



## Radiological Health Risk Assessment of Naturally Occurring Radionuclides in Road Dusts from Road Construction Sites in Ijebu-Ode, Ogun State, Nigeria

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### ABSTRACT

This study assessed the activity concentrations and radiological health risks associated with naturally occurring radionuclides in road dust samples obtained from road construction sites in Ijebu-Ode, Ogun State, Nigeria. Fifteen soil samples were collected from road construction sites within the Ereko and Talbort Streets, Ijebu-Ode. The soil samples were air-dried, homogenized, sieved, treated and analysed using gamma-ray spectrometry at the University of Ibadan for the concentrations of Uranium-238, Thorium-232, and Potassium-40. Descriptive statistics, Pearson correlation, two-way analysis of variance (ANOVA), hierarchical clustering, and principal component analysis (PCA) were employed for statistical evaluation of the data. The mean activity concentrations of Uranium-238, Thorium-232, and Potassium-40 were  $8.36 \pm 1.81$ ,  $15.17 \pm 1.53$ , and  $370.20 \pm 47.44$  Bq/kg, respectively. Potassium-40 exhibited the highest concentration across all sampling locations. The two-way ANOVA revealed a significant difference among radionuclide types ( $p < 0.05$ ), whereas spatial variation among sampling locations was not statistically significant. A strong positive correlation ( $r = 0.976$ ) was observed between absorbed dose rate and radium equivalent activity. The calculated absorbed dose rate, annual effective dose equivalent, radium equivalent activity, external hazard index, internal hazard index, and excess lifetime cancer risk were all below internationally recommended safety limits. PCA and hierarchical clustering further indicated relatively homogeneous radiological characteristics across the study area, with slight variations associated primarily with Potassium-40 distribution. The findings indicate that the investigated road dust samples do not pose significant radiological health hazards to construction workers or residents within the study area.

**Keywords:** Natural Radionuclides, Road Dust, Gamma Spectrometry, Radiological Health Risk, Principal Component Analysis

### INTRODUCTION

The lithosphere contains a wide array of elements capable of exhibiting both natural and artificial radioactivity. Naturally occurring radionuclides such as uranium, thorium, and radium are ubiquitous in geological materials, while potassium-40 represents another significant contributor to terrestrial background radiation (UNSCEAR, 2000). In addition to these naturally occurring radioactive materials, anthropogenic activities have introduced artificial radionuclides into the environment, further complicating the radiological profile of soils and sediments (IAEA, 2014). The presence of these radionuclides, whether natural or artificial, raises important concerns regarding human exposure and associated health risks.

In recent years, increased attention has been directed towards the potential health risks associated with dust generated during road construction activities. Construction processes often involve excavation, drilling, and transportation of soil materials, which can release radionuclide-bearing particles into the atmosphere. Workers and nearby residents may therefore be exposed through inhalation or direct contact. Previous studies have identified the presence of radionuclides in soils from drilling sites, excavated areas, and road construction zones, suggesting that such environments may serve as pathways for human exposure (Avwiri *et al.*, 2013; Ademola, 2008).

Specifically, earlier investigations conducted along Ejinrin Road, Adeola Odutola Road, old Ondo-Benin Road, Folagbade Road, and Okun-Owa Road in Ijebu-Ode reported detectable levels of radionuclides in road soils, although concentrations were found to be below internationally recommended safety thresholds (Ademola, 2008). Despite these reassuring findings, variations in geological

composition and construction practices necessitate site-specific assessments. Accordingly, the present study focuses on soil samples collected from road construction sites along Ereko and Talbort Streets in Ijebu-Ode, Ogun State. The aim is to determine the concentrations of radionuclides present and to evaluate their potential radiological implications for public health.

### MATERIALS AND METHODS

#### Study Area

Ijebu-Ode is an urban centre in Ogun State, south-western Nigeria, located at approximately  $6^{\circ}49'N$  and  $3^{\circ}55'E$ . It lies within the humid tropical rainforest zone and experiences two distinct seasons: a wet season (March–October) and a dry season (November–February). Annual rainfall ranges from 1,500 to 2,000 mm, with mean temperatures between  $24^{\circ}C$  and  $32^{\circ}C$  and consistently high relative humidity (Nigerian Meteorological Agency, 2022). These climatic conditions favour the mobilisation, and redistribution of road dust particles.

