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Radionuclide Depth Profile Baseline and Radiation Hazard Indices of the Reclaimed Old Nekede Mechanic Village, Owerri, Imo State, Nigeria

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Abstract Radionuclide concentration in soil samples collected at the old Nekede auto-mechanic village in Owerri were determined using gamma spectroscopy. A total of 15 soil samples were collected at depths of 10-cm, 20-cm and 30-cm at 5 different sites respectively. From the results, the mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th were 132.66±5.61 Bq/Kg, 26.38±3.88 Bq/Kg, and 73.24±4.91 Bq/Kg respectively for samples collected at 10cm depth. At 20cm depth the mean values obtained were 111.95±6.51 Bq/Kg, 32.63±3.48 Bq/Kg, and 89.76±5.20 Bq/Kg for ^{40}K, ^{226}Ra, and ^{232}Th respectively, while 102.88±4.62 Bq/Kg, 30.03±2.77 Bq/Kg, and 76.08±6.65 Bq/Kg were obtained at the 30 cm depth for ^{40}K, ^{226}Ra, and ^{232}Th respectively. The calculated absorbed dose rate and annual effective dose have an average value of 66.6687 nGyh^{-1} and 0.0912 mSv.y^{-1}. The 10cm depth presented the lowest dose rate and annual effective dose rate with values of 61.9564 nGyh^{-1} and 0.0847 mSv.y^{-1} respectively. While the highest values were obtained at 30cm depth with values of 64.0913 nGyh^{-1} and 0.0876 mSv.y^{-1} respectively. The value of the annual effective dose lies within the world average value of 1.0 mSvy^{-1} annual effective dose equivalent rate. The hazard indices corresponding to the collected samples was also estimated to have a mean value of 0.142, which is below the recommended world average.

Keywords Radionuclide concentration, External and Hazard indices, Mechanic village, Annual effective dose

1. Introduction

Several studies have reported on the effects of effluents discharged from anthropogenic activities to contain toxic substances that cause adverse effects to the environment and its inhabitants; such studies were reported by [1], [2]. In Nigeria, mechanic village is a place where various automobile repairs are carried out – such as, welding and fabrication, soldering, car battery recharging, scrapping, spraying, and painting of vehicle parts, gear box recycling, panel beating of scratched vehicles, discharge of condemned petroleum products (oils, greases, hydraulics fluids)" [3]. In a study on the impact of such activities on the physicochemical and microbial behavior of the soils from three mechanic villages in and around Abuja, Nigeria; the authors from their findings showed a high level of heavy metal concentrations which exceeded the recommended levels for industrial areas. [4] Also, another research carried on radiation levels within a mechanic village in Abuja, showed a background radiation that was less than the 1 mSv/yr provided by the Basic Safety Standards (BSS). Furthermore, research work by [5], found that Neem, Cashew and Mango trees takes up heavy metals from a contaminated Mechanic village. These trees in turn produce edible parts that are consumed by the local dwellers, thus exposing the inhabitants to secondary uptake of heavy metals and radionuclides. Several other studies have also shown that radionuclides can easily be transferred from contaminated soil into the food chain. This is because the plants naturally take up mineral contents within the shoot system. Sometimes these radionuclides are concentrated in the plants in levels higher than what is obtainable in the contaminated soil, such results were obtained by [6]. This uptake of radionuclides by plants are described through the soil-to-plant transfer factors [7].

Naturally occurring radionuclide materials (NORM) are ubiquitous in our environment and can in most cases can be concentrated in amount which may pose health concern to the public. These enhanced concentration because of technological activities are regarded as technological enhanced natural occurring radionuclide materials (TENORM). Many non-nuclear industrial processes have been observed to concentrate NORM to TENORM, as

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suggested by [8], the intent of those activities was not designed for such purposes. In so many places, little attention is given to NORM related activities, but as suggested by [9], the environmental and regulatory implications of NORM sites deserve more attention; they argued that this is so because in many cases, the diffused NORM wastes are produced a long time ago and most time is treated as non-radioactive remnant materials; and some industries who produce NORM wastes are not even aware of such production.

Radiation monitoring and regulation is well established in the oil and gas sector in Nigeria, but this is not the case in many other sectors like mineral sand processing, quarry sites, scrap yards, etc. In a recent research, the NNRA conducted a survey on occupation dose for nuclear energy related activities [10], such surveys are rarely seen amongst non-nuclear energy related activities. In our area of study, the state government has recently relocated the Nekede mechanic village, and the place is being reclaimed for private settlements. In our previous study [2] on the soil and water physicochemical water parameters and heavy metals, the study shows that the reclaimed land would not be suitable for agricultural and recreational purposes due to the high level of heavy metal contamination.

