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Full Length Research Paper

Terrestrial gamma dose rates and physical-chemical properties of farm soils from ex- tin mining locations in Jos-Plateau, Nigeria

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The result of the decades of commercial tin mining activities left a legacy derelict landscapes and impoverished agricultural farm lands in the Jos, Plateau Nigeria. This situation is largely seen to impede environmental, agricultural sustainability and development in the area. It is the purpose of this study to provide a better perspective on the high radioactivity area in Jos Plateau and its implication on farm soil and would seek for any correlation between natural radioactivity and soil physical-chemical properties following the decades of mining activities in the area. To achieve this, soil samples were collected from different cultivated farmlands in three prominent ex-mining areas; Bitsichi, Bukuru and Ropp. The soil samples were analyzed for radioactivity levels due to ^{226}Ra, ^{232}Th and ^{40}K using gamma-ray spectroscopy while physical-chemical parameters were determined using standard methods. Most of the physical and chemical properties of farm soils indicated low values in heavy mined area (Bitsichi) and relatively high values in low mined areas (Bukuru and Ropp). The farm soils across the locations were essentially acidic. Results also showed no obvious correlation between physical-chemical properties and the radionuclide concentration of ^{226}Ra, ^{232}Th and ^{40}K in the farm soils. The outdoor radiation exposure to a farmer during farming operations in these mining areas and the likely associated radiological health risks were considered low and almost insignificant.

Key words: Farm soil, tin mining, terrestrial gamma effective dose rate, soil physical-chemical properties, natural radionuclide concentration, Jos-Plateau, Nigeria.

INTRODUCTION

Geography and geology of Jos Plateau

The Jos Plateau and the study areas lie within Latitude 09°46'02N and Longitude 008°51'39E with elevation of 1279 m. On the average Jos Plateau has an elevation of about 1250 m above sea level and stands at a height of 6000 m above the surrounding plains. Its climate is the wet and dry type classified as tropical rainy climate and characterized by an annual rainfall of 1250 mm (1050 to 1403 mm). The mean annual temperature is about 22°C with monthly values varing between 19.4 and 24.5°C.

The soil temperature regime is inferred to be isohyperthermic. The geology of the area comprises Precambrian basement complex rocks (migmatite, gneiss and old granite), the Jurassic younger granites (Biotite granites) and the tertiary quaternary volcanic rocks (basalts, pumice, lava flows and ash deposits. The geological formations and tin fields of Jos Plateau is shown in Figure 1. The tin deposits of the Jos Plateau are within the Nigerian younger granite province. The Younger granites intrude the Nigerian Precambrian basement gneiss and granite complex occur characteristically as ring

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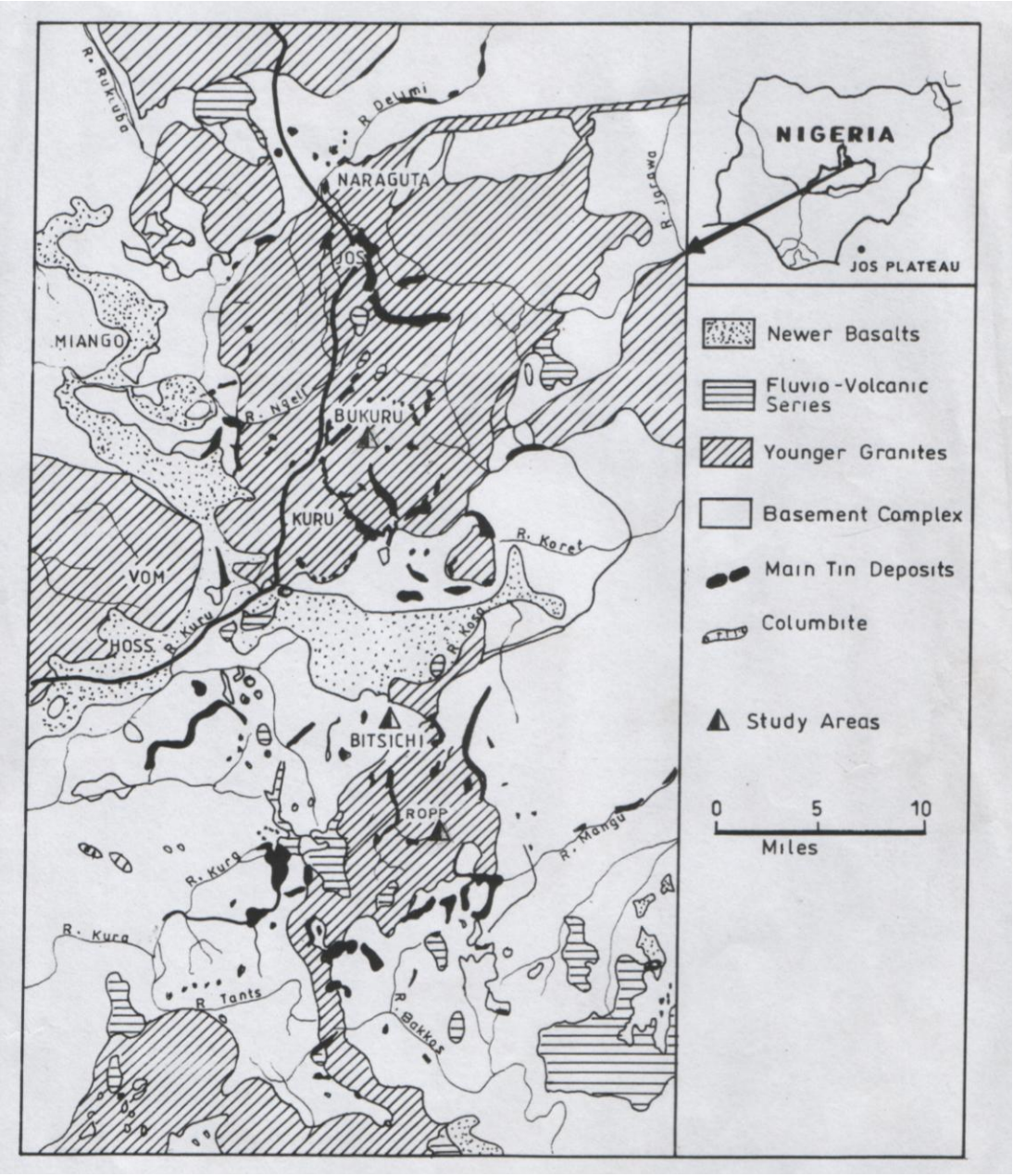

