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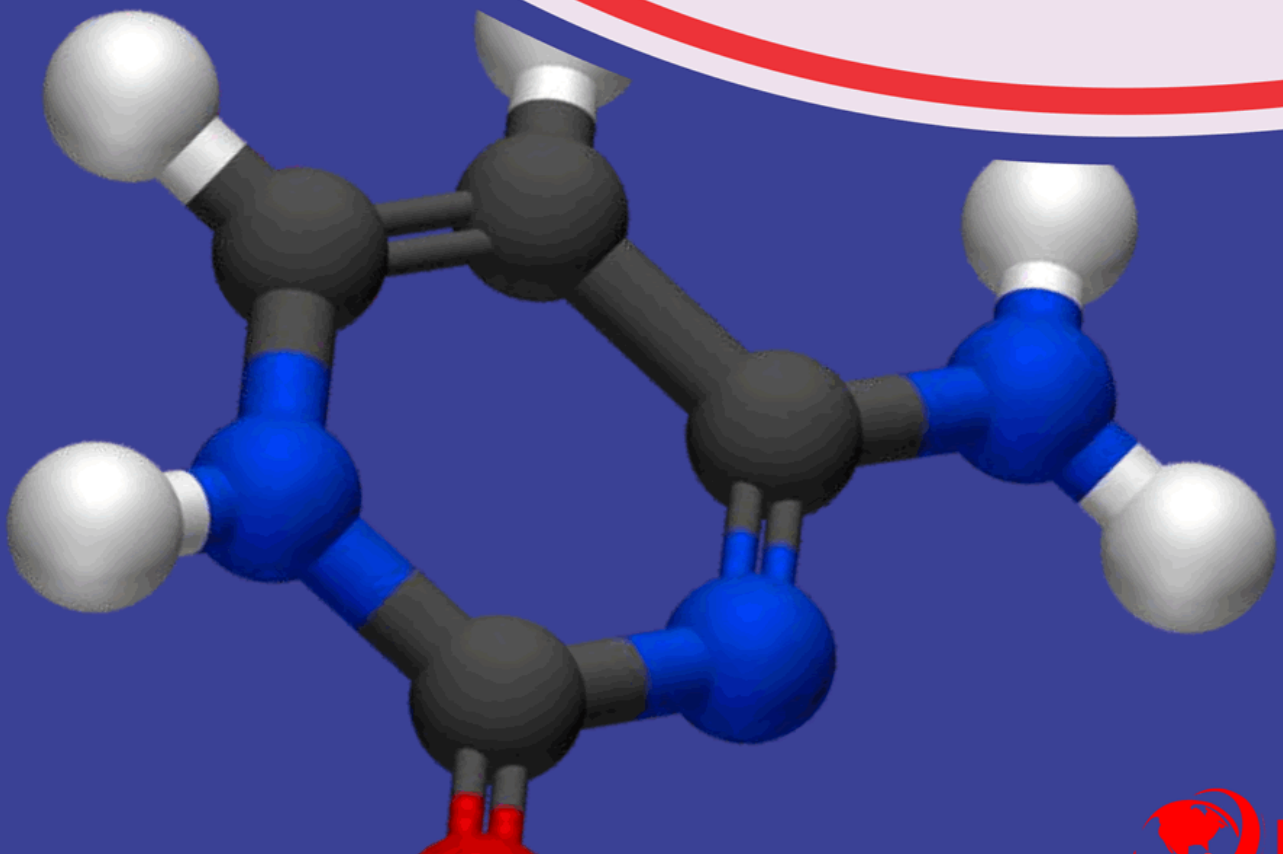

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Natural Radioactivity and Excess Lifetime Cancer Risk Associated With Soil in Kargi Area, Marsabit – Kenya

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Abstract

Purpose: The main aim of investigating activity concentrations together with distribution of radionuclides naturally in soil from Kargi was to evaluate radiological health hazard together with environmental radioactivity. Research shows radionuclides as one source of exposure due to radiation with detrimental effects health wise for populations found in areas considered high background radiation.

Methodology: After collecting 117 soil samples from the area, analysis was done in order to measure their natural radioactivities due to ^{40}K, ^{232}Th and ^{226}Ra radionuclides. Measurements method of gamma spectrometry employing a high purity germanium (HPGe) detector was employed basically to evaluate the radiological hazard of radioactivities. For ^{40}K, ^{232}Th and ^{226}Ra, mean calculated activities were 353.19±110.07, 7.98±3.98 and 7.37±2.60 Bqkg^{-1} respectively. Mean values of absorbed and effective dose rates, external and internal hazard indices together with radium equivalent activity were 23.82±6.59 nGyh^{-1} and 0.14±0.04 mSvy^{-1}, 0.12±0.03 and 0.14±0.04 and 45.90±12.65 Bqkg^{-1} respectively. Comparing with approved global values, the values were found to be below the given global limits.

Findings: Evidence of involvement of metasomatic activity of the radioelements or fractionation during weathering is seen as calculations give a higher value Th/U. Excess cancer risk, calculated from the samples showed lower values as compared to global standard values hence minimal chance of getting cancer disease. The area is safe from cancer causing radionuclides.

Unique Contribution to theory, Practice and Policy: It is recommended that High Background Radiation Area (HBRA) are healthy and good for human settlement.

Keywords: *Kargi-Marsabit, Nuclear Science, Gamma-Ray Spectrometry, Lifetime Cancer Risk, Activity.*

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INTRODUCTION

Radioactive elements found in rocks, soil, water, air, and in food from the earth make their way in our bodies when we breathe in air or eat foods which contain them. These naturally occurring radio isotopes such as carbon-14, potassium-40, thorium-232, uranium-238, polonium-218 and tritium (hydrogen-3) expose us to radiation from within our bodies.

Exposure to radiation is injurious to living tissues owing to its ionizing power in matter. This ionization can directly destroy living cells directly, by breaking up the chemical bonds of key biological molecules like DNA, or indirectly, by creating chemical radicles from water molecules in the cells, which can chemically attack biological molecules (UNCEAR, 1993). Somehow, these molecules are mended by use of natural biological procedures; effectiveness of this mending however depends on the size of damage. Obviously, if cell repair is not properly done or not repaired at all, the cell then may suffer either of these possible fates (Cember, 1996):

i. Cell demise
ii. Cell impairment leading to somatic effects, that is physical effects suffered by the irradiated person like cancer disease.
iii. Genetic mutation, considered a permanent alteration of the cell and which is passed to the later generations.

The presence of radionuclides in natural environment has been noticed always. Wherever universally present in little amounts in building materials and earth, thorium together with uranium series, together with potassium 40 (^{40}K) are considered leading natural donors to external exposure from γ-radiation. (UNSCEAR 2008).