Geologically, the area is underlain by Precambrian Basement Complex rocks, including gneisses, schists, and quartzites. These rocks may contain naturally occurring radionuclides, such as uranium (U), thorium (Th), and potassium-40 ( $^{40}K$ ) (Rahaman, 1988). Weathering processes and human activities contribute to their presence in surface dust.

Ijebu-Ode has experienced rapid urbanisation, which may lead to increased traffic density and road surface disturbance. Many roads are poorly maintained, enhancing dust generation. Road dust comprises a mixture of soil particles, vehicular emissions, and construction residues capable of adsorbing radionuclides (Amato *et al.*, 2014). High-traffic areas and roadside commercial activities increase human

exposure through inhalation, ingestion, and dermal contact, making the area suitable for assessing environmental and health risks.

### Sample Collection and Treatment

A total of fifteen (15) road dust samples were collected from four major construction zones along Ereko and Talbort Streets, Ijebu-Ode, Ogun State. The sampling locations were selected based on active road construction activities, high human and vehicular traffic, and a high potential for dust resuspension. The samples were coded as A1–A4, B1–B4, C1–C4, and D1–D3 to reflect their respective sampling zones. Field sampling was conducted in June 2025. At each location, surface dust was collected from the top layer (0–5 cm depth) using a clean plastic brush and container. Multiple subsamples were obtained from different points within each site and homogenised to form a representative composite sample. The collected samples were carefully transferred into labelled polythene bags to minimise contamination during handling and transportation (Addo *et al.*, 2020).

In the laboratory, the samples were air-dried at room temperature to eliminate moisture content. Dried samples were then sieved through a 2 mm mesh to remove stones, debris, and other coarse materials. The processed samples were weighed and transferred into standard counting containers, which were subsequently hermetically sealed. The sealed samples were stored for a period of four weeks to allow for secular equilibrium between radium and its progeny prior to radiological analysis (Ademola, 2009; Avwiri *et al.*, 2013; UNSCEAR, 2000; IAEA, 2003).

### Gamma Spectrometry

Gamma spectrometric analysis of the prepared soil samples was performed using a gamma spectrometer at the University of Ibadan. The instrument was calibrated for energy and efficiency using certified reference materials to ensure measurement accuracy and reliability. Soil samples were dried, homogenised, sealed, and stored to establish secular equilibrium between radionuclides and their progeny. Each sample was counted for an adequate duration to achieve statistically reliable results.

Radionuclides were identified and quantified based on their characteristic gamma-ray emissions. The activity concentration of potassium-40 ( $^{40}\text{K}$ ) was determined from its 1460 keV gamma-ray peak. Uranium-238 ( $^{238}\text{U}$ ) activity was estimated indirectly through the gamma emissions of bismuth-214 ( $^{214}\text{Bi}$ ) and lead-214 ( $^{214}\text{Pb}$ ). Thorium-232 ( $^{232}\text{Th}$ ) activity was evaluated using gamma emissions from thallium-208 ( $^{208}\text{Tl}$ ) and actinium-228 ( $^{228}\text{Ac}$ ). Net peak areas were integrated following background correction, and activity concentrations were calculated using detector efficiency and emission probabilities.

Results were expressed in becquerels per kilogram ( $\text{Bq kg}^{-1}$ ), following internationally accepted procedures for environmental radioactivity assessment (UNSCEAR, 2000; IAEA, 2003).

### Radiological Health Risk Assessment Parameters

Radiological health risk indices were computed using standard equations.

#### Absorbed Dose Rate (D)

The absorbed dose rate (D) was estimated using equation (1)

$$D = 0.462 A_U + 0.604 A_{Th} + 0.0417 A_K \quad (\text{UNSCEAR, 2000}) \quad (1)$$

Where  $A_U$  = Activity concentration of U-238 ( $\text{Bq/kg}$ ),  $A_{Th}$  = Activity concentration of Th-232 ( $\text{Bq/kg}$ ),  $A_K$  = Activity concentration of K-40 ( $\text{Bq/kg}$ ). The unit of D is  $\text{nGy/h}$ .

#### Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent (AEDE) was calculated for the radionuclides in the soil using equation (2).

$$\text{AEDE} = D \times 8760 \times 0.7 \times 0.2 \times 10^{-6} \quad (\text{ICRP, 1990; WHO, 2016}) \quad (2)$$

Where D stands for absorbed dosage rate ( $\text{nGy/h}$ ), 8760 represents the number of hours per year, 0.7 is the conversion coefficient from absorbed dose in the air to the effective dose ( $\text{SvGy}$ ), 0.2 stands for the outdoor factor, while  $10^{-6}$  is the unit conversion factor. AEDE is expressed in  $\text{mSv/year}$ .

#### Radium Equivalent Activity ( $R_{\text{eq}}$ )

Radium equivalent activity ( $R_{\text{eq}}$ ) is a radiological hazard index used to estimate the overall gamma radiation hazard associated with naturally occurring radionuclides in a material, particularly uranium-238 ( $^{226}\text{Ra}$ ), thorium-232 ( $^{232}\text{Th}$ ), and potassium-40 ( $^{40}\text{K}$ ).

$$R_{\text{eq}} = A_U + 1.43 A_{Th} + 0.077 A_K \quad (\text{Beretka \& Mathew, 1985}) \quad (3)$$

The interpretation of unknown expressions in equation (3) is stated in Section 2.4.1. The coefficients 1.43 and 0.077 account for the different gamma dose contributions from thorium and potassium relative to radium. The  $R_{\text{eq}}$  is expressed in  $\text{Bq/kg}$ , and the internationally acceptable safe limit for radium equivalent activity is  $R_{\text{eq}} \leq 370 \text{ Bq/kg}$ . This corresponds to an external gamma radiation dose of approximately 1  $\text{mSv/year}$  to the public (UNSCEAR, 2000).

#### External Hazard Index ( $H_{\text{ex}}$ )

The external hazard index ( $H_{\text{ex}}$ ) is a radiological parameter used to evaluate the potential external exposure risk from gamma radiation emitted by naturally occurring radionuclides in soil. It is calculated using the expression in equation (4).

$$H_{\text{ex}} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (\text{Beretka \& Mathew, 1985}) \quad (4)$$

The parameters ( $A_U$ ,  $A_{Th}$ , and  $A_K$ ) are radiological values explained in Section 2.4.1. The denominators 370, 259, and 4810 represent the activity concentration limits of radium, thorium, and potassium, respectively that produce the same gamma dose rate. The acceptable safety limit for the external hazard index is  $H_{\text{ex}} \leq 1 \text{ mSv/year}$  for the public.

#### Internal Hazard Index ( $H_{\text{in}}$ )

The internal hazard index ( $H_{\text{in}}$ ) is a radiological parameter used to assess the potential internal exposure risk arising from inhalation of radioactive gases and their short-lived decay products, particularly radon-222 from radium-226. Also, it evaluates the likelihood of internal radiation hazards to human health due to the presence of naturally occurring radionuclides in soils. The internal hazard index is calculated using the expression in equation (5)

$$H_{\text{in}} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (\text{ICRP, 1990}) \quad (5)$$

The radionuclide parameters ( $A_U$ ,  $A_{Th}$ , and  $A_K$ ) are explained in Section 2.4.1. The constants 185, 259, and 4810 represent the activity concentration limits for uranium, thorium and potassium, respectively that produce that same gamma dose rate. The acceptable international safety limit for the internal hazard index is  $H_{\text{in}} \leq 1$ .

#### Excess Lifetime Cancer Risk (ELCR)

The ELCR estimates the probability of an individual developing cancer over a lifetime due to prolonged exposure to ionization radiation from radionuclides. The excessive lifetime cancer risk is usually calculated using the expression in equation (6)

$$\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \quad (\text{UNSCEAR, 2000}) \quad (6)$$

AEDE stands for the annual effective dose equivalent ( $\text{mSv/year}$ ), DL is the average human lifespan, taken as 70 years, and RF represents the risk factor for stochastic effects.

According to the International Commission for Radiological Protection (ICRP), the RF value is  $0.05 \text{ Sv}^{-1}$  (Taskin et al., 2009). The worldwide averagely accepted value is approximately  $0.29 \times 10^{-3}$ .

### Statistical Analysis

Statistical analysis was performed using descriptive and inferential techniques. Pearson correlation analysis was used to evaluate relationships among radionuclides and radiological hazard indices. A two-way ANOVA was conducted to assess spatial differences in radionuclide concentrations among sampling locations at a 5% significance level ( $p < 0.05$ ) (Field, 2018). Principal Component Analysis (PCA) was applied to identify the major factors influencing

radionuclide distribution and to simplify interpretation of the dataset through dimensionality reduction (Jolliffe, 2011).