There have been several documentations on the accumulation of NORM to TENORM due to human activities; this concentration poses radiation risks not only to the human population within the affected area but also to the flora and fauna within such area; some of these radionuclides have been found to accumulate in earthworms within such areas [11]. The enhanced radiation due to NORM has become an issue of importance in radiological protection of humans and biota. As such, source characterization, comprising the radionuclide speciation, distribution and mobility analysis, is crucial in the environmental risk and impact assessment [12]. In this study, we intend to establish the radionuclide baseline concentration with at 10 cm, 20 cm and 30 cm depth profile within the reclaimed mechanic village and assess the radiation hazard indices, this, when combined with our previous study, will provide a holistic view of both radionuclide, heavy metal, and physicochemical parameters state of the reclaimed mechanic village. This will invariably provide a robust data for environmental impact assessment within the area under investigation.

2. Materials and Methods

Study Area

The study area is as described in our previous study [2].

Sample Collection

A total of 15 soil samples were collected within the reclaimed Nekede auto-mechanic village. The soil samples were taken at depths of 10, 20 and 30 cm at each site respectively, using hand – driven soil auger; this was done to determine the radionuclide profiling with depth in the area under investigation. 400 g of each sample were collected with a polythene bag and taken to the laboratory for preparations. The samples were labeled as S_1-10 cm, S_2-10 cm and S_3-10 cm, representing samples from first, second and third locations at 10 cm depth respectively. Another sampling site was chosen as S_1-20 cm, S_2-20 cm and S_3-20cm, representing samples from the three locations at the depth of 20 cm respectively, and lastly S_1-30 cm, S_2-30 cm and S_3-30 cm which represents samples from the three locations at the depth of 30 cm respectively.

Sample Preparation for Gamma Spectroscopy

All the samples were sun dried in constant humidity condition for 15 days until a constant weight was achieved. The samples were then sieved using 0.6 mm sieve to remove extraneous materials and sealed in cylindrical plastic containers with appropriate labels and was kept for 30 days to attain secular equilibrium. The gamma spectroscopic analysis was carried out as reported in [7], at the well-established laboratory located at the Centre for Energy Research and Training, Zaria, Nigeria.

The gamma-ray spectrometry set-up is made up of a 7.62 cm by 7.62 cm NaI (Tl) detector housed in a 6 cm thick lead shield (to assist in the reduction of the background radiation) and lined with cadmium and copper sheets [13]. The samples were placed on the detector surface and each counted for about 29,000 seconds in reproducible sample detector geometry. The configuration and geometry were maintained throughout the analysis, as previously characterized based on well-established protocol of the laboratory (at the Centre for Energy Research and Training, Zaria). A computer based Multichannel Analyzer (MCA) MAESTRO Programme from ORTEC was used for data acquisition and analysis of gamma spectra. The 1764 keV Gamma-line of ^{214}Bi for ^{238}U was used in the assessment of the activity concentration of 226Ra, while 2614.5 keV Gamma-line of ^{208}Tl was used for ^{232}Th. The single 1460 keV Gamma-line of 40K was used in its content evaluation. The activity concentration (C) in Bq/kg of the radionuclides in the samples was calculated after decay correction using the expression [14].

$$C_s = \frac{C_a}{\varepsilon_\gamma \times M_s \times t_c \times P_\gamma}$$

Where C_s is sample activity concentration, C_a = net peak area, ε_γ =efficiency of the detector for γ-energy of intensity, M_s= sample mass, t_c= total counting time, P_γ= the abundance of the γ-line in a radionuclide.

Data Analysis

The data analysis was performed using MS-EXCEL.

Assessment of Radiological Hazard

To evaluate the radiation hazard of the gamma rays, due to the occurring radionuclides, the radiation hazard index used is the radium equivalent activity (Ra_{eq}) [8]. It provides a useful guideline in regulating the safety standard in dwellings. The radium equivalent concentration Ra_{eq} is

given by the following relation.

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

Where $\Gamma_{Ra}, \Gamma_{Th}, and\ \Gamma_{K}$ are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The relation in equation 1 is based on the estimation that 1 Bq/kg of ^{226}Ra, O.7 Bq/kg of ^{232}Th and 13 Bq/kg of ^{40}K produce the same radiation dose rates [13].

