Radioactivity concentrations in anthill soils used for building construction: A case study of Oshikoto region, Namibia

Karizitus Auchumeb*, Vaino Indongo, Markus Hitila
Namibia University of Science and Technology (NUST), 13 Jackson Kaujeua Street, P/Bag 13388, Windhoek, Namibia
karlzitusauchumeb@gmail.com, vindongo@nust.na, mhitila@nust.na

Abstract
The background radioactivity levels are gradually increasing due to human activities. Humans are exposed to radiation either from terrestrial sources emanating from these activities or cosmological sources. The main aim of the study was to measure the radioactivity concentrations in anthill soils used for building residential dwellings in the northern region. The study was conducted along the B1 road of the Oshikoto region to determine the natural activity concentration of terrestrial radionuclides of ^{238}U (^{226}Ra), ^{232}Th and ^{40}K by using a high-purity germanium detector and to assess the radiological health parameters associated with the anthill building material. The average activity concentrations for (^{226}Ra), ^{232}Th and ^{40}K were found to be 8.01 ± 0.43, 11.75 ± 0.48 and 159.33 ± 5.19 Bq/kg, respectively. All measured average activity concentrations of the radionuclides were below the world safety limits. The corresponding radiological parameters of interest of the study (absorbed dose rate, annual effective dose equivalence, radium activity, external hazard index, and internal hazard index) were estimated. The averages for the absorbed dose rate and annual effective dose equivalent were found to be 17.02 ± 0.42 nGy/h and 0.02 ± 0.00 mSv/y, respectively, whilst the averages for radium equivalent activity, external hazard index and internal hazard index were 36.08 ± 0.92 Bq/kg, 0.10 ± 0.00 and 0.12 ± 0.00, respectively. The absorbed dose rate was approximately three times (x3) lower than that of the world average. The spread of data from the mean value was 5.94 nGy/h for the absorbed dose rate, 6.29 mSv/y for annual effective dose, 11.02 Bq/kg for radium equivalent activity, 0.03 for the external hazard index and 0.04 for the internal hazard index. The average values for the external and internal hazard indices were below unity, implying that the external exposure of humans to radiation is negligible and therefore, the soil materials are safe for building constructions of human shelters.

Keywords: anthill soil, buildings, shelter, dwellings, activity concentration, radiological hazards, Oshikoto region.

Received: July 2024
Received in revised form: May 4, 2025
Accepted: May 13, 2025
Published: May 13, 2025

1. Introduction

Radioactivity is a process of spontaneous decay and transformation of unstable radioactive nuclei to stable nuclei (Lilley, 2001). Natural radioactivity is the emission of radiation by naturally occurring radionuclides, which are ^{226}Ra, ^{210}Pb, ^{238}U, ^{232}Th and ^{40}K and their decay products.

Environmental radionuclides can be divided into groups, such as radionuclides of primordial origin, radionuclides generated by cosmic-ray interaction in the atmosphere and radionuclides generated by human activities. Primordial radionuclides are inherently present in small but measurable quantities in rocks, soil, water and the atmosphere that constitute the earth's surface (Tzortzis & Tsertos, 2004).

Termite anthill is a mound of debris brought up by ants from underground when digging their nests, which are often seen as a pyramid of moulded cray soil made by termites and ants resembling a small hill structure. It is made mostly of clay materials and other fine-grained soils that the plasticity properties have been further enhanced by the secretions from the insects while being used in building the mound (Mijinyawa et al., 2007). Anthill soil has been used for many different purposes, including walkways with significant foot traffic and as foundation support for shelters (Kamau et al., 2020). Furthermore, the soil is used in the agricultural sector as a fertilizer and some pregnant women consume the soil to satisfy their cravings. Several houses in the Oshikoto and most other northern regions have huts or shelters constructed from the use of anthill soil as a supplementary building material (SBM). Anthill soil contains Naturally Occurring Radioactive Materials (NORMs) and the presents of these materials in large concentrations can result in radiological hazards. Traditional dwellings are the most common type of dwellings in the Oshikoto region. They make up 69.7 percent of the households in the region and about 42.2 percent of the rural households used sticks with mud, clay and cow dung (Namibia Statistics Agency, 2013), which is often associated with the use of anthill soil as a supplementary building material (SBM). A few people that reside in the rural areas of the region spend most of their time in shelters constructed with the use of anthill soils and are the very same people that contribute to the socio-economic development of the country. This study is the first of its kind in the country and will serve as a blueprint for future research purposes in the same field of study. In addition, the results of the research will be significant to the communities that use this soil for different purposes, as it will ascertain whether the use of anthill soil is safe. The main aim was to assess the radioactivity levels in anthill soil samples collected in the region. Hence, the research would be useful for various aspects such as environmental assessment companies, planners, and policymakers.

2. Materials and Methods

2.1 Description of the study area

The Oshikoto is a region located in the north-central part of Namibia and its one of the fourteen regions in the country. Omuthiya is the capital town of the region, and it is situated about 650 km from Windhoek. The town is the heart of the region and is often where most of the economic activities take place. The demographic population of the region was estimated at 161,007 in totality, with a population density of 4.2 persons per km^2, according to the Namibia Statistic Agency data of 2013. The region is made up of ten constituencies, as shown in Figure 1, with Onipa having the largest population statistics (Namibia Statistics Agency, 2013). The Oshikoto region is mostly flat with pockets of higher ground at the Otavi Mountain Range and the mountain at Halali near Etosha National Park (ENP). The most common rock types in the region are the Damara sandstones, Otavi dolomites and Nosib quartzite. The Northern Kalahari Sanveld covers the eastern part of the region, while medium textured, bleach or white Aeolian sands cover the north-central area of the region. The name of the region is derived from the Otjikoto Lake, which means “deep hole “in the Herero language ((Namibia Statistics Agency, 2013).

