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Analysis of Natural Radioactivity and Radiation Exposure Levels in Eburru Geothermal Field, Kenya

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ABSTRACT

In Kenya, the use of geothermal energy for power supply has becomes increasingly attractive as part of an alternative energy mix and from the current rate of geothermal installation it may soon overtake hydro as the leading source of energy. Although geothermal energy has been termed as clean, risks associated with the use of deep thermal fluids require intensive evaluation and communication made to the community and with the public since natural radioactivity is crucial for the earth system as the slow decay of radioactive elements produces approximately half of the heat that drives major earth's processes such as continental drift, ocean spreading and plate tectonics. The results of a survey on the radionuclide concentration undertaken in Eburru geothermal field in different rock formations are hereby presented. This research measured activity concentrations of the naturally occurring radioactive elements ^{40}K, ^{238}U, and ^{232}Th by use of NaI(Tl) gamma-ray spectrometer, estimated the absorbed dose rate, annual effective dose rates and the hazards index due to natural radionuclides and their decay products in Eburru geothermal field. The mean activity concentrations concentration of ^{238}U, ^{232}Th and ^{40}K were 70.521±10.48Bqkg^{-1}, 50.65±5.13Bqkg^{-1} and 588.511±156.14Bqkg^{-1} in rock samples. The average absorbed dose rates, annual effective dose rate and hazard index in rocks samples were found to be 87.71± 6.44 nGyh^{-}, 0.11±0.01mSvy^{-1} and 0.50±0.03. From the obtained results, the studied hazard indices were within the world acceptable safety limits and therefore human exposure to radiation is within safety levels. This indicates that the level of the studied radioactive elements in geothermal rocks within Eburru geothermal field is within the acceptable range.
Keywords : Geothermal Field, Radioactivity, Dose Rate, External Hazard Index

I. INTRODUCTION

Geothermal energy is derived from heat that is naturally generated and stored within the interior of the earth. Heat is produced by the decay of radioactive elements, including ^{40}K, ^{238}U, and ^{232}Th [1]. This natural radioactivity is crucial for the earth system since the slow decay of radioactive elements is estimated to produce approximately half of the heat that drives major processes such as continental drift, ocean spreading and plate tectonics [2]. Therefore, radioactive decay helps to produce a temperature gradient beneath our feet for geothermal energy exploitation.

Most of the geothermal fields occur in continental rifts which are characterized by high heat flows and volcanism. These geothermal fields may be associated with the volcanoes or fissure eruptions that occur on the floors of these rift systems [3]. Such areas are known to exhibit higher than normal background radiation levels which have been associated with the volcanology rocks, [4]. This suggests high activity concentration levels of radionuclides in volcanic areas. Such places include among others Homa and Ruri hills in South Nyanza [4]), Mrima hill at the Coast [5], Oldonyo Nyegi [6] and in Magadi area [7]-all in Kenya, and Oldonyo Lengai to the south of Lake Natron in northern Tanzania [8].

Eburru being one of the volcanic and productive geothermal fields in Kenya, [9] was therefore considered for characterization of natural radioactivity systematic. The geothermal features consist of fumaroles, altered grounds and seepages distributed within the field. Due to their interaction with the underlying magmatic intrusions which heat them, geothermal rocks may have enhanced NORM levels which may impact region. The water sinks into the reservoir from other sources through the natural faults located on the walls of the greater east African rift and permeable and porous zones that have different rock formations and mineralogy within which is then heated into steam to run the turbine. A comprehensive radiometric analysis within the Eburru geothermal system is necessary in order to characterize radionuclide levels. Environment monitoring and assessment is vital in regulatory and advisory policy making for the safety of public due to radiation exposure.

Samples of rocks from sites within Eburru geothermal field were studied in order to verify the hypothesis of radio pollutants presence in Eburru geothermal field. Of great interest were sites adjacent to fumaroles; this is because the fumaroles are believed to be the entry points for the radio pollutants from the reservoir.

