribution and Lifetime Cancer Risk due to Gamma Radioactivity in Yelagiri Hills, Tamilnadu, India. Egyptian Journal of Basic and Applied Science 1, 38 – 48.

European Commission (EC) 1999. Radiation Protection, 112-Radiological Protection Principles Concerning the Natural Radioactivity of Building Materials. Directorate-General Environment. Nuclear Safety and Civil Protection.

Fatoba, J.O., Sanuade, O.A., Hammed, O.S., Igboama, W.W. 2017. The use of multivariate statistical analysis in the assessment of groundwater hydrochemistry in some parts of southwestern Nigeria. Arab. J. Geosci. 10, 328. https://doi.org/10.1007/s12517-017-3125-7.

Food and Agriculture Organization of the United Nations (FAO) 2013. Agricultural Mechanization in Sub Saharan Africa: Guidelines for preparing a Strategy. Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Rome. ISBN 978-92-5-107762-7

Gbadebo, A.M., Amos, A.J. 2010. Assessment of Radionuclide Pollutants in Bedrocks and Soils from Ewekoro Cement Factory, Southwest Nigeria. Asian Journal of Applied Sciences 3(2), 135 – 144.

Ibrahiem, N. 1999. Natural Activity of 238U, 232Th and 40K in Building Materials. Journal of Environmental Radioactivity 43(3), 255 – 258.

International Atomic Energy Agency (IEAE)1989. Construction and Use of Calibration Facilities for Radiometric Field Equipment. Technical Reports Series no. 309, IAEA, Vienna.

International Commission on Radiological Protection (ICRP)-60 1990. Protection: 1990

Recommendations Methods Part I. Monoenergetic Sources of Natural Radionuclides in the Ground. GSF-B2/90 of ICRP. Pergamon Preis.

Isinkaye M.O. and Emelue H.U. 2015. Natural radioactivity measurements and evaluation of radiological hazards in sediment of Oguta Lake, South East Nigeria. Journal of Radiation Research and Applied Sciences, 8: 459 – 469.

Isola G.A., Oni O.M., Akinloye M.K., Awodugba A.O. 2015. Determination of absorbed dose rate and effective dose equivalent due to natural radionuclide present in soil in Oyo and Osun state, South-western Nigeria. Impact: International Journal of Research in Applied, Natural and Social Sciences, 3(3): 27 – 32.

Jackson, J.E. 1991. A user's guide to Principal Components. New York: Wiley.

Jones, H.A., Hockey, R.D. 1964. The geology of the southwestern Nigeria. Geol. Surv. Nig. Bull.31, pp 101.

Kaiser, H.F. 1960. The application of electronic computers to factor analysis. Educ. Psychol.Meas. 20,141–151.

Krieger, R. 1981. Radioactivity of Construction Materials. Betonw. Fert. Tech. 47, 468 – 473.

Obaje, N.G. 2015. Geology and mineral resources of Nigeria. In: Brooklyn, S.B., Bonn, H.J.N., Gottingen, J.R., Graz, K.S. (Eds.), Lecture notes in Earth Sciences 120. Springer, Pp 221.

Odunaike, R.K., Ozebo, V.C., Alausa, S.K., Alausa, I.M. 2008. Radiation Exposure to Workers and Villagers in and around some Quarry sites in Ogun State of Nigeria. Environmental Research Journal 2(6), 348 – 350.

Oladejo, O.P., Sunmonu, L.A., Ojoawo, A., Adagunodo, T.A. and Olafisoye, E.R. 2013. Geophysical investigation for groundwater development at Oyo state housing estate Ogbomosho, southwestern Nigeria. Research Journal of Applied Science, Engineering and Technology 5(5), 1811 – 1815.

Olafisoye, E.R., Sunmonu, L.A., Adagunodo, T.A., Oladejo, O.P. 2013. Impact Assessment of Solid Waste on Groundwater: a Case Study of Aarada Dumpsite, Nigeria. ARPN Journal of Earth Sciences 2(2), 45–53.

Olafisoye, E.R., Sunmonu, L.A., Ojoawo, A., Adagunodo, T.A., Oladejo, O.P. 2012. Application of Very Low Frequency Electromagnetic and Hydro-physicochemical Methods in the Investigation of Groundwater Contamination at Aarada Waste Disposal Site, Ogbomoso, Southwestern Nigeria. Australian Journal of Basic and Applied Sciences 6(8), 401–409.

