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Levels Of Natural Radionuclides in Khat (*Catha Edulis*) Leaves and Soils In Selected Areas In Embu County, Kenya

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ABSTRACT

Over the past years, khat (*Catha edulis*) has been the major cash crop grown in some parts of the Eastern side of Kenya.The leaves from this plant are chewed for their stimulating effect. However, some studies have reported detrimental effects on the users of khat. This research established the level of human exposure due to radiation by natural sources in the khat growing areas of Embu County by measuring the specific activities of ^{238}U, ^{232}Th and ^{40}K, estimate the dose rate absorbed and obtain the hazard indices due to these radionuclides. A total of 30 samples were collected from different areas distributed throughout Embu County, 15 for khat and 15 for soil samples. The samples were then prepared and analyzed using the Thallium activated Sodium Iodide Detector (NaI (Tl). Mean activities for khat leaves were obtained as 875.8±11 Bq/kg, 10.1±1 Bq/kg and 51.1±4 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively. The activities of soil in the same region were obtained as 344±12 Bq/kg, 22±11 Bq/kg and 33±5 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively. The mean absorbed dose rates obtained for soil was 44±0 $nGyh^{-1}$ while the average Annual Effective Dose (AED) for ingested radionuclides for khat was 0.45±0.19 mSv/y. Average values of soil hazard indices for soil 0.26, 0.32, 0.70 and 0.76 for external index (H_{ex}), internal index (H_{in}), gamma index (γ) and Excess Lifetime Cancer Risk (ELCR) respectively. All the indices in this work were within the safe limit.

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1. INTRODUCTION

1.1 Background of the Study

Knowledge of the effects of radiation exposure is of extreme importance to the society, health professionals, research, and scientific importance [1]. According to [2], khat consumption causes genotoxic effects on humans. A report by the National Cancer Institute (Kenya) detailing cancer prevalence per county listed Embu County as one of the leading in Oesophagus and prostate cancers. The report indicates a 21.0% prevalence of Oesophagus cancer and 24.1% for prostate cancer per 100,000 people [3]. Statistics on cancer cases in Kenya has shown elevated numbers of stomach and esophageal cancers in the northern parts of Meru and Embu where khat chewing is common [4]. Natural radionuclides of earth origin are found in varying amounts in almost all materials in our environment, the human body being included [5]. Some foods items, substances and water from certain areas have been known to contain primordial radionuclides of natural origin however in small amounts. Tobacco, for instance contains minute quantities of radioactive series of Uranium and Thorium which can increase the internal intake and radiation dose due to natural radionuclides when inhaled. Primordial radionuclides occur in nature because their half-lives are comparable with the earth's age. These radionuclides include ^{238}U, ^{232}Th, ^{235}U and ^{40}K. However, of these radioactive materials (NORM), ^{40}K is the most plentiful on the earth's crust.

1.2 The Khat plant, Consumption and its Health Implications

Some other names used to refer to khat include Miraa, Muguka Abyssinia tea, Gat, Muguka, Tohai, jaad among others. The Muguka variety is mainly grown in Embu County which is the study area. It is a small evergreen bush plant that is indigenous to the area stretching from Eastern side of Africa to South Africa, as well as the northeast of Africa [6]The plant is grown as a shrub. The plant takes about three years to attain the optimum height for harvesting. Its young buds and tender leaves are chewed to attain a state of euphoria and stimulation. The leaves have an aromatic odor. Fresh khat leaves are glossy and crimson-brown in color. The taste is astringent and slightly sweet. The plant is seedless and hardy, growing in a variety of climates and soils. The khat tree (Muguka variety) has its height varying from about 1m to 1.5 m. The khat tree spans a length of about 0.5m on either side from its base. Figure 1 represents a mature khat plant of Muguka variety showing the crimson, brown young and tender buds that are ready for harvesting.

Figure 1: Khat plant (Muguka) showing the fresh bud ready for picking

Majority of the population who use khat in Kenya and the world over do so by chewing. Only a small number ingest it by making a drink from dried leaves, or even very rarely, by smoking dried leaves. The effect on the users is however the same. The chewer fills his or her mouth with leaves and stalks in bits, and then chews slowly and intermittently to release the active components in the juice, which is then swallowed with saliva. The plant material is chewed into a ball, which is kept for a while in the cheek, causing a characteristic bulge [7]. The khat chewing mainly happens in social setting and only a minority frequently chews alone. A session may last for several hours. During this time chewers drink copious amounts of non-alcoholic fluids such as soda (cola), tea or coffee and cold water.

Many studies have reported that khat – chewing has both positive and negative health implications. The positive uses of khat range from recreation (mood elevation) to its use as medicine as a remedy for fatigue. The harm from Khat has been debated globally ([8]; [9]; [10]). The dominant negative effects of khat are mostly of the nervous and the digestive systems but have also been known to affect the cardiovascular, endocrine and respiratory systems. Additionally, [11] reported existence of a strong correlation between khat chewing and oral cancer.

