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Determination of Natural Radioactivity Levels due to Mine Tailings from Selected Mines in Southwestern Uganda

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Abstract

The aim of this study was to determine the natural radioactivity levels of primordial radionuclides in soil mine tailings from selected mines in Southwestern Uganda. This was achieved by analyzing thirty six samples of soil mine tailings from three mining sites using NaI(Tl) gamma ray spectrometer. The specific activity concentrations of ^{238}U (Uranium), ^{232}Th (Thorium) and ^{40}K (Potassium-40) in the samples were computed. The specific activity concentrations varied from 35.5 to 147.0 Bq kg^{-1} for ^{238}U, 119.3 to 376.7 Bq kg^{-1} for ^{232}Th and 141.0 to 1658.5 Bq kg^{-1} for ^{40}K. The outdoor absorbed dose rates in air 1.0 m above the ground level were determined. The mean absorbed dose rates for Mashonga Gold Mine, Kikagati Tin Mine and Butare Iron Ore mine were 181.2±66.8 nGy h^{-1}, 167.2±43.0 nGy h^{-1} and 191.6±29.6 nGy h^{-1} respectively which are more than three times the world wide average value of 59 nGy h^{-1}. The mean outdoor annual effective dose rates for the three mines were 0.37±0.14 mSv y^{-1}, 0.34±0.09 mSv y^{-1} and 0.39±0.06 mSv y^{-1} respectively which are more than five times the world average value of 0.07 mSv y^{-1}. Thus the mine tailings (soil) from these areas must not be used as major building material to minimize radiological hazards.

Key words: Activity concentration, Gamma index, Soil mine tailings

1.Introduction

Human beings are always exposed to ionizing radiations of natural origin since they live in an environment that has the sources of these radiations (BEIR VII). Ionizing radiation in our environment comes as cosmic radiation from outer space and as terrestrial radiation from sources such as the soil and rocks that contain naturally occurring radioactive materials. Cosmic rays are streams of charged and uncharged nuclear particles consisting of protons and heavy nuclei. The dose rate from cosmic radiation at the sea level is about 30 nGy h^{-1} (UNSCEAR 2000) while that of terrestrial radiation is due to the presence of naturally occurring radioactive materials mainly; potassium (^{40}K) and the radionuclides in the decay series of uranium (^{238}U) and thorium (^{232}Th). Naturally occurring radionuclides of terrestrial origin, also termed primordial radionuclides, have half-lives comparable to the age of the earth and are present in various degrees in all environmental media, including the human body (UNSCEAR 2000). The levels of these radionuclides differ in the soil and rock structures and depend on the local geology and geographical conditions of the area (UNSCEAR 2008; IAEA 2003). The levels due to the terrestrial background radiation are related to the types of rocks from which the soils originate. Higher radiations levels are associated with igneous rocks while lower levels are associated with sedimentary rocks (UNSCEAR 2000; NCRP 1993).

Gamma radiation from ^{40}K and radionuclides in the decay series of ^{238}U and ^{232}Th by far represents the main external source of irradiation of the human body. Mining and processing of mineral ores can enhance the levels of each of these radionuclides in the mine tailing resulting in higher background gamma radiation levels in and around the mines. The measurement of natural gamma radioactivity levels is paramount in implementing precautionary measures whenever the source is found to exceed the recommended limits. The most common radiation induced health effects are incidence of cancers and genetic effects. Lung cancer induction is the most common effect due to inhalation radiation exposure (WHO 2009).

Previous studies (e.g. Caspah Kamunda et al. 2016; Mugaiga et al. 2016; Adewale et al. 2015; Kisolo 2007 & Banzi et al. 2000) have shown that soils and rocks of granite composition contain significant amounts of terrestrial radionuclides. When brought to the surface through mining activities, these radionuclides in mine tailings may result in enhanced background radiation levels, exposing the miners and the people living around the mines with higher doses of gamma radiation.

An Assessment of the Radiological Hazards from Gold Mine Tailings in the Province of Gauteng in South Africa, found average specific activities for ^{238}U, ^{232}Th and ^{40}K. These were 785.3±13.7 Bq kg^{-1} for ^{238}U, 43.9 ±1.0 Bq kg^{-1} for ^{232}Th and 427.0±13.1 Bq kg^{-1} for ^{40}K for the gold mine tailings and 17.0.1±0.4 Bq kg^{-1}, 22.2±0.5 Bq kg^{-1} and 496.8±15.2 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively in the control area. The average external hazard index and internal hazard index were 2.4 and 4.5, which are much higher than the recommended maximum permissible limit of unity. This shows that the gamma radiation levels in this area pose significant health hazard to the workers and the public.

