Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/100107

Radiological Assessment of Contaminated Soils from Selected Mechanic Sites in Ibadan, Southwestern Nigeria

O. T. Aruna[1*], *S. K. Alausa*[2], *A. O. Olabamiji*[3], *O. Ajiboye*[4]

[1]Nigerian Institute of Science Laboratory Technology, Samonda, Ibadan, Nigeria.
[2]Department of Physics, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.
[3]Department of Science Laboratory Technology, Lagos State University, Lagos State, Nigeria.
[4]Department of Mathematical and Computing Sciences, KolaDaisi University, Ibadan, Oyo State, Nigeria.

Received: 21 Oct. 2024, Revised: 25 Nov. 2024, Accepted: 23 Dec. 2024.
Published online: 1 Jan 2025.

Abstract: The research aimed at measuring the activity concentrations and radiological impacts of human activities on soil samples from five mechanic sites around the Ibadan metropolis, Southwestern Nigeria. The activity concentrations of radionuclides in a total of twenty-five soil samples obtained from the study areas were analyzed using a single crystal NaI(TI) detector. From the study, the weighted average activity concentrations of ^{40}K, ^{238}U, and ^{232}Th were 320.51±251.60, 12.49±6.17, and 10.11±5.83Bq/kg respectively. The average gamma absorbed and effective dose rates were 25.23±15.76 nGy/h and 30.94±19.23 µSv/y respectively. The mean radium equivalent value ranged between 38.05 to 83.17 (Bqkg^{-1}) with a weighted average of 50.36Bqkg^{-1}. All the estimated values of radiation hazard indices and representative gamma index obtained were less than one (1.0). These values and the radiological hazard indices were within the world-recommended limits by UNSCEAR. The results showed that radiological health hazards associated with radiation exposure from the study areas may not pose any serious radiological effect to the environment and public. Although human activities in the study areas influenced the increase in activity concentrations of the measured radionuclides, it could still be concluded that human exposure to radiation from the study areas poses neither short nor long-term significant health risks.

Keywords: Absorbed dose rate, Automobile workshop, Radiation hazard indices, Radiological health risk, Radium equivalent activity.

1 Introduction

Exposure to radiation from naturally occurring radionuclides has since been creating anxiety due to its deleterious effect on humans [1]. Radionuclides are known as unstable nuclides that undergo spontaneous disintegration leading to the creation of other nuclides and release of energy**.** Humans are generally exposed to natural primordial radionuclides that are abundantly found in the earth's crust [2]. Natural background radiation accounts for roughly 80% of the total radiation exposure of humans and activities such as mining and quarrying have been observed to influence the increase of radiation exposure [1, 3].

Radiation exposure may occur through ingestion or inhalation; however, the source, type, quantity, and nature of the radiation dose and the radionuclide's biochemical characteristics influence how much damage is done [4, 5]. Although there are over 60 naturally occurring radionuclides found in the earth's crust or environment, the main dose-forming radionuclides are from the daughters of ^{238}U, ^{226}Ra, and ^{232}Th decay series and radioactive ^{40}K [2, 6].

Urban soils are significantly altered by anthropogenic activities. Soil that forms as a result of weathering acts as a source of radiation exposure for humans and also as a medium of transfer of radionuclides to biological systems. The measurement of soil radioactivity is basic and it is considered the most informative method for natural background radiation determination and dose rate assessment [7].

Automobile repair workshops host a variety of artisans including auto-mechanic repairers, panel-beaters, auto-electricians, sprayers, painters, and vulcanizing technicians who offer different services to vehicle users. Alausa *et al.* [8] have reported that continuous technological and human

[*]Corresponding author e-mail: yemiaruna@yahoo.com

activities are the bane of the elevation of radioactivity and exposure to the environment. The activities at the automobile repair workshops involve the generation of various forms of waste dumped on the soil surface in the surrounding areas. The wastes include spent oil, batteries, and scratched motor parts some of which may be radioactive or contain radionuclides particularly artificial radionuclides like ^{137}Cs. Running rainwater may wash these radionuclides into the soil surface, where they decompose and emit ionizing radiation particles that are harmful to human health [9-12].

