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Measurement of Natural Radioactivity Concentration Levels in Selected Vegetables Grown at Akaki-Kality, Addis Ababa, Ethiopia Using Hpge Detector

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Abstract

Measurements of the activity concentration of natural radioactivity in eatable vegetables are essential for the healthy and safe life of a community. In the present work, the activity concentration of natural radionuclides in the four vegetable food stuffs, namely Cabbage, Carrot, Red Onion and Potato Grown at Akaki-Kality has been measured using a High Purity Germanium (HPGe) Detector. The measured activity concentrations of ^{40}K in Cabbage, Carrot, Red Onion and Potato samples were 840 ± 49 Bq/Kg, 480 ± 29 Bq/Kg, 390 ± 23 Bq/Kg and 680 ± 34 Bq/Kg, respectively, while the measured activity concentration of ^{226}Ra and ^{232}Th were 2.13 ± 1.09 Bq/Kg in Carrot sample and 3 ± 1.3 Bq/Kg in Cabbage sample respectively. In the other vegetable samples the two radionuclides were below the detecteion limit. The activity concentration of ^{40}K was found to be high in all vegetables in this work ,this can be attributed to the use of fertilizers and irrigate with wastewater to a large extent affecting the radionuclides concentrations. Based on the measured activity concentration, absorbed dose rate, radium equivalent and external and internal hazard indices have been estimated.

Keywords: Vegetable Food; Radionuclides Concentrations; Activity Concentration; Absorbed Dose Rate; External and Internal Hazard Indices

Introduction

Humans are naturally exposed to ionizing radiation coming from different sources such as cosmic rays and natural radionuclides in food, air and water. Vegetables is one of the most widespread crops in the world that has great economic significance. Natural radionuclides such as ^{238}U, ^{232}Th and ^{40}K can be found almost everywhere; in soil, public water supplies, oil and thereby subjecting human beings to reasonable exposure [1].

The presence of ^{226}Ra (^{238}U-series), ^{232}Th, and ^{40}K in the soil is both a direct and indirect source of radiation exposure for humans. Direct exposure channels can be found in the environment or the construction of dwellings using soil-based bricks. Indirect exposure can also result from soil swallowing during farming operations, airborne dust load during farming, plant uptake, and eventual human ingestion [2]. Human beings inhale or ingest many radionuclide and their radioactive isotopes present all around us, from which they are mainly exposed by outdoor natural terrestrial radiations that originates predominantly from upper 30 cm layer of soil present on earth [3]. The presence of ^{238}U, ^{232}Th and ^{40}K radionuclide in soil also leads us to identify the origin and abundance of their daughter elements like radon, thoron and their progenies. Exposure to uranium (U) and radium (Ra) causes several health problems, including chronic lung disorders, acute leucopenia, anemia, and oral necrosis. Exposure to radium causes bone, cranial, and nasal tumors, while thorium causes lung, pancreas, hepatic, bone, and kidney malignancies, as well as leukemia [4]. The activities of radioactive nuclides exist in agricultural soil and irrigation water, and they may transfer to vegetables growing on it.

Food becomes a vital source of radioactivity inside of human bodies, which is significant for radioactivity level measurements [5]. In earlier years, exposures to human beings from background radiation were measured and analyzed at the natural radioactivity levels of surface soil, agricultural soil, farm soil, irrigated soil, environmental soil, residential soil, and uncultivated soil samples in different areas of the world. In the literature, there are various studies from different countries on the measurement of radionuclide concentrations in vegetables, fruits and soil [6-12].

The aims of the study are to determine activity concentration, radium equivalent activity, absorbed dose rate and internal and external hazard index from Akaki Kality, Addis Ababa, Ethiopia using a coaxial HPGe detector in a low background configuration through gamma-ray spectrometry technique. In this study may be provided very important information for the radiological safety of the environment after a radiation fallout that may occur in the future. That is, such information can be used to form the basis for future comparative analysis of high activity concentrations due to human activities in the occupational and residential situation [13].

Experimental Technique

Study Area

Akaki Kality Sub-cities are among the area where there has been a noticeable increase in the activities of the surrounding industrial zone. Most of the waste products from the industries are released into the environmental vegetable. Vegetables are then contaminated by heavily dosed radioactive from the industry that seeps into them.