Figure 1. The map of Jos Plateau showing the study locations with the geology and tin deposits.

complexes with the prominent topographic features in the Northern region of Nigeria. The extraction and smelting of tin in Northern Nigeria began as long as 900 BC; it remained a small-scale local activity until 1904 when prospectors from Niger Company discovered the source of the cassiterite to be in the alluvium of rivers draining the granite complexes of the Jos-Bukuru-Ropp area of the Jos-Plateau.. The mining localities under investigation in this study are also indicated in the figure 1. With the discovery of the source area, commercial Exploitation of the deposits began immediately (Alexander, 1990; Alexander and Kidd, 2000)

Impact of tin mining on farm soil

Soil is a three dimensional natural body on earth's surface that is essential to numerous ecosystem functions including production of biomass and net primary productivity, moderation of climate, purification of water, biodegradation of pollutants, storage of water and plant nutrients and recycling of elements. It is the essence of all terrestrial life (Lai, 2009). Soil quality refers to capacity of the soil to perform several of these ecosystem functions. Soil degradation means decline in the quality and capacity of soil through natural and anthropogenic

perturbations. Soil degradation reduces crop yields by increasing susceptibility to drought stress and elemental imbalance that are consequence of natural perturbations such as mining activities (Zheqi et al., 1995). Mining is one of the important pathways by which soils are contaminated. It has considerable implication on the air and water quality, loss of biodiversity, soil pollution and land degradation. According to Adewole and Adesina (2011) mining could also result to clearing of vegetation, reduces biological activities and decreases productivity of the soil. Generally, mineral exploration and exploitation directly or indirectly affects both the living and non-living things through the physical and chemical modification of the soil environment (Adewole and Adesina, 2011).

Mining is a capital intensive industry and also its aftermath is always devastating to the ecology of the host community, hence, the result of the decades of commercial mining left a legacy of damaged or derelict landscapes and impoverished agricultural farm lands as well as environmental problems in the Jos Plateau (Aigbedion and Iyayi, 2007; Pasquini and Alexander, 2005). The traditional farming system of the indigenes has become distorted today as a result of shortage of land so that the people especially in these mining communities because of socio-economic pressure have to farm on the same piece of land yearly and with the poor quality of the land, produce yields have been reported very poor (Jibiri et al, 2007 a, b, Jibiri and Agomuo, 2007). Food security is one of the thematic goals of the United Nations and Food and Agicultural Organization. It implies physical, social and economic access to sufficient, safe and nutritious food by all people at all times in order to meet their dietary and food preferences for an active and healthy life (Lai, 2009; FAO, 2005). Food security can be divided into four components: (1) food production through agronomic management of soil resources, (2) stability of food production and availability at all times, (3) food access through economic capacity of household community and (4) food safety through nutritious and biological quality (Lai, 2008). A sustainable food production or agronomic system is one that will maintain or enhance quality of soil resources base, provides sufficient, accessible, safe and nutritious food supply and creates adequate economic and social rewards to the members of the society.

Research reports on environmental radioactivity studies in the Jos Plateau have indicated high gamma radiation dose rates several orders of magnitude higher than world average value (Oresegun and Babalola, 1990, 1993, Farai and Jibiri, 2000). Majority of these reports attributed these high levels primarily on the influence of tin and its mining activities in the area while the influence of the geological formation of the area was also identified as a factor (Farai and Jibiri, 2000; Jibiri et al., 2007a, b; Ademola, 2008). Food security in the area is important and therefore, there is the need to consider the Physical-Chemical properties of the farm soil relevant to plant growth and production as well as the food safety by assessing the radioactive contaminants in the agricultural farm soil. It also the purpose of this study to seek for any correlation between natural radioactivity and soil physical-chemical properties following the decades of mining activities for the purposes of agricultural sustainability in the areas under consideration.

