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Assessment of ^{137}Cs in the Environment of Hetauda City, Nepal by In-Situ Gamma Ray Spectrometry

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ABSTRACT

A significant amount of ^{137}Cs radioactive fallout have been spread in the atmosphere due to nuclear weapon testing and nuclear reactor disasters. This fallout eventually settles on the Earth's surface, and because ^{137}Cs has a long half-life, it remains in the environment for an extended period. Mapping the distribution of ^{137}Cs is crucial, and this study aims to assess the radioactive deposition of ^{137}Cs in the ground to establish baseline data for its distribution in the environment of Hetauda City, Nepal. Recently, Hetauda City has been designated as the capital city of the Bagmati province. To measure ^{137}Cs deposition, portable (backpack) gamma ray spectrometer was used with a 0.347-liter NaI(Tl) detector. Rapid measurement was carried out while walking at a pace of less than 2 km/h, and the distance between the detector and the ground was maintained at less than 1 m with the detector pointing downward. The surface activity of ^{137}Cs was measured in the range of 0.003 to 2.382 kBq/m^2, with an average value of 0.581 ± 0.343 kBq/m^2. The spatial variability of ^{137}Cs was found to be smooth in the area, and the mean annual effective dose calculated was 0.379 ± 0.224 μSv. The low dose rates and smooth spatial distribution of ^{137}Cs in the environment indicate no contamination, and the trace amount present could be due to global fallout from weapons testing and nuclear accidents. The results were compared with previously reported values worldwide.

INTRODUCTION

World population is continuously exposed to ionizing radiation from natural sources. Cosmic ray particles and radionuclides present in Earth's crust (^{238}U, ^{232}Th and ^{40}K) are the main contributors of natural radiation exposure [1]. In-situ gamma spectrometry is widely used for environmental gamma ray study [2,3]. Natural radiation exposure is the major contributor of the total exposure, however, the world population is also exposed to manmade radiation released to the environment. These includes atmospheric nuclear testing, nuclear weapon manufacturing, nuclear power production, radioisotope production, and accidents involving radioactive sources. Most of the exposure from manmade sources is from the nuclear weapon testing in which radioactive material is released directly in the environment [1]. From the fallout, the nuclides are transported by air over several distances and get deposited on the Earth's surface by rain.

The global fallout from nuclear weapon testing and nuclear disaster have caused considerable amount of ^{137}Cs spread in the atmosphere. The radioelement ^{137}Cs is one of the common fission products formed by nuclear fission. The contaminated soil is the source of radionuclides contaminating agricultural products and water resources. Since, ^{137}Cs has a long half-life of 30.17 years, it remains in the environment for a long time after deposition which makes its mapping important [4].

Even after 80 years of initial deposition of global fallout, the spatial pattern of radionuclides (Chernobyl accident versus nuclear weapon testing) is highly uncertain and therefore assessments in small region scale are needed [5]. After Chernobyl accident, several systematic measurements of artificial radionuclides were done (airborne gamma surveys and in-situ gamma spectrometry measurements) in Europe. The database of ^{137}Cs

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was updated with efficacy later [6]. A detailed study of global fallout were not conducted before the Chernobyl accident, and hence the ^{137}Cs deposition measurements made before Chernobyl accident have higher uncertainties. The magnitude of the global fallout from nuclear weapon was usually neglected while taking consideration of Chernobyl accident [7].

The surface soil is enriched with ^{137}Cs due to atmospheric fallout exposure [8] and the Earth system is now permanently altered by anthropogenic activities [9]. The raw measured data is important for improving global understanding of ^{137}Cs dynamics also in soil erosion research [10]. Most of the studies have included ^{137}Cs modelling source contribution. ^{137}Cs were measured to provide the magnitude and spatial distribution of the soil to explore the soil redistribution rate influence on fingerprint properties [11]. ^{137}Cs is a very effective tracer for assessing soil erosion magnitude when performed with suitable and statistically sound sampling method [12]. ^{137}Cs was used to determine the relative contribution of sediments source types to design effective control strategies for soil erosion [13]. ^{137}Cs was also studied for understanding sediment source contributions from mining activities for guiding and implementing effective management measures against erosion [14].

