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Soil To Plant Transfer Factors of Natural Radionuclides in Khat (*Catha endulis*) from Igembe South Subcounty, Kenya.

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ABSTRACT

This study evaluated the soil to plant transfer factors of khat (*Catha endulis*) to determine the absorption potential of natural radionuclides. Soil and leaves of Khat were sampled from Igembe south subcounty, Kenya and analyzed for concentrations of primordial radionuclides using a Thallium doped NaI gamma ray detector. Soil to plant transfer factors were calculated from activity concentrations and radiological safety of the ingested radionuclides was determined by annual effective dose (IAED), internal hazard index (H_{in}) and risk assessment parameter (RAP). Test results showed that the average soil to plant transfer factors for ^{232}Th,^{238}U and ^{40}K were 0.0825, 0.143 and 1.575 respectively. The transfer factors of ^{40}K were greater than 1 in more than 88% of the samples. The soil to plant transfer factors varies directly with energy of the gamma ray emitted and inversely with activity concentration of the radionuclides. The average IAED, H_{in}, and RAP were 1.136±0.390mSv/y, 0.210±0.070, 0.0568±0.021% respectively. Radiation hazard indices were within the safe limits and the fatality percentage was negligible. Therefore, there is no radiation risk associated with chewing of the sampled khat, and most of the radionuclides present in soil are not absorbed by Khat.

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1. INTRODUCTION

Since primordial times, life on earth has constantly been bombarded by radiation of both terrestrial and non-terrestrial origin [2]. Such radiation also finds its way into living bodies through several pathways. The main exposure routes for human beings are inhalation of micro-radionuclides in air, dermal contact with environmental radiation and ingestion of food and water contaminated with traces of the radionuclides. Natural and anthropogenic processes extrude radioactive uranium, thorium, potassium, and other trace elements such as lead, cesium, cadmium magnesium and iron among others from the earth's crust. The abundance of these elements in the earth's crust is about 2-3ppm for uranium and 8-12ppm for thorium while potassium constitutes about 0.1% of limestone, 1% for sandstones and 3.5% of some granites [1, 3, 4]. Application of fertilizers and other farm inputs containing heavy metals and phosphate compounds is also a source of radionuclides in soil and the environment. The concentration of these elements in geological samples has been studied using various methods [5-8] in an attempt to control or prevent their harmful effect especially when they exceed permissible limits.

Soil forms the dominant surface of an ecosystem and is the sink to most wastes from anthropogenic activities such as farming, construction, and industrial processes. Indiscriminate disposal of waste into soil builds up the concentration of harmful radionuclides [9]. Since soil is the main substrates for plant growth, the radionuclides are absorbed into foliage, fruits and other parts of the plant and consumption of these plant products lead to human ingestion of the radionuclides.

Interactions between natural radionuclides in soil and plants are determined by species and shape of plants, soil properties, behavior of radionuclides and climatic conditions [10]. Such interactions are very complicated and the transfer of the radionuclides from soil to different plants depends on chemical properties and several other plants and soil parameters. The migration and accumulation of pollutants from soil to plant is an assessment model commonly used for the concentration ratio of soil-plant activity known as transfer factor (TF) [11]. This parameter describes the amount of radionuclides entering food plants from the soil and can be used as an index to study the accumulation of radionuclides in food plants as a result of plant root uptake [12, 13].

Khat (*Catha endulis*) is a small bush shrub native to east Africa, southern Africa and the Arab peninsula. It is grown as a cash crop with major markets in Yemen, Ethiopia, Djibouti, Somalia, and Kenya. It is estimated that these countries together constitute over 10 million users (about 50% women and 80% men) [14]. Khat is mainly consumed by chewing the leaves or young shoots and twigs. The consumer slowly chews the leaves or shoots to release its extract in a juice that is then swallowed with saliva. Khat chewing popular as a recreational habit and it is enjoyed for its psycho-stimulant and euphorigenic effects [15].