MATERIALS AND METHODS

Soil sample collection

At each farmland soil samples were collected to a depth of 150 mm from 3 to 5 spots with an average area of 2 m^2; each spots being separated from each other by at least 10 m. About 0.5 kg of soil from each spot was collected. All the samples from each spot were mixed thoroughly as a composite sample that is representative for the farm. They were transferred into a polythene bag and taken to the laboratory for processing. At the laboratory, extraneous materials like plant materials, roots, pebbles were deliberately not removed. This was done in order that all contributing elements in the farm soil samples of the areas under investigation are retained in the analysis. The soil samples along with the extraneous materials were dried at 110°C in a temperature controlled oven until there was no detectable change in the mass of the sample. The dried samples were thoroughly crushed, grounded and pulverized to powder. The powder was passed through a 2 mm sieve. Due to the limited space of the detector shield only 200 g of the soil samples (dry– weight) were used for analysis since, this is quantity it could conveniently take. The samples after weighing were transferred to radon-impermeable cylindrical plastic containers of uniform size (60 mm height by 65 mm diameter) and were sealed for a period of about 30 days. This was done in order to allow for Radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy. The reference soil was also transferred to a container of the same material and dimensions as were used for the soil samples. This is to ensure that the geometry configuration remained the same. The standard reference soil sample used was prepared from Rocketdyne Laboratories California; USA which is traceable to a mixed standard gamma source (Ref. No. 48722-356) by Analytic Inc. Atlanta, Georgia.

Method of measurement

A lead-shielded 76 × 76 mm NaI(Tl) detector crystal (Model No. 802 series, Canberra Inc.) that is coupled to a Canberra Series 10 plus Multichannel Analyzer (MCA) (Model No.1104) through a preamplifier was used for the radioactivity measurements. It has a resolution (FWHM) of about 8% at energy of 0.662 MeV (^{137}Cs) which is considered adequate to distinguish the gamma ray energies of interest in the present study. The choice of gamma-ray peaks of the radionuclides to be used for measurements was made considering the fact that the NaI(Tl) detector used in this study had a modest energy resolution. This was to ensure that the photons emitted by the radionuclides would only be sufficiently discriminated if their emission probability and their energy were high enough, and the surrounding background continuum low enough. Therefore, the activity concentration of ^{214}Bi (determined from its 1.760 MeV γ-ray peak) was chosen to provide an estimate of ^{226}Ra (^{238}U) in the samples, while that of the daughter radionuclide ^{208}Tl (determined from its 2.615 MeV γ-ray peak) was chosen as an indicator of ^{228}Th (^{232}Th). Potassium-40 was determined by measuring the 1.460 MeV γ-rays emitted during its decay.

The soil samples were placed symmetrically on top of the

detector and measured for a period of 10 h. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peaks. From the net area, the activity concentrations in the samples were obtained using the equation (Obed et al., 2005; Jibiri and Bankole, 2006):

$$C\left(Bq.kg^{-1}\right) = kC_n \quad (1)$$

where $k = \frac{1}{\varepsilon P_\gamma M_s}$, C is the activity concentration of the radionuclide in the sample given in Bq kg^{-1}, C_n is the count rate under the corresponding peak, ε is the detector efficiency at the specific γ-ray energy, P_γ is the absolute transition probability of the specific γ-ray, and M_s is the mass of the sample (*kg).* The detection limit (DL) of a measuring system describes its operating capability without the influence of the sample. The DL given in Bq kg^{-1} which is required to estimate the minimum detectable activity in a sample, was obtained using equation 1 (Jibiri et al., 2007a, b):

$$DL(Bq\ kg^{-1}) = 4.65\frac{\sqrt{C_b}}{t_b}k \quad (2)$$

Where C_b is the net background count in the corresponding peak, t_b is the background counting time (s) and k is the factor that converts counts per second (cps) to activity concentration (Bq kg^{-1}) as given in equation (1). With the measurement system used in this work, detection limits obtained were 17.3, 4.2, and 5.1 Bq kg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th, respectively. Values below these numbers were taken in this work as being below the detection limit (BDL) of the detector The detailed energy and efficiency calibration of the detector and procedures can be found in our earlier publications (Obed et al., 2005; Jibiri and Bankole, 2006).

Physical – chemical properties

The analysis of the physical and chemical properties of the soil samples was carried out at the soil Science laboratory of the Institute for Agricultural Research and Training (IART) of the Obafemi Awolowo University, Ile-Ife, Nigeria. Standard methods were employed in the determination of the physical and chemical properties of the farm soil samples at the laboratory.

RESULTS

Activity concentration levels of the radionuclides and the physico-chemical parameters

Using Equation 1 the activity concentrations of the radionuclides in the farm soil samples were determined. The range, mean and standard deviation of the measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the farm soils for the three areas are presented in Tables 1, 2 and 3 respectively for Bitschi, Bukuru and Ropp while the range and mean of the physical and chemical properties of the farm soils are presented in Table 4 for each of the location. The correlation between the physical properties and the radionuclides were carried and the correlation coefficients obtained between each pair of variables are presented in Table 5 while that between the radionuclides and chemical properties are presented in Table 6.

