

FULL PAPER

Evaluation of Natural Radioactivity in Soil Samples from Western Darfur District-Sudan

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Abstract

The objective of this research is to assess levels of naturally occurring radioactivity in soil samples collected from Jebel Mun in Western Darfur, Sudan. A total of 46 sample sites were read using a Radex meter (RD1706), and approximately 45 samples were investigated using Gamma-Ray spectroscopy with a high-purity Germanium (HPGe) detector. The survey meter measured the background ionizing radiation level in microsieverts per hour. The fallouts of the study exhibited that the reading detected by survey meter 0.06 to 1.60, while Annual Equivalent Dose (AED) 0.11 to 9.81 and average values was 1.90 mS/yr, whereas Annual effective Dose Rate (AEDR) revealed 0.53 to 14.0 Ms/yr the showed several location with notable 32 of sites exceeding recommended safety limits established by the International Commission on Radiological Protection (ICRP) 1 mSv/yr. The activity concentration of radionuclides was only 45, as analyzed by HPGe. The outcomes displayed that the activity concentrations of ^{232}Th , ^{226}Ra , and ^{40}K were 24.7 to 283 Bq/kg, 18.3 to 273 Bq/kg, and 278.0 to 1820 Bq/kg, respectively. The calculated findings of the radiological risk Annual Dose rate Affective absorbed dosage level under atmospheric conditions are highest in the other regions (ADRA), which was recorded 40.2 to 372 nGy-h⁻¹, Radium equivalent activity (Req) was 18.3 to 273 Bq/kg the results exhibiting four sites above the United Union Scientific for Exposure Atomic Radiation (UNSEAR) 370. In contrast, the Hazards external and internal are recorded as 0.23 to 2.18 and 0.28 to 2.92, respectively. Therefore, eight sites exceed the ICRP limit by more than 1. Finally, the Gamma index in the study areas, which comprises about thirty-three sites, is higher than the limit of one.

Key words: Natural radioactivity, soil Samples, Gamma-ray spectroscopy

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Introduction

Natural radioactivity contributes significantly to ionizing radiation in the human population due to its presence in the surroundings in varying quantities, resulting from its natural occurrence. This presence is part of the natural background radiation that surrounds the world population with varying amounts of radiation (Daniel et al., 2018; Y. Raghu et al., 2015). The radionuclide is responsible for broad-scale population exposure. The exposure to cosmic rays strongly depends on the radionuclide concentrations of series such as ^{238}U , ^{232}Th , their progenies, and ^{40}K , which, representing 70% of the sources, in turn

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depend on the geological and geochemical formations of the regions (Darko et al., 2011). The Environment as a source of ionizing radiation dose to major organs has been studied for many years, including soil, rocks, flora, food, water, and even air. (Al-Alawy et al., 2018; Ahmad et al., 2015). The gamma rays are released by naturally occurring radioactive materials related to ^{40}K and radioactive elements from the ^{232}Th and ^{238}U families, together with their breakdown products, which are present in small quantities in the soils of various regions worldwide (Montana et al., 2018; Al-Ma et al., 2006). The primary source of pollution to the Environment from radioactive and synthetic dust in the air stemmed from nuclear device testing and reactor incidents, notably the Three Mile Island accident in 1979 and the Chernobyl disaster in 1986. The uncontrolled dissemination of substantial quantities of radioactive particles into the surrounding atmosphere continues, causing extensive spread in the air and deposit on soil. (Sajih, 2010). However, this area is affected by flow-out resulting from nuclear incidents, and approximately 10 samples of caesium-137 and caesium-134 artificial nuclides were detected in soil samples during the project titled "Evaluation of natural radioactivity and determination of concentration of some elements around Jebel Mun in Western Darfur" (H. A. A. Amin, 2012). The project's primary goal is to establish a baseline table for monitoring radioactive levels in topsoil.

2. Components and Techniques

2.1 Geographical Overview

The research site is situated in the western Darfur region. The region's geography is characterized by basalt and syenite breaches, which are significant characteristics associated with circular obstacles, dike swarms, and Nubian sedimentary deposition (Adam Sam., et al., 2002).

2.2 Gathering and Processing of Samples by Radex (RD1706) Meter

Seventy-four soil specimens were collected from diverse places throughout the research region. The names of sampling locations and coordinates were documented using GPS. Measurements of exposure level were carried out using a Radex 1706 radiation survey meter, which measured the radiation absorbed dose rate in microsieverts per hour ($\mu\text{Sv/h}$). The meter was switched on and allowed to absorb radiation for a few seconds, and the meter read at the high, stable point (Essien, I.E., et al., 2016). The radiation meter was placed at ground level, with its window directed towards the different piles of waste material. Table 1 presents the chosen sampling locations, GPS coordinates, Annual Equivalent Dose (AED) and Annual Effective Dose Rate (AEDR), which were subsequently converted to a yearly functional dose in mSv/y .

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2.3 Soil samples preparation and measurement by gamma spectroscopy

Before taking the samples, the uncultivated field was sampled, and sampling stations were chosen in populated areas. At each sampling point, the moisture content of the soil surface was removed using a tap, and then soil samples were taken to a depth of 25cm by means of a stainless steel sampler. Coordinates were recorded using GPS. All soil samples were sun-dried and then crushed into a fine powder utilizing a grout. The soil sample size was to be ground into powder and homogenized by passing it through a 1mm mesh size (100 μm). Sample weight: 500 gm. The homogenized samples were transferred to Mariella beakers and sealed in 500 ml bottles, and then left for more than one month to allow secular equilibrium between thorium $^{228}\text{Th}/^{208}\text{Tl}$ within the ^{232}Th series and their products (Hamdi, A.A. Amin, 2021).

2.4 Radiometric Analysis by Gamma-ray spectroscopy (HPGe)

Gamma-ray spectrometry is the quantitative analysis of the radiation bands emitted by gamma-ray sources, with applications in nuclear power generation, geological research, and astronomy. The activities of ^{232}Th , ^{226}Ra , and ^{40}K in soil samples were measured using a high-resolution gamma spectrometer with a high-purity germanium detector (HPGe). The detector was calibrated concerning energy efficiency and resolution using an Amersham mixed radionuclide standard. ^{232}Th was analyzed through photo peaks ^{228}Ac (911 keV) and ^{208}Tl (583 keV). The activity of ^{226}Ra was determined by measuring the progeny photo peaks of ^{214}Bi (609 keV) and ^{214}Pb (352 keV). At the same time, the activity of ^{40}K was calculated at (1461 keV). Locally prepared Meri standard (rock samples from high background area in the Nuba Mountains, A.K.S. and N. Abbas, 200).

2.5. Quality control Measures

The following quality control measure was implemented:

Energy calibration: The energy calibration was performed utilizing a mixed radionuclide standard.

Efficiency calibration: The efficiency calibration was applied using a mixed radionuclide standard.

Background measurement: The background measurement was performed regularly to ensure that the detector was not contaminated.

Duplicate analysis: Duplicate analysis was performed to ensure the accuracy and precision of the results.