Potassium, uranium and thorium radioactive elements together with any of their decay outcomes like radon and radium are examples of Naturally Occurring Radioactive Materials (NORM) considered long-lived. These elements have always existed in the atmosphere and earth's crust. NORM issue relates to radon exposure in homes, particularly those built on granitic ground. By using building materials with relatively high activity concentration of ^{226}Ra and building techniques that stipulate the influx of radon from the ground e.g. well insulated housing, the radiation dose to the population dose is still further increased *(*Aguko *et al.,* 2013).

Approximation of the radiation dose distribution is key in gauging the health risk to a populace and serves as a reference point for registering changes in environmental radioactivity owing to anthropogenic activities (Obed *et al*., 2005).

Exposure to radiation for a long period of time is presumed to have some probability of cancer causing disease, thus everyone is at risk contracting cancer. An additional risk a person might have of contracting cancer disease due to long time exposure to materials causing cancer disease is called excess lifetime cancer risk (ELCR) (Aziz *et al.,* 2014).

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www.iprjb.org

For outdoor occupation evaluating the terrestrial gamma dose rate, estimation of the natural radioactivity level is very important for geological samples, usually determined from the ^{40}K, ^{232}Th and ^{226}Ra contents (UNSCEAR, 2000). Activity concentrations of ^{40}K, ^{232}Th and ^{226}Ra in collected soils have been estimated mainly by gamma ray spectrometry, although the fission track registration technique has also been used for the analysis of uranium concentration of these samples (Sing *et al.*, 2005). They found the absorbed dose rate as found in air, calculated the gamma dose rate from concentration of radionuclides of ^{40}K, ^{232}Th and ^{226}Ra from which they deduced the effective dose the inhabitants receive annually.

MATERIALS AND METHODS

Study Area

Kargi, found between longitudes 37°32´34´´ and 37°36´07´´ E and latitudes 2°28´37´´ and 2°31´15´´ N is a small village in Marsabit, Kenya covering an area of approximately 31.26 km^2 as seen in figure 1.0. Bordering Kargi is Chalbi, Gabra and Samburu.

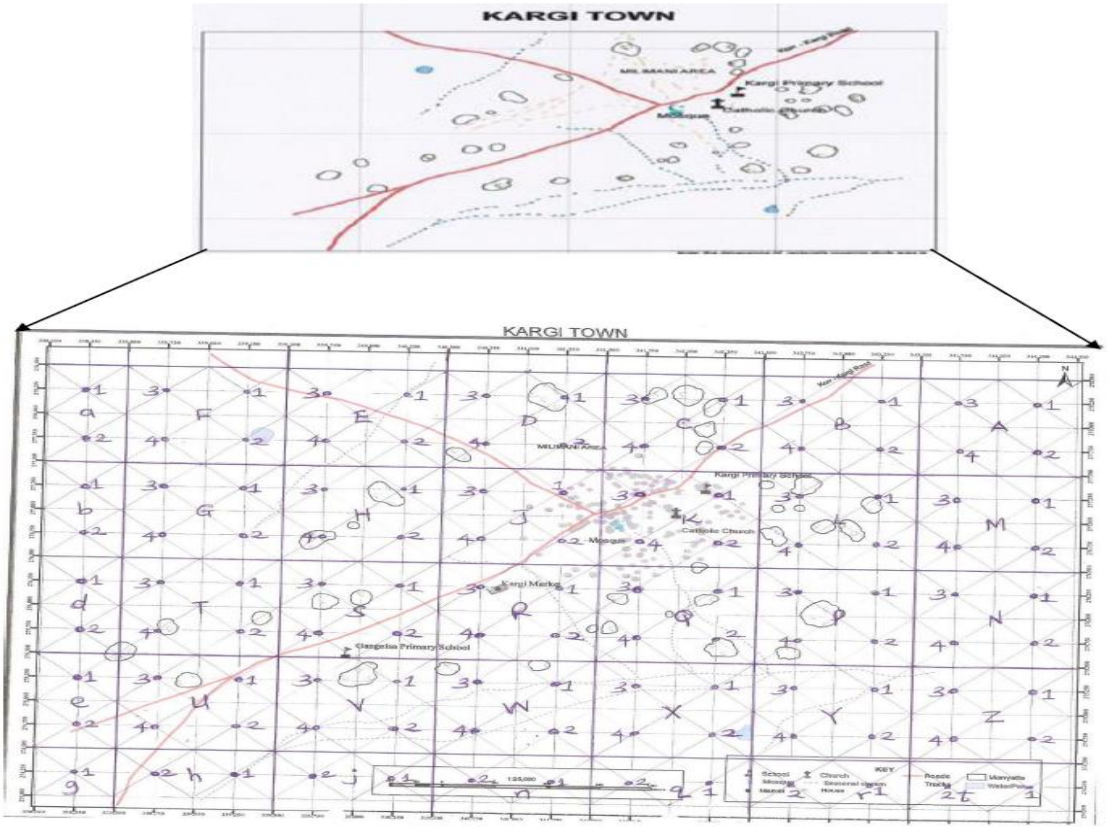

Figure 1: Map Showing Kargi Area (Survey of Kenya, 2017, Modified).

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Vol. 1, Issue 1, No. 3, pp 31 - 48, 2023

www.iprjb.org

Sample Collection and Preparation

A total of 117 samples were collected according to the internationally established experience (Tzortzis, M. and Tsertos, H., 2004). Systematic grid sampling method, generally considered unbiased was employed during sampling. The area was divided in to a regular square, and samples collected from the nodes (IAEA TECDOC 486, 2019) (Figure 1.0).

The EPA, 1995, describes that the factors which determine the distance between sampling locations in the grid are the size of the area to be sampled and the number of samples. For each sample collection, an area of about 0.5 km x 0.5 km was marked to help get a good representation of the area. To avoid samples contamination from top soil containing leaves and other contaminations, samples were collected 10 centimetres from the surface (Monika *et al.*, 2010). These samples were packed and clearly marked before transporting to Nairobi.

Rock together with soil samples were sun dried after their collection, separately crushed in powder form to help homogenize them. Sieving the crushed powder through a 0.6 mm mesh sieve was done, oven dried for 24 hours at 100°C to remove water completely from these samples. Crushed powder samples were individually weighed, parked in a special marked containers (plastic) before being closed tightly for about 4 weeks which was enought time to allow ^{238}U and ^{232}Th to reach secular equilibrium with their daughters before measurement of radioactivity (Hassan *et al.*, 2016).

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www.iprjb.org

Table 1: Sample Collection Plan, Average Activity Concentration (Bql^{-1}) and Radium Equivalent (Bql^{-1}).