## RESULTS AND DISCUSSION

### Mean Activity Concentrations of Radionuclides in Road Dusts

The activity concentrations of Uranium-238, Thorium-232, and Potassium-40 measured in the road dust samples from locations A, B, C, and D are presented in Table 1. The mean activity concentrations of Uranium-238 ranged from 7.55 to 9.13 Bq/kg, with the lowest value recorded at location B and the highest at location D. Thorium-232 concentrations varied between 14.24 and 16.25 Bq/kg, while Potassium-40 exhibited substantially higher activity concentrations, ranging from 339.72 to 416.46 Bq/kg across the sampling locations.

**Table 1: Mean Activity Concentrations of Radionuclides in Road Dust Samples**

Radionuclide	Variation	Soil Grouping (Bq/kg)				Overall Mean $\pm$ SD (Bq/kg)
		A	B	C	D	
Uranium-238	Min	7.42	5.12	5.66	8.09	8.36 $\pm$ 1.81
	Max	10.59	10.25	10.52	10.79	
	Mean	9.09 $\pm$ 1.35	7.55 $\pm$ 2.44	7.89 $\pm$ 2.13	9.13 $\pm$ 1.46	
Thorium-232	Min	14.36	13.48	12.90	14.47	15.17 $\pm$ 1.53
	Max	16.46	16.88	16.17	19.16	
	Mean	15.49 $\pm$ 1.04	14.98 $\pm$ 1.51	14.24 $\pm$ 1.54	16.25 $\pm$ 2.52	
Potassium-40	Min	310.80	308.87	365.16	305.11	370.20 $\pm$ 47.44
	Max	385.65	398.71	485.47	375.12	
	Mean	359.75 $\pm$ 35.58	357.26 $\pm$ 39.20	416.46 $\pm$ 51.78	339.72 $\pm$ 35.20	

Potassium-40 exhibited the highest activity concentrations across all sampling locations, reflecting the abundance of potassium-bearing minerals within the study area's geological formations. The highest mean Potassium-40 concentration was recorded in location C (416.46 Bq/kg), indicating relatively enhanced potassium mineralisation. In contrast, Uranium-238 and Thorium-232 occurred at comparatively

lower concentrations, consistent with typical levels reported for natural soils. Compared with the findings of Alausa (2014), the present study recorded lower radium concentrations, slightly higher thorium concentrations, and Potassium-40 activity concentrations within the previously reported range.

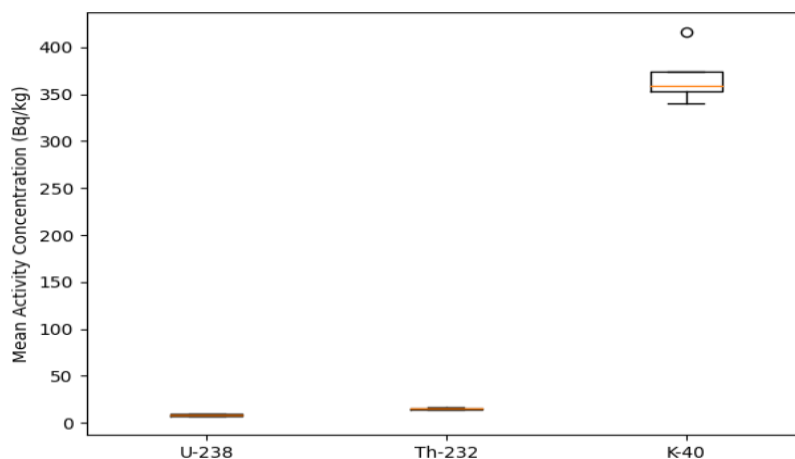


Figure 1: Boxplots of Uranium-238, Thorium-232, and Potassium-40 in Road Dust Samples

The variations observed among the sampling locations may reflect differences in local geological composition, mineral distribution, and the influence of road construction activities, such as excavation, drilling, and redistribution of subsurface materials. Nevertheless, the overall activity concentrations remained below internationally recommended safety limits for environmental exposure. These results further indicate that the road dusts investigated are not significantly contaminated by radionuclides.