Description of the study location

Addis Ababa, is the capital and largest city of Ethiopia, founded in 1886, it is the political and economic capital of the country located on the shewan plateau. Addis Ababa city administration has 10 Sub cities. Akaki Kality is one of the Sub City roughly 10 kilometers from the city center of Addis Ababa. Addis Ababa city administration which is located at 8°51”12”’ to 8°56”17”’N latitude and 38°45”19”’to 38°50”23”’ longitude (Figure 1).

Sample Preparation

Four separate home gardens were selected to serve as the sampling sites for this study. Each garden was dedicated to growing Cabbage, Red Onion, Carrot and Potato as shown in Table 1. Twenty-four samples were collected from each of home garden and composited into one sample for each vegetable. The twenty-four samples, each weighing exactly one kilogram, were crushed, mixed, and sieved to a mesh size of roughly 75µm. After air drying, the samples were placed in an oven for 24 hours at 110˚C. Samples that had been weighed were put into 250 cm³ polyethylene bottles with a 75 µm hole size sieve (Figure 2). To achieve adequate homogeneity around the HPGe detector, the homogenized samples were then moved to General Purpose Marinelli Beakers with constant volume. A computerized weighing balance with great sensitivity was used to evaluate the sample weighting. To enable gamma spectrometry to quantify the radioactive equilibrium between 238U and 232Th and their associated daughters, the Beakers were fully sealed for over a month to allow radioactive equilibrium to be reached between ^{238}U and ^{232}Th and their corresponding daughters to be measured by gamma spectrometry.

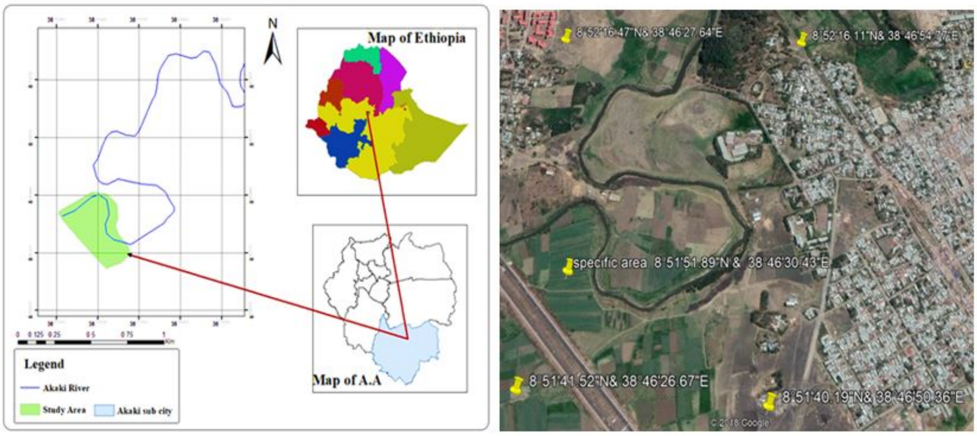


Figure 1 Location Map of sampling area in Akaki Kality, Addis Ababa, Ethiopia.

Figure 1

Figure 2 : Photograph of dried, grinder and sieve sample analysed with using High Purity Germanium

Figure 2: Photograph of dried, grinder and sieve sample analysed with using High Purity Germanium detector

Table 1: Four different vegetable species samples collected from the study area

Local name	Common name	Scientific name	Origin
Gomen	Cabbage	Brassica abyssinica	Ethiopia
Key Shinkurt	Red Onion	Allium cepa	Italy
Carrot	Carrot	Daucus catota	Iran
Dinchi	Potato	Solanum tuberosum	Peru

General purpose Marinelli Beakers having vegetable samples were kept to the detector vicinity to determine the activity concentration of the ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K radionuclides. Gamma spectrometry was used to determine primordial radionuclides present in the vegetable samples.

Measurement of radioactivity using High Purity Germanium (HPGe) detector

Vegetable radioactivity levels were analyzed using a gamma-ray spectrometry setup featuring a High Purity Germanium (HPGe) detector. The device was an n-type coaxial CAMBERRA HPGe detector with a 72.5 mm diameter and 72.5 mm thickness crystal, offering 80% relative efficiency. The detector was connected to a computer-based multichannel analyzer (MCA) system, which utilized Genie 2000 software to quantify characteristic photopeak areas.