Sample area code	Number of samples collected	Sampling area, km^{20}	Activity, Bq/kg			Radium equivalent activity, (Ra_{eq}) in $Bqkg^{-1}$
			^{232}Th	^{238}U	^{40}K	
A	4	1.00	4.32±2.04	5.80±1.92	276.14±46.70	33.24±3.40
B	4	1.00	5.63±1.86	6.78±2.25	405.39±84.53	46.04±5.52
C	4	1.00	7.03±2.29	6.08±1.23	324.42±70.37	41.11±4.75
D	4	1.00	8.42±2.23	6.83±1.59	287.93±76.28	41.04±8.04
E	4	1.00	10.07±4.31	6.75±3.02	281.74±119.85	42.84±14.55
F	4	1.00	9.35±5.51	8.86±1.60	361.70±117.59	50.08±18.37
G	4	1.00	8.96±3.21	7.77±1.44	455.26±101.45	55.64±7.39
H	4	1.00	6.97±3.65	7.89±1.30	259.89±54.69	37.86±6.61
J	4	1.00	8.43±0.33	6.30±1.82	242.56±89.52	37.03±7.61
K	4	1.00	6.84±1.12	9.75±5.62	287.13±98.99	41.64±13.41
L	4	1.00	6.62±2.61	5.93±0.70	436.01±40.84	48.96±6.08
M	4	1.00	6.37±0.68	5.71±1.16	330.39±21.92	40.25±1.65
N	4	1.00	9.70±5.47	6.13±0.68	308.68±116.39	43.76±16.76
P	4	1.00	2.74±2.59	6.07±2.40	349.51±70.58	36.91±2.73
Q	4	1.00	9.70±3.70	8.51±2.73	405.47±155.79	53.60±17.31
R	4	1.00	7.49±2.78	8.72±2.26	398.65±33.46	50.13±6.43
S	4	1.00	6.71±1.63	7.93±0.24	330.12±49.75	42.94±3.89
T	4	1.00	10.66±5.89	10.53±3.51	425.98±131.73	58.57±18.03
U	4	1.00	8.33±3.20	7.73±1.75	380.98±168.08	48.97±16.99
V	4	1.00	8.96±12.51	6.36±3.62	440.90±151.62	53.12±32.96
W	4	1.00	6.54±4.26	6.85±1.33	450.12±52.19	50.86±9.57
X	4	1.00	9.34±5.98	9.05±4.68	380.08±264.93	51.67±29.07
Y	4	1.00	9.31±5.13	11.96±2.81	231.27±86.67	43.07±11.16
Z	4	1.00	12.34±3.14	8.53±2.09	311.59±33.34	50.17±5.64
a	2	0.50	7.70±0.86	5.61±1.61	438.06±143.71	50.34±10.68
b	2	0.50	9.75±5.96	5.54±0.32	472.49±57.64	55.85±3.77
d	2	0.50	8.73±4.47	4.04±1.05	369.76±115.25	45.00±1.44
e	2	0.50	6.98±0.07	6.78±1.77	404.28±82.71	47.89±8.24
g	1	0.25	9.89±0.00	5.75±0.00	407.13±0.00	51.24±0.00
h	2	0.50	8.65±0.64	8.58±2.57	387.28±42.80	50.76±6.78
j	2	0.50	9.83±0.14	6.12±2.27	372.98±32.05	48.89±0.40
n	2	0.50	6.87±0.69	7.61±0.08	333.28±32.51	43.09±1.59
q	2	0.50	5.18±0.71	6.46±2.55	286.89±11.60	35.95±4.46
r	2	0.50	8.54±1.34	4.94±1.21	324.75±10.59	42.15±1.53
t	2	0.50	8.27±2.07	8.78±1.49	259.57±128.33	40.58±11.35
Total	117	**Average**	8.03±1.91	7.23±1.67	354.81±67.06	46.04±6.28

Activity Concentration of Natural Radionuclide and Absorbed Doses

A high-purity germanium (HPGe) gamma-ray detector, 76 mm outside diameter, active volume of 144 mm^3 with an efficiency and a resolution of 31.6% and 1.8keV respectively was used for measurement of activity concentrations. individual sample was put in a marinelli beaker of 500cm^3, filled up to same IAEA standard reference soil level (RGK-1, RGU-1 and RGTh-1) and then positioned in a lead shielded detector, adopting 22000 – 62000 seconds as counting time. Soil sample reference standards from International Atomic Energy Agency (IAEA) (RGU-1, RGTh-1, RGK-1 and IAEA-375 soil) were used for method validation together with calibration of spectrometer using Maestro software (IAEA 2003).

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A comparative method was then employed to compute the activity concentration of each radionuclide. There were five notable 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 for each sample. A gamma line of 1461keV gave activity of ^{40}K, the activity of ^{238}U from 352 keV and 609 keV gamma lines of $^{214}P_b$ and $^{214}B_i$ respectively and that of ^{232}Th from 238 keV and 912 keV gamma lines of $^{212}P_b$ and $^{228}A_c$ respectively.

Measurement

Outdoor External Gamma Dose-Rate (D_{out})

The outdoor dose-rates (D_{out}) due to γ-radiations in air, measured 1 m above surface of ground for even spread of naturally occurring radionuclides (^{40}K, ^{232}Th and ^{226}Ra) were computed based on UNSCEAR 2000 provided guidelines. Assuming that the contributions coming from other naturally occurring radionuclides to be unimportant, then D_{out} can be computed from:

$$D_{out}(nGyh^{-1}) = (0.467\, C_{Ra} + 0.662C_{Th} + 0.043C_K) \quad \ldots 1$$

Where,

C_k , C_{Ra} and C_{Th} are the average activities of potassium, radium and thorium respectively in the sample and $nGyh^{-1}$ (nano Gray per hour) is the unit of the absorbed dose rates (D).

Indoor External Gamma Dose Rate (D_{in})

European Commission, 1999 gives a formula for calculating indoor external dose rate as:

$$D_{in}(nGyh^{-1}) = (0.92C_{Ra} + 1.1C_{Th} + 0.081C_K) \quad \ldots 2$$

Where,

C_k , C_{Ra} and C_{Th} are the average activities of potassium, radium and thorium respectively in the sample and $nGyh^{-1}$ (nano Gray per hour) is the unit of the absorbed dose rates (D).

Radium Equivalent Activity (Ra_{eq})

Radium equivalent (Ra_{eq}) activity, a weighted sum of ^{40}K, ^{232}Th and ^{226}Ra activities is established on approximation that 13 Bq kg^{-1} of ^{40}K, 1 Bq kg^{-1} of ^{238}U and 0.7 Bq kg^{-1} of ^{232}Th produce the similar radiation dose rates. Avwiri *et al.*, 2013 estimates radium equivalent activity as:

$$Ra_{eq}(Bqkg^{1}) = C_U + 1.43C_{Th} + 0.077C_K \quad \ldots 3$$

Where,

C_U, $1.43C_{Th}$ and $0.077C_K$ are activity concentrations in Bqkg^{-1} or Bql^{-1} of ^{238}U, ^{232}Th and ^{40}K.

