Determination of Natural Radioactivity Levels and Radiation Hazards from the Soil of Tin Mining in Kyerwa District, Tanzania

Abstract:

Gamma spectrometry was used to determine the activity concentrations of the natural radionuclides 226Ra, 232Th, and 40K in soil samples from the Tin mining in Kyerwa District, Tanzania. The study findings revealed that the mean activity concentrations of 226Ra, 232Th, and 40K were 90.68, 65.45, and 630.95 Bq/kg, respectively. These values were all greater than the average global activity concentrations for 226Ra, 232Th, and 40K which are 32 Bq/kg, 45 Bq/kg, and 420 Bq/kg, respectively. Assessments of the radiological risks associated with these naturally occurring radionuclides were done. In this case, the radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), and radioactivity level index ($I\gamma$) were calculated. The results show that the mean values of Ra_{eq}, H_{ex}, H_{in}, and $I\gamma$ were 230.6, 0.628, 0.861, and 0.831 Bq/kg, respectively. These results were below the global criteria levels for Ra_{eq}, H_{ex}, H_{in}, and $I\gamma$, which are 370, 1, 1, and 2 Bq/kg, respectively. Estimates for the absorbed dose rate in the air (DR), the annual effective dose equivalent (AEDE), and the annual gonadal equivalent dose (AGED) were also made. The findings revealed that the corresponding mean values for DR, AEDE, and AGED were 106.8 nGy/h, 1.07 mSv/y, and 744.4 Sv/y. The mean values exceeded the global average value of 57 nGy/h for DR, 0.07 mSv/y for AEDE, and 2984 Sv/y for AGED. Therefore, Tin mining activities in the Kyerwa District could endanger the mining community from natural radioactive sources. In this study, therefore, we recommend performing a periodic inspection of the mining areas, monitoring the mining workers, and determining the level of activity and concentrations of different radionuclides in the mining area.

Keywords: Natural Radioactivity Levels, Activity Concentration, Radiation Hazards, Radionuclides.

1. INTRODUCTION

Humans are exposed to varied levels of radioactivity depending on the natural radioactive elements found in each place. To undertake background tests and identify environmental radioactivity levels, researchers investigated natural environmental radiation and radioactivity in soil [1]. Radioactivity levels can be used to evaluate radioactive pollution and population exposure rates, as well as to forecast changes in environmental radioactivity that might be caused by nuclear accidents, industrial processes, and other human activities [2]. The majority of radiation doses that people receive are caused by the natural elements potassium-40, uranium-238, thorium-232, and their decay products. There have been detected about 60 radionuclides that are widely dispersed. Radionuclides can quickly build up in the food chain and can be found in geological formations like soil or rocks, water bodies such as rivers, lakes, and seas [1, 3]. One of the potential causes of exposure to naturally occurring

radioactive materials (NORM) is Tin mining. NORM makes up a sizable portion of radiation doses from internal or external radiation sources; therefore, tin mining and processing may result in higher concentrations.

Depending on the type of rock from which the soil is formed, different dose levels apply. Igneous rocks like granite have higher radioactivity levels, while sedimentary rocks have lower levels [4]. Higher activity concentrations of 226Ra, 232Th, and 40K have been reported by the studies on uranium and gold mining in Tanzania that assessed the activity concentration of natural radionuclides in soil [5, 6].The reported concentrations were higher than the global average concentrations of these radionuclides described in UNSCEAR (2000). Additionally, research has demonstrated that human activities like mining and oil and gas production might lead to increases in radioactivity levels from naturally occurring radioactive materials that might become high enough to require regulatory control [2, 7].

