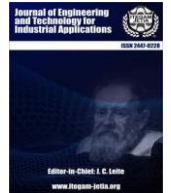




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## RESEARCH ARTICLE





## OPEN ACCESS

## NATURAL RADIOACTIVITY AND EXTERNAL DOSE RATES IN TAILING SAMPLES FROM ROSTERMAN GOLD MINE, KAKAMEGA COUNTY, KENYA

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## ABSTRACT

In this article, documented results of natural radionuclide concentrations in tailings at Rosterman gold mine, Kakamega county, Kenya were evaluated. Thirty tailing samples from Rosterman gold mine were collected as per standard sampling procedures and were analyzed for <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K by NaI (TI) gamma-ray spectroscopy. The activities of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K was found to vary from  $39 \pm 1.63$  Bq/Kg to  $118 \pm 4.43$  Bq/Kg,  $72 \pm 2.24$  Bq/Kg to  $223 \pm 8.36$  Bq/Kg and  $85 \pm 3.6$  Bq/Kg to  $362 \pm 10.65$  Bq/Kg respectively. Radium equivalent activities were found below 370 Bq/Kg in all the collected samples. External gamma dose rates estimated from the levels of radionuclides in tailings had a range of  $32 \pm 3.4$  nGy/h to  $68 \pm 5.83$  nGy/h. Hence, mining of gold at Rosterman has minimal significant health implications to the general population and the miners.



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## I. INTRODUCTION

The earth has always been bombarded by high energy particle showers in the lower atmosphere. Additionally, the earth's crust contains radionuclides. For most individuals, exposure to natural background radiation is the most significant part of their total exposure to radiation [1]. Radon is usually the largest natural source of radiation contributing to the exposure of members of the public, sometimes accounting for half the total exposure from all sources [2]. Besides the shielding provided by the earth's magnetic field, life is shielded against cosmic radiations by an air layer of approximately 10,000kg/m<sup>2</sup>, which is comparable to a 10m thick water layer [1]. As a result, at sea level the cosmic radiation contributes about 10% of the total dose rate from natural radiation to which human beings have always been exposed [3].

Artisan mining is an important economic sector in many developing countries. However, limited resources and training, and the availability of cheap, but potentially hazardous methods of extraction and processing of minerals can cause significant threats to both miners and the local environment [4]. The natural

radioactivity and the suspected high dose rates in these mining areas could probably complicate health problems. The relationship between mining and environment is particularly complex and not yet fully understood especially in developing countries [4]. In Kenya, it is noted that this complexity is due partly to the levels of research and lack of adequate and analytical capabilities as well as foolproof diagnostic ability for environmentally related health conditions [5]. It is on this ground that this research work was carried out to determine the contributions of tailings from the mining site to the natural radioactivity exposure levels in the area.

## II. MATERIALS AND METHODS

## II.1 STUDY AREA

The study was carried out at Rosterman which is within Lurambi sub – county, Kakamega Municipality, Kakamega county. Lurambi sub – county is bordered by Navakholo, Malava, Shinyalu, Khwisero, Mumias East, Ikolomani and Butere sub – counties. The study area is shown in Figure 1.