Thus, the goal of this study is to determine the activity concentrations of naturally occurring radionuclides (^{40}K, ^{238}U, and ^{232}Th) in soils from some selected automobile repair workshops within the Ibadan metropolis; to determine the outdoor gamma dose and effective dose rates; and estimate the radium equivalent, internal and external hazard indexes and gamma representative index.

2 Experimental Section

2.1 Study Area

The study was carried out within the Ibadan metropolis. Ibadan is in the southwest geopolitical zone and the third largest city by population in Nigeria. It is situated on Lat 7.3767N and Long 3.9397E. The city is situated within the tropical rainforest zone in Nigeria.

Because of their high traffic volume and proximity to residential areas, the mechanic sites at Bodija, Samonda, Aerodrome, Ashi-Basorun, and Sango were taken into consideration for the study. The sample codes and GPS coordinates of the sites are shown in Table 1.

Table 1: GPS coordinates of the sampling points in the study area.

Site		Long	Lat	Elevation(m)
Bodija	S1	7.426545N	3.909565” E	120
	S2	7.426544N	3.909562” E	100
	S3	7.426547N	3.903182” E	100
	S4	7.426543N	3.903181” E	100
	S5	7.426541N	3.903184” E	110
Aerodrome	S1	7.433156N	3.903186”E	99
	S2	7.433154N	3.903180” E	101
	S3	7.433151N	3.905459” E	101
	S4	7.433153N	3.904457” E	102
	S5	7.433152N	3.905459” E	100
Sango	S1	7.432635N	3.905452”E	100
	S2	7.432435N	3.905453” E	99
	S3	7.432632N	3.899848” E	99
	S4	7.432631N	3.899845” E	98
	S5	7.432621N	3.898842” E	98

Ashi-Basorun	S1	7.431645N	3.899743"E	98
	S2	7.431643N	3.898843" E	99
	S3	7.431445N	3.93373" E	111
	S4	7.431635N	3.933903" E	100
	S5	7.431655N	3.93373" E	98
Samonda	S1	7.422567N	3.933708"E	120
	S2	7.423467N	3.933912" E	122
	S3	7.422567N	3.909565" E	120
	S4	7.42239N	3.909562" E	110
	S5	7.423139N	3.903182" E	110

2.2 Materials

Five (5) sampling grids of 3 by 4 m^2 each were mapped within each mechanic site. Five (5) soil samples were then collected from each grid and thoroughly mixed to form a representative sample. At each sampling point, soil samples were collected from a depth between 150mm and 200mm below the soil surface. The soil samples were then packed in polythene bags, labeled properly, and taken to the laboratory at the Department of Physics Olabisi Onabanjo University, Ago-Iwoye for preparation.

In the laboratory, the samples were air-dried and later oven-dried at a temperature of 110^{0}C to remove moisture, and sieved with a 2mm mesh size to ensure removal of particles (stones). 200g of each soil sample was measured into a container of volume 500 and tightly sealed to ensure that radioactive gas (radon) generated as a result of radium disintegration did not escape. The samples were then kept for 28 days to allow for secular equilibrium before being counted using a thallium-doped sodium-iodide (NaI) detector.

2.3 Radioactivity Measurement

The efficiency and energy calibrations were carried out to ensure precise identification and expresses the relation between the activity concentration and count rate at the photon peak of the nuclides [13].

$$C = \frac{C_n}{\varepsilon_p I_\gamma m_s} \qquad (1)$$

While C is the activity concentration of the radionuclide in the sample (Bqkg^{-1}), I_γ is the absolute transition probability of a given γ-ray, ε_p is the detector efficiency at the specific γ -ray energy, C_n is the count rate under the photo peak, and m_s is the mass of the sample (kg).

2.4 Outdoor absorbed dose rate

This is the amount of energy that an irradiated item absorbs per unit mass. The absorption dose is the energy that affects living organisms. The outdoor dose rate at a height of one meter above the ground surface was calculated using equation (2) [7].

$$D_R(nGy/h) = 0.462A_U + 0.604A_{Th} + 0.0417A_k \qquad (2)$$

Where the activity concentrations of A_U are ^{238}U, A_{Th} is ^{232}Th, A_K is ^{40}K and D_R is the absorbed dose rate in nGyh^{-1}.