Omeje, M., Wagiran, H., Ibrahim, N., Lee, S.K., Sabris, S. 2013. Comparison of Activity Concentration of 238U, 232Th and 40K in different Layers of Subsurface Structures in Dei-Dei and Kubwa, Abuja Northcentral Nigeria. Radiation Physics and Chemistry 91, 70 – 80.

Organization for Economic Cooperation and Development (OECD) 1979. Exposure to Radiation from the Natural Radioactivity in Building Materials. Report by a group of Experts, Nuclear Energy Agency, Paris, France.

Palomo, M., Penalver, A., Aguilar, C., Bornull, F. 2010. Presence of Naturally Occurring Radioactive Materials in Sludge Samples from several Spanish Water Treatment Plants. Journal of Hazardous Materials 181(1 – 3), 716 – 720.

Qureshi, A.A., Tariq, S., Din, K.U., Manzoor, S., Calligaris, C., Waheed, A. 2014. Evaluation of Excessive Lifetime Cancer Risk due to Natural Radioactivity in the Rivers Sediments of Northern Pakistan. Journal of Radiation Research and Applied Sources 7, 438 – 447.

Rafique, M., Rahman, S.U., Basharat, M., Aziz, W., Ahmad, I., Lone, K.A., Ahmad, K., Matiullah 2014. Evaluation of Excess Life Time Cancer Risk from Gamma Dose Rates in Jhelum Valley. Journal of Radiation Research and Applied Sciences 7, 29 – 35.

Raghu Y., Ravisankar R., Chandrasekaran A., Vijayagopa P., Venkatraman B. 2017. Assessment of natural radioactivity and radiological hazards in building materials used in the Tiruvannamalai District, Tamilnadu, India, using a statistical approach. Journal of Taibah University for Science, 11: 523 – 533.

Ramasamy, V., Suresh, G., Meenakshisundaram, V., Ponnusam, V. 2011. Horizontal and Vertical characterization of radionuclides and minerals in river sediments. Appl. Radiat. Isot. 69, 184 – 195.

Ravisankar, R., Chandramohan, J., Chandrasekaran, A., Jebakumar, J.P., Vijayalakshmi, I., Vijayagopal, P., Venkatraman, B. 2015. Assessments of Radioactivity Concentration of Natural Radionuclides and Radiological Hazard Indices in Sediment Samples from the East Coast of Tamilnadu, India with Statistical Approach. Marine Pollution Bulletin 97, 419 – 430.

Ravisankar, R., Chandrasekaran, A., Vijayagopal, P., Venkatraman, B., Senthilkumar, G., Eswaran, P., Rajalakshmi, A. 2012. Natural Radioactivity in Soil Samples of Yelagiri Hills, Tamil Nadu, India and the Associated Radiation Hazards. Radiation Physics and Chemistry 81, 1789 – 1795.

Ravisankar, R., Raghu, Y., Chandrasekaran, A., Gandhi, M.S., Vijayagopal, P., Venkatraman, B. 2016. Determination of Natural Radioactivity and the Associated Radiation Hazards in Building Materials used in Polur, Tiruvannamalai District, Tamilnadu, India using Gamma Ray Spectrometry with Statistical Approach. Journal of Geochemical Exploration 163, 41 – 52.

Ravisankar, R., Rajalakshmi, A., Eswaran, P., Gajendrian, V., Meenakshisundram, V. 2007. Radioactivity Levels in Soils of Salt Field are Kelambakkam, Tamil Nadu, India. Nucl. Sci. Tech. 18, 372 – 375.

River of Yorubaland. 2017. Oba River. Categories from Rivers of Nigeria, Osun State, Rivers of Yorubaland, https://en.wikipedia.org/wiki/Oba_River. Retrieved on October 15, 2017.

Rodriguez-Barroso, M.R., Garcia-Morales, J.L., Coello-Oviedeo, M.D., Quiroga-Alousa, J.M. 2009. An assessment of heavy metal contamination in surface sediments using statistical analysis. Environmental Monitoring Assessment 163, 489–501.

Sahoo, S.K., Hosoda, M., Kamagata, S., Sorimachi, A., Ishikawa, T., Tokonami, S., Uchida, S. 2011. Thorium, Uranium and Rare Earth Elements Concentration in Weathered Japanese Soil Samples. Progress in Nuclear Science and Technology 1, 416 – 419.

Sahoo, S.K., Yonehara, H., Kurotaki, K., Shiraishi, K., Ramzaev, V., Barkovski, A. 2001. Determination of Rare Earth Elements, Thorium and Uranium by Inductively Coupled Plasma Mass Spectrometry and Strontium Isotopes by Thermal Ionization Mass Spectrometry in Soil Samples of Bryansk region Contaminated due to Chernobyl Accident. J. Radioanal. Nucl. Chem.247(2), 341 – 345, doi: 10.1023/A:1006757718985.