### A Two-Way Analysis of Variance with Repetition

The results of the two-way analysis of variance (ANOVA) demonstrated that radionuclide type had a statistically significant effect on the measured activity concentrations ( $F = 1134.53$ ,  $p < 0.05$ ) (Table 2). This indicates that significant differences existed among the concentrations of Uranium-238, Thorium-232, and Potassium-40 in the analysed samples.

**Table 2: A Two-Way Analysis of Variance (ANOVA) with Repetition (p<0.05))**

Source of variation	SS	df	MS	F	p-value
Sample Location	3879.45	3	1293.15	2.28	0.096
Radionuclide Type	1,285,092.30	2	642,546.15	1134.53	<.05
Location vs Radionuclide Interaction	8587.58	6	1431.26	2.53	0.037
Error	18,688.19	33	566.31		
Total	1,316,247.52	44			

However, the effect of sampling location was not statistically significant ( $F = 2.28$ ,  $p = 0.096$ ), which suggests that radionuclide concentrations did not vary markedly among locations A, B, C, and D. This finding implies relative uniformity in the radiological characteristics of the study area. Conversely, the interaction between radionuclide type and sampling location was statistically significant ( $F = 2.53$ ,  $p = 0.037$ ). This interaction outcome indicates that the distribution pattern of the radionuclides differed slightly across the sampling locations.

Generally, the results suggest that naturally occurring radionuclides are present in the road dust samples at varying concentrations, with Potassium-40 identified as the dominant contributor to radioactivity in the study area. The relatively low activity concentrations and insignificant spatial variation further indicate minimal radiological contamination associated with the road construction activities within the investigated locations.

### Radiological Health Risk Assessment of Radionuclides in Road Dusts

The radiological health risk assessment parameters, including absorbed dose rate (D), annual effective dose equivalent (AEDE), radium equivalent activity (Raeq), external hazard index (Hex), internal hazard index (Hin), and excess lifetime cancer risk (ELCR), are presented in Table 3. Absorbed dose rates ranged from 27.43 to 29.61 nGy/h, with all values remaining below the global average limit of 59 nGy/h recommended by UNSCEAR (2000), indicating low external gamma radiation exposure. The AEDE values (0.0336–0.0363 mSv/y) were substantially lower than the public exposure limit of 1 mSv/y prescribed by the ICRP (2007), suggesting negligible radiological health effects from prolonged exposure.

**Table 3: Summary of Radiological Health Risk Assessment of Radionuclides in Road Dust Samples**

Soil Grouping	Uranium-238 (Bq/kg)	Thorium-232 (Bq/kg)	Potassium-40 (Bq/kg)	D (nGy/h)	AEDE (mSv/y)	Raeq (Bq/kg)	Hex	Hin	ELCR ( $\times 10^{-3}$ )
A	9.09	15.49	359.75	28.56	0.0350	58.94	0.159	0.184	0.1226
B	7.55	14.98	357.26	27.43	0.0336	56.48	0.153	0.173	0.1178
C	7.89	14.24	416.46	29.61	0.0363	60.32	0.163	0.184	0.1271
D	9.13	16.25	339.72	28.20	0.0346	58.53	0.158	0.183	0.1210

Radium equivalent activity ranged from 56.48 to 60.32 Bq/kg, considerably below the recommended safety limit of 370 Bq/kg (OECD, 1979), indicating minimal external radiation hazards. Similarly, the external hazard index (0.153–0.163) and internal hazard index (0.173–0.184) remained below the permissible threshold of unity, confirming insignificant external and internal radiological risks (Beretka & Mathew, 1985). Excess lifetime cancer risk values (0.1178–0.1271  $\times 10^{-3}$ ) were lower than the global reference value of (0.29  $\times 10^{-3}$ ) (UNSCEAR, 2000), indicating a very low probability of radiation-induced cancer. Although soil group C exhibited slightly elevated values relative to the other groups, all radiological parameters were within internationally accepted limits, demonstrating that the road dust samples pose no significant radiological health risk and that the investigated road construction activities have not resulted in substantial radiological contamination of the environment.