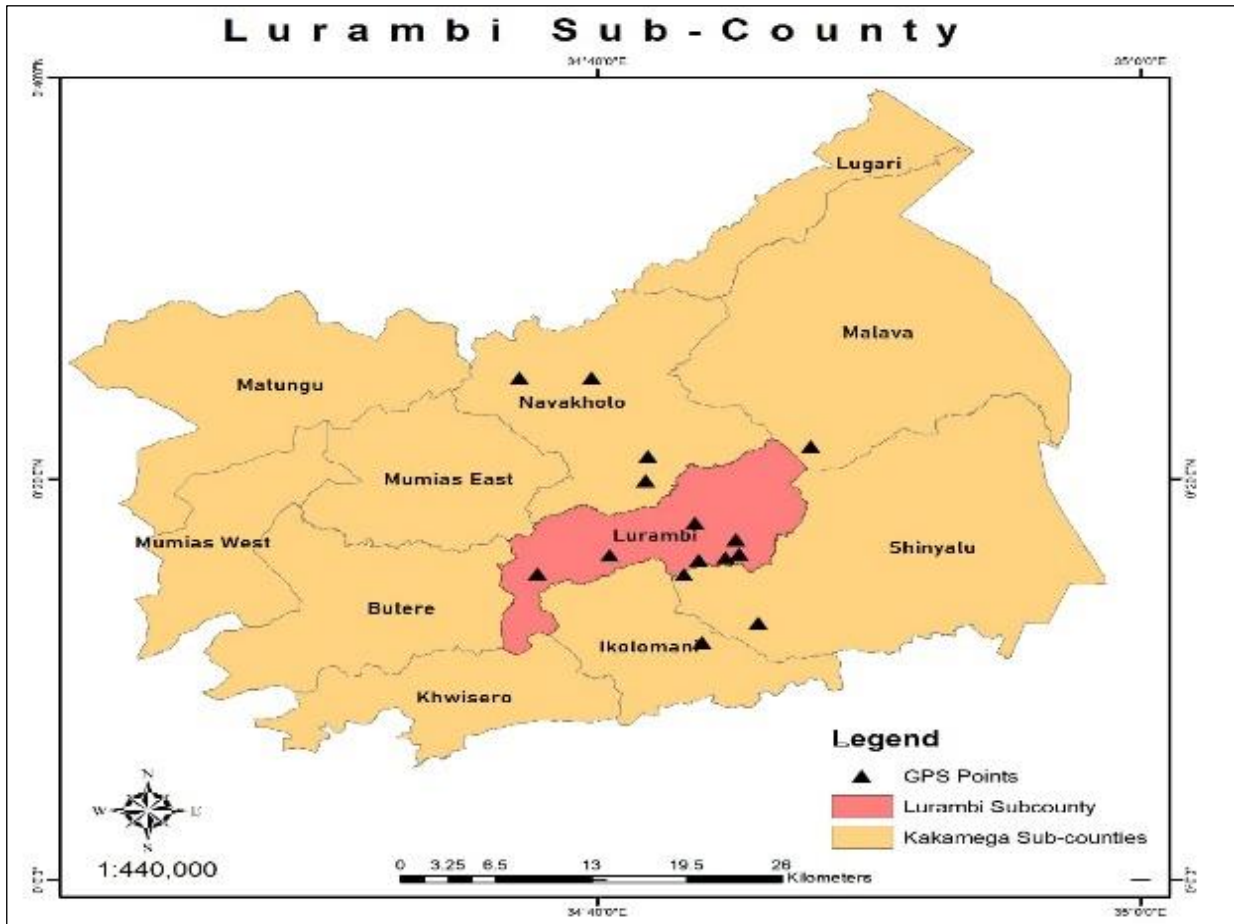


Figure 1: Map of the Lurambi Sub County and its Neighboring Sub Counties.  
Source: [6].

Rosterman is globally located at N00°16.964, 34° 45.112'E. Figure 2 shows the sampling points.

