Assessment of Environmental Radioactivity in Soil Samples from Kathmandu Valley, Nepal

P. Lamichhane, B. Rijal, P. Shrestha and B. R. Shah
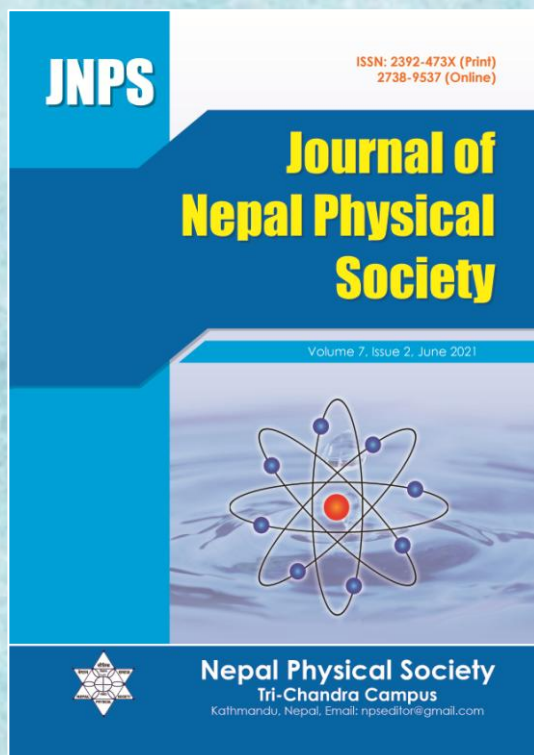
Assessment of Environmental Radioactivity in Soil Samples from Kathmandu Valley, Nepal

P. Lamichhane[1, 2], B. Rijal[1], P. Shrestha[2] and B. R. Shah[1, *]

[1]Physical Science Laboratory, Faculty of Science, Nepal Academy of Science and Technology, Khumaltar, Lalitpur, Nepal

[2]Department of Physics, Amrit Campus, Tribhuvan University, Kathmandu, Nepal

[*]Corresponding Email: buddharshah25@gmail.com

ABSTRACT

This study was conducted to determine the amount of naturally occurring radioactivity in the soil of Nepal's Kathmandu valley. The activity of naturally occurring radionuclides was determined in these soil samples using a sodium iodide detector. Activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were found in the range: 32.00-111.38 Bq kg^{-1}, 33.52-130.04 Bq kg^{-1}, and 342.50-897.71 Bq kg^{-1}, respectively. These values are well within the permissible range as recommended by UNSCEAR. The soil samples with the highest activity concentrations were primarily found in the valley's northern region. The activity concentrations were also used to calculate the radiation hazard indices: the mean value obtained were 96.63 nGy hr^{-1} for Absorbed Gamma Dose Rate in Air, 200.04 Bq kg^{-1} for Radium Equivalent Activity, the 0.12 mSv yr^{-1} for Annual Effective Dose, and 0.55 for External Hazard Index. These calculated hazard indices were used to estimate the potential radiological health risk from the soil, and the dose rates associated with it were significantly less than their permissible limit. The overall findings indicate no radiological threat to the population's health in the study area. Additionally, the findings of this study provide baseline information on potential radionuclides that contribute mostly for radiation exposure from natural sources.

Keywords: Absorbed dose rates, Annual Effective Dose Rates, Environmental radioactivity, External Hazard Index, Radium Equivalent Activity

1. INTRODUCTION

Soil is one of the key sources of human exposure to ionizing radiation. There has recently been a growing demand for soil data and information. All rocks, soils and minerals contain radionuclides that occur naturally, for example, Potassium (K-40), Uranium (U), Thorium (Th) and their progenies [1]. The Uranium and Thorium decay chains found in nature are related to very long half lives of the parent of these chains. Naturally occurring radioactive compounds in the earth's crust are not uniformly distributed and their concentration levels in soil are extremely variable, which are influenced by local geology, altitude, weather, geochemistry, economic and technical activities carried by human, etc. of the region [2]. Uranium is a primordial radioactive element and it exists in nature as a set of three radioisotopes, with a relative abundance of ^{238}U (99%) with half life of 4.468x10^9 years, ^{235}U (0.71%) with half life of 7.038x10^8 years and ^{234}U (0.006%) having half life of 2.445x10^5 years [3]. It is both chemically toxic and radioactive. Because of its solubility in water, plants readily consume it through food chains and soil/water systems and eventually take place in human's food chain.