In a study to determine radioactivity levels and dose rates due to natural radionuclides in rocks from selected mines and quarries in Eastern Uganda, the specific activities for ^{238}U, ^{232}Th and ^{40}K obtained, varied from 13.95±0.31 to 698.02±3.38 Bq kg^{-1} for ^{238}U, 98.68±1.30 to 2397.78±19.64 Bq kg^{-1} for ^{232}Th, and 45.97±2.48 to 2183.80±17.89 Bq kg^{-1} for ^{40}K. The annual outdoor effective dose rates also varied from 0.30 to 1.37 mSv y^{-1}, which are much higher than the world wide average of 0.07 mSv y^{-1} (UNSCEAR, 2000). This shows that the mining activities have increased the background radiation levels, suggesting possible radiological hazards to the miners and the public in those areas.

A natural radioactivity study of ^{40}K, ^{238}U and ^{232}Th in soils and mine tailings of Awo and Ede areas of Osun State, Nigeria, found that the specific activities levels of ^{40}K varied from 316.67±14.23 to 1487.35±3.03 Bq kg^{-1} with a mean value of 620.05±9.57 Bq kg^{-1}; for ^{238}U, 13.11±2.36 to 88.26±3.03 Bq kg^{-1} with a mean value of 27.50±3.14 Bq kg^{-1}; and for ^{232}Th, 26±1.00 to 55.81±2.99 Bq kg^{-1} with a mean value of 18.26±2.17 Bq kg^{-1}. The mean values obtained for Absorbed Dose rate and External Hazard Index were 48.12 nGy hr^{-1} and 0.26, which are lower than the world wide averages of 59 nGy h^{-1} and unity respectively.

In a Radon Monitoring and Dosimetry study in Uganda, the rock samples from Kilembe copper mines were analysed for ^{238}U and ^{232}Th. Their mean activity concentrations were found to be 187 Bq kg^{-1} and 19 Bq kg^{-1} respectively. The effective dose rate was greater than 20 mSv y^{-1}, the maximum permissible occupation dose limit (ICRP 2009; UNSCEAR 2000). Thus Kilembe mines are radiologically not safe for the workers, if not well protected against the hazardous radiations.

The results of a radiological study carried out on Minjingu phosphate rocks in Tanzania showed that the activity concentration of radium-226 (^{226}Ra) was very high. The mean activity concentration was 5760 ± 107 Bq kg^{-1} in phosphate rock, 4250 ± 98 Bq kg^{-1} in waste rock, 650 ± 11 Bq kg^{-1} in wild leaf vegetation, 393 ± 9 Bq kg^{-1} in edible leaf vegetation and 4.0 ± 0.1 Bq kg^{-1} in chicken feed. This suggests a radiation health risk particularly from inhalation of radon (^{222}Rn) gas, which originates from decay of radium. The radiation dose from ambient air over five years at this phosphate mine averaged 1415 nGy h^{-1}. This implies that the workers in the mines and those who live around the mines are at a very high risk of suffering radiation effects such as cancer.

Southwestern Uganda is endowed with many precious minerals particularly, Gold from Kigezi and Buhweju-Mashonga gold fields, Tin from Kikagati and Iron ore from Butare and other places in Kabale and Kisoro (Mining Journal Uganda 2012). Mining in these areas has been going on for many years, mainly by the artisanal miners using hand hoes, spades, basins, iron rods and without any form of protection. Mashonga and Butare mines are generally shallow with pits below 10 m in depth, while Kikagati mine has deep underground tunnels. These mines are found in the Akanyaru Ankole mesopretrozoic rock system, which is part of the Kibaran belt that extends to the Katanga in Southern part of the Democratic Republic of Congo (Mining Journal Uganda 2012). Porphyritic granite bodies in their cores contain radioactive mineral ores such as uranium and thorium (Mining Journal Uganda 2012; Nagudi 2011; Baguma 2009) which are exposed by mining activities and are left in the tailings. Furthermore, the monazite resulting from weathered granites contains uranium and thorium, and potassium-40 is mainly concentrated in feldspar, mica rocks and other accessory minerals such as zircon (UNSCEAR 2000) and all these may be concentrated in the tailings.

Since mining activities are known to increase the background gamma radiation levels by exposing naturally occurring radioactive materials to the surface (UNSCEAR 2000), it is therefore important to measure the activity concentrations of the major primordial radionuclides in the soil mine tailings in this region and assess the level of gamma radiation exposure to the miners and the people living around them.