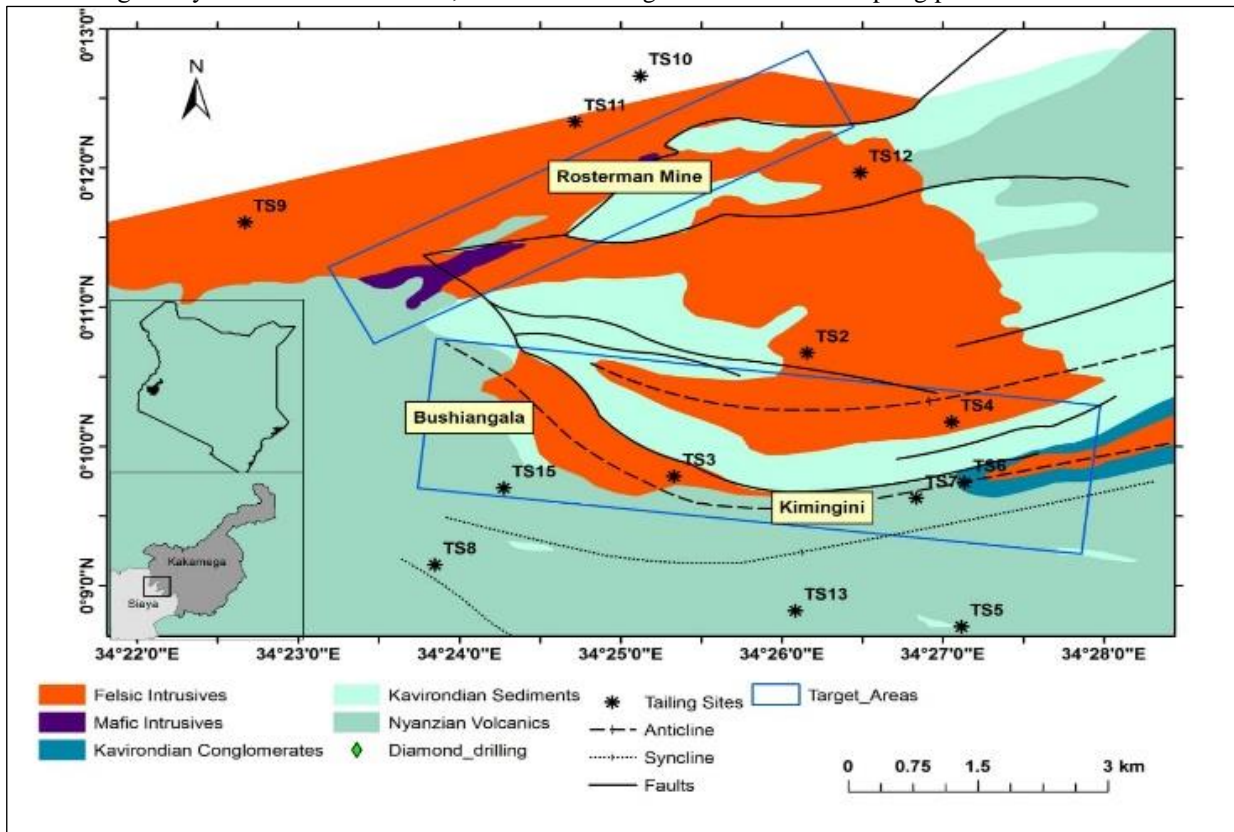


Figure 2: Sampling Points at the Study Area.  
Source: [7].

The area of research involves artisanal mining activities that may result in exposure to natural radioactivity levels to the miners and the general public.

## II.2 SAMPLE COLLECTION AND PREPARATION

A total of 30 samples were randomly collected within the selected tunnels of the Rosterman gold mine. In the laboratory, each of the tailing samples was dried under sunlight for 5 days and then oven dried at a temperature of 105 °C for about four hours until all moisture content was completely expelled. The dried samples were then grinded into fine powder using a mortar and pestle and then sieved through a 2 mm mesh size [8]. They were then poured into 200g mass plastic containers. The plastic containers were then sealed, weighed and stored for 4 weeks to allow the short-lived daughters of <sup>238</sup>U and <sup>232</sup>Th decay series to attain secular equilibrium with their long-lived parent radionuclides [8]. The soil samples were each counted using a NaI (TI) gamma ray detector for a period of 36,000 S [9].

## II.3 INSTRUMENT CALIBRATION

The tailing samples measurement were made by direct non-destructive instrumental analysis with a computerized gamma spectrometry system made up of NaI(Tl) detector. The calibration of NaI(Tl) gamma-ray spectrometer and decomposition of measured spectrum into components were done using three standard materials (RGK-1, RGU-1 and RGTH-1 for potassium, uranium and thorium, respectively) which were obtained from International Atomic Energy Agency [10]. The <sup>226</sup>Ra activities for samples assumed to be in radioactive equilibrium were estimated from <sup>214</sup>Pb (351.92 keV) and <sup>214</sup>Bi (609.31 keV). The gamma-ray energies of <sup>212</sup>Bi, <sup>212</sup>Pb and <sup>228</sup>Ac were used to estimate activity of <sup>232</sup>Th. The activity concentrations of <sup>40</sup>K were measured directly by its own gamma rays (1460.81 keV).