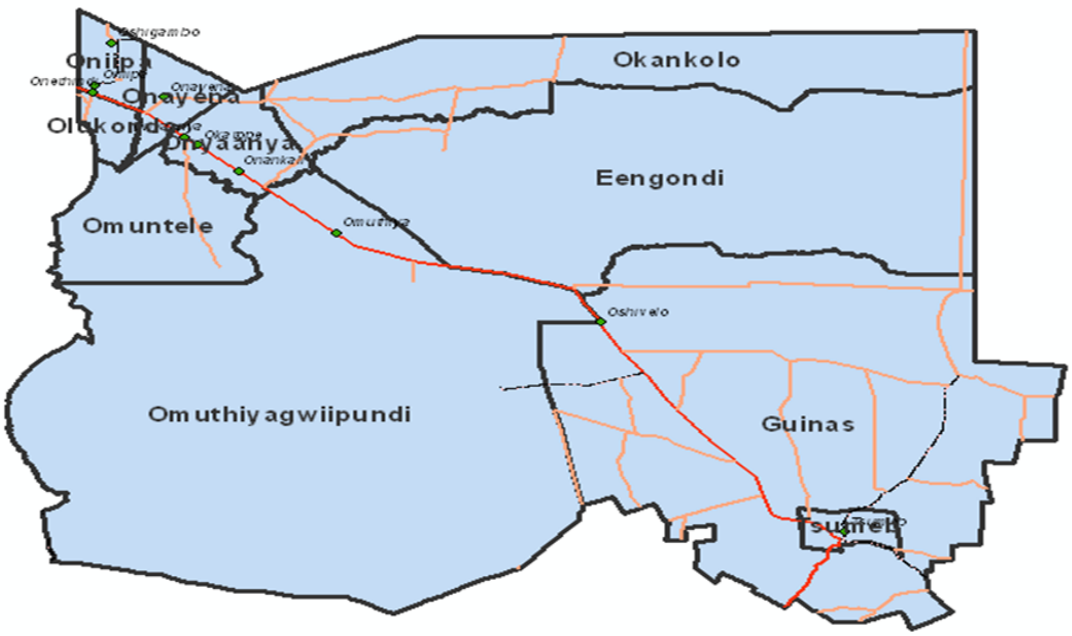

Figure 1: Map of Oshikoto region displaying the ten different constituencies and the main towns (Namibia Statistics Agency, 2013).

2.2 Sample collections

A total of twenty (20) anthill soil samples were collected from twenty geographical areas in the Oshikoto region as shown in Figure 2. The samples were randomly selected along the B1 road from areas with natural morphology, with Figure 3 showing an image of an anthill soil along the B1 road. The position of the different anthill soils where the samples were collected was clearly marked with a geographical position system (GPS).

Figure 2: Map showing the different geographical locations where the anthill soil samples were collected.

Figure 3: Anthill soil along the B1 road of the Oshikoto region.

2.3 Sample preparations

The samples were allowed to dry under laboratory temperature for 72 hours after collection to ensure that all the samples are moisture free. The samples were crushed, pulverized, sieved through a 2 mm sieve, and homogenized. The sieved samples were then oven dried for 12 hours to attain constant weight. Each soil sample with a mass of approximately 500g was carefully packed in a polythene plastic bottle. The samples were sealed hermetically to prevent emanation of ^{222}Rn and ^{220}Rn, this was done to attain secular equilibrium in the long-lived parent radionuclide with their short- lived progenies (Ameh, 2016). The sealed samples were stored for 720 hours (30 days) to allow ^{226}Ra, ^{222}Rn and their short-lived gamma emitting decay products (^{214}Bi and ^{214}Pb) to reach secular equilibrium before measurement via gamma-ray spectrometry.

2.4 Instrumentation and Calibration

The most cost-effective method of determining radionuclides in soil sediments is by using a high resolution, low-level gamma spectrometry technique with a HPGe detector. In simple terms, the radionuclides within the soils (or sediments) emit gamma photons at known energies (Building et al., 1991). The study was successfully completed by using a coaxial Canberra gamma-ray spectrometer with 45% relative efficiency and resolution of 2.00 KeV (FWHM) at 1.33 MeV peak of ^{60}Co and 1.200 keV (FWHM) at 122 keV that was made up of a preamplifier, amplifier, HPGe coaxial detector and a multichannel analyzer (MCA). The function of the MCA is to collect pulses in all voltage ranges at once and displays this information in real time as results or as data for further analysis (Herrmann & Bucksch, 2014). A Genie® 2000 software was used to analyze the spectra acquired in the measurements. The counting of each sample was carried out for 43200 seconds. Gamma lines of known energies were used to determine the relationship between channel numbers and gamma-ray energies. The gamma spectrometry system was energy and efficiency calibrated using a range of gamma-ray energies, ranging from 0.060 MeV to 2 MeV. This energy ranges were analyzed for absolute photo-peak efficiency and energy calibration of the HPGe detector using a multi-nuclide calibration standard with an initial activity of 40 kBq homogeneously distributed in silicone matrix, which was supplied by Eckert & Ziegler Nuclitec/GmbH, Germany, SN. AM 5599 and validated using IAEA NORM reference materials RGK-1, RGTh-1 and RGU-1 for ^{40}K, ^{232}Th and ^{238}U, respectively.