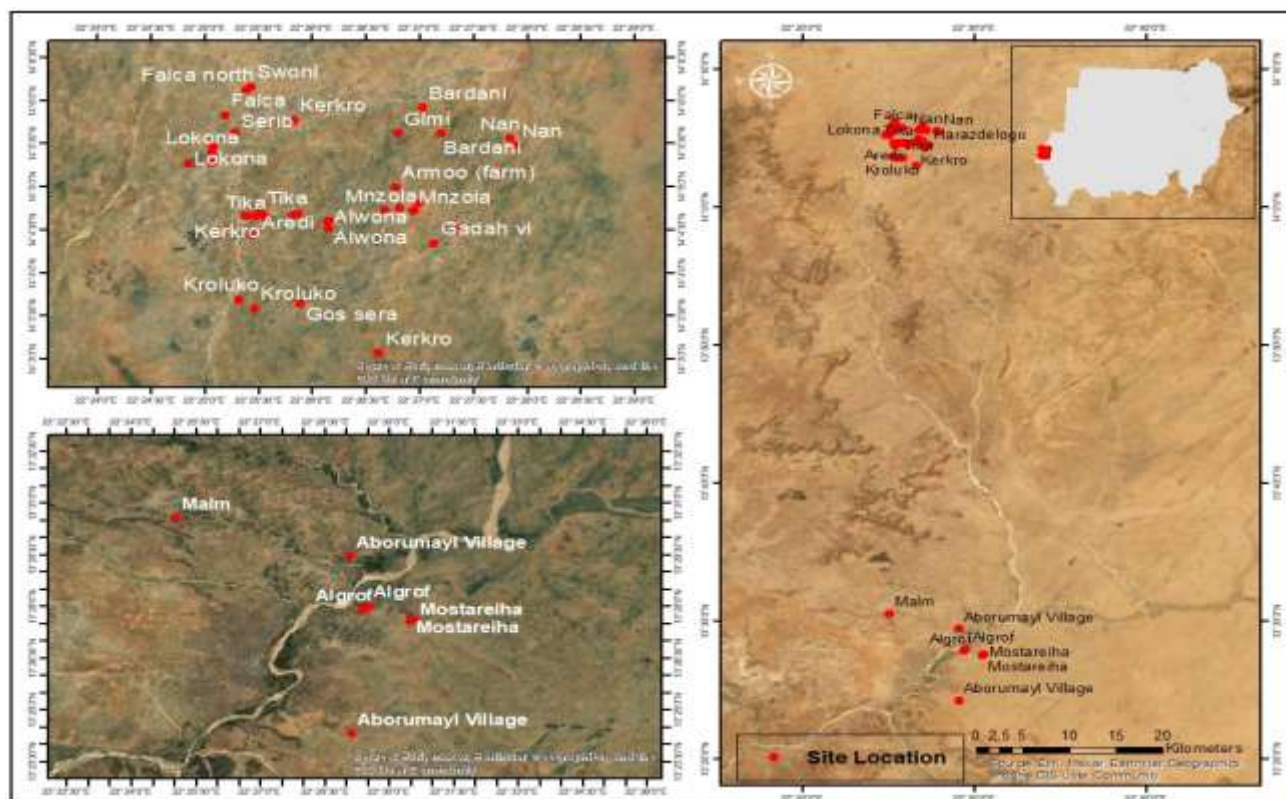


Figure 1: Soil sample location of radionuclides by RD and Gamma spectroscopy Jebel Mun areas