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Annual Effective Dose (De)

Two main classification of annual effective dose are annual outdoor (D_{out}) and indoor (D_{in}) effective doses respectively. In estimating the yearly effective dose rates, coefficients of conversion from absorbed dose to effective dose of 0.7 $Sv.Gy^{-1}$ together with 0.2$Sv.Gy^{-1}$ (UNSCEAR 2008) proposed outdoor occupancy factor

are used. Mustapha, 1999 estimates occupancy factors, that is mean time consumed indoor and outdoor as 0.6 and 0.4 respectively. According to UNSCEAR, 2008 the respective global mean outdoor and indoor occupancy factors are 0.2 and 0.8.

Annual Outdoor Effective Dose (De_{out})

In estimating the yearly effective dose (D_e), coefficients of conversion from absorbed dose as measured in air to effective dose $\left(0.7SvGy.^{-1}\right)$ and an outdoor occupancy factor of 0.2 as proposed by UNSCEAR 2008 are used. The following formula therefore gives the effective dose rate:

$$De_{out}(mSv.y^{-1}) = D(nGy.h^{-1}) \times 8760h.yr^{-1} \times 0.4 \times 0.7SvGy^{-1} \times 10^{-6} \ldots\ldots\ldots\ldots 4$$

Where,

$mSvy^{-1}$ (milli sieverts per year) is the unit for annual effective dose rate (De)

$nGyh^{-1}$ (nano Gray per hour) is the unit of the absorbed dose rates (D)

hyr^{-1} (hour per year) given by 24hours (in a day) X 365days (in a year)

Annual Indoor Effective Dose (De_{in})

This can be taken as that dose a person receives while in the indoor environment and can be computed from formula 5 (UNSCEAR 2000). Annual indoor effective dose depends on time of stay inside a building, dose factors for conversion together with gamma ray dose existing within buildings.

$$De_{in}(mSv.y^{-1}) = D(nGy.h^{-1}) \times 8760h.yr^{-1} \times 0.6 \times 0.7SvGy^{-1} \times 10^{-6} \ldots\ldots\ldots\ldots 5$$

Where,

$mSvy^{-1}$ (milli sieverts per year) is the unit for annual effective dose rate (De)

$nGyh^{-1}$ (nano Gray per hour) is the unit of the absorbed dose rates (D)

hyr^{-1} (hour per year) given by 24hours (in a day) X 365days (in a year)

Annual Gonadal Equivalent Dose (AGED)

UNCEAR (2000) considers bone marrow, bone surface cells and gonads to be organs of interest due to their radiation sensitivity. AGED increase has been known to interfere with bone marrow thereby red blood cells causing a cancer disease known as leukemia which is lethal. The AGED for the inhabitant using such material for building may be evaluated by the following equation (Avwiri *et al.*, 2014):

American Journal of Physical Sciences

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Vol. 1, Issue 1, No. 3, pp 31 - 48, 2023

www.iprjb.org

$$AGED(\mu Svy^{-1})C = 3.09C_U + 4.18C_{Th} + 0.314C_K \quad \ldots\ldots 6$$

Excess Lifetime Cancer Risk (ELCR)

Potential carcinogenic effects that are characterized by estimating the probability of cancer incidence in a populace of individuals for a particular lifetime from projected exposures and intakes is called Excess Lifetime Cancer Risk (ELCR). Taskin *et al.*, 2009 and Azis *et al.*, 2014 calculates ELCR using equations 7 and 8.

$$ELCR = D_{e_{in}} \times DL \times RF \quad \ldots\ldots 7$$

$$ELCR = D_{e_{out}} \times DL \times RF \quad \ldots\ldots 8$$

Where,

ELCR = Excess Lifetime Cancer Risk

$D_{e_{in}}$ = Annual indoor effective Dose

$D_{e_{out}}$ = Annual outdoor effective Dose

DL = Average Duration of Life in year (≈ 70)

RF = Risk Factor in Sv^{-1}, that is, lethal cancer risk.

For stachostic effects, ICRP-60, 1990 and Taskin *et al.*, 2009 uses RF as 0.05 for public.

Hazard Indices

Hazard Indices for External Gamma Radiation (H_{ex} and I_γ)

Two indices were used in assessing the gamma radiation excess from materials used in building to ensure these materials safety. From the building materials, a hazard index describing the external gamma radiation dose is given as (Berekta and Mathew, 1985, Raghu *et al*., 2017):

$$H_{ex} = \frac{A_{Ra}}{370\ Bq\ kg^{-1}} + \frac{A_{Th}}{259\ Bq\ kg^{-1}} + \frac{A_K}{4810\ Bq\ kg^{-1}} \quad \ldots\ldots 9$$

For safe use of building materials, H_{ex} value needs to be less than unity, corresponding to 370 Bq kg^{-1}, an upper limit of Ra_{eq}. In order to substantiate whether European Commission (EC) guidelines for usage of building materials are met, EC proposed an index (I_γ) given by:

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \leq 1 \quad \ldots\ldots 10$$

An exception criterion of 0.3 together with an upper limit of 1 mSv y^{-1} are the two dose criteria used for the gamma dose of construction materials as introduced by European Commission (EC.

Many countries put in their control on 1 mSv y-1, the upper limit. If exception criterion of 0.3 together with an upper limit of 1 mSv y^{-1} are taken into consideration, then I_γ values ought to be below 0.5 and 1 respectively for materials (cement and brick) used in bulk. For building materials (tiles and board) considered superficial, restricted application should be implemented and I_γ ought to be below 2 and 6 respectively, supposing values of control of 0.3 and 1 mSv y^{-1}.

Hazard Indices for Internal Alpha Radiation (H_{in} and I_α)

Alpha (I_α) and internal hazard (H_{in}) indices are the two indices used in assessing alpha radiation excess due to radon gas coming from building materials. Raghu *et al*., 2017 mathematically defines H_{in} as in equation 11 below and can be used for internal radiation excess consideration owing to ^{222}Rn inhalation together with its short lived decay products from building materials.

$$H_{in} = \frac{A_{Ra}}{185\ Bq\ kg^{-1}} + \frac{A_{Th}}{259\ Bq\ kg^{-1}} + \frac{A_K}{4810\ Bq\ kg^{-1}} \quad \ldots\ldots 11$$

For safe use of materials in building construction, the computed H_{in} value should be less than unity.

For us to neglect the radiation hazard, values of the indices (H_{ex}, H_{in}) as from equations 9 and 11 respectively must be less than unity (Harb *et al.*, 2010).

Equation 12 gives the quantity I_α as:

$$I_\alpha = \frac{A_{Ra}}{200} \leq 0.5 \quad \ldots\ldots 12$$

The recommended respective values of I_α and I_γ are below 0.5 and 1 (Krieger, 1981, Raghu *et al*., 2017).

