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Radiometric Analysis Of Natural Radioactivity Levels Of Tailings From Rosterman Gold Mine, Western Kenya

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***Abstract*— Radiological hazards associated with naturally occurring radionuclides materials from Rosterman gold mine was assessed after thirty samples were analyzed. In this radiometric survey, gamma ray spectrometric analysis of tailing samples reported an average activity concentration of 245±12.39 Bqkg^{-1}; 110±5.15 Bqkg^{-1}, 84±4.23 Bqkg^{-1} for ^{40}K, ^{232}Th and ^{238}U respectively. The average absorbed dose rate was 53.65±6.2 nGy^{-1}, the annual effective dose of 0.4±0.02 $mSvy^{-1}$ for indoor and 0.3±0.01 $mSvy^{-1}$ for outdoor were reported. The average values of radiological parameters were 0.7±0.03 $mSvy^{-1}$, 0.9±0.04 $mSvy^{-1}$ and 278±13.08 Bq/Kg for internal hazard index, external hazard index and radium equivalent respectively. Since all the radiological parameters were within the recommended permissible limits, mining of gold at Rosterman has no significant radiological health implication on the miners and population around.**

Keywords—: NaI(TI) spectrometry; Radiological Parameters; Naturally Occurring Radioactive Materials.

1. INTRODUCTION

Naturally occurring radioactive materials (NORMs) has existed in the environment around us since the formation of the earth [1]. This implies that all living organisms in the universe are exposed to ionizing radiation from natural and artificial sources. Geological materials such as rocks, sand, sediments, water, soil and tailing wastes from mining contributes significantly to the radiation exposure [2]. The availability of these radiations in the environment is always at levels that are not potentially harmful to human life. A major concern arises when the levels are raised due to human activities such as mining and natural hazards such as earth quakes [3].

Mining involves extraction and disposal of large quantities of wastes containing radionuclides in the decay series of ^{232}Th and ^{238}U and ^{40}K. Miners may experience internal exposure as a result of radon, thoron and their short – lived decay products, radionuclides in ingested and air bone dust [4]. The miners may also experience exposure due to extraction, transportation and processing of the minerals such as gold. The exposure of the general public living around the mining sites may be as a result of ingestion through drinking water or uptake through food chain [5]. Exposure to the public may also be as a result of use of mine wastes (mine waters and tailings) in construction [6].

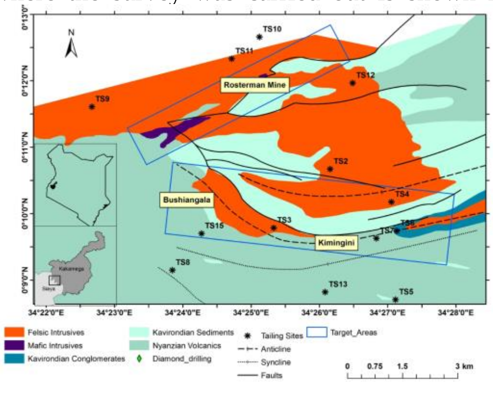
The NORMs produced from mining activities continue to decay until a stable nuclide is formed. In this decay process, ionizing radiation that is produced causes biological damage to human organs [7]. Radiological surveys have shown high mortality rates from Europe. More human evidence of the harmful nature of ionizing radiation was also reported by early radiological studies [8]. These studies have shown consistence carcinogenic properties of ionizing radiation. Survivors of the Hiroshima atomic bomb exposed to radiation above one milli sievert showed a significant increase in the incidence of leukemia [9].

Extensive work has been carried out in many nations to assess the radiological impacts of technologically enhanced radioactivity on human beings and the environment. In Kenya, previous radiological studies in rocks, sand, water and mining sediments show both low and high levels of environmental radioactivity [10], [2]. Most workers at the artisanal gold mining sector and the general public are unaware of the problems associated with the correlation between NORM and mining. In this study, a radiological survey and the associated radiological hazards at the Rosterman gold mine was determined using the NaI(TI) gamma ray detector. From the radiological parameters, the health implications of the gold mine to the population were then evaluated.