The most stable isotope, ^{232}Th, has a half life of 14.05 billion years or the era of the universe. It slowly decays through alpha decay, beginning a sequence of decay termed the series of thorium ending at ^{208}Pb [4]. Meanwhile ^{40}K is a rare instance of an isotope undergoing both beta and gamma decay. It decays to ^{40}Ca with the emission of beta particle of up to 1.31 MeV and antineutrino in approximately 89.28% of occurrences. It decays

in about of 10.72% of the occurrences into [40]Ar by electron capture, with emission of neutrino and a gamma ray of energy 1.460 MeV and very rarely (0.001%) it decays by emitting a positron and neutrino and collapses to [40]Ar [5, 6].

Various studies on natural radioactivity and dose rate have been conducted in different regions of Nepal. According to the literature, radionuclide [40]K has been assessed in the soil of Kathmandu valley using gamma spectroscopy indicating that the northern portion of the valley having higher activity than the southern portion and the activity was in the range of 26 Bq/kg to 716 Bq/kg [7, 8]. [40]K was determined in the northern part of the Kathmandu valley using gamma spectroscopy and atomic emission spectroscopy. The report indicated that the specific activity of water and soil samples ranged between 2.25-17.87 Bq/kg and 17.48-412.26 Bq/kg, respectively [9]. The concentration of ^{137}Cs in Lichens and Moses was determined using a Multichannel Analyzer coupled to a NaI(Tl) detector system and was found to be 410 Bq/Kg in Ramalina sp. from Ranipauwa; additionally, the study discovered a high concentration in samples collected from the DoodhPokhari watershed area in Kathmandu valley [10]. A reverse-electrode Ge detector was used to determine the natural radioactivity level of selected rocks in Hetauda. The specific activities of [238]U were found to be between 17 and 95 Bq/kg, [232]Th was found to be between 24 and 260 Bq/kg, and [40]K was found to be between 32 and 541 Bq/kg. Additionally, this literature included dose rates absorbed in the air and annual effective dose, both of which are well below the UNSCEAR-recommended level for the majority of samples, with the exception of Granite Schist 66, which has a dose rate of 1.57 mSv/yr [11].

Similarly, the HpGe detector was used to quantify the specific activity and hazard indices in soil samples of the Lambordia region in Northern Italy, eastern Haryana in India, the Republic of Srpska, and the Araba valley in Jordan. The results for Araba [2], Srpska [3], and Haryana [12] are similar compared to the global median and within the range of the UNSCEAR report, whereas the Lambordia region's

radioactivity levels are higher due to high content of uranium [13].

A bibliographic survey showed that no statistics were available for the Kathmandu valley, Nepal. Keeping that in focus, assessment of terrestrial radioactivity in Kathmandu's topsoil have been carried out and analyzed to determine their essential elements and possible radioactive elements and radionuclides that emit gamma by using digital gamma spectrometer coupled with a 14-PIN digiBASE PMT NaI Detector system. This study aims at providing assessment on radioactivity in the environment of Kathmandu valley due to radionuclides of uranium and thorium series and the potassium-40 in soil samples collected from various locations around the Kathmandu valley.

2. MATERIALS AND METHODS

2.1 Study Area

Kathmandu valley, the study site, is the capital city of Nepal with an area of 570 Km^2 spanning Kathmandu, Lalitpur and Bhaktapur districts [14]. A total of 30 locations within the valley assuming Ratnapark as centre were identified for sample collection. Site locations have been shown in figure (1). The details of site locations with their latitude and longitude are given in Table 1.
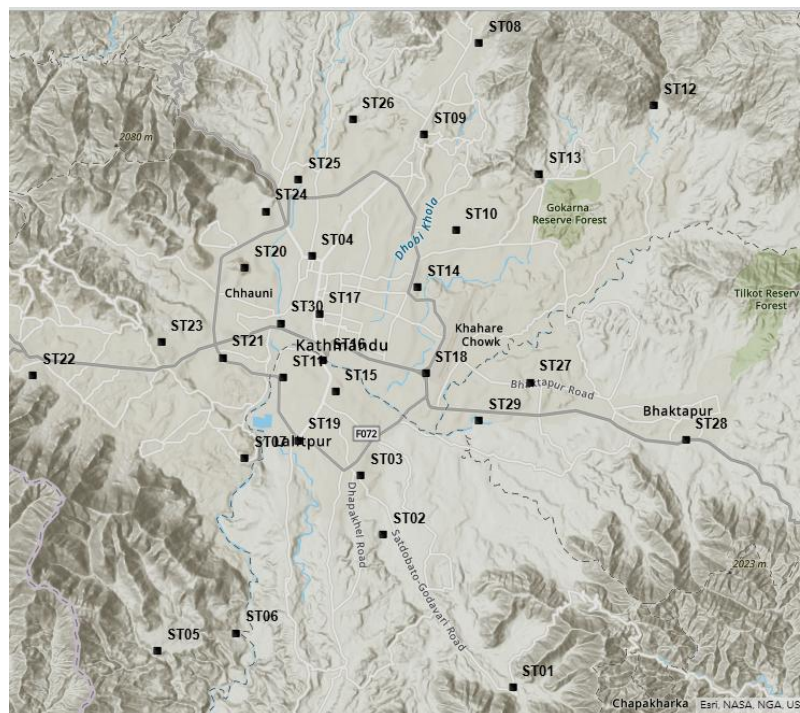