2. RESEARCH METHODS

2.1 Study area and sampling

Embu County which is the study area is bounded longitude 37°3' and 37°9' East, and latitudes 0°8' and 0°50' South. The neighboring counties are Kitui to the east, Tharaka Nithi to the North, Muranga to the South West, Machakos on the south, Meru to the North West and Kirinyaga which is the nearest from Embu town and borders on the west. The county has huge markets for khat (Muguka) trade, the major ones being Embu town's Kamuketha Muguka Market, Muraru market, Meka and Siakago markets. The main economic activity in Embu County is Agriculture beside other activities like sand harvesting, mining for quarry stones. The main cash crop in lower Embu (Mbeere North and Mbeere South) is khat while in the upper parts of Embu (Manyatta and Runyenjes); the main cash crop is coffee, tea and khat which have gained prominence in recent years. In khat growth, inorganic and organic fertilizers are used to boost productivity. Besides, pesticides are used in control of diseases, to speed up maturity and ensure the aromatic coloration of the fresh buds in order to fetch better prices in the market. The county has a total population of 608,599 and demography of 216 persons per square kilometer [12]

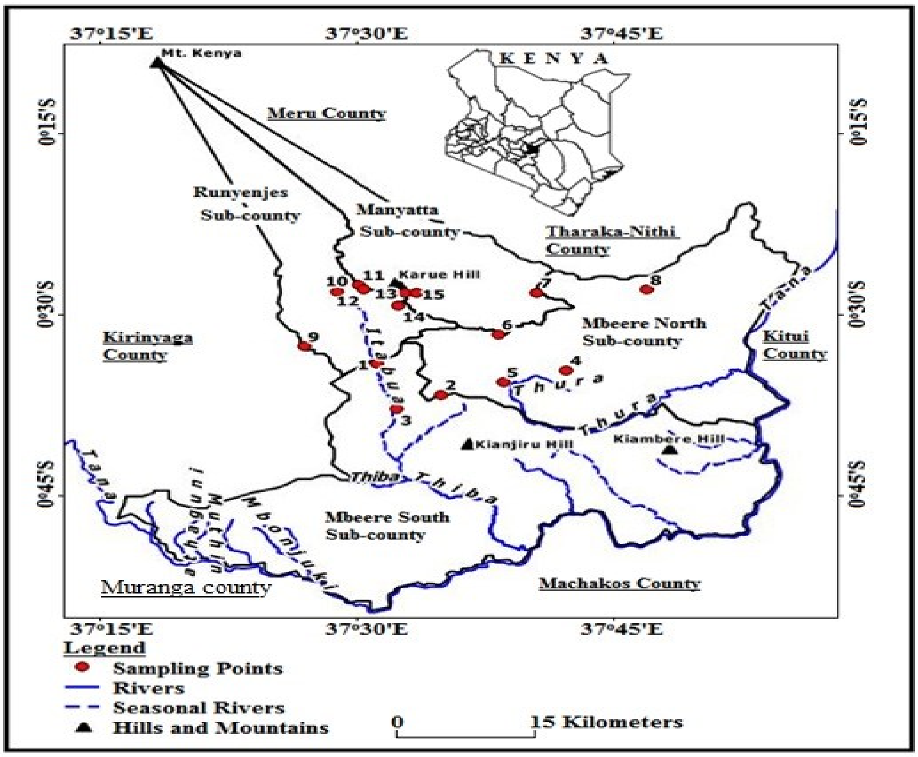

Figure 2: Topographical Map of Embu County showing the Sampling Points

Samples of khat (*Catha edulis*) leaves and soils were collected during the dry season in the months of February and March. In order to attain statistical sensitivity, the simple random sampling was employed in sample collection [13] .15 soil and 15 samples of khat leaves were collected making a total of 30 samples. The sampling points were identified throughout the county in the four sub counties namely Mbeere North, Mbeere South, Manyatta, and Runyenjes. Five of the sampling areas were in Mbeere North being one of the areas where Muguka is expansively grown. Four sampling areas were in Runyenjes while three samples were collected from each of the remaining sub counties (Mbeere South and Manyatta). In Mbeere North, the samples were collected in areas around Muchonoke, Siakago and Kanyuambora, BAT and Witwa. The samples in Mbeere South were collected from the region around Kiritiri, Muraru and Meka. Manyatta samples were collected around Makengi, Mwanagiti and Kathigiri while in Runyenjes; the samples were collected from areas in Kathageri, Ugweri, Makutano and Karurumo. From each of the sampling areas, a sample of soil and a sample of khat leaves were collected. For the soil samples, once the position of soil had been determined, the ground was cleared of any foreign material and about 300g of soil collected at an extent of about 10cm below the surface [14]. Three soil samples were collected from each area and merged to get one for the sake of homogeneity and quality assurance. The handheld GPS was used in mapping the geographical positions of the sampling points as in figure 2. Also, about 1500g of the khat leaves were picked. The collected soil material and khat leaves were placed in coded polythene bags for transportation to the laboratory for activity measurements.

2.2 Sample Processing

The khat leaves were first dried in air for a period of two months until they were moisture free and then blended and shredded into a powder form of very fine particles using a 240V, 5000W blender. The leaves had a high fiber content and therefore took long to be finely crushed. Each sample took between 30-45 minutes to be well grounded. Samples of the grounded khat from each sampling site were then dried at 103^0C for about 16 hours to ensure material homogeneity ([15]; [16]). The fine powder obtained was then sifted through a 200 µm mesh. They were then weighed and put in coded 150ml plastic containers (the containers were sealed using masking tape to prevent the escape of airborne Rn-222 and Rn-220 from the samples) and stored for 30 days to allow ^{238}U and ^{232}Th and the daughter radionuclides attain secular equilibrium before radioactivity measurements [17]). The mass of the khat samples ranged from a minimum of 46.95 g to 98.14 g. The soil samples were grounded using pestle and mortar and similar steps followed. The soil samples were also stored in 150ml plastic containers. The mass of the soil samples ranged from 113.6g to 184.7g. A spectrometry system made up of an assembly of NaI(Tl) was then used for activity determination in the khat leaves and soil samples.