2. MATERIALS AND METHODS.

2.1 Survey Area

The study area is a gold mining area situated in Western Kenya, Kakamega County. The Rosterman gold mine site is therefore situated in Lurambi sub-county, Kakamega municipality and 3.4 km from Kakamega town. Lurambi Sub County is one of the elective constituencies in Kenya situated in Kakamega County. It is bordered by Ikolomani constituency to the south and globally located at 0° 31.08 N, 34° 75.18E with approximately 420 km^2. The population projection of Lurambi Sub County was estimated at 297,394 people according to the 2019 population census. The area where the survey was carried out is shown in Figure 2.1



- Figure. 2.1: Map of Rosterman Gold Mine Site

- Currently, the population may have increased due to birth rates and increased job opportunities as a result of the presence of the Rosterman gold site.

2.2 Sample Preparation

- Thirty tailing waste samples were collected randomly from Rosterman gold mining site, Lurambi Sub-County, Kakamega County, Western Kenya. Each sample was then collected at a depth of 50 cm and had a net weight of 0.3 kg. Each raw sample was temporarily packed into 500g plastic bottle well coded with date of collection, sample identification number and tunnel number. The plastic bottles were sealed to avoid leakage and contamination. The samples were then dried under sunlight independently and ground to ensure homogeneity. The samples were then sieved with a 2 mm mesh wire and then packed in water and air tight 300g plastic containers and kept for at least thirty days in order to establish secular equilibrium among some progenies of ^{232}Th and ^{238}U series [11].

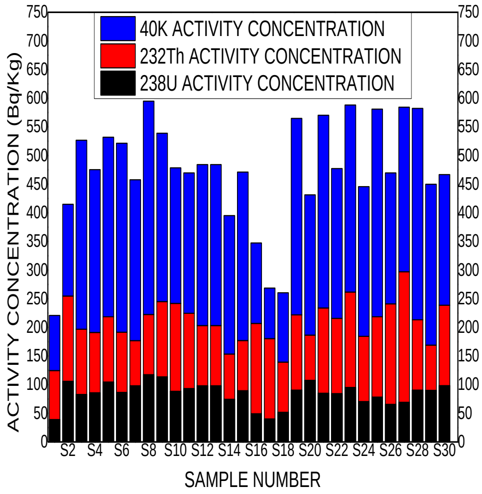
2.3 Instrument Calibration

- In this study a NaI(TI) gamma ray spectrometer was used to determine the radionuclides of interest and their corresponding abundance [12]. The calibration was done by the standard materials obtained from the international atomic energy agency whose activities are 4900 Bq/Kg for RGU-1, 3280 Bq/Kg for RG Th-1 and 13400 Bq/Kg for RGK-1 [13]. Two tailing samples were run per day for a live time of eight minutes each. The activity concentration of ^{232}Th and ^{226}Ra were determined assuming a secular equilibrium with their decay products. The gamma energy transitions of 609.2 keV for ^{214}Bi and 351.9 keV for ^{214}Pb were used to determine the concentrations of ^{238}U series. The gamma energy transition of 583 keV for ^{208}Tl was used to determine the concentrations of ^{232}Th series. The activity concentration of ^{40}K was determined from a photo peak of 1460keV.

3.0 RESULTS AND DISCUSSION

- 3.1 Activity Concentration of ^{238}U, ^{232}Th and ^{40}K in Tailing Samples
- The mean activity concentrations for each tailing sample were calculated using equation 3.1, [14]

- $A_c = \frac{N_D}{p.n.m}$ (3.1)
- Where A_c is the specific activity concentration in Bqkg^{-1} for each sample, N_D is the net count rate at energy E_γ , p is the gamma-ray emission probability for a transition at energy E_γ , η is the photo peak detection efficiency at specific gamma-ray energy E_γ and m is the mass of the tailing sample in kg.
- The results for the activity concentration of the three radionuclides (^{232}U, ^{232}Th and ^{40}K) were then compared as shown in Figure 3.1 below.