The mobility of radionuclides depends on the climatic condition, soil properties, and human activity. Thus, the ^{137}Cs measurement in soil is necessary for radioecology and radiological protection. The aim of this work is to assess the current level of deposition of ^{137}Cs in the environment of Hetauda City in Nepal and to provide spatial distribution profile of the area. The data will be preliminary data of human exposure prediction for future.

MATERIALS AND METHODS

Study area

Hetauda is the capital city of Bagmati Province in Central Nepal. It is one of the big cities of Nepal and has the largest industrial estate. It is located at a distance of 76 km from Kathmandu. It is situated in the confluence of two main highway (Tribhuvan highway and Mahendra highway) and lies in $27^0 25^{'}$ N latitude and $85^0 02^{'}$ E longitude at 300 to 390 m above sea level. The city has a population of approximately 2,466,138 inhabitants. The area of the city is 261 km^2 (97 % land and 3 % water). Geographically, the city is a Doon (an open valley) surrounded by mountains (Mahabharat Range) to the north, and Sivalik Hills and low land ‘Terai’ to the south. The city is surrounded by the Rapti river to the west, the Samari river to the north and the Karra river to the south which run through the city and flows south west to meet the Narayani river (one of the biggest rivers of Nepal). The measurement is taken along the yellow path shown in Fig. 1.

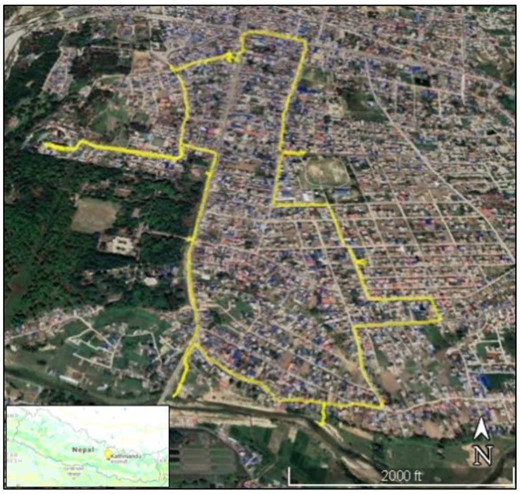

Fig. 1: Google Earth Pro map of area showing the path studied.

^{137}Cs activity measurement

The measurement was carried out using portable gamma ray spectrometer. The spectrometer was carried in a backpack maintaining a height less than 1 m from the ground, pointing detector downward, and walked around the study area with a speed less than 2 km/h. The study was carried out along the main road and the inner road of Hetauda City.

Fig. 2: Gamma ray spectrometer (PGIS 2).

The gamma spectrometer (PGIS 2) used (Fig. 2) is equipped with a 0.347 litre NaI(Tl) detector which is coupled to multichannel analyzer with 512 channels. The detector can measure within the energy range of 20 keV to 3 MeV. The window-based gamma spectrometric approach was used to extract elemental and activity concentration from spectral windows, 662 keV for ^{137}Cs [4]. The spectrometer consists of detector unit integrated with GPS and a data logger and control unit developed for android based device via wireless (Bluetooth) connection. It is auto-calibrated and the tuning time is less than 60 seconds. The continuous measurements was taken at 1 second interval. The recorded data was extracted in laboratory and analyzed using PEI View software. The map was prepared using Surfer software and the statistical analysis was done using Grapher software.

Dosimetry

The outdoor absorbed dose rate (D) in air at 1 m above the ground surface for ^{137}Cs was calculated using Eq. (1) [15].

$$D = 7.6 \times 10^{-4} \times C \qquad (1)$$

where C is the surface activity concentration in kBq/m^2, and 7.6 × 10^{-4} [(µGy/h)/(kBq/m^2)] is the conversion factor for converting ^{137}Cs surface activity to dose rate.

The external annual effective dose rate (E) (µSv) was calculated using Eq. (2) [16].

$$E = D \times U \times S \times OF \times T \qquad (2)$$

where U is the unit conversion coefficient (0.7 Sv/Gy) [1] for the conversion of absorbed dose rate in air to effective dose rate, S is the shielding factor for 1 m above the ground (0.7 for typical land) [17], OF is the outdoor occupancy factor (0.2) [1] and T is the hours in a year (8760 h).