Fig. 1: Sampling stations (Courtsey: ArcGIS)

Table1: Stations with latitude and longitude (Etrex Garmin H7262 GPS)

Location's Local Name	Location Code	Latitude (North)	Longitude (East)
Godawari	ST01	27°35'47.5"	85°22'36.9"
Harisiddhi	ST02	27°38'22.9"	85°20'07.8"
Satdobato	ST03	27°39'23.6"	85°19'41.7"
Thamel	ST04	27°43'06.5"	85°18'46.0"
Dakxinkali	ST05	27°36'24.7"	85°15'48.1"
Pharping	ST06	27°36'43.1"	85°17'18.8"
Chobhar	ST07	27°39'40.9"	85°17'28.3"
Budanilkantha	ST08	27°46'43.7"	85°21'58.2"
Bansbari	ST09	27°45'10.0"	85°20'55.1"
Chabahil	ST10	27°43'32.9"	85°21'31.2"
Sanepa	ST11	27°41'03.3"	85°18'12.6"
Sundarijal	ST12	27°45'40.2"	85°25'19.6"
Gokarna	ST13	27°44'29.9"	85°23'07.3"
Pasupati	ST14	27°42'35.2"	85°20'47.3"
Patandhoka	ST15	27°40'48.8"	85°19'13.1"
Kupandol	ST16	27°41'20.2"	85°18'58.7"
Tundikhel	ST17	27°42'07.2"	85°18'54.4"
Tinkune	ST18	27°41'07.0"	85°20'56.8"
Ekantakuna	ST 19	27°39'58.9"	85°18'30.1"
Swayambhu	ST20	27°42'54.8"	85°17'28.5"
Khasibazar	ST21	27°41'23.3"	85°17'03.2"
Chandragiri	ST22	27°41'04.9"	85°13'24.9"
Old Naikap	ST23	27°41'39.0"	85°15'53.0"
Bohoratar	ST 24	27°43'52.2"	85°17'52.4"
Balaju(Gumba)	ST25	27°44'24.7"	85°18'30.1"
Tokha(Housing)	ST 26	27°45'26.0"	85°19'33.0"
Sanothimi	ST27	27°40'58.0"	85°22'56.6"
Suryabinayak	ST28	27°39'59.4"	85°25'56.1"
Kausaltar	ST29	27°40'19.6"	85°21'57.7"
Teku(Paropakar)	ST30	27°41'58.2"	85°18'10.7"

2.2 Sample Collection and Preparation

Three soil samples from each station at depth 14-15 cm were taken randomly within a circle of 1 m diameter dug in the location. A total of 90 specimens were taken by removing the vegetation on the surface level of the floor. The samples were collected in the plastic bags with the help of hoe and shovel, and the packet containing the sample was labeled and secured after sampling. Soils having high earthworm activity and rodent activity were avoided because of uneven mixing of the soil to considerable depth [15, 16]. The samples were then kept in the sun rays to remove any moisture and short living radionuclides for half of month. The samples were then crushed to pass through 2 mm sieve, homogenized, and harmonically sealed for one month in the zipper storage bag to attain radioactive equilibrium.