- Figure 3.1: Comparison of activity concentration of ^{40}K (Pottassium-40), ^{238}U (Uranium-238) and ^{232}Th (Thorium-232) in the collected tailing sample at Rosterman gold mine.
- The activity concentration results from this study are presented in Figure 3.1. It presents varying levels of ^{232}Th from sampled tailings, implying that the spread of natural radionuclides is not uniform in the earth's crust. The crustal abundance of ^{40}K in the surveyed area was generally high compared to ^{232}Th and ^{238}U, which is a common geological occurrence in most of the crustal sediments [15]. The mean activity concentrations of ^{40}K, ^{232}Th and ^{238}U for the 30 tailing samples averaged were 245 ± 12.39 Bq/Kg, 110 ± 5.15 Bq/Kg and 84 ± 4.23 Bq/Kg respectively. The activity concentration of ^{238}U and ^{232}Th were above the world's average of 35 Bqkg^{-1} and 45 Bqkg^{-1} respectively, while that of ^{40}K was below the world's mean of 400 Bqkg^{-1} [16]. The reported averages were within the documented world's exemption levels of 1000 Bq/Kg for ^{232}Th and ^{238}U [17].

3.2 Radium Equivalent (Ra_{eq}) in Tailing Samples

- Determination of gamma-ray emission from different radionuclides of ^{238}U, ^{232}Th and ^{40}K was done using NaI(TI) spectrometer was calculated using equation 3.2, [18].
- $Ra_{eq} = C_{Ra} + 1.423 C_{Th} + 0.077 C_K$ (3.2)
- Where C_{Ra}, C_{Th} and C_K are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.
- The average and the ranges of radium equivalent in tailing samples are recorded in Table 3.1. The reported mean radium equivalent for all the tailing samples was 278 ± 13.08 Bqkg^{-1}. Radium equivalent indices for all the samples were below the recommended level of 370 Bq/kg, [19], and thus the mining of gold at Rosterman has no radiological harm to the population carrying out artisanal mining.

3.3 Absorbed Dose Rate

- Absorbed dose rate (D) was estimated from the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K using equation 3.3 and conversion factors (nGy^{-1} per $Bqkg^{-1}$) of 0.427, 0.662 and 0.043 for ^{226}Ra, ^{232}Th and ^{40}K, respectively [20].
- $D(nGyh^{-1}) = 0.427C_{Ra} + 0.662C_{Th} + 0.043C_K$ (3.3)
- The activity to dose conversion factor of (0.427) ^{238}U is appropriate for ^{226}Ra since at secular equilibrium their decay rate is the same [21].

Parameter	Range	Average
Ra_{eq}(Bq/Kg)	168 ± 8.42 – 358 ± 16.68	278±13.08
Absorbed dose rate (nGy/h)	38 ± 4.98 – 78± 9.17	53.65±6.2
AEDR Outdoor (mSv/y)	0.10 ± 0.00 – 0.40 ± 0.02	0.30 ± 0.01
AEDR Indoor (mSv/y)	0.20 ± 0.01 – 0.50 ± 0.02	0.40 ± 0.02
H_{ex}	0.50 ± 0.02 – 1.1 ± 0.05	0.90 ± 0.04
H_{in}	0.40 ± 0.02 – 1.0 ± 0.05	0.70 ± 0.03

- Table 3.1: Analytical results for all the collected tailing samples.

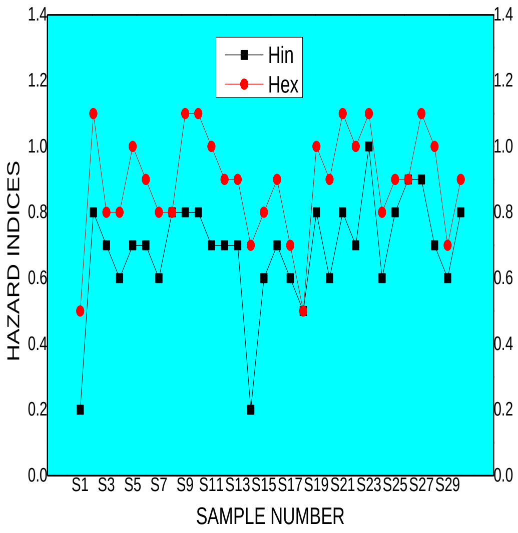
- The data in table 3.1 shows that the absorbed dose from the tailing samples varied from 38 ± 4.98 $nGyh^{-1}$ to 78 ± 9.17 $nGyh^{-1}$ with an average of 53.65 ± 6.2 $nGyh^{-1}$. This is below the world's average value of 60 $nGyh^{-1}$ [22].