2.3 Energy Calibration and Resolution

This was achieved by assigning the energies of the standard materials to the channel number. ^{137}Cs and ^{60}Co were used as a standard source of gamma energies of 662keV, 1170 keV and 1330keV for the purpose of calibration. The sources were placed on the detector in the same kind of beakers used for the experimental measurements for about 36000s [18]. The energy calibration linear fit for the NaI detector used in this work is as shown in Figure 3. The linear fit equation was used in energy calibration.

$$y = 3.7x + 34.9 \quad (1)$$

with y representing the energy (the photon), x represents the count of the channels and 3.7 and 34.9 being the fit coefficients.

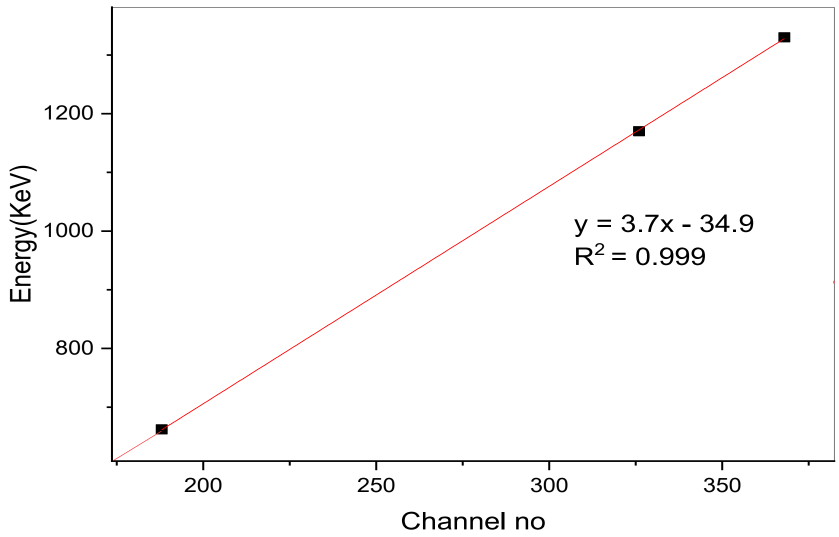

Figure 3: Linear Fit for the Energy Calibration

The detector resolution was determined by measuring a standard ^{137}Cs source on the detector and a spectrum of the full energy peak (FEP) located at 662 keV for 600 seconds. This resolution is given in terms of the Full Width at Half Maximum (FWHM) divided by the location of the peak centroid energy E (keV).

$$Resolution = \frac{FWHM}{E} \times 100\% \quad (2)$$

An energy resolution of 7.12% was obtained for the NaI detector used in this work. This energy resolution was low as is the case with most scintillation detectors. Low energy resolution is due to statistical fluctuations. The low detector resolution is offset by other favorable properties.

2.4 Detection Efficiency of the NaI(Tl) Spectrometer

This was done in order to convert the count rates (cps) response of the spectrometer to desirable activity in Bq for each radionuclide; ^{40}K, ^{238}U and ^{232}Th. The reference standard materials were counted, and regions of interest (ROI) was created. The counting efficiencies were calculated and recorded for all gamma transitions. This was done using equation 3

$$E_i = \frac{n_s - n_b}{P_1 c m_s} \quad (3)$$

where E_i is the absolute counting efficiency of gamma energy (counts/s/Bq), n_s is count rate in a particular energy window filled with containers (counts/s), P_1 is emission probability of gamma energy, C is the activity of the reference material in Bq/kg and m_s is the mass of the sample in kg.

2.5 Background Radiation of the NaI(Tl) Detector and Spectral Data Acquisition

Background measurements were done by placing a sample of distilled water in a plastic beaker then placing it in the detector's active volume for a period of 30000 s (the same period used for other measurements). The actual counts were determined by deducting the background counts from the counts recorded by running the actual sample over the same time using equation 4

$$I_S = I_T - I_B \quad (4)$$

where I_S is the sample's intensity, I_T is the total intensity and I_B is the background counts.
All the samples were analyzed for 30,000s including distilled water for background measurement and a standard reference sample. The same detector geometry was maintained for all samples. The activity concentration of ^{214}Bi (1765 keV) a gamma ray emitter was used for activity measurement of ^{238}U while the energy peak of ^{208}Tl (2615 keV) was used in determination of the activity concentration of ^{232}Th since the radionuclides ^{238}U and ^{232}Tl are alpha emitters and would otherwise not be detected directly using the gamma ray spectrometer. Activity levels of ^{40}K were measured at 1460 keV gamma peak.

2.6 Evaluation of Radiological Parameters

2.6.1 Radionuclide Activities in Soil and Khat Samples

These were calculated using equation 5 [19]

$$A_S = \frac{CPS}{\varepsilon I_{\gamma M}} \quad (5)$$

In this equation, A_s is the activity concentration of radionuclides in Bq/kg, CPS is the net count per second for each sample obtained by subtracting the background from the total area under the most prominent photo peaks, ε refers to the detector efficiency expressed as a percentage, I_γ is the gamma emission probability, M mass of the sample in kilograms. The detection efficiency is a measure of the percentage of radiation that a given detector detects from the overall yield emitted from the source. It can vary depending on the volume and shape of the detector material, absorption cross-section in the material, attenuation layers in front of the detector, and distance and position from the source to the detector.

