# Radiological Assessment of the Activity concentrations of $^{40}K$, $^{232}Th$, $^{238}U$ and Exposure Levels in the Rosterman Gold Mine of Lurambi Area, Western, Kenya

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***Abstract*: Lurambi - Rosterman gold mine consist of miners who engage in daily small-scale artisanal gold mining activities. The gold mine wastes may contain naturally occurring radioactive materials (NORM) which may pose a potential health risk to this population. In this survey, thirty samples were collected from sediments in the tunnels for radioactivity measurements using the NaI(Tl) gamma ray spectrometer. The activity concentrations of $^{40}K$, $^{232}Th$ and $^{238}U$ were 262 ± 11.48, 114 ± 5.78 and 84 ± 2.64 $Bqkg^{-1}$, respectively. The mean radium equivalent for all the collected samples was 274 ± 12.90 $Bqkg^{-1}$ which is less than the recommended limit of 370 $Bqkg^{-1}$. The mean outdoor and indoor annual effective dose rates were 0.4 ± 0.02 and 0.3 ± 0.01 $mSvy^{-1}$ respectively. Since the radium equivalent was less than the recommended criterion value, mining of gold at Rosterman poses no radiological hazardous health risk to the miners and the general public.**

***Key Words:*** **Annual Effective Dose Rate, Gamma Ray Spectrometric Measurements, Secular Equilibrium**

**Subject Area: Nuclear Physics and Radiations**

## I. INTRODUCTION

Ionizing radiations may expose human beings to radiation doses from atomic species like Uranium-238, Thorium-232, Potassium-40, and their decay products which widely spread in the earth's environment. Naturally Occurring Radioactive materials (NORM) including Uranium and Thorium are found in traces in almost all types of rocks, soil, sands and Waters (1), with specific mean elemental activity concentration for uranium in rock and soil being around 30 Bq/kg (2). Previous studies show that the activity levels of $^{238}U$, $^{232}Th$, $^{40}K$ and their decay products in sediments depend on local geological composition (3), geographical conditions during rock formation and distributions in the earth crust as well as the geochemical features (2). Other scholarly work shows that natural radiation sources deliver the highest radiation dose to which human beings are exposed to (4). Uranium-238 (half-life 4.5 $x10^9$ years) is primordial radionuclides whose decay progenies contribute majorly to radiation doses (gamma rays, beta and alpha particles) in dwellings and other environs (5). Radon is a daughter radionuclide of $^{238}U$, and immediate radioactive decay product of Radium-226 (half-life of 1620 years), with a half-life of 3.8 days. When radon is formed it decays with emission of alpha particles to Polonium-218, which undergoes alpha decay to Lead-214 which emits both beta particle and a gamma ray to become Bismuth-214 in successive steps. After radon gas is formed in rocks or soils, it diffuses from its point of formation and enters the atmosphere, the extent at which radon diffuses into the atmosphere depends on the type of rock, soil matrix, water content and meteorological factors (6). Radon in the atmospheric medium may be ingested or inhaled by human beings (7).

Thorium-232 decay also enriches background radiation dose significantly by its short-lived decay products which emit both gamma and beta particles. Thoron is also referred to as Radon-220 and is a member of the Thorium-232 (half-life 1.4 x $10^{10}$ years) decay series (8). Its immediate parent is radium-224 (half-life 4.6 days). From the perspective of radiation dose to lung tissue due to inhalation, the most important airborne thoron decay product is lead-210 (half-life 10.64 hours). While lead-210 itself is a beta particle emitter when it decays in the lung, it gives rise to the alpha-emitting decay products bismuth-212 (half-life 60.5 minutes) (9)

Studies on the activity concentrations levels of natural radionuclides have been done in different parts of Kenya, Mrima Hills in the South Coast, studies shows that it's one of the regions in the country with the highest level of background radiation, with documented outdoor gamma exposure of up to 106 mSv/y (10) and absorbed dose rates of between 253 and 733nGy/h (10).The lower absorbed dose rate is over 4 times higher than the global average of 60nGy/h (5). Radiological analysis of rock and soil samples was also done in Kitui County (8), with aim of establishing the safety of sand for use as building material before harvesting. The study established that the radium equivalent activity for all samples was below the recommended limit of 370 $Bqkg^{-1}$ (11) and all the radiation hazard indices were within the accepted values thus save for exploration and use (8). Due to the variation of radionuclides levels in different environments, humans should

be aware of their immediate natural environment with regard to the radiation levels and their effects. The current research intends to assess the activity concentration levels of natural radionuclides at Rosterman gold mine, Lurambi sub – county, Kakamega county, Kenya and compare them with the global permissible thresholds.

## II. MATERIALS AND METHODS.

### *2.1 Study Area.*

The study was carried out at Lurambi Sub County which is one of the constituencies found in Kakamega County. It is bordered by Navakholo, Malava, Shinyalu, Khwisero, Mumias East, Ikolomani and Butere sub – counties. The study area is shown in Figure 2.1.