### Pearson Correlation Analysis between Radionuclides and Radiological Hazard Parameters

The Pearson correlation analysis revealed strong relationships between radionuclide concentrations and radiological hazard parameters in the road dust samples

(Table 4). Absorbed dose rate (D) exhibited very strong positive correlations with annual effective dose equivalent (AEDE) ( $r = 1.000$ ), radium equivalent activity (Raeq) ( $r = 0.976$ ), external hazard index (Hex) ( $r = 0.985$ ), and excess lifetime cancer risk (ELCR) ( $r = 1.000$ ), indicating close interdependence among these parameters. Radium equivalent activity showed an almost perfect correlation with Hex ( $r = 0.999$ ) and a strong correlation with Hin ( $r = 0.901$ ), suggesting that increasing radionuclide concentrations corresponded with increased radiological hazards. Potassium-40 demonstrated strong positive correlations with most hazard indices, indicating its significant contribution to the radiological characteristics of the study area. Conversely, Thorium-232 exhibited negative correlations with several hazard parameters and a strong negative correlation with Potassium-40 ( $r = -0.901$ ), suggesting differing distribution patterns and geological origins. Uranium-238 showed moderate positive correlations with Thorium-232 and Hin but weaker associations with other hazard indices. Clearly, the results indicate that the radiological hazard parameters were strongly interrelated and influenced predominantly by Potassium-40, while the low hazard index values confirmed minimal radiological risk within the study area.

**Table 4: Pearson Correlation Matrix between Radionuclides and Radiological Hazard Parameters**

Variables	U-238	Th-232	K-40	D	AEDE	Raeq	Hex	Hin	ELCR
U-238	1.000	0.793	-0.515	0.076	0.089	0.286	0.236	0.673	0.068
Th-232	0.793	1.000	-0.901	-0.487	-0.472	-0.286	-0.330	0.136	-0.495
K-40	-0.515	-0.901	1.000	0.810	0.801	0.663	0.699	0.280	0.815
D	0.076	-0.487	0.810	1.000	1.000	0.976	0.985	0.788	1.000
AEDE	0.089	-0.472	0.810	1.000	1.000	0.979	0.988	0.797	1.000
Raeq	0.286	-0.286	0.663	0.976	0.979	1.000	0.999	0.901	0.974
Hex	0.236	-0.330	0.699	0.985	0.988	0.999	1.000	0.878	0.984
Hin	0.673	0.136	0.280	0.788	0.797	0.901	0.878	1.000	0.783
ELCR	0.068	-0.495	0.815	1.000	1.000	0.974	0.984	0.783	1.000

**Hierarchical Clustering Dendrogram of Radionuclides in Road Dust Samples**

The hierarchical clustering dendrogram of radionuclide activity concentrations across the combined soil groups (A, B, C, and D) is presented in Figure 2. Hierarchical cluster analysis was employed to evaluate the degree of similarity among the sampled soil groups based on the mean activity

concentrations of Uranium-238, Thorium-232, and Potassium-40. The clustering procedure was performed using Ward’s linkage method and Euclidean distance measurements, which are widely applied in environmental and radiological studies for pattern recognition and classification of multivariate datasets (Jolliffe, 2011).

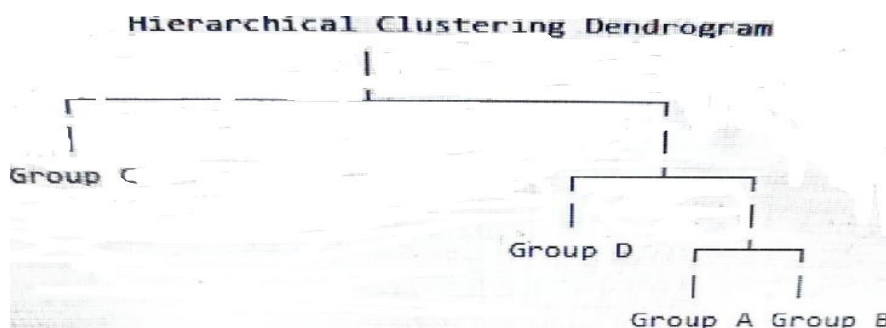


Figure 2: Hierarchical Clustering Dendrogram of Radionuclides in Road Dust Samples

The hierarchical clustering dendrogram revealed two principal clusters among the soil groups. Soil groups A and B clustered closely, indicating similar radionuclide compositions and radiological characteristics, while soil group D showed moderate similarity to this cluster. In contrast, soil group C formed a distinct cluster and exhibited the greatest dissimilarity, primarily due to its elevated Potassium-40 activity concentration. The observed clustering pattern suggests limited spatial variation across the study area, with differences largely attributable to localised variations in Potassium-40 distribution. Generally, the results indicate that natural geological factors predominantly govern radionuclide occurrence, while localised conditions contribute to the unique characteristics of soil group C.