2.5 Outdoor annual effective dose

Annual effective dose is the parameter to evaluate possible long-term consequences of public exposure to ionizing radiation. The two important parameters for calculating the effective dose are the conversion coefficient and the occupancy factor. The UNSCEAR [7] recommended a value of 0.7SvGy^{-1} for the conversion coefficient between the dose that was absorbed in the air and the dose that is effectively received by individuals [7]. It is presumed that the average adult stays outdoors for about 20% of their time. As a result, 0.2 was assigned as the outdoor occupancy factor for adults, respectively. Equation (3) states the expression for the annual outdoor effective doses [2].

$$E_D = D_R \times 0.2 \times 0.7 \times 8760 \qquad (3)$$

Where E_D is the effective dose, D_R for dose rate in air, 8760 μSvy^{-1} represents the time in hours for a year.

2.6 Radium equivalent activity

This is an indicator to describe the gamma output from different mixtures natural of radionuclides in a material. It is a useful guideline in regulating the safety standards on radiation protection for the public at large and is calculated as the total weighted activities of ^{238}U, ^{232}Th, and ^{40}K based on the assumption that 10Bqkg^{-1} of ^{238}U, 7Bqkg^{-1} of ^{232}Th, and 130 Bqkg^{-1} of ^{40}K delivers the same gamma dose rate. Equation (4) was used to compute the radium equivalent [14].

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \qquad (4)$$

Where the activity concentrations of A_U are ^{238}U, A_{Th} is ^{232}Th and A_K is ^{40}K respectively.

2.7 Radiation Hazard Indices

These indices were used to estimate the level of gamma radiation hazard associated with the natural radionuclide from the soil samples. The external radiation hazard (Hex) and the internal radiation hazard (H_{in}) were calculated using equations (5) and (6) [15].

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} < 1 \qquad (5)$$

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} < 1 \qquad (6)$$

Where, $A_{U,}$ $A_{Th,}$ and A_K in Bqkg^{-1} are the radioactivity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively.

2.7 Gamma Representative Index

Materials that tend to pose health risks to humans are identified using the gamma index (Iγ). The potential radiation risk posed by natural radionuclides in the soil samples under study was estimated using a representative gamma index [13].

Table 2: Activity concentrations of ^{40}K, ^{238}U, and ^{232}Th, gamma and effective dose rates in the samples from the study areas.

Sites	^{40}K	^{238}U	^{232}Th	Gamma Dose rate (nGyh^{-1})	Effective dose rate (µSvy^{-1})
	(Bq/kg)				
Bodija	220.3±15.1	11.6±4.0	5.3±3.6	17.94	22.00
	366.6±18.5	12.9±5.7	14.3±4.0	30.74	37.71
	*864.0±21.2	15.8±2.0	6.8±3.2	48.40	59.36
	*600.4±28.0	23.1±4.0	6.8±3.1	40.18	49.28
	169.9±22.1	14.3±2.0	8.4±3.4	18.95	23.24
Mean±σ	*444.3±28.1	15.5±4.5	8.3±3.5	31.24±13.25	38.32±16.25
Aerodrome	203.8±2.1	16.3±2.0	13.9±5.3	24.88	30.51
	305.0±2.1	21.50±1.9	1.6±3.10	23.35	28.64
	208.5±1.1	11.40±3.1	14.7±3.0	23.56	28.90
	358.7±2.4	15.83±2.3	15.4±8.0	32.37	39.70
	357.0±3.1	10.0±0.1	15.7±8.0	25.78	31.61
Mean±σ	286.6±76.6	13.0±8.1	12.3±6.0	25.99±3.70	31.87±4.54
Sango	195.9±1.9	5.6±5.3	5.9±1.2	14.71	18.05
	159.7±1.9	17.3±2.0	8.2±21.2	19.68	24.14
	*678.4±2.0	22.6±2.1	7.1±3.2	43.52	53.37
	222.0±3.1	15.1±5.3	12.3±3.2	24.14	29.61
	177.6±7.1	10.6±1.90	9.0±6.1	18.14	22.24
Mean±σ	286.7±220.2	14.2±2.0	8.5±2.4	24.04±11.41	29.48±13.92