Estimation of Hazard Indices

Activities carried out in the past at the study area may have contributed to external gamma dose rates. To limit the external gamma-radiation dose due to naturally occurring radionuclides, the following criteria must be satisfied [15].

$$H_{ex} = \frac{\Gamma_{Ra}}{370} + \frac{\Gamma_{K}}{4810} + \frac{\Gamma_{Th}}{259} \quad (2)$$

$$H_{in} = \frac{\Gamma_{Ra}}{185} + \frac{\Gamma_{K}}{4810} + \frac{\Gamma_{Th}}{259} \quad (3)$$

Where $\Gamma_{Ra}, \Gamma_{Th}, and\ \Gamma_{K}$ are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The value of these radiation hazard indices must be less than unity respectively for the radiation hazard to be negligible [16]. When individuals are exposed to these radiations internally, they encounter significant health threats, like certain respiratory diseases like cancer and asthma.

Estimation of Radiation doses

Equations 4 and 5 were used to estimate the outdoor annual radiation dose and external outdoor absorbed gamma dose from the radionuclides respectively [17], [18].

$$D(nGy.h^{-1}) = 0.0417\Gamma_{K} + 0.604\Gamma_{Th} + 0.462A\Gamma_{Ra} \quad (4)$$

$$E\ (mSv.y^{-1}) = D \times 24 \times 365.25 \times 0.2 \times 0.7Sv/Gy \times 10^{-6} \quad (5)$$

Where; D(nGy.h^{-1}) is the absorbed dose rate in air, 24 is the number of hours in one day, 0.2 is the outdoor occupancy factor, 0.7 Sv/Gy is the conversion coefficient from absorbed dose in air to effective dose received by adults, 10^{-6} is the conversion factor between nano (n) (10^{-9}) and milli (m) (10^{-3}).

Representative Gamma Index (I_{yr})

Equation 6 is used to estimate the radiation hazard associated with the natural radionuclide in specific investigated samples. The representative gamma index as reported by [19] is given by

$$I_{yr} = \frac{\Gamma_{K}}{1500} + \frac{\Gamma_{Th}}{100} + \frac{\Gamma_{Ra}}{150} \quad (6)$$

I_{yr} was used to estimate, if materials from the study area could pose health threats when used for domestic purposes.

3. Results and Discussion

The results generated from the spectroscopic analysis of the soil samples from the five selected sites are shown in Table 1. Only the primordial radionuclides—Potassium-40, Radium-226, and Thorium-232 (i.e ^{40}K, ^{226}Ra and ^{232}Th) were observed, thereby suggesting that the auto repair activities did not introduce any anthropogenic source of radiation. The data obtained shows variations in the mean activity concentrations of the analyzed radionuclides with depths. The average Activity profile of ^{40}K were 132.66 ± 5.61 Bqkg^{-1}, 111.95 ± 6.51 Bqkg^{-1}, and 102.88±4.62 Bqkg^{-1} for 10, 20 and 30 cm depths, respectively. ^{226}Ra average values were 26.38 ± 3.88 Bqkg^{-1}, 32.63 ± 3.88 Bqkg^{-1}, and 30.03 ± 2.27 Bqkg^{-1} 10, 20 and 30 cm depths, respectively.

Table 1. Activity Concentration of identified radionuclides in the soil samples

Sample ID	K-40 (Bq/Kg)	Error ±(Bq/Kg)	Ra-226 (Bq/Kg)	Error ±(Bq/Kg)	Th-232 (Bq/Kg)	Error ±(Bq/Kg)
S1-10 cm	168.3381	2.6814	31.5659	4.6350	76.5148	4.8362
S1-20 cm	136.5903	6.4890	15.5033	4.7549	101.876	3.8926
S1-30 cm	128.3316	2.8959	30.4579	4.0356	109.307	5.4260
S2-10 cm	37.4859	3.8076	18.599	2.7970	76.0036	4.5610
S2-20 cm	91.7038	10.672	20.8175	4.4752	98.2188	3.7746
S2-30 cm	85.1075	6.7571	31.6858	3.0767	106.161	4.4824
S3-10 cm	183.3003	7.1325	18.2603	4.6350	96.1349	3.5780
S3-20 cm	124.8994	6.5962	51.6642	3.2365	83.2383	3.4601
S3-30 cm	94.9751	5.3092	28.4093	2.6771	80.4073	3.5780
S4-10 cm	152.6787	7.6688	27.6901	3.5162	102.741	4.2858
S4-20 cm	109.9909	7.2398	44.5043	3.9957	100.814	5.1901
S4-30 cm	97.0666	6.1672	14.5043	0.6793	19.8954	10.1050
S5-10 cm	121.5209	6.7571	35.8013	3.7959	14.8233	7.3133
S5-20 cm	96.5839	1.5552	30.6469	0.9590	64.6404	9.6725
S5-30 cm	108.9183	1.9842	45.0713	3.3564	64.6404	9.6725
Average	*115.8328*	*5.5809*	*29.6788*	*2.7038*	*79.6944*	*5.5885*