Radium, thorium, and potassium concentrations in mining operations range from an order of magnitude greater than the typical background value [8]. When heavy minerals like tin are mined and processed in any sizeable quantity, the requirements for suitable radiation safety measures become apparent in such radioactive element concentrations. This article is aiming to assess the natural radioactivity levels and radiation hazards in the soil of Tin Mining in the Kyerwa District in order to compare the radionuclide concentration levels with the recommended values set by National Authorities and International Organizations.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

One of the eight districts that make up the Kagera region is Kyerwa District. It is located between 31° and 32° east of the standard meridian and 0° to 5° south of the equator (Figure1). It covers 3,086 km2 area within the Kagera region. Both Rwanda and Uganda share a border with this area. The border between Kyerwa, Rwanda and Uganda is demarcated by the Kagera River. The District is made up of mountain ranges that are divided by wetlands and marshy valley bottoms. While valley bottoms and moist areas are 1,150 to 1,450 meters above sea level, the altitudes range from 1,500 to 1,800 meters above sea level. The climate in the District is tropical highland with 26°C mean temperature annually. The bimodal distribution of rainfall has its peaks in March and May and from

September through December. The District experiences yearly precipitation of 800 to 1000 mm. Rainfall typically declines from east to west and exceeds 1000mm/yr on high hills.

The parent material, age, prehistoric terrain, climatic circumstances, and biological history of Kyerwa soils all vary substantially from one location to the next. Approximately 60% of the district is coated with minerals, with tin accounting for the majority of this coverage. Tin is mined by small-scale miners, and various firms have submitted plans to the executive director of the Kyerwa district for larger-scale mining [9].

2.2. Sampling Methodology

The sampling area from the mine was divided into three zones: the northern (Kabingo, Kabagambe mine), the central (Kabushoke mine), and the southern (Chabitembe mine). Sampling locations are depicted in Figure 1. Six samples of soil were collected randomly from each sampling zone to make a total of 18 samples of soil. The samples were taken at a depth of 0 to 5 cm, as previously described Ajayi [4]. The collected samples were then sent to the TAEC laboratory for processing and analysis in labeled polythene bags.

Figure 1. Map of the Study Area in Kyerwa Mining

2.3. Sample Preparations

To eliminate larger items, soil samples were sieved in the lab using a 2 mm sieve, and then they were ground into a fine powder using a mortar and pestle to match the reference sample's matrix. The samples were then placed in a desiccator to prevent moisture absorption after being dried for several hours in an oven at about 45 to 50°C until the weight remained constant [10]. Each sample weighed around 500 g, and the Marinelli beaker's 500 cm3 volume was sealed with silicone and plastic tapes to ensure airtightness. To achieve a radioactive secular equilibrium between radon gas 222Rn and its decay products (214Pb, 214Bi, and 226Ra) from the 238U decay series, the samples were stored for a month.

2.4. Gamma-Ray Spectrometry

A coaxial HPGe detector (High Purity Germanium Detector) serial number 57-P51572A with relative efficiency of 51% and resolution sufficient to resolve the relevant gamma ray energies at Full Width Half Maximum (FWHM) of roughly 7.2% at any energy of o.662 MeV. Three layers of copper, cadmium, and lead, each measuring 30 mm, 3 mm, and 100 mm thick, respectively were used to shield the detector chamber. Daily calibrations of the gamma-ray energy were carried out using standard radiation sources such as 133Ba, 109Cd, 54Mn, 57Co, 60Co, 65Zn, 22Na, and 137Cs. Using the Genie 2000 software's In Situ Object Counting-system (ISOCS), efficiency calibration was established. The corresponding gamma-ray lines emitted by the decay products were used to calculate the activity concentrations of the radionuclides in the samples. The gamma lines with weighted mean activity levels of 911.1 keV (228Ac), 2614.5 keV of 208Tl, and 583.1 keV (212Pb) were used to calculate 232Th. To calculate 226Ra, gamma lines at 609.3 keV (214Bi), 1764 keV of 214Bi, 295.2 keV (214Pb) and 186.1 keV (226Ra) were employed. Its gamma line energy of 1460.8 keV was used to calculate the 40K.

International Atomic Energy Agency (IAEA) soil 375 was utilized as a standard reference material to evaluate the findings' precision and accuracy. The certified value was compared to the standard's activity at various energies following decay modification, using the datasheet of December 31, 1991, as a guide. The standard was counted for 10 hours, the same as that used for the samples. The experimental concentration values matched the designed values within 10% as shown in Table 1.

Table 1: The experimental activity values ($Bq/kg \pm SD$) and the standard reference values.