RESULTS AND DISCUSSION

The ^{137}Cs surface activity concentrations observed in the environment of Hetauda City ranges from 0.003 to 2.382 kBq/m^2 with a mean value of 0.581±0.343 kBq/m^2. The radiological map showing a spatial distribution of ^{137}Cs surface activity concentrations is depicted in Fig. 3. The 58 % of total ^{137}Cs surface activity lies below 0.597 kBq/m^2 in the area, 35.9 % below 1.192 kBq/m^2, 5.7 % below 1.787 kBq/m^2 and 0.3 % above it. The contour map created by interpolating the data of surface activity of the ^{137}Cs using ordinary kriging interpolation method is shown in Fig. 4. It shows smooth variation of the distribution of he ^{137}Cs in the area showing most values below 0.6 kBq/m^2.

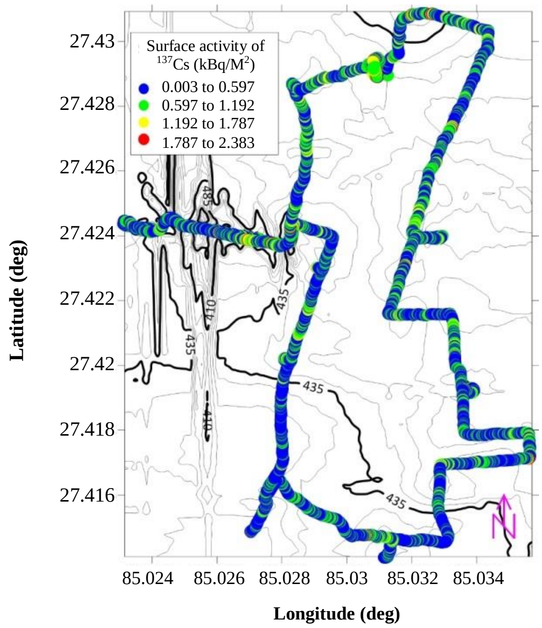

Fig. 3. Spatial distribution of surface activity of ^{137}Cs in the environment of Hetauda City overlaid on altitude contour.

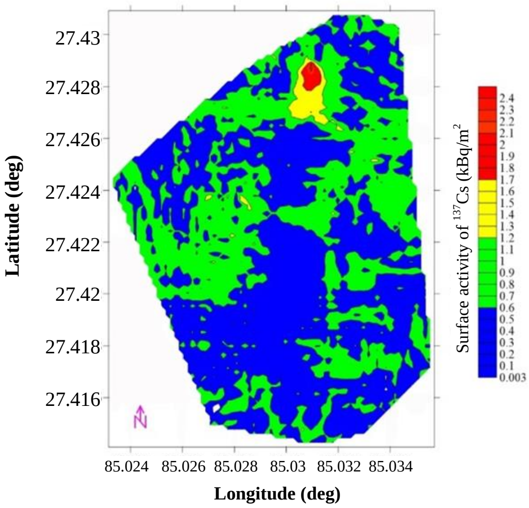

Fig. 4. Contour map showing surface activity of ^{137}Cs in the environment of Hetauda City.

The artificial radionuclide ^{137}Cs dispersed in the environment due to nuclear weapon tests and accident in nuclear power plants like Chernobyl disaster were found in atmosphere as a fallout [18]. The Chernobyl accident was thought to be the origin of the artificial radionuclides in atmosphere [19]. The presence of ^{137}Cs in the study area is probably due to the global fallout from Chernobyl accident in 1986. Latitude and precipitation are the major factors for the worldwide distribution of ^{137}Cs in the atmosphere which appears as a background in the northern hemisphere [20]. Hence, it can be said that the study area is exposed to fallout due to meteorological condition and rainfall after the Chernobyl accident. The major deposition process of ^{137}Cs was deposited in terrestrial environments mainly by wet deposition process after the accident and the ^{137}Cs derived by this process on soil ground was initially retained on vegetation and ground surface [21].

The frequency distribution (count) of surface activity of ^{137}Cs is shown in Fig. 5. The distribution is skewed right indicating most of the values lie below 0.581 kBq/m^2. The distribution of surface activity of ^{137}Cs through their quartiles is shown as box and whisker plot (Fig. 6). It also shows that the data is skewed right and has outliers with most values within 0.322 to 0.779 kBq/m^2.