II. METHODS AND MATERIAL

2.1 The Study Area

Eburru geothermal field is among the 23 geothermal prospects in the Kenyan Rift. The field covers an area of about 16km^2 with an altitude of up to 2800 m.a.s.l. [10]. The geothermal field is approximately 140 km north-west of Nairobi and 40 km north of the Olkaria geothermal power plants. (Figure 1). The Kenya rift is part of the East African rift system that runs from Afar triple junction at the Gulf of Eden in the north to Beira, Mozambique in the south [11]. It is the segment of the eastern arm of the rift that extends from Lake Turkana to the North to Lake Natron, northern Tanzania to the south. The rift is part of a continental divergent zone where spreading occurs resulting to the thinning of the crust hence eruption of lavas and associated volcanic activities [12].

Sites in the Eburru geothermal field were sampled for rock analysis. The sampling sites were adjacent to fumaroles. Samples were packed in labelled containers ready for transportation to the laboratory. The rock samples were unsealed and air dried over a period of one week before being crushed and pulverized into fine powder. The pulverizing machine was set for 150 microns particle size. Pulverizing was done to ensure homogeneity in the samples. The samples were then be placed into labelled 300 cc plastic jars, weighed and sealed using airtight lids to prevent escape of gaseous ^{220}Rn and ^{222}Rn. The masses of the samples were weight then stored for 21 days before gamma-ray analysis was done in order to allow for the in-growth of gaseous ^{222}Rn (half-life of 3.8 days) and achievement of secular equilibrium between ^{226}Ra and the decay products of ^{222}Rn (214Bi and 214Pb) [13].

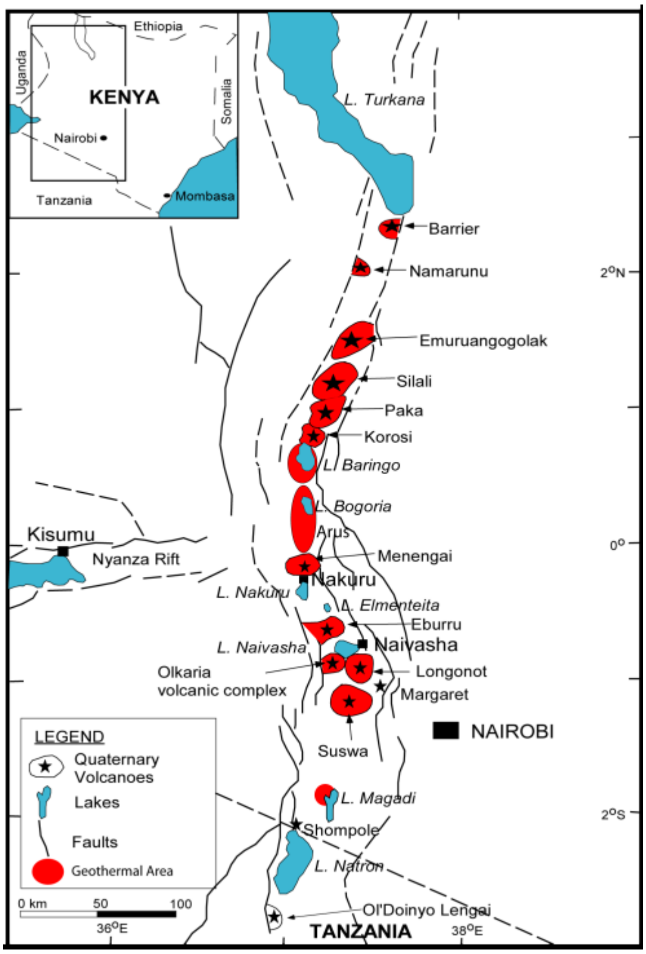

Figure 1 : Map of the Kenya rift showing the location of Eburru geothermal field and other Quaternary volcanoes along the rift axis (Omenda, 2008)

2.2 Activity Concentration

The activity concentration A_S of the samples was calculated using equation 1 (Mustapha, 1999)

$$A_S = (M_r \times A_r \times I_S)/(M_S \times I_r) \quad (1)$$

where M_r, A_r, and I_r are the mass, activity concentration and intensity of specific radionuclide in respectively while M_S and I_S are the mass of the sample and the intensity of specific radionuclide in the sample under study respectively.

2.3 Absorbed Dose Rate

The absorbed dose rate at 1 metre above the ground was calculated from the measured activities of ^{238}U, ^{232}Th and ^{40}K in samples using equation 2 [13; 14]

$$D\ nGyh^{-1} = 0.462C_U + 0.604C_{Th} + 0.0417C_K \quad (2)$$

where D is the absorbed dose rate, C_U, C_{Th} and C_K are the activity concentrations (in $Bqkg^{-1}$) of ^{238}U, ^{232}Th and ^{40}K respectively in the samples.