Radionuclides	Energy (keV)	Certified reference value	Experimental activity concentration	Accuracy (%)
226Ra	186.2	20.0 ± 0.9	20.54 ± 09	3.0
214Bi	1764	19.96 ± 0.4	19.97 ± 0.9	4.5
	2477.4	19.96 ± 0.9	20.46 ± 12	6.4
228Ac	338.5	20.46 ± 0.3	20.58 ± 1.5	7.8
	910.8	20.46 ± 0.5	20.29 ± 0.7	3.7
	968.5	20.46 ± 0.5	23.69 ± 0.9	4.8
40K	1460.7	423.40 ± 0.2	499.91 ± 2.2	0.4
208Tl	860.4	20.46 ± 0.3	21.20 ± 1.1	4.7
	2614.5	20.46 ± 0.6	22.44 ± 1.7	8.0
214Pb	295.2	19.96 ± 0.8	19.46 ± 0.8	3.6
	351.92	19.96 ± 0.5	20.61 ± 1.1	5.7

The following analytical expression, which is stated in equation (1) below, was used to compute the activity concentration ($Bqkg^{-1}$) of 226Ra, 232Th, and 40K in the samples [5, 6].

$$XEi = \frac{BEi}{\gamma d \; x \; \varepsilon E \; x \; ms \; xT} \qquad (1)$$

Where BEi is the net peak area at energy E, εE is the detection efficiency at the energy E, T is the counting live time in seconds, γd is the gamma ray yield per disintegration of the specific radionuclide for a transition at energy E, and ms is the mass of the dry weight in kg of the measured sample.

3. RESULTS

3.1. Radioactivity Concentrations in Soil

Tables 2, 3, and 4 provide the activity concentrations of 226Ra, 232Th, and 40K in soil samples taken from various places in the three zones of the Kyerwa district as well as the average values for the zones. Compared to the Northern zone (NS) and Southern zone, the Central zone (CZ) has the highest average activity concentrations of 226Ra and 40K. (SZ). In comparison to the Central Zone and the Southern Zone, the Northern Zone (NS) has the greatest average activity concentrations of 232Th.

Table 2: Activity concentration with their total uncertainties in the soil samples from Tin mine in the Northern Zone (NZ) together with the average activity concentration of the zone

Sample Code	Activity concentrations ($Bqkg^{-1}$)		
	^{226}Ra	^{232}Th	^{40}K
KS1	56.4 ±3.4	91.00±2.4	1397.9±3.3
KS2	51.9±1.7	92.6±3.7	1616.6±26.2
KS3	45±2.30	64.00±2	466.0±23
KS4	948.4±1.1	84.3±1.5	23.00±8.1
KS5	82.60±20	42.2±1.4	667.9±19.4
KS6	56.4 ± 3.4	84.9±3.3	1456±26.6
Mean	207.9±1.7	76.00±2.4	937±17.1
Range	(45-948)	(42-92)	(23-1616)

Table 3: Activity concentration with their total uncertainties in the soil samples from Tin Mine in the Central Zone (CZ) together with the average activity concentration of the zone

Sample Code	Activity concentrations ($Bqkg^{-1}$)		
	^{226}Ra	^{232}Th	^{40}K
CB1	23.8 ±2.2	41.80±1.6	615.0±22
CB2	18.20±1.2	36.40±1.0	84.0 ±7.4
CB3	20.00±2.0	37.00±2.0	102.0±8.2
CB4	19.01±0.9	42.01±0.1	106.0±1.2
CB5	23.00±0.8	38.80±4.0	122.0±0.2
CB6	40.60 ±9.7	45.00±0.1	98.40±7.2
Mean	24.10±2.3	40.16±2.0	187.80±7.7
Range	(18-40)	(41-88)	(84-1543)
Mean(mining area)	90.68 ±2.5	65.45±2.7	630.95±15.9