Correlation between ^{238}U and ^{232}Th, ^{238}U and ^{40}K and ^{232}Th and ^{40}K

According to Avwiri *et al*., 2014, the elemental concentrations (ppm) of U-238, Th-232 together with percentage potassium can be computed from activity concentrations of Th-232, U-238 together with K-40 in $Bqkg^{-1}$ as measured using the below conversion factors:

1 ppm Th = 4.06 $Bqkg^{-1}$ (of Th-232)……………………………13

1 ppm U = 12.35 $Bqkg^{-1}$ (of U-238) ……………………………..14

1 % K = 313 $Bqkg^{-1}$ (of K-40) (IAEA Technical Report No. 1363)……………..….15

American Journal of Physical Sciences

ISSN: 2958-969X (Online)

Vol. 1, Issue 1, No. 3, pp 31 - 48, 2023

www.iprjb.org

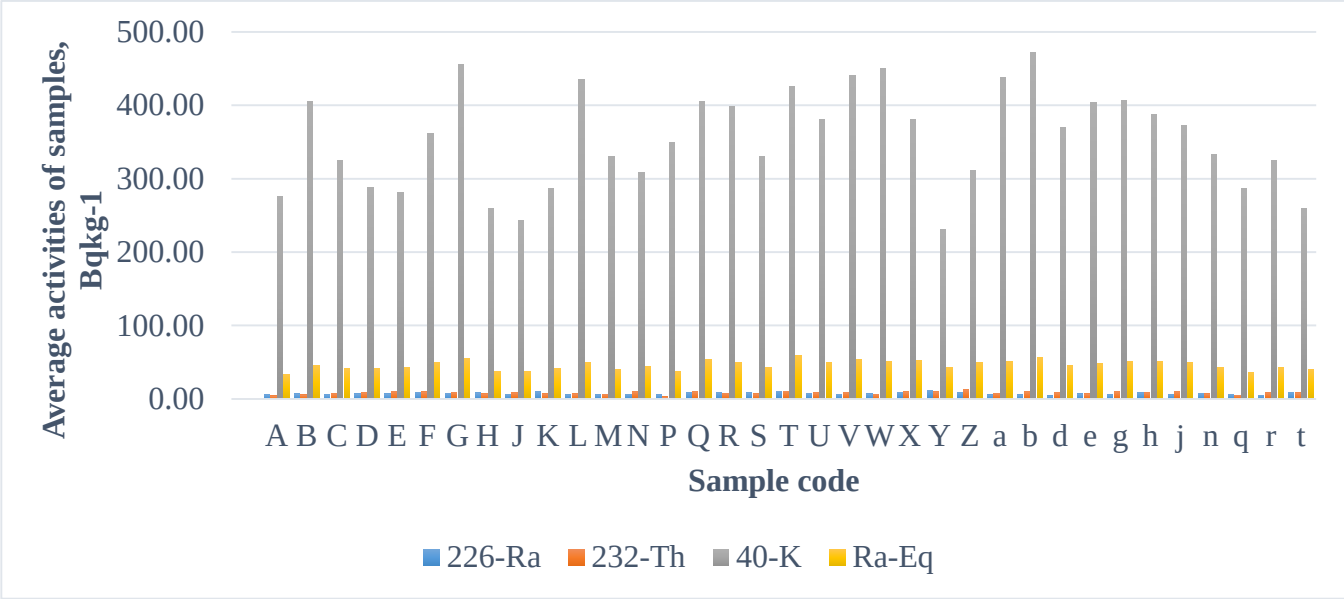

Figure 2: Activity Values of Samples due to ^{226}Ra, ^{232}Th, ^{40}K Together with Ra_{eq} In Kargi.

Table 2 compares and summerises values of activities of ^{40}K, ^{232}Th, ^{226}Ra together with Ra_{eq} in soil samples from Kargi to those from similar investigations in other countries.

Table 2.0: The Activities in Bqkg^{-1} of ^{40}K, ^{226}Ra and ^{232}Th of the Samples Investigated in Comparison with Other Countries

Country	Activity concentration (Bqkg^{-1})			Ra_{eq} (Bqkg^{-1})	Reference
	^{226}Ra	^{232}Th	^{40}K		
Kenya, Kargi	7	8	355	46	Present work
Iraq, Destroyed fuel facility	16	14	306	60	Abdulla *et al.*, 2016
India, Tamilnadu	116	44	300	201	Raghu *et al.*, 2017
Nigeria, Port Harcourt	5	4	16	11	Avwiri *et al.*, 2014
Kenya, Sakwa Wagusu	44	40	640	141	Aguko *et al.*, 2013
Turkey, Kirklareli	37	40	667	-	Taskin *et al.*, 2009
World average	37	33	400	370	UNSCEAR, 2008; Lu Xinwei *et al.*, 2006

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RESULTS AND DISCUSSION

Calculations give specific activities of ^{238}U and ^{232}Th series as well as ^{40}K, expressed in $Bqkg^{-1}$ for samples obtained from Kargi area as summerised in table 1. Obtained values for ^{226}Ra, ^{232}Th, ^{40}K together with Ra_{eq} varied from 3.30 to 18.12 $Bqkg^{-1}$, 0.00 to 17.80 $Bqkg^{-1}$, 36.87 to 667.77 $Bqkg^{-1}$, and 18.09 to 102.34 $Bqkg^{-1}$ with arithmetic mean and standard deviation as 7.40±2.61, 7.98±4.01, 351.74±109.63 and 45.90±12.65 respectively. This is seen from table 1. Globally, recommended values are respectively 37.0 $Bqkg^{-1}$, 33.0 $Bqkg^{-1}$, 400.0 $Bqkg^{-1}$ (UNSCEAR, 2008) and 370 $Bqkg^{-1}$ (Lu Xinwei *et al*., 2006). Figure 2 gives a more illustrative levels of the activities.

All mean activities for ^{226}Ra, ^{232}Th, ^{40}K together with Ra_{eq} were less than the global values recommendation.

Mean calculated absorbed dose rates for all soil samples was 23.87±3.48 **$nGyh^{-1}$** against the global median value of 54 **$nGyh^{-1}$** (UNSCEAR, 2000). The values varied between 16.06±1.09 and 29.35±1.32 **$nGyh^{-1}$,** figures which are less than the required value (table 4). The AEDE (De) values were found lower than the global value of 1 $mSvy^{-1}$ (ICRP, 2000) with a mean and standard deviation value of 0.14±0.03 $mSvy^{-1}$, varying from 0.11±0.01 to 0.18±0.06 $mSvy^{-1}$.

Excess lifetime cancer risk is an added risk that one might have on contracting cancer disease if susceptible for longer time to cancer disease causing materials. Taking 70 years as mean life duration with a risk factor of 0.05 per Sv (ICRP, 2008; Taskin *et al.*, 2009) and a median annual effective dose rate of 0.14 $mSvy^{-1}$, then excess cancer risk is computed as 0.05%. This value is less than world agreed value of 0.145 % (Taskin *et al.*, 2009, UNSCEAR, 2000). Table 4 tabulates the above values.