	58.4±3.2	11.5±5.3	4.0±2.0	10.08	12.36
	321.9±1.9	7.9±1.2	22.1±1.9	31.85	39.05
Ashi-Basorun	158.6±21.2	11.5±1.9	4.1±6.1	14.44	17.71
	152.0±2.0	21.0±5.3	7.1±5.3	20.23	24.81
	126.3±2.0	10.4±1.9	8.1±3.2	15.24	18.9
Mean±σ	163.5±97.1	12.5±5.0	9.1±7.5	18.37±8.35	22.53±10.21
	*923.4±51.0	18.3±2.0	25.9±2.0	*64.67	79.31
	409.6±21.8	17.8±2.0	8.4±2.01	30.77	37.74
Samonda	143.1±8.5	5.6±2.0	3.5±1.90	10.86	13.32
	*581.8±12.0	24.2±2.1	16.6±8.5	46.36	56.85
	*950.4±28.0	17.5±1.0	16.1±2.0	58.91	72.34
Mean±σ	*601.6±343.7	16.7±6.8	14.1±8.5	42.33±21.82	51.91±26.8
Weighted Avg.	320.5±251.6	12.5±6.2	10.1±5.8	25.23±15.73	30.94±19.32

Table 3: Radium equivalent, internal and external hazard index, and gamma representative index from the study.

Sample Location		**Ra_{eq}**	**H_{IN}**	**H_{ex}**	**I_{γ}**
Bodija	Range	36.16-92.05	0.1-0.3	0.1-0.2	0.1-0.4
	Mean	61.64	0.21	0.20	0.22
	Sdv	24.36	0.07	0.07	0.10
Aerodrome	Range	47.27-65.46	0.1-0.2	0.1-0.2	0.2-0.3
	Mean	52.60	0.20	0.11	0.23
	Sdv	7.38	0.03	0.02	0.03
Sango	Range	29.10-84.99	0.1-0.3	0.1-0.2	0.1-0.3
	Mean	48.48	0.21	0.12	0.21
	Sdv	21.73	0.07	0.06	0.09
Ashi-Basorun	Range	21.73-64.29	0.1-0.2	0.1-0.2	0.1-0.2
	Mean	38.05	0.12	0.11	0.12
	Sdv	16.51	0.04	0.04	0.06
Samonda	Range	21.62-126.44	0.1-0.4	0.1-0.3	0.1-0.5
	Mean	83.17	0.31	0.22	0.33
	Sdv	42.31	0.13	0.11	0.17
Weighted average		50.36±30.51	0.17±0.10	0.14±0.08	0.19±0.12

Sdv = standard deviation

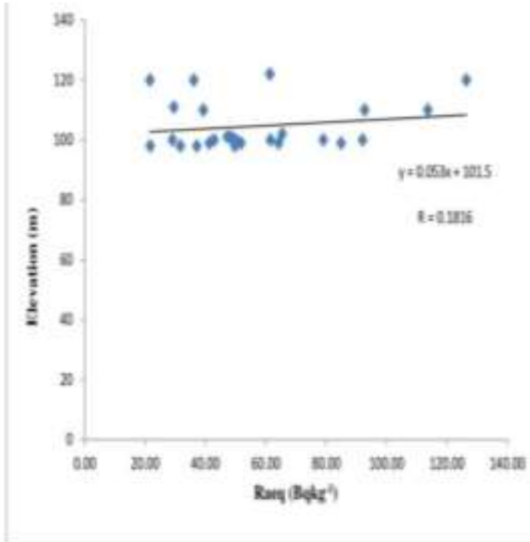

Fig.1: Correlation between elevation (m) and radium equivalent (Ra_{eq}).

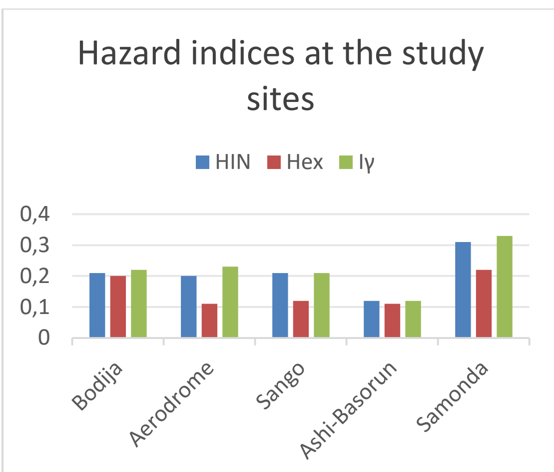

Fig. 2: Bar diagrams of the hazard indices at the mechanic sites.