Background measurements were conducted monthly using an empty container to monitor counting rate stability. For accurate isotope identification, qualitative assessment, and quantitative analysis, the system underwent energy and efficiency calibration. To ensure that the instrument calibration is impartial, a standard calibration source with radionuclides Am-241, Ce-139, Cs-137, Sn-113, Cd-109, Co-60, Y-88, Sr-85, Co-57 and Cr-51. Energy calibration employed point sources including ^{241}Am (59.5 keV), ^{137}Cs (661.6 keV), and ^{60}-Co (1173.2/1332.5 keV), while efficiency calibration used a certified MGS6M315 mixed standard alongside ^{125}Sb (176.3/427.9/600.6 keV), ^{155}Eu (60.0/86.5/105.3 keV), ^{54}Mn (834.8 keV), and ^{40}K (1460.8 keV). Genie 2000 software calculated absolute efficiency and associated uncertainties, with both samples and background measured for 18,000 seconds.

The activity concentration of ^{226}Ra was calculated using energy lines of 295.2 keV and 51.9 keV for ^{214}Pb and 609.3, 1120.3, and 1238.1 keV for ^{214}Bi. The activity concentration of ^{232}Th was calculated using 300.1 keV of ^{212}Pb, 277.4 and 860.6 keV of ^{208}Tl, 209.3 and 911.1 keV of ^{228}Ac, and 723.3 and 785.3 keV of ^{212}Bi gamma lines. The activity of 40K was directly calculated using the 1460.8 keV gamma line.

The net count rates beneath the most prominent photopeaks of all radionuclides were computed by subtracting the respective background count rate from the gross count rate for all radionuclides acquired during the same counting period. The radionuclide activity was then computed using Equation 1.

Calculations of radiological parameters

Determination of Activity

The activity concentrations were calculated using the formula below [14-16].

[

$$A = \frac{N}{P_\gamma \times \varepsilon \times W} \quad (\mathrm{BqKg^{-1}}) \quad (1)$$

Where:

N = Net counts per second (C.P.S) = (Sample C.P.S – background C.P.S)

Pγ = Intensity of the radionuclide / *P* is the emission probability of radionuclide.

ε = Efficiency in %

W = Weight of sample in kilograms

Determination of absorbed dose rate

The determination of the absorbed dose rate is the very first step in evaluating the health-related risk. With regards to biological effects, the radiological effects are directly related to the absorbed dose rate in the air at 1 meter above the ground surface [17]. The measured activity concentrations of ^{226}Ra (^{238}U), ^{232}Th, and ^{40}K were converted into doses by applying the conversion factors 0.462, 0.604 and 0.0417 for Uranium, Thorium, and Potassium, respectively.

The absorbed dose rate Dγ(nGy h^{-1}) due to gamma radiations in outdoor air at 1 m above the ground surface was calculated as follows [17-19].

$$D_\gamma\,(\mathrm{nGy\ h^{-1}}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (2)$$

Where Dγ is the absorbed dose rate in $nGy.h^{-1}$, A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

Radium equivalent activity

The radiation hazards associated with the radionuclides were estimated by calculating the Radium equivalent activity (Ra_{eq}). This is weighted sum of activities of ^{226}Ra, ^{232}Th and ^{40}K basing on the assumption 370 Bq/Kg of ^{226}Ra, 259 Bq/Kg of ^{232}Th and 4810 Bq/Kg of ^{40}K produce the same gamma radiation dose rate.

The formula below defines Radium equivalent [20].

$$Ra_{eq} = A_{Ra} + 1.4286A_{Th} + 0.07692A_K \quad (3)$$

Where A_{Ra}, A_{Th} and A_k are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K respectively. The conversion constants for Thorium and Potassium are 1.4286 and 0.07692 respectively.

A widely used hazard Index (reflecting the external exposure) called the external hazard index (H_{ex}) is defined as follows [21].

External and internal hazard indices

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (4)$$

There is also a radiation hazard to respiratory organs due to the ^{226}Ra decay product ^{222}Rn and its short-lived decay products. To account for this hazard, the maximum permissible radium concentration must be reduced to half of the normal limit [22].