Dose calculations

Absorbed dose rate and outdoor effective dose rate

The external absorbed dose rate, D (nGy.h^{-1}) in air at 1 m above the ground level for soils containing the concentrations of the radionuclides measured in the samples is calculated using the equation (UNSCEAR, 2000; Mustapha et al., 2007):

$$D_{ext} = \sum_R A_R DC_{ext,R} \quad (3)$$

where $DC_{ext,R}$ is the coefficient of dose rate per unit activity concentration of radionuclide R (in Bq kg^{-1}) and A_R is the concentration of the radionuclide R in the sample (Bq kg^{-1}). The United Nation Scientific Committee on the Effects of Atomic Radiation UNSCEAR (2000) prescribes $DC_{ext,R}$ coefficient of ^{226}Ra as 4.27 × 10^{-10} Gy.h^{-1}/Bq. kg^{-1}, ^{232}Th as 6.62 × 10^{-10} Gy.h^{-1}/Bq.kg^{-1}), ^{40}K as 0.43 × 10^{-10} Gy h^{-1}/Bq.kg^{-1} and ^{137}Cs as 0.30 × 10^{-10} Gy.h^{-1}/Bq.kg^{-1}). Since ^{137}Cs was not detected in any of the samples, its coefficient was taken as zero. The absorbed γ-dose rates in air are usually related to human absorbed γ-dose in order to asses radiological implications. The external effective dose D_{ext} (Sv y^{-1}) received by an individual due to the radionuclides in the farm soil during farming was evaluated. In assessing the outdoor effective dose equivalent to members of the population, two important factors were considered. The first is a factor that converts the absorbed dose rates (Gy.h^{-1}) in air to human outdoor effective dose rates (Sv.y^{-1}) while the second factor gives the proportions of the total time for which the typical individual is exposed to outdoor or indoor radiation. The United Nation Scientific Committee on the effect of Atomic Radiation (UNSCEAR, 2000) has recommended 0.7 Sv Gy^{-1} as the value of the first factor and 0.2 and 0.8 as for outdoor and indoor occupancy factors, respectively. This second factor implies that the average individual spends only 4.8 hours (about 5 hours per day) outdoors. In this work, only outdoor exposure from γ-rays sources due to the concentrations of the primordial radionuclides in the farm soil were considered. Since we are considering exposure scenario to farmers resulting from radionuclide concentrations in farm soil, the outdoor occupancy factor was modified to reflect that for a typical peasant farmers in Nigeria. An average occupancy factor of (10 hrs) was adopted for a typical peasant farmer in Nigeria. The

Table 1. The activity concentrations due to ^{226}Ra, ^{232}Th and ^{40}K and outdoor gamma effective dose rates in farm soils from Bitsichi area.

Farms	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Outdoor effective dose rate (mSv y^{-1})
1	315 ± 24	180 ± 9	534 ± 34	0.33
2	217 ± 26	295 ± 15	778 ± 44	0.40
3	116 ± 21	128 ± 9	437 ± 29	0.19
4	149 ± 26	513 ± 17	326 ± 30	0.51
5	160 ± 28	527 ± 18	648 ± 43	0.55
6	89 ± 18	235 ± 11	810 ± 38	0.28
7	110 ± 26	581 ± 18	240 ± 25	0.54
8	198 ± 39	604 ± 18	329 ± 33	0.61
9	94 ± 21	236 ± 10	709 ± 37	0.28
10	125 ± 21	237 ± 11	808 ± 38	0.30
11	88 ± 24	389 ± 15	390± 31	0.39
12	143 ± 28	570 ± 18	477 ± 38	0.56
13	148 ± 26	219 ± 12	449 ± 34	0.28
14	91 ± 26	421 ± 16	352 ± 32	0.41
15	146 ± 29	706 ± 20	542 ± 41	0.68
16	67 ± 22	247 ± 12	250 ± 23	0.25
17	180 ± 26	394 ± 15	623 ± 40	0.45
18	82 ± 20	144 ± 9	313 ± 24	0.18
19	152 ± 21	101 ± 8	389 ± 28	0.18
20	129 ± 20	163 ± 9	750 ± 36	0.24
21	163 ± 23	210 ± 11	352 ± 28	0.27
22	127 ± 20	93 ± 7	631 ± 34	0.18
23	132 ± 23	328 ± 13	761 ± 39	0.38
24	304 ± 29	574 ± 19	370 ± 34	0.64
25	256 ± 27	463 ± 17	663 ± 42	0.55
26	201 ± 24	252 ± 11	652 ± 37	0.34
27	223 ± 27	494 ± 17	906 ± 47	0.57
28	157 ± 23	272 ± 13	741 ± 39	0.34
29	140 ± 21	156 ± 8	452 ± 29	0.22
30	145 ± 23	275 ± 13	483 ± 35	0.12
31	86 ± 24	377 ± 15	482 ± 31	0.38
32	145 ± 16	374 ± 9	93 ± 10	0.38
33	175 ± 19	515 ± 10	136 ± 7	0.51
34	109 ± 15	123 ± 8	166 ± 12	0.11
35	73 ± 14	168 ± 8	129 ± 17	0.18
36	427 ± 12	1036 ± 9	BDL	1.07
37	471 ± 11	2190 ± 9	55 ± 12	2.02
Mean	163 ± 92	451 ± 368	466 ± 221	0.43 ± .033

effective dose rate resulting from the absorbed dose rate values was calculated using the following relation:

$$E_{ext} = T\, f\, Q D_{ext}\, \varepsilon \qquad (4)$$

where E_{extr} is the effective dose rate (μSv.y^{-1}), T is time being 8766 h.y^{-1}, f is the outdoor occupancy factor that corrects for the average time spent outdoors (~ 10 h), Q is the quotient of the effective dose rate and absorbed dose rate in air (0.7 Sv Gy^{-1}), ε is a factor converting nano (10^{-9}) into micro (10^{-6}) and D_{ext} is the absorbed dose rate in air (nGy.h^{-1}).The values of the outdoor effective dose rates obtained across the farms are also presented in Tables 1, 2 and 3 respectively for Bitschi, Bukuru and Ropp.