Elemental radionuclide concentrations in the samples were calculated from the activity concentrations in $Bqkg^{-1}$ by use of conversion factors in equations 13 – 15. These results are presented in table 5. From the table, the calculated elemental concentrations ranged from 0.74 to 1.51 %, 0.68 to 3.04 ppm and 0.33 to 0.97 ppm for potassium, uranium and thorium respectively with respective arithmetic mean and standard deviation of 1.13 ± 0.21 %, 1.98 ± 0.47 ppm, 0.59 ± 0.13 ppm.

Tzortzis and Tsertos (2004) and Al-Hamarneh and Awadalla (2009) noted that a high or low value of Th/U ratios as measured in some studied locations may be an indication of a uranium depletion or thorium enrichment due to natural processes alteration in that area. They approximated the theoretical normal continental crust values of Th/U elemental ratios to be 3.0. From table 5, our Th/U results ranged from 1.19 ± 0.85 to 6.35 ± 1.72 with mean and standard deviation of 3.57±1.13. Other correlation ratios of K/U together with K/Th varied from 0.84±0.46 to 3.89±2.13 together with 0.34±0.09 to 1.94±2.42 with mean and standard deviations of 2.15±0.67 and 0.68±0.30 respectively.

Correlations existing between activities ^{232}Th and ^{238}U, ^{40}K and ^{238}U together with ^{40}K and ^{232}Th showed a weak relationship existing on ^{232}Th against ^{238}U, ^{40}K against ^{238}U together with ^{40}K against ^{232}Th with correlation coefficients of 0.405, 0.134 and 0.319 respectively.

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Vol. 1, Issue 1, No. 3, pp 31 - 48, 2023

www.iprjb.org

Respective mean values together with their standard deviations of representative alpha (I_α), representative gamma (I_γ), internal hazard (H_{in}), external hazard (H_{ex}) indices and Annual Gonadal Equivalent Dose (AGED) values, as seen from table 3 are 167.32±23.56, 0.12±0.02, 0.14±0.02, 0.18±0.03 and 0.03±0.01 $mSvy^{-1}$ with ranges from 122.70±13.39 to 210.84±62.88, 0.09±0.01 to 0.16±0.05, 0.11±0.01 to 0.17±0.05, 0.13±0.01 to 0.23±0.07 and 0.02±0.01 to 0.05±0.02 $mSvy^{-1}$. A pictorial representation of hazard indices is shown in figure 3.

Table 3.0. Calculated Values of Representative Alpha (I_α), Representative Gamma (I_γ), Internal Hazard (H_{in}), External Hazard (H_{ex}) Indices and Annual Gonadal Equivalent Dose (AGED).

Sample area code	AGED (Svy^{-1})	External hazard index, (H_{ex})	Internal hazard index, (H_{in})	Representative gamma index (I_γ)	Representative alpha index (I_α)
A	122.70±13.39	0.09±0.01	0.11±0.01	0.13±0.01	0.03±0.01
B	171.76±21.89	0.12±0.01	0.14±0.02	0.19±0.02	0.03±0.01
C	150.02±19.38	0.11±0.01	0.13±0.02	0.16±0.02	0.03±0.01
D	146.71±29.63	0.11±0.02	0.13±0.02	0.16±0.03	0.03±0.01
E	151.40±53.02	0.12±0.04	0.13±0.05	0.17±0.06	0.03±0.02
F	180.02±64.35	0.14±0.05	0.16±0.05	0.20±0.07	0.04±0.01
G	204.42±29.93	0.15±0.02	0.17±0.02	0.22±0.03	0.04±0.01
H	135.11±22.23	0.10±0.02	0.12±0.02	0.15±0.03	0.04±0.01
J	130.86±30.13	0.10±0.02	0.12±0.02	0.14±0.03	0.03±0.01
K	148.85±48.37	0.11±0.04	0.14±0.05	0.16±0.05	0.05±0.03
L	182.89±21.25	0.13±0.02	0.15±0.02	0.20±0.02	0.03±0.00
M	147.99±6.13	0.11±0.00	0.12±0.01	0.16±0.01	0.03±0.01
N	156.40±59.19	0.12±0.05	0.13±0.05	0.17±0.07	0.03±0.00
P	139.97±10.12	0.10±0.01	0.12±0.01	0.15±0.01	0.03±0.01
Q	194.17±64.19	0.14±0.05	0.17±0.05	0.21±0.07	0.04±0.01
R	183.43±21.01	0.14±0.02	0.16±0.02	0.20±0.02	0.04±0.01
S	156.20±15.13	0.12±0.01	0.14±0.01	0.17±0.02	0.04±0.00
T	210.84±62.88	0.16±0.05	0.19±0.06	0.23±0.07	0.05±0.02
U	178.32±64.35	0.13±0.05	0.15±0.05	0.19±0.07	0.04±0.01
V	195.54±110.31	0.14±0.09	0.16±0.10	0.21±0.12	0.03±0.02
W	189.85±31.53	0.14±0.03	0.16±0.03	0.21±0.04	0.03±0.01
X	186.35±106.41	0.14±0.08	0.16±0.09	0.20±0.12	0.05±0.02
Y	148.45±39.66	0.12±0.03	0.15±0.02	0.16±0.04	0.06±0.01
Z	175.79±17.49	0.14±0.02	0.16±0.02	0.19±0.02	0.04±0.01
a	187.03±43.74	0.14±0.03	0.15±0.02	0.20±0.05	0.03±0.01
b	206.20±5.84	0.15±0.01	0.17±0.01	0.22±0.01	0.03±0.00
d	165.08±14.28	0.12±0.00	0.13±0.00	0.18±0.01	0.02±0.01
e	177.05±31.75	0.13±0.02	0.15±0.03	0.19±0.03	0.03±0.01
g	186.95±0.00	0.14±0.00	0.15±0.00	0.20±0.00	0.03±0.00
h	184.24±24.06	0.14±0.02	0.16±0.03	0.20±0.03	0.04±0.01
j	177.10±3.64	0.13±0.00	0.15±0.01	0.19±0.00	0.03±0.01
n	156.86±7.55	0.12±0.00	0.14±0.00	0.17±0.01	0.04±0.00
q	131.67±14.49	0.10±0.01	0.11±0.02	0.14±0.02	0.02±0.03
r	152.92±5.20	0.11±0.00	0.13±0.00	0.17±0.01	0.02±0.01
t	143.17±44.34	0.11±0.03	0.13±0.03	0.16±0.05	0.04±0.01
Average	**167.32±23.56**	**0.12±0.02**	**0.14±0.02**	**0.18±0.03**	**0.03±0.01**

American Journal of Physical Sciences

ISSN: 2958-969X (Online)

Vol. 1, Issue 1, No. 3, pp 31 - 48, 2023

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Table 4.0. Gamma Dose Rates, AEDE (De) and Excess Lifetime Cancer Risk (ELCR) As Per Sources

