ASSESSMENT OF RADIATION EXPOSURE LEVELS ASSOCIATED WITH GOLD MINING IN SAKWA WAGUSU, BONDO DISTRICT, KENYA

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Abstract
The concentrations and distribution of natural radionuclides in soils from Sakwa Wagusu area, Kenya were investigated with an aim of evaluating the environmental radioactivity and radiological health hazard. Thirty nine rock and soil samples were collected from ten sites of Sakwa Wagusu area, Bondo district to measure their natural radioactivity concentrations due to ^{226}Ra, ^{232}Th and ^{40}K radionuclides. Measurements were done by use of gamma spectrometry method with a high purity germanium (HPGe) detector. To evaluate the radiological hazard of the natural radioactivity, the radium equivalent activity, the external hazard index, internal hazard index, the absorbed dose rate and the effective dose rate were calculated and compared with internationally approved values. The calculated radio activities for ^{226}Ra ranged from 7.2 – 113.8 Bqkg^{-1} (mean: 44.2Bqkg^{-1}), for ^{232}Th, 4.6 – 100.7 Bqkg^{-1}(mean: 40.3Bqkg^{-1}) and 119.3 – 1611.8Bqkg^{-1} (mean: 639.6Bqkg^{-1}) for ^{40}K. The mean absorbed dose rate for the ten pits/mines, measured at 1m below the surface was 141.6nGyh^{-1} while the mean calculated total absorbed dose rates was 69.8nGyh^{-1}. The natural activity values were more than the accepted world average values; hence this area should be considered High Background Radiation Area (HBRA). The radium equivalent activity values of all samples were lower than the limit of 370Bqkg^{-1}. The calculated mean outdoor effective dose rate was 0.17mSvy^{-1} and which is less than 1mSvy^{-1} upper limit recommended for the public by ICRP. An excess cancer risk of 0.02% was achieved with an assumption of 30% occupancy factor, the mean annual effective dose rate of 0.17mSvy^{-1}. It is recommended that proper ventilation be put in the buildings in this area.

Key words: Natural radioactivity, exposure, Gamma-ray spectrometry, Sakwa Wagusu, activity

1.0 Introduction

Radionuclides have always been present in the natural environment. The main natural contributors to external exposure from gamma-radiation are the uranium and thorium series, together with potassium 40 (^{40}K) wherever universally present in small quantities in the earth and in the building materials. Long-lived radioactive elements such as uranium, thorium and potassium and any of their decay products, such as radium and radon are examples of Naturally Occurring Radioactive Materials (NORM). These elements have always been present in the earth's crust and atmosphere. Throughout the history of life on earth, organisms have been continuously exposed to cosmic rays in the atmosphere, and from naturally occurring radionuclides which are ubiquitously distributed in all living and non-living components of the biosphere (Wicker and Schults, 1982).

A wide range of activity concentrations in a wide variety of materials is reported (IAEA-TECDOC-1660, 2011). Examples of ores that have been found to be associated with elevated radionuclide concentrations include those of uranium, tin, tantalum, niobium, rare earths, aluminium, copper, gold and phosphate. The mining and processing of these ores can lead to further increases in radionuclide concentrations in the products, by-products or residues (IAEA-TECDOC-1660, 2011).

Natural atmospheric radioactivity is determined by the concentration of radon and its daughter elements in air. Radon is formed in the decay chain of naturally occurring primordial radionuclides ^{238}U, ^{232}Th and ^{235}U present in the earth's crust. When radon is formed, it may diffuse from the rocks and soils to enter the atmosphere. The extent to which radon will diffuse into the atmosphere depends on the geological (type of rock or soil matrix, water content) and meteorological (atmospheric temperature, pressure) factors (Schery *et al.*, 1998; Nazaroff, 1992; Schubert *et al*., 2002; Sannappa *et al.*, 1997, 1999; UNSCER, 1993). Radioactivity is due to alpha (α), beta (β) and gamma (γ) radiation from the unstable isotopes in the composition. For the most part, minerals that contain potassium (K), uranium (U) and thorium (Th) are radioactive.

Sakwa Wagusu goldmine employs many people, both men and women. The mining is done manually by using hoes, mattocks and spades and when hard rocks are reached, blasting is done. As the pits are dug, underground water is detected which is then pumped out and used for panning. Planning around the mines is commonly done by women.