The internal hazard index (H_{in}) is calculated using the following formula [21].

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

Where A_{Ra}, A_{Th} and A_k have the same meaning as in Equation 3 and Equation 4.

Results and Discussion

Results

[In the present study, a total of four vegetable samples (Cabbage, Carrot, Red Onion and Potato) were analyzed. The radionuclides detected and corresponding activity concentrations in four different vegetable samples have been summarized in Table 2.

Table 2: Shows the activity concentrations ^{226}Ra, ^{232}Th and ^{40}K in all vegetable samples

Vegetable Samples	Activity concentration of radionuclides(Bq/Kg)		
	226Ra	232Th	40K
Cabbage	BDL	3±1.3	840±49
Carrot	2.13±1.09	BDL	480±29
Red Onion	BDL	BDL	390±23
Potato	BDL	BDL	680±34
Worldwide valueb	35	30	400

BDL - Below detectable limit and [b] Data from United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [23]

The radionuclides found in the samples were ^{214}Pb, ^{214}Bi, ^{228}Ac (due to ^{238}U and ^{232}Th decay) and ^{40}K. The activity concentration of ^{232}Th was determined from its decay products ^{228}Ac (911.21 keV and 968.97keV), while the activity concentration of ^{226}Ra was determined from ^{214}Bi (609.31 keV) and ^{214}Pb (351.92 keV) and taken to be equal to ^{238}U activity concentration on the assumption of the prevalence of secular equilibrium in ^{238}U series. The activity concentration of ^{40}K was determined from its 1460.82 keV gamma spectrum. More details of the gamma ray energy levels of radionuclide and their emitter nuclides. are shown in Table 3.

Table 3: The gamma ray energy levels of radionuclide and their emitter nuclides

Gamma-ray energy(keV)	Emitter nuclides	Radionuclides
609.31	^{214}Bi	^{226}Ra
351.92	^{214}Pb	
911.21	^{228}Ac	^{232}Th
968.97	^{228}Ac	
1460.82		^{40}k

The calculated Radium equivalent activities, absorbed dose rate, and external and internal hazard indices in four vegetable samples from Akaki Kality, Addis Ababa, Ethiopia, were calculated as shown in this Table 4.

Table 4: Radium equivalent activities, absorbed dose rate and external and internal hazard indices

Samples	Radiological index			
	Ra_{eq}(Bq/kg)	D(nGyh^{-1})	H_{ex}	H_{in}
Cabbage	68.94	37.28	0.187	0.187
Carrot	39.09	21.16	0.112	0.106
Red Onion	30.03	16.38	0.081	0.081
Potato	52.36	28.56	0.14	0.14
Worldwide values	370	55	≤1	≤1

Discussion

The Activity Concentration of vegetable samples

The highest activity concentrations displayed in Table 2 correspond to the naturally occurring radionuclide ^{40}K. The highest concentration of ^{40}K was 840 ± 49 Bq/kg which is measured in the Cabbage sample. The spread of measured values is rather large; Red Onion sample was with the lowest concentration of 390 ± 23 Bq/kg. The activity concentration of ^{40}K was found to be high in all vegetables in this work; the measured concentration value of ^{40}K was higher than the worldwide value 400 Bq/Kg except Red Onion sample. This can be attributed to the use of fertilizers and irrigate with waste water to a large extent affecting the radionuclides concentrations, especially potassium. But the high value of ^{40}K may also is due to the soil origin and the nature of some vegetables. In this context, ^{40}K is a key biological element in human tissue through metabolic control. As shown in Figure 3 obtained activity concentration of ^{226}Ra and ^{232}Th was 2.13 ± 1.09 Bq/Kg in Carrot and 3 ± 1.3 Bq/Kg in Cabbage which is the highest value of ^{226}Ra and ^{232}Th respectively in this study.

In the rest vegetable samples (Cabbage, Red Onion and Potato) no measured activity concentration of ^{226}Ra was found and in vegetable samples (Carrot, Red Onion and Potato) no activity concentration of ^{232}Th also was found, their values were below minimum detectable limit. In the present study, the measured activity concentrations of ^{226}Ra and ^{232}Th in all vegetable samples are lower than the worldwide values 35 Bq/Kg and 30 Bq/Kg respectively [23-24].