The Northern (NZ) includes the area around Kabingo and Kabagambe mines, the Central Zones (CZ) includes the area around the Kabushoke mine, and the Southern Zones (SZ) includes the area around the Chabitembe mine. Table 4 compares the average values of the three radionuclides from the three Kyerwa District zones with those from other locations in Tanzania and around the world. The measured activity concentration of 226Ra in Tin mining soil samples ranged from 24.10±2.3 Bqkg−1to to 207.9±1.7 Bqkg−1, with a mean value of 90.68±2.6 Bqkg−1. The concentration of 232Th ranged from 40.16±2.0 Bqkg−1 to 88.20±3.3 Bqkg−1, with an average value of 68.12± 5.5 Bq kg−1. The activity concentration of 40K ranged from 187.80±7.7 Bqkg−1 to 937±17.1 Bqkg−1, with an average value of 630.95 ± 15.9 Bqkg−1. The recommended reference levels of 226Ra, 232Th, and 40K are 35, 30, and 400 Bqkg−1, respectively, as registered in the world average concentrations published by UNSCEAR (2000).The average concentrations of 226Ra and 232Th obtained in the current study are higher than the recommended reference levels.

Table 4: Comparison of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in the Soil samples under this study with those from other places

Location	Activity concentrations (Bqkg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
	Mean (range)	Mean (range)	Mean (range)	
NZ	40 (24-75)	88 (69-130)	768 (220-1543)	Present study
CZ	207 (45-948)	76 (42-92)	937 (23-1616)	Present study
SZ	24 (18-40)	40 (41-88)	188 (84-1543)	Present study
Bahi, Tanzania	37 (9–60)	51 (28–107)	875 (542–1385)	[11]
Likuyu-Tanzania	52	36	564	[5]
Mkuju,-Tanzania	245 (132 – 316)	80 (39 – 114)	1407 (1169 – 1651)	[12]
Indonesia	1042 (320-2195)	1756 (993- 2683)	232 (116-438)	[13]
Nile Delta-Egypt	23.59	35.53	266.41	[14]
Iraq	26 (17-38)	10 (2-22)	360 (278-395)	[15]
Ghana	14 (2–31)	24 (6-94)	162 (40–552)	[16]
Nigeria	55 (9-198)	91 (5-502)	287 (35-1,359)	[4]
Namibia	25 (18-34)	35 (25-48)	518 (382-622)	[17]
World wide	32 (16-110)	45 (11-64)	420 (140-850)	[2]

The range and average of the natural radioactivity concentration levels reported in different locations in Tanzania were compared to the mean radioactivity concentrations of the soil samples from this study (Table 4). The results show a greater mean concentration of 226Ra, 232Th, and 40K than those found in Bahi and Likuyu village, except 40K, which is slightly higher in Bahi. The current study's mean activity concentrations are lower than those found in Mkuju, Tanzania.

These results were also compared with those reported in studies conducted in other countries (Table 4). The mean activity concentrations of natural radioactivity of 226Ra, 232Th, and 40K in this study are higher than those reported in Egypt, Iraq, Ghana, Nigeria, and Namibia, although the concentration of 232Th is slightly higher in Nigeria.

3.2. Radiological Hazard Assessment

3.2.1. Assessment of Radium Equivalent (Ra_{eq})

Calculating radium equivalent activity allows one to evaluate the risks of gamma radiation from people who are engaged with the soil from the mining locations listed in Table 5. This yields a single index that characterizes the gamma output from various mixtures of 226Ra, 232Th, and 40K in the samples [18]. The mathematical formula for radium equivalent activity (Raeq) is expressed in equation (2) below [2].

$$Ra_{eq}\ (Bqkg{-}1) = C\text{Ra} + 1.43C\text{Th} + 0.077C\text{K} \quad (2)$$

Where CRa, CTh, and CK are the activity concentrations of 226Ra, 232Th, and 40K (in Bqkg−1), respectively.

3.2.2. The Absorbed Dose Rate in Air

When 226Ra, 232Th, and 40K are present in a certain activity concentration in the air at a height of 1 meter above the ground, the absorbed dose rate (DR) in Bq/kg indicates the effects of gamma radiation [19]. The value of DR estimated in Table 6 is defined by Equation (3).

$$DR\ (nGy/h) = 0.462CRa + 0.604CTh + 0.042CK \quad (3)$$

Where DR is the dose rate in nGyh−1 and CRa, CTh, and CK are the activity concentrations (Bqkg−1) of radium (226Ra), thorium (232Th), and potassium (40K), respectively.