**Principal Component Analysis of Radionuclides in Road Dust Samples**

Principal Component Analysis (PCA) was employed to evaluate the mean activity concentrations of Uranium-238, Thorium-232, and Potassium-40 across soil groups A–D. The analysis effectively reduced data complexity and identified the major factors influencing radionuclide distribution. PCA revealed the underlying relationships among the radionuclides and highlighted sources of variability within the study area. The technique further facilitated the assessment of potential geological controls on radionuclide occurrence (Jolliffe, 2011).

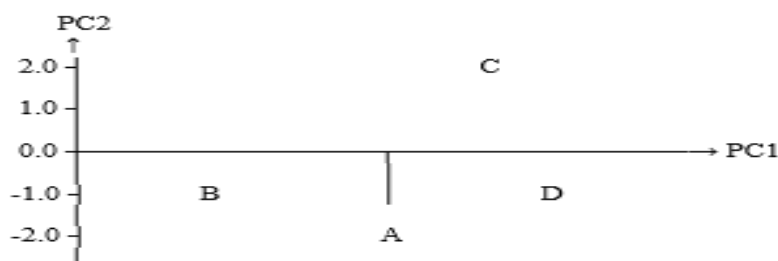


Figure 3: PCA Distribution Plot of Soil Groups A-D

The PCA showed that PC1 and PC2 accounted for 82.81% and 16.38% of the total variance, respectively, explaining 99.19% of the variability in the radionuclide dataset. The high cumulative variance indicates that the model effectively represented the dominant distribution patterns of radionuclides within the study area. Soil group C was

distinctly separated along PC1, primarily due to its elevated Potassium-40 concentration, whereas soil groups A and D clustered closely, reflecting similar radiological characteristics. Soil group B occupied an intermediate position, indicating moderate variation. The clustering pattern corroborated the hierarchical clustering and ANOVA results,

which suggested low spatial variability with minor localised differences. The findings indicate that natural geological factors, particularly potassium-bearing minerals,

predominantly control radionuclide distribution, resulting in generally homogeneous radiological characteristics across the study area (Jolliffe, 2011; UNSCEAR, 2000).

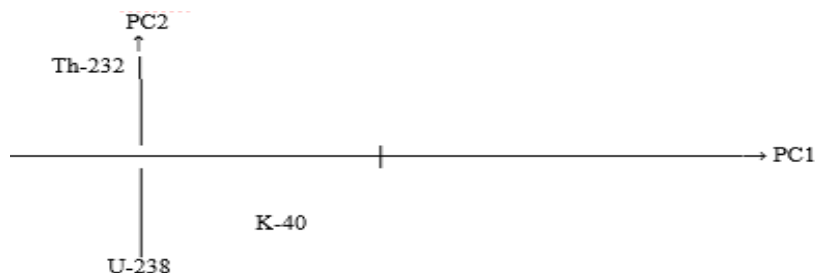


Figure 4: PCA Loading Relationship of Radionuclides in Road Dust Samples

The PCA loading plot revealed that Potassium-40 had the strongest positive contribution to PC1 and was the principal factor influencing variability among the road dust samples. In contrast, Thorium-232 was more strongly associated with PC2, while Uranium-238 exhibited a comparatively moderate contribution to the observed variance.

### CONCLUSION

The present study assessed the activity concentrations and radiological health risks of naturally occurring radionuclides in road dust samples collected from road construction sites along Ereko and Talbort Streets, Ijebu-Ode, Ogun State, Nigeria. Potassium-40 exhibited the highest activity concentrations (305.11-485.47 Bq/kg), whereas Uranium-238 (5.12 -10.79 Bq/kg) recorded the lowest values among the analysed radionuclides. All evaluated radiological hazard parameters, including absorbed dose rate, annual effective dose equivalent, radium equivalent activity, external hazard index, internal hazard index, and excess lifetime cancer risk, were below internationally recommended safety limits, indicating negligible radiological health risks. Pearson correlation analysis revealed strong associations among the radiological hazard indices, while principal component analysis and hierarchical clustering demonstrated largely homogeneous radionuclide distributions with minor localised variations. The findings suggest that natural geological factors predominantly control radionuclide occurrence within the study area and that current road construction activities have not resulted in significant radiological contamination of the surrounding environment.

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