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Radiological Hazard Assessment of Soils from Lumoru Dumpsite, Kenya

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***Abstract*— This study assessed the radiological status of soils from Lumoru dumpsite, Kenya, by measuring activity concentrations of ^{40}K, ^{232}Th, and ^{238}U using a thallium-activated sodium iodide (NaI(Tl)) detector, and evaluating radium equivalent (Ra_{eq}), absorbed dose rates, and annual effective dose equivalents (AEDE). Average activities were 25 Bq/kg for ^{40}K, 57 Bq/kg for ^{232}Th, and 7 Bq/kg for ^{238}U, all below global average thresholds of 420, 45, and 35 Bq/kg, respectively. Ra_{eq} averaged 91 Bq/kg, absorbed dose rate 39.2 nGy/h, $AEDE_{out}$ 0.09 mSv/y, and $AEDE_{in}$ 0.20 mSv/y, all within recommended safety limits, although indoor exposure was higher. Spatial heterogeneity, particularly of ^{232}Th, was linked to mineral-rich construction debris and uneven waste disposal. Patterns align with Machinjoni and Dandora dumpsites in Kenya, and sites in Dar es Salaam, Tanzania. Overall, Lumoru soils are broadly safe, but localized hotspots and elevated indoor exposure highlight the need for monitoring, improved waste management, and public awareness.**

Keywords*— *Lumoru dumpsite; natural radionuclides; radium equivalent; absorbed dose rate; annual effective dose; ^{232}Th hotspots; radiological risk; Kenya

I. INTRODUCTION

Soil serves as a natural reservoir for radionuclides and other contaminants, controlling how these substances move through the air, water, and living organisms, and ultimately influencing the environment we all rely on [1]. Municipal waste dumpsites introduce radionuclides into the soil, often in concentrated pockets due to construction debris and uneven disposal practices, creating localized hotspots that pose potential health risks to nearby communities [2]. These radioactive substances can enter the human body through inhalation, ingestion, or skin contact, gradually accumulating through the food chain [3]. Human activities, including the generation, management, and disposal of waste, can exacerbate these impacts, highlighting the need for effective waste management and community awareness to safeguard both environmental and public health [4]. In agricultural regions such as Bungoma County, studies on maize and beans have shown that radionuclides from soils can accumulate in food crops, linking environmental contamination directly to human exposure [5].

According to the World Health Organization, approximately one quarter of all diseases affecting humans are linked to environmental risks, with children being particularly vulnerable. Among children under the age of five, environmentally related diseases account for over 4.7 million deaths annually. In developing countries, 25% of all deaths are attributed to environmental factors, compared with 17% in developed countries. While proper waste disposal is essential for public health and environmental protection, failure to comply with regulations such as the Environmental Management and Coordination Act (EMCA) of 1999 can aggravate health risks and environmental degradation.

Lumoru dumpsite, an open dump without leachate collection or treatment, has been a source of growing concern for residents, with reports of increased health complaints since its establishment in 2016 (Republic of Kenya in the Environment and Land Court at Bungoma, 2019). This study assessed the levels of natural radioactivity in topsoil from the Lumoru dumpsite, Bungoma County, by analyzing composite samples using a thallium-activated sodium iodide (NaI(Tl)) detector. The activity concentrations of key radionuclides, ^{238}U, ^{232}Th, and ^{40}K were measured, and radiological parameters including absorbed dose rate, radium equivalent, and annual effective dose equivalents were calculated to evaluate potential health risks to the local population. The study provides essential baseline information on naturally occurring radionuclides at the site, highlighting spatial heterogeneity and localized hotspots, particularly of ^{232}Th, which may be influenced by construction debris and uneven waste disposal. These findings are critical for informing regulatory oversight by the National Environment Management Authority (NEMA), supporting compliance with the Environmental Management and Coordination Act (EMCA) of 1999, and raising public and governmental awareness about environmental contamination and potential radiological risks from unmanaged waste.

II. MATERIALS AND METHODS

A. Area of study

Lumoro dumpsite is geographically located at latitude 0.3360^0 N and longitude 34.3300^0 E, within Muanda village, South Bukusu Ward, Bumula Sub-County, Bungoma County, Kenya. The surrounding village has a total population of 14,320, with approximately 257 households situated near the dumpsite [6]. The site is also in close proximity to an active commercial area

consisting of numerous Juakali workshops, located about 200 meters from the dumpsite along the route to Bungoma town, highlighting the potential for human exposure and interaction with waste-derived contaminants.