Khat is a mild stimulant very popular among people aged between 15 to 65 years. Many studies have focused on its chemistry, pharmacology, and toxicology properties with minimal documented reports on its potential for absorption and retention of radionuclides [15, 16]. This study utilized gamma ray spectroscopy to quantify the activity concentration of natural radionuclides in khat and soil in the vicinity of khat bushes. The translocation and accumulation of the radionuclides from the soil to khat was estimated through a soil to plant transfer factor.

2. RESEARCH METHODOLOGY

2.1. Study area

This research was carried out in Igembe South subcounty, Meru County of Kenya. The subcounty boarders Tigania east subcounty to the northwest, Igembe central subcounty to the northeast, Tharaka Nithi county to the southwest, Isiolo county to the east and Kitui county to the south. A large area of the subcounty is within the Meru national park. The inhabited area is about 255.2 km^2 with a population of 161,646 of almost equal gender distribution [17]. Figure 1 shows the map of the study area showing the sampling sites. The GPRS coordinates of the sampling points are indicated in Table 1.

Basement rock systems found in the study area are due to post-volcanic erosion. Some sections have exposed basement complex inliers which were part of a larger hill zone extending discontinuously from Shaba in the north into Kitui District in the south. The Basement system rocks are mainly sediments-grits, sandstones, shales and limestones that have been metamorphosed by heat and pressure or by impregnation by pervading fluids. Other types include heterogeneous gneisses, granulites and schists of varied and complex origin [18].

The main economic activity is *Catha endulis* farming which is usually sold to the other parts of Kenya and the bigger fraction is exported to Somalia and Ethiopia. Farmers in the area rely heavily on solid and foliar organic and inorganic fertilizers to boost khat productivity. In addition, they apply a range of pesticides and other chemicals for disease control, to speed up maturity and to induce aromatic scents and coloration of the fresh shoots and leaves so that they can fetch better prices in the market.

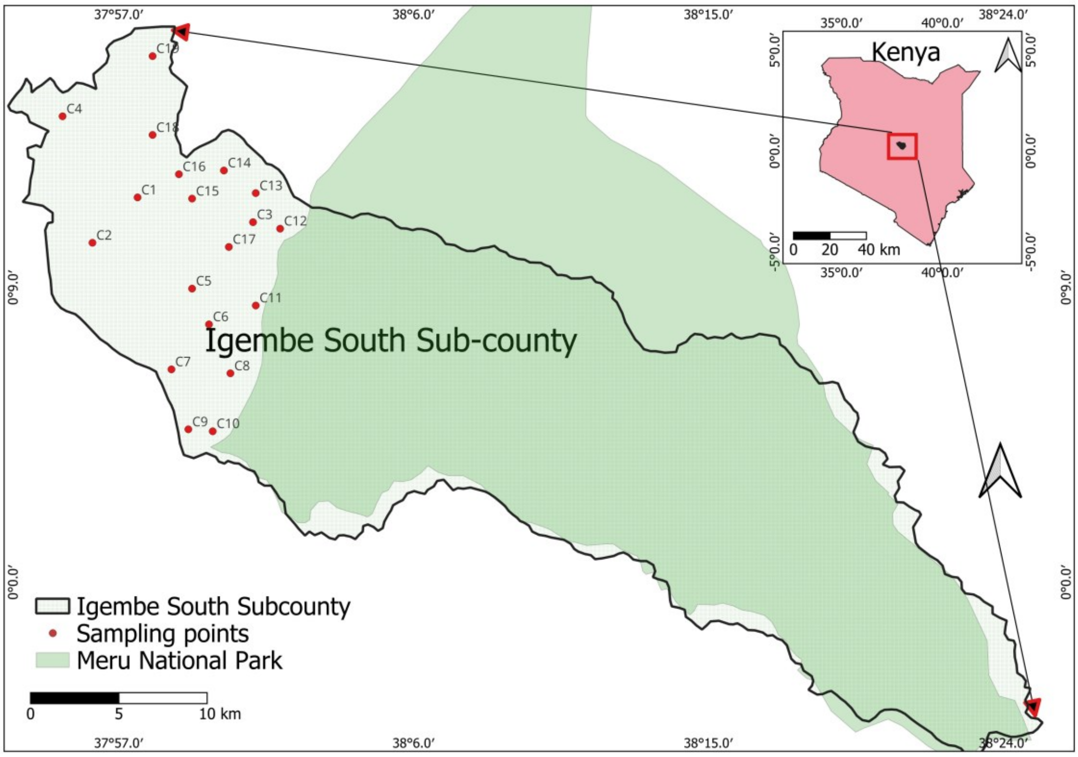

Figure 1. Map of the study area showing the sampling sites.