2.4 Hazard Index (Hex)

The external hazard index was calculated using relations in 3 [13]

$$Hex = (C_U/370) + (C_{Th}/259) + (C_K/4810) \quad (3)$$

Where C_U, C_{TH} and C_K are the activity concentrations in $Bqkg^{-1}$ of ^{238}U, ^{232}Th and ^{40}K radionuclides respectively present in the samples.

2.5 Annual Effective Dose Rate (AEDR)

The annual effective dose rates, AEDR were estimated using equation 4 [15]

$$AEDR\ mSvy^{-1} = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (4)$$

Where D is dose rate in $nGyh^{-1}$, the value 8760 are the hours in a year, the conversion coefficient from the absorbed dose in the air to the effective dose is 0.7 $SvGy^{-1}$ and outdoor occupancy factor is 0.2 as proposed by [14]

III. RESULTS AND DISCUSSION

3.1 Activity Concentration of Natural Radionuclides

The average activity concentrations of the radionuclides in rock Samples are summarized in Table 1

Table 1: Activity concentrations of the natural radionuclides in samples

site	^{40}K	^{238}U	^{232}Th
1	636.28±4.49	77.095±1.63	50.75±2.15
2	597.23±2.11	71.4±2.08	47.9±1.58
3	430.525±2.07	58.83±1.87	62.37±1.90
4	643.06±1.82	82.77±1.39	51.67±3.26
5	682.67±4.52	66.75±3.74	50.36±2.82
6	776.69±3.48	57.61±1.58	49.34±1.58
7	328.98±2.39	70.385±2.47	45.93±1.66
8	635.81±4.72	66.63±2.36	43.02±1.84
9	770.57±1.95	63.06±1.38	53.33±1.39
10	383.3±2.76	90.68±2.94	51.84±1.55
Mean	**588.51±156.14**	**70.52±10.48**	**50.65±5.13**

From the table, a total of 10 point was surveyed across the entire Eburru geothermal field for background environmental radiation with the maximum activity concentrations of the radionuclides in rock samples for ^{40}K, ^{238}U and ^{232}Th being 776.69±3.48$Bqkg^{-1}$, 90.68 ±2.94$Bqkg^{-1}$ and 62.37±1.90$Bqkg^{-1}$ respectively while the minimum activity concentrations for the same radionuclides were 328.98±2.39$Bqkg^{-1}$, 57.61±1.58$Bqkg^{-1}$ and 43.02±1.84$Bqkg^{-1}$ respectively. The mean concentrations of ^{40}K, ^{238}U and ^{232}Th in the rocks from Eburru geothermal field were 588.51±156.14$Bqkg^{-1}$, 70.52±10.48$Bqkg^{-1}$ and 50.65±5.13$Bqkg^{-1}$ respectively.

There is a remarkable spatial variability of the activity concentrations of the radionuclides in the rock samples from the area. These variations could be due to the variation of concentration of these radioactive elements in the geological formations, and micro-cracks and defects in the rocks within the area. The relatively high values of ^{40}K are comparable with the values reported by [7] and maybe as a result of its abundance in the earth crust [16]. The average concentrations of ^{238}U are slightly higher compared to that of ^{232}Th. This could be attributed to the fact that ^{238}U is moderately soluble in water and is found more abundant than ^{232}Th in atmosphere [17]. The mean activities of ^{40}K, ^{238}U and ^{232}Th in rock samples were higher than the world average values of 400BqKg^{-1}, 35BqKg^{-1} and 30BqKg^{-1} respectively [14]. This could be associated with mylonitized granite gneiss, augen gneiss, garnetiferous mica schist and micaceous quartzite and tectonically emplaced bodies of granite. The values were however much lower compared to those for known High Background Radiation Areas whose activities are as high as 13 times the world averages [4; 5; 7 and 18].

Therefore, the Eburru geothermal field may be regarded as a quasi-high background radiation area (HBRA).