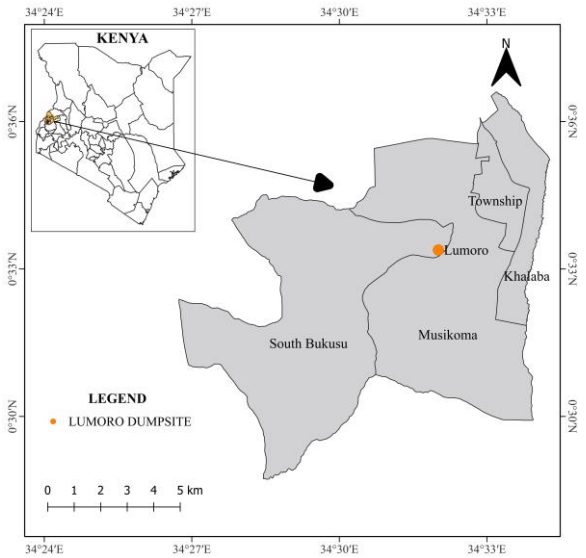

Figure 1: study area

B. Sample collection and preparation

Soil sampling was conducted at 15 administrative locations within the study area. A random sampling technique was employed to enhance the statistical representativeness of the samples[7][8]. At each location, three soil samples were collected using a trowel at depths ranging from 10 to 50 cm. The samples from each site were combined to form a single composite sample weighing approximately 700 g. In the laboratory, the soil samples were initially air-dried on plastic sheets at room temperature for one week, followed by oven drying at 110°C for 8 hours. Stones and organic matter were removed, and the dried soil was pulverized to a particle size appropriate for gamma spectroscopic analysis. The soil was then sieved through a 2 µm mesh to ensure homogeneity [8]. Finally, the homogenized soil was treated with concentrated hydrochloric acid and STORED for at least one month to achieve secular equilibrium between radon and its progeny prior to gamma spectroscopic measurement [9].

C. NaI (Tl) Spectrometer Calibration and sample analysis

Detector calibration was performed to convert counting rates into gamma-ray intensities for ^{214}Bi, ^{208}Tl, and ^{40}K, with corrections applied for background radiation, atmospheric noise, and Compton scattering [10]. Sample analysis employed a 7.6 cm × 7.6 cm NaI (Tl) detector coupled to a photomultiplier tube (PMT), housed within a 6 cm lead shield lined with cadmium and copper to minimize background and scattered radiation. Soil samples were placed in the detector cavity and measured for 29,000 seconds each. The peak area of each energy spectrum was used to calculate specific activity concentrations and associated radiological hazard parameters[11].

D. Radiological parameters

1) Specific Activity Concentration

The calculation for specific activity concentration was done by procedure given in equation 1 [12][13].

$$A_C(Bq/kg) = \frac{C_a}{nP_r m_s} \quad (1)$$

Ca- Net gamma counting rate (counts per second), n- Detector efficiency of the specific gamma ray, Pr- The absolute transition probability of gamma decay and Ms - The mass of the sample(kg).

2) Radium Equivalent (Ra_{eq})

This radiological parameter will be estimated using empirical equation 2[14].

$$Ra_{eq} = C_{Ra} + 1.423C_{Th} + 0.077C_K \quad (2)$$

Where C_{Ra} is the mean activity of ^{226}Ra, C_{Th} is the mean activity ^{232}Th and C_K is the mean activity concentrations of ^{40}K in soil samples expressed in Bq/kg.

3) Absorbed Dose Rate (ADR)

It is a measure of radiation dose intensity (or. It can also be defined as a measure of the chemical or physical effect created by given radiation exposure or physical effect created by given radiation exposure to a living matter. The absorbed gamma dose rates were calculated from activity concentration of ^{232}Th, ^{238}U and ^{40}K using the activity concentration-dose (nGy-1 per Bq/kg) conversion coefficients of 0.622, 0.462 and 0.0432 as provided by UNSCEAR reports. Equation 3.3 shows the model used to estimate the dose rate from the activity concentrations.[15]

$$ADR\ (nGy/h) = 0.427\ C_U + 0.622\ C_{Th} + 0.043\ C_K \quad (3)$$

where C_U, C_{Th}, and C_K are the average activities concentration of ^{238}U, ^{232}Th and ^{40}K respectively.

4) Annual Effective Dose Rate (AED) .