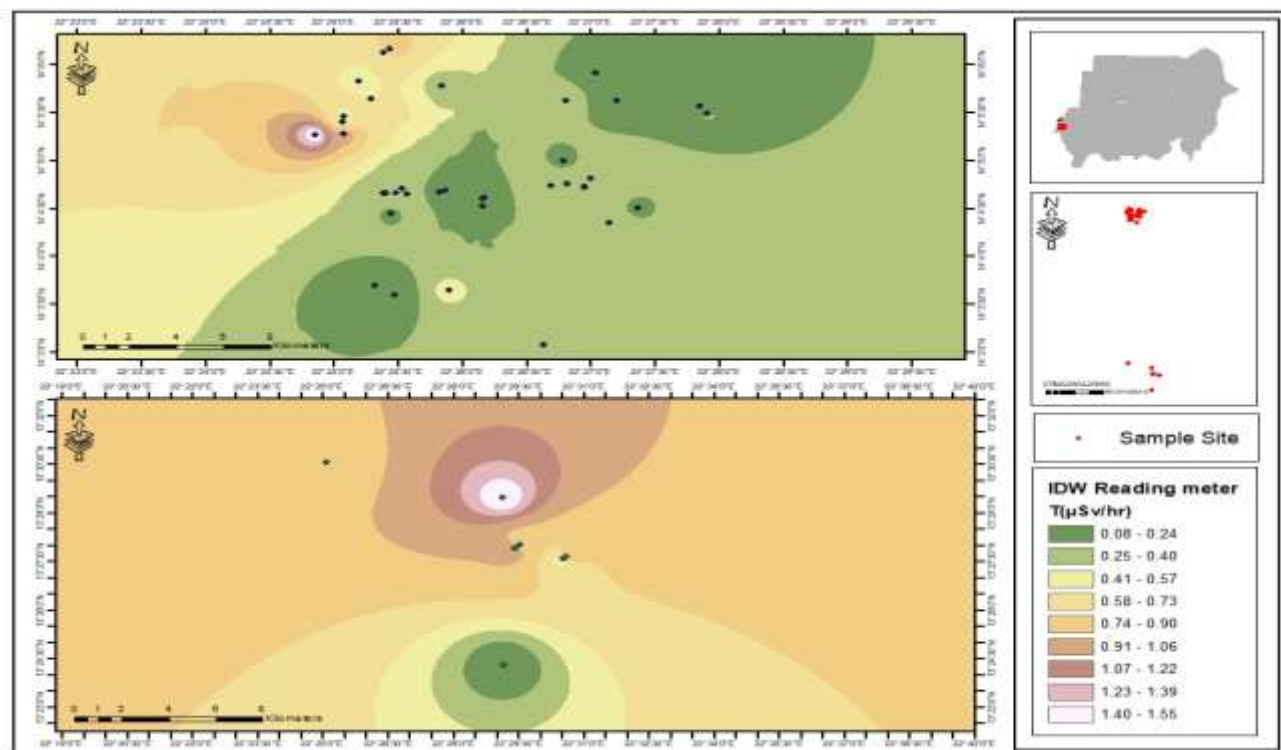


Figure 2: RD1706 Reading meter survey of Background Radiation

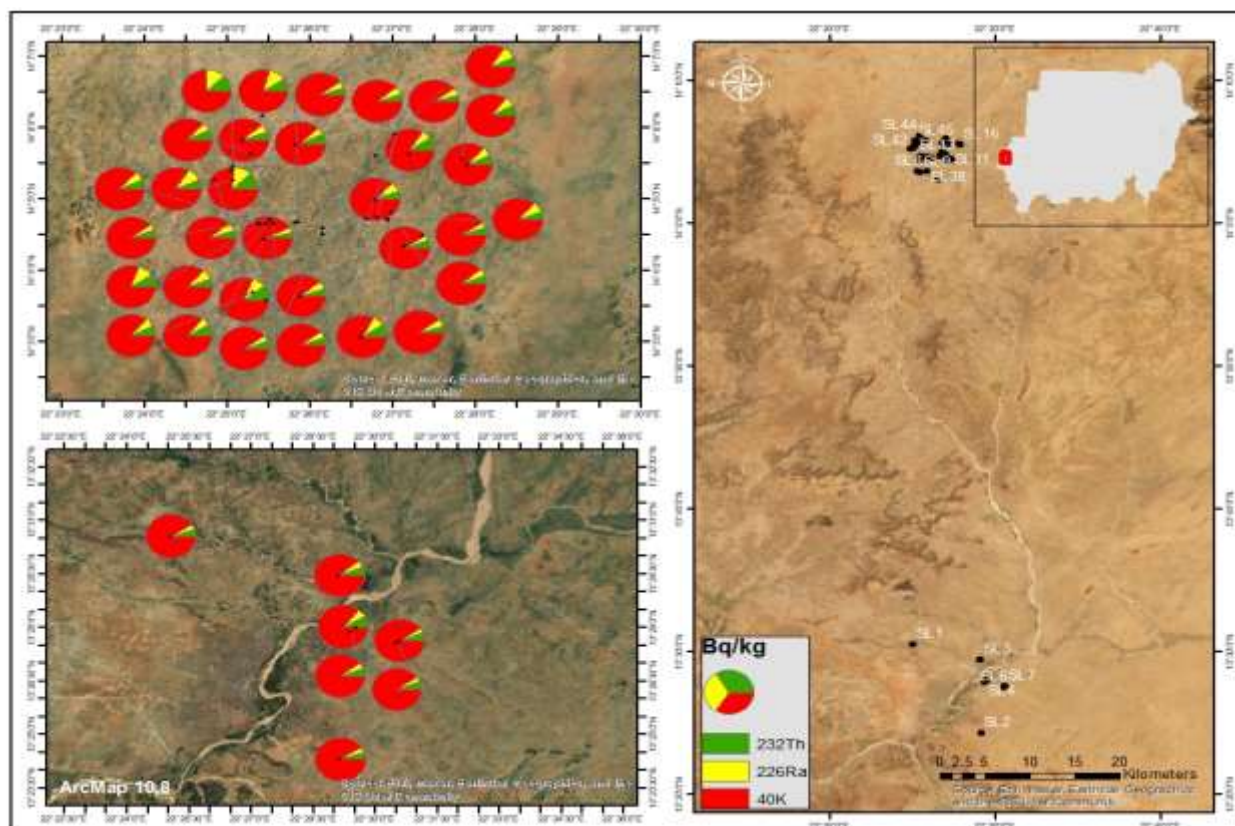


Figure 3: distribution of ^{232}Th , ^{226}Ra and ^{40}K radionuclides in study area.

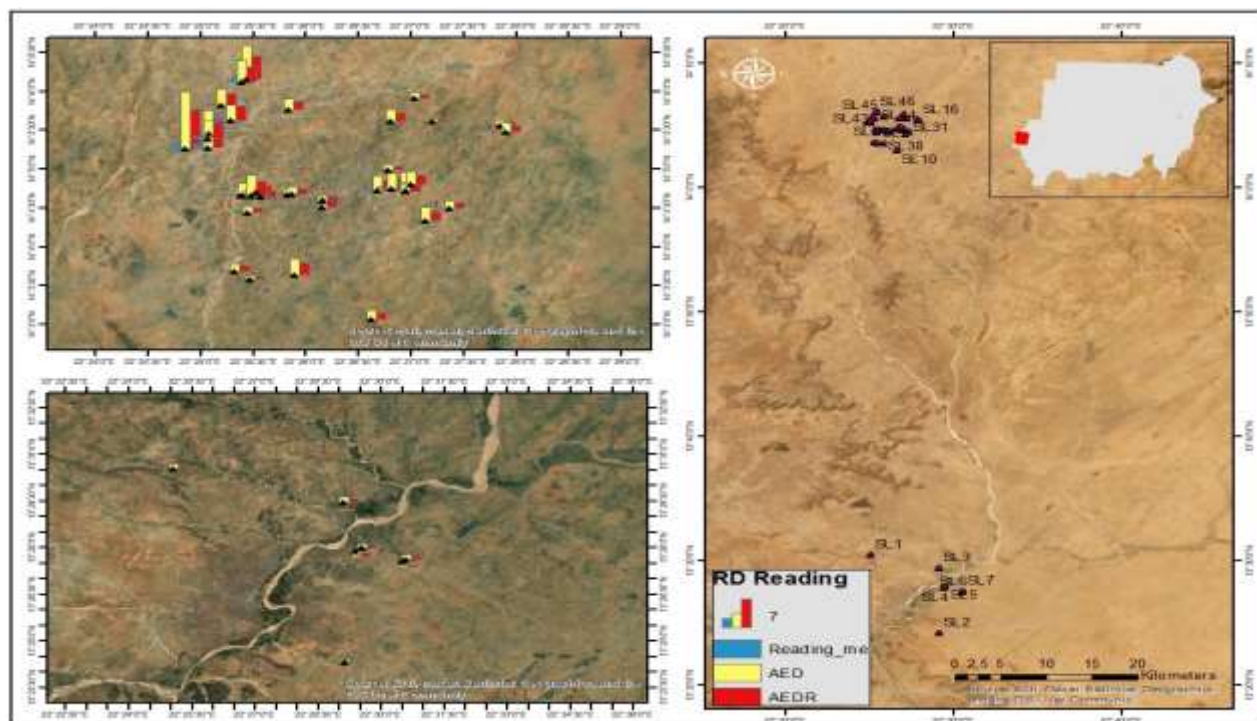


Figure 4: Annual equivalent dose and absorbed dose rate distribution

3. Theory Concepts

3.1. Annual Equivalent Dose (AED) by RD Survey meter 1706 AED (mSv/y) = the corresponding of meter readings in hours to years were done using equation 1.

3.1.2 Annual effective Dose Rate (AEDR)

$$T = (\mu\text{Sv/hr}) * 24 * 365 / 1000 \quad (1)$$

Conversion factor from equivalent dose to effective dose rate using $\text{AED} \times 0.7$

3.2 Absorption Radiation Level in Air

The amount of outside land gamma radiation has been established based on the radioactive concentrations in the ground. Using equation (2), the gamma dose absorbed amount in the atmosphere is determined depending on the radionuclide quantities of ^{226}Ra , ^{232}Th , and ^{40}K .

$$\text{ADRA} = 0.461 \times \text{ARa} + 0.623 \times \text{ATh} + 0.0417 \times \text{AK} \quad (2)$$

Where ARa, ATh, and AK are the vitality realization (Bq/kg) of ^{226}Ra , ^{232}Th , and ^{40}K unconnectedly in the sand sample (Kapdan, E., et al, 2011).

3.2.1 Yearly Average Amount Calculated from HPGe (YAA)

The quantity of absorbed energy must be quantified to assess the adverse effects on the individual. An absorption coefficient of 0.7 Sv Gy^{-1} is used to translate the inhaled air quantity into the actual dosage received by humans, utilizing an external utilization proportion of 0.2 and an internal value of 0.8, by equation 3.

$$\text{YAA (mSv/yearly)} = \text{Absorbed dose (nGy-h}^{-1}) \times 8760 \text{ hr}^{-1} \times 0.2 \times 0.7 \times 10^{-6} \quad (3)$$

D (nG/h) represents the entire external fresh air received dosage level; 8760 h denotes the whole hours in a single year; 0.2 signifies the external usage take; 0.7 Sv Gy^{-1} is the transformation ratio from consumed air dosage to the real quantity received by older people; and 10^{-6} is the ratio of change in nonmetric and mill metric measures (Alzubaidi, Hamid., et al, 2016).

