

Health Risk Assessment of Natural Radioactivity in soil from Helao Nafidi dumpsite, Omafo, Namibia

Onjefu Sylvanus Ameh¹, Nandjovo Maria Ndeshipanda¹, Hitila Markus¹, Indongo Vaino¹, Zivuku Munyaradzi¹, Ejembi Emmanuel¹, Hamunyela Roswita Hambeleleni^{2*}

¹Department of Biology, Chemistry and Physics, Faculty of Health, Natural Resources and Applied Sciences, Namibia University of Science and Technology, Windhoek, Namibia

²Department of Radiography, School of Allied Health Sciences, Hage Geingob Campus, University of Namibia, Windhoek, Namibia.

* rhamunyela@unam.na

ABSTRACT

Humans are exposed to radiation in dumpsite areas due to the natural presence of cosmic and terrestrial radiation in the environment. Residents, including children, frequently visit these sites to scavenge for food and other materials, which increases their risk of radiation exposure. The aim of the study was to ascertain whether natural radioactivity found in the Helao Nafidi dumpsite pose a threat to human health. In this work, the activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K in 19 soil samples were measured using a high purity germanium gamma-ray spectrometer. Several radiological parameters were computed based on these activities. The average activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K were 4.83 ± 0.58 , 4.72 ± 0.62 and 51.31 ± 5.41 Bq.kg⁻¹, respectively. The average estimated Ra_{eq} value of the dumpsite soil was 15.53 Bq.kg⁻¹. All the soil samples Ra_{eq} values were less than the average global value of 370 Bq.kg⁻¹. The average AEDE value was 0.01 mSv.y⁻¹, less than the 0.48 mSv.y⁻¹ global recommendation. The Dumpsite soil's Annual Gonadal Dose Equivalent (AGDE) value was 50.77 Sv.y⁻¹, which was found to be less than the 298 Sv.y⁻¹ global critical value. The average values of RLI and H_{ex} were found to be 0.11 and 0.04, respectively. These indices were less than the world accepted-limit values. The average value of the excess lifetime cancer risk (ECLR) was found to be 0.03×10^{-4} and lower than the world average of 2.9×10^{-4} . The findings suggest that the natural radioactivity in the soil at the Helao Nafidi dumpsite currently does not pose a radiological health risk.

Keywords: Natural radioactivity; dumpsite soil; radiological hazards; Helao Nafidi

Received: June 2023

Received in revised form: March 2025

Accepted: October 27, 2025

Published: October 30, 2025

1. INTRODUCTION

In recent years, increased radiation exposure in dumpsite soils has emerged as a significant concern, following the latest findings on the health risks linked to elevated levels of naturally occurring radioactive materials (NORMs) (IAEA, 2015). Numerous studies have been conducted on various aspects of naturally occurring radioactive materials (NORM), including their origins, environmental pathways, types of ionizing radiation, modes of exposure, interactions of gamma radiation with matter, and health risk assessments in dumpsite soils (Penabei et al., 2018). Certain natural resources inherently contain radionuclides, which are often found in significant concentrations within igneous geological formations and ores (IAEA, 2003). These substances, which come from the crust of the earth, are found in the soil, water, air, food, and construction materials (Adedokun et al., 2019). Building materials containing radioactive materials have been used for decades in many regions of the world (European Commission, 1999). Radioactive materials end up in goods, byproducts, residues, and waste because of human actions that exploit these resources (Andric & Gajic-Kvascev, 2021). Increased radiation exposure could happen if these residues containing naturally occurring radionuclides are not handled carefully and disposed of in secure dumpsites.

Humans can be exposed to radiation either internally or externally; External exposure is the type where exposure occurs when the radiation source is outside the body. While scavenging at landfills, NORM is spread over people's skin and clothing. Some of the items in the dumpsite can be swallowed if normal hygiene precautions like washing hands and changing clothes after handling them are not followed (IAEA, 2005), this may affect sensitive organs in the human body (Avwiri & Olatubosun, 2014). Gamma radiation has the highest effect on external exposures due to its high penetrating power. Doses from external exposure depend on factors such as the extent of the exposure, closeness to the radiation source, and the radionuclide concentration (ARPANSA, 2008). The most common modes of entry for naturally occurring radionuclides to the body are via inhalation and ingestion (Oladapo et al., 2012). For internal exposures, alpha radiation has the most impact because of its relatively high energy and weak penetrating strength (Kant et al., 2015). Dosages from internal exposures depend on the radionuclide concentrations in food, air, and materials being handled, the duration of the exposure, and the rate of intake of material into the body

(ARPANSA, 2008). Radon-222 is inhaled when ^{226}Ra decays. The radiological risk associated with radon is because the half-lives of the radon decay products are similar with the residence time of air in the lungs. These radionuclides may be attached to dust particles in some cases. The radionuclides in the dust can then decay within the body if it is inhaled. In this study, the activity concentrations from the soil were used to carry out health risk assessment in terms of radium equivalent activity (Ra_{eq}), absorbed dose rate in air (D), annual gonadal dose equivalent ($AGDE$), , the annual effective dose equivalent (AED), and excess lifetime cancer risk ($ELCR$). The external hazard index (H_{ex}), and the representative level index (RLI), are the other radiological factors assessed in the study.

2. MATERIALS AND METHODS

2.1 Study area

This study was undertaken in the dumpsite soils of Helao Nafidi dumpsite, in Ohangwena region, Namibia (Figure 1). The study was conducted in August 2021, with the samples obtained from Helao Nafidi dumpsite where scavenging is a common practice (Figure 2). The settlement is inhabited by approximately 5000 people (Namibia Statistic Agency, 2015), dominated by crop and livestock farming of Ovakwanyama communities, a subgroup of the Ovambo people. The dumpsite is located at $17^{\circ}26'2''\text{S}$ latitude, and $15^{\circ}52'58''\text{E}$ longitude.