Sample area code	Absorbed gamma dose rate, D, $nGyh^{-1}$	Annual effective dose rate, De, $mSv.y^{-1}$			Excess Lifetime Cancer Risk (ELCR)
		Out	In	Total	Adults
A	17.44±1.85	0.04±0.01	0.06±0.01	0.11±0.01	0.37±0.04
B	24.32±3.01	0.06±0.01	0.09±0.01	0.15±0.02	0.52±0.06
C	21.44±2.63	0.05±0.01	0.08±0.01	0.13±0.02	0.46±0.06
D	21.14±4.22	0.05±0.01	0.08±0.02	0.13±0.03	0.45±0.09
E	21.93±7.58	0.05±0.02	0.08±0.03	0.13±0.05	0.47±0.16
F	25.88±9.37	0.06±0.02	0.10±0.03	0.16±0.06	0.56±0.20
G	29.14±4.09	0.07±0.01	0.11±0.02	0.18±0.03	0.63±0.09
H	19.47±3.29	0.05±0.01	0.07±0.01	0.12±0.02	0.42±0.07
J	18.95±4.17	0.05±0.01	0.07±0.02	0.12±0.03	0.41±0.09
K	21.42±6.92	0.05±0.02	0.08±0.03	0.13±0.04	0.46±0.15
L	25.90±3.11	0.06±0.01	0.10±0.01	0.16±0.02	0.56±0.07
M	21.09±0.74	0.05±0.00	0.08±0.00	0.13±0.01	0.45±0.02
N	22.56±8.60	0.06±0.02	0.08±0.03	0.14±0.05	0.48±0.18
P	19.68±1.37	0.05±0.00	0.07±0.01	0.12±0.01	0.42±0.03
Q	27.83±9.11	0.07±0.02	0.10±0.03	0.17±0.06	0.60±0.20
R	26.17±3.13	0.06±0.01	0.10±0.01	0.16±0.02	0.56±0.07
S	22.34±2.10	0.05±0.01	0.08±0.01	0.13±0.01	0.48±0.05
T	30.29±9.15	0.07±0.02	0.11±0.03	0.18±0.06	0.65±0.20
U	25.40±9.07	0.06±0.02	0.09±0.03	0.15±0.06	0.55±0.19
V	27.86±16.38	0.07±0.04	0.10±0.06	0.17±0.10	0.60±0.35
W	26.89±4.71	0.07±0.01	0.10±0.02	0.17±0.03	0.58±0.10
X	26.75±15.19	0.07±0.04	0.10±0.06	0.17±0.09	0.57±0.33
Y	21.69±5.77	0.05±0.01	0.08±0.02	0.13±0.04	0.47±0.12
Z	25.55±2.67	0.06±0.01	0.09±0.01	0.15±0.02	0.55±0.06
a	26.55±6.00	0.07±0.01	0.10±0.02	0.17±0.04	0.57±0.13
b	29.35±1.32	0.07±0.00	0.11±0.00	0.18±0.01	0.63±0.03
d	23.61±1.49	0.06±0.00	0.09±0.01	0.15±0.01	0.51±0.03
e	25.17±4.43	0.06±0.01	0.09±0.02	0.15±0.03	0.54±0.10
g	26.74±0.00	0.07±0.00	0.10±0.00	0.17±0.00	0.57±0.00
h	26.38±3.47	0.06±0.01	0.10±0.01	0.16±0.02	0.57±0.07
j	25.40±0.41	0.01±0.00	0.01±0.00	0.02±0.01	0.06±0.02
n	22.43±0.98	0.06±0.00	0.08±0.00	0.14±0.01	0.48±0.02
q	16.06±1.09	0.04±0.00	0.06±0.00	0.10±0.01	0.34±0.02
r	21.92±0.78	0.05±0.00	0.08±0.00	0.13±0.00	0.47±0.02
t	20.73±6.19	0.05±0.02	0.08±0.02	0.13±0.04	0.44±0.13
Average	**23.87±3.48**	**0.06±0.01**	**0.09±0.02**	**0.14±0.03**	**0.50±0.11**

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ISSN: 2958-969X (Online)

Vol. 1, Issue 1, No. 3, pp 31 - 48, 2023

www.iprjb.org

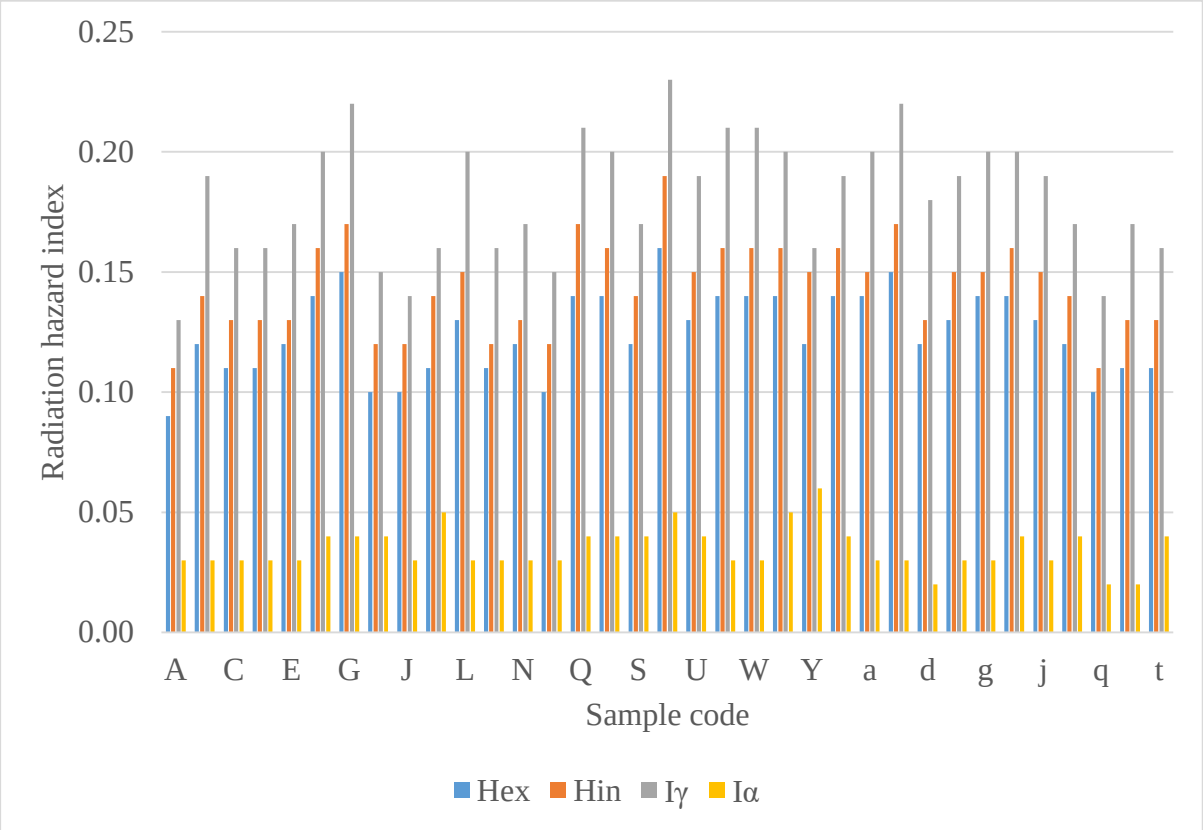

Figure 3: Hazard Indices Values for Entire Kargi Area

American Journal of Physical Sciences

ISSN: 2958-969X (Online)