2.2. Sample collection

Thirty-eight samples (nineteen each for soil and Khat) were collected from the sampling area. A random sampling method was used to ensure statistical sensitivity of the samples. About 0.5 kg of soil was scooped at a depth of 10 cm below the earth surface at three points around the sampling site. The three samples were then mixed to attain homogeneity and then reduced to about 0.5kg. To accurately correlate radiological data for the soil and Khat, the soil samples were collected as close as possible to the plant's root system. Using a GPS system, the precise location of each sampling site was recorded. About 1kg of khat twigs and leaves were collected from bushes growing at the sampling site. The collected samples of soil and Khat leaves and twigs were then packed in coded polythene bags and transported to the laboratory for further processing.

2.3. Sample preparation

The soil and Khat samples were sundried for about 15 days and later oven dried for six hours at 110^0 C in order to completely remove moisture [19]. The dried samples were then pulverized and sieved using a 1mm sieve to yield a homogeneous powder. Marinelli beakers of the same geometry as the detector were used to pack 250g of soil and 100g of Khat. The beakers were covered with an aluminum foil, sealed tightly to prevent leakage of radon, and then stored for 30 days for the decay products to attain secular equilibrium. Three samples of deionized water to be used for background count were also prepared in the same manner as the field samples.

2.4. Determination of activity concentration

A lead shielded NaI(TI) gamma ray detector was used to count the activity of the samples for 28,800s. The detector was first calibrated using an IAEA certified sample containing ^{241}Am, 137Cs, and ^{60}Co within the range from 59.5 -1332keV. The certified sample was considered sufficient to cover the energy range of interest. The photo peaks of ^{212}Pb,^{214}Pb and ^{40}K at energies of 239Kev, 352Kev and 1460Kev were utilized in calculating the activity concentration of ^{232}Th, ^{238}U, and ^{40}K. The net count was determined from the difference between the count from the field samples and the count from the deionized water according to equation 1.

$$C_n = C_g - C_b \quad (1)$$

C_n, C_g and C_b represent the net count of the sample, gross count of the field sample and background count around the detector. The specific activity concentration of the radionuclides in each sample A_s was determined using equation 2.

$$A_s = \frac{C_n}{\varepsilon t I_\gamma * M_s} \quad (2)$$

Where, C_n, ε, t, Iγ, and M_s are the net gamma ray count at full energy peak, detection counting efficiency of the radionuclide, counting live-time, gamma emission probability of a particular radionuclide and mass of the field sample respectively.

2.5. Evaluation of radiological parameters
The determined specific activity of the Khat (A_p) and the soil (A_s) was then used to calculate the soil to plant transfer factor (TF) according to equation 3 [20-22].

$$TF = \frac{A_p}{A_s} \quad (3)$$

The annual effected dose due to the radionuclides ingested as a result of khat chewing (IAED) was determined as a summation of the contribution of the radionuclides using equation (4).

$$IAED = \sum\left(A_p \times L \times 365days \times D_c\right) \quad (4)$$

where a consumption load, L of 0.5kg/day is assumed per adult person [23] and D_L is the dose coefficient for adults as provided in [24]. The public's exposure to internal gamma dosage rates is influenced by the ingestion Khat. The number fatalities likely to be suffered by residents of the study area was estimated using risk assessment parameter (RAP) given by equation 5 [24]. In this study, the population aged 15 to 60 years was considered active users of Khat.

$$RAP = IAED \times D_R \times P \quad (5)$$

Where D_R is the dose risk conversion factor of 0.5/Sv [24] and P is the population of active Khat users assumed to be the total adult population in the area. The risk associated with this exposure was estimated using the internal hazard index (H_{in}) which gives the internal exposure to radon and its short-lived progeny and is given by equation 6 [25].

$$H_{in} = \frac{A_{RA}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

Where, A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in $Bqkg^{-1}$ [26].