Figure 1: Location of Helao Nafidi dumpsite the map of Namibia



Figure 2: Part of Helao Nafidi dumpsite, with animals and people scavenging

2.2 Sample collection and Preparation

A total of 19 soil samples were collected from various locations across the dumpsite at depths ranging from 30 cm to 50 cm. Each sample was then transferred into plastic bags, which were sealed, labelled, and taken to the lab for storage and sample preparation. Samples were air dried for 72 hours under laboratory conditions, homogenized and sieved with a 2.00 mm sieve, before oven dried for 12 hours at 80 °C to achieve moisture free samples. Approximately 500 g of each sample was weighed out then transferred into 1liter Marinelli beaker and stored for more than 31 days to prevent the escape of ^{220}Rn and ^{222}Rn . This enables ^{226}Ra and ^{232}Th and their daughter to reach secular equilibrium.

2.3 Gamma-ray Spectrometer

A Gamma-ray spectrometer, with High purity germanium detector, which consist of a coaxial cable (62.80 X 64.80 mm), was used in this study. The detector, manufactured by Canberra and is made up of germanium crystals contained in a 100 mm thick cylindrical classified lead shield (Model No. GC4520 SN 10882 Canberra), to reduce background radiation and cooled by liquid nitrogen. The detector has a resolution of 2.00 keV full width at half maximum at 1.33 MeV peak of ^{60}Co , 45 % relative efficiency

and 1.200 keV (FWHM) at 122 keV. For data acquisition and analysis, computer-based software, Genie 2000 from Canberra was used (Nicolas Fourches, 2019).

To minimize uncertainty in gamma ray intensities, energy and efficiency calibrations of the detector were performed using specific efficiency for the radionuclides of interest. The standard reference source, IAEA – RGTh⁻¹(3250 Bq · kg⁻¹) thorium ore was prepared in a 1-liter Marinelli beaker and used for energy calibration. Moreover, three samples of uranium (RGU⁻¹), thorium (RGTh⁻¹) and potassium (KCl) were prepared in a 100ml bottle and used as standard sources for efficiency calibration.

Samples were counted for 43000s in a reproducible manner with the arrangement and geometry sustained during the analysis. The 295.22 keV and 351.93keV energy lines of ²¹⁴Pb and the 609.32 keV, 1120.29 keV and 1764.49 keV of ²¹⁴Bi were used for assessment of activity concentration of ²²⁶Ra. Similarly, 609.32 keV, 1120.29 keV and 1764.49 keV for ²¹⁴Bi gamma lines were used for assessment of activity concentration of ²²⁶Ra, while 911.21 keV for ²²⁸Ac and 968.97 keV and 238.63 keV for ²¹²Pb were used for ²³²Th. The isotope of ⁴⁰K was obtained from the single 1460 keV Gamma-line of ⁴⁰K (IAEA, 2015).

2.4 Radiological parameters

Several parameters were utilized to assess radiation hazards linked with NORM in soil samples of Helao Nafidi dumpsite.

2.4.1 Radium equivalent activity (Ra_{eq})

This is the weighted sum of ²²⁶Ra, ²³²Th and ⁴⁰K activity concentrations, and assumes that, 370 Bq. kg⁻¹ of ²²⁶Ra, 259 Bq. kg⁻¹ of ²³²Th and 4810 Bq. kg⁻¹ of ⁴⁰K produce the same dose rate. Radium equivalent activity was calculated using equation 1 (Tufail, 2011):

$$Ra_{eq} = \left(\frac{AC_{Ra}}{370} + \frac{AC_{Th}}{259} + \frac{AC_K}{4810} \right) \times 370 \quad (1)$$

where AC_{Ra} , AC_{Th} and AC_K are the activity concentrations in Bq.kg⁻¹ of ²²⁶Ra, ²³²Th and ⁴⁰K respectively. The maximum dose Ra_{eq} in soil samples must be less than the recommended value of 370 Bq. kg⁻¹ in soil.

2.4.2 Annual Effective Dose Equivalent (AEDE)

Annual effective dose equivalent is the dose received by people from radioactivity concentrations found in soil and was measured in unit of mSv y^{-1} . The AEDE was determined from equation 3.

$$\text{AEDE} (\text{mSv. y}^{-1}) = D_r (\text{nGy h}^{-1}) \times 8760 (\text{h}) \times 0.2 \times 0.7 (\text{Sv Gy}^{-1}) \times 10^{-6} \quad (2)$$

where D is the absorbed dose rate, and 0.7 Sv Gy^{-1} is the conversion factor from absorbed dose to effective dose, 0.2 signifies the outdoor occupancy factor, and 8760 hours is the time for one year with a conversion factor of 10^{-6} . The maximum dose equivalent of 1.0 mSv. y^{-1} is recommended by ICRP for the public.

2.4.3 Absorbed dose rate in air (D_r)

Absorbed dose rate depends on activity concentrations of ^{226}Ra , ^{40}K and ^{232}Th in soil where other radioactive isotopes are negligible. The absorbed dose rate was calculated using equation 4.

$$D_r (\text{nGy h}^{-1}) = 0.442 AC_{\text{Ra}} + 0.604 AC_{\text{Th}} + 0.0417 AC_{\text{K}} \quad (3)$$

where D_r is the absorbed dose rate, and AC_{Ra} , AC_{Th} and AC_{K} have the same meaning as in equation 2.