To evaluate the effective dose to the population attributable to radioactivity in the soil a conversion factor of 0.7 Sv/Gy was used [15]. The evaluation of the indoor and outdoor doses used the occupancy factors of 0.6 and 0.4 respectively for Kenyan setup [16]. The corresponding indoor and outdoor AED was evaluated using the resulting equations 4 and 5 respectively in the mixture of the soil samples.

$$AED_{IN}(mSvy^{-1}) = ADR(nGyh^{-1}) \times 8760 \times 0.6 \times 0.7(SvGy^{-1}) \times 10^{-6} \quad (4)$$

$$AED_{OUT}(mSvy^{-1}) = ADR(nGyh^{-1}) \times 8760 \times 0.4 \times 0.7(SvGy^{-1}) \times 10^{-6} \quad (5)$$

where; AED_{IN} and AED_{OUT} are Annual effective dose rate for indoor and outdoor environments respectively, $ADR(nGyh^{-1})$ is the absorbed dose rate in air, 8760 is the time in hours for one year, 0.7 ($SvGy^{-1}$) is the conversion factor which converts the absorbed dose rate in the air to an effective dose, 0.6 is the indoor occupancy factor and 0.4 is the outdoor occupancy factor [11][14].

III. Results and Discussions

3.1 The activity concentrations

The activity concentrations of three primordial radionuclides (^{238}U, ^{232}Th, and ^{40}K) were measured in all samples and presented in Table 1.

Table1: Activity Concentration, Absorbed Dose Rate and Annual Effective Dose Rate.

SAMPLE	Activity Concentration (Bq/Kg)			Dose (nGy/h	Ra_{eq} (Bq/Kg)	AED_{in}	AED_{out}
	^{238}U	^{232}Th	^{40}K				
D1	4±0.2	43±2.19	15±0.76	29±1.45	67±3.38	0.1±0	0.07±0
D2	7±0.38	58±2.92	30±1.52	40±2	93±4.65	0.1±0	0.09±0
D3	6±0.3	81±4.08	18±0.92	53±2.65	123±6.19	0.1±0	0.13±0
D4	7±0.38	52±2.62	17±0.87	36±1.8	83±4.18	0.1±0	0.08±0
D5	6±0.33	52±2.62	15±0.76	35±1.77	82±4.13	0.1±0	0.08±0
D6	6±0.34	70±3.5	28±1.41	46±2.33	108±5.43	0.1±0	0.11±0
D7	3±0.15	40±2.04	41±2.06	27±1.39	64±3.22	0.1±0	0.06±0
D8	4±0.2	40±2.04	14±0.7	27±1.36	63±3.17	0.1±0	0.06±0
D9	12±0.63	35±1.75	68±3.42	29±1.49	67±3.39	0.1±0	0.07±0
D10	11±0.55	35±1.75	23±1.19	27±1.36	62±3.14	0.1±0	0.06±0
D11	6±0.31	37±1.89	16±0.81	26±1.32	61±3.08	0±0	0.06±0
D12	2±0.12	81±4.08	16±0.81	51±2.55	120±6	0.1±0	0.12±0
D13	11±0.56	87±4.38	22±1.14	59±2.95	137±6.88	0.2±0.01	0.14±0
D14	8±0.44	52±2.62	25±1.25	36±1.84	85±4.28	0.1±0	0.09±0
D15	17±0.87	90±4.52	22±1.14	63±3.18	148±7.4	0.2±0.01	0.15±0
AVERAGE	**7±0.38**	**57±2.87**	**25±1.25**	**39±1.96**	**91±4.57**	**0.1±0**	**0.09±0**

The activities for ^{40}K varied from 14 ±0.7 Bq/kg to 68 ± 3.42 Bq/kg with an average of 25±1.25Bq/kg, ^{232}Th had activities that ranged from 35 ± 1.75 Bq/kg to 90±4.52 Bq/kg with an average of 57±2.87 Bq/kg and ^{238}U had activities that ranged from 2 ± 0.12 Bq/kg to 17 ± 0.87 Bq/kg with an average of 7±0.38 Bq/kg, Table 1. The global average activity concentration according to UNSCEAR for the radio nuclides for instance ^{40}K, ^{232}Th and ^{238}U are 420 Bq/kg, 45 Bq/kg and 35 Bq/kg respectively. The activities of ^{40}K and ^{238}U were within safe levels and therefore causing no risks for human exposure.