2.6.2 Absorbed Dose Rate, D_R (nGy/h) in Soil

Calculation of D_R is the initial and paramount step for evaluating radiological health risk. It is globally acknowledged that the radiological and clinical effects are normally directly related to the absorbed dose rate [20]. The absorbed dose rate D_R (nGy/h) was computed using:

$D_R = 0.46(Gy/h)A_U + 0.6(Gy/h)A_{Th} + 0.042(Gy/h)A_K$ (6)
Where A_U, A_{Th}, A_K are the activity concentration in Bq/kg of ^{238}U, ^{232}Th and ^{40}K respectively. [5] and [21] gives a world weighted average value of 57nGy/h.

2.6.3 Annual Effective Dose Rate for External Exposures (AEDE) due to Soil Samples

Computation of AEDE was done in this work to help in assessing the risk on the living in or outside the houses constructed from soils in Embu County. Equations 7 and 8 were used.

$$AEDE_{Indoor}(mSy^{-1}) = D_R \times 8760h \times 0.7(Sv/Gy) \times 0.2 \times 10^{-6} = D_R \times 1.21 \times 10^{-3} \quad (7)$$

$$AEDE_{Outdoor}(mSvy^{-1}) = D_R \times 8760h \times 0.7(Sv/Gy \times 0.8 \times 10^{-6} \quad (8)$$

where D_R (nGy/h) is as defined in equation 6, 8760 is the time in hrs/year (24×365), 0.7 is the conversion coefficient from absorbed dose in air to effective dose received by adults as used in [1] while 0.2 and 0.8 are coefficients for the time spent by house dwellers for indoors and outdoors respectively.

2.6.4 AED (Ingested Radionuclides)

(ICRP 1996b, ICRP 2012) has provided various ingestion dose coefficients of chosen 31 elements for different age groups for instance toddlers (3 months), children (ages 1, 5, 10 and 15 years) and also for adults. In each case, the values given are of committed active dose per Bq that gets into the body of an individual in those age brackets. This study focused on dose coefficients for ^{238}U, ^{232}Th and ^{40}K.
$AED_{Internal\ exposure} = \sum I_t \times 365(days) \times D_C$ (9)
Where I_t is the daily radionuclide intake = specific activity in khat (Bq/kg) × (khat chewed (kg/day) and D_C is the coefficient for an adult as per table 4.2 ([22]; [23]). This work used the dose coefficients for adults, that is: $4.5\times10^{-8}(Sv/Bq)$, 2.3×10^{-6} $(Sv/Bq)$and $2.3\times10^{-6}(Sv/Bq)$ for ^{238}U, ^{232}Th and ^{40}K respectively. AED due to khat chewing was estimated assuming a daily khat intake for an adult person at 0.5 kg/d [24].

2.6.5 Annual Gonadal Equivalent Dose (AGED) in Soil Samples

UNSCEAR, 2008 gives the organs of interest as thyroid, alveoli, bone marrow, osteoblasts, the testes, ovaries among others. The world average value of AGED is 300μSvy^{-1} for the reproductive organs (gonads). AGED was obtained using equation 10 [21]
$AGED\ (\mu Svy^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.31A_K$ (10)
In this formula; factors 3.09, 4.18 and 0.314 transform the specific activities into total dose received by the gonads.

2.6.6 External Hazard Index, H_{ex}

The external hazard index is used to evaluate the indoor radiation dose rate due to the external exposure to gamma radiation from the natural radionuclides in building materials of dwellings. It is normally evaluated to understand the risks due to external exposure from the excess gamma radiation. H_{ex} was calculated using equation 11 [25]

$$H_{ex}(revised) = {A_{Ra}}/{370(Bq/kg)} + {A_{Th}}/{283(Bq/kg)} + {A_K}/{4099(Bq/kg)} \quad (11)$$

2.6.7 Internal Hazard Index, H_{in}

Radon is often the single largest contributor to an individual's background radiation dose and is the most variable from location to location. Exposure to radon or its daughter could lead to complications of the respiratory system and especially the lungs [26]

$$H_{in} = {A_{Ra}}/{185(Bq/kg)} + {A_{Th}}/{259(Bq/kg)} + {A_K}/{4810(Bq/kg)} \quad (12)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively. The safety limit for these indices is unity [27]

2.6.8 Gamma Index, I_γ

Gamma index is normally applied in estimating Iγ (representative gamma index) hazard that is interconnected to occurring natural radionuclides in any particular substance under investigation and in this work, it was used for soil. It is a parameter that discriminates to confirm the concurrence of soil materials to the set world standards. I_γ should be less than 1 and corresponds to AED of <1 mSv [28]. Gamma index is also used to correlate the annual dose rate due to the excess external gamma radiation caused by superficial materials. It is a screening tool for identifying materials that might be of health concern when used for building construction

$$I_\gamma = {}^{A_{Ra}}/_{150(Bq/kg)} + {}^{A_{Th}}/_{100(Bq/kg)} + {}^{A_K}/_{1500(Bq/kg)} \quad (13)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively.