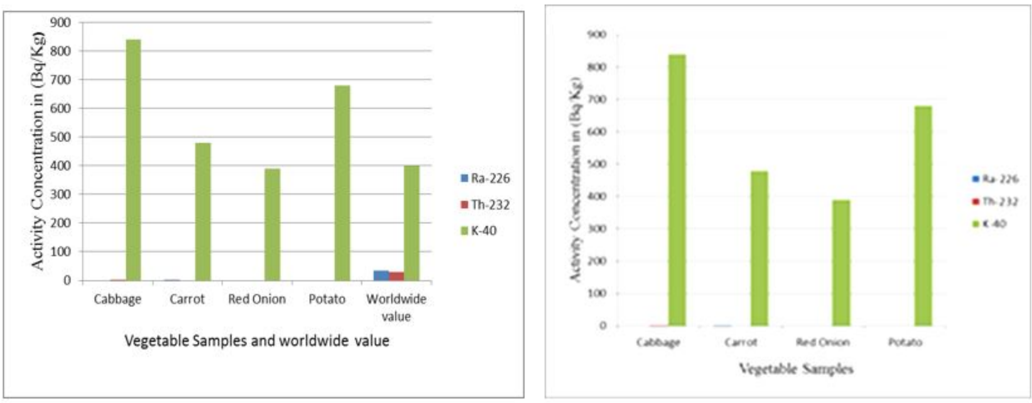


Figure 3: (A) Activity concentration for 226Ra, 232Th and 40K present work (B) Activity concentration for 226Ra, 232Th and 40K World average in Bq/Kg

BDL-refers below the detection limit.

Radium Equivalent Activity (Ra_{eq})

Radium Equivalent Activity (Ra_{eq}) calculated using Eq. 3. The Ra_{eq} for Cabbage, Carrot, Red Onion and Potato samples were 68.94 Bq/kg, 39.09 Bq/kg, 30.03 Bq/kg and 52.36 Bq/kg respectively. As shown in Table 4 and Bar graph in Figure 4 the maximum calculated value of Ra_{eq} was 68.94 Bq/Kg in the Cabbage sample, while the minimum calculated value of Ra_{eq} was 30.03 Bq/Kg in Red Onion sample. These values are far below the allowable limit (370 Bq/kg) (Figure 4) recommended by the International Atomic Energy Agency [23].

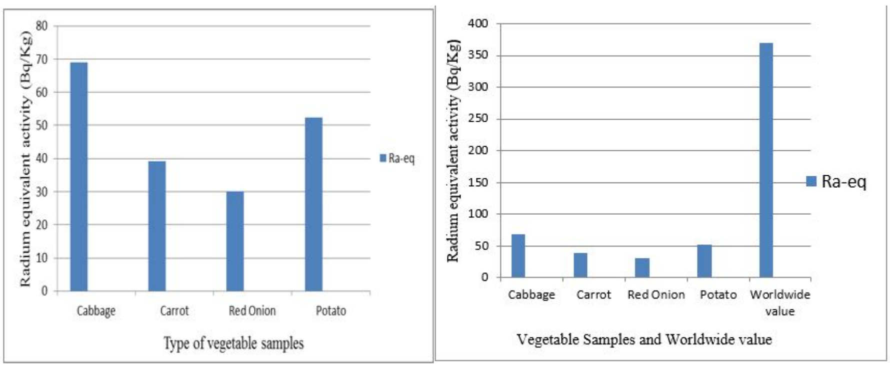
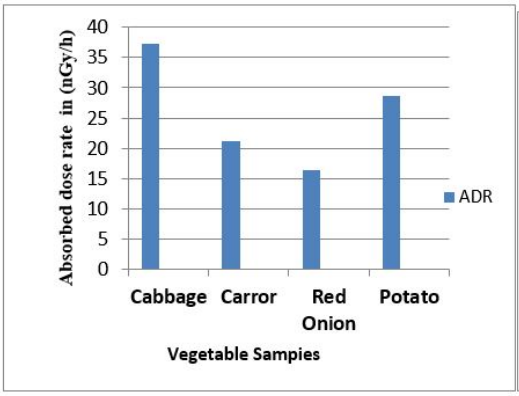