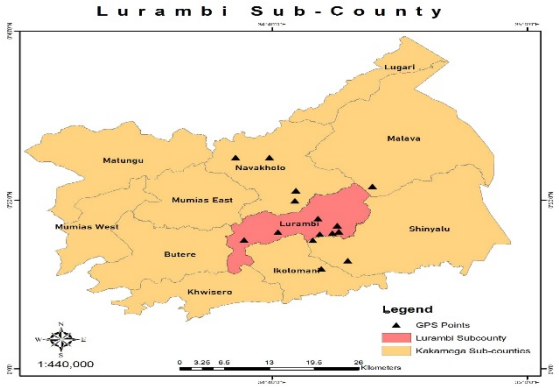


Figure 2.1: Map of the Lurambi Sub County and its Neighboring Sub Counties.

It is globally located at N00°16.964, 34° 45.112'E with approximately 420 km$^2$. The samples were collected from Rosterman gold mining site that is located in Lurambi Sub County. Figure 2.1 shows the sampling points.

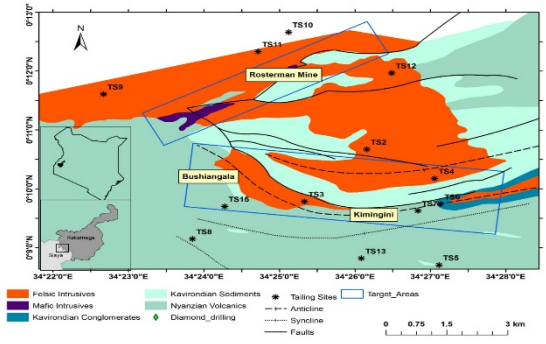


Figure 2.2: Sampling Points at the Study Area

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

### *2.2 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 sediment 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. 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 $^{238}$U and $^{232}$Th decay series to attain secular equilibrium with their long-lived parent radionuclides (12). The soil samples were each counted using a NaI (TI) gamma ray detector for a period of 30,000 S (13).

### *2.3 Instrument Calibration*

The sediment samples measurement were made by direct non-destructive instrumental analysis with a computerized gamma spectrometry system made up of NaI (TI) 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 (14). The $^{226}$Ra activities for samples assumed to be in radioactive equilibrium were estimated from $^{214}$Pb (351.92 keV) and $^{214}$Bi (609.31 keV). The gamma-ray energies of $^{212}$Bi, $^{212}$Pb and $^{228}$Ac were used to estimate activity of $^{232}$Th. The activity concentrations of 40K were measured directly by its own gamma rays (1460.81 keV).

### *2.4 Sample Analysis.*

#### *2.4.1 Activity Concentration of Radionuclides in Bqkg$^{-1}$*

Equation 2.1 is the analytical equation that was used in the calculation of the radionuclide activity concentrations in Bqkg$^{-1}$ (13).

$$A_c = \frac{N_D}{p.n.m} \quad \text{.....(2.1)}$$

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).

#### *2.4.2 Annual Effective Dose Rate (AED).*

To determine the hazardous levels of the radionuclides, the absorbed dose rates in all the samples were converted to annual effective dose rates. Annual effective dose rate due to radioactivity in the sediments was determined by considering the conversion factor of 0.7 Sv/Gy (7). This conversion factor was used in the conversion of the absorbed dose in the air to effective dose by adults. The average fraction of time spent indoor and outdoor (occupancy factors) in Kenya are 0.6 and 0.4, respectively (15). The indoor and outdoor annual effective doses were calculated by using the given equations:

$$E_{in}(mSvy^{-1}) = D(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.8 \times 0.7(SvGy^{-1}) \times 10^{-6} \text{.....(2.2)}$$

$E_{out}$ (mSv $y^{-1}$) = D (nGyh$^{-1}$) x 8760(h $y^{-1}$) x 0.4x0.7 (SvGy$^{-1}$)x$10^{-6}$……..……(2.3)

Where; $E_{in}$ and $E_{out}$ are Annual Effective Doses for indoor and outdoor respectively, D (nGyh$^{-1}$) is the absorbed dose rate in air, 8760(h $y^{-1}$) is the time in hours for one year, 0.7 (SvGy$^{-1}$) is the conversion factor which converts the absorbed dose rate in the air to effective dose, 0.6 is the indoor occupancy factor and 0.4 is the outdoor occupancy factor (16).

*2.4.3 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. 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 (17). The internal hazard index was calculated using equation 2.4 while external hazard index was determined using equation 2.5 as given below (18);

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.4)$$

$$H_{Ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

Where $C_{Ra}$, $C_{Th}$, and $C_K$ represent the mean activity concentrations of radionuclides in Bqkg$^{-1}$

## III. RESULTS AND DISCUSSION

*3.1 Activity Concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ Radionuclides.*

The values of activity concentrations of radionuclides $^{238}$U, $^{232}$Th and $^{40}$K in sediment samples from Rosterman gold mine were computed. The minimum activities of $^{238}$U, $^{232}$Th and $^{40}$K calculated were 39±1.95, 78±3.94 and 88 ± 4.4 Bqkg$^{-1}$ and the maximum values were 117±5.87, 227±11.38 and 369±18.45 Bqkg$^{-1}$ respectively. The average concentrations of $^{40}$K, $^{232}$Th and $^{238}$U, in the samples were 262 ± 11.48, 114 ± 5.78 and 84 ± 2.64 Bqkg$^{-1}$respectively. The activity concentration of $^{232}$Th in all the collected samples is shown in Figure 3.1.