3.2.2 Radium equivalent activity (Ra_{eq})

The health risk is linked to natural radioactivity in soil utilized as construction materials. The threat index (Ra_{eq}) was used to evaluate the consistency of specific actions in substances having varying quantities of ^{226}Ra , ^{232}Th , and ^{40}K . Generate a corresponding nuclear dosage level to the radium activity. The Ra equivalent can be determined using equanimity 4.

$$\text{Raeq} = \text{ARa} + 1.43 \times \text{ATh} + 0.077 \times \text{AK} \quad (4)$$

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ARa, ATh, and AK are energy levels in ^{226}Ra , ^{232}Th , and ^{40}K in Bq/kg correspondingly. The radium' identical effectiveness originated on the precision concentration overtakes 370 Bq/kg, and it is disheartened to stay away from radionuclide danger (Blanchard et al, 2017).

3.2.3 Exterior and Interior Danger Index (Hex , H in)

A commonly used risk score (representing external and internal threat indicators) is called the External Threat Index Hex. The external hazard index is an assessment of the hazard posed by natural gamma radiation, specifically from ^{226}Ra , ^{232}Th , and ^{40}K . The subsequent equation describes a normal radionuclide. (Taiwo A. O., et al, 2014).

$$\text{Hex} = (\text{ARa}/370) + (\text{ATh}/259) + (\text{AK}/4810) \leq 1 \quad (5)$$

The worth of Hex must be smaller amount than one of radiation danger $\text{Hex} \geq 1$. Usually, the maximum value of Ra_{eq} (370 Bq/kg) (Abu Samreh., et al, 2014). The interior hazard index (Hin) can be calculated by equanimity 6.

$$\text{Hin} = (\text{ARa}/185) + (\text{ATh}/259) + (\text{AK}/4810) \leq 1 \quad (6)$$

wherever ARa, ATh, and AK are radioactivity concentrations in Bq.kg^{-1} correspondingly. The number measured must be below one for the nuclear hazard. $\text{Hin} \geq 1$ (Almashadani, 2014).

3.4 Radioactivity level index

The subsequent equation determines the assessed radiation risk index, known as the analogous value index, I_{γ} .

$$I_{\gamma} = \frac{\text{CRa}}{150 \text{ Bqkg}^{-1}} + \frac{\text{CTh}}{100 \text{ Bqkg}^{-1}} + \frac{\text{CK}}{1500 \text{ qkg}^{-1}} \leq 1 \quad (7)$$

CRa , CTh , and CK have the particular behavior of ^{226}Ra , ^{232}Th , and ^{40}K in Bq/kg, individually (Al-Trabulsy., et al, 2011).

4. Results and discussions:

4.1 Summarized survey meter radix (RD1706 and outdoor effective dose

Table 1: summarized survey meter reading in soil location detected between 0.06 and 1.60 $\mu\text{Sv/hr}$, with an average of 0.31 $\mu\text{Sv/hr}$. At the same time, Annual Equivalent Dose (AED) was 0.53 to 14.0 mSv/yr, and average value 0.54mSv/yr, whereas Annual Effective Dose Rate (AEDR) was 0.11 to 9.81 mSv/y and average 1.90 mSv/yr. However, about 32 sites were observed to exceed the ICRP limit of 1 mSv/y (ICRP 2007). Figure 5 displays the level of Annual Effective Dose compared by ICRP.

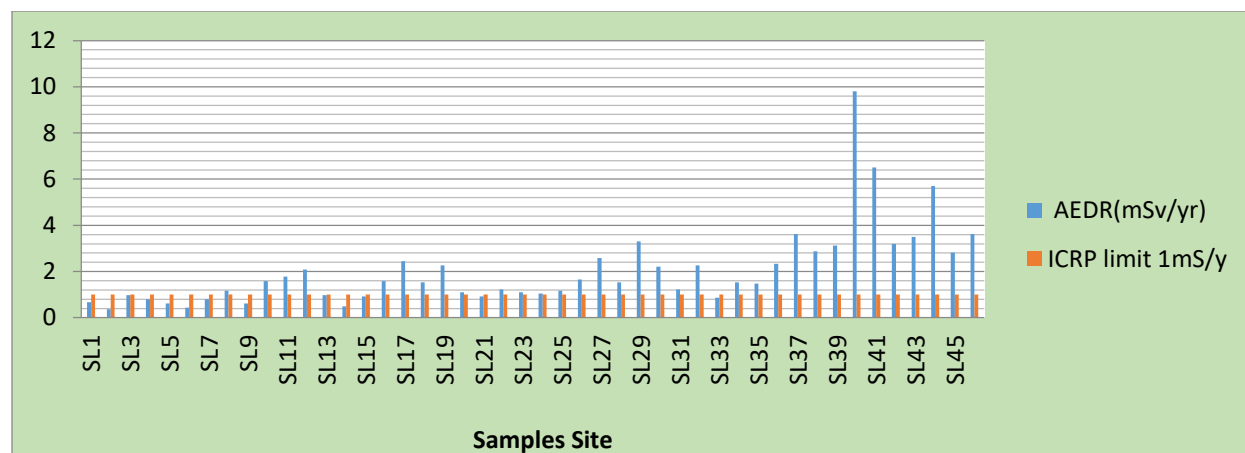


Fig 5: Annual Effective Dose Rate compared to ICRP

4.2 ^{226}Ra , ^{232}Th , and ^{40}K activity levels in samples

The activity concentrations of ^{232}Th , ^{226}Ra , and ^{40}K in soil specimens diversified from 24.7 to 283 Bq/kg, 18.3 to 273 Bq/kg, and 278.0 to 1820 Bq/kg, with average values of 66.1, 63.8, and 818.1 Bq/kg for ^{232}Th , ^{226}Ra , and ^{40}K , respectively. Individually, Table 2 demonstrates the activity levels of radionuclides. Therefore, the results achieved in this study exceed the average value published for the southern and western regions of Sudan, Marrah Mountain and South Kordofan (Ahmed, 2016; Amana, 2016; Hajo, 2016; Fadoletal, 2015) and are also comparable to the corresponding levels obtained worldwide, as presented in Table 5. Figure 6 displays the average activity concentrations of radionuclides ^{232}Th , ^{226}Ra , and ^{40}K .