Figure 4: (A). Shows Bar graph of Radium equivalent activity present study (B) Radium equivalent activity (Bq/Kg) Worldwide values

Absorbed Dose Rate

[The absorbed dose rate, ADR (nGy h^{-1}) depends on the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K natural radioisotopes. The absorbed dose rate was calculated using (Eq.2) on the basis of the UNSCEAR (2000) guideline and is given in Table 4. In the present study, the dose rate due to ^{226}Ra, ^{232}Th and ^{40}K in Cabbage, Carrot, Red Onion and Potato samples are 37.28 $nGyh^{-1}$, 21.16 $nGyh^{-1}$, 16.38 $nGyh^{-1}$ and 28.56 $nGyh^{-1}$, respectively. As shown in Figure 5 the maximum absorbed dose rates were observed in Cabbage sample, while the minimum absorbed dose rates were obtained in Red Onion sample. The obtained values in all samples are below the world average of 55 $nGyh^{-1}$ (Figure 5) [25].



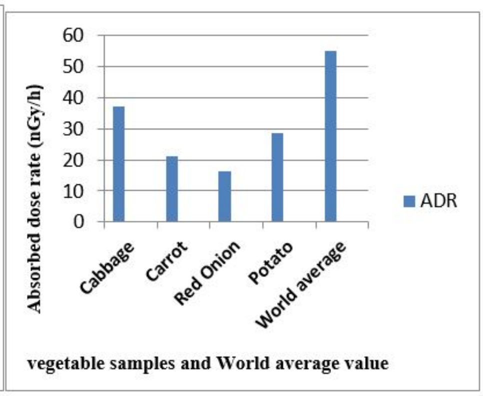


Figure 5: (A) Absorbed dose rate of the present study (B)Absorbed dose rate of world average value in nGy/h

External and Internal Hazard Indices

Hazard Indices (H_{ex} and H_{in}) are two indices that represent the external and internal radiation hazards. These indices are calculated using (Eq.4) and (Eq.5). The calculated H_{ex} and H_{in} values for all vegetable samples in this study are shown in Figure 6. The calculated external hazard indices for Cabbage, Carrot, Red Onion and Potato in this study were 0.187, 0.112, 0.081 and 0.14, respectively.

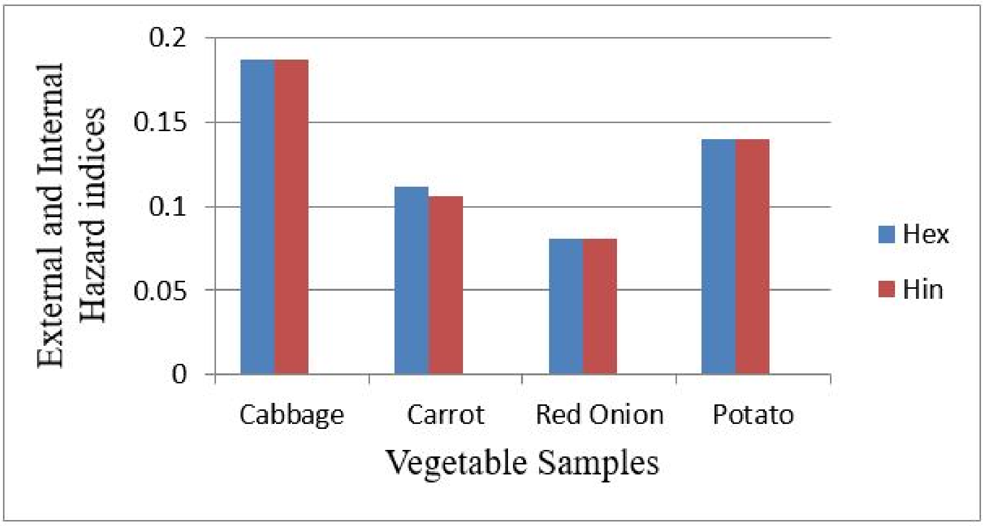


Figure 6: External and Internal radiological hazard indices in vegetable samples

As shown in Table 4, the highest calculated external hazard index was 0.187 in the Cabbage sample, while the lowest external hazard index was 0.081 in Red Onion sample. In our study, the vegetable samples H_{in} values were 0.187, 0.106, 0.081 and 0.14 for Cabbage, Carrot, Red Onion and Potato respectively. As shown in Figure 6, the internal hazard indices (H_{in}) in Cabbage were greater than Potato, H_{in} in Potato was greater than Carrot, and H_{in} in Carrot was greater than Red Onion. Therefore, the highest and the lowest internal hazard indices (H_{in}) were calculated in Cabbage and Potato respectively. The calculated H_{ex} and H_{in} values for all vegetable samples should be below unity, which does not cause harm to the populations of the investigated region in Akaki Kality, Addis Ababa, Ethiopia.