2.4.4 Annual Gonadal Dose Equivalent (AGDE)

Gonads are the main reproductive organs, ovaries in the female and testes in male. As a result of the gonads high radio sensitivity, gonadal dose to the general population needs to be reduced. It is also known that the bone marrow responsible for producing red blood cells is impacted by an increase in AGDE levels (Mohamed et al., 2014). This may lead to cancer of the blood called leukemia, which is often fatal. Other organs of interest are the thyroid, lungs, liver, colon, and bladder. For this reason, they are considered as organs of interest for dosimetry purposes. The annual gonadal dose equivalent (AGDE) in $\mu\text{Sv. y}^{-1}$ is determined by using the formula in equation 5.

$$\text{AGDE} (\mu\text{Sv. y}^{-1}) = 3.09 AC_{\text{Ra}} + 4.19 AC_{\text{Th}} + 0.314 AC_{\text{K}} \quad (4)$$

2.4.5 Representative Level Index (RLI)

This is the gamma radioactivity Representative Level Index associated with naturally occurring radioactive elements and was calculated using equation 6. The maximum recommended value in soil is 1.

$$RLI = \frac{1}{150AC_{Ra}} + \frac{1}{100AC_{Th}} + \frac{1}{1500AC_K} \quad (5)$$

2.4.6 External Hazard Index (H_{ex})

Different radionuclides contribute to the total gamma dose received by human. To quantify radiological hazards as a single quantity, the hazard index was used. For radiological purposes, the H_{ex} should be less than one to keep exposure to radiation hazard negligible. The external hazard index was calculated using equation (7).

$$H_{EX} = \frac{AC_{Ra}}{370} + \frac{AC_{Th}}{259} + \frac{AC_K}{4810} \leq 1 \quad (6)$$

2.4.7 Excess Lifetime Cancer Risk (ELCR).

The likelihood that a person will get cancer over their lifetime at a specific dose is provided by the excess lifetime cancer risk (ELCR) for outdoor exposure. (IAEA, 2003). The ELCR was calculated with the presumption that the dose and the relevant stochastic effects are linearly related. This was calculated using equation 8.

$$ELCR = AEDE \times DL \times RF \leq 0.05 \quad (7)$$

Where AEDE is the Annual Effective Dose Equivalent, DL is the Duration of Life (70 years), and RF is the risk factor (Sv^{-1}). The International Commission on Radiological Protection (ICRP) employed the value 0.05 for stochastic effects for the public.

3. Results and Discussion

3.1 Activity concentrations

The activity concentrations of ^{232}Th , ^{226}Ra and ^{40}K analyzed from the soil in the dumpsite are presented in Table 1. Average activity concentrations in Bq.kg^{-1} of ^{226}Ra ranged from 2.15 ± 0.32 to 15.14 ± 1.21 , while ^{232}Th ranged from 3.24 ± 0.26 to 7.10 ± 0.97 and ^{40}K from 13.66 ± 3.78 to $150.39 \pm 8.64 \text{Bq.kg}^{-1}$ respectively (Figure 3). Also, it was shown that neither average activity concentration exceeded the global permissible level of 35, 30 and 400 Bq.kg^{-1} (UNSCEAR, 2000). The average value was 4.83 ± 0.58 , Thorium with 4.72 ± 0.62 and Potassium with $150.39 \pm 8.64 \text{Bq.kg}^{-1}$ respectively.

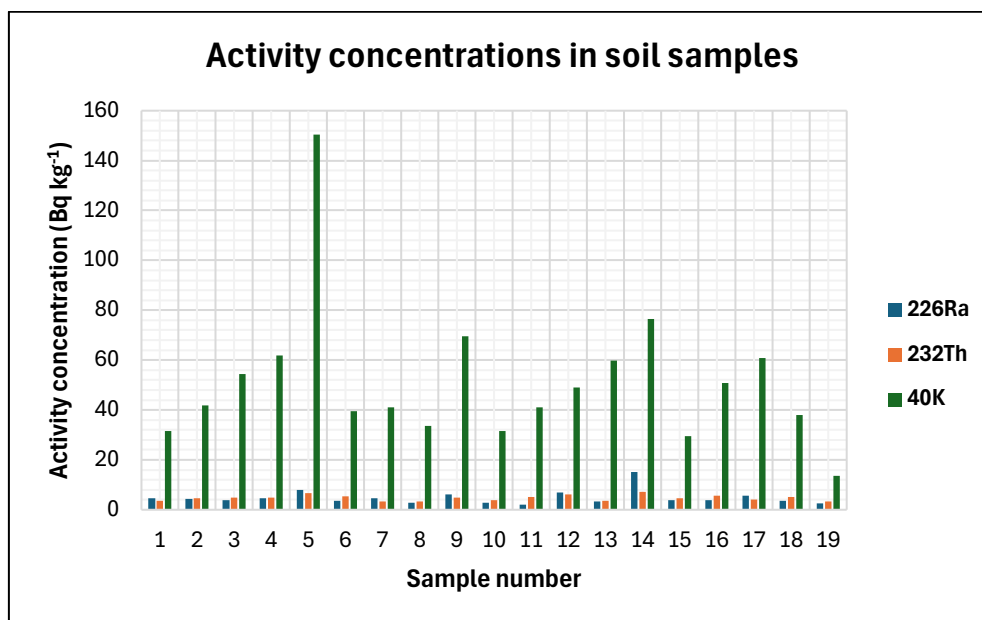


Figure 3: Activity concentrations of the samples from waste dumpsite

3.2 Radium equivalent

Radium equivalent (Table 1) (Figure 4) has the highest value of 31.18Bq.kg^{-1} , and lowest value of 18.17Bq.kg^{-1} , with an average value of 15.53Bq.kg^{-1} , which is less than the world accepted limit of 370Bq.kg^{-1} according to (UNSCEAR, 2000).