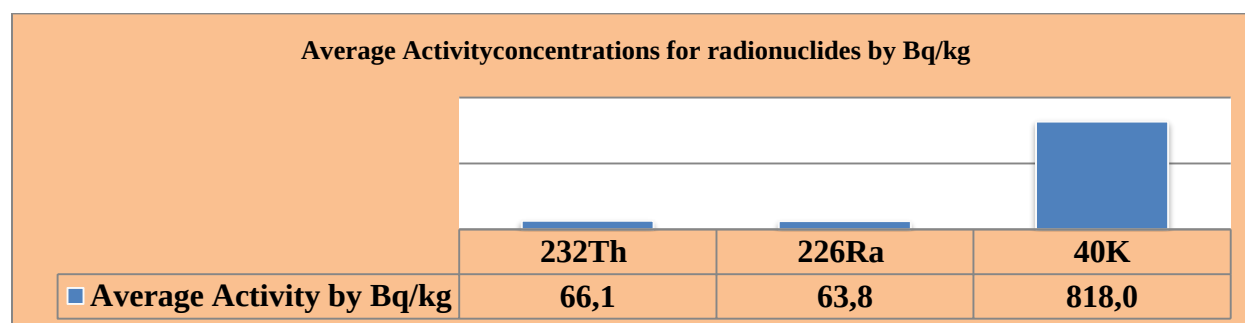


Figure 6: Average concentration activity between radionuclides ^{232}Th , ^{226}Ra , and ^{40}K

4.3 Radiometric parameters

4.3.1 Absorbed dosage level under atmospheric conditions

This study's absorbed dosage level under atmospheric conditions is the highest in other regions of Sudan, such as the Elgash area at 37.5 nGyh^{-1} and Sinnar at 38.80 nGyh^{-1} . However, measurements were revealed in the study with similar values to those of Jebel Mun (200 nGy^{-1}) and Kurun (190 nGy

h^{-1}), as reported by Fadol et al. (2015). The external received gamma radiation rate of the soil specimens in the investigation ranged from 40.2 to 372 nGyh^{-1} , with an average of 107 nGyh^{-1} .

4.3.2 Radium equivalent activity (Raeq)

The overall radiological risk efficiency attributed to the construction materials (Asaduzzaman et al., 2015). The (Ra eq) in all dirt samples separated from 84.2 to 808 Bq/kg, with an average value of 227 Bq/kg. The study found that four sites were greater than the allowed limit of UNSCEAR 370 Bq/kg, indicated in Table 3: Specify the quantified radium comparable behavior in soil specimens from diverse locations within areas exhibiting (SL29 = 466, SL39 = 808, SL42 = 562 and SL44 = 470 Bq/kg. The result indicated non-uniform radiation exposure. Figure 6 displays radium equivalent activity and compares it with the limit for building materials.

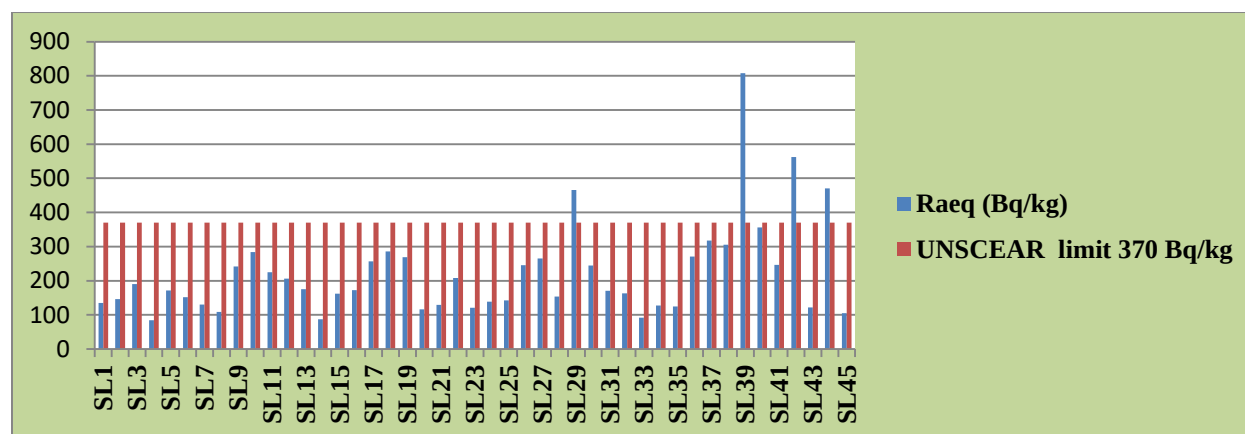


Figure 6: Radium Equivalent Activity in soil samples compared by UNSCER.

4.4.3 External and Internal Hazard Index (Hex and H in)

Endogenous intake of radon and its progeny is hazardous and may result in breathing-related conditions such as asthma and cancer (Avwiri et al., 2013). The gamma-ray radiation hazards, external and internal, arising from terrestrial radionuclides as the radiation risk from external exposure to gamma ray (Alawy et al., 2018; Erkül et al., 2016), exterior and interior danger index, The numerates value of (H ex and H in) for the (Hex) The quantity of dirt samples evaluated from 0.23 to 2.18 and average value 0.61. The external hazards index value must remain below one to ensure a minimal risk of danger; hence, four sites surpass the ICRP threshold of one, as demonstrated by the study, which showed four sites above one: SL29 = 1.26, SL39 = 2.92, SL42 = 1.52, and SL44 = 1.27. The table can show the external hazard dose that may be administered. According to the calculated values, these points are located within the mountain, indicating that radionuclides from the rocks are released during the rainy

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season. According to the Radiation Safety 112 study, dirt from these four locations is deemed hazardous. It should not be used as a building component, as it poses an important radiological danger to the inhabitants. At the same time, the internal Hazard Index (H_{in}) was estimated to be 0.28 to 2.92, with an average value of 0.79. The results revealed that four locations are above unity: SL 29 = 1.76, SL 39 = 2.92, SL 40 = 1.24, and SL 42 = 2.03. Figure 7 illustrates the exterior and interior risk levels compared to the limit of 1 ICRP.

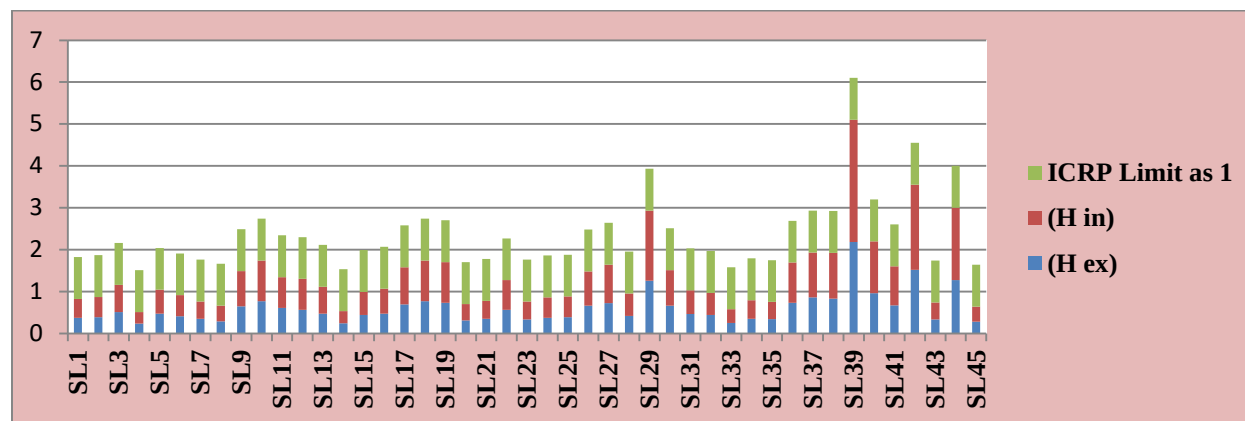


Fig 7: external and internal hazard compared to ICRP limit as 1.