Comparison of activity concentration (Bq/Kg) in this study with different countries

[[[The present study in the Measurement of activity concentration of ^{40}K, ^{232}Th and ^{226}Ra of selected vegetables samples were compared with that were reported in the literature. It may be concluded that the activity concentration of ^{40}K in all the same vegetables and the activity concentration Carrot sample are higher than the values from reported in Table 5.

Table 5: Comparison of activity concentration (Bq/Kg) in vegetables obtained in this study with different countries

Country	Food categories	Activity Concentration (Bq/kg)			Reference
		^{226}Ra	^{232}Th	^{40}K	
South India	Leafyvegetable	0.03±0.01	1.03±0.5	49.5±8.4	[11]
	potato	0.06±0.03	0.17±0.02	71.92±8.4	
Najaf (Iraq)	Potato	-	3.11±0.07	116.91±0.07	[24]
	Carrot	-	5.24±0.11	124.06±0.83	
	Onion	-	3.08±0.05	274.65±3.07	
Alexandria(Egypt)	Potato	0.80±0.49	-	118.75± 2.34	[18]
	Carrot	-	-	42.38 ± 3.93	
Lublin(Poland)	Carrot	-	-	943.6	[26]
Malaysia	Cabbage	-	-	1066 ± 150	[27]
	Carrot	-	-	792 ± 50	
Turkey	Cabbage	0.95 ± 0.09	BDL	26.95 ± 0.95	[15]
	potato	0.45 ± 0.08	0.64± 0.09	10.73 ± 0.70	
AkakiKality (A.A, Ethiopia)	Cabbage	BDL	3±1.3	840±49	Present study
	Carrot	2.13±1.09	BDL	480±29	
	Red Onion	BDL	BDL	390±23	
	Potato	BDL	BDL	680±34	

Conclusion

This study aimed to measure the activity concentrations, gamma absorbed dose rates (Dγ), radium equivalent activity (Ra_{eq}) and hazard indices (H_{ex} and H_{in}) of the naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K as well as the artificial radionuclide ^{137}Cs in selected vegetable samples (Cabbage, Carrot, Red Onion and Potato) has been assessed due to consumption of various popular vegetables locally grown in Akaki Kality, Addis Ababa, Ethiopia and matched well with world values. There was no 137Cs activity concentration in any of the samples from this location, indicating that artificial radioactive fallout did not occur.

The measured activity concentrations (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Cabbage sample were BDL, 3 ± 1.3 and 840 ± 49, in Carrot sample were 2.13 ± 1.09, BDL and 480 ± 29, in Red Onion sample were BDL, BDL and 390 ± 23 and in Potato sample were BDL, BDL and 680 ± 34. It was observed that the activity levels of ^{40}K in the vegetable samples were not uniform, varying with the types of vegetables. Moreover, the activity of ^{40}K exceeded by far the values of both ^{226}Ra and ^{232}Th, being the most abundant radioactive element present in the environment and it also being noted that potassium is used extensively as part of an NPK (Nitrogen,Phosphorous and Potassium) fertilizer in intensive farming activities to promote dynamic growth. In this study, the value of Ra_{eq} activity was found to be less than 370 Bq/kg, while the absorbed dose rate was less than the worldwide value 55 nGyh^{-1} and internal and external hazard indices were found to be less than acceptable limit of unity.This shows that the concentrations of radionuclides found in the surveyed area were nominal and do not pose any potential health hazard to the general public.

Therefore, with an activity concentration ^{40}K higher than the worldwide average values recommended by UNSCEAR, regular monitoring is required to identify contamination trends and provide public awareness campaigns promoting safe farming, as well as policy interventions to regulate agricultural inputs, particularly near industrial zones.

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