## II.4 SAMPLE ANALYSIS

### II.4.1 Activity Concentration of Radionuclides in Bqkg<sup>-1</sup>

Equation 1 is the analytical equation that was used in the calculation of the radionuclide activity concentrations in Bqkg<sup>-1</sup> [9].

$$A_c = \frac{N_D}{p \cdot n \cdot m} \quad (1)$$

Where  $N_D$  is the net count rate (cps), measured count rate minus background count rate,  $p$  is the gamma-ray emission probability,  $n$  ( $E$ ) is the absolute counting efficiency of the detector system,  $m$  is the mass of the sample (kg).

### II.4.2 Radium Equivalent (Raeq)

Equation 2 shows the analytical equation used for calculating the radium equivalent [8].

$$Ra_{eq} = C_{Ra} + 1.423C_{Th} + 0.077C_K \quad (2)$$

Where  $C_{Ra}$ ,  $C_{Th}$  and  $C_K$  are the mean activity concentrations of <sup>226</sup>Ra, <sup>232</sup>Th, and <sup>40</sup>K in tailing samples respectively expressed in Bqkg<sup>-1</sup>.

### II.4.3 Estimation of Absorbed Dose Rate (D)

The absorbed dose rate was calculated from activity concentration of <sup>232</sup>Th, <sup>238</sup>U and <sup>40</sup>K using the activity concentration-dose (nGy<sup>-1</sup> per Bq/kg) conversion factors of 0.622, 0.462 and 0.0432 [10]. Equation 3 below shows how to calculate the dose rate given the activity concentrations [11].

$$D(nGy^h) = 0.427A_U + 0.622A_{Th} + 0.043A_K \quad (3)$$

Where  $A_U$ ,  $A_{Th}$ , and  $A_K$  is the average activities concentration of <sup>238</sup>U (<sup>226</sup>Ra), <sup>232</sup>Th, and <sup>40</sup>K in Bqkg<sup>-1</sup>, respectively in the mixture of the tailing samples.

### II.4.4 Hazard indices

Internal hazard index ( $H_{in}$ ) measures the internal exposure due to intake of terrestrial radionuclides by inhalation while external hazard index ( $H_{ex}$ ) measures the external exposure to gamma radiation from the natural radionuclides in the gold mining site. External exposure may occur when the body comes in contact with radiation whose energy is elevated [12]. For radiation to be considered to have negligible hazardous effects to the public, both internal and external hazard indices should be less than 1 unit [13]. The internal hazard index was calculated using Equation 4 while external hazard index was determined using Equation 5 as given below [14].

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (4)$$

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

Where  $C_{Ra}$ ,  $C_{Th}$ , and  $C_K$  represent the mean activity concentrations of radionuclides in Bqkg<sup>-1</sup>.

## III. RESULTS AND DISCUSSIONS

### III.1 ACTIVITY CONCENTRATION OF THE RADIONUCLIDES

The specific activity concentrations of <sup>238</sup>U, <sup>232</sup>Th, and <sup>40</sup>K in tailings were evaluated separately using the analytical Equation 1 and the results showing the range and average activity of tailings tabulated in Table 1.

Table 1: Mean and Range of Activity Concentrations of the Radionuclides.

Radionuclide	Activity concentration values		
	<sup>226</sup> Ra	<sup>232</sup> Th	<sup>40</sup> K
Minimum	39 ± 1.63	72 ± 2.24	85 ± 3.6
Maximum	118 ± 4.43	223 ± 8.36	362 ± 10.65
Mean	83 ± 4.67	108 ± 4.75	250 ± 11.24

Source: Authors, (2020).

The mean activity concentration of <sup>40</sup>K, <sup>232</sup>Th and <sup>226</sup>Ra for the tailing samples collected were 250 ± 11.24 Bq/Kg, 108 ± 4.75 Bq/Kg and 83 ± 4.67 Bq/Kg. The average activity concentration of <sup>40</sup>K in the collected sediments was below the world's mean of 400 Bq/Kg while that <sup>238</sup>U and <sup>232</sup>Th were higher than the worlds average of 35 Bqkg<sup>-1</sup> and 45 Bqkg<sup>-1</sup> respectively [15]. The high abundance of <sup>40</sup>K was as a result of presence of silicate minerals in the sampled tailing [16]. However, the mean values of <sup>238</sup>U and



$^{232}\text{Th}$  were far below the exemption level of  $1000 \text{ Bqkg}^{-1}$  for  $^{238}\text{U}$  and  $^{232}\text{Th}$  [13]. The activity concentration of  $^{238}\text{U}$  in the collected tailing samples is shown in Figure 3.