3. RESULTS AND DISCUSSIONS

3.1. Soil to plant Transfer factors (TFs)
The activities of ^{238}U, ^{232}Th, and ^{40}K in soil and Khat were estimated using equation 2 and the signature peaks corresponding to ^{214}Pb at 352 keV from the ^{238}U series, ^{212}Pb at 239 keV from the ^{232}Th series and the single radionuclide ^{40}K at 1460 keV. These activities were then used to calculate the soil to plant transfer factor according to equation 3. Figure 2 shows the soil to plant transfer factors of the radionuclides for the sampled sites.

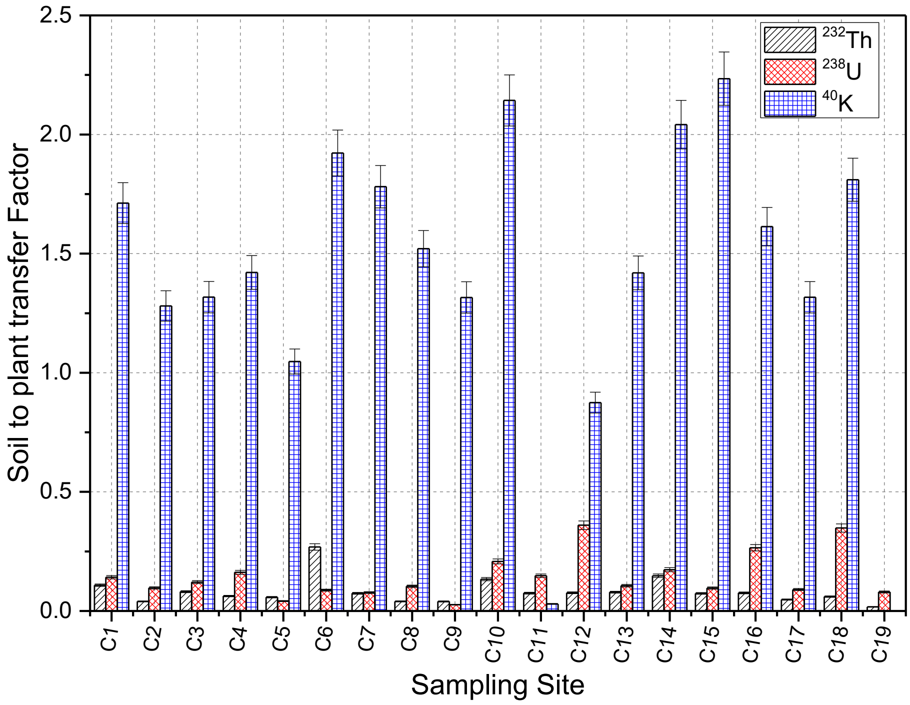

Figure 2. Soil to pant transfer factors at different sampling points

The transfer factor ratios for ^{232}Th, ^{238}U and ^{40}K ranged from 0.017±0.0008 to 0.269±0.013, 0.027±0.001 to 0.360±0.018 and from 0.875±0.043 to 2.234±0.111 respectively with an average of 0.0825±0.004, 0.143±0.007 and 1.575±0.079 respectively for radionuclides. The transfer factors of ^{232}Th and ^{238}U were very low indicating a very low uptake of these radionuclides or low retention rates in the Khat leaves and twigs. The transfer factors of ^{40}K were very high, with values greater than 1 in more than 88% of the samples, indicating a higher concentration of the radionuclide in the leaves and twigs than in soil. Similar findings were reported elsewhere by Njagi et al 2022, [23] with values of 1.548, 0.459 and 2.2.546 for ^{232}Th,^{238}U and ^{40}K respectively. A transfer ratio of greater than one implies that the leaves and twigs of Khat received additional radionuclides from other sources apart from soil. In this case, a possible source of the additional radionuclides is the foliar pesticides and fertilizers used in the plants. In addition to these foliar inputs, high root uptake of phosphate fertilizers and high retention ratios of leaves and twigs of Khat could be a contributing factor.