2.Materials and Methods

In this section, sample collection and preparation procedures have been presented. Gamma ray detector calibration, radionuclide identification, activity concentration measurements, gamma dose rates and radiological hazard indices have been discussed in the following subsections.

2.1Sample Collection and Preparation

Three mining sites were considered in this study. These were Mashonga Gold Mine in Bushenyi District, Kikagati Tin Mine in Isingiro District and Butare Iron Ore Mine in Kabale District. Twelve soil tailing samples were collected from each of the sites. The total number of samples collected from all the three sites was thirty six (36). The samples were randomly collected from the tailings to ensure a good statistical representation of the sampling sites (IAEA 2004).

The samples were sun dried for a period of one week and there after oven dried at a temperature of 200 ^{0}C for many hours until constant masses were obtained. This was done to ensure that moisture was completely removed from the samples in order to avoid clamping of the sample particles during crushing. The samples were then crushed using a mortar and pestle into powder form in order to increase the surface area. A sieve of mesh size 2 mm recommended in IAEA (2003) was used to obtain uniform particle sizes. The sieved samples were weighed using an analog beam balance to determine their dry masses. The samples were then sealed in standard 500 ml plastic Marinelli beakers and kept for a period of 30 days to attain secular equilibrium between radon and its daughters (IAEA 2003).

2.2 Detector Calibrations

The Sodium Iodide detector (GDM 20 series) was used to detect the gamma rays and their energy. The gamma ray detector was first calibrated. The energy and efficiency calibrations of the detector were done using Europium (Eu-152) radioisotope as a reference material. Eu-152 was used in the calibration procedure because it emits many gamma rays of known intensity and energy. The Eu-152 solution was placed on the detector and its spectrum was obtained for a period of 6000 s. The peaks of known energies were analysed using AutoDas software to convert the channel number scale into an energy scale. After the energy and efficiency calibrations, the resolution of the detector was also determined.

To obtain the background radiation, an empty Marinelli beaker was placed on the detector and a spectrum generated for a period of 6000 s. The background radiation spectrum was later subtracted from the gamma ray spectra of the samples to obtain the net counts.

2.3Radionuclide Identification

Each sample was put on the gamma ray detector and surrounded the detector with 10 cm thick lead cylinder with a movable top, to minimize the background radiation. Counting was done for a minimum time of 6000 s to obtain a clear spectrum. Using AutoDas software, the energy and intensity of the gamma rays were obtained for each sample spectra. Every observed energy peak on the gamma spectrum was compared with the standard energy peaks for the various radionuclides in nature. The radionuclides resulting into the observed energy peaks on the spectrum of each sample were identified.

2.4Measurement of Activity Concentration

The activity levels for each radionuclide identified in the samples were determined by subtracting the background radiation counts from the total photo-peak areas. The activity of ^{238}U was determined from its decay products ^{214}Pb (295.2 keV) and ^{214}Pb (351.9 keV) in secular equilibrium with radium (^{226}Ra). The activity of ^{232}Th was determined from its decay products ^{212}Pb (238.6 keV) and ^{208}Tl (583.2 keV), while the activity concentration of ^{40}K was determined from its own gamma spectrum at 1460.8 keV (IAEA 2007).

The Specific activity concentration levels, *SAC* (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in each sample in Bq kg^{-1} (dry mass) was calculated using the following equation:

$$SAC = \frac{N/T}{m \times \kappa \times \eta} \text{ (Bq kg}^{-1}\text{)}, \qquad (1)$$

where N/T is the net activity rate, N is the net photo-peak area, m is the mass of the sample, κ is the absolute gamma emission probability (branching ratio), η is the detector efficiency and T is the counting time for each sample. The branching ratio, κ for each identified radionuclide was obtained from the standard radionuclide data tables according to IAEA (2007). The detector efficiency, η was determined using the equation:

$$\eta = \frac{Y}{AT}, \quad (2)$$

where Y is the net photo-peak area of the calibration spectrum, A is the activity of Eu-152 (reference radionuclide) and T is the counting time of the calibration spectrum.

2.5Measurement of Gamma Dose Rates

The gamma absorbed dose rate, (D_o nGy h^{-1}) in air at one metre above the ground surface was calculated from the measured specific activity concentrations using the equation:

$$D_o = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \text{ (nGy h}^{-1}\text{)}, \quad (3)$$

where 0.462, 0.604 and 0.0417 nGy h^{-1} per Bq kg^{-1} are absorbed dose rate conversion factors for ^{226}Ra, ^{232}Th, and ^{40}K respectively (UNSCEAR 2000) and A_{Ra}, A_{Th}, and A_K are their respective average specific activities.