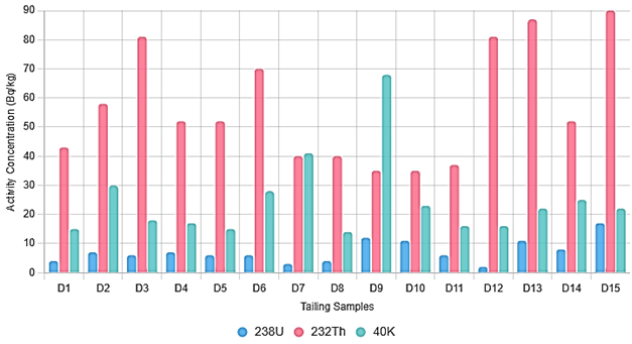

Figure 2: Activity Concentration of ^{40}K, ^{232}Th, and ^{238}U in the samples collected from Lumoru Dumpsite.

Despite having the low activity concentration of uranium (^{238}U) but comparatively homogeneous within the region with only a minimal number of the extreme values (17 0.87 Bq/kg in D15, 12 0.63 Bq/kg in D9), thorium (^{232}Th) was on the other hand, uniformly distributed in the region where a small amount of the samples indicated a high activity concentration (90 4.52 Bq/kg in D15) , see figure 1, This is owing to the fact that thorium is highly mobile compared to uranium and also due to dumping of construction materials rich in granites, sandstone and quartzite since this is a municipal dumpsite. Activity concentration of ^{40}K in all samples was below permissible value of 420 Bq/kg hence no significant radiological threat due to this radionuclide in the study area.

The difference in activity levels across soil samples at the Lumoru dumpsite can be explained by variations in dumping practices. Activities such as selective waste sorting, periodic turning of waste to enhance decomposition, open burning, and scavenging disturb soil layers and redistribute radionuclides unevenly. Similar influences have been documented in West Africa, where dumpsites like Accra's municipal solid waste site showed that burning and heterogeneous disposal practices contributed to localized radiological anomalies [17]. In Nigeria, Ademola *et al*. [18] reported that construction debris and waste handling methods introduce measurable variability in natural radionuclide concentrations. Within Kenya, Barasa *et al*. [19] observed comparable patterns at Machinjoni dumpsite in Kitale, where thorium enrichment was partly attributed to dumping of construction waste and site-specific waste management practices. These parallels suggest that the spatial variations observed at Lumoru are not unique, but consistent with the broader regional evidence that waste handling and composition strongly influence radiological distribution.

3.2 Radium equivalent

Radium equivalent that was found in all the samples varied between 61±3.08 Bq/kg to 148±7.4 Bq/kg at an average of 91±4.57 Bq/kg as indicated in Table 1. The spread in radium equivalent of the soil samples changed because of the unequal distribution of terrestrial radionuclide in the soils and rocks of the study area. The average of the radium equivalent which was reported by the present study in all the whole samples collected is 91 ± 4.57 Bq/kg and this was not in excess of the proposed radioactivity criterion levels so this is less than the recommended optimal level of 370 Bq/kg[15].

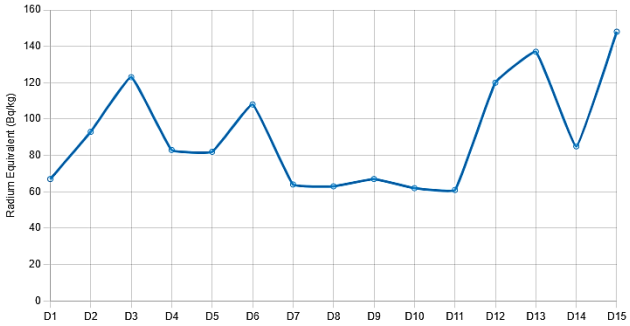

Figure 3: Radium Equivalent.

However, localized peaks in samples such as D15 and D13 suggest spatial heterogeneity, Figure 3, likely arising from both natural geological variability and the disposal of mineral-rich construction debris. When compared internationally, current study mean Ra_{eq} was considerably lower than values reported in Brazil, where Santos *et al*. [20] observed average Ra_{eq} levels of 319 Bq/kg in granite-rich soils, with some samples reaching 758 Bq/kg. In India, Mehra [21] reported Ra_{eq} values between 92.7 and 140.6 Bq/kg, with a mean of 111.8 Bq/kg, which is slightly higher but broadly comparable to current study values. Regionally, Barasa *et al*. (2024) documented Ra_{eq} values at Machinjoni dumpsite that similarly showed elevated ^{232}Th and variable Ra_{eq} distributions attributed to the disposal of construction debris and local geology, mirroring the localized thorium enrichment and Ra_{eq} variability at Lumoru. Importantly, health studies from other Kenyan dumpsites such as Dandora highlight the risks of chronic exposure: Gitau [22] reported elevated cases of respiratory illnesses, skin disorders, and possible bioaccumulation among workers and residents chronically exposed to contaminated soils and wastes. Together, these comparisons emphasize that while Lumoru's average Ra_{eq} values remain within safe global limits, the existence of localized hotspots and parallels with other dumpsites suggest that sustained monitoring and health surveillance are essential to prevent long-term radiological and non-radiological health burdens.