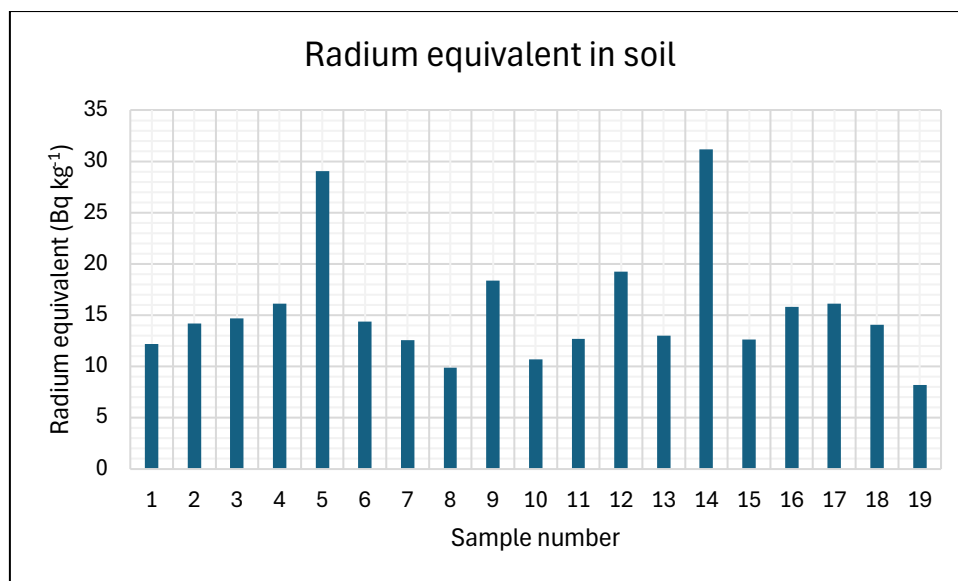


Figure 4: Radium equivalent as a function of sample number

3.3 Absorbed dose rate

Absorbed dose rate (Table 1), ranged from the value of 3.68 to 14.50 nGy.h⁻¹, with an average value of 7.24 nGy.h⁻¹, which is lower than the world accepted limit of 59 nGy.h⁻¹, (UNSCEAR, 2000). Figure 5 presents the graphical representation of the absorbed dose rate.

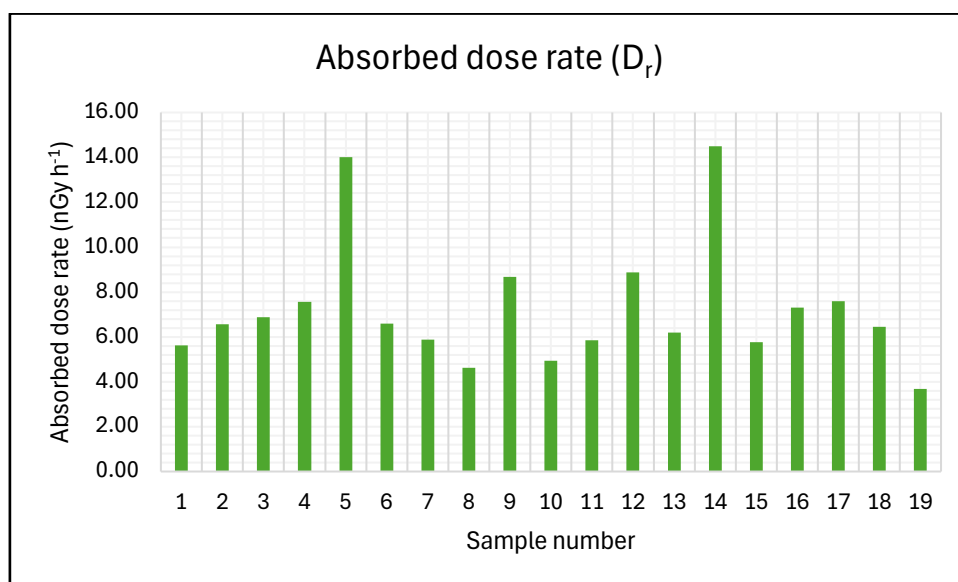


Figure 5: Graphic representation of the absorbed dose rate (nGy h⁻¹) in air.

Table 1: Activity concentrations (^{226}Ra , ^{232}Th and ^{40}K), Radium Equivalent and Absorbed Dose

	Activity concentrations (A_i) in Bq. kg^{-1}				
Sample number	^{226}Ra	^{232}Th	^{40}K	R_{eq} (Bq. kg^{-1})	D_r (nGy. h^{-1})
1	4.62±0.41	3.60±0.61	31.62±4.11	12.19	5.63
2	4.27±0.48	4.70±0.66	41.88±4.60	14.21	6.57
3	3.75±0.85	4.74±0.72	54.30±6.44	14.71	6.88
4	4.49±0.32	4.80±0.26	61.92±3.93	16.12	7.57
5	7.89±0.60	6.68±0.47	150.39±8.64	29.03	14.00
6	3.54±1.21	5.44±0.82	39.54±6.66	14.36	6.58
7	4.69±0.46	3.29±0.69	41.11±5.12	12.57	5.88
8	2.69±0.47	3.24±0.66	33.68±4.59	9.91	4.61
9	6.08±0.52	4.87±0.75	69.53±6.29	18.40	8.67
10	2.90±0.43	3.75±0.29	31.61±3.95	10.69	4.93
11	2.15±0.59	5.17±0.75	41.04±6.00	12.70	5.84
12	6.82±0.56	6.06±0.66	49.04±5.48	19.27	8.87
13	3.39±0.66	3.50±0.51	59.84±4.80	13.01	6.19
14	15.14±0.36	7.10±0.54	76.55±3.78	31.18	14.50
15	3.75±0.58	4.61±0.97	29.59±6.40	12.62	5.76
16	3.87±0.60	5.60±0.72	50.93±5.91	15.80	7.31
17	5.60±0.59	4.08±0.60	60.74±6.74	16.11	7.60
18	3.69±0.81	5.22±0.60	37.86±5.32	14.07	6.45
19	2.48±0.58	3.24±0.50	13.66±4.01	8.17	3.68
MINIMUM	2.15 ±0.32	3.24 ±0.26	13.66 ±3.78	8.17	0.004
MAXIMUM	15.14±1.21	7.10 ±0.97	150.39±8.64	31.18	0.02
AVERAGE	4.83 ±0.58	4.72 ±0.62	51.31 ±5.41	15.53	0.01
WORLD AVERAGE	35	30	400	370	0.48

3.4 Annual effective dose equivalent (AEDE)

Annual effective dose equivalent (Table 2) varied from 0.004 to 0.02 mSv.y⁻¹ (Figure 6), with an average value of 0.01 mSv.y⁻¹ which is less than the value of 0.48 mSv.y⁻¹, the world accepted limit (UNSCEAR, 2000).