2.3 Sample Analysis

A representative sample of 500±5 gram was kept inside a GA-MA 133N Marinelli beaker whose

geometry allows 4π symmetry. The detection of sample was performed using 3"x3" NaI(Tl) (ORTEC) scintillation detector coupled to a pc based 14-pin digiBASE photo-multiplier tube. The system comprises a miniaturized preamplifier and detector high voltage (0V to +1200V bias in steps of 1.25V under computer control) with a powerful digital multichannel analyzer and special features for fine-time resolution measurements, all incorporated into a lightweight (287gm), compact (63 mm diameter-87 mm length) tube base with a USB connection [17]. Gamma Vision-version 8 software was used for this study providing time of analysis of 3600 seconds of live time for each sample. The gamma spectrometer used for the analysis has detector with relative efficiency of 4.03% and a resolution at full width at half maximum (FWHM) of 48.54 keV at 778.90 keV of ^{152}Eu. A heavy lead shield (^{210}Pb < 50 Bq/kg) with a thickness of around 5 cm enclosed the detector to eliminate background interference. Following a count time of 3600 seconds for each sample, ^{238}U activity concentration was estimated through its daughter nuclide ^{214}Bi at 609.312 keV and ^{214}Pb at 351.932 keV [17, 18]. ^{232}Th activity concentration was calculated through its daughter nuclei ^{212}Pb at 238.632 keV and ^{228}Ac at 911.196 keV [18, 19]. ^{40}K activity was measured through direct transition at 1.46 MeV [18, 19].

3. RESULTS AND DISCUSSION

3.1 Activity Concentration

The activity concentration of ^{40}K, ^{238}U and ^{232}Th along with deviation in concentration within soils from particular location has been given in table 2. ^{40}K activity concentration ranged from 409.99 Bq/kg to 814.13 Bq/kg with average of 592.46 Bq/kg. The lowest ^{40}K level was found in soil samples of station 23 and highest in samples of station 10. ^{238}U activity concentration ranged from 35.43 Bq/kg to 97.09 Bq/kg with an average of 59.06 Bq/kg. The lowest and highest ^{238}U has been found in station 7 and station 16 respectively. Similarly the activity concentration of ^{232}Th ranged from 35.58 Bq/kg to 115.15 Bq/kg with mean of 69.59 Bq/kg. Soils from station 23 and station 10 were found to have lowest and highest ^{232}Th activity concentration respectively. The activity concentrations of all the radionuclides of all the soil samples were found above worldwide average for them respectively, i.e. 400 Bq/kg for ^{40}K, 35 Bq/kg for ^{238}U and 30 Bq/kg for ^{232}Th [20]. The average activity concentrations for ^{40}K, ^{238}U and ^{232}Th have been found 1.48, 1.69 and 2.32 times higher than worldwide average values for the respective radionuclides. A typical spectrum recorded for a soil sample on digiBASE spectrometer indicating radionuclides of interest has been shown in figure (2).
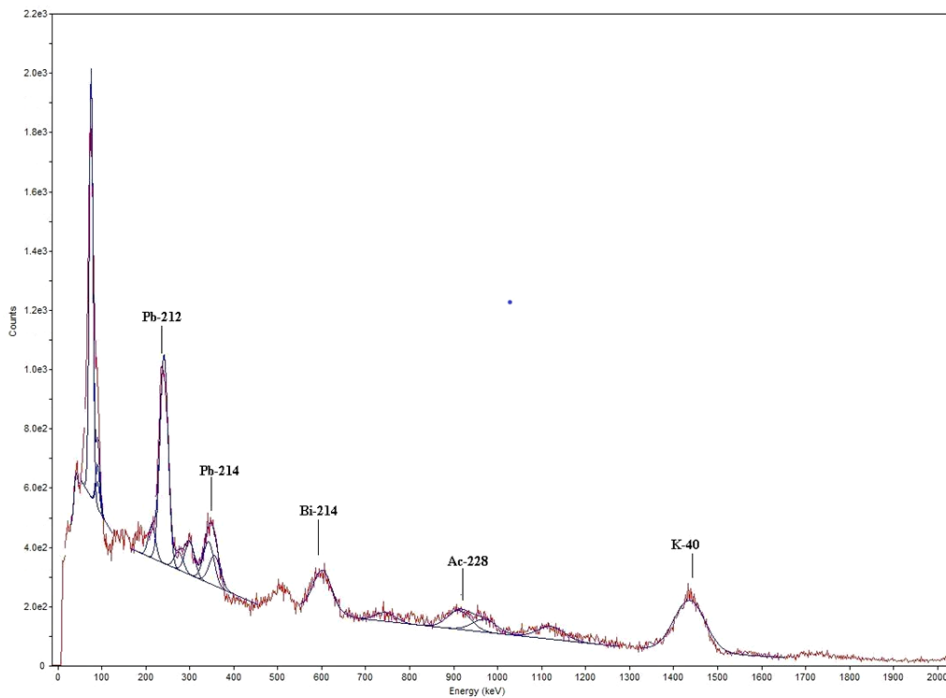

Fig. 2: Analyzed photo-peaks of a soil sample recorded on digiBASE Spectrometer.