3.3 Absorbed Dose Rate of Soil Samples

The absorbed dose rates in soils from the Lumoru dumpsite ranged between 26.132 and 63.318 nGy/h, with a mean of 39.196 nGy/h (Table 1). Localized peaks, particularly in samples D15 and D13, Figure 4, reflected uneven radionuclide distribution arising from the disposal of ^{232}Th-rich construction debris such as sandstone, quartzite, and granite. Despite these hotspots, the mean value remained below the global average of 60 nGy/h [15], indicating minimal radiological health risks under current conditions. Comparable findings have been reported at the Machinjoni dumpsite in Trans-Nzoia County, Kenya, where Barasa *et al*. [19] observed elevated dose rates linked to construction materials and heterogeneous dumping practices, underscoring that localized anomalies are common in municipal dumpsites. Similarly, Kassenga [23] reported that solid waste disposal sites in Dar es Salaam, Tanzania, not only influenced soil radiological profiles but also posed broader environmental risks through contamination of surface and groundwater, illustrating the multifaceted pathways by which dumpsites affect human and ecosystem health. Taken together, these comparisons suggest that although Lumoru's mean absorbed dose rate is within safe limits, localized variations may present chronic exposure pathways for waste pickers and surrounding communities, emphasizing the importance of regular monitoring and integrated waste management strategies.

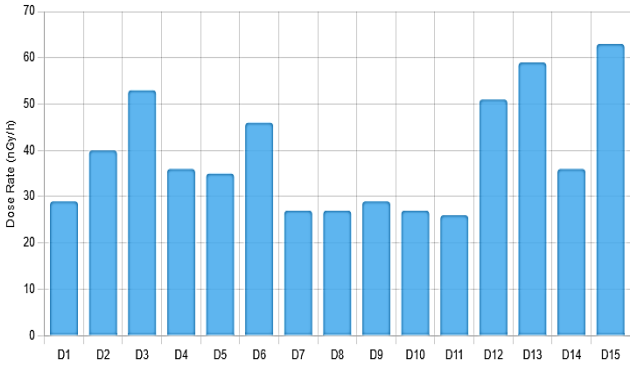

Figure 4: Absorbed Dose Rate for the samples.

3.4 Annual effective Dose

At Lumoru dumpsite, the $AEDE_{out}$ ranged between 0.06 and 0.15 mSv/y (average 0.09 mSv/y), while $AEDE_{in}$ ranged between 0.10 and 0.02 mSv/y (average 0.01 mSv/y). Although both are within the 1 mSv/y safety limit, $AEDE_{in}$ is consistently higher, meaning that people living or working indoors near the dumpsite are at greater radiological risk than those outdoors. Over time, this higher indoor exposure could contribute to subtle but cumulative health effects, including increased risk of respiratory complications, weakened immunity, and a slightly elevated lifetime cancer risk [5] [15], especially among vulnerable groups such as children and waste-pickers who spend extended hours in close proximity to the site.

Conclusion

The radiological assessment of soils from Lumoru dumpsite shows that the average activity concentrations of ^{40}K, ^{232}Th, and ^{238}U were 25, 57, and 7 Bq/kg respectively, while the mean radium equivalent was 91 Bq/kg, the absorbed dose rate was 39.2 nGy/h, and the annual effective doses were 0.09 mSv/y outdoors and 0.20 mSv/y indoors. These values are all within internationally recommended safety limits. However, localized hotspots, particularly for ^{232}Th, and elevated indoor exposure indicate potential health risks for residents engaging with the site through scavenging and reuse of construction debris. These patterns are consistent with findings from other East African and global dumpsites, highlighting the need for continuous monitoring, improved waste management, and heightened public awareness to mitigate long-term environmental and health impacts.

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Conflicts of interest

The authors declare no conflict of interest.

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