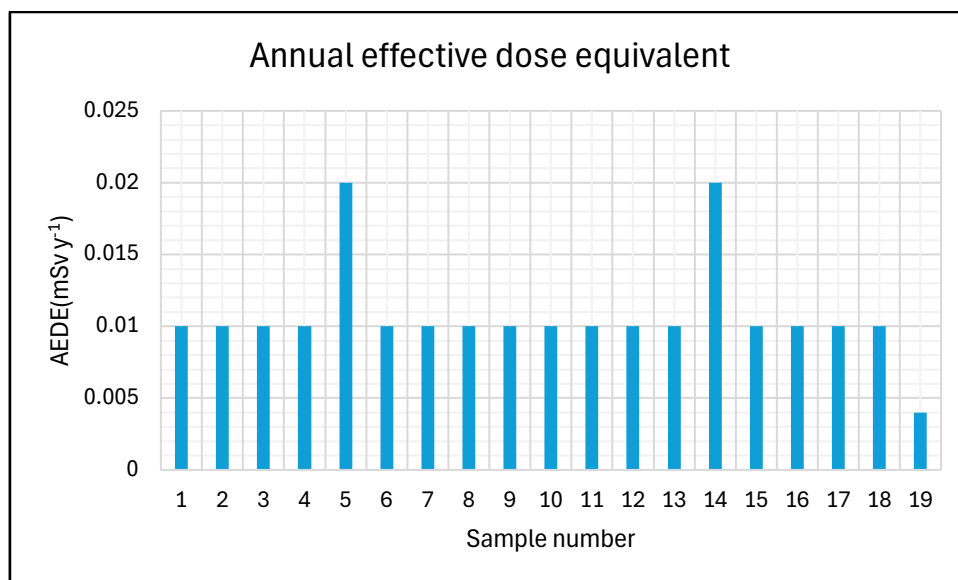


Figure 6: Graphical representation of AEDE for each soil sample.

3.5 Representative Level Index (RLI)

The Representative Level Index (RLI), ranged from 0.06 - 0.22 (Figure 7), with an average of 0.11. The RLI calculated is lower than the world average of 1 (UNSCEAR, 2000), which makes the radionuclides found in the dumpsite soil less hazardous to human for now.

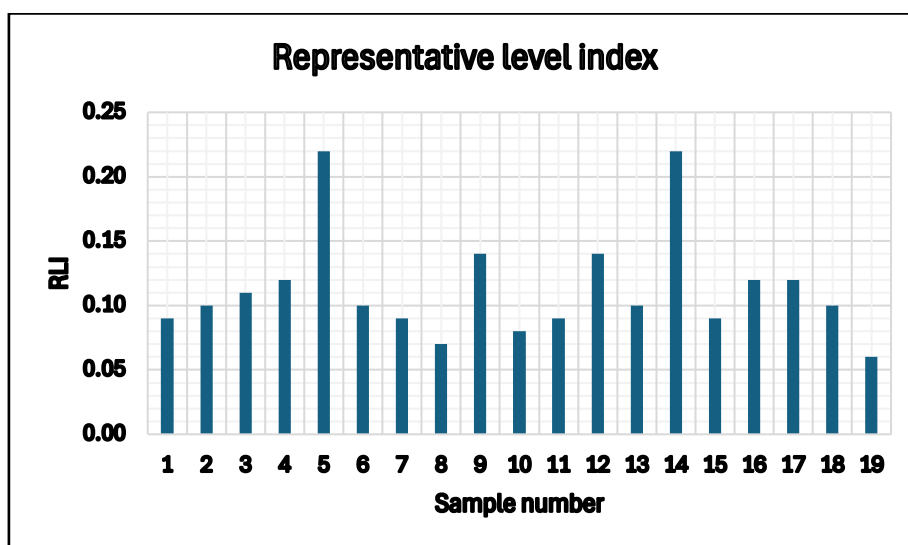


Figure 7: Graphic view of the representative level index in soil samples.

3.6 Annual Gonadal Dose Equivalent (AGDE)

The Annual Gonadal Dose Equivalent ranged from 25.50 -100.49 $\mu\text{Sv} \cdot \text{y}^{-1}$ (Figure 8), with an average of 50.77 $\mu\text{Sv} \cdot \text{y}^{-1}$ in the dumpsite soil. This value was less than the world average of 298 $\mu\text{Sv} \cdot \text{y}^{-1}$ (UNSCEAR, 2000).

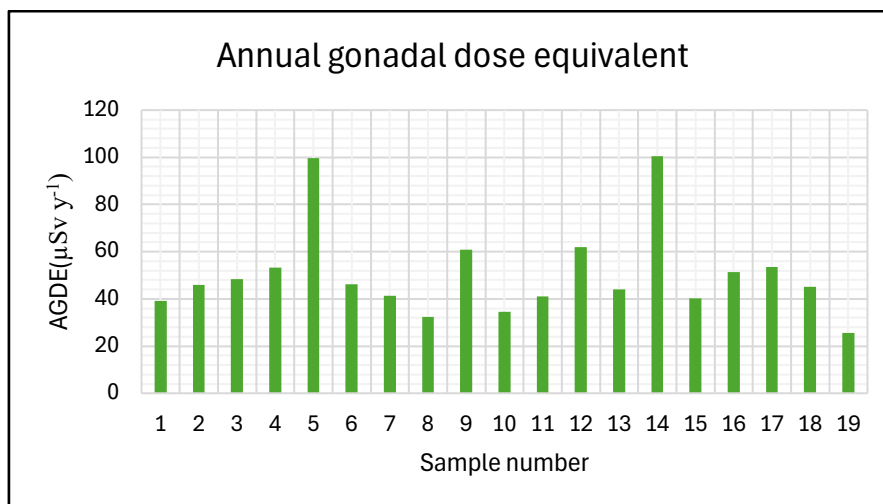


Figure 8: Graph showing the AGDE ($\mu\text{Sv} \cdot \text{y}^{-1}$) in each soil sample.