3.4 Annual Effective Dose Rate

- The annual effective dose rate (AEDR) was evaluated using equation 3.4, [23]
- $E = D \times T \times Q \times 10{-}6$ (3.4)
- Where *E*, *D*, *T* and *Q* are the AEDR, dose rate, occupancy time and dose-conversion factors, respectively. UNSCEAR recommends the use of occupancy factors of 0.2 and 0.8 for calculation of the global annual mean outdoor and indoor effective dose rates, respectively. However, in Kenya, most adults spend ~40% of their time outdoors and 60% indoors. Therefore, the constants 0.6 and 0.4 were used as the time fractions for the indoor and outdoor occupancy factors in determination of internal and external annual effective doses. Due to the difference in fractions of time spent indoors and outdoors, equation 3.4 was modified using occupancy factors of 0.6 and 0.4 for indoor and outdoor AEDR, respectively, to give equations 3.5 and 3.6, [24].
- $E_{in}(mSvy{-}1) = D(nGyh{-}1) \times 8760(hy{-}1) \times 0.6 \times 0.7(SvGy{-}1) \times 10{-}6$ (3.5)
-
- $E_{out}(mSvy{-}1) = D(nGyh{-}1) \times 8760(hy{-}1) \times 0.4 \times 0.7(SvGy{-}1) \times 10{-}6$ (3.6)
- Where E_{in} and E_{out} are the indoor and outdoor AEDR, respectively, *D* is the absorbed dose rate, 8760 hy^{-1} is the time expressed in hours for 1 y, 0.7 ($SvGy^{-1}$) is the dose conversion factor and 0.6 and 0.4 are the indoor and outdoor occupancy factors, respectively. To estimate effective individual's annual exposure and evaluate total risks due to radiation and radionuclides intake, the absorbed dose was converted to the effective dose (AEDR) using mathematical construct suggested by International Commission on Radiation Protection, [16]. The findings for this work report a mean indoor AEDR for the tailing samples of 0.40 ± 0.02 mSvy−1, which is below the world's average of 0.41 $mSvy^{-1}$ and the corresponding permissible limit of 1 $mSvy^{-1}$. The average outdoor AEDR was 0.3 ± 0.01 $mSvy^{-1}$ (Table 3.1). The mean level of indoor AEDR suggests that the mining of gold from Rosterman poses no radiological health threat to population mining and residing at the mining site [25]. The mean of outdoor AEDR was below the safety limit of 1 $mSvy^{-1}$, suggesting that the human population interacting with the tailings are safe from harmful effects associated with elevated doses of radiations.

3.5 Internal and external hazard indices

- The external hazard index Hex estimates the potential radiological hazard posed by different tailing samples. The internal exposure to radon and its daughter products is quantified by the internal hazard index, Hin. The calculation of internal hazard index was done using equation 3.7, [26]
- $H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1$ (3.7)
- Where C_{Ra}, C_{Th} and C_K are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in $BqKg^{-1}$ respectively.
- The external hazard index was estimated from Raeq equation which caps Ra_{eq} at 370 $BqKg^{-1}$ as given in equation 3.8, [27].
- $H_{Ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1$ (3.8)
- For any material to have insignificant hazardous effect due to radiation, the Hex index should be less than 1 $mSvy^{-1}$, which is equivalent to 370 $BqKg^{-1}$ [28]. The average internal and external hazard indices for the tailing samples were 0.70 ± 0.03 $mSvy^{-1}$ and 0.90 ± 0.04 $mSvy^{-1}$ respectively (Table 3.1). The range of both internal and external hazard indices is shown in Figure 3.2



- Figure 3.2: A comparison of internal and external hazard indices of the collected tailing samples at Rosterman gold mine.

- 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 predispose the miners and the general public to harmful health effects due to direct gamma radiation from ^{40}K species and inhalation of decay daughters from ^{238}U and ^{232}Th decay series.

4.0 CONCLUSION

- 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 relative abundance trend in activity concentration due to naturally occurring radionuclides was ^{40}K > ^{232}Th > ^{226}Ra. The average absorbed dose rate for the tailing samples was lower than the worlds reported mean of 60 nGy/y. Both indoor and outdoor AEDRs for the samples analyzed were below the world's average of 0.41 mSv/y and permissible dose constraint of 1 mSv/y. Mean Radium equivalent in the samples was below 370 Bq/kg. 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. Based on the present results, gold mining at Rosterman has no health hazardous effect on the miners and the general public.

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CONFLICT OF INTEREST

- The author declares no conflict of interest regarding publication of this paper.

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