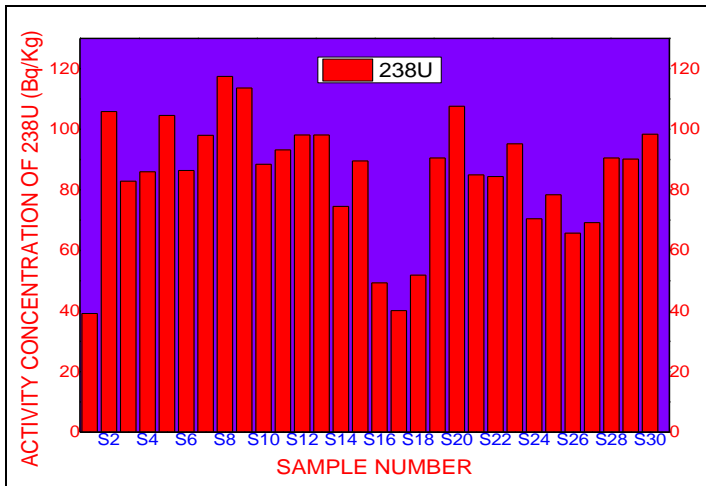


Figure 3: Activity Concentrations of  $^{238}\text{U}$  in the Collected Tailing Samples. Source: Authors, (2020).

The activity concentration of  $^{238}\text{U}$  of the collected samples in  $\text{Bq/Kg}$  ranged from  $39 \pm 1.63$  to  $116 \pm 4.43$  (Figure 3). The average activity concentration for the analyzed samples was  $83 \pm 4.67 \text{ Bq/Kg}$ . This is above the recommended value of  $35 \text{ Bqkg}^{-1}$  [17]. Most of the samples reported an activity concentration above the agreed value but below the recommended exceptional value of  $1000 \text{ Bq/Kg}$  [18].

### III.2 DOSE RATES

Evaluation of absorbed gamma dose rates  $\text{DR} (\text{nGyh}^{-1})$  in air 1 m above the ground was done by converting specific activity concentration to absorbed dose using the suggested conversion factors of 0.427, 0.662 and 0.043 for  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively [19]. To estimate annual individual's total risks as a result of gamma radiation exposure, the absorbed dose was modified to Annual Effective Dose Rates  $\text{AED} (\text{mSvy}^{-1})$  using guidelines and estimated Kenyan occupancy factors for indoor and outdoor exposures [7]. The average values of absorbed dose rate and annual effective dose rates in all the collected samples were tabulated as shown in Table 2.

Table 2: Radiological Results for the Tailing Samples.

Quantity	Range	Average
Radium Equivalent (Bq/kg)	$164 \pm 6.92$ to $354 \pm 16.52$	$272 \pm 12.24$
Absorbed dose rate (nGy/h)	$32 \pm 3.4$ to $68 \pm 5.83$	$52.45 \pm 5.4$
AEDR Outdoor (mSv/y)	$0.10 \pm 0.00$ – $0.40 \pm 0.02$	$0.30 \pm 0.01$
AEDR Indoor (mSv/y)	$0.20 \pm 0.01$ – $0.50 \pm 0.02$	$0.40 \pm 0.02$
$H_{\text{ex}}$	$0.50 \pm 0.02$ – $1.0 \pm 0.05$	$0.90 \pm 0.04$
$H_{\text{in}}$	$0.30 \pm 0.02$ – $1.10 \pm 0.04$	$0.80 \pm 0.03$

Source: Authors, (2020).