2.5 Determination of radionuclide activity concentrations and associated radiological health hazards

Every soil sample was counted for a period of twelve (12) hours and the data obtained was stored in a computer and the spectrum of each sample was analyzed by using known energies of the reference materials. Genie 2000 software was used for calculating the net peak areas in the spectrum. The obtained net peak areas were used to measure the activity concentrations of the samples. The activity concentration of each radionuclide in the soil sample was calculated by using the net peak area corresponding to the energy of interest. The analyses of the radionuclides from anthill soil samples were carried out based on the energy peaks of the progenies. The activity concentration for ^{226}Ra was estimated using 295.22 and 351.93 keV energy lines for ^{214}Pb as well as 609.31, 1120.29 and 1764.49 keV energy lines for ^{214}Bi. For ^{232}Th, the energy lines used were 238.63 keV for ^{212}Pb, 338.32 and 911.20 keV for ^{228}Ac. A single gamma energy line of 1460 keV was used for ^{40}K content evaluation.

2.5.1 Radiological health parameters

2.5.1.1 Absorbed dose (D)

The absorbed dose rate (nGy/h) in outdoor air, D, at 1 m over the ground was calculated using the equation below (UNSCEAR, 2000):

$$D = 0.462C_U + 0.604C_{Th} + 0.0417C_K \quad (1)$$

where, D is the absorbed dose rate in the outdoor air at 1.0 m above the ground (nGy/h), and C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K of soil samples in Bq/kg, respectively. The conversion factors used to compute absorbed dose rate (D) in air per unit activity concentration in Bq/kg (dry-weight) corresponds to 0.462 nGy/h for ^{226}Ra (of U-series), 0.604 nGy/h for ^{232}Th and 0.0417 nGy/h for ^{40}K (UNSCEAR, 2000).

2.5.1.2 Annual effective dose equivalent (AEDE)

The annual outdoor effective dose equivalent (AEDE) was calculated by considering the conversion coefficient from absorbed dose rate in air to the effective (0.7 Sv/Gy) and the outdoor occupancy factor 0.2 (UNSCEAR, 2000). The AEDE (μSv/y) can be calculated by using the equation below:

$$\mathrm{AED}E\ \left(\frac{\mu Sv}{y}\right) = D\ \left(\frac{nGy}{h}\right) \times 8760\mathrm{h} \times 0.7\,\frac{\mathrm{Sv}}{\mathrm{Gy}} \times 0.2 \times 10^{-3} \quad (2)$$

where D (nGy/h) is the absorbed dose rate, 0.7 Sv/Gy is the conversion factor used to convert the absorbed dose in air to effective dose received by the adult (Uosif et al., 2014), and 8760 h is the total time of the year in hours.

2.5.1.3 Radium equivalent activity (Ra_{eq})

The Radium equivalent activity is a radiological index that represents the activity levels of ^{238}U, ^{232}Th and ^{40}K as a single quantity, it considers the radiation hazards associated with each component (Diab et al., 2008). The most extreme rational value of Ra_{eq} must be 370 Bq/kg to be dependable, utilize with an effective dose of 1 mSv for the overall population (UNSCEAR, 2000). The Ra_{eq} (Bq/kg) is given by the expression:

$$Ra_{eq} = C_{\mathrm{Ra}} + 1.43C_{Th} + 0.077C_K \quad (3)$$

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

2.5.1.4 Internal (H_{in}) and External hazards (H_{ex}) indices

Two indices are used for the measurement of external and internal radiation hazards. The external hazard index (H_{ex}) is an index that evaluates the indoor radiation dose rate due to the external exposure to gamma radiation from the natural radionuclides in the construction of building materials for dwellings. To keep the radiation hazard insignificant the index value should be less than unity. The external hazard index is calculated using the equation,

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (4)$$

where, C_{Ra}, C_{Th} and C_K are the radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg of soil samples, respectively (UNSCEAR, 2000). The value of the external index must be less than unity for the radiation hazard to be negligible and this value corresponds to upper limit of Ra_{eq} of 370 Bq/kg (G. R. Gilmore & Wiley, 2011). Radon and its short-lived products are hazardous to the respiratory system of humans. The internal hazard index (H_{in}) quantifies the exposure to radon and its progeny by the equation,

$$H_{In} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

where C_{Ra}, C_{Th}, and C_K are the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg, respectively (G. Gilmore, 2011). The H_{in} should be less than unity for materials to be used safely for building construction (Iqbal et al., 2000).

3. Results and Discussion

An analysis on both radioactivity concentrations and radiological health hazards was performed in the study. Table 1 displays the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K obtained from the twenty (20) geographical locations.

3.1 Natural radioactivity concentrations in anthill soils

Table 1: Average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in anthill soils