2.0 Materials and Methods

2.1 Sample Collection and Preparation

A total of 10 soil and 29 rock samples were collected from four areas (Wagusu market, Abimbo, Nyang'oma and Nango) Figure 2. Samples were collected from different depths from the ground level at all the 10 sites visited (Table1).

After collection, the samples were dried and then crushed separately into powder form. The crushed powder were then sieved through a 0.6 mm mesh sieve, dried in an oven at 100°C for 24 hours, completely removemoisture from the samples. Each sample was then weighed and packed in special polyethylene plastic containers and tightly closed for about 4 to attain a state of secular radioactive equilibrium after their progeny (Karahan and Bayulken, 2000). After this period, the samples were then taken to Institute of Nuclear Science & Technology, University of Nairobi for spectroscopic analysis. Both the field and laboratory aspect of this project were carried out between August, 2012 and March, 2013.

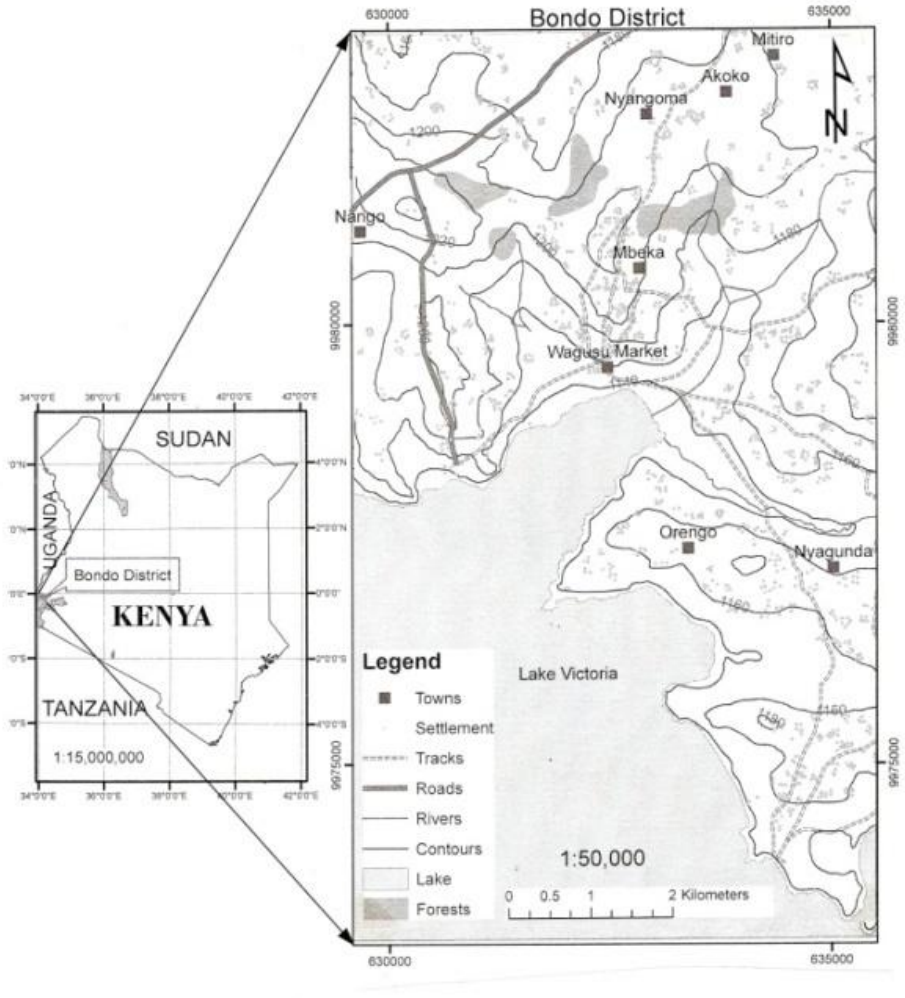


Figure 1: Location of the study area and sampling sites

Table 1: Location, site and depth of soil and rock samples collection

Location/Area	Site name	Depth of soil collection (m)	Depth of rocks collection (m)
Wagusu market	K'Onduru 3	0.2	2.0, 5.0, 15.0, 30.0
	K'Onduru 4	0.3	2.0, 8.0, 15.0
	K'Opiyo	0.3	2.0, 3.0, 5.0, 8.0
	K'Otieno Manyala	0.2	1.0, 3.5, 8.0
Abimbo	Ka'Nyasembo	0.2	2.0, 5.0, 7.0, 35.0
	K'Opiyo	0.3	5.0, 7.0, 15.0, 25.0
Nyang'oma	K'Ondoro	0.1	1.5, 4.0, 9.0
	Ka'John	0.1	1.5, 6.5
	K'Okumu	0.03	1.0
Nango	K'Ogoch	0.3	6.0