2.6.9 Risk Assessment, G

This estimates the number of people likely to die in the area of study as a result of the AED. This was calculated using equation 14

$$G = F_C H_R P \quad (14)$$

G refers to estimated number of deaths, H_R the annual effective dose rate (AED), F_C the dose to risk conversion factor at 0.05 Sv^{-1} (ICRP, 1996b)and P the population of adults between 20 -60 years (population with high prevalence for khat chewing according to [29] in Embu County), taken to be 300,774 [12] Equation 14 is associated with internal exposure since it factors in the Annual Effective Dose (AED) and was therefore applied for khat samples.

2.6.10 Excess Lifetime Cancer Risk (ELCR)

This refers to the degree of the likelihood of development of malignant tumors to an individual. It is estimated from AEDE. [30]computes the ELCR using equation 15

$$ELCR = AEDE \times D_L \times R_F \quad (15)$$

AEDE is defined by relation 4.7 above, D_L is the number of years an individual will be at risk of exposure taken as 67y, the life expectancy in Kenya [31] while R_F is the constant giving risk factor to the community given as 0.05 Sv^{-1} [23]. The equation 15 is applicable to external radiation exposure since it estimates the risk using AEDE.

3. RESULTS AND DISCUSSION

3.1 Activity levels for khat and soil samples

a) Soil samples

Equation 5 was used in computing the activity concentrations. Minimum activity concentrations were determined to be 114±7, 5±1 and 1±0 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively. Maximum values for ^{40}K, ^{238}U and ^{232}Th were 520±16, 50±20 and 57±6 Bq/kg respectively. The average concentration levels for each of the radionuclides in the soil samples were determined as 344±12, 22±11 and 33±5 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively. All these values are below the world average values of 420,33 and 45 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively. Samples EMS 1 and EMS 2 however registered higher activity values compared with the other sites. This could be owed to their close proximity to Itabua River and being on the lowland where there could be a possible huge deposition of the radioactive rich gneiss and granite from the uplands. Samples EMS 14 and EMS 15 also had higher values of ^{40}K compared to other sites possibly due to high usage of potassium rich inorganic fertilizers in the large maize farms within the area. The two sampling points were also close to Karue hill (an inselberg of igneous origin).This could have led to degradation of the hill by natural processes of weathering, erosion and human practices like grazing and cultivation. These could lead to removal and subsequent displacement of granite, feldspars and mica which are known to be very rich in ^{40}K to the neighboring lands. The values are however not significantly high.
A graphical representation is shown in figure 4.

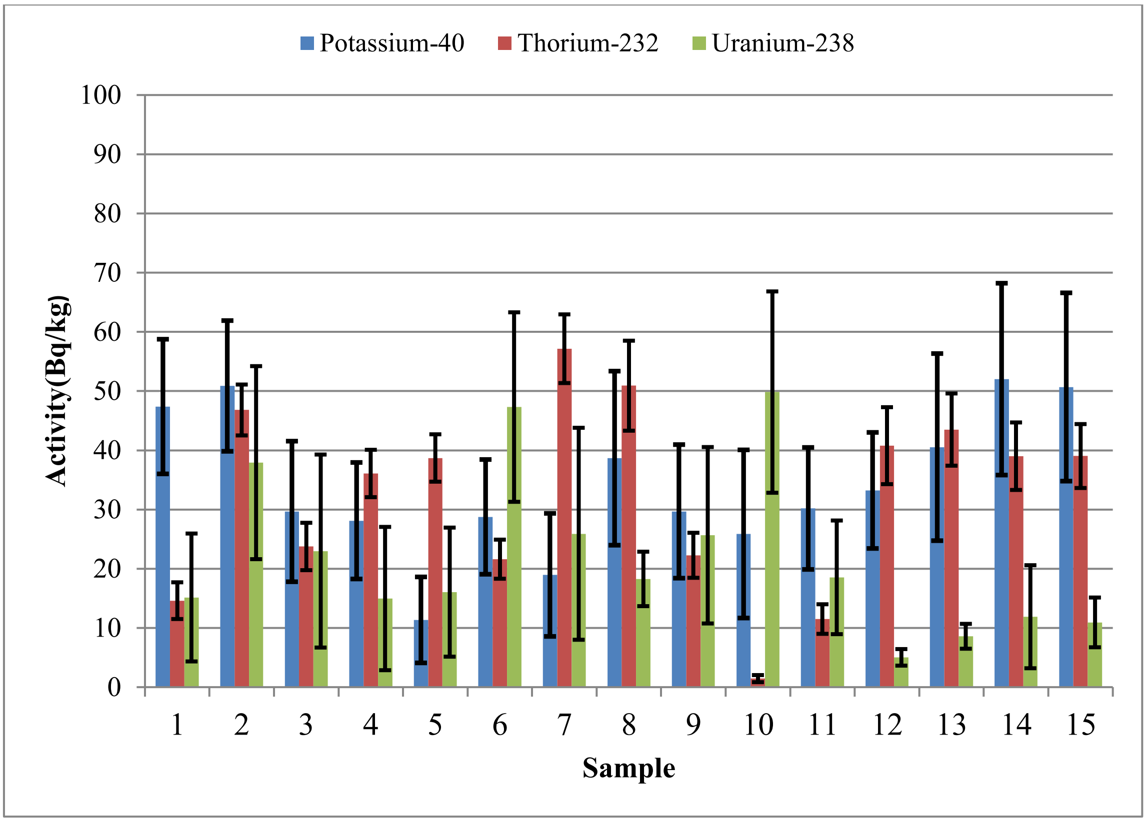

Figure 4: Activities of primordial radionuclides in Soils collected from Embu County

N.B: The values of K-40 have been down sized by 10
A summary of the average activities for the soil against the world averages is as illustrated in table 1:

Table 1: Average Activities for Soil Samples against the World Averages

Radionuclide	This study(Soil)(Bq/kg)	World weighted Average(Bq/kg)
^{40}K	344±12	420
^{232}Th	33±5	45
^{238}U	22±11	33

b) Khat Samples

The minimum activities were obtained as 451.5±5 Bq/kg for sample 11, 12±1 Bq/kg at sample 14 and 2±0 Bq/kg at sample 3 for ^{40}K, ^{232}Th, ^{238}U respectively. Maximum activities were obtained as 1610±11 for sample 13, 122±4 for sample 13 and 33±2 Bq/kg for sample 13 for ^{40}K, ^{232}Th and ^{238}U respectively. Average values were obtained as 875.8±11, 51.1±4 Bq/kg and 10.1±1 for ^{40}K, ^{232}Th and ^{238}U respectively. The average activities in khat for ^{40}K and ^{232}Th were higher than in soil which could be attributed to the chemicals used in pest control in khat and also the root uptake of phosphate fertilizers used in khat growing. Airborne radionuclides deposited on the khat leaves could also be factor towards the high activities in the khat leaves compared to the soil samples.

The visual representation of the activity concentrations for all the samples is as shown below in figure 5

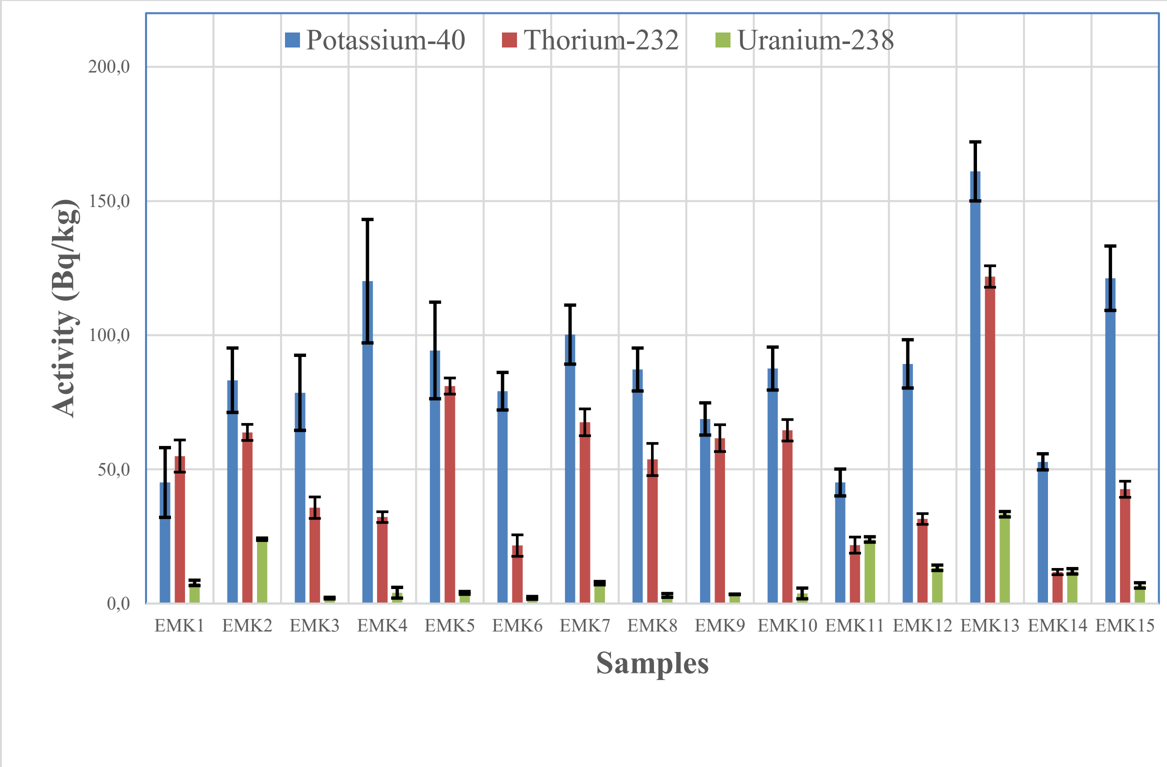

Figure 5: Levels of ^{40}K, ^{238}U and ^{232}Th activities of in Khat Samples.

N.B: The values of ^{40}K have been scaled down by a factor of 10.

The table 2 shows the activity concentration ok khat in this study when compared with activities of khat and tobacco leaves in Yemen [32]). A comparison has also been done with tea leaves in Kericho, Kenya [33] and also Tobacco leaves from Egypt [34]

Table 2: Comparison of Average Activities in Catha edulis (this study) with Catha edulis (Yemen), Tobacco (Yemen and Egypt) and Kericho tea leaves (Kenya)

Radionuclide	Catha edulis(This study)	Catha edulis in Yemen [32]	Tobacco in Yemen [32]	Kericho Tea [33]	Tobacco leaves in Egypt [34]
^{40}K	875.8±11	687±38	1126±56.2	667±8	1289.53
^{232}Th	51±4	50.25±4.88	71.35±8.84	43±2	3.94
^{238}U	10.1±1	0.28±0.05	0.81±0.04	48±5	4.56

3.2 Absorbed Dose Rates from Soil Samples

The mean dose rate for soil was obtained as 44±0 nGy/h. The dose rates for the soil samples ranged from 28±1 to 55±1 nGy/h. The average dose rate for soil was therefore below the world average of 57 nGy/h [21]. All values of the dose rates are below the world average.