Sample Code	Radionuclide Concentration [Bq/kg]		
	^{226}Ra	^{232}Th	^{40}K
AHS_01	7.47 ± 0.42	8.47 ± 0.30	107.81 ± 4.35
AHS_02	9.02 ± 0.39	9.23 ± 0.66	136.01 ± 4.56
AHS_03	6.04 ± 0.80	9.75 ± 0.59	160.75 ± 5.07
AHS_04	12.52 ± 0.40	18.65 ± 0.69	255.01 ± 6.69
AHS_05	6.14 ± 0.39	7.18 ± 0.29	127.85 ± 4.60
AHS_06	14.24 ± 0.42	11.09 ± 0.60	188.16 ± 5.52
AHS_07	9.20 ± 0.49	9.25 ± 0.31	174.76 ± 5.35
AHS_08	10.50 ± 0.44	25.43 ± 0.62	243.38 ± 6.39
AHS_09	10.63 ± 0.39	11.12 ± 0.62	157.03 ± 5.05
AHS_10	10.30 ± 0.44	9.30 ± 0.60	158.90 ± 5.01
AHS_11	7.69 ± 0.39	6.69 ± 0.28	105.43 ± 4.29
AHS_12	4.86 ± 0.40	7.01 ± 0.44	112.61 ± 4.34
AHS_13	7.32 ± 0.41	11.56 ± 0.84	197.55 ± 5.54
AHS_14	5.69 ± 0.35	6.72 ± 0.28	162.32 ± 5.27

AHS_15	5.84 ± 0.40	10.90 ± 0.33	105.48 ± 4.14
AHS_16	6.06 ± 0.38	10.15 ± 0.56	84.68 ± 4.02
AHS_17	8.47 ± 0.37	11.51 ± 0.33	176.44 ± 5.32
AHS_18	6.95 ± 0.47	15.24 ± 0.38	246.44 ± 6.33
AHS_19	4.62 ± 0.42	10.40 ± 0.58	144.10 ± 4.71
AHS_20	6.55 ± 0.37	11.47 ± 0.34	141.86 ± 7.19
Minimum value	4.62 ± 0.42	6.69 ± 0.28	84.68 ± 4.02
Maximum value	14.24 ± 0.42	25.43 ± 0.62	255.01 ± 6.69
Average of all samples	8.01 ± 0.43	11.75 ± 0.48	159.33 ± 5.19

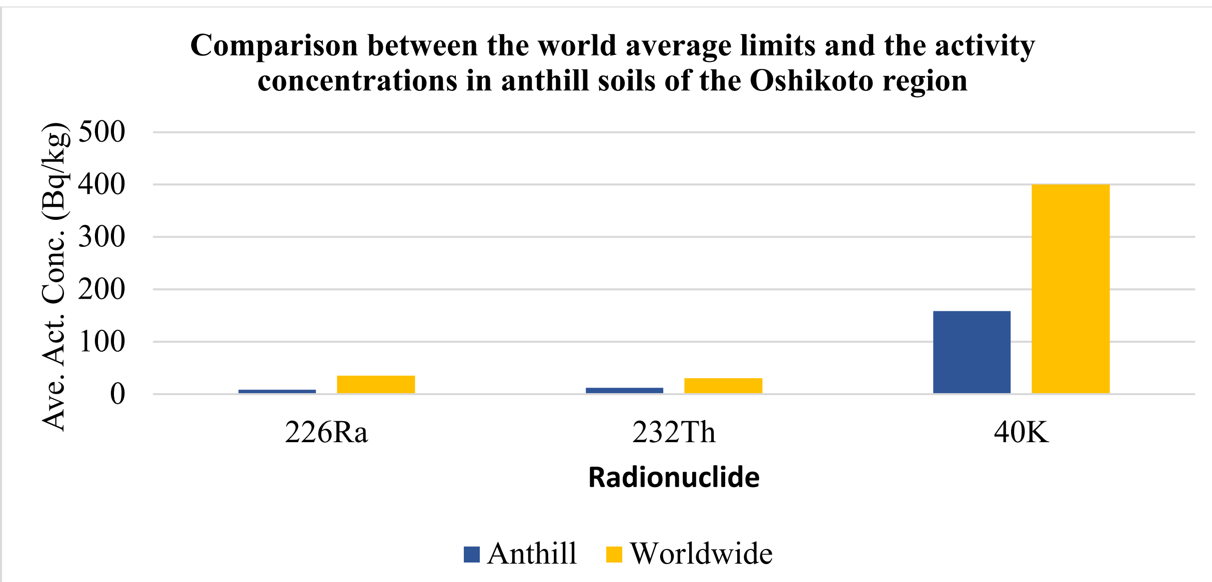

Figure 4: A comparison between the world average limits and the average concentrations of the anthill soils.

The highest concentration of ^{226}Ra was 14.24 Bq/kg obtained from the geographical location (18°03’05” S, 16°14’03” E) and the minimum was 4.62 Bq/kg from the geographical location (18°23’51” S, 16°37’55” E). The highest activity concentrations for ^{232}Th and ^{40}K were 25.43 Bq/kg and 255.01 Bq/kg whilst the minimum concentrations were 6.69 Bq/kg and 84.68 Bq/kg. Amongst all the average concentration, ^{226}Ra was the lowest while ^{40}K had the highest average concentration as shown in Table 1. Hence, the average radioactivity concentrations are given by the relation: ^{40}K >^{232}Th >^{226}Ra. This is a common pattern observed in most of the Western parts of the country, including, Walvis Bay, Usakos, Swakopmund, and Wlotzkasbaken, to name a few.

Additionally, this pattern has also been observed in other African nations, like Egypt (Al-Sharkawy et al., 2012). However, radioactivity concentrations from ^{40}K of the present study is comparatively low compared to the aforementioned locations. Furthermore, the distribution of radionuclides in the region's soil is not uniform, as indicated by the average radioactivity concentration of ^{232}Th in certain sites (e.g, AHS_08) being more than twice that of others (e.g., AHS_14).