2.2 Activity Concentration of Natural Radionuclide and Absorbed Doses

Measurement of activity concentrations was performed with high-purity germanium (HPGe) gamma-ray detector with 144 mm^3 active volume and outside diameter of 76 mm. The detector has an efficiency of 31.6% and a resolution of 1.8keV. Each sample was put in a malineri beaker of 500 cm^3 and filled up to the same level as the certified reference standard soil (IAEA –RGK-1, IAEA-RGU-1, IAEA-RGTh-1 and IAEA-375 soil) then placed in a lead shielded detector. A counting time of between 22000 – 179000 seconds was adopted. A soil sample (IAEA –RGK-1, IAEA-RGU-1, IAEA-RGTh-1 and IAEA-375 soil) was analysed for the method of validation and spectrometer calibration using PCA 2 (Version 1.00 software).

The activity concentration of each radionuclide was then calculated using the comparative method. For each sample, there were five significant gamma lines, ^{40}K line, $^{214}P_b$ and $^{214}B_i$ lines from ^{238}U and $^{212}P_b$ and $^{228}A_c$ lines from ^{232}Th. The activity of ^{40}K was evaluated from 1461keV gamma line while the activity of ^{238}U from 352keV and 609keV gamma lines of $^{214}P_b$ and $^{214}B_i$ respectively and that of ^{232}Th from 238keV and 912keV gamma lines of $^{212}P_b$ and $^{228}A_c$ respectively.

2.2.1 Absorbed Dose

Two approaches were used to estimate the external doses that result from deposition of radionuclides in soil surfaces: direct measurement and calculations based on radionuclide deposition densities.

2.2.2 Measurement of Absorbed Dose Rate in Air

The absorbed dose rates in air at 1m above the ground surface were measured for each pit mine using a hand-held survey meter Thermo Scientific, FH 40G-L10 Radiameter with a reading range of $10nSvh^{-1}$ – $100mSvh^{-1}$. The absorbed dose rates in air in $nGyh^{-1}$ were computed from the dose rates in $nSvh^{-1}$ as measured in the field using the conversion coefficient factor of $0.7SvGy^{-1}$ as recommended by UNSCEAR, 2000.

2.3 Radiation Hazard Indices

The total absorbed dose rates (D) due to gamma radiations in air of the naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K were calculated based on guidelines provided by UNSCEAR 2000. Assumption was that the contributions from other naturally occurring radionuclides were insignificant. D can therefore be calculated from equation (1):

$$D\ (nGy.h^{-1}) = 0.427A_{Ra} + 0.662A_{Th} + 0.043A_K \quad \text{.....(1)}$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations ($Bqkg^{-1}$) of radium, thorium and potassium respectively in the samples, and 0.427, 0.662 and 0.043 are the dose conversion factors for converting the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K into dose ($nGy.h^{-1}$ per $Bqkg^{-1}$) as given by UNSCEAR 2000.

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in air to effective dose ($0.7Sv.Gy^{-1}$) and outdoor occupancy factor (0.2) proposed by UNSCEAR 2000 are used. In Kenya, the average of time spent indoor and outdoor (occupancy factors) are 0.6 and 0.4 respectively (Mustapha, 1999). The world

average indoor and outdoor occupancy factors are 0.8 and 0.2 respectively (UNSCEAR, 2000). Therefore, the effective dose rate in units of $mSvy^{-1}$ was estimated using the formula (UNSCEAR, 1998)

$$Effective\ dose\ rate\ = Dose\ rate\ (D) \times 8760h.y^{-1} \times 0.4 \times 0.7\ Sv.Gy^{-1} \times 10^{-6} \quad \text{.....(2)}$$

The most widely used radiation hazard index, radium equivalent activity (Ra_{eq}), can be calculated using the formula as (Berekta *et al.,* 1985):

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + .077C_K \quad \text{.....(3)}$$

A widely used hazard index, reflecting the external exposure, called the external hazard index, H_{ex}, is defined as (Harb *et al.,* 2010):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \text{.....(4)}$$

In addition to external hazard index, radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by the internal hazard index, H_{in}, which is given by the equation (Harb *et al.,* 2010):

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \text{.....(5)}$$

The values of the indices (H_{ex} and H_{in}) must be less than unity for the radiation hazard to be negligible.