Table 2: Activity Concentrations, Dose Rates, Radium Equivalent and Effective Dose due to radionuclides in soil samples

S.N.	Location	Concentrations in Soil (Bq/kg) ±σ			Absorbed Dose Rate (nGy/hr)	Radium Equivalent (Bq/kg)	Annual Effective Dose (mSv/yr)
		40K	**238U**	**232Th**			
1	ST 01	591.69±53.93	47.06±2.36	86.26±4.33	102.54	211.83	0.13
2	ST 02	526.66±26.85	41.17±4.28	82.13±8.50	94.52	195.48	0.12
3	ST 03	531.66±5.12	36.52±2.31	78.81±8.26	90.52	186.43	0.11
4	ST 04	491.98±81.84	65.56±3.56	82.8±11.40	104.00	218.40	0.13
5	ST 05	458.45±30.43	48.41±2.20	81.36±5.04	94.26	196.85	0.12
6	ST 06	705.85±53.52	39.42±5.84	52.22±3.56	81.37	163.50	0.10
7	ST 07	597.49±10.97	35.43±1.15	58.53±17.74	79.31	160.95	0.10
8	ST 08	740.72±23.34	63.99±1.08	86.11±7.53	115.98	238.98	0.14
9	ST 09	523.1±63.73	63.83±5.64	66.31±10.88	93.58	195.27	0.11
10	ST 10	814.13±99.68	95.37±12.44	115.15±12.63	151.89	317.02	0.19
11	ST 11	601.91±44.88	39.22±7.14	55.63±2.45	79.19	160.90	0.10
12	ST 12	645.83±46.09	93.51±6.83	99.18±3.94	133.39	280.55	0.16
13	ST 13	637.68±65.16	70.89±2.30	71.94±5.80	105.18	218.40	0.13
14	ST 14	672.19±18.24	58.98±1.29	64.96±3.31	96.86	198.93	0.12
15	ST 15	565.52±23.18	50.25±3.19	70.69±13.86	92.44	190.92	0.11
16	ST 16	656.65±23.83	97.09±13.28	79.62±8.95	122.35	256.91	0.15
17	ST 17	667.94±45.27	55.44±0.77	42.21±0.51	80.00	162.56	0.10
18	ST 18	641.14±5.19	96.22±13.80	105.79±9.32	138.76	292.38	0.17
19	ST 19	554.02±22.74	48.51±4.92	46.6±2.34	75.16	153.93	0.09
20	ST 20	503.78±25.81	57.09±1.91	50.49±14.97	79.33	164.56	0.10
21	ST 21	457.66±25.58	45.44±3.19	42.3±3.85	66.93	137.97	0.08
22	ST 22	775.33±58.25	58.16±3.05	58.76±1.60	96.71	196.46	0.12
23	ST 23	409.99±28.88	41.54±2.78	35.58±0.98	58.78	121.12	0.07
24	ST 24	682.86±42.23	68.05±3.47	56.13±6.70	95.32	196.12	0.12
25	ST 25	626.37±24.30	81.24±0.53	73±11.10	109.86	229.48	0.13
26	ST 26	614.23±13.26	70.1±0.76	75.03±4.30	105.91	220.39	0.13
27	ST 27	536.03±16.40	58.26±2.52	84.48±6.45	103.83	216.59	0.13
28	ST 28	564.59±5.92	44.07±3.06	37.85±3.08	67.87	137.72	0.08
29	ST 29	520.04±13.09	47.63±5.92	67.53±15.47	87.30	180.60	0.11
30	ST 30	458.22±86.38	53.44±7.86	80.16±11.09	95.61	200.14	0.12
	Average	592.46	59.06	69.59	96.63	200.04	0.12

3.2 Absorbed Dose Rate in air

The activity concentrations reported have been used to determine the absorbed gamma dose rate in air 1 m above the ground using the formula given below [20, 21].

$$D_R = 0.43A_U + 0.666A_{Th} + 0.042A_K \; ... (1)$$

Where, A_U, A_{Th} and A_K are activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively. The calculated absorbed dose rate in air is given in figure (3). The absorbed dose rate in air ranges from 58.78 nGy/hr at station 23 to 151.89 nGy/hr at station 10 with an average of 96.63 nGy/hr, which is a bit higher than the global average of 60 nGy/hr (range: 18-93