Vol. 1, Issue 1, No. 3, pp 31 - 48, 2023

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Table 5.0. Elemental Concentration of Specific Activity of ^{40}K, ^{238}U Together with ^{232}Th (Ppm) in Samples with their Ratios

Sample area code	^{238}U	^{232}Th	^{40}K	Th/U	K/U	K/Th
A	0.47±0.16	1.06±0.50	0.88±0.15	2.64±1.76	2.06±0.89	1.06±0.67
B	0.55±0.18	1.39±0.46	1.30±0.27	2.52±0.29	2.62±1.08	1.04±0.44
C	0.49±0.10	1.73±0.56	1.04±0.22	3.67±1.71	2.13±0.43	0.68±0.35
D	0.55±0.13	2.07±0.55	0.92±0.24	3.84±0.96	1.78±0.77	0.45±0.14
E	0.55±0.24	2.48±1.06	0.90±0.38	5.06±2.26	1.68±0.46	0.40±0.21
F	0.72±0.13	2.30±1.36	1.16±0.38	3.06±1.23	1.58±0.21	0.57±0.20
G	0.63±0.12	2.21±0.79	1.45±0.32	3.74±1.97	2.32±0.37	0.75±0.35
H	0.64±0.11	1.72±0.90	0.83±0.17	2.69±1.42	1.35±0.47	0.65±0.45
J	0.51±0.15	2.08±0.08	0.77±0.29	4.33±1.24	1.61±0.74	0.37±0.13
K	0.79±0.45	1.68±0.28	0.92±0.32	2.46±0.79	1.29±0.46	0.54±0.12
L	0.48±0.06	1.63±0.64	1.39±0.13	3.53±1.64	2.94±0.51	0.98±0.44
M	0.46±0.11	1.57±0.19	1.06±0.08	3.50±0.77	2.38±0.56	0.69±0.15
N	0.50±0.06	2.39±1.35	0.99±0.37	4.71±2.28	1.99±0.67	0.45±0.13
P	0.49±0.19	0.68±0.64	1.12±0.23	1.19±0.85	2.60±1.12	1.24±1.23
Q	0.69±0.22	2.39±0.91	1.30±0.50	3.57±0.98	1.88±0.33	0.58±0.30
R	0.71±0.18	1.84±0.69	1.27±0.11	2.67±0.90	1.87±0.35	0.77±0.30
S	0.64±0.02	1.65±0.40	1.05±0.16	2.57±0.58	1.64±0.25	0.67±0.18
T	0.85±0.28	2.62±1.45	1.36±0.42	2.92±1.11	1.68±0.56	0.64±0.32
U	0.63±0.14	2.05±0.79	1.22±0.54	3.31±1.23	1.98±0.82	0.62±0.30
V	0.51±0.29	2.21±3.08	1.41±0.48	3.08±2.98	2.99±0.73	0.68±0.66
W	0.55±0.11	1.61±1.05	1.44±0.17	2.68±1.53	2.67±0.61	1.94±2.42
X	0.73±0.38	2.30±1.47	1.21±0.79	3.03±0.52	2.00±1.72	0.64±0.57
Y	0.97±0.23	2.29±1.26	0.74±0.23	2.65±1.67	0.84±0.46	0.40±0.20
Z	0.69±0.17	3.04±0.77	1.00±0.11	4.56±1.40	1.52±0.47	0.34±0.09
a	0.45±0.13	1.90±0.21	1.40±0.46	4.42±1.73	3.37±1.98	0.73±0.16
b	0.45±0.03	2.40±1.47	1.51±0.18	5.46±3.59	3.36±0.22	0.80±0.57
d	0.33±0.08	2.15±1.10	1.18±0.37	6.35±1.72	3.89±2.13	0.68±0.52
e	0.55±0.14	1.72±0.02	1.29±0.26	3.24±0.82	2.37±0.14	0.75±0.15
g	0.47±0.00	2.44±0.00	1.30±0.00	5.23±0.00	2.79±0.00	0.53±0.00
h	0.69±0.21	2.13±0.16	1.24±0.14	3.17±0.72	1.83±0.35	0.58±0.02
j	0.50±0.18	2.42±0.03	1.19±0.10	5.27±2.02	2.63±1.18	0.49±0.04
n	0.62±0.01	1.69±0.17	1.06±0.10	2.75±0.31	1.73±0.15	0.64±0.13
q	0.52±0.21	1.27±0.18	0.92±0.04	2.57±0.68	1.88±0.67	0.72±0.07
r	0.40±0.10	2.10±0.33	1.04±0.03	5.53±2.18	2.69±0.74	0.50±0.06
t	0.71±0.12	2.04±0.51	0.83±0.41	2.97±1.22	1.23±0.79	0.39±0.10
Average	**0.59±0.13**	**1.98±0.47**	**1.13±0.21**	**3.57±1.13**	**2.15±0.67**	**0.68±0.30**

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Conclusions

Results from the study give the mean activities for the area as 354.81±67.06, 7.23±1.67 and 8.03±1.91 Bqkg^{-1} against the world standard values of 400, 35 and 30 Bqkg^{-1} for ^{40}K, ^{226}Ra together with ^{232}Th (UNSCEAR, 2000) respectively. The area generally cannot be classified as a High Background Radiation Area (HBRA), thus good for human settlement.

Mean evaluated absorbed dose rate was below recommended values by almost half. Annual effective dose rate values were found lower than global value of 1 mSvy^{-1}, which, for the public exposure is the annual effective dose rate limit (ICRP, 2000).

Hazard indices (H_{in}, H_{ex}, I_{γ} and I_{α}) together with Radium equivalent (Ra_{eq}) values for the studied area wass lower that values recommended of 1 (H_{in}, H_{ex} and I_{γ}), 0.5 (I_{α}) and 370 Bqkg^{-1} (IAEA, 2007, Lu Xinwei *et al*., 2006). Radiation risk associated with these soils can be considered negligible making the rocks and soils in the area be safe for construction causing no important radiological threat to populace.

Excess cancer risk, calculated from the samples showed lower values hence minimal chance of getting cancer disease. The area is safe from cancer causing radionuclides.

Because Th/U value was higher than the recommended, the study can therefore conclude that there could have been a fractionation during weathering or involvement of metasomatic activity of the radioelements.

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