3.7 External Hazard Index (H_{ex})

External Hazard Index (H_{ex}) ranged from a value of 0.02 to 0.08 (Figure 9), with an average of 0.04 (Table 2).

The calculated results showed that all the values for H_{ex} were lower than 1, which is the allowed maximum value by (UNSCEAR, 2000), making the dumpsite soil safe to the population in the area.

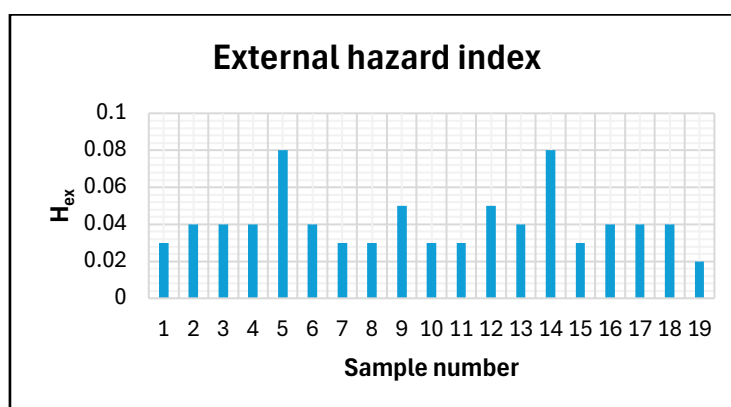


Figure 9: External hazard index in soil samples of Helao Nafidi dumpsite.**Table 2:** Annual Effective Dose Equivalent (AEDE), Representative Level Index (RLI), Annual Gonadal Dose Equivalent, External Hazard Index (H_{ex}) and Excess Lifetime Cancer Risk (ELCR) of Helao Nafidi dumpsite soils, Ohangwena region, Namibia.

Sample number	AEDE ($mSv.y^{-1}$)	RLI ($Bq.kg^{-1}$)	AGDE ($\mu Sv.y^{-1}$)	H_{ex}	ELCR $\times 10^{-4}$
1	0.01	0.09	39.22	0.03	0.02
2	0.01	0.10	45.96	0.04	0.03
3	0.01	0.11	48.47	0.04	0.03
4	0.01	0.12	53.37	0.04	0.03
5	0.02	0.22	99.55	0.08	0.06
6	0.01	0.10	46.08	0.04	0.03
7	0.01	0.09	41.18	0.03	0.02
8	0.01	0.07	32.42	0.03	0.02
9	0.01	0.14	60.97	0.05	0.04
10	0.01	0.08	34.54	0.03	0.02
11	0.01	0.09	41.15	0.03	0.02
12	0.01	0.14	61.83	0.05	0.04
13	0.01	0.10	43.90	0.04	0.03
14	0.02	0.22	100.49	0.08	0.06
15	0.01	0.09	40.14	0.03	0.02
16	0.01	0.12	51.36	0.04	0.03
17	0.01	0.12	53.42	0.04	0.03
18	0.01	0.10	45.10	0.04	0.03
19	0.004	0.06	25.50	0.02	0.02
Minimum	0.004	0.06	25.50	0.02	0.02
Maximum	0.02	0.22	100.49	0.08	0.06
Average	0.01	0.11	50.77	0.04	0.03
World Average	0.48	1	298	1	2.90

3.8 Excess lifetime cancer risk (ELCR)

Excess lifetime cancer risk varied from 0.02×10^{-4} to 0.06×10^{-4} (Figure 10), with an average of 0.03×10^{-4} (Table 2). These evaluated results were found to be less than the world critical value of 2.90×10^{-4} .

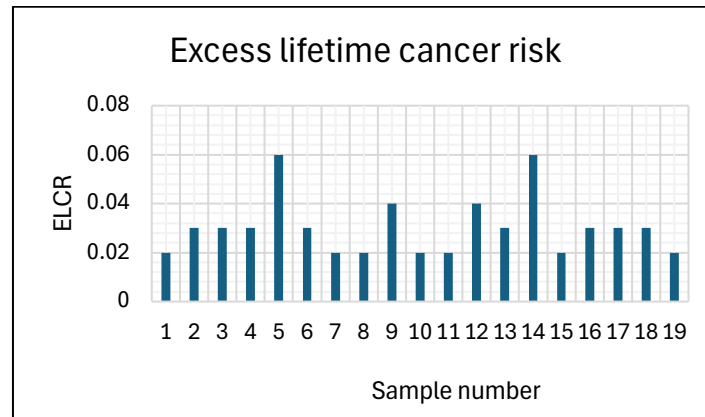


Figure 10: Excess lifetime cancer risk in the dumpsite soil.

3.9 Correlation between Radionuclides in soil samples

To determine any relationship that exists between the radionuclides, the correlation between ^{226}Ra and ^{232}Th , ^{226}Ra and ^{40}K , and ^{232}Th and ^{40}K was drawn (Figure 11-13). Clearly, there was moderate correlation between ^{226}Ra and ^{232}Th with $R^2 = 0.45$ (Figure 11) and weak correlation between ^{40}K and ^{226}Ra , with $R^2 = 0.31$ (Figure 12), respectively. Also, the correlation coefficient between ^{232}Th and ^{40}K was 0.37, suggesting a weak relationship between ^{232}Th and ^{40}K in the analyzed samples (Figure 13).