Table 2. The activity concentrations due to ^{226}Ra, ^{232}Th and ^{40}K and outdoor gamma effective dose rates in farm soils from Bukuru area.

Farms	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Outdoor effective dose rate (mSv y^{-1})
1	137 ± 23	204 ± 12	1077 ± 42	0.29
2	114 ± 23	247 ± 12	734 ± 36	0.29
3	106 ± 20	69 ± 6	753 ± 33	0.15
4	97 ± 20	79 ± 6	614 ± 30	0.15
5	146 ± 23	245 ± 11	1334 ± 43	0.35
6	51 ± 20	BDL	824 ± 37	0.07
7	157 ± 22	225 ± 10	597 ± 31	0.30
8	99 ± 18	238 ± 11	1500 ± 47	0.32
9	136 ± 21	152 ± 9	953 ± 36	0.25
10	119 ± 19	189 ± 10	1238 ± 45	0.28
11	80 ± 17	124 ± 8	990 ± 41	0.18
12	84 ± 18	137 ± 9	1138 ± 43	0.21
13	81 ± 18	160 ± 9	823 ± 38	0.22
14	122 ± 16	166 ± 10	1154 ± 43	0.26
Mean	109 ± 28	154 ± 56	981 ± 263	0.24 ± 0.08

Table 3. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and outdoor gamma effective dose rates in farm soils from Ropp area.

Farms	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Outdoor effective dose rate (mSv y^{-1})
1	87 ± 18	85 ± 6	831 ± 35	0.16
2	105 ± 22	124 ± 8	942 ± 41	0.20
3	43 ± 19	66 ± 6	1110 ± 41	0.14
4	60 ± 15	155 ± 14	527 ± 21	0.19
5	44 ± 14	118 ± 7	530 ± 21	0.15
6	76 ± 16	145 ± 8	324 ± 17	0.17
7	168 ± 27	150 ± 9	1854 ± 53	0.31
8	110 ± 25	160 ± 10	1572 ± 48	0.27
9	136 ± 27	107 ± 8	1796 ± 53	0.25
10	115 ± 30	116 ± 8	881 ± 33	0.20
11	196 ± 27	115 ± 8	1515 ± 49	0.28
12	136 ± 27	151 ± 10	1393 ± 47	0.27
13	163 ± 34	401 ± 16	618 ± 44	0.44
14	293 ± 34	194 ± 11	525 ± 32	0.34
Mean	129 ± 65	147 ± 75	1062 ± 199	0.24 ± 0.08

DISCUSSION

As could be observed from the Tables 1 to 3, the highest concentration of ^{40}K in the study was obtained in Ropp whereas those of ^{226}Ra and ^{232}Th were only obtained in Bitsichi. The concentration of the three radionuclides as could be seen from Tables 1-3 were higher than the world average in soils which are; 420 Bq kg^{-1}, 32 Bq kg^{-1} and 45 Bq kg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th, respectively (UNSCEAR, 2000). This is indication that the radioactivities in the farm soil from these areas are high. A comparison of radioactivity from farm soils in non-mining areas and roadside soil radioactivity clearly indicates high radioactivities in the farm soils from the three areas under consideration (Jibiri and Bankole, 2006; Jibiri and Agomuo, 2007). In order to find what extent these radionuclides can exit together at a particular location, a correlation studies were carried between each pair of the radionuclides. The regression carried was between ^{40}K and ^{232}Th, ^{40}K and ^{226}Ra and,

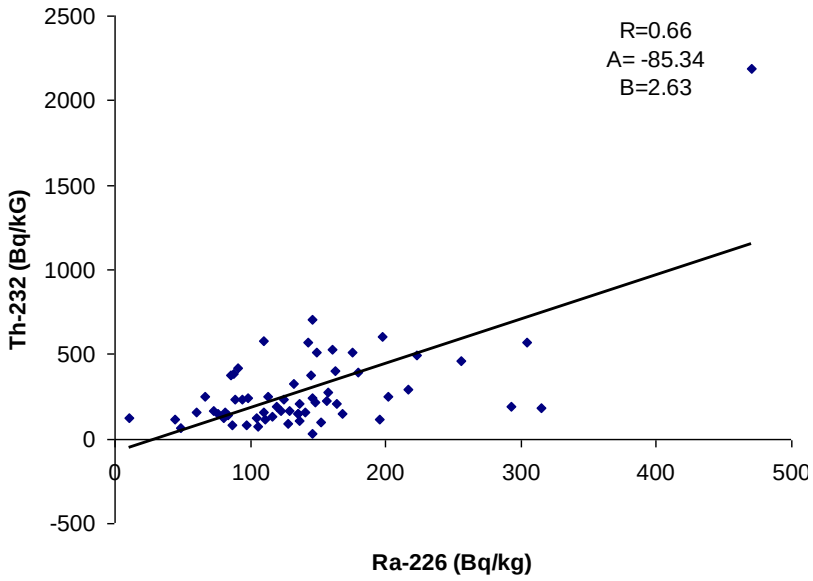

Figure 2. Correlation between ^{232}Tha and ^{226Th}.