3.2.3. The Annual Effective Dose Equivalent (AEDE)

The Annual Effective Dose Equivalent (AEDE), which was determined in Table 6 as part of the radiological hazard assessment for miners and the surrounding communities in Kyerwa, provides an explanation for the dose rate that will be responsible for biological damage to human tissues [20]. Equation (4) was used to calculate the annual effective dose equivalent (AEDE) for miners or the general population in (mSv/y) [2].

$$AEDE\ (mSv/y) = (0.46CRa + 0.79CTh + 0.048CK) \times 8.76 \times 10^{-3} \quad (4)$$

3.2.4. External Hazard Index (H_{ex}).

The external hazard index for samples under investigation was calculated using the equation (5) defined by [21]. The estimated results of Hex are depicted in table 5.

$$H_{ex}=CRa/370+CTh/259+CK/4810 \quad (5)$$

Where CRa, CTh, and CK are the activity concentrations of 226Ra, 232Th, and 40K in (Bqkg−1), respectively.

3.2.5. Internal hazard index (H_{in})

The underground miners' respiratory systems are also at risk from radon and its transient products. Hence, the internal hazard index, as given in Table 5, is used to quantify internal exposure to radon and its transient derivatives. Equation 6 in [22] expresses this mathematically.

$$H_{in}=CRa/185+CTh/259+CK/4810\leq 1 \quad (6)$$

3.2.6. The Radioactivity Level Index

Radioactivity level index (Iγ) is additional radiological factor which can be calculated. The radioactivity level index (Iγ) given in Table 5 is used to estimate the rate of γ-radiation hazards linked with natural radionuclide in investigated samples [2]. The Iγ is defined by Equation 7.

$$I\gamma = CRa/300+CTh/200+CK/3000 \quad (7)$$

3.2.7. Annual gonadal equivalent dose

Gonads, active bone marrow, and bone surface cells are regarded as the organs of interest by [23]. Hence, Equation (8) was used to estimate Annual Gonadal Equivalent Dose (AGED mSv y-1) for the miners and the public around the mining areas due to the specific activity of 226Ra, 232Th, and 40K given in Table 6 [24].

$$AGED\ (\mu Svy\text{-}1) =3.09CRa+4.18Th+0.314CK \quad (8)$$

Table 5: Radium Equivalent (Ra_{eq}), External Hazard Index (H_{ex}).Internal hazard index (H_{in}) and Radioactivity Level Index estimated for the mining areas and the normal living areas in Kyerwa mining.

Location	Ra_{eq} ($Bqkg^{-1}$)	H_{ex}	H_{in}	Iγ
KB1	301.4	0.814	1.016	1.121
KB2	348.3	0.940	1.057	1.310
KB3	207.7	0.561	0.627	0.759
KG1	192.1	0.518	0.607	0.687
KG2	148.5	0.401	0.468	0.529
KG3	161.2	0.434	0.545	0.574
KS1	294.1	0.793	0.946	1.108
KS2	308.7	0.833	0.974	1.174
KS3	172.4	0.465	0.587	0.625
KS4	1070	2.893	5.456	3.590
KS5	194.4	0.525	0.748	0.708
KS6	289.9	0.781	0.935	1.097
CB1	130.9	0.353	0.417	0.493
CB2	76.72	0.317	0.256	0.270
CB3	80.76	0.214	0.272	0.285
CB4	87.25	0.235	0.286	0.308
CB5	87.87	0.237	0.299	0.311
CB6	112.5	0.303	0.413	0.393
Mean (mining area)	230.6	0.628	0.861	0.831

Table 6: Absorbed Dose Rate in Air (DR), Annual Effective Dose Equivalent (AEDE) and Annual gonadal equivalent dose (AGED) estimated for the mining areas and the normal living areas in Kyerwa mining.