At the depth 10 cm, ^{232}Th has an average activity concentration of 73.24 ± 4.91 Bqkg^{-1}, 89.76 ± 5.20 Bqkg^{-1} at 20 cm depth and 76.08 ± 6.65 Bqkg^{-1} at the depth of 30 cm. The comparison of radionuclide concentration profile, statistically illustrated in figure 1, shows that relatively high values of ^{40}K were obtained within the three soil depth profiles. This result is comparable with the values reported by [9] in the evaluation of natural occurring radionuclide variation with lithology depth profile of Udi and Ezeagu local government areas of Enugu state, Nigeria. The result is also like evaluations carried out by [20] and maybe attributed to the relative abundance of ^{40}K in the earth crust. It was observed from figure 1 that the variation of the radionuclides from 10 cm depth, down the depth of 30 cm was not in a definite order, for each radionuclide.

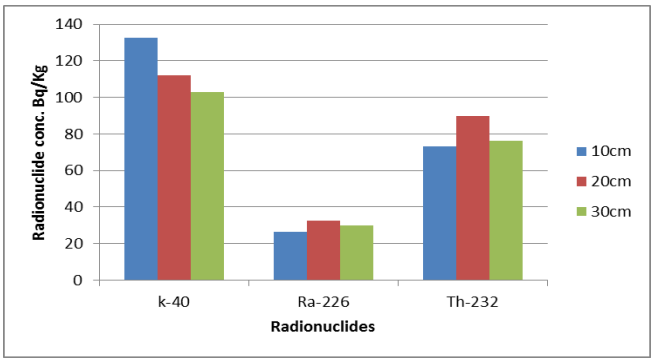

Figure 1. Average activity profile of the radionuclides with soil depth profile

The activity concentrations ratios are presented in table 2. From the table it could be observed that except for site 2, ^{40}K has the highest concentration at the 10 cm depth for all the other four sites, the concentration ratios show a gradual decrease of ^{40}K as we go down with depth suggesting that most of the ^{40}K remains close to the surface. Such was not the case for ^{226}Ra and ^{232}Th, where higher concentration ratios were observed in some of the sites as the depth increases and also decreases in some other areas. Generally, from the activity concentration ratios, there is an inhomogeneity in the distribution of the observed radionuclides with depth. The increase in concentration with depth could be attributed to the specific type of job and the duration of such job that was performed in such locations before the government stopped all the auto mechanic activities in the area.

Table 2. Radionuclide Depth ratio from 10cm-20cm-30cm

	K-40	Ra-226	Th-232
Site 1	1 : 0.81 : 0.76	1 : 0.49 : 0.96	1 : 1.33 : 1.42
Site 2	1 : 2.44 : 2.27	1 : 1.11 : 1.70	1 : 1.29 : 1.39
Site 3	1 : 0.68 : 0.51	1 : 2.82 : 1.55	1 : 0.86 : 0.83
Site 4	1 : 0.72 : 0.63	1 : 1.60 : 0.52	1 : 0.98 : 0.19
Site 5	1 : 0.79 : 0.89	1 :0.85 : 1.25	1 : 4.36 : 4.36

The radiation hazard indices as calculated from equation 3 and 4 are shown in Table 3. The calculated absorbed dose rate (D(nGyh^{-1})) and annual effective dose (E (mSv.y^{-1})) have an average value of 66.6687nGyh^{-1} (ranging from 61.9564 to 64.0913 nGyh^{-1}) and 0.0912 mSv.y^{-1} (ranging from 0.0847 to 0.0876 mSv.y^{-1}). The obtained value of the absorbed dose rate is higher compared with the values obtained by [9] in analysis of soil samples collected at Oji River, Enugu state, and also higher than the world average value of 55 nGyh^{-1}. This suggests that the reclaimed land would not be suitable for agricultural and recreational purposes, which agrees with our previous result on heavy metal and physicochemical assessment of the site [2]. Of the three depth profiles, 10 cm had the lowest dose rate and annual effective dose rate with values of 61.9564 nGyh^{-1} and 0.0847 mSv.y^{-1} respectively. While the highest values were obtained at 30 cm depth with values of 64.0913 nGyh^{-1} and 0.0876 mSv.y^{-1} respectively. This could be because of leaching of radionuclides from the surface down the depth. The value of the annual effective dose lies within the world average value of 1.0 mSvy^{-1} annual effective dose equivalent rate [21]. Figure 2 shows that the estimated H_{ex} and H_{in} values for the soil samples were found to be ranged from 0.382 (at 10 cm) to 0.396 (at 30 cm), with an average value of 0.142, which was considerably lower than the world recommended value of 1.0 [22]. This implies that there would be no significant health threats to the dwellers. Materials from the area can also be used for construction purposes without any significant health risk. The calculated Ra_{eq} is shown in Figure 3. The average value (232.677 Bq/kg) and ranges of the Raeq (217. 580 to 247.188 Bq/kg) lies well below the maximum permissible value of 370 Bq/kg [23].