The results of the activity concentration of ^{238}U, ^{232}Th, and ^{40}K, gamma absorbed dose, and the effective dose rates are presented in Table 2. Table 3 presents the representative gamma index, internal radiation hazard index, external radiation hazard index, and radium equivalent activity.

The activity concentrations (Bqkg^{-1}) ranged from 58.4 to 950.4 (^{40}K), 5.6 to 24.2 (^{238}U), and 4.1 to 25.9 (^{232}Th) for the entire sampling points, and ^{40}K is highest in each of the samples. As could be seen, the weighted average activity concentrations of all the radionuclides are below the world recommended values of 420 (^{40}K), 35 (^{238}U), and 30 (^{232}Th) [14], however, the results showed the activity concentrations of ^{40}K at Bodija and Samonda exceeded these limits. The variations in the results may be due to several factors such as the latitude of the area, the geological formation of the study areas, and of course the level of contamination of the soil in each mechanic site.
The weighted average value of ^{40}K obtained in this study was relatively higher than values reported from similar research by [16, 18]. However, Shittu, *et al.* [15] reported higher average activity concentrations for ^{40}K than the result in the present study.

The minimum mean outdoor absorbed dose rate (nGyh^{-1}) in the study was between 18.37±8.35 at Sango and the maximum 42.33±21.8 at Aerodrome while the weighted average was 25.23±15.7. Although these values were lower than the world average value of 59nGyh^{-1} [14], however a sample at Samonda exceeded this limit which may lead to significant radiological health risks to people within the vicinity. Usikalu *et al*. [19] and, Masok *et al.* [20] reported greater values of absorbed dose rates than the mean value obtained in the present study.

The estimated annual effective dose rates (µSvy^{-1}) for each sampling site in this investigation were below the global average limit of 290 µSvy^{-1} [14], indicating that there is likely no significant radiological health risk to the population at the mechanic locations.

In the study, radium equivalent (Ra_{eq}) was used to estimate the total amount of gamma radiation produced by the radionuclides in each soil sample. From the results, the mean Ra_{eq} value ranged between 38.05 to 83.17 (Bqkg^{-1}) with a weighted average of 50.36±30.51Bqkg^{-1}. The weighted average of radium equivalent in the study is lower than the recommended limit of 370Bqkg^{-1} [21-24]. In addition, each of the radiation hazard indices and representative gamma index obtained in the study is less than 1 (one). The results showed that radiation hazards associated with the soil samples in the study areas may pose negligible health impacts on the people within the study areas.

A correlation plot between the elevation (m) and the radium equivalent, Ra_{eq} (Bqkg^{-1}) in Figure 1 shows a positive but very weak regression value of 0.18. The weak regression indicated poor correlation and it is not a good predictor of measured radium equivalent Ra_{eq} over the elevation.

Figure 2 shows the bar chart of the internal hazard index (Hin), external hazard index (Hex), and gamma index (Iγ) for all the study sites. It is clear from the figure that each of the hazard indices is less than 1 (one). It was also observed that Samonda had higher index values than any of the other corresponding study sites.

4 Conclusions

The present study has established radiometric data on the soil samples from selected automobile repair workshops (mechanic sites) within the Ibadan metropolis, Southwestern Nigeria using a well-calibrated NaI(Tl) detector. The findings in the present work are similar to reports of [16]. The weighted average activity concentrations of the three natural radionuclides (^{40}K - 320.5±251.6; ^{238}U - 12.5±6.2 and; ^{232}Th - 10.1±5.8) were less than the global average recommended value.

The gamma-absorbed dose rates and annual effective dose rates for all the sampling sites were lower than the recommended limits. Also, the radium equivalent activity, radiation hazard indices, and representative gamma index were less than the recommended limits.

Although the radioactivity levels in the study appear low, it could still be concluded that human exposure to soil from the study areas should be discouraged because long-term exposure may be detrimental to human health.

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