The external outdoor annual effective dose rates are normally calculated using the absorbed dose conversion coefficient of 0.7 Sv Gy^{-1} for adult humans and an outdoor occupancy factor of 0.2 proposed in UNSCEAR (2000) report. In Uganda, about 82% of the labour force is majorly rural (UBOS 2013). The average time spent on economic and care labour activities per week by the rural dwellers is 55 hours (about 7.86 hours per day) which is about 33% (UBOS 2013). Therefore, the average outdoor and indoor occupancy factors for the rural community are 0.33 and 0.67 respectively. The world average outdoor and indoor occupancy factors are 0.2 and 0.8 respectively (UNSCEAR 2000).

Thus the external outdoor Annual Effective Dose Rate (E_o mSv y^{-1}) for the studied mines in Southwestern Uganda was calculated using the equation (UNSCEAR 2000):

$$E_o = D_o \times DCF \times OF \times T \text{ (mSv y}^{-1}\text{)}, \quad (4)$$

where D_o, *DCF, OF* are the average absorbed dose rate in air (nGy h^{-1}), dose conversion factor (0.7 Sv Gy^{-1}), outdoor occupancy factor for Southwestern Uganda (0.33) respectively and $T = 8766$ h, is the annual exposure time .

The Excess Lifetime Cancer Risk (*ELCR*) was calculated to estimate the number of extra cancers expected as a result of exposure to the external gamma radiation. Excess Lifetime Cancer Risk is a measure of the probability that a certain stochastic effect will occur in an individual or group of individuals exposed to low doses of ionizing radiation over a given period of time (UNSCEAR 2000). This was determined using the equation:

$$ELCR = E_o \times DL \times RF, \quad (5)$$

where *DL* is the duration of life assumed to be 70 years (UNSCEAR 2000), and *RF* is the risk factor per sievert for stochastic effects, given as 0.05 Sv^{-1} (ICRP 1990).

2.6 Measurement of Radiological Hazard Indices

Radiological hazard indices were determined in order to assess the gamma ray exposure levels that can be hazardous to the exposed people. This study has therefore determined the radium equivalent activity, external hazard index, internal hazard index and gamma index.

The radium equivalent activity was determined to measure gamma radiation hazard if the soil mine tailings are used as building materials. For the materials to be assumed as radiologically safe for use as building materials, the radium equivalent activity value must be less than 370 Bq kg^{-1}. The radium equivalent activity (Ra_{eq}) was calculated using the equation (Beretka & Mathew 1985):

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \text{ (Bq kg}^{-1}\text{)}. \quad (6)$$

It was assumed that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 1410 Bq kg^{-1} of ^{40}K produce the same gamma dose (Beretka and Mathew 1985). When the human body is exposed to gamma radiation, a dose is produced in the tissues. The effect of the dose depends on how the body is exposed to the radiation. The hazard

produced depends on many factors such as the dose absorbed, the duration of exposure, the age and sex of the person e.t.c.

External hazard index (external gamma ray hazard) and the internal hazard index (internally deposited radionuclides hazard) are the two radiological hazard indices used to assess the gamma radiation exposure hazard whose maximum value must be less than one (unity).

The external hazard index (H_{ex}) due to external gamma radiation was calculated using the equation (Beretka & Mathew 1985):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{1410}. \quad (7)$$

The internal hazard index (H_{in}) due to gamma radiation from internally deposited radionuclides was calculated using the equation (Beretka & Mathew 1985):

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{1410}. \quad (8)$$

The Gamma index is another hazard index used as a screening tool for materials containing ^{238}U(^{226}Ra), ^{232}Th and ^{40}K that can become a hazard when used as building materials. The gamma index (I_γ) was calculated using the equation (EC 1999):

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000}. \quad (9)$$

Values of $I_\gamma \leq 0.5$ correspond to a dose rate criterion of 0.3 mSv y^{-1} for materials normally used in bulk such as concrete and sand and the material must never be used if $I_\gamma > 6$ (EC 1999).

3.Results and Discussion

In this section, results obtained in this study are presented and discussed.

3.1Detected Radionuclides

The radionuclides detected in the samples are presented in Table 1.

Table 1: Detected Radionuclides in the Soil Mine Tailings from Mines in Southwestern Uganda

Element	Gamma Ray Energy (keV)	Emitter Radionuclide	Half-life	Branching ratio κ(%)	Efficiency η(%)
Uranium (U-238)	295.2	Pb-214	26.8 minutes	18.5	5.6
	351.9	Pb-214	26.8 minutes	35.6	6.7
Thorium (Th-232)	238.6	Pb-212	10.6 hours	43.6	13.9
	351.9	Tl-208	3.1 minutes	30.6	3.3
Potassium (K-40)	1460.8	K-40	1.3 billion years	10.66	2.2

The resolution of the NaI(Tl) detector varied from 7% to 10%. This falls within the operational range of the GDM 20 gamma ray detectors.