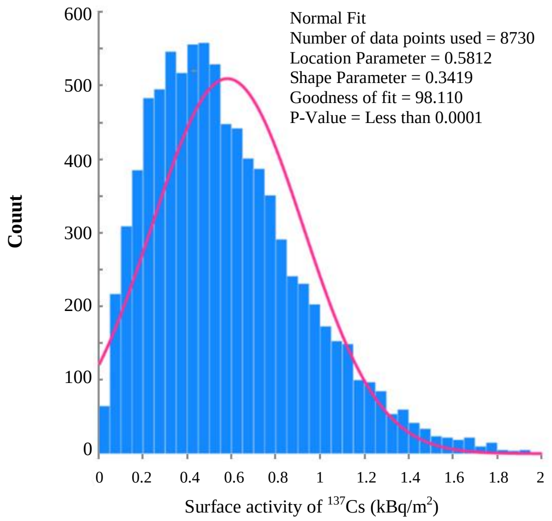

Fig. 5. Frequency distribution of surface activity of ^{137}Cs.

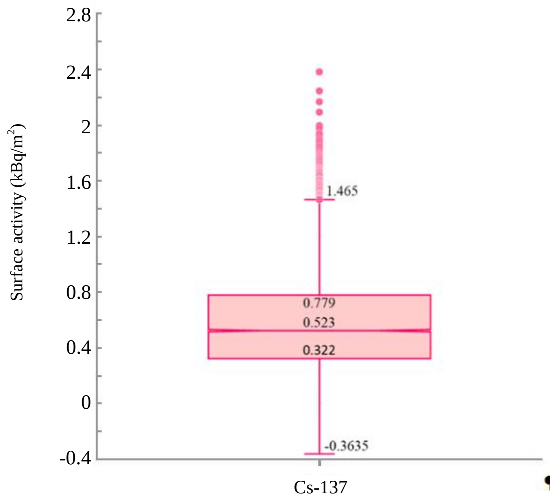

Fig. 6. Surface activity of ^{137}Cs.

The absorbed dose rates and annual effective dose rates were calculated from the surface activity of the ^{137}Cs in the soil. The results showed that the absorbed dose rates and annual effective dose varied from 0.002 nGy/h to 1.81 nGy/h with mean value of 0.442 nGy/h, and 0.002 µSv to 1.554 µSv with the mean value of 0.379 ± 0.224 µSv, respectively. The annual effective dose rates in the study area are compared with the other places and found to be lower than that of Sultanate of Oman and Turkey but higher than that of Pakistan and Saudi Arabia (Table 1).

Table 1: Comparison of the annual effective dose from ^{137}Cs in soil.

Country	Annual Effective Dose (µSv)	References
Azad Kashmir, Pakistan	0.012 to 0.54	[22]
Riyadh Province, Saudi Arabia	0.44 to 0.70	[23]
Musandam Peninsula, Sultanate of Oman	0.02 to 8.48	[24]
Ordu, Turkey	2.5 to 10.1	[19]
Eastern Black Sea, Turkey	0.98 to 28.11	[25]
Manisa Province, Turkey	3.66 to 13.81	[26]
Gandula Region, Libya	0.0028	[27]
Hetauda, Nepal (present study)	0.002 to 1.554	

The low exposures from ^{137}Cs were also reported in Greece and Pakistan [28,29]. The difference in AED was reported in different countries as the level of ^{137}Cs concentration varies according to the latitude, location, soil texture, and other environmental parameters.

CONCLUSION

The ^{137}Cs in the environment of Hetauda City was measured using in-situ gamma ray spectrometry, and the annual effective dose was estimated. The surface activity concentrations of ^{137}Cs was found to lie in the range from 0.003 to 2.382 kBq/m^2. The mean annual effective dose was found 0.379 ± 0.224 µSv. The result was found higher than Saudi Arabia, Pakistan, Libya, but lower than Turkey.

The spatial variability of the ^{137}Cs in the investigated area is smooth and mainly attributed to weapons testing and Chernobyl disaster. The obtained results in this study revealed that the radiation level from ^{137}Cs in Hetauda City poses no health risk to the public and environment. The results are expected to be helpful for radioactive pollution prediction and can be used as a baseline data for any worldwide radiological accident.

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AUTHOR CONTRIBUTION

The authors confirm contributions to the paper as follows: concept and validation: both, formal analysis, investigation, methodology, visualization and original draft preparation: Anita Mishra, supervision, review and editing: Raju Khanal. Anita Mishra and Raju Khanal approved the final version of the paper.

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