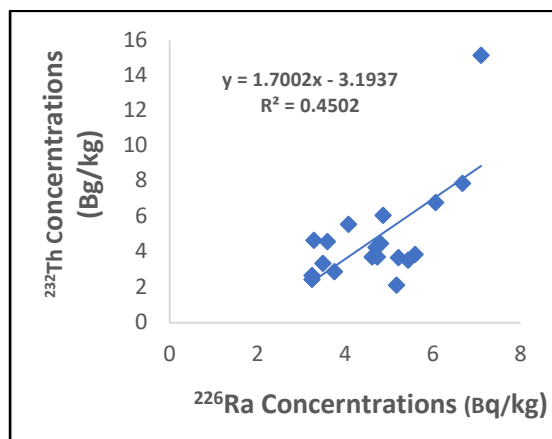


Figure 11: Correlation between ^{232}Th and ^{226}Ra

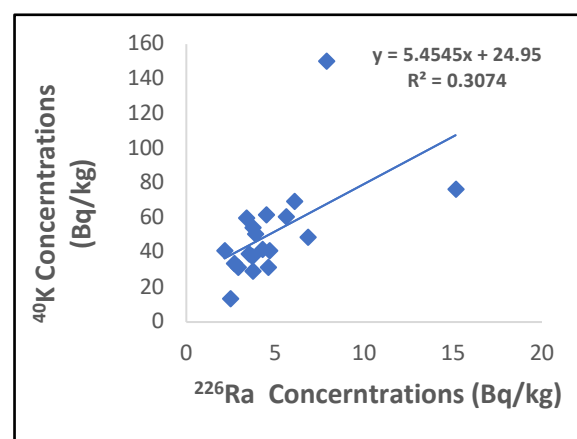


Figure 12: Correlation between ^{40}K and ^{226}Ra

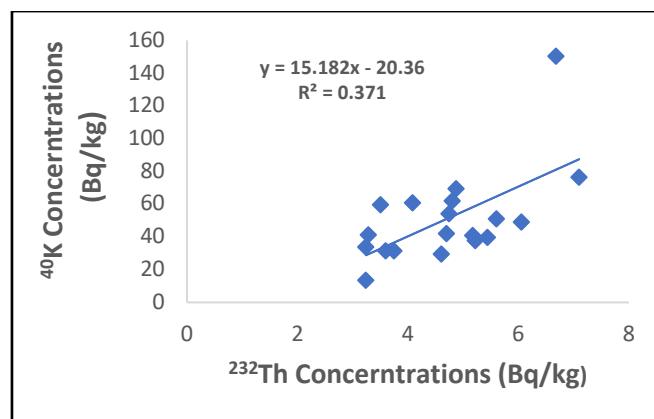


Figure 13: Correlation between ^{40}K and ^{232}Th

4. Conclusion

The health risk assessment of radioactive compounds in the soils of the Helao Nafidi dumpsite was conducted by analyzing 19 soil samples using a gamma spectrometer. The readings were all below the 35, 30 and 400 $\text{Bq} \cdot \text{kg}^{-1}$ permissible concentration levels. (UNSCEAR, 2000). The soil in the Dumpsite had an average R_{eq} value of 15.53 $\text{Bq} \cdot \text{kg}^{-1}$. All the soil samples had R_{eq} levels that were less than the global average of 370 $\text{Bq} \cdot \text{kg}^{-1}$. The absorbed dose rate was 7.24 $\text{nGy} \cdot \text{h}^{-1}$, which is less than the 57 $\text{nGy} \cdot \text{h}^{-1}$ global average that is advised. In addition, the average AEDE value was 0.01 $\text{mSv} \cdot \text{y}^{-1}$, which is less than the world recommended value of 0.48 $\text{mSv} \cdot \text{y}^{-1}$. The Dumpsite soil's Annual Gonadal Dose Equivalent (AGDE) value was 50.77 $\mu\text{Sv} \cdot \text{y}^{-1}$, which was found to be less than the 298 $\mu\text{Sv} \cdot \text{y}^{-1}$, global limit. Furthermore, average values of RLI and H_{ex} were 0.11 and 0.04. These indices were less than the world accepted-limit values. The average value of the excess lifetime cancer risk (ECLR) calculated was 0.03×10^{-4} , which is less than the accepted limit of 2.9×10^{-4} according to (UNSCEAR,2000). These findings indicate that there is no cause for concern regarding NORMs in the soil of Helao Nafidi dumpsite.

References

1. Adedokun, M. B., Aweda, M. A., Maleka, P. P., Obed, R. I., Ogungbemi, K. I., & Ibitoye, Z. A. (2019). Natural radioactivity contents in commonly consumed leafy vegetables cultivated through surface water irrigation in Lagos state, Nigeria. *Journal of Radiation Research and Applied Sciences*, 12(1), 147–156. <https://doi.org/10.1080/16878507.2019.1618084>
2. Andric, V., & Gajic-Kvascev, M. (2021). The radioactivity parameters in the food chain - Legislation, control and critical points. *IOP Conference Series: Earth and Environmental Science*, 854(1). <https://doi.org/10.1088/1755-1315/854/1/012003>
3. Apuke, O. D. (2017). QUANTITATIVE RESEARCH METHODS A SYNOPSIS APPROACH. *Arabian Journal of Business and Management Review (Kuwait Chapter)*, 6(10), 40-47. doi:10.12816/0040336
4. ARPANSA (Australian Radiation Protection and Nuclear Safety Agency). (2008, August). Management of Naturally Occurring Radioactive Material(NORM). *Radiation Protection Series Publication*, 15, 20-30. Retrieved from www.arpansa.gov.au/aboutus/committees/norm.cfm
5. ARPANSA. (2008). *Radiation Protection Series Publication : Management of Natural Occurring Radioactive Materials (NORM)* (Vol. 15). Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).
6. Awwiri, G. O., & Olatubosun, S. A. (2014, April). Assessment Of Environmental Radioactivity In Selected Dumpsites In Port Harcourt, Rivers State, Nigeria. *INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH*, 3(4), 263-269. Retrieved from <http://www.ijstr.org>
7. Chen, J. (2015). *A Study on Properties of Novel Metallic Foam for Nuclear Applications*. doi:10.13140/RG.2.1.2700.6804
8. European Commission: Directorate-General for Environment . (1999). *Radiological Protection Principles concerning the Natural Radioactivity of Building materials*. DirectorateGeneral Environment, Nuclear Safety and Civil Protection. . Luxembourg.: EU Publications. doi:CR-26-99-126-EN-C
9. Gilmore, G. R. (2008). *Practical Gamma-ray Spectrometry* (2nd ed.). West Sussex, England: John Wiley.
10. Groot, A. (2009). *Salt-marsh sediment Natural γ -radioactivity and spatial patterns*, PhD. (Mathematics and natural sciences). Dissertation, University of Groningen.
11. IAEA. (2003). Extent of environmental contamination by naturally occurring radioactive. *Technical Report Series : International Atomic Energy Agency*, 4-5.
12. IAEA. (2005). Naturally occurring radioactive materials:Proceedings of an international conference held in Szczyrk, Poland, 17–21 May 2004.