The natural radionuclides of Uranium, Thorium and Potassium were found present in significant levels in all the samples studied. Other natural radionuclides appeared at trace levels in all the samples studied and were ignored.

The presence of Uranium (^{238}U) and Thorium (^{232}Th) and Potassium-40 (^{40}K) in the soil mine tailings was expected since these radionuclides occur in nature in all soil types but with varying elemental concentrations.

This study revealed enhanced levels of ^{238}U and ^{232}Th and ^{40}K in the studied soil mine tailings from mines in Southwestern Uganda. This is true for soils of granite composition, potassium feldspar, quartz-mica, monazite and other accessory minerals (IAEA 2003; UNSCEAR 2000). Gold, Tin and Iron ore in Southwestern Uganda are mined from granitic bodies (Mining Journal Uganda 2012).

Anthropogenic or manmade radionuclides, such as Cesium (^{137}Cs) were not detected in all the samples. This means that Southwestern Uganda is free of anthropogenic radionuclides that originated from nuclear weapons testing and accidents.

3.2Activity concentrations

Various spectra were generated from the spectrometric analysis of the samples and were used to identify different radionuclides in each sample.

Potassium (^{40}K) and the radionuclides in uranium (^{238}U), and thorium (^{232}Th) series were identified from the spectra and their activities calculated. The specific activity concentration levels of ^{238}U, ^{232}Th and ^{40}K in the soil tailing samples from Mashonga, Kikagati and Butare mines were obtained using Equation 2.

Their mean specific activity concentration levels ± Standard Error of the mean for ^{238}U, ^{232}Th and ^{40}K for the three mines and their ranges were obtained. The results are presented in Table 2 and graphically illustrated in Fig 1.

Table 2: Mean Specific Activity Concentrations of ^{238}U, ^{232}Th and ^{40}K in Soil Tailing Samples from Mashonga, Kikagati and Butare Mines

Site	Mean Specific Activity Concentration /Bq kg^{-1}			Mean Total Activity Concentration/Bq kg^{-1}
	^{238}U	^{232}Th	^{40}K	
Mashonga	58.7±8.8	193.5±19.8	892.9±93.2	1145.1±121.8
Kikagati	49.7±3.1	211.7±17.3	391.5±46.3	652.9±66.6
Butare	57.6±2.9	244.4±10.9	416.4±42.7	718.4±56.6
Range	35.5 - 147.0	119.3 - 376.7	141.0 - 1658.5	295.8 - 2182.2

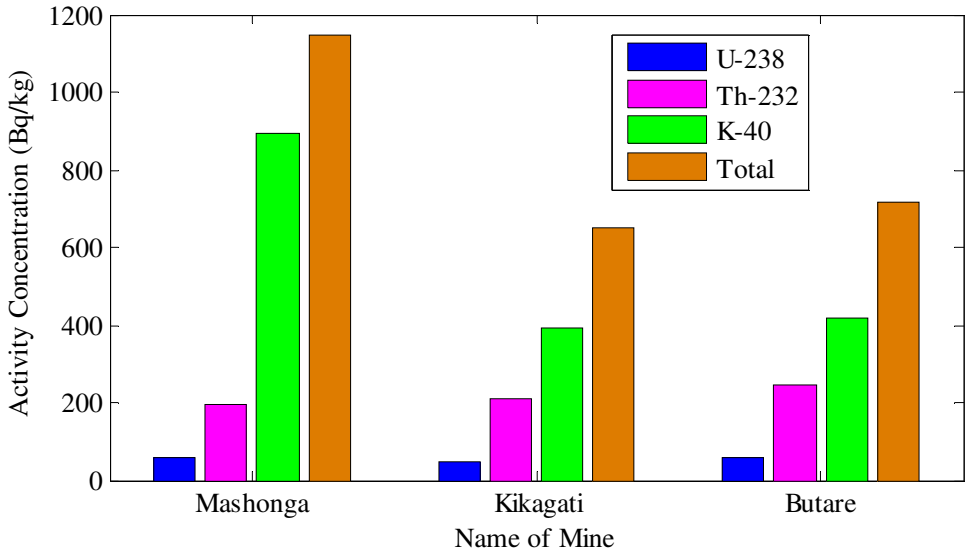

Figure 1: Activity Concentrations of ^{238}U, ^{232}Th and ^{40}K in Soil Mine Tailings from Mashonga, Kikagati and Butare Mines

Potassium-40 (^{40}K), had the highest mean activity concentration, followed by ^{232}Th and ^{238}U. This could be due to the natural abundance of ^{40}K, ^{232}Th and ^{238}U. Potassium-40 is found in most terrestrial materials with an abundance of 0.012% while ^{232}Th is about four times more abundant than ^{238}U (UNSCEAR 2000). Therefore, the activity levels of ^{232}Th are expected to be higher than those of ^{238}U.