A comparison between activity concentrations for ^{238}U, ^{232}Th and ^{40}K at Eburru geothermal field and other places in the world was done and details of the comparison are presented in Table 2. It was observed that the activity concentrations for ^{238}U, ^{232}Th and ^{40}K at Eburru geothermal field was slightly higher as compared to the non geothermal regions. This indicates that tectonic regions with geothermal manifestations could have elevated activity concentrations of naturally occurring radioactive elements.

Table 2 : Comparison of activity concentrations at Eburru geothermal field and other places in the world

Country	^{238}U	^{232}Th	^{40}K	References
Persian gulf, Iran	35	26	340	[19]
Safaga, Egypt	25	21.4	618	[20]
Xianyang, China	31.1	44.9	776	[21]
Kericho, Kenya	66	55	819	[22]
Nakuru, Kenya	36.9	43.5	708.3	[23]
Eburru, (Kenya)	**70.52**	**50.65**	**588.51**	**This study**

3.2 Absorbed Dose Rate

The total absorbed dose rates from the rocks collected from all the sampling sites was calculated and using equation 2 and recorded in table 3. The average absorbed dose rates were found to be 87.71±6.4nGyh^{-1}. The outdoor air absorbed dose rate due to terrestrial gamma rays at 1m above the ground for ^{238}U, ^{332}Th and ^{40}K was higher than the world average value of 60 nGyh^{-1}. However these values compared to some of the other high background radiation areas (HBRAs,) are relatively lower. Examples of such high background radiation areas include the eastern coast of Orissa, India, whose value is reported to range between 650.00 to 3150.00nGyh^{-1} with a mean value of 1925.00 ± 718.00nGyh^{-1} and Udagamandalam, also in India whose reported value is in the range 31.6nGyh^{-1} to 221.1nGyh^{-1} with a mean value of 121.08nGyh^{-1} [24; 25].

Table 3: Average for radiological parameters of the natural radionuclides in rock samples

site	D(nGy/h)	Hex	AEDR	Req
1	80.09	0.46	0.10	169.61
2	89.29	0.51	0.11	187.11
3	70.06	0.40	0.09	147.49
4	99.94	0.58	0.12	214.63
5	114.23	0.66	0.14	243.49
6	68.76	0.41	0.08	152.35
7	53.93	0.32	0.07	119.66
8	68.02	0.39	0.08	145.29
9	72.30	0.43	0.09	159.45
10	89.04	0.51	0.11	189.89
Mean	**87.71±6.44**	**0.47±0.08**	**0.10±0.02**	**172.90 ±30.39**

A comparison between absorbed dose rates at Eburru geothermal field and absorbed dose rates at other places in the world was done and details of the comparison presented in Table 4. It was observed that absorbed dose rates at Ebburu geothermal field was within the range as compared to other non geothermal regions.

Table 4 : Comparison of absorbed dose rates in Eburru geothermal field with other regions

Region and Country	Absorbed dose rate	References
Orisa, India	1925	[25]
Ruri Hill, Kenya	949	[4]
Tabaka, Kenya	184	[26]
Kericho, Kenya	98	[22]
Nakuru, Kenya	71.97	[23]
Eburru, Kenya	**87.71**	This study
Minas, Brazil	220	[27]

3.3 Annual Effective Dose Rate

The annual effective dose rate (AEDR) for rocks from Eburru geothermal field was calculated using equation 4 and the results obtained tabulated in Table 3.

The average annual effective dose rate for rocks in Eburru geothermal site samples was found to be 0.11mSvy^{-1}. The maximum and the minimum values were 0.12mSvy^{-1} and 0.09 mSvy^{-1} respectively. The resulting average of the annual effective dose is obtained in rock samples from the study side were less compared to the world wide average of the annual effective dose of 0.48mSvy^{-1}.

3.4 Hazard Index

The average hazard index calculated for rock samples from Eburru geothermal was found to be 0.50. The maximum and the minimum values in Eburru geothermal samples were 0.55 and 0.43 respectively as shown in Table 3.

The calculated values of external hazard index obtained in this study from all the sampling sites were less than unity. Since these values are lower than unity, the radiation hazard is insignificant for the population living in the investigated area according to, [28]

IV. CONCLUSION

From the obtained results, the studied hazard indices were within the world acceptable safety limits and therefore human exposure to radiation is within safety levels. This indicates that the level of the studied radioactive elements in geothermal rocks within Eburru geothermal field is within the acceptable range.

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