13. IAEA. (2006). Classification of soil systems on the basis of transfer factors of radionuclides from soil to reference plants: *proceedings of a final research coordination meeting organized by the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture and held in Chania, Crete, 22-26 September 2003*. International Atomic Energy Agency.
14. IAEA. (2015). Naturally Occurring Radioactive Material (NORM VII). *Proceedings of an International Symposium on naturally occurring radioactive material / organized by the China Institute of Atomic Energy and the Nuclear and Radiation Safety Centre, with IAEA , held in Beijing, China, 22-26 April 2013*. 7, pp. 17-20. VIENNA: IAEA in Austria. doi:14–00945
15. Ibrahim, D., Zahi, A. F., Martin , J. W., & James , K. M. (2015). New Applications of Cardiac Computed Tomography: Dual-Energy, Spectral, and Molecular CT Imaging. *J A C C : C A R D I O V A S C U L A R I M A G I N G*, 8(6), 710-723. Retrieved from <https://www.sciencedirect.com/science/article/pii/S1936878X15001904>
16. Knoll, G. F. (1989). *Radiation detection and measurement*. (2nd ed.). New York USA.: John Wiley and sons Inc.
17. Kant, K., Gupta, R., Kumari, R., Gupta, N., & Garg, M. (2015). Natural radioactivity in Indian vegetation samples. <https://doi.org/10.7508/ijrr.2015.02.004>
18. Mohamed , D., Mark , R., Ahmed , E., David , F., & Magdi , H. Y. (2014). Radiation in medicine: Origins, risks and aspirations, *Global Cardiology Science and Practice. Bloomsbury Qatar Foundation journals*, 437-448. doi:10.5339/2014.57
19. Namibia Statistic Agency, N. (2015). *CENSUS and STATISTICS*. Cencus Report. Retrieved from <https://nsa.org.na>
20. NHC, I. (2021). *Infrastructure -Namibia High Commission*. Retrieved 10 8, 2021, from Infrastructure -Namibia High Commission website: <http://www.ifrastructure-nhcdelhi.co>
21. Nicolas Fourches, M. Z. (2019). High Purity Germanium: From Gamma-Ray Detection to Dark Matter Subterranean Detectors. In B. A. Almayah, *Use of Gamma Radiation Techniques in Peaceful Applications*. doi:10.5772/intechopen.82864
22. Oladapo , O. O., Oni , E. A., Olawoyin , A. A., Akerele , O. O., & Tijani , S. A. (2012, Nov-Dec). Assessment of Natural Radionuclides Level in Dumpsite Soils around Olusosun Dumpsite Lagos, Nigeria. *IOSR Journal of Aplied Physics (IOSR-JAP)*, 2(3), 38-43. Retrieved from WWW.IOSRJOURNALS.ORG
23. Onjefu, S. A., Kamunda, C., & Abah, J. (2021). Health Risk Assessment of Natural Radioactivity in Dumpsite Soils in Okakarara , Namibia. *Arab Journal of Nuclear Sciences and Applications*, 54(2), 143-150.
24. Penabei, S., Bongue, D., Maleka, P., Dlamini, T., Saïdou, Guembou Shouop, C. J., Halawlaw, Y. I., Ngwa Ebongue, A., & Kwato Njock, M. G. (2018). Assessment of natural radioactivity levels and the associated radiological hazards in some building materials from Mayo-Kebbi region, Chad. *Radioprotection*, 53(4), 265–278. <https://doi.org/10.1051/radiopro/2018030>
- 25.

26. Pochin, E. (1979). The Importance of Radiation Risk Assessment. *IAEA BULLETIN*, 21(4).
27. Podgorsak, E. (2005). *RADIATION ONCOLOGY PHYSICS: A HANDBOOK FOR TEACHERS AND STUDENTS*, International Atomic Agency. VIENNA: IAEA in Austria.
28. Tufail, M. (2011, 09). Radium equivalent activity in the light of UNSCEAR report. *Environmental monitoring and assessment*, 184, 5663-7. doi:10.1007/s10661-011-2370-6
29. UNSCEAR (2000) United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources Effects and Risks of Ionizing Radiation*, United Nations Report to the General Assembly, With Annexes: (UNSCEAR): New York, USA.
30. V Pierre, R. J. (2017). The discovery of radioactivity. *Comptes Rendus Physique*, 18, 544-550. Retrieved from <http://creativecommons.org/licenses/by-nc-nd/4.0/>
31. Wirawan, R. (2012). *Simulation of energy absorption spectrum in NaI crystal detector for multiple gamma energy using Monte Carlo method* (Vol. 1656). doi:10.1063/1.4917139