Figure 3 shows the correlation between the soil to plant transfer factors and the activity and energy of the radionuclides. A linear model was used to fit the parameters in order to assess the possible correlation.

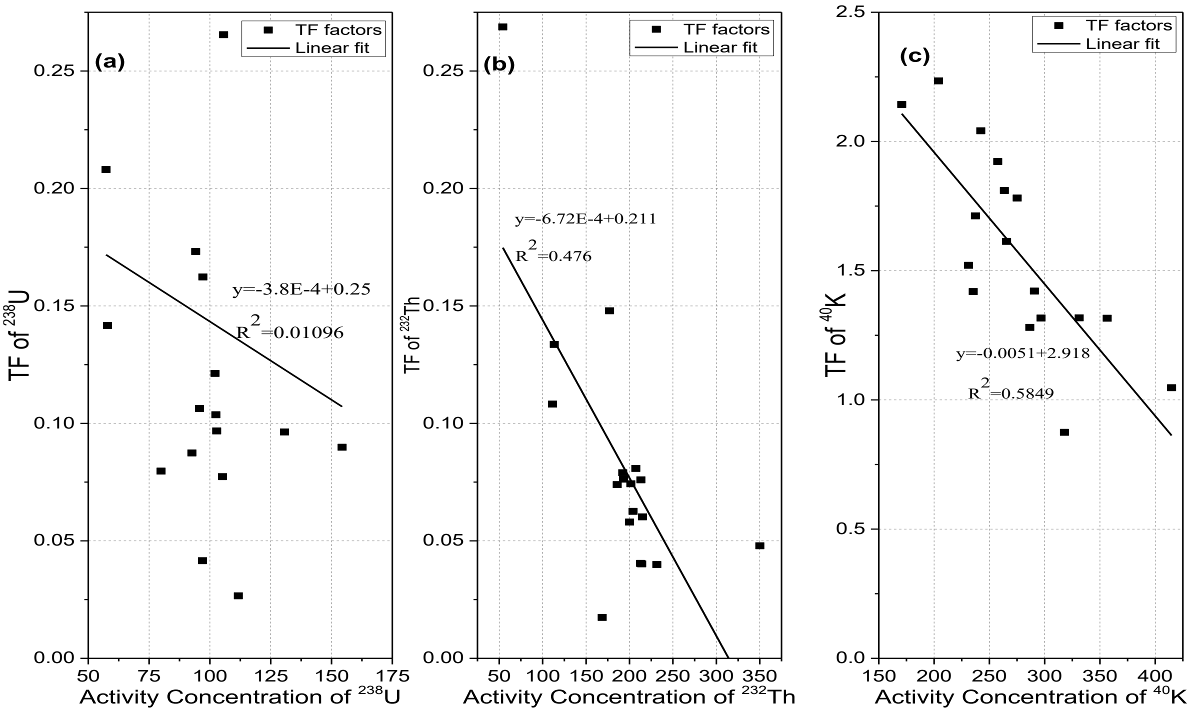

Figure 3. Correlation between the soil transfer factors and the activity of the radionuclides. (a) ^{238}U, (b) ^{232}Th and (c) ^{40}K.

Figure 3 shows that there is a general decrease in soil to plant transfer factors with increase in activity concentration. Nevertheless, the low values of the coefficient of determination (R^2) values imply that there is a non-linear correlation between the transfer ratios and the activity concentration. This implied that the uptake or retention of the radionuclide by leaves and twigs of Khat were independent on the count rate of the individual radionuclides. Taking into consideration the energy of the radionuclides, it is also evident from figure 3 that an increase in the energy of the emitted gamma ray increased the migration or retention factor of the radionuclides. Consequently, among the radionuclides, the concentration of ^{40}K was highest in all the samples of Khat. The variations of transfer factor could have been influenced by ion exchange capacity of the stable element concentration in soil, electrical conductivity or the impacts of organic fertilizers such as soil retention qualities and the pH.