The average activity concentrations of all three radionuclides are lower than the average value. This implies the background radiation in the Oshikoto region is normal. According to UNSCEAR report of 2000, the world average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are 35, 30 and 400 Bq/kg, respectively. The average activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K for the study were 8.01, 11.75 and 159.33 Bq/Kg, respectively. Figure 4 displays the comparison between the radionuclides of interest to the world limit of exposure per year. The low concentration of ^{232}Th in the present study may be attributed to the low content of monazite (Örgün et al., 2007). The activity concentration level of ^{40}K is attributed by the presence of loamy and clay sediments (El-Gamal et al., 2007).

3.3 Assessment of the radiological health hazards in the anthill soils

Radiological health hazards are determined from the measurement of natural radioactivity concentrations determined in samples. The radiological health parameters in this study were determined from the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K radionuclides. Five (5) radiological health parameters (absorbed dose rate, annual effective dose, radium equivalent activity, external hazard index and internal hazard index) were calculated to assess the radiological health hazards to humans due to natural radionuclides present in anthill soils. The highest absorbed dose rate observed at 1 m above the ground for the samples was 30.36 nGy/h as shown in figure 5. The average value of the absorbed dose rate was 17.02 nGy/h. Compared to a few studies in Namibia on the amount of radiation in the soil, the current study's absorbed dose had the lowest average dose, as shown in figure 10. The average limit for Ra_{eq} was 36.60 Bq/kg. Figure 6 presents the Ra_{eq} for the twenty (20) anthill soil samples in the Oshikoto region. The average value of Ra_{eq} calculated is lower than the world average maximum admissible value of 370 Bq/kg (Joshua et al., 2009). The average limit of the annual effective dose of the 20 samples was calculated to be 0.02 mSv/y. This value was below 1 mSv/y set by the International Commission on Radiological Protection (ICRP) for the public (Protection, 2003). A comparison between the annual effective dose for the study and the world limit of exposure is presented in figure 7. The average value for the internal hazard index was 0.12. A comparison between the internal hazard index from the study and the world limit of exposure per year is presented in figure 8. The average value for the internal hazard index was approximately 8.3 times less than unity. The external hazards index (H_{ex}) values ranged from 0.06 to 0.18, with an average of 0.10. In addition, the individual external hazard indices of the twenty (20) anthill soils were compared with the world limit of exposure as presented in figure 9.

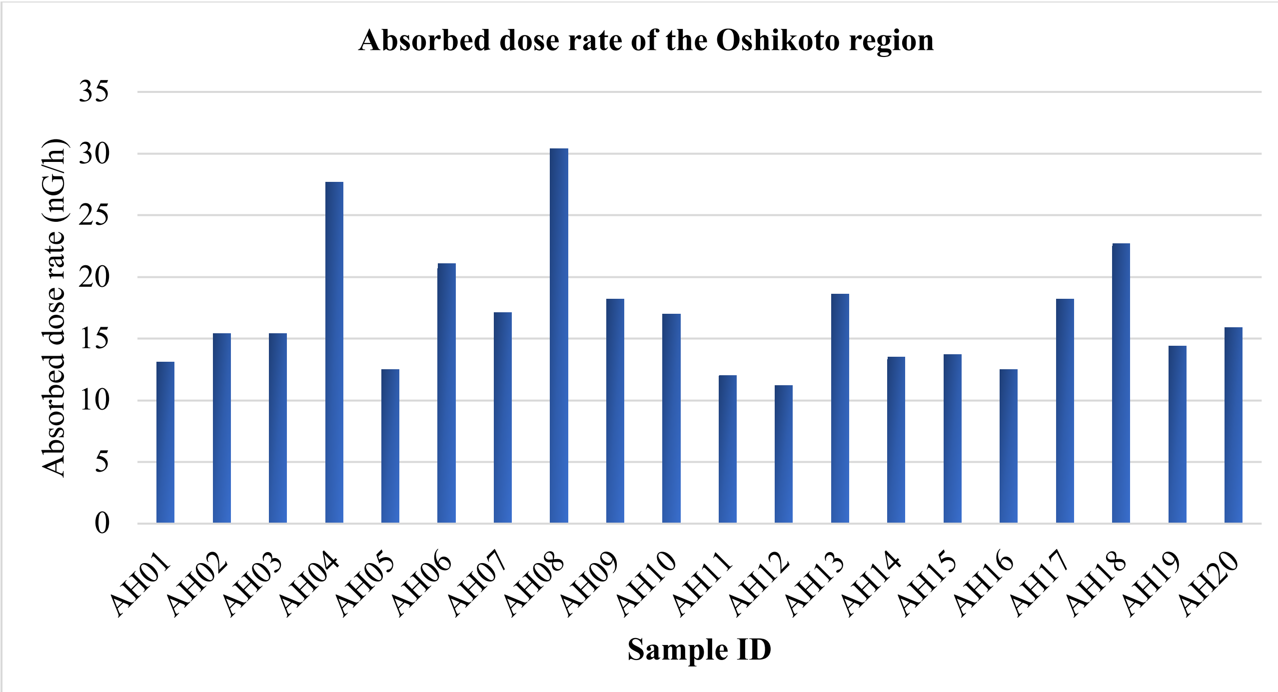

Figure 5: Absorbed dose rate in the 20 anthill soil samples.

