Activity Concentration Levels of Natural Radionuclides in the Sediment Samples from Rosterman Gold Mine, Lurambi Sub – County, Kakamega County, Kenya

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Abstract: **Rosterman, located in Lurambi sub - county, Kakamega County, Western Kenya consists of gold mining that is done locally (artisanal gold mining). The activity concentration of ^{238}U, ^{232}Th and ^{40}K in sediment samples from the wastes of gold mining were determined by gamma ray spectrometry using NaI (Tl) detector and decomposition of measured gamma-spectra. As a measure of radiation hazard to the general population, gamma radiation dose rates were also evaluated. The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K were 85±2.24, 114±5.78and 260±12.18Bqkg^{-1}, respectively. The mean absorbed dose rate in air was 52.5±4.2nGyh^{-1} while the annual average effective dose rate for indoor and outdoor were 0.4±0.02 and 0.3±0.01mSvy^{-1} respectively. The absorbed dose rate due to gamma radiation from naturally occurring radioactive materials was below the global average value of 60 nGyh^{-1}. Hence, mining of gold at Rosterman has minimal hazardous health implication to the general public.**

Key words: **Activity concentration, Dose rate, Gamma ray spectrometry, Natural radionuclides, Radiological parameters**

Subject area: **Nuclear physics**

I. INTRODUCTION

Mining has been identified as one of the potential sources of exposure to NORM (1). Mining leads to the production of large quantities of wastes, which pollutes soil over a large surface area (2). Therefore, they impact the environment and human health negatively (2). The decay series of ^{238}U, ^{232}Th, and ^{40}K highly contribute to the rise in the concentration of the NORMS in the environment (3). Thus, knowledge of ^{238}U, ^{232}Th, and ^{40}K decay activities are useful in analyzing the absorption doses and evaluating the radiological hazards. The decay activity of these primordial radioisotopes progresses until a stable nuclide is formed (4). Other artificial activities that may lead to elevation of radiation levels besides mining are the use of phosphate fertilizers in farming, trace elements in agriculture and in medical practices (3).

Radioactive materials decay spontaneously and produce ionizing radiation, which may have sufficient energy to strip away electrons from atoms creating two charged ions or to break some chemical bonds (5). Therefore, any living tissue in the human body can be damaged by ionizing radiation in a unique manner. All ionizing radiation causes similar damage at cellular level. Because beta(β) and alpha(α) are relatively non penetrative, external exposure does not cause a lot of damage however, they become more dangerous when swallowed (6). The penetrative power of gamma radiation makes it be absorbed in the body and thus can easily cause radiation effects (7). It is worthwhile to note that exposure to the radiation doses should be kept as low as reasonably achievable (1).

Human beings have always been exposed to ionizing radiations of natural origin, namely terrestrial and extra-terrestrial radiation (6). Radiation of extra-terrestrial origin is from high energy cosmic ray particles and at sea level it is about 30 nGyh^{-1} (4), while that of terrestrial origin is due to the presence of naturally occurring radionuclides; mainly ^{40}K, rubidium and the radionuclides in the decay chains of ^{232}Th and ^{238}U (6). These radionuclides have half-life comparable to the age of the earth. Gamma radiation from these radionuclides represents the main external source of irradiation of the human body. Natural radioactivity in geological materials, mainly rocks and soil, comes from ^{232}Th and ^{238}U series and natural ^{40}K. Artificial radionuclides such as ^{137}Cs which result from weapon testing and the Chernobyl nuclear accident could also be present (3). The levels due to the terrestrial background radiation are related to the types of rock from which the soils originate. Higher radiation levels are associated to igneous rocks such as granite and lower levels with sedimentary rocks (8). There are some exceptions however, since some shales and phosphate measurement of natural radioactivity is crucial in implementing precautionary measures whenever the source is found to exceed the recommended limit (1). The present study aims at investigating naturally occurring radioactive elements and exposure levels to ionizing radiation at the Rosterman gold mine, Kakamega county Kenya.

II. MATERIALS AND METHODS

2.1 Study Area

The current studywas conducted in Lurambi Sub County where the Rosterman gold mine site is situated. It is 3.4 km from Kakamega town. It is globally located at 0°17.569 N, 34°39.812E with approximately 420 km^2. The sampling points are shown in Figure 2.1

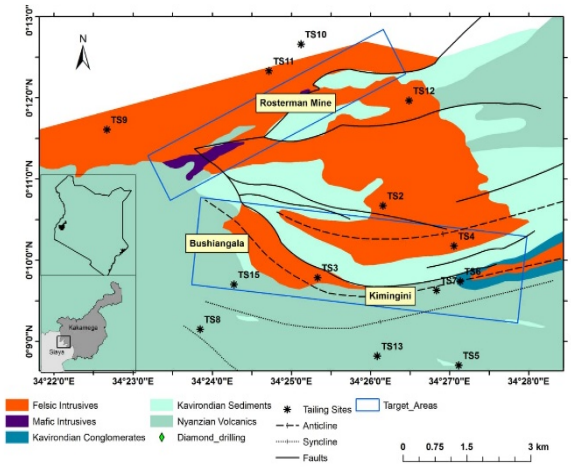

Figure 2.1: Map of the Study Area

The area of research was identified because of numerous human activities that may result in exposure to natural radioactivity levels to workers and the population at large.