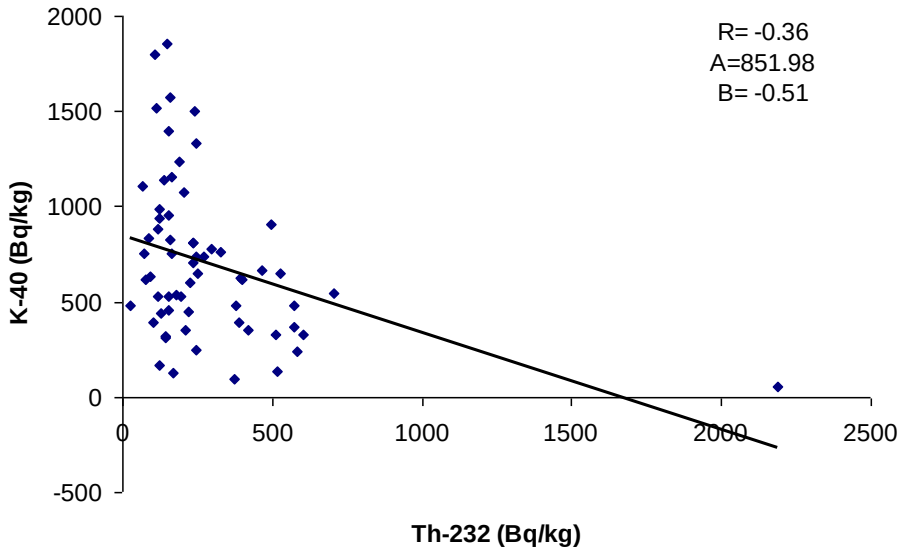

Figure 3. Correlation between ^{232}Th and ^{226}Ra.

^{226}Ra and ^{232}Th. The scatter plots for each pair is show in Figures 2 to 4 while the correlation co-efficients calculated from the data are also displayed in the figures. It is evident from the figures that correlations are not very strong between ^{40}K and ^{232}Th, ^{40}K and ^{226}Ra but was strong between ^{226}Ra and ^{232}Th. This trend between ^{226}Ra and ^{232}Th has been similarly reported by Shiva Prasad et al. (2008) with correlation greater than 0.5. The poor correlation between the other two pair indicates that individual results for any one of the radionuclide concentrations is not therefore, a good predictor of the individual values for the other. Though in Shiva Prasad et al. (2008) report ^{226}Ra and ^{40}K, and ^{232}Th and ^{40}K correlation values were positive with very poor correlation as observed however, the reverse appears to be the case in this study. This may be attributed to the influence of different farm practices employed in improving the soil fertility due to poor yield of farm products from these areas and the extraneous concentration values at the farms resulting from tin tailings. According to Jibiri et al. (2007 a, b) and Alexander (2005), heavy applications of different brands chemical fertilizers and refuse ash were used by local farmers to improve the soil fertility and reclamation initiatives. Mittra et al. (2003) reports that one of the possible ways of enhancing productivity of acidic soil is use of fly ash in appropriate combination with