Location	D_R (nGy/h)	AEDE (mSv/y)	AGED (μSvy-1)
KB1	142.0	1.45	1004.2
KB2	163.5	1.72	1162.8
KB3	98.0	1.03	699.1
KG1	85.6	0.91	596.4
KG2	65.8	0.71	457.7
KG3	72.3	0.76	502.6
KS1	139.7	1.44	993.5
KS2	147.8	1.52	1055
KS3	79.01	0.82	552.8
KS4	490.0	4.41	3290
KS5	91.70	0.91	641.3
KS6	138.4	1.42	986.3
CB1	62.07	0.64	441.3

CB2	32.92	0.36	234.7
CB3	35.87	0.37	242.8
CB4	38.60	0.41	267.6
CB5	39.18	0.41	271.5
CB6	50.07	0.51	344.5
Mean (mining area)	106.8	1.07	744.4

4. DISCUSSION

Gamma spectrometry was used to measure the radioactivity concentration of 18 soil samples collected from Tin Mining in Kyerwa District, located in North West of Tanzania. Results showed that the mean activity concentrations of 226Ra, 232Th, and 40K for the mining area are 90.68 ±2.5, 65.45±2.7 and 630.95±15.9Bqkg^{-1}, respectively. The measured values are higher than the world-recommended values.

On the other hand, the activity concentrations of each radionuclide were compared from each zone (Figure 2). In that case, the activity concentration of 226Ra at the central zone (CZ) was higher than the southern zone (SZ) by 88% and 81% from the north zone (NZ). The activity concentration of 232Th at the northern zone (NZ) was higher than the central zone (CZ) by 14% and 55% from the southern zone (SZ). Similarly, the activity concentration of 40K at the central zone (CZ) was higher than the northern zone (NZ) by 18%and 80% from the southern zone (SZ).

Radiological hazard assessments due to these natural radionuclides were also performed. Radium equivalent (Ra_{eq}) which is a single term that represents the combined specific activities of 226Ra, 232Th and 40K and used to indicate the external dose to the public was estimated. Other radiological hazard indexes such as external hazard index (Hex), internal hazard index (H_{in}) and radioactivity level Index (Iγ) were also calculated. The results revealed that the mean values of Ra_{eq}, H_{ex}, H_{in} and Iγ were 230.6, 0.628, 0.861 and 0.831Bq/kg, respectively.

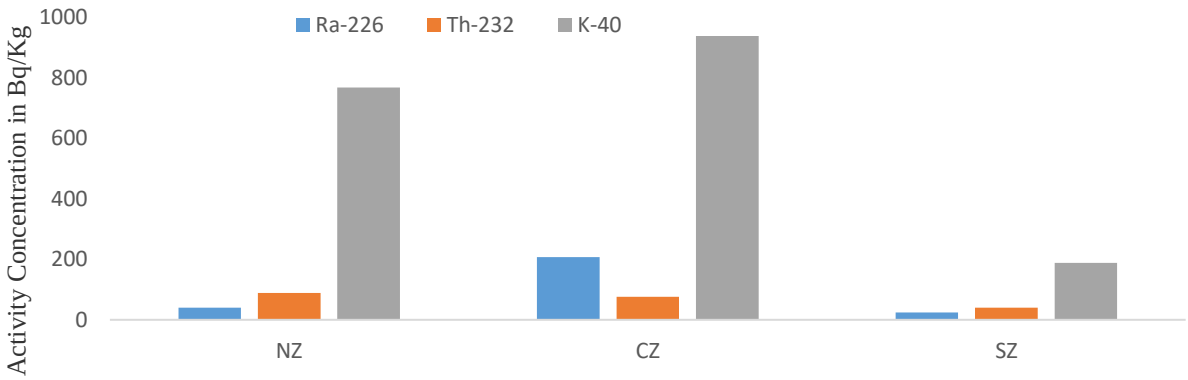

Figure 2. Comparison of Activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the study locations