3.0 Results and Discussion

The specific activity concentrations of ^{238}U series, ^{226}Ra, ^{232}Th series (^{232}Th) as well as ^{40}K, expressed in $Bqkg^{-1}$ for samples obtained from Wagusu market, Abimbo, Nyang'oma and Nango areas are presented in table 2. There was no particular relationship between activity of the radionuclides and depth of the point of collection of the samples.

Table 2: Average activity concentration of sites and locations

Location	**Site name**	**Average activity concentration , $Bqkg^{-1}$**			**Average activity concentration , $Bqkg^{-1}$**		
		^{226}Ra	**^{232}Th**	**^{40}K**	**^{226}Ra**	**^{232}Th**	**^{40}K**
Wagusu market	K'Onduru 3	35.0	20.0	401.4	**35.4**	**28.6**	**438.4**
	K'Onduru 4	25.6	27.0	406.0			
	K'Opiyo	47.8	41.8	612.1			
	K'Otieno Manyala	33.0	25.6	334.2			
Abimbo	Ka'Nyasembo	34.5	27.4	568.4	**36.0**	**29.9**	**575.5**
	K'Obonyo	37.4	32.3	582.6			
Nyang'oma	K'Ondoro	71.4	43.1	733.3	**44.2**	**40.7**	**647.7**
	Ka'John	26.7	35.0	682.1			
	K'Okumu	34.6	44.1	527.6			
Nango	K'Ogoch	61.2	61.9	896.6	**61.2**	**61.9**	**896.6**

The average values of ^{40}K and ^{226}Ra were higher than the worldwide recommended values of 400 and 35 $Bqkg^{-1}$ respectively (UNSCEAR, 2000). The average values of ^{232}Th were within the limits for Wagusu market and Abimbo areas and higher than the worldwide recommended value of 30 $Bqkg^{-1}$ (UNSCEAR, 2000) in Nyang'oma and Nango areas. Figure 2 shows comparisons between the average activity concentrations of the radionuclides ^{40}K, ^{226}Ra and ^{232}Th in the obtained samples.

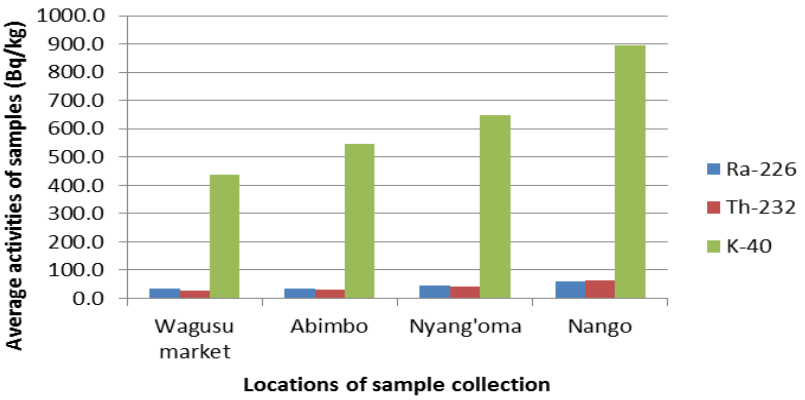


Figure 2: Average value of sample activities due to ^{226}Ra, ^{232}Th and ^{40}K in within the study site

3.1 Comparison of Activity Concentrations with Similar Studies

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil and rock samples from studied area was compared with those from similar investigations in other countries and found to be comparable.