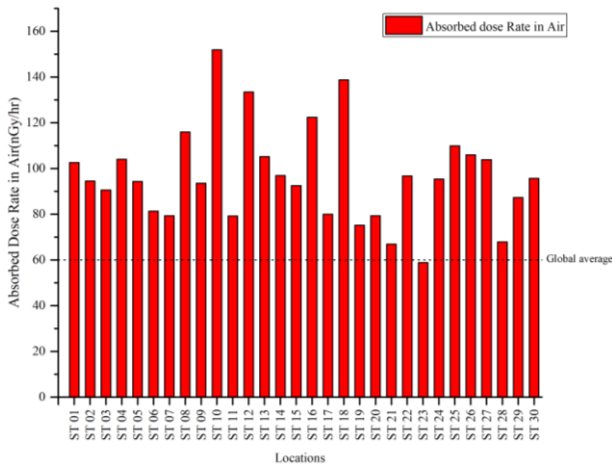nGy/hr) but does not pose any health threat or radiation risks [20].

Fig. 3: Absorbed Dose Rate in air versus Location

3.3 Radium Equivalent

For the assessment of radiation hazard posed by these radionuclides in the soil samples, Radium equivalent or concentrations has been calculated using the following equation [22]. This radium equivalent is weighted sum of activities of ^{40}K, ^{238}U and ^{232}Th radionuclides and is based on assumption that 4810 Bq/kg of ^{40}K, 370 Bq/kg of ^{238}U and 259 Bq/kg of ^{232}Th yield same gamma dose rate [23].

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.07A_k \; ... \; (2)$$

Where, A_U, A_{Th} and A_K are activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

As can be seen from figure (4) the radium equivalent of soil samples varied from 121.12 Bq/kg to 317.02 Bq/kg with an average value of 200.04 Bq/kg. The radium equivalent of all the soil samples is below recommended value of 370 Bq/kg [22] and does not pose any radiation hazard.
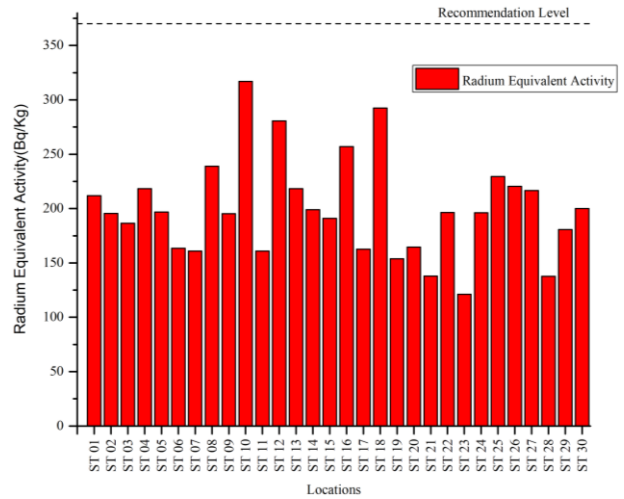

Fig. 4: Radium Equivalent of soil samples versus location

3.4 Annual Effective Dose (AED)

Considering the conversion factor for absorbed dose in air to effective dose and outdoor occupancy factor an annual effective dose equivalent has been calculated. Conversion factor of 0.7Sv/Gy and outdoor occupancy factor of 0.2 have been used for the calculations as per UNSCEAR reports [20]. The mathematical equation for calculating annual effective dose has been given below [24].
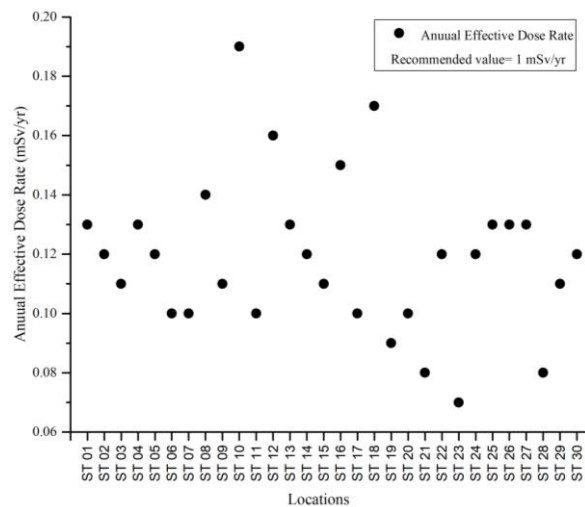
$$AED = D_R(nGy \; h^{-1})X8760(h \; year^{-1})X0.2X0.7(Sv \; Gy^{-1})X10^{-6} \; ... \; (3)$$

Where, D_R is dose rate as measured in equation 1 above.