Sartandel, S.J., Jha, S.K., Bara, S.V., Tripathi, R.M., Puranik, V.D. 2009. Spatial Distribution of Uranium and Thorium in the Surface Soil around Proposed Uranium Mining Site at Lambapur and its Vertical Profile in the Nagarjuna Sagar Dam. J. Environ. Radioact. 100, 831 – 834.

Sunmonu, L.A., Adagunodo, T.A. Olafisoye, E.R., Oladejo, O.P. 2012. The Groundwater Potential Evaluation at Industrial Estate Ogbomoso Southwestern Nigeria. RMZ-Materials and Geoenvironment 59(4), 363–390.

Tanaskori, I., Golobocanin, D., Milijevic, N. 2012. Multivariate statistical analysis of hydrochemical and radiological data of Serbian spa waters. J. Geochem. Explor. 112, 226 – 234.

Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hidiroglu, S., Karahan, G. 2009. Radionuclide Concentrations in Soil and Lifetime Cancer Risk due to the Gamma Radioactivity in Kirklareli, Turkey. J. Environ. Radioact. 1000, 49 – 53.

Tzortzis, M., Tsertos, H. 2004. Determination of Thorium, Uranium and Potassium Elemental Concentrations in surface Soils in Cyprus. Journal of Environmental Radioactivity 77 (3), 325 – 338.

Turhan S. 2009. Radiological impacts of the usability of clay and kaolin as raw material in manufacturing of structural building materials in Turkey. J. Radiol. Prot., 29: 75 – 83.

United Nations Scientific Committee on the Effects of Arsenic Radiation (UNSCEAR). 1988. Sources, Effects and Risks of Ionizing Radiation. New York: United Nations.

United Nations Scientific Committee on the Effects of Arsenic Radiation (UNSCEAR). 2000. Sources and Effects of Ionizing Radiation. UNSCEAR 2000 Report Vol. 1 to the General Assembly, with Scientific Annexes, United Nations Sales Publication, United Nations, New York.

United Nations Scientific Committee on the Effects of Arsenic Radiation (UNSCEAR). 1993. Sources and Effects of Ionizing Radiation. UNSCEAR 1993 Report Vol. 1 to the General Assembly, with Scientific Annexes, United Nations Sales Publication, United Nations, New York.

Uosif, M.A.M., Mostafa, A.M.A., Elsaman, R., Moustafa, E. 2014. Natural Radioactivity Levels and Radiological Hazards Indices of Chemical Fertilizers Commonly used in upper Egypt. Journal of Radiation Research and Applied Sciences 7, 430 – 437.

Usikalu, M.R., Akinyemi, M.L., Achuka, J.A. 2014. Investigation of Radiation Levels in Soil Samples Collected from Selected Locations in Ogun State, Nigeria. IERI Procedia 9, 156 – 161.

Usikalu M.R., Fuwape I.A., Jatto S.S., Awe O.F., Rabiu A.B., Achuka J.A. 2017. Assessment of Radiological Prameters of Soil in Kogi state, Nigeria. Environmental Forensics, 18(1): 1 – 14.

Wint, C., Cherney, K. 2017. High Potassium. Healthline Media. Medically Reviewed by Weatherspoon D on May 22, 2017, Retrieved on October 18, 2017. https://www.healthline.com/health/high-potassium-hyperkalemia#about1

Wunderlin, D.A., Diaz, M.D.P., Ame, M.V., Pesce, S.F., Hued, A.C., Bistoni, M.D. 2001. Pattern recognition techniques for the evaluation of spatial and temporal variations in water quality. A case study: Suquia River Basin (Cordoba-Argentina). Water Res 35(12), 2881–2894. doi: 10.1016/s0043-1354(00)00592-3.

Xing-an, C., Yong-e, C., Huijuan, X., Guodong, F., Yun-hui, D., Zhi-Liang, F., Liang, C., Mao, H.X., Ying-Jie, Y., Huan, D.Z., Rong, Z. 2014. A twenty-year Follow-up study on Health Effects following Long-term Exposure to Thorium Dusts. A project from National Natural Science Foundation of China (Project no. 3860285) and IAEA (Project no. 7715/RB and 11526RBF) https://www.ipen.br/biblioteca/cd/irpa/2004/files/1b9.pdf