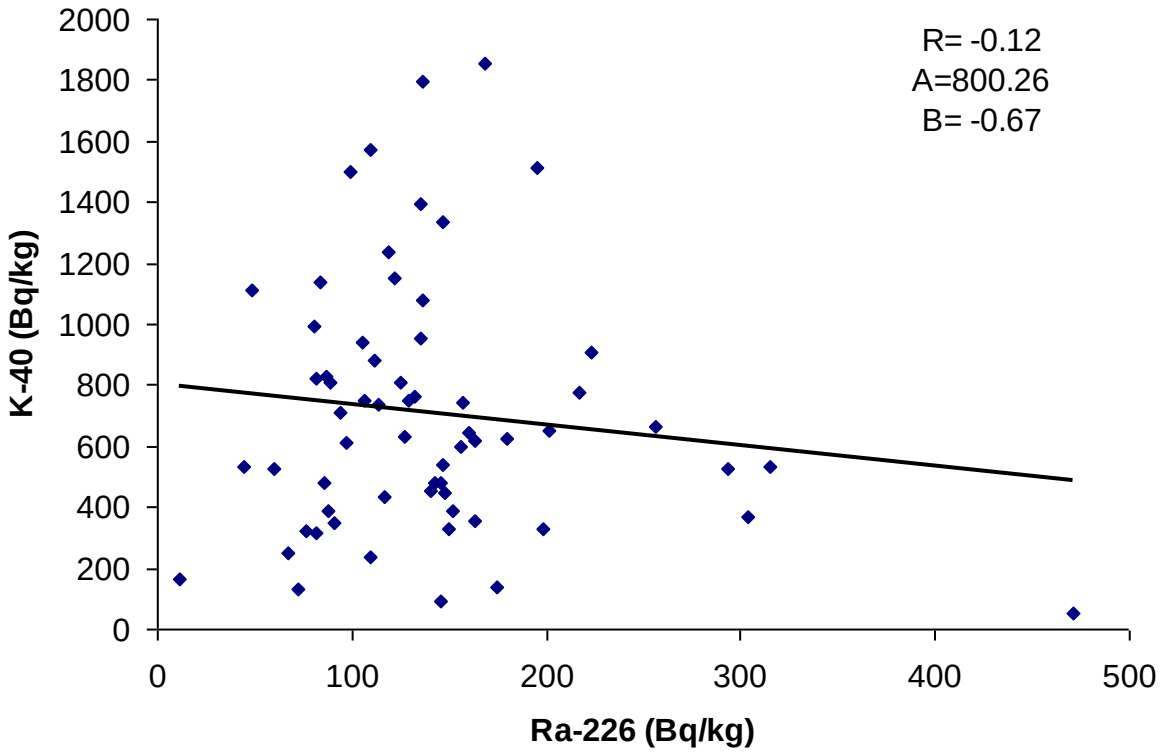

Figure 4. Correlation between ^{40}K and ^{226}Ra.

organic matter and chemical fertilizer which would act as soil amendment and source of nutrient supply system. These practices would have modified the concentrations of these radionuclides and their distribution hence altering their natural processes in the farm soils in these areas under investigation as against farm soils where such influences do not exist. From the Table 4 the soil properties across the mining areas appear not significantly different in their values. However, both physical and chemical properties recorded lower values in Bitsichi compared to other two areas except clay content which was more than 50% higher than those in Ropp and Bukuru. This could explain why higher ^{232}Th concentrations were obtained in Bitsichi relative to the other two locations. This observation was in agreement with van Egmond et al. (2008) that, high correlations exist between clay content and ^{232}Th concentration in soil. It is also a further indication of the effect of tin mining on these parameters. Comparatively heavy mining activities actually took place in Bitsichi than in the other two areas. The chemical properties obtained in these areas are far less than those in the tin tailings where values as high as 7.39 Cmol kg^{-1} of Ca, 3.04 Cmol kg^{-1} of Mg, 6.2 Cmol kg^{-1} of K were obtained (Alao and Adeoye, 2004). Excess Ca usually leads to low solubility of P, Fe, Mn, B and Zn (Pandey et al., 2005). Calcium has the ability to capture P to form Calcium triphosphate, thus rendering P unavailable to plants. The abundance of Ca in the tin tailings and subsequent deposition on soil will decrease the availability of other nutrients especially Nitrogen. Nitrogen is one of the major soil nutrients for good growth and yield of crops. These factors may cause low productivity of crops in these mining areas. This justified the use of soil amendment procedures and fertilizer applications in the farm soils by farmers in the area as explained above. Generally, the soil from these areas affected by mining in the Jos–Plateau is acidic. This may therefore suggest that water from ponds and streams from these areas would be acidic and may be regarded as unsuitable for domestic, industrial and irrigation purposes. The detailed implications of these farm soil properties with respect to plant nutrient amendments and produce yields was not carried but may be subject for future considerations. From Tables 5 and 6, the correlation coefficients between the Physico-chemical parameters and the radionuclide concentrations indicated no obvious relationship. The annual outdoor effective dose due to external exposure as could be seen from Tables 1 to 3 varied from 0.07 mSv in Bukuru to 2.02 mSv in Bitsichi. The higher effective doses greater than 1 mSv y^{-1} were only obtained in the farm soils mixed with tin spoil tailings while majority of the farms indicated values less than 1 mSv recommended annual dose limit for the members of the public by the International Commission on Radiological Protection (ICRP, 1996). The outdoor radiation exposure to a farmer during farming operations in these mining areas and the likely radiological health risks are considered low and almost insignificant.

Table 4. The range, mean and standard deviation of the physical and chemical parameters of the farm soils from the three mining areas