2.2 Sample Collection and Preparation

A total of thirty sediment samples were randomly collected within a radius of 2 km from Rosterman gold mine site at a depth of 8 to 12 cm. Figure 2.1 shows the sampling points in the study area. The samples were oven dried at 110°C to remove the moisture content and ground to ensure homogeneity. The dried samples were sealed in thick walled water and air tight plastic containers and kept for 28 days to achieve radioactive equilibrium between ^{226}Ra and ^{232}Th and their daughter radionuclides (9).

2.3 Instrument Calibration

Calibration of NaI(Tl) 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). Energy calibration of the spectrometer was performed using the following gamma-lines: ^{214}Pb (352 keV), ^{40}K (1460 keV), ^{214}Bi (609 keV), and ^{208}Tl (2615 keV)., The background count in the spectrum was determined by counting distilled (de-ionized) water in the same geometry as was for the sample. This background spectral data was always subtracted from the counts obtained for each sample before further analysis. The time of acquisition of data for each sediment sample was 36000 s.

2.4 Sample Analysis

2.4.1 Activity Concentration

Equation 2.1 is the analytical equation used in the calculation of the specific radionuclide activity concentrations in Bqkg^{-1} (11)

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

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

2.4.2 Absorbed Dose Rate

Radiation emitted by a radioactive substance is absorbed by any material it encounters (1) has given the dose conversion factors for converting the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (nGyh-1 per Bqkg-1) as 0.427, 0.662 and 0.043, respectively. Using these factors, the total absorbed dose rate in air was calculated using Equation (2.1) (4).

$$D = (0.427C_{Ra}+0.662C_{Th} + 0.043C_K)\ nGyh^{-1} \quad (2.2)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations (Bqkg-1) of Radium, Thorium and Potassium, respectively in the sediment samples.

2.4.3 Annual Effective Dose Rate

To determine the annual effective dose (AED), took into account the conversion coefficient, (0.7 SvGy-1) from the absorbed dose in air to effective dose and the outdoor occupancy factor (~ 20 %) (4). The average fraction of time spent indoor and outdoor (occupancy factors) in Kenya are 0.6 and 0.4, respectively (12). The world average indoor and outdoor occupancy factors are 0.8 and 0.2, respectively (3). The effective dose rate in units of mSvy-1 were estimated by using equation 2.3 and 2.4 (13);

$$E_{in}(mSvy^{-1})=D(nGyh^{-1})x8760(hy^{-1})x0.6x0.7(SvGy^{-1})x10^6 \quad (2.3)$$

$$E_{out}(mSvy^{-1})=D(nGyh^{-1})\ x\ 8760(h\ y^{-1})\ x\ 0.4\ x\ 0.7(SvGy^{-1})x10^{-6} \quad (2.4)$$

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 (14).

III. RESULTS AND DISCUSSION

3.1. Activity Concentration of the Radionuclides

The general activity of ^{226}Ra, ^{232}Th and ^{40}K in the collected sediment samples were in the range of 39 ± 1.95 to 117 ±

5.87, 78 ± 3.94 to 227 ± 11.38 and 88 ± 4.4 to 369 ± 18.45 Bqkg^{-1}, respectively (Table 3.1).

Table 3.1. Range of Activity Concentrations of the Radionuclides

	Activity concentration values		
Radionuclide	^{226}Ra	^{232}Th	^{40}K
Maximum	117±5.87	227±11.38	369±18.45
Minimum	39±1.95	78±3.94	88±4.4

There was no particular relationship between activity of the radionuclides and depth of the point of collection of the sample. This could be attributed to the fact that there was mixing of rock debris during mining of gold. In the sediment samples, ^{40}K had the highest activity concentration, which is a normal behaviour of its composition in sedimentary and igneous rocks.

The average values of ^{226}Ra and ^{232}Th were higher than the world wide average activity concentrations which are 35 and 30 Bqkg^{-1} respectively, except for ^{40}K which was below 400 Bqkg^{-1} (15). Figure 3.1 shows comparisons between the average activity concentrations of the radionuclides ^{40}K and ^{232}Th in the samples collected.