4.5 Radioactive Decay Index

The radioactive level index serves as crucial for quality control of gamma radiation efficacious dosages as well as tracking radiation inside the human body to guarantee that radiation does not override the global limit, hence ensuring profit. The soil ecosystem must be predominantly stable or devoid of hazards. (Abu Samreh et al. 2014). The calculated radioactive level index (I_γ) for soil samples under investigation is given in Table 3. The (I_γ) in earth samples varies from 0.63 to 5.78 with an average of 1.67. The activity of gamma rays correlates with varying amounts of specific radionuclide activities, such as ^{232}Th , ^{226}Ra and ^{40}K . According to the results obtained in the study areas observed, approximately thirty-three sites exceed the limit of one, as shown in Table 3. Figure 8 displays the level of the hazard index.

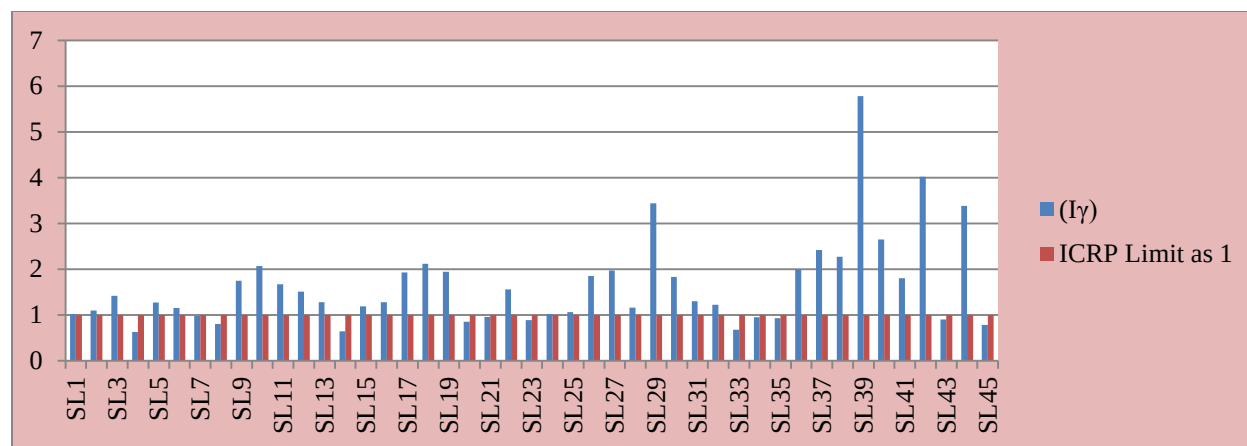


Figure 8: Hazard level index compared to ICRP Limit as 1.

Table 1; Soil sampling location sites and Radex(RD 1706) reading

Sample		Geographic Data		Reading meter	AED	AEDR
No.	site Location	Latitude N	Longitude E	T(μ Sv/hr)	(AED mSv/yr)	AEDR(mSv/yr)
SL1	Malm	22.41.763	13.50.932	0.11	0.96	0.67
SL2	Aborumayl Village	22.48.580	13.47.051	0.06	0.53	0.37
SL3	Aborumayl Village	22.48.547	13.49.096	0.16	1.40	0.98
SL4	Algrof	22.49.004	13.46.498	0.13	1.14	0.80
SL5	Algrof	22.49.221	13.46.691	0.10	0.88	0.61
SL6	Mostareiha	22.50.863	13.45.957	0.07	0.61	0.43
SL7	Mostareiha	22.50.981	13.46.053	0.13	1.14	0.80
SL8	Kroluko	22.42.201	14.06.157	0.19	1.66	1.17
SL9	Kroluko	22.42.460	14.05.985	0.10	0.88	0.61
SL10	Kerkro	22.44.380	14.05.119	0.26	2.28	1.59
SL11	Kerkro	22.43.059	14.09.627	0.29	2.54	1.78
SL12	Gelmi	22.44.675	14.09.368	0.34	2.98	2.08
SL13	Bardani	22.45.059	14.09.858	0.16	1.40	0.98
SL14	Bardani	22.45.341	14.09.371	0.08	0.70	0.49
SL15	Nan	22.46.408	14.09.276	0.15	1.31	0.92
SL16	Nan	22.46.510	14.09.143	0.26	2.28	1.59
SL17	Adraba	22.44.476	14.07.886	0.40	3.50	2.45
SL18	Aredi north	22.42.305	14.07.767	0.25	2.19	1.53
SL19	Aredi north (farm)	22.42.345	14.07.762	0.37	3.24	2.27
SL20	Aredi north (farm)	22.42.407	14.07.407	0.18	1.58	1.10
SL21	Beibi (farm)	22.43.036	14.07.786	0.15	1.31	0.92
SL22	Beibi (farm)	22.43.115	14.07.815	0.20	1.75	1.23
SL23	Alwona (farm)	22.43.614	14.07.676	0.18	1.58	1.10
SL24	Alwona (farm)	22.43.599	14.07.664	0.17	1.49	1.04
SL25	Alwona	22.43.601	14.07.530	0.19	1.66	1.17
SL26	Alwona	22.43.601	14.07.530	0.27	2.37	1.66
SL27	Mnzola (Est)	22.44.691	14.07.922	0.42	3.68	2.58
SL28	Mnzola	22.44.924	14.07.878	0.25	2.19	1.53

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SL29	Mnzola	22.44.915	14.07.859	0.54	4.73	3.31
SL30	Mnzola(farm)	22.44.995	14.08.020	0.36	3.15	2.21
SL31	Harazdelogo	22.45.606	14.07.510	0.20	1.75	1.23
SL32	Gadah vi	22.45.240	14.07.240	0.37	3.24	2.27
SL33	Armoo (farm)	22.44.648	14.08.333	0.14	1.23	0.86
SL34	Tika	22.42.614	14.07.751	0.25	2.19	1.53
SL35	Tika	22.42.546	14.07.846	0.24	2.10	1.47
SL36	Aredi	22.42.466	14.07.763	0.38	3.33	2.33
SL37	Kerkro	22.42.468	14.07.763	0.59	5.17	3.62
SL38	Gos sera	22.43.157	14.06.067	0.47	4.12	2.88
SL39	Lokona	22.41.795	14.09.099	0.51	4.47	3.13
SL40	Lokona	22.41.424	14.08.775	1.60	14.02	9.81
SL41	Falca mountain	22.41.793	14.08.793	1.06	9.29	6.50
SL42	Lokona	22.41.781	14.08.998	0.52	4.56	3.19
SL43	Serib	22.42.149	14.09.397	0.57	4.99	3.50
SL44	Swoni	22.42.391	14.10.276	0.93	8.15	5.70
SL45	Falca	22.41.994	14.09.716	0.46	4.03	2.82
SL46	Falca north	22.42.316	14.10.217	0.59	5.17	3.62
Minim				0.06	0.11	0.53
Maximum				1.60	9.81	14.0
Average				0.31	1.90	2.88

Table 2: Radionuclide activity concentration s by Bq/kg from soil sample in Jebel Mun areas