Parameter	Bitsichi		Bukuru		Ropp	
	Range	Mean ± σ	Range	Mean ± σ	Range	Mean ± σ
	N = 31		N= 14		N = 14	
Na (Cmol kg^{-1})	0.30 - 0.52	0.36 ± 0.40	0.30 – 0.63	0.4 ± 0.08	0.30 – 0.40	0.35 ± 0.03
K (Cmol kg^{-1})	0.13 – 0.25	0.18 ± 0.06	0.14 – 0.29	0.2 ± 0.17	0.14 – 0.21	0.18± 0.02
Ca (Cmol kg^{-1})	0.86 – 1.30	1.00 ± 0.08	0.89 – 1.28	1.04 ± 0.11	0.89 – 1.23	1.01 ± 0.09
Mg (Cmol kg^{-1})	0.72 – 1.00	0.88 ± 0.06	0.78 -1.10	0.91 ± 0.05	0.76 – 1.11	0.9 ± 0.08
Av P (mg kg^{-1})	3.98 – 11.80	5.80 ± 1.57	4. 90 – 13.00	7.35 ± 2.84	4.29 -8.06	6.00 ± 1.07
H^+	0.10 -0.16	0.12 ± 0.02	0.08 – 0.15	0.11 ± 0.05	0.09 – 0.13	0.11 ± 0.02
Cation exchange capacity (Cmolkg^{-1})	2.21 – 3.07	2.51 ± 0.30	2.26 – 3.39	2.67 ± 0.19	2.24 – 2.97	2.48 ± 0.18
pH (H_20)	5.10 – 6.30	5.57 ± 0.36	5.30 – 6.60	6.05 ± 0.33	5.30 – 6.60	6.02 ± 0.35
pH (KCl)	4.10 – 5.40	4.81 ± 0.39	4.10 – 5.30	4.94 ± 0.20	4.80 – 5.80	5.07 ± 0.28
Base Saturation (%)	93.1 – 96.8	95.14 ± 0.90	93.36 – 97.35	95.80 ± 0.95	93.30 – 97.31	95.52 ± 0.96
Organic Carbon (%)	0.49 – 1.08	0.68 ± 0.48	0.59 – 1.10	0.81 ± 0.16	0.55– 0.88	0.70 ± 0.09
N (%)	0.049 – 0.108	0.068 ± 0.048	0.059 – 0.110	0.081 ± 0.016	0.055– 0.088	0.070 ± 0.009
Organic matter (%)	0.84 – 1.86	1.17 ± 0.22	1.02 – 1.89	1.39 ± 0.28	0.95 – 1.51	1.21 ± 0.16
Silt (%)	3.00 – 19.80	9.40 ± 3.79	6.98 – 14.00	10.15 ± 1.86	4.70 – 19.00	17.75 ± 7.92
Clay (%)	5.00 – 51.00	24.98 ± 13.59	3.00 – 31.00	12.92 ± 7.57	8.92 – 41.00	19.84 ± 12.63
Sand (%)	43.00 – 89.00	65.63 ± 11.95	60.00 – 89.00	77.00 ± 7.64	49.30 – 80.10	68.17 ± 10.34
Water holding capacity (%)	10.02 – 19.24	14.22 ± 3.30	10.98 – 20.00	16.30 ± 2.39	12.90 – 18.34	16.00 ± 1.73
Bulk density (g cm^{-3})	1.02 – 7.40	3.41 ± 2.32	1.20 – 6.30	3.82 ± 2.03	1.00 – 6.80	3.43 ± 2.29
Porosity (%)	3.00 – 16.48	8.59 ± 4.47	6.16 – 18.96	12.25 ± 3.43	3.89 – 16.98	9.09 ± 3.82
Hydraulic conductivity (cm hr^{-1})	0.43 – 3.10	1.48 ± 0.92	0.96 – 2.89	2.20 ± 0.59	0.59 – 2.90	1.78 ± 0.77
Moisture content (%)	16.00 – 29.10	21.53 ± 3.57	18.90 – 29.36	25.07 ± 3.81	17.98 – 29.99	22.44 ± 3.60
Permeability (%)	4.91 – 26.28	12.80 ± 5.92	4.98 – 24.00	15.25 ± 5.39	8.10 – 21.03	14.12 ±3.70

Conclusion

The activity concentrations of natural radionuclides have been determined in soil samples from agricultural farmlands in three old tin mining areas in Jos-Plateau Nigeria using gamma-ray spectroscopy. The physical and chemical properties of these soils were equally determined. The activity concentrations of the radionuclides in the farm soils were higher than the world average values for normal background radiation areas. The outdoor effective dose rates calculated ranged between 0.07 and 2.02 mSv y^{-1} across the three areas. The tin mining activities is found to have significantly affected the radio-nuclide concentration levels in the farmlands where the tin spoil tailing are in mix with the soil farms. The Physical-Chemical parameter values were found low in the area where substantial mining took place (Bitsichi) compared to the other areas where mining activities were not in large scale. No obvious correlation was found between radionuclide concentrations in the farm soil with the physical-chemical properties.

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Table 5. The correlation coefficients of the chemical parameters with radionuclide concentration of the farm soil.

Parameter	^{40}K	^{226}Ra	^{232}Th
Na (Cmol kg^{-1})	0.18	0.06	0.08
K (Cmol kg^{-1})	0.16	0.04	0.14
Ca (Cmol kg^{-1})	0.34	-0.22	0.16
Mg (Cmol kg^{-1})	0.26	0.08	0.09
H^+	-0.43	0.02	-0.07
Cation exchange capacity (CEC)	0.13	0.03	0.10
pH (H_2O)	0.45	-0.02	0.08
pH(KCL)	0.31	0.04	0.08
% Base Saturation	0.40	-0.03	0.09
% Organic carbon (OC)	0.19	0.02	0.19
% N	0.19	0.02	0.19
% Organic matter (OM)	0.19	0.02	0.18

Table 6. The **c**orrelation coefficients of the physical parameters with radionuclide concentration of the farm soil.

Parameter	^{40}K	^{226}Ra	^{232}Th
Clays %	-0.313	-0.235	0.008
Sand %	0.259	0.257	-0.014
Silt %	0.218	0.043	0.053
Water Holding Capacity %	0.256	0.105	0.001
Bulk Density (kg^{-3})	0.291	0.130	0.051
Porosity %	0.376	0.047	-0.001
Hydraulic conductivity cm/hr	0.298	0.099	-0.040
Moisture Content %	0.351	-0.007	-0.070
Permeability %	0.262	0.101	0.017

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