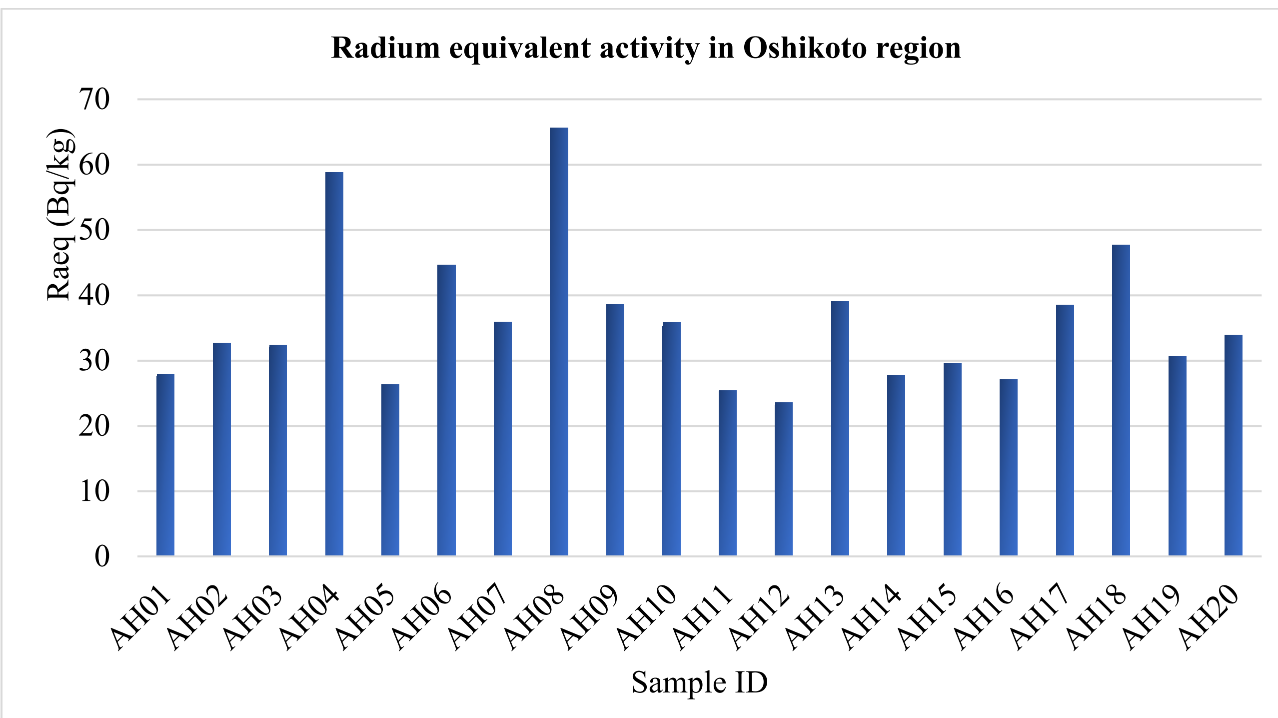

Figure 6: Radium dose equivalence for Oshikoto region.

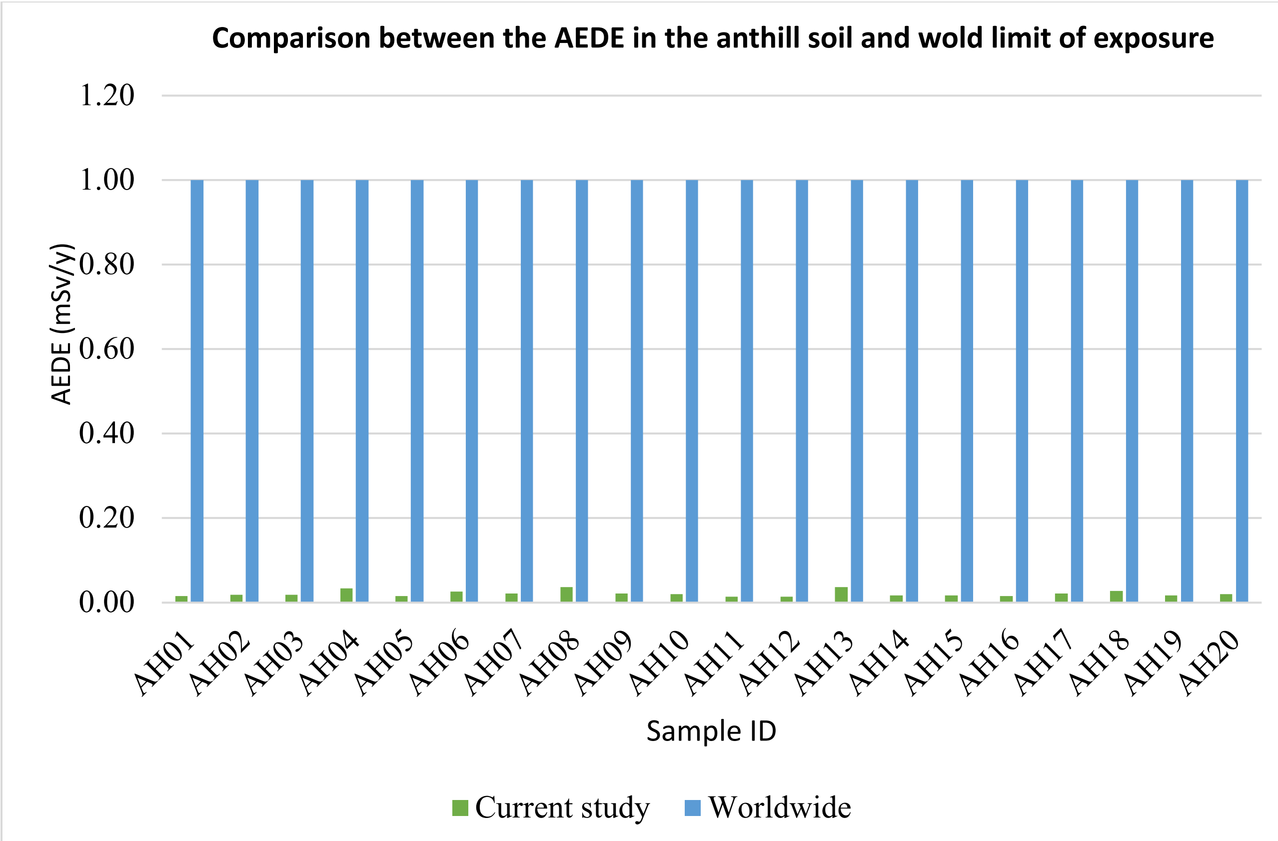

Figure 7: Comparison between the AEDE from anthill soils and the world limit of exposure.