3.2. Annual effective dose of the Ingested Radionuclides (IAED)

The annual dose received by Khat users due to the ingested radionuclides was estimated using equation 4 and the results are presented in table 1.

Table 1: IAED and RAP results for the Khat samples

Sampling Site	GPRS Coordinates		IAED (mSv/y)	RAP %
	latitudes	longitudes		
C1	0.1958	37.9596	1.0334±0.3913	0.0052±0.0020
C2	0.1727	37.9366	0.8583±0.3880	0.0043±0.0019
C3	0.1832	38.0183	1.2987±0.3882	0.0065±0.0019
C4	0.2371	37.9214	1.1323±0.3885	0.0057±0.0019
C5	0.1494	37.9873	1.0118±0.3883	0.0051±0.0019
C6	0.1312	37.9959	1.2382±0.3890	0.0062±0.0019
C7	0.1083	37.9768	1.2500±0.3937	0.0063±0.0020
C8	0.1063	38.0068	0.8458±0.3894	0.0042±0.0019
C9	0.0778	37.9854	0.9432±0.3919	0.0047±0.0020
C10	0.0768	37.9978	1.1481±0.3917	0.0057±0.0020
C11	0.1408	38.0197	0.8202±0.3876	0.0041±0.0019
C12	0.1799	38.0321	1.223±0.3917	0.0061±0.0020
C13	0.198	38.0197	1.0989±0.3903	0.0055±0.0020
C14	0.2095	38.0035	1.7931±0.3932	0.0090±0.0020
C15	0.1952	37.9873	1.1960±0.3921	0.0060±0.0020
C16	0.2076	37.9806	1.3946±0.3913	0.0070±0.0020
C17	0.1706	38.006	1.2598±0.3906	0.0063±0.0020
C18	0.2276	37.9672	1.3876±0.3935	0.0069±0.0020
C19	0.2677	37.9672	0.6514±0.3892	0.0033±0.0019
Mean			**1.1360±0.3905**	**0.0057±0.0020**

The total due to the contribution of ^{232}Th,^{238}U and ^{40}K ingested by Khat users ranged from 0.6513±0.3876 to 1.7931±0.3937 with an average of 1.1360±0.3905 mSv/y. About 79% of the samples Khat could lead to ingestion of annual effective doses above the weight average of 0.87 mSv/y determined by UNSCEAR [27]. Although the values of IAED were higher than the world averages, the safety and effect of this ingestion would be more accurately determined based on the estimates of the risk assessment parameter (RAP) and H_{in}.

3.3. Risk Assessment Parameter (RAP)

The percentage number of fatalities that could result from the ingestion of the annual effective doses (IAED) was estimated using equation 5 and the findings are summarized in table 1. The values of percentage RAP show that between 0.0033% to 0.009% of the Khat user population in Igembe south subcounty is at risk of death from the ingestion of radionuclides in Khat. The percentage fatality estimate is fairly low implying that Khat grown in Igembe south subcounty poses minimal risk of death to the population aged 15 to 60 years. In this study, a constant consumption load of 0.5kg/day was used for all the ages. However, this load could reduce significantly for women, younger users, and elderly users in the 15 to 60 years age bracket. Consequently, a lower value of percentage RAP would be attained if the actual loads for different gender and age brackets were considered.

3.4. Internal Hazard Index (Hin)

Ingestion of radionuclides in Khat could expose body organs to harmful radon gas and its short-lived progenies. The risk of such exposure was estimated using the internal health hazard index according to equation 6. Figure 4 presents the H_{in} of the sampled Khat as well as the permitted safe limit.