These values were lower than the world-recommended values, which are 370 for Ra_{eq}, ≤ 1 for H_{ex}, ≤ 1 for H_{in} and ≤ 1 for Iγ respectively [25]. Absorbed Dose Rate in Air (DR), Annual Effective Dose Equivalent (AEDE) and Annual gonadal equivalent dose (AGED) were also calculated. The results indicate that the mean values for DR, AEDE and AGED were 106.8nGy/h, 1.07mSv/y, and 744.4μSvy-1 respectively. The estimated mean values were higher than those of the worldwide average which are 57 nGyh-1 for DR, 0.07mSv/y for AEDE and 2984μSv/y for AGED [26]. Due to the elevated mean calculated values of the radiological hazard indexes therefore, the mining activities in Kyerwa District can pose a radiological hazard to the mining community. Regular inspection of Tin Mining and monitoring of mining workers is recommended for further assessment of the level of activity concentrations of different radionuclides in the mining area.

5. CONCLUSIONS

The activity concentrations of 226Ra, 232Th and 40K in soil samples from the Kyerwa Tin Mining area have been studied using NaI (Tl) gamma-ray spectrometry. The mean activity concentrations of 226Ra, 232Th and 40K in the soil samples from the mining sites were estimated to be 90.68, 65.45 and 630.95Bq/kg, respectively. The results of the mean activity concentrations of 226Ra, 232Th and 40K in the mining sites are higher than the world average. The mean effective dose in this study is about 100% higher when compared to the world average. The results in the study area

show that there are high levels of natural radionuclides in the mining areas than the worldwide average. Therefore, mining activities in Kyerwa pose a radiological hazard to the mining communities.

REFERENCES

[1] ALZUBAIDI, G., HAMID, F. B., & ABDUL RAHMAN, I. Assessment of Natural Radioactivity Levels and Radiation Hazards in Agricultural and Virgin Soil in the State of Kedah, North of Malaysia. Scientific World Journal, 2016. Available at https://doi.org/10.1155/2016/6178103

[2] UNSCEAR- United Nations Scientific Committee on the Effects of Atomic Radiation, "Sources and Effects of Ionizing Radiation," UNSCEAR 2000 Report Vol.1 to the General Assembly, with scientific annexes, United Nations Sales Publication, United Nations, New York.

[3] B.SKWARZEC AND L. FALKOWSKI, "Accumulation of 210Po in Baltic invertebrates," Journal of Environmental Radioactivity, 1988.vol. 8, no. 2, pp. 99–109.

[4] AJAYI, O. S. Measurement of activity concentrations of 40K, 226Ra and 232Th for assessment of radiation hazards from soils of the southwestern region of Nigeria. Radiation and Environmental Biophysics, 2009. vol 48(3), p. 323-332, https://doi.org/10.1007/s00411-009-0225-0.

[5] MOHAMMED, N. K., & MAZUNGA, M. S. Natural radioactivity in soil and water from likuyu village in the neighborhood of mkuju uranium deposit. International Journal of Anal Chem, 2013, pg. 501856. https://doi.org/10.1155/2013/501856.

[6] ERASTO FOCUS, MWEMEZI J. RWIZA, NAJAT K. MOHAMMED, FIRMI P. BANZI, The influence of gold mining on radioactivity of mining sites soil in Tanzania, EQA - International Journal of Environmental Quality 2021. Vol. 46 pg 46-59.

[7] S. HARB, K. SALAHEL DIN, A. ABBADY AND M. MOSTAFA, Activity Concentration For Surface Soil Samples Collected From Armant, Qena, Egypt, 2010. Proceedings of the 4th Environmental Physics Conference, Hurghada, Egypt.

[8] HEWSON GS. Overview of radiation safety in the tin by-product (amang) industry of South East Asia. Rad, Safety Journal-Health Phys. 1996 pg 225-34.

[9] DISTRICT ADMINISTRATION AND LOCAL GOVERNMENT, Kyerwa District Investment Profile,2017.https://kyerwadc.go.tz/storage/app/media/uploadedfiles/Investment%20Profile%20Kyerwa.pdf.

[10] B.HOLYNSCA AND J. A. JASION. "Simultaneous determination of some trace metals in plant material by EDXRF," Journal of Radio analytical and Nuclear Chemistry, Volume 105: Issue 2.