Table 3: Comparison of natural radioactivity levels in soil samples under investigation with those in other countries

Country	Activity concentration ($Bqkg^{-1}$)			References
	^{226}Ra	^{232}Th	^{40}K	
Saudi Arabia, Taif	23.8	18.6	162.8	El-Aydarous, 2007
Syrian	20	20	270	UNSCEAR, 2000
Turkey (Istanbul)	21	37	342	Karahan *et al.*, 2000
Cyprus	7.1	5	104.6	Tzortzis *et al.*, 2004
Denmark	17	19	460	UNSCEAR, 2000
Canada (Saskatchewan)	19	8	480	Kiss, J *et al.*, 1988
World average	37	33	400	UNSCEAR, 2008
Kenya (Sakwa Wagusu area)	44	40	640	Present work, 2013

3.2 Absorbed Dose Rates

Both the calculated absorbed dose rates and measured absorbed dose rates for the locations are represented in table 4. The mean calculated and mean measured absorbed dose rates for the area was 70 $nGyh^{-1}$ and 141 $nGyh^{-1}$ respectively.

Table 4: Calculated and measured absorbed dose rates ($nGyh^{-1}$) of the samples from locations

Location	Calculated Absorbed dose rates				Measured Absorbed dose rate
	Dose rates due to ^{232}Th	Dose rates due to ^{226}Ra	Dose rates due to ^{40}K	Total average absorbed dose rate	Average absorbed dose rate ($nGyh^{-1}$)
	Average	Average	Average		
Wagusu market	17.2	11.1	18.9	47.2	124.4
Abimbo	19.8	10.7	24.7	55.2	138.7
Nyang'oma	27.0	16.4	27.8	71.2	151.3
Nango	40.9	26.1	38.6	105.6	151.8

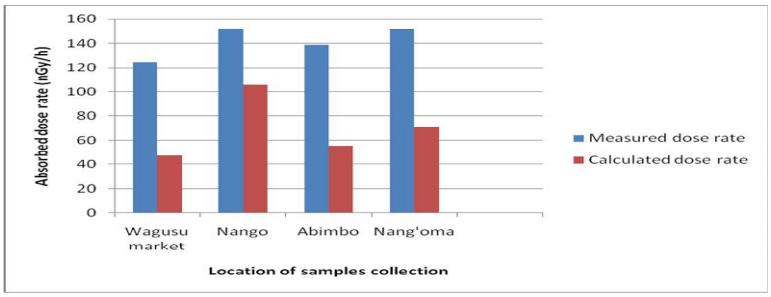
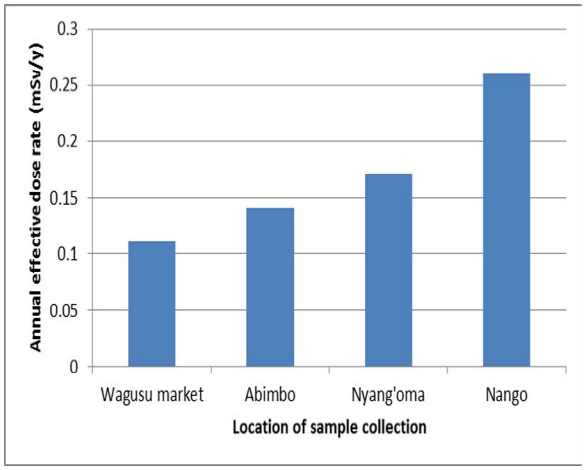


Figure 3: Average absorbed dose rates as measured 1m above the surface at each location, and average absorbed dose rates as calculated at each location

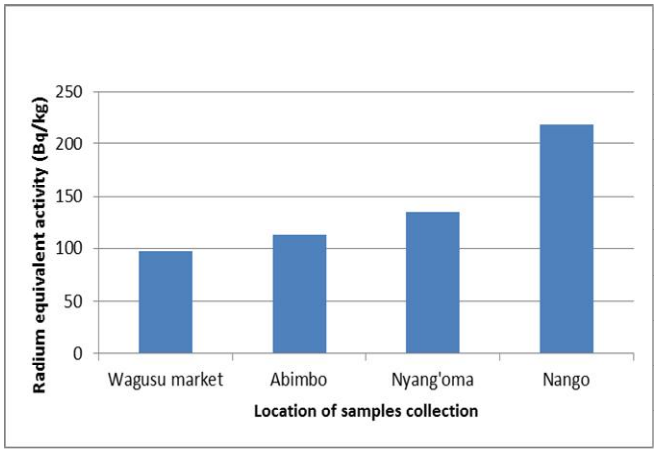
The estimated annual effective dose, the external hazard index (H_{ex}), the internal hazard index (H_{in}) and Radium equivalent activity (Ra_{eq}) were calculated and are as represented in Table 4. Assuming that the mine workers work in the mines for 30years, the mean annual effective dose rate is 0.17mSvy^{-1} and the risk factor is 0.04 per Sv (ICRP, 2008), then the excess cancer risk is 0.02%.