Soil mine tailing samples from Mashonga gold mine had the highest mean total activity concentrations and those from Kikagati tin mine had the lowest mean total activity concentrations. The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K were higher than the world wide averages (33, 45 and 420 Bq kg^{-1}) respectively, according to UNSCEAR (2000) report. This may be due to granite rocks, potassium feldspar, monazite and other accessory minerals. According to the Mining Journal Uganda (2012); Nagudi, (2011) & Baguma (2009), gold and tin in Southwestern Uganda are extracted from quartz-mica rocks and granite rocks that cover most of the region. Monazite and other accessory minerals and potassium feldspar, are responsible for the high levels of radioactivity determined.

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K are much higher than the world averages. The results of this study also appear to be in agreement with results obtained in similar studies in Uganda and around the world (Table 3).

Table 3: Comparison of Results of Activity Concentrations obtained in this Study with Previous Studies

Site	Country	Reference	Specific Activity Concentration /Bq kg^{-1}		
			^{238}U	^{232}Th	^{40}K
Awo and Ede	Nigeria	Adewale (2015)	37.04	23.54	840.04
Jos Plateau	Nigeria	Davou (2015)	762.4	17258.3	5901.4
Sakwa Wagusu	Kenya	Aguko (2013)	44.2	40.3	639.6
Tarkwa	Ghana	Faanu (2011)	15.2	26.9	157.1
Bubenzi Quarries	Uganda	Mugaiga (2016)	60.7	244.9	1587.3
Nandotome Quarries	Uganda	Mugaiga (2016)	51.3	1291.9	1816.9
Kilembe Mines	Uganda	Kisolo (2007)	187	19	--------
Mashonga	Uganda	Present study	58.7	193.5	892.9
Kikagati	Uganda	Present study	49.7	211.7	391.5
Butare	Uganda	Present study	57.6	244.4	416.4
World		UNSCEAR (2000)	33	45	420

3.3Gamma Dose Rates

The mean outdoor absorbed dose rates (D_o) at a height of one metre above the ground and the mean outdoor annual effective dose rates (E_o) were calculated using Equation 3 and 4 respectively. The mean Excess Lifetime Cancer Risk (ELCR) was obtained using Equation 5. The results (Mean±Standard Deviation) are presented in Table 4.

Table 4: Mean Outdoor Absorbed Dose Rate, Annual Effective Dose Rate and Excess Lifetime Cancer Risk (ELCR) for Mashonga, Kikagati and Butare Mines

Site	Absorbed Dose Rate /nGy h^{-1}	Annual Effective Dose Rate /mSv y^{-1}	ELCR×10^{-3}
Mashonga	181.2±66.8	0.37±0.14	1.3±0.5
Kikagati	167.2±43.0	0.34±0.09	1.2±0.3
Butare	191.6±29.6	0.39±0.06	1.4±0.2

The mean outdoor absorbed dose rates were very high, about 3 times the world wide average value of 59 nGy h^{-1} (UNSCEAR 2008; 2000) in all the studied mines. This could be due to a higher outdoor occupancy factor of 0.33 which is 1.65 times the world average outdoor occupancy factor of 0.2 (UNSCEAR, 2000). However the values obtained are consistent with those obtained in radiological studies of samples from mines around the world. Kinyua (2011), obtained an average dose rate of 177.6 nGy h^{-1} and an outdoor annual effective dose rate of 0.44 mSv y^{-1} from Tabaka soapstone quarry in Kenya.

The outdoor annual effective dose rates were about 5 times the world wide average of 0.07 mSv y^{-1}. This is an indication of elevated levels of outdoor gamma radiation from radionuclides in the studied soil mine tailings, although the values are still in the range of the world (0.3 – 0.6 mSv y^{-1}). Since the dose level is lower than the maximum permissible dose limit of 1 mSv y^{-1} (ICRP 1990) for the public, the radiation levels in Mashonga, Kikagati and Butare mines are still safe.

The average excess lifetime cancer risks in all the three studied mines were very high as compared to the world average of 0.245 (UNSCEAR 2000). Butare had the highest value followed by Mashonga and Kikagati, which are 5.3, 4.9 and 5.7 times the world average. Therefore, increase in gamma radiation induced cancer cases and other health hazards are highly expected in the exposed miners and the population living around the mines.