The annual effective dose has been represented in the figure (5). According to the figure the minimum and maximum values for annual effective dose were 0.07 mSv/yr and 0.19 mSv/yr respectively with mean 0.12 mSv/yr. This mean annual effective dose is 1.71 times that of world average value [20] and is lower than the 1.0 mSv yr^{-1} recommended by ICRP[25].

3.5 External Hazard Index

Since the soils of the location could be used for construction purpose, for evaluating the hazard of natural gamma radiation, external hazard index has been calculated using following equation [23].

Fig. 5: Annual Effective Dose versus Location

$$H_{ex} = \frac{A_U}{370\ Bq\ Kg^{-1}} + \frac{A_{Th}}{259\ Bq\ Kg^{-1}} + \frac{A_K}{4810\ Bq\ Kg^{-1}}$$

$$... (4)$$

Where, A_U, A_{Th} and A_K are activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

The external hazard indices for the soil samples have been given in figure (6). The highest, lowest and average values of the indices are 0.87, 0.33 and 0.55 respectively which are well below recommended level 1.
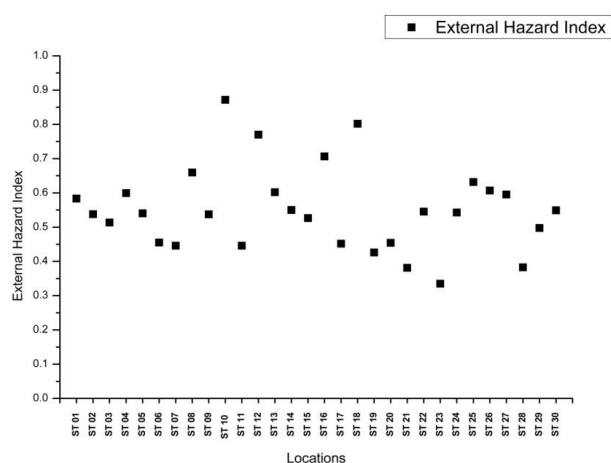

Fig. 6: External Hazard Index versus location

4. CONCLUSION

The average activity concentrations of the radionuclides ^{40}K, ^{238}U and ^{232}Th in the soil samples are 592.46 Bq/kg, 59.06 Bq/kg and 69.59 Bq/kg respectively. On the basis of these measurements, it seems that the distribution of natural radionuclides is variable. This study shows an increment in ^{40}K concentration than previous study which might be attributed to excessive use of fertilizer and building materials contaminating the top soil. Activity concentrations of radionuclides were higher in soils from northern part in comparison to southern part of valley which might indicate presence of magmatic rock rich in uranium and thorium. In addition to the activity concentrations, the Absorbed Gamma Dose Rate in air, Radium Equivalent activity, Annual Effective Dose and External Hazard Index have been calculated for the soil samples. The calculated Hazard indices show that no radiological threat due to radionuclides on inhabitants of the study area. Further, this study has provided baseline information on the state of natural radioactivity in the study area which will serve as a reference for a future study.

REFERENCES

[1] Miah, F. K.; Roy, S.; Touchiduzzaman, M. and Alam, B. Distribution of radionuclides in soil samples in and around Dhaka City. *Applied Radiation and Isotopes,* **49**(1-2): 133-137 (1998).

[2] Daulta, R.; Garg, V. K. and Singh, B. Natural Radioactivity in Soil, Associated Radiation Exposure and Cancer Risk to Population of Eastern Haryana, India. *Journal of the Geological Society of India,* **94**(5): 525-532 (2019).

[3] Janković, M.; Todorović, D. and Savanović, M. Radioactivity measurements in soil samples collected in the Republic of Srpska. *Radiation Measurements,* **43**(8): 1448-1452 (2008).

[4] Chikkur, G. C. and Umakantha, N. Half-life of thorium-232: a laboratory experiment. *American Journal of Physics,* **45**(11): 1120–1122 (1977).

[5] Glendenin, L. E. and Steinberg, E. P. Fission Radiochemistry (Low-Energy Fission). *Annual Review of Nuclear Science,* **4**(1): 69–80 (1954).