Samples No	²³² Th	²²⁶ Ra	⁴⁰ K
SL1	36.6	32.1	660.0
SL2	40.8	32.2	714.0
SL3	54.6	49.0	820.0
SL4	25.2	18.3	388.0
SL5	59.5	40.5	606.0
SL6	46.6	31.6	704.0
SL7	43.1	21.0	611.0
1SL8	36.4	27.2	384.0
SL9	87.0	68.3	642.0
SL10	98.0	76.9	865.0
SL11	78.1	46.2	868.0
SL12	58.6	68.1	704.0
SL13	49.6	60.1	573.0
SL14	32.1	20.4	278.0
SL15	54.3	40.5	572.0
SL16	51.2	48.9	663.0
SL17	65.0	71.7	1200
SL18	90.0	74.3	1081
SL19	84.0	92.1	732.0
SL20	40.4	28.2	387.0
SL21	39.1	31.9	534.0
SL22	54.2	56.4	961.0
SL23	33.3	39.7	441.0

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SL24	39.4	42.0	523.0
SL25	43.1	38.0	569.0
SL26	72.1	56.4	1122
SL27	70.0	76.6	1144
SL28	37.7	42.7	747.0
SL29	120	154	1820
SL30	66.0	68.5	1070
SL31	45.8	38.8	869.0
SL32	49.6	32.9	764.0
SL33	24.7	28.8	362.0
SL34	34.2	35.3	566.0
SL35	38.9	27.1	546.0
SL36	74.0	86.1	1021
SL37	75.0	76.2	1750
SL38	76.0	98.2	1290
SL39	283	273	1690
SL40	94.0	105	1510
SL41	63.0	95.6	797.0
SL42	197	190	1170
SL43	38.9	30.7	460.0
SL44	143	172	1210
SL45	30.5	28.1	435.0
MINA	24.7	18.3	278.0
MAXA	283	273	1820
Average	66.1	63.8	818.3

Table 3: Radiation Hazard parameter of soil samples calculated from the HPGe results

Sample code	ADRA(nGy/hr)	Raeq (Bq/kg)	(H ex)	(H in)	(I _y)
SL1	64.9	135	0.37	0.45	1.02
SL2	69.8	146	0.39	0.48	1.10
SL3	90.6	190	0.51	0.65	1.42
SL4	40.2	84.2	0.23	0.28	0.63
SL5	80.8	172	0.47	0.57	1.27
SL6	72.7	152	0.41	0.50	1.15
SL7	61.8	130	0.35	0.41	0.98
SL8	51.1	109	0.29	0.37	0.80
SL9	112	242	0.65	0.84	1.75
SL10	132	284	0.77	0.97	2.07
SL11	106	225	0.61	0.73	1.67
SL12	97.0	206	0.56	0.74	1.51
SL13	82.3	175	0.47	0.64	1.28
SL14	40.9	87.7	0.24	0.29	0.64
SL15	76.2	162	0.44	0.55	1.19
SL16	81.9	173	0.47	0.60	1.28
SL17	123	257	0.69	0.89	1.93
SL18	135	286	0.77	0.97	2.12
SL19	125	269	0.73	0.97	1.94
SL20	54.2	116	0.31	0.39	0.85

SL21	61.2	129	0.35	0.43	0.96
SL22	99.6	208	0.56	0.71	1.56
SL23	57.3	121	0.33	0.43	0.89
SL24	65.6	139	0.37	0.49	1.02
SL25	67.9	143	0.39	0.49	1.06
SL26	117	246	0.66	0.82	1.85
SL27	126	265	0.72	0.92	1.97
SL28	74.1	154	0.42	0.53	1.16
SL29	221	466	1.26	1.67	3.44
SL30	117	245	0.66	0.85	1.83
SL31	82.4	171	0.46	0.57	1.30
SL32	77.7	163	0.44	0.53	1.22
SL33	43.7	92.0	0.25	0.33	0.68
SL34	61.0	128	0.35	0.44	0.95
SL35	59.3	125	0.34	0.41	0.93
SL36	128	271	0.73	0.96	1.99
SL37	154	318	0.86	1.07	2.42
SL38	146	306	0.83	1.09	2.27
SL39	372	808	2.18	2.92	5.78
SL40	169	356	0.96	1.24	2.65
SL41	116	247	0.67	0.93	1.80
SL42	259	562	1.52	2.03	4.02
SL43	57.4	122	0.33	0.41	0.90
SL44	218	470	1.27	1.73	3.38
SL45	50.0	105	0.28	0.36	0.78
Min	40.2	84.2	0.23	0.28	0.63
Max	372	808	2.18	2.92	5.78
Average	107	227	0.61	0.79	1.67

Table 4: Comparative summary of the activity concentration of radioisotopes in dirt samples from Jebel Mun juxtaposed with several places in Sudan and other countries globally.

²²⁶ Ra (Bq/kg)			²³² Th (Bq/kg)		⁴⁰ K (Bq/kg)		
Country	Range	Average	Range	Average	Range	Average	References
Egypt	5.00 to 64.0	17.0	2.00 to 96.0	18.0	29.0 to 65.0	320	(UNSCEAR 2000)
Hong Kong	20.0 to 110	59.0	16.0 to 16.0	95.0	80.0 to 110	530	(UNSCEAR, 2000)
India	7.00 to 81.0	29.0	14 to 60.0	64.0	38.0 to 760	400	(UNSCEAR, 2000)
Malaysia	38.0 to 94.0	67.0	63.0 to 110	82.0	170 to 430	310	(UNSCEAR, 2000)
Poland	5.00 to 120	26.0	400 to 77.0	21.0	110 to 970	410	(UNSCEAR, 2000)
Bulgaria	12.0 to 210	45.0	7.00 to 160	30.0	40.0 to 800	400	(UNSCEAR, 2000)
United States	8.00 to 160	40.0	4.00 to 130	35.0	100 to 700	370	(UNSCEAR, 2000)
Sweden	12.0 to 170	42.0	14.0 to 94.0	42.0	560 to 1150	780	(UNSCEAR, 2000)
Denmark	9.00 to 29.0	17.0	8.00 to 30.0	19.0	240 to 610	460	(UNSCEAR, 2000)

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Switzerland	10.0 to 900	40.0	4.00 to 70.0	25.0	40.0 to 1000	370	(UNSCEAR, 2000)
Romania	8.00 to 600	32.0	11.0 to 75.0	38.0	250 to 1100	490	(UNSCEAR, 2000)
Portugal	1.00 to 240	25.0	8.00 to 65.0	44.0	220 to 1230	840	(UNSCEAR, 2000)
Spain	6.00 to 250	32.0	2.00 to 210	33.0	25.0 to 1650	470	(UNSCEAR, 2000)
Current study	18.3 to 273	66.2	24.7- 283	67.8	278.0 to 1820	827	

5. Conclusions

The specimens were recently collected from the Jebel Mun locality in western Darfur, Sudan. The four terrestrial radionuclides ^{232}Th , ^{226}Ra , and ^{40}K were quantified in 45 dirt samples. Using a Gamma-ray spectrometer. The mean radionuclide content in dirt samples ranged from 66.1 Bq/kg for ^{232}Th , 63.8 Bq/kg for ^{226}Ra and 818 Bq/kg for ^{40}K . Apart from gamma analysis, the calculated radioactive parameter, absorbed gamma Dose Rate in Air (ADRA), had an average value of 107 nG/yh^{-1} . In contrast, the average Radium Equivalent activity (Ra eq) was 227 Bq/kg. Moreover, outside and interior danger indices (H_{ex} , H_{in}) recorded an average of 0.61 and 0.79, respectively. The radioactivity level index (I_{γ}) had an average value of 1.67. The outcomes of this research align favorably with those from different nations and the global mean activity levels. This analysis indicated that the yearly actual dose danger at five sites exceeds the permissible limit set by the ICRP of 1 mSv/year. These findings emphasise the need for continuous environmental monitoring, public awareness, and potential restrictions on land use in high-risk areas, particularly for residential or agricultural purposes. The elevated levels can be attributed to local geological formations and the weathering processes that occur in mountain regions, reinforcing the importance of site-specific radiological assessments in natural hazard management.