3.4Radiological Hazard Indices

The sand in Mashonga gold mine is bought by building constructors and is used as one of the essential materials for building construction in Bushenyi district. In Butare iron ore mine, the soil mine tailings are used to make walls of temporary and semi permanent houses. The external outdoor gamma radiation exposure and exposure from building materials containing $^{238}U(^{226}Ra)$, ^{232}Th and ^{40}K may be hazardous to the inhabitants of such houses and buildings. Thus, the radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), and gamma index (I_{γ}) were measured. This was done in order to assess the level of gamma radiation hazard from the natural radionuclides in the soil mine tailings when used as building materials.

The radium equivalent activity of the soil mine tailings was calculated using Equation 6. The external hazard index, internal hazard index and gamma index were obtained using Equation 7, 8 and 9 respectively. The results (Mean±Standard Deviation) are presented in Table 5.

Table 5: Mean Radiological Hazard Indices of the Soil Mine Tailings of Mashonga, Kikagati and Butare Mines

Site	Ra_{eq}/Bq kg^{-1}	H_{ex}	H_{in}	I_{γ}
Mashonga	404.1±149.1	1.1±0.4	1.3±0.5	1.5±0.5
Kikagati	382.6±99.3	1.0±0.3	1.2±0.3	1.4±0.4
Butare	439.2±67.8	1.2±0.2	1.3±0.2	1.6±0.2

The maximum acceptable value of radium equivalent activity is 370 Bq kg^{-1} (Beretka & Mathew 1985). The mean radium equivalent activities for soil mine tailings for Mashonga, Kikagati and Butare mines are all greater than 370 Bq kg^{-1}. This means that they can produce significant gamma radiation when used as building materials and therefore must be avoided.

The mean external hazard index and the mean internal hazard index for Mashonga, Kikagati and Butare mines are greater than the maximum permissible limit of unity. This means that the gamma radiation exposure from the soil mine tailings of all the three mines exceeded the public exposure limit of 1 mSv y^{-1} (ICRP 1990). Thus, hazards due to external gamma radiation exposure and hazards due to internally deposited radionuclides, mainly due to radon exposure, may be significant.

The mean gamma index values of the soil mine tailings of all the three mines are greater than 0.5 but less than 6. According to EC (1999), these materials should not be used in bulk but can be used in moderation to prevent gamma radiation exposure hazards.

Therefore, the soil mine tailings such as the sand at Mashonga gold mine should not be used as a major building material in bulk to avoid significant gamma radiation exposure.

4.Conclusion

The natural radioactivity levels of mine tailings from selected mines in Southwestern Uganda were determined. The activity concentration levels of ^{238}U, ^{232}Th and ^{40}K in soil mine tailing samples were much higher than the world wide averages resulting in enhanced background radiation levels. The external and internal gamma radiation exposure levels are significant. Potential radiological effects on miners and the people living in the vicinity of the sites due to external gamma irradiation are expected. The soil mine tailings must be used in moderation in order to avoid serious radiological hazards. There is need to improve waste management practices in the mining sites and miners should use protective gear in order to prevent radiation exposure hazards.

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References

Adewale, O.O., Tubosun, I.A. & Ojo, J.O. (2015) 'Assessment of Terrestrial Naturally Occurring Radioactive Material in Soil and Mine Tailings of Awo and Ede, Osun-State, Nigeria, Ile-Ife, Osun State, Nigeria', *Ife Journal of Science*, **17** (1).

Aguko, W.O., Kinyua, R. & Ongeri, R.M. (2013) 'Radiation Exposure Levels Associated with Gold Mining in Sakwa Wagusu Area, Bondo District, Kenya', *Journal of Physical Science and Innovation* **5**(1).

Baguma, Z. (2009) 'Status of Radioacive Elements in Uganda', Department of Geological Survey and Mines, *Technical Meeting on Uranium from Unconventional Resources*, Vienna Austria.

Banzi, F.P., Kifanga, L.D. & Bundala, F.M. (2000) 'Natural radioactivity and radiation exposure at the Minjingu Phosphate mine in Tanzania', *Journal of Radiological Protection* **20**, 41-51.

Baxter, B.S. (1993) 'Environmental radioactivity', A perspective on industrial contributions, IAEA Bulletin **2** for Marine studies, Marine Environment Laboratory in Monaco, *Journal of Environmental Radioactivity*.