Table 3. Calculated hazard indices and radiological parameters for the sample depth profile

Soil Depth(cm)	Average activity conc. (Bqkg^{-1})	Ra eq. (Bqkg^{-1})	H_{ex}	Hin	I_{yr}	Absorbed dosed rate D(nGyh^{-1})	Annual Effective dose E(mSv.y^{-1})
10cm	77.427	233.261	0.382	0.453	0.9967	61.9564	0.0847
20cm	78.113	247.188	0.458	0.546	1.1898	73.9584	0.1011
30cm	74.023	217.580	0.396	0.477	1.1660	64.0913	0.0876
Average	**76.521**	**232.677**	**0.412**	**0.492**	**1.1175**	**66.6687**	**0.0912**

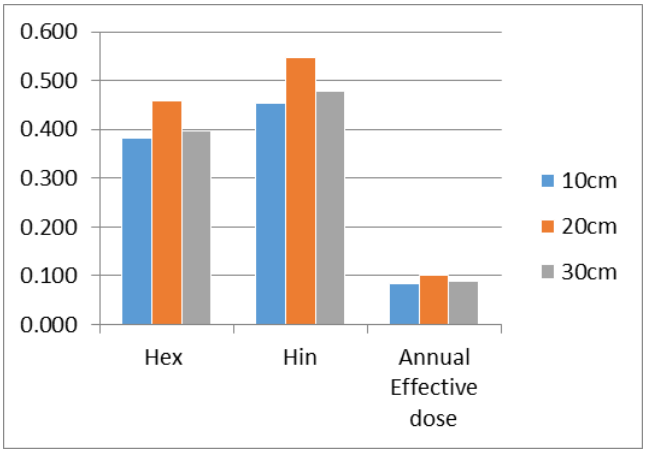

Figure 2. Distributive pattern of hazard indices with soil depth profile

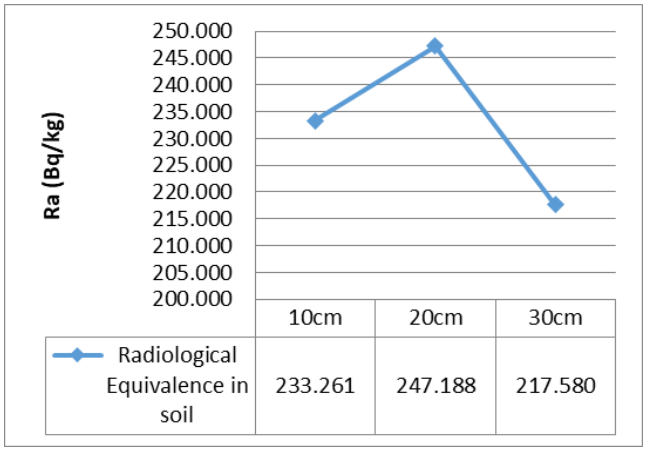

Figure 3. The calculated Ra_{eq} for different lithology of the soil sample

4. Conclusions

The profiling of identified radionuclide concentration with depth in the reclaimed auto-mechanic village in Nekede, Imo state Nigeria, has been carried out. It was observed that ^{40}k has relatively high concentration compared to other two identified radionuclides. In terms of depth, relatively high concentration of the natural radionuclides, was observed in 10 cm depth, while 20 cm and 30 cm were just moderately concentrated. However, the radionuclides were observed to be distributed at an irregular pattern down soil lithology, which could be attributed to the mineralogy, carbonate content in the lithology. The average radionuclide levels and calculated health hazard indices of the soil was estimated to be lower than the world standards for such environment and as such exposure to the environment pose no significant health threat to human lives especially those who now dwell within the study area. Hence, the environment is said to be radiologically habitable.

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