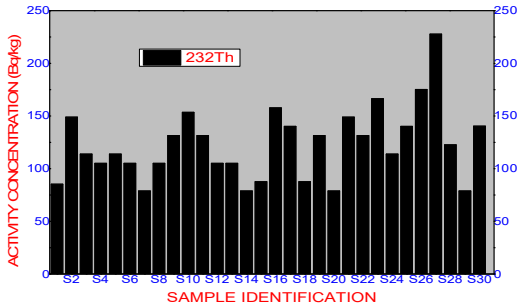


Figure 3.1: Activity Concentration Levels of $^{232}$Th (Thorium – 232) Radionuclide

From Figure 3.1, all the activity concentrations of $^{232}$Th in the collected samples were below 1000 Bqkg$^{-1}$ which is the exceptional limit (19).

*3.2 Annual Effective Dose Rates*

The calculated absorbed dose rate in air at a height of 1 m above the ground level obtained from different sampling points ranged from 36.8 ± 4.5 to 72.1 ± 6.8 nGyh$^{-1}$ with an average of 52.6 ± 5.4 nGyh$^{-1}$. This value was lower than the worldwide average of 60 nGyh$^{-1}$ (20). These values of absorbed dose rate were then converted to annual effective dose rates. The annual effective dose rates in all the samples were calculated using equation 2.2 and 2.3. The average indoor and outdoor annual effective dose rates were 0.4±0.02 and 0.3±0.01 mSvy$^{-1}$ respectively. These values are less than the average annual effective dose rate of 1 mSvy$^{-1}$ which is recommended for the public exposure (21). Figure 3.2 shows the comparison between indoor and outdoor annual effective dose rates.

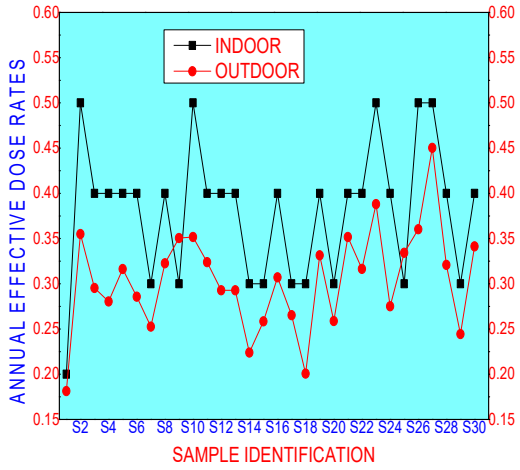


Figure 3.2: Comparison of Indoor and Outdoor Annual Effective Dose Rates.

The annual effective dose rates in all the collected samples were less than a unit. The maximum indoor and outdoor annual effective dose rates were 0.5 ± 0.01 mSvy$^{-1}$ and 0.45 ±0.02 mSvy$^{-1}$ respectively (Figure 3.2). From all the collected sediment samples, the minimum indoor and outdoor annual effective dose rates were 0.2 ± 0.01 mSvy$^{-1}$and 0.18 ± 0.00 mSvy$^{-1}$ respectively (Figure 3.2). All these values are less than one unit and therefore, mining of gold at Rosterman has minimal health risks to the miners and the general population.

*3.3 Hazard Indices*

For any sediment to have insignificant hazardous effect due to radiation, the $H_{ex}$ index should be less than 1 mSvy$^{-1}$, which is equivalent to 370 BqKg$^{-1}$ (22). The average external and internal hazard indices for the tailing samples were 0.70 ± 0.03 mSvy$^{-1}$ and 0.80 ± 0.03 mSvy$^{-1}$ respectively (Table 3.1).

Table 3.1: Comparison of Internal and External Hazard Indices with their Permissible Values.

| | Hazard Indices | | |
|---|---|---|---|
| | Range | Average | Permissible Limit |
| Internal | 0.50 ± 0.02 –1.0 ± 0.05 | 0.80±0.03 | 1 (21) |
| External | 0.40±0.02– 0.90± 0.04 | 0.70±0.03 | 1 (11) |

Since the recorded averages for both internal and external indices were less than a unit (Table 3.1), mining of gold at Rosterman does not expose miners and the general public to significant harmful health effects due to inhalation of decay daughters from $^{238}U$ and $^{232}Th$ decay series and direct gamma radiation from $^{40}K$ species.

## IV. CONCLUSION

The activity concentration of the three radionuclides $^{238}U$ and $^{232}Th$ at Rosterman gold mine was higher than the world average value except for $^{40}K$. However, these values are within the exceptional limit recommended by ICRP. The absorbed dose rate due to gamma radiation from natural radioactivity was below the global average of 60 $nGyh^{-1}$. Both the external and internal hazard indices were less than a unit. Hence, mining of gold at Rosterman has minimal health risk to the miners and the general public.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this paper

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