[11]EBENEZER E. KIMARO AND NAJAT K. MOHAMMED. Natural Radioactivity Levels in the Area around the Uranium Deposit of the Bahi District in Dodoma Region, Tanzania, International Research Journal of Pure & Applied Chemistry, 2015 pg 1-10.

[12]MWALONGO DA. Determination of Background Radioactivity Levels and Elemental Composition at Mkuju Uranium Deposit in Tanzania. M.Sc. (Physics) Dissertation, University of Dar Es Salaam, 2011.

[13]NUROKHIM, KUSDIANA1 AND EKO PUDJADI. Assessment of natural radioactivity levels in soil sample from Botteng Utara Village, Mamuju Regency Indonesia, Journal of Physics: Conference Series, 2019 Volume 1436.

[14]GAD, A., SALEH, A., & KHALIFA, M. Assessment of natural radionuclides and related occupational risk in agricultural soil, southeastern Nile Delta, Egypt. Arabian Journal of Geosciences, 2019. https://doi.org/10.1007/s12517-019-4356-6

[15]JABBAR H. JEBUR et al. Measure the rate of Radiation Activity in Soil sample from the depth of Sindbad land in Basrah Governorate, IOP Conference Series in Materials Science and Engineering (2019).

[16]A. FAANU, E. O. DARKO AND J. H. EPHRAIM. Determination of Natural Radioactivity and Hazard in Soil and Rock Samples in a Mining Area in Ghana, West African Journal of Applied Ecology, 2011. vol. 19.

[17]OYADELE JA. Assessment of the natural radioactivity in the soils of Windhoek city, Namibia, Southern Africa. Journal of Radiation Protection Dosimetry. 2006 vol 121, pg 337–340.

[18]ADEMOLA, A. K., BELLO, A. K., & ADEJUMOBI, A. C. Determination of natural Radioactivity and hazard in soil samples in and around gold mining area in Itagunmodi, South-western, Nigeria, Journal of Radiation Research and Applied Sciences, (2014). Pg 249- 255. https://doi.org/10.1016/j.jrras.2014.06.001

[19]SIDDEEG, S. SULIMAN, M., BEN REBAH, F., MNIF, W., AHMED, A., & SALIH, I. Comparative Study of Natural Radioactivity and Radiological Hazard Parameters of Various Imported Tiles Used for Decoration in Sudan, 2018. MPPI Journal of Symmetry. https://doi.org/10.3390/sym10120746

[20]DAYO A. AYENI AND FESTUS M. ADEBIYI. Evaluation of Natural Radioactivity and Radiation Hazards of Soils around Petroleum Products Marketing Company using Gamma Ray Spectrometry. Tanzania Journal of Science, 2022. Vol.48 (2) pg 304-312.

[21]A. EL-TAHER, "INAA and DNAA for uranium determination in geological samples from Egypt, Applied Radiation and Isotopes, 2010.vol. 68, no. 6, pp. 1189–1192.

[22]BEREKTA, J. AND MATHEW, P.J. Natural Radioactivity in Australian Building Materials, Industrial Waste and Byproduct. Health Physics, 1985.

[23]UNSCEAR- United Nations Scientific Committee on the Effects of Atomic Radiation, 1982 Report to the General Assembly, with annexes

[24]ARAFA, W. Specific activity and hazards of granite samples collected from the Eastern Desert of Egypt. Journal of Environmental Radiation, 2004. Pg 315-327. https://doi.org/10.1016/j.jenvrad.2004.01.004

[25]OLUSEGUN SOWOLE AND KOLAWOLE A EGUNJOBI. Radioactivity Assessment of 40K, 238U and 232Th in Surface Soil Samples of Igbokoda, Southwest of Nigeria, Tanzania Journal of Science 2019 vol 45(3) pg 307-314.

[26]GAD, A., SALEH, A., & KHALIFA, M. Assessment of natural radionuclides and related occupational risk in agricultural soil, southeastern Nile Delta, Egypt. Arabian Journal of Geosciences, (2019). https://doi.org/10.1007/s12517-019-4356-6