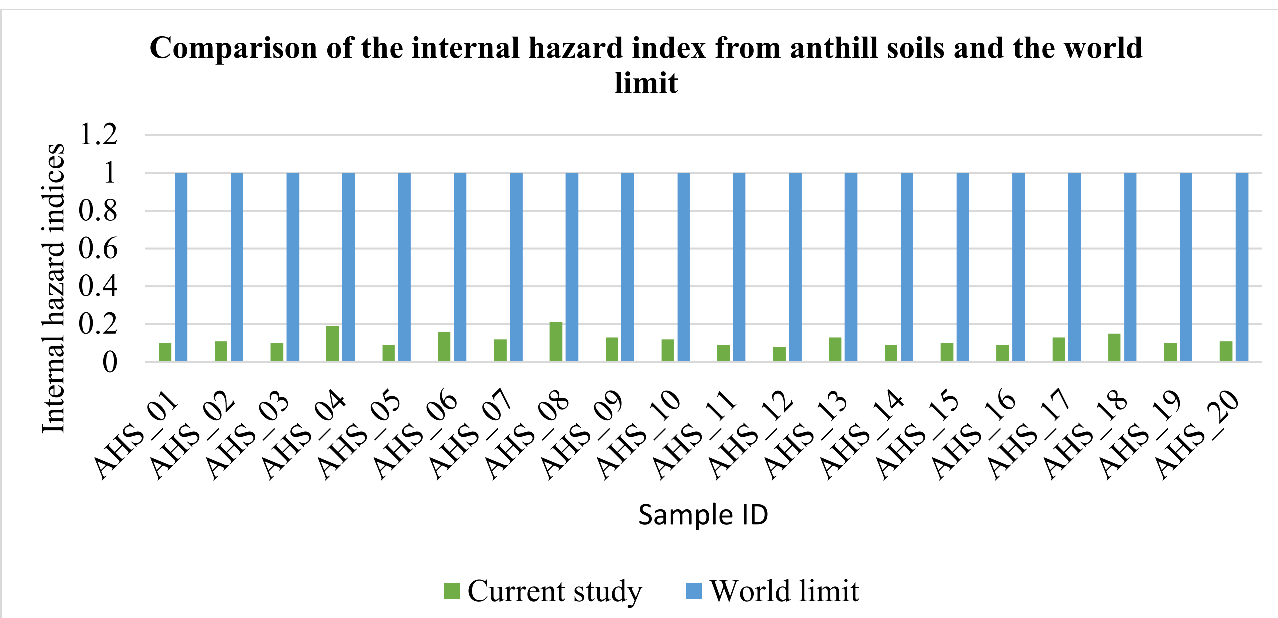

Figure 8: Comparison between the internal hazard index from anthill soils and the world limit of exposure.

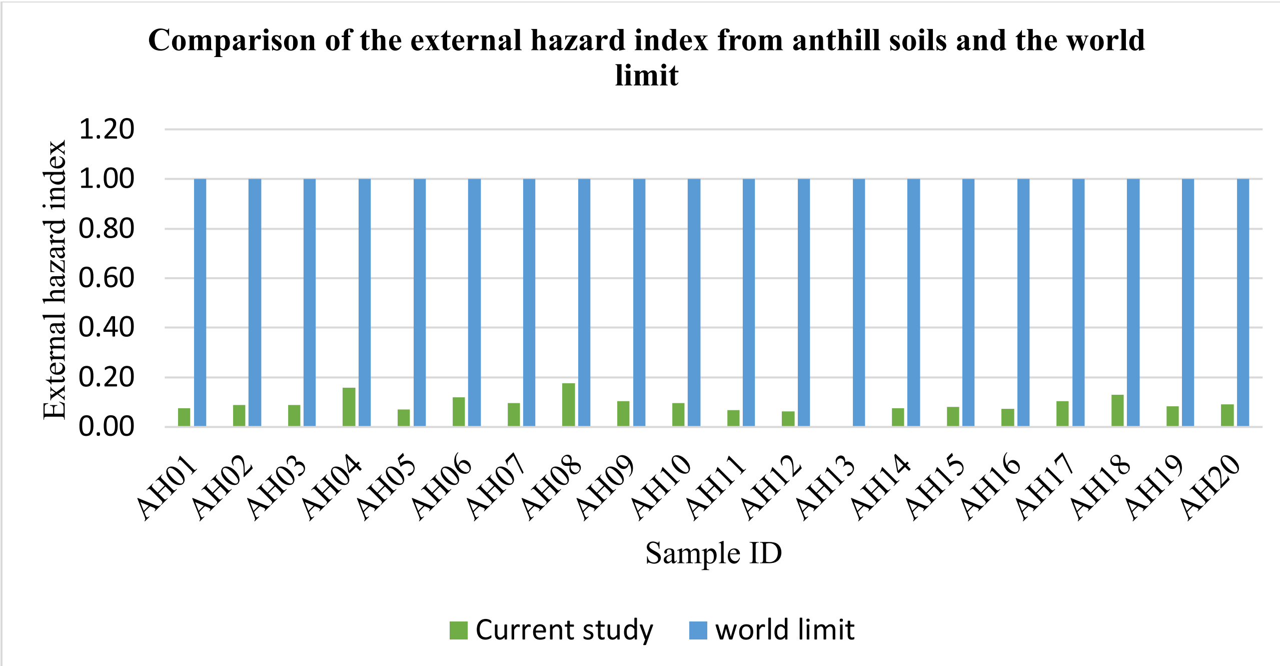

Figure 9: Comparison between the external hazard index from anthill soils and the world limit of exposure.