Biological Effects of Ionizing Radiation National Academy of Sciences (BEIR). (2006) 'Health risks from exposure to low levels of ionizing radiation', BEIR VII, Phase 2, Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, Board on Radiation Effects, Research Division on Earth and Life Studies, *National Research Council of the National Academies*, ISBN: 0-309-53040-7.

Beretka, J. & Mathew, P.J. (1985) 'Natural radioactivity of Australian Building Materials, Industrial Wastes and by-products', *Health Physics*, **48**, 87-95.

Caspah Kamunda, Manny Mathuthu and Morgan Madhuku, (2016) 'An Assessment of Radiological Hazards from Gold Mine Tailings in the Province of Gauteng in South Africa', *International Journal of Environmental Research and Public Health*, **13**(138).

Davou, L.C. & Mangset, W.E. (2015) 'Evaluation of Radiation Hazard Indices and Excess Lifetime Cancer Risk Due To Natural Radioactivity in Mined Tailings in Some Locations in JOS Plateau State Nigeria', *Journal of Applied Physics*, **7**(10), 67-72.

Department of Geological Survey and Mines (2012) 'Geology and mineral Occurrences in Uganda', Ministry of Energy and Mineral development, Entebbe, *Mining Journal Special Publication-Uganda*.

Dickson, B.L. & Scott, K.M. (1997) 'Interpretation of aerial gamma-ray surveys; adding the geochemical factors', *Journal of Australia Geology and Geophysics*, **17**(2), 187-200.

European Commission (EC). (1999) 'Radiological Protection Principles concerning the Natural Radioactivity of Building Materials', *Radiation protection 112 with Annexes I and II*.

Faanu, A. (2011) 'Assessment of Public Exposure to Naturally Occurring Radioactive Materials from Mining and Mineral Processing Activities of Tarkwa Goldmine in Ghana', *Ph.D Dissertation*, Department of Chemistry, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi-Ghana.

International Atomic Energy Agency (IAEA). (2003) 'Guidelines for radioelement mapping using gamma ray spectrometry data', IAEA-TECDOC-1363, ISBN 92-0-108303-3.

International Atomic Energy Agency (IAEA). (2004) 'Radiation, People, and the Environment', Soil sampling for environmental contaminants, *Division of radiation and Waste safety*, Vienna, Austria , IAEA TEC-DOC-1415.

International Atomic Energy Agency (IAEA). (2007) 'Update of X Ray and Gamma Ray Decay Data Standards for Detector Calibration and Other Applications', STI/PUB/1287 (1), Vienna Austria, ISBN 92-0-113606-4.

International Commission on Radiological Protection (ICRP). (1990) '*Recommendations of the International Commission of Radiological Protection*', Publication **60**, Pergamon Press, Oxford.

Kinyua, R., Atambo, V.O. & Ongeri, R.M. (2011) 'Activity concentrations of ^{40}K, ^{232}Th, ^{226}Ra and radiation exposure levels in the Tabaka soapstone quarries of the Kisii Region, Kenya', Institute for Energy and Environmental Technology, Jomo Kenyatta University of Agriculture and Technology, Kenya, *African Journal of Environmental Science and Technology*, **5**(9), 682-688.

Kisolo, A., Barifaijo, E. & Strand, T. (2007) 'Radon monitoring and Dosimetry in Uganda', Department of Physics, Makerere University & Norwegian Radiation Protection Authority, Grinaerings **5**, Oestraus, Norway, *The Second All African IRPA Regional Radiation Protection Congress*, 22-26.

Mugaiga, A., Jurua, E., Oriada, R. & Turyahabwa, S. (2016) 'Radioactivity Levels and Dose Rates from Rocks in Selected Mining Areas and Quarries in Eastern Uganda', *International Journal of Research in Engineering and Technology*, **5**(3).

Nagudi, B. (2011) 'Status of Geological Resources in Uganda', For the Embassy of the Republic of Korea in Uganda.

Uganda Bureau of Statistics (UBOS). (2013) 'National Labour force and Child Activities Survey', 2011/2012, *National Labour force Survey Report*, 44 – 48.

United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR). (2000) 'A report to the general assembly', *Radiological protection bulletin with annexes A and B*.

United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR). (2008) 'Sources and Effects of Ionizing Radiation', A Report to the General Assembly with Scientific Annexes, ISBN 978-92-1-142274-0.

United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR). (2008) 'Sources and Effects of Ionizing Radiation', *Report to General Assembly, with Scientific Annexes, C, D and E*, **2**.

World Health Organisation (WHO). (2009) 'Handbook on Indoor Radon, A Public Health Perspective', *Department of Public Health and Environment, Geneva*, ISBN 978-92-4-1547673.