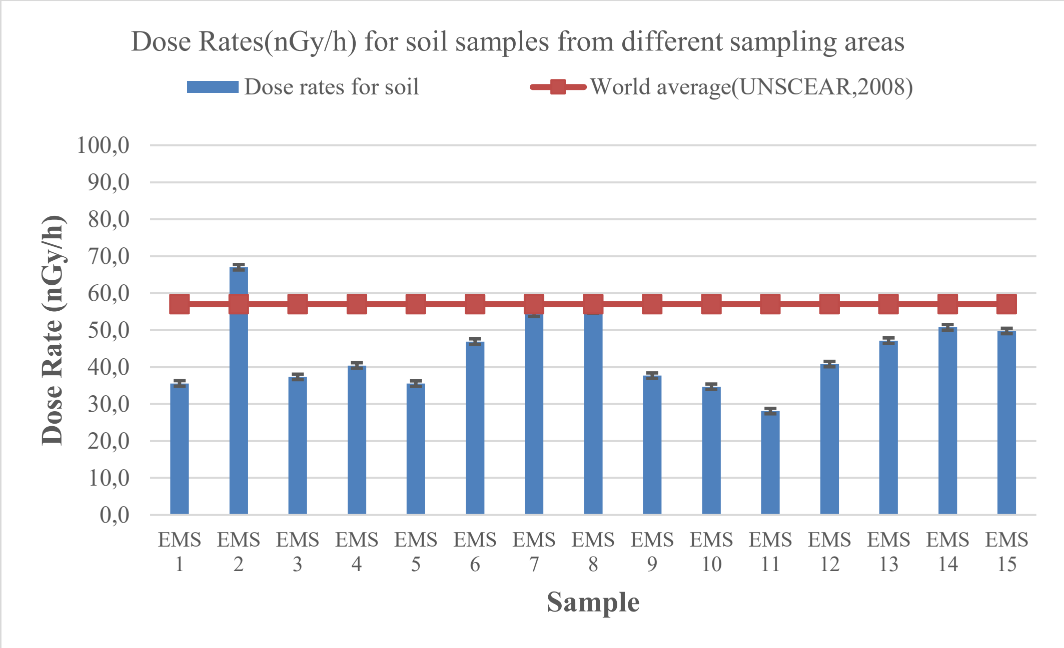

Figure 6: Dose Rates (nGy/h) for Soil Samples from different Sampling Sites

3.3 Annual Effective Dose (AED) in Khat Samples

The obtained mean value of AED for ingested radionuclides for khat was 0.450±0.11 mSv/y which was lower than [5] populated weight average of 0.87 mSv/y. This therefore implies that the Catha edulis grown in Embu may be considered safe. The range of the AED (Internal exposure) spanned from 0.11±0.09 to 1.06±0.34 mSv/y. These values are as shown in table 3

Table 3: AED (mSv/y) for Khat Samples

Sample	AED for khat(mSv/y)
EMK 1	0.47±0.12
EMK 2	0.56±0.21
EMK 3	0.32±0.32
EMK 4	0.30±0.21
EMK 5	0.70±0.21
EMK 6	0.20±0.11
EMK 7	0.59±0.19
EMK 8	0.47±0.32
EMK 9	0.53±0.23
EMK 10	0.56±0.13
EMK 11	0.20±0.12
EMK 12	0.29±0.12
EMK 13	1.06±0.34
EMK 14	0.11±0.09
EMK 15	0.39±0.09
AVERAGE	**0.450±0.19**

3.4 Annual Effective Dose Equivalent (AEDE) in Soil Samples

The average obtained for the indoor AEDE (soil samples) was 0.05±0.02 mSv/y with a range of 0.03±0.01 - 0.08±0.01 mSv/y. This average value for the indoor AEDE is below the global average of 0.40 $mSvy^{-1}$ [21]. The mean for outdoor AEDE was 0.22±0.10 mSv/y with range of 0.14±0.01 - 0.34±0.13 mSv/y.

3.5 Annual Gonadal Equivalent Dose (AGED)

The obtained AGED value for soil samples had a mean of 310±9 µSv/y with most of the sample sites registering a value lower than the worldwide mean value of between 316.68 and 415.65 µS/y [35]. The range of AGED for soil samples being 199±9 μSv/y to 389±7μSv/y. The values are lower when compared to most of the areas where AGED values have been computed for example, a value of 594.21 μSv/y was obtained for soils in the northeastern part of Burkina Faso [36].

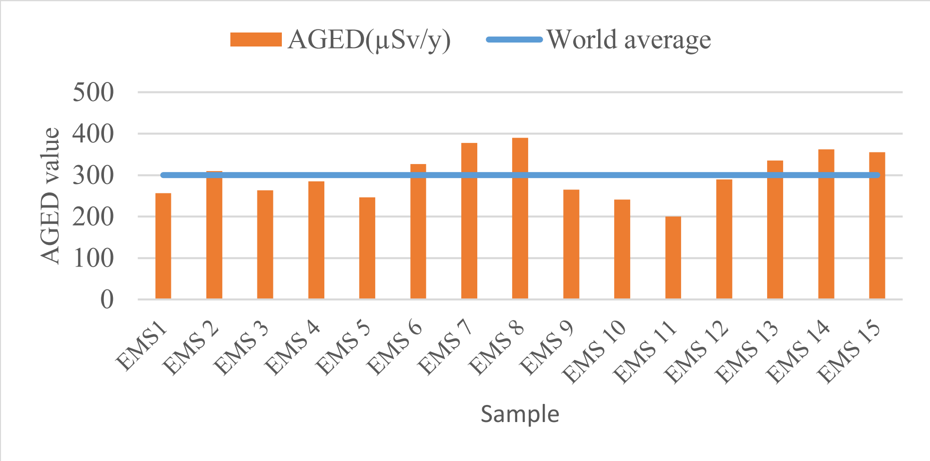

Figure 7: Graphical representation of Annual Gonadal Effective Dose (μSv/y) in Soil Samples