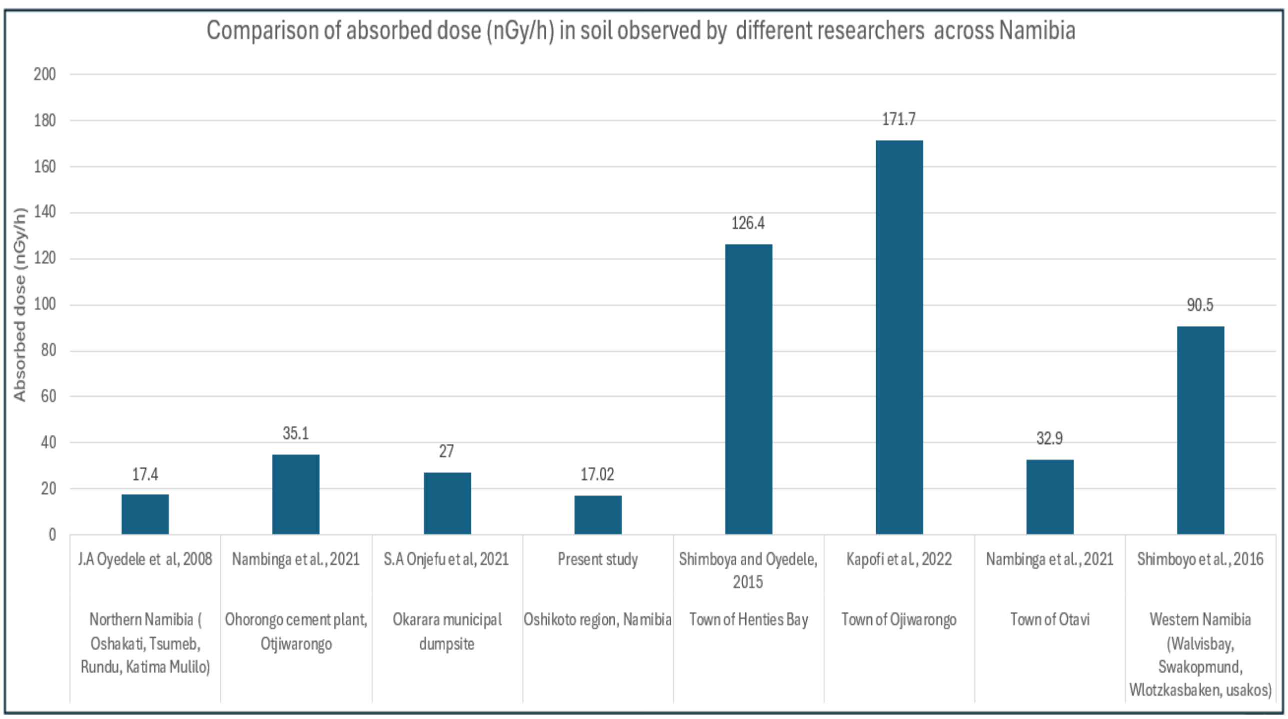

Figure 10: Comparison of different average absorbed dose rates observed in soil by different studies in Namibia.

4. Conclusion

The radioactivity concentration levels in the anthill soil samples were successfully determined by using a low-level gamma spectroscopy technique. The activity concentrations of ^{238}U were below the detectable limit of the gamma spectrometer, hence the daughter nuclei ^{226}Ra was used to quantify ^{238}U, assuming the existence of secular equilibrium. The average activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K were 8.01, 11.75 and 159.33 Bq/kg, respectively. All the averages of the radionuclides were below the world limit due to exposure per year. The absorbed dose rate of the soil was approximately three times lower than the global average. Also, we can conclude that the amount of dose absorbed per organ, or tissue is relatively low and the background radiation of the Oshikoto region is below the maximum permissible limit. Furthermore, the results from the external and internal hazard indices show that the external exposure of humans due to radiation is negligible and that the use of the soil as a supplementary material for building construction is safe since both indices were below unity.

Lastly, long-term monitoring should be promoted even though the current levels are safe to identify any future changes brought on by anthropogenic or natural factors (such as mining or industrial operations). Local people can be informed about radioactivity in soil by government agencies and environmental associations, which can also raise awareness of possible contamination sources while reaffirming that measured levels are safe.

Future research could concentrate on anthill soils in areas prone to high radioactivity concentrations, as well as analyze additional health factors such as Excess Lifetime Cancer Risk (ELCR).

Acknowledgement

Firstly, we will love to thank God for giving us the strength and opportunity to complete the project. In all sincerity this project would not have been possible without his grace and mercy. A special thanks to Namibia University of Science and Technology (NUST) for providing us with the gamma spectrometer to run and analyze the radioactive samples.

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