6 Recommendations

The future project may consist of monitoring the annual effective dose caused by radon Inhalation. Moreover, the characterization of heavy metals at the studied sites was used to determine whether to correlate the natural radioactivity level with the presence of radioisotopes or to determine if pollution by radionuclides is due to natural activity.

References:-

1. A.K.S .and N. Abbas. (2000). Assessment of Radioactivity and the Associated Hazards in Local and Imported Cements Types Used in Sudan.J.Radiation Protection Dosimetry, 93 (3), 275-277.
2. Abu Samreh, Mohammed, ,et al. (2014).Measurement of activity concentration levels of radionuclides in soil samples collected from Bethlehem Province, west bank, Palestine. Turkish Journal of Engineering and Environmental Sciences ,38(2),113–125.
3. Adam .K. Sam ,et al.(2002). Assessment of Gamma Dose Rate over a Suspected Uranium Mineralisation Area of Jebel Mun, Western Sudan.J.Radiation Protection Dosimetry, 102(2),169–74.
4. Ahmad, Nisar ,et al . (2015). Measurements of Natural Radioactivity in Malaysia. Journal of Radiation Research and Applied Sciences, 8(1), 136 – 41.
5. Al-Alawy, I. T., et al. (2018).Determination of Radioactivity Levels Hazard, Cancer Risk and Radon Concentrations of Water and Sediment Samples in Al-Husseiniya River (Karbala, Iraq). Journal of Physics: Conference Series, (1), 1032.
6. AlMashhadani , Adel .Mehdi ,et al . (2014). Natural Radioactivity Concentration and Estimation of Radiation Exposure in Environmental Soil Samples from Al-Sader City Iraq. International Journal of Current Engineering and Technology ,4(4),2902–6.
7. AlMasri, M. S., et al.(2006). External Gamma Radiation Dose to Syrian Population Based on the Measurement of Gamma Emitters in Soils. Journal of Radio analytical and Nuclear Chemistry,(2), 43(2),267:337.
8. Huda .Al-sulaiti, Abdulrahman. (2011).Determination of Natural Radioactivity levels in the State of Qatar using High- Resolution Gamma-Ray Spectrometry.Thesis Ph. University of Surrey.
9. Al-Trabulsy., et al (2011). Radioactivity levels and Radiological Hazard Indices at the Saudi Coastline J. of Radiation Physics and Chemistry, 80(3),343–48. doi: 10.1016/j.radphyschem.2010.09.002.
10. Alzubaidi, Ghazwa., et al (2016).Assessment of Natural Radioactivity levels and Radiation Hazards in Agricultural and Virgin Soil in the State of Kedah, North of Malaysia. Scientific World Journal 9. doi: 10.1155/2016/6178103.
11. Blanchard, Dallou, Guy. Ngoa, Engola. Louis ,et al. (2017). NORM Measurements and Radiological Hazard Assessment in the Gold Mining Areas of Eastern Cameroon. J. Radiation Environment and Medicine, 6(1),22–28.

12. Daniel-Umeri, K., et al (2018). Outdoor and Indoor Radiation levels Measurement in Ozoro Delta State Nigeria. *Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 12(6), 8–11. doi: 10.9790/2402-1206010811.
13. Darko., et al. (2011). Preliminary Study of Natural Radioactivity in Soils of Some Selected Towns along the Bosumtwi Lake Ghana . *Elixir International Journal*, 41(5), 5761–65.
14. Essien, I.E and Essiet, A.A. (2016). Investigation of Radiological Hazards Within Uyo Metropoils Central Dumpsite, Akwa Ibom State ,Nigeria. *Int. Journal of Scientific and Research* ,5, 2250-3153.
16. Hamdi.A.A.Amin.(2021). Evaluation of natural radioactivity and determination of concentrations of some elements around Jebel Mun areas in Western Darfur. Thesis Ph.D. University of Al-Neelain, Khartoum Sudan, (143).
17. Hag Idriss. A. Salih, S., et al. (2016). Environmental-Impact Assessment of Natural Radioactivity around Traditional Mining Area in Al-Ibedia, Sudan. *J. Arch Environ Contam Toxically*, 70(4), 783–92.
18. Kapdan .E. ,et al. (2011). Radioactivity levels and Health Risks due to Radionuclides in the Soil .*Int. Journal. of Environ Res* ,5(4), 837–46.
19. Maxwell, O., H., et al .(2015). Natural Radioactivity and Geological Influence on Subsurface Layers at Kubwa and Gosa Area of Abuja Northcentral Nigeria. *J. Radio analytical and Nuclear Chemistry*, 303,(1), 821–30. doi: 10.1007/s10967-014-3442-1.
20. Moontaha, Sidratul., et al. (2018). Real Time Environmental Gamma Radiation Dose Rate Measurement around Major Nuclear and Radiological Facilities in Bangladesh. *Journal of Scientific Research and Management (IJSRM)* ,06(03), 39–49. doi: 10.18535/ijssrm.
21. Ndontchueng. Maurice ,Moyo ., et al . (2014). Gamma Emitting Radionuclides in Soils from Selected Areas in Douala-Bassa Zone Littoral Region of Cameroon. *Journal of Hindawi* , (8).
22. Rahman, A. L. I. Abdel., et al (1997). An Investigation of Trace and Radioactivity Elements in Elgash Area. Thesis Ph .D .University of Khartoum.
23. Theremino System. (2015). Gamma Radionuclides and X Ray Spectrometry.
24. Sajih. Mustafa. (2010). Identification and Characterization of Radioactive Particles in the Environment. Thesis Ph.D. University of Manchester.

25. Adam ,Khatier .Sam.(1993).Radium-226 Levels in Some Sudanese Plants and Soils.Thesis Ms.C University of Khartoum.
26. Taiwo A. O ., et al (2014).Determination of Radium Equivalent Activity from Natural Occurring Radionuclide around a Superphosphate Fertilizer Factory in Nigeria. JArch. Appl. Sci. Res 6(1):28–32.
27. United Nations Scientific Committee on the Effects of Atomic Radiation (2000a). *Sources and Effects of Ionizing Radiation. Vol. I*. New York: United Nations.
28. United Nations Scientific Committee on the Effects of Atomic Radiation). 2000. Sources and Effects of Ionizing Radiation. Vol. I. New York: United Nations.
29. Y.Raghu, et al. (2015). “Assessment of Natural Radioactivity and Associated Radiation Hazards in Some Building Materials Used in Kilpenathur” African Journal of Basic & Applied Sciences 7(1):16–25. doi: 10.5829/idosi.ajbas.2015.7.1.1140.