Table 5: Annual effective dose rates, external (H_{ex}), internal (H_{in}) hazard indices and radium equivalent activity (Ra_{eq}) as per locations

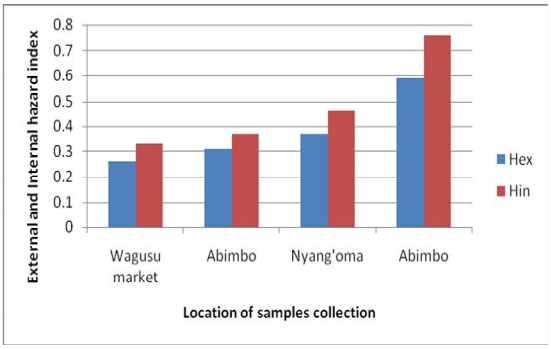
Location	Annual effective dose rate (mSvy^{-1})		External hazard index, (H_{ex})		Internal hazard index, (H_{in})		Radium equivalent activity, (Ra_{eq}) in (Bqkg^{-1})	
	Range	Average	Range	Average	Range	Average	Range	Average
Wagusu market	0.02 – 0.26	0.11	0.04 – 0.57	0.26	0.04 – 0.64	0.33	14.1 – 212.5	96.94
Abimbo	0.03 – 0.27	0.14	0.06 – 0.62	0.31	0.06 – 0.78	0.37	20.7 – 230.3	112.02
Nyang'oma	0.07 – 0.33	0.17	0.16 – 0.80	0.37	0.18 – 1.10	0.46	58.5 – 294.5	135.15
Nango	0.21 – 0.31	0.26	0.47 – 0.71	0.59	0.60 – 0.91	0.76	175.8 – 261.5	218.63



(a)



(b)



(c)

Figure 4: The average value of: (a) annual effective dose (b) radium equivalent activity (c) external and internal hazard index in all the area under investigation

4.0 Conclusions

The average activity concentration for the area under study is 639.6, 44.2 and 40.3 Bqkg^{-1} against the worldwide accepted limit of 400, 35 and 30 Bqkg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th (UNSCEAR, 2000) respectively. This area can therefore be classified as a High Background Radiation Area (HBRA) and proper precautions need to be taken when doing the gold mining.

The mean absorbed dose rate, measured 1m from the ground was 140.8nGyh^{-1}, while the mean calculated absorbed dose rate was 69.8nGyh^{-1}. The measured absorbed dose rate was higher than the calculated dose rate, a fact that could be attributed that calculated dose rate does not include cosmic rays. These values were higher than the worldwide recommended value of 60nGyh-1 (UNSCEAR, 2000). This area may therefore be characterized as a High Background Radiation Area (HBRA). The values of annual effective dose rate were lower than the worldwide value of 1mSvy^{-1}, which is the annual effective dose rate limit for the public exposure (ICRP, 2000), thus gold products can be said to be safe to consumers.

Radium equivalent (Ra_{eq}) values for the studied areas varied from 96.4 to 218.6 Bqkg^{-1}, with an average of 140.7 Bqkg^{-1}. These values were lower than the internationally accepted value of 370 Bqkg^{-1} (Lu Xinwei *et al*., 2006). The values of external hazard index (H_{ex}) and internal hazard index (H_{in}) are lower than acceptable limit of unity. The radiation risk from these soils can therefore be negligible and the soils and rocks here can be safely used in construction without posing any significant radiological threat to population.

Acknowledgement

The authors thank National Council for Science, Technology and Innovation (NACOSTI), Kenya for the research grant, Institute of Nuclear Science and Technology (INST), University of Nairobi for the their laboratory and gamma-ray spectrometer, Kenya Bureau of Standards (KEBS) for using their oven for drying and Jomo Kenyatta University of Agriculture & Technology (JKUAT).

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