[6] Kelly, W. H.; Beard, G. B. and Peters, R. A. The beta decay of K40. *Nuclear Physics,* **11**: 492–498 (1959).

[7] Shah, B. R. Rapid Determination of K-40 in samples of soil from within Kathmandu valley using multichannel spectrometer (Master's Thesis), Central Department of Physics, Tribhuvan University (1994).

[8] Shah, B. R. Preliminary study for the detection of K-40 in the soil samples of the Kathmandu district. *In Proc. of 2nd National conference on Science and Technology*, RONAST, June 8-11, 1994, 769-774.

[9] Yadav, P.; Rajbhandari, P. and Shrestha, K. Estimation of Concentration of K-40 by Gamma Spectroscopy and Atomic Emission Spectroscopy in the Environmental Samples of Northern Kathmandu Valley. *Journal of Nepal Chemical Society,* **29:** 75-80 (2013).

[10] Chetry, M. K.; Shah, B. R. and Pradhananga, T. M. ^{137}Cs Monitoring Using Lichens and Mosses from Kathmandu Valley. *In Proc. III National Conference of Science and Technology*, RONAST, Kathmandu, Nepal (1999).

[11] Wallova, G.; Acharya, K. K. and Wallner, G. Determination of naturally occurring radionuclides in selected rocks from Hetaunda area, central Nepal. *Journal of Radioanalytical and Nuclear Chemistry,* **283**(3): 713–718 (2009).

[12] Abusini, M.; Al-Ayasreh, K. and Al-Jundi, J. Determination of uranium, thorium and potassium

activity concentrations in soil cores in Araba valley, Jordan. *Radiation protection dosimetry,* **128**(2): 213–216 (2008).

[13] Guidotti, L.; Carini, F.; Rossi, R.; Gatti, M.; Cenci, R. M. and Beone, G. M. Gamma-spectrometric measurement of radioactivity in agricultural soils of the Lombardia region, northern Italy. *Journal of Environmental Radioactivity,* **142**: 36-44 (2015).

[14] Retrieved from website, https://en.wikipedia.org/wiki/Kathmandu_Valley, retrieved on 5 April, 2021.

[15] Muller-Lemans H. and van Dorp F. Bioturbation as a mechanism for radionuclide transport in soil: relevance of earthworms. *Journal of Environmental Radioactivity,* **31**(1): 7-20 (1996).

[16] Arthur III, W. J. and Markham O. D. Small mammal soil burrowing as a radionuclide transport vector at a radioactive waste disposal area in southeastern Idaho. *Journal of Environmental Quality,* **12**(1): 117-122 (1983).

[17] ORTEC, PMT Base with Integrated Bias Supply, Preamplifier, and Digital Multichannel Analyzer for NaI Spectrometry and Counting (2014).

[18] Singhal, R. K.; Basu, H.; Saha, S.; Kumar, A. and Pimple, M. Estimation of ^{232}Th Concentration in environmental matrices by tracking activity of major daughter products (^{212}Bi, ^{212}Pb and ^{228}Ac) with time in a hermetically sealed container. *Journal of Environmental Analytical Chemistry.* **3**(4): 2380-2391 (2016).

[19] Hamby D. M. and Tynybekov A. K. Uranium, thorium, and potassium in soils along the shore of Lake Issyk-Kyol in the Kyrghyz Republic. *Environmental Monitoring and Assessment*, **73**(2): 101-108 (2002).

[20] UNSCEAR, Sources and Effects of Ionizing Radiation*, Report to the General Assembly*, New York: United Nation (2000).

[21] Beck, H. L. Physics of environmental gamma radiation fields (1972).

[22] Beretka J. and Matthew P. J. Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health physics*, **48**(1): 87-95 (1985).

[23] Sivakumar R. An assessment of natural radioactivity levels and radiation hazards in the soil of Coonoor, South India. *Environmental earth sciences,* **72**(12): 5063-5071 (2014).

[24] Ravisankar R.; Chandrasekaran A.; Vijayagopal P.; Venkatraman B.; Senthilkumar G.; Eswaran P. and Rajalakshmi A. Natural radioactivity in soil samples of Yelagiri Hills, Tamil Nadu, India and the associated radiation hazards. *Radiation Physics and Chemistry*, **81**(12): 1789-1795 (2012).

[25] ICRP, Recommendations of the International Commission on Radiological Commission, *ICRP Publication* **60**, Pergamon Press. New York (2000).