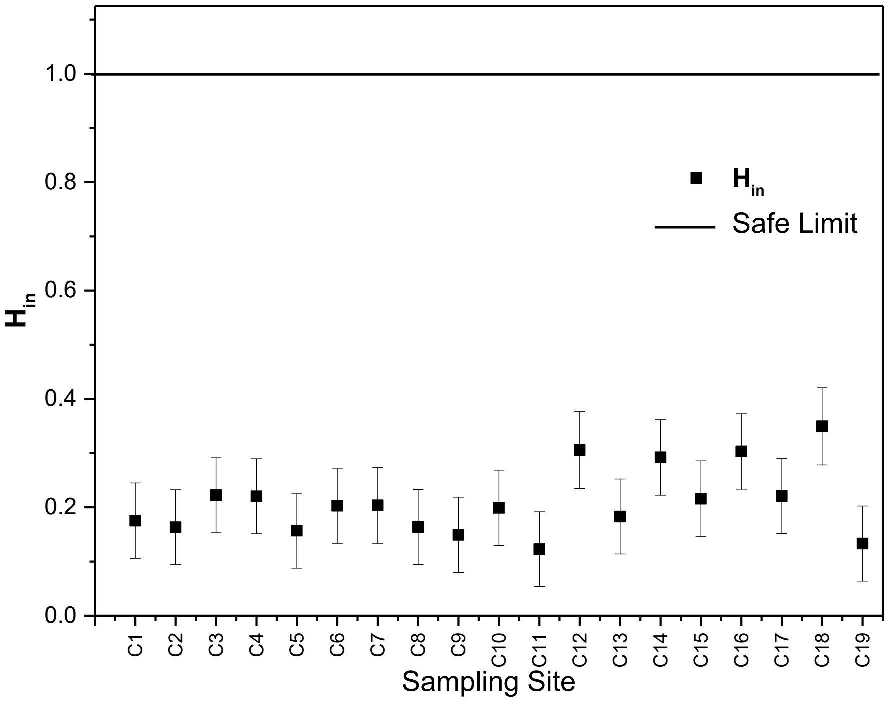

Figure 6: Internal health hazard index in Khat samples

The average internal health hazard index ranged from 0.1228±0.06889 to 0.3495±0.07121 with a mean of 0.2097±0.0696. These results show that Khat leaves and twigs from Igembe South subcounty have H_{in} lower than recommended safe limit of 1, hence their consumption does not pose risk of exposure to harmful radiations. This agrees with the findings on risk assessment parameter. Therefore, the high ingested annual effective dose does not translate to higher risks of exposure due to ingestion of radionuclides in Khat.

4. CONCLUSIONS

Gamma ray spectroscopy was used to determine the soil to plant transfer factors as well as the radiological safety of Khat grown in Igembe subcounty, Kenya. The transfer factor was computed from the activity concentration of primordial radionuclides (^{232}Th,^{238}U and ^{40}K) present in the Khat, and the radiological safety was estimated using annual effective dose (IAED), internal hazard index (H_{in}) and risk assessment parameter (RAP). Based on the test results and the analysis presented, the following conclusions could be drawn:

- Soil to plant transfer factors of ^{232}Th and ^{238}U were very low indicating a low uptake or retention of these radionuclides in Khat leaves and twigs. The transfer factors of ^{40}K were higher than 1 in more than 88% of the samples, indicating a higher concentration of the radionuclide in the leaves and twigs than in soil. This implied a possible additional ^{40}K absorption from foliar inputs such as pesticides and foliar fertilizers.
- Soil to plant transfer factors in Khat vary nonlinearly with both the activity concentration of primordial radionuclides and the energy of gamma rays emitted by the radionuclides. Increase in activity concentrations lowers the soil to plant transfer factors. Radionuclides that emit higher energy gamma rays have a higher transfer factor from soil to leaves and twigs of Khat.
- Khat users in the samples area ingest an average annual dose of 1.1360±0.3905 mSv/y which is above the populated weight average of 0.87 mSv/y. Nevertheless, risk assessment parameter shows that only 0.0033% to 0.009% of the Khat users are likely to suffer fatality due to the habit. Similarly, all Khat samples had posed an internal health hazard index below the permitted safe limit. Therefore, use of Khat grown in Igembe south subcounty, Kenya does not pose any radiation risk.

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