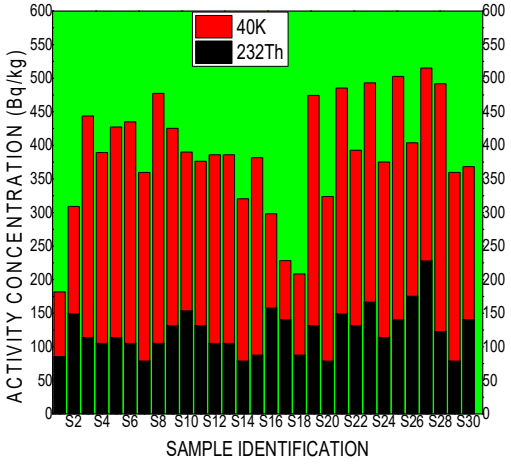

Figure 3.1: Comparison of Activity concentration of ^{40}K and ^{232}Th Radionuclides.

The variation of natural radioactivity levels at different sampling sites was due to the variation of concentrations of radionuclides in the geological formations. The younger granites represent the highest elevation while the older rock is relatively low. The Presence of such high radioactivity in younger granites may be attributed to the presence of relatively increased amount of accessory minerals such as zircon, iron oxides, fluorite and other radioactive related minerals (16).

3.2 Absorbed Dose Rates

The calculated average absorbed dose rates due to the presence of ^{226}Ra, ^{232}Th and ^{40}K for the collected samples was 52.5±4.2nGyh^{-1}. This is lower than the world average of 60 nGyh^{-1} (17). The calculated absorbed dose rates for all the thirty collected samples are shown in Figure 3.2.

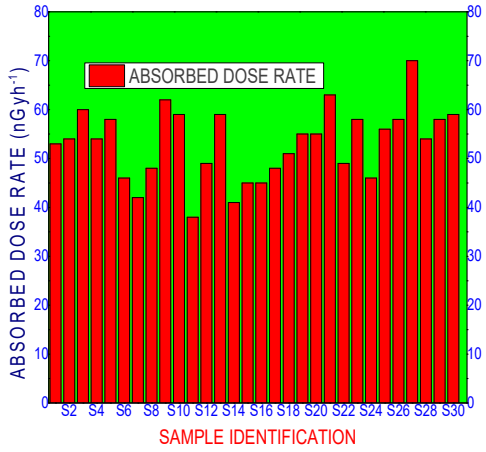

Figure 3.2: Absorbed Dose Rates of the Collected Sediment Samples

From Figure 3.2, the maximum and minimum absorbed dose rates for the collected sediment samples were 70 ± 6.17 and 38± 4.59 nGyh^{-1} respectively. Most of the samples recorded values that were less than recommended dose criterion value except a few samples posted values greater than 60 nGyh^{-1} (17). This was due to non – uniform distribution of the natural radionuclides in the sediments. However, the absorbed dose rates were then converted to annual effective dose rates to determine their hazardous levels.

3.3 Annual Effective Dose Rates

The annual effective dose rates in all the collected samples were calculated using equation 2.3 and 2.4. The average indoor and outdoor annual effective dose rates were 0.4±0.02 and 0.3±0.01mSvy^{-1} respectively. These values are less than the average annual effective dose rate of 1 mSvy^{-1} which is recommended for the public exposure (18). However, care has to be taken since it is believed that radiation at any level poses a risk (19). The range of the calculated annual effective dose rates are shown in Table 3.2.

Table 3.2. Annual Effective Dose Rates of the Collected Samples

	Annual Effective Dose Rate values		
	Minimum	**Maximum**	**Average**
Indoor	0.2±0.01	0.5±0.02	**0.4±0.02**
Outdoor	0.1±00	0.4±0.02	**0.3±0.01**

From Table 3.2, the maximum and minimum values of both indoor and outdoor annual effective dose rates were below the recommended limit of 1 mSvy^{-1} (17). Hence mining of gold at Rosterman has minimal significant health risk to the miners and the general public.

IV. CONCLUSIONS

The activity concentrations of ^{226}Ra and ^{232}Th were all found to be above the world's average except ^{40}K. In all samples, ^{40}K had the highest activity concentration. The calculated average absorbed dose rate in air due to gamma-ray emitters in the Rosterman gold mine was less than the recommended average value of 60 $nGyh^{-1}$. The mean values for both indoor and outdoor annual effective dose rates were less than one unit, the criterion value recommended by ICRP. Therefore, mining of gold at Rosterman poses minimal health threats to the miners and the general population. Further research should be done at the same study area to determine the activity concentration levels of natural radionuclides in the newly excavated sediments.

ACKNOWLEDGEMENT

We appreciate Kenyatta university physics department for the gamma spectrometric analysis of the samples. Kibabii university; science, engineering and technology department for providing materials that were used for sample collection

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this article.

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