3.6 Hazard Indices in Soil Samples

External index had a mean of 0.26 with a range of between 0.16 and 0.39 while the internal hazard index had an average of 0.32 and a range of between 0.21 and 0.49.The gamma representative index had a mean value of 0.70 with minimum value of 0.44 and maximum of 1.06. ELCR was also determined and an average of 0.76×10^{-3} was obtained. ELCR value was found to be below the world average of 1.45×10^{-3}. Figure 8 is a representation of the hazard indices.

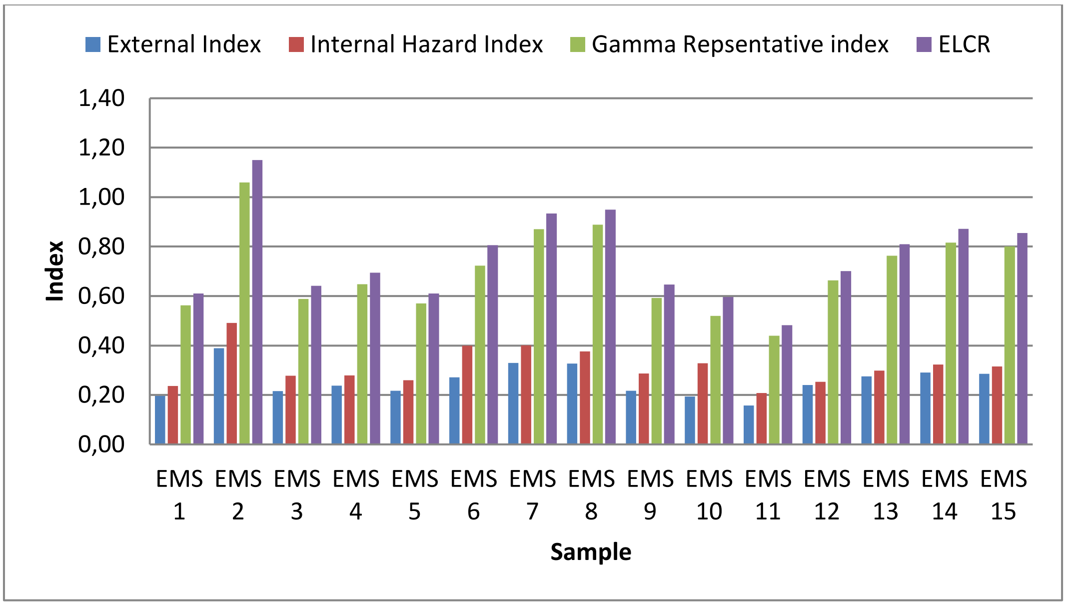

Figure 8: Visual Representation of the Hazard Indices in Soil Samples

3.7 Risk Assessment, G

This was computed to estimate the number of people likely to die as a result of chewing khat in this area. This was done assuming the age group of 20-60 years has the highest prevalence of khat chewing. The fatalities percentage were however negligible at 0.0000366% .This percentage would be much lower if the actual number of khat chewers was used since this research did not factor in gender variation with regard to khat chewing practice.

4. CONCLUSION

This research undertook radioactivity measurements of ^{238}U, ^{232}Th and the naturally occurring ^{40}K in both khat leaves and soils in Embu County using the gamma spectrometric technique. The khat samples showed mean activity concentrations of 875.8±11, 51±4 and 10.1±11 Bq/kg for ^{40}K, ^{232}Th and ^{238}U respectively. The activities of soil in the same region showed values lower than the world average for soil. These mean activity concentrations were obtained as 344±12, 22±11 and 33±5 Bq/kg for ^{40}K , ^{238}U and ^{232}Th respectively. High activities in khat could probably be owed to the uncontrolled and rampant use of chemicals and pesticides in khat cultivation. The mean absorbed dose rates obtained was 44±0 $nGyh^{-1}$ for soil samples. This value is lower than the world average of 57nGy/h and also lower than the acceptable safe limit of 1500 nGy/h [21]. The AED for ingested radionuclides for khat had a mean value of 0.450±0.19 mSv/y. The average obtained for the indoor AEDE (soil samples) was 0.05±0.02 mSv/y with a range of 0.03±0.01 - 0.08±0.01 mSv/y. This average value for the indoor AEDE is below the global average of 0.40 $mSvy^{-1}$ [21]. The mean for outdoor AEDE was 0.22±0.10 mSv/y with range of 0.14±0.01 - 0.34±0.13 mSv/y. All the hazard indices computed for soil samples (external index, internal index and gamma representative index) indicated values below unity which is considered the safe limit by many researchers. Owing to this, it can be concluded that the khat grown in the study area poses no significant risk to the consumers and the general populace. The soils from the area are also safe due to the low radionuclide levels obtained in this work.

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