All the absorbed dose rates were below the recommended criterion value of  $60 \text{ nGy/h}$  except a few samples. Both the indoor and outdoor annual effective dose rates were below the recommended limit of  $1 \text{ mSv/y}$  [19]. Hence mining of gold at Rosterman has minimal health implication to the miners and the general population.

### III.3 RADIOLOGICAL HAZARD INDICES

The values for radium equivalent, internal and external hazard indices varied for each sample suggesting the non-uniform crustal distribution of natural radionuclides [20]. The average values for radium equivalent, internal and external hazard indices for the tailing samples were presented in Table 2. The mean values for radiological indices such as Radium equivalent was below the Permissible level of  $370 \text{ Bq/Kg}$  while that of external hazard index was also below the permissible limit of a unit [15]. The internal hazard index for the collected tailing samples is shown in Figure 4.

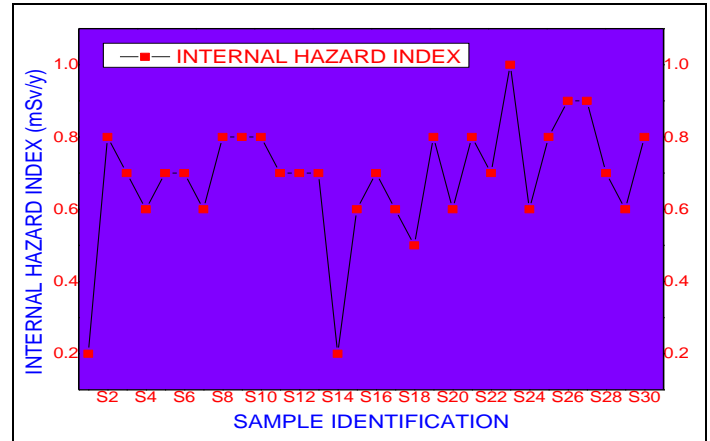


Figure 4: Internal Hazard Index for the Collected Samples. Source: Authors, (2020).

All the collected samples reported internal hazard index value below the recommended average value of  $1 \text{ mSv/y}$  (Figure 4). Since the average radium equivalent was below a permissible limit of  $370 \text{ Bq/Kg}$  [13], while internal hazard index and external hazard index were below a unit, the radiation exposure to the miners and the public due to the tailings from Rosterman gold mine was insignificant.

### IV. CONCLUSIONS

The radiological analysis of all the collected tailing samples has been evaluated. Generally, the variation in the activity concentration in the tailing samples was attributed to the differences in the minerals present in the individual sample. The average absorbed dose rate for the tailing samples was lower than the worlds reported mean of  $60 \text{ nGy/y}$ . Both indoor and outdoor AEDs for the samples analyzed were below permissible dose limit of  $1 \text{ mSv/y}$  recommended by UNSCEAR and ICRP bodies, respectively. Radium equivalent in the samples were below  $370 \text{ Bq/kg}$ , the recommended limit for a material to be considered to cause significant health hazards. The possible risks associated with exposure to gamma radiation through inhalation or direct external irradiation was examined by calculating the internal and external radiation hazard indices, which were found to be within the globally acceptable range, hence, gold mining at Rosterman has minimal health threat on the miners and the general public.

### V. AUTHOR'S CONTRIBUTION

**Introduction:** Conrad Khisa Wanyama, John Wanjala Makokha and Michael Nakitare Waswa.

**Methodology:** Conrad Khisa Wanyama and Fred Wekesa Masinde.

**Investigation:** Conrad Khisa Wanyama and John Wanjala Makokha.

**Discussion of results:** Conrad Khisa Wanyama, John Wanjala Makokha and Fred Wekesa Masinde.

**Writing – Original Draft:** Conrad Khisa Wanyama.

**Writing – Review and Editing:** Conrad Khisa Wanyama and Fred Wekesa Masinde.

**References:** Fred Wekesa Masinde, Michael Nakitare Waswa and Conrad Khisa Wanyama.

**Supervision:** John Wanjala Makokha, Fred Wekesa Masinde and Michael Nakitare Waswa.

**Approval of the final text:** Conrad Khisa Wanyama, John Wanjala Makokha, Fred Wekesa Masinde and Michael Nakitare Waswa.

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