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In-Situ Radiometric Study Along the Kaligandaki River: Focus on the Deepest Gorge

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Abstract. An in-situ radiometric survey was conducted along the Kaligandaki River in Nepal, a geologically significant region that features the world's deepest gorge and the presence of Shaligram fossilized ammonites, which hold both cultural and scientific importance. The Kaligandaki River, one of the major rivers of Nepal, originates from Damodarkund near Lomanthang, where large uranium deposits have been confirmed by the Department of Mines and Geology, Nepal. The Shaligram fossil is found exclusively in this region. For the study, a portable gamma-ray spectrometer (PGIS-2) equipped with a NaI(Tl) detector was used. Radiological hazard parameters associated with naturally occurring radionuclides were determined, including radium equivalent activity (Ra_{eq}), absorbed gamma dose rate in air (ADR), annual effective dose rate (AEDR), external hazard index (H_{ex}), and internal hazard index (H_{in}). Mean values of all three radionuclides exceeded the worldwide average values reported by UNSCEAR. Radiological parameters were found to be: Ra_{eq} = 96.02–421.04 Bq kg^{-1} (mean: 219.89 ± 72.89 Bq kg^{-1}), H_{in} = 0.46–1.47 (mean: 0.81 ± 0.23), and H_{ex} = 0.26–1.13 (mean: 0.59 ± 0.20), all within internationally accepted safety limits. This study highlights the necessity for periodic monitoring to ensure environmental and public safety in regions with elevated levels of naturally occurring radioactive materials.

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1. INTRODUCTION

The Kaligandaki River is one of the major rivers in Nepal and holds significant geological and radiometric importance. Originating at Damodarkund in Mustang region, it flows south through the Himalayas, cutting the world's deepest gorge between the Dhaulagiri and Annapurna ranges. Geologically, the Kaligandaki River section in western Nepal is part of the Himalayan thrust belt, characterized by a complex tectonic setting shaped by ongoing deformation. This region contains prominent structural units, including the Sub-Himalayan thrust system, Lesser Himalayan imbricate zone, Dadeldhura thrust sheet, and the Main Central Thrust (MCT) [1].

Few studies have been conducted in Nepal to examine the activity concentration of naturally occurring radionuclides such as ^{238}U, ^{232}Th and ^{40}K. These include studies on rock samples from the Hetauda Region [2], in-situ measurements at the premises of Tribhuvan University [3], in-situ measurements radiation dose in air and associated scattering phenomena [4], assessment in the mining area of Lalitpur [5], and analysis of rock samples from Central and Far-western Nepal [6]. Few studies have been conducted in Nepal to measure radioactivity level but there have been no previous in-situ gamma spectrometric studies along the Kaligandaki gorge. The present study aims to investigate radiological concentrations and associated radiological parameters along the Kaligandaki riverside. This river is also well known for fossilized stones known as Shaligram, which hold both cultural and scientific value. Furthermore, sediments, rocks, sand, and aggregates from this region are used extensively in construction activities, raising the importance of understanding their radiological characteristics. This work provides insight into the current status of radioactive mineral sources and potential radiological hazards along the riverside, originating from both natural and possible anthropogenic sources. In this context, an in-situ radiometric survey along the Kaligandaki River is essential for understanding the distribution and concentration of natural radionuclides in relation to the underlying geology.

2. MATERIALS AND METHODS

The Kaligandaki Valley in Nepal is a geologically significant region that forms the Earth's deepest gorge (Andha Galchhi), separating Dhawalagiri and Annapurna, linking the Tibetan Plateau to the Indian plains [7]. An in-situ radiometric survey was conducted from Galeshwor (855 m) to Gorge (Andha Galchhi) (1560 m). The study area can be seen in Fig. 1(c). The portable gamma-ray spectrometer PGIS-2, a NaI(Tl) detector, used for the study, provides a cost-effective and efficient method of in-situ measurements for quantitative determination of gamma-ray emitting radioisotopes [8, 9]. This system, featuring auto calibration through natural photo peaks, comprises a detector unit integrated with GPS and a data logger unit. The detectors use a thallium-activated sodium iodide (NaI (Tl)) crystal with a volume of 0.347 liters, detecting energies from 20 keV to 3 MeV. Data collection involved walking through area while carrying the detector at speeds below 4 km hr^{-1}. A total of 28 locations were selected along the Kaligandaki River from Galeshwor to Tatopani (GLTP) and near world's deepest gorge. At each location, 50 readings were taken. PGIS-2 is auto calibrated with natural photo peaks and provides data every second. Gamma ray spectrometry measures potassium concentration in rocks and soils by detecting gamma rays with an energy of 1461 keV, emitted by ^{40}K. The estimation of ^{40}K is reported in % K (percent potassium) and 1% K in rock is equal to 313 Bq kg^{-1} [10]. Uranium content is determined by identifying 1765 keV gamma rays from ^{214}Bi, a byproduct of ^{238}U decay. This method provides an indirect measure of uranium, with results presented as parts per million of equivalent uranium (ppm eU) to indicate the assumption of a stable decay chain in the ^{238}U series [11]. Thorium content is determined by identifying 2615 keV gamma rays from ^{208}Tl, a byproduct of ^{232}Th decay. According to IAEA guidelines 1 ppm U in rock is equal to 12.35 Bq kg^{-1} of ^{238}U and 1 ppm Th in rock is equal to 4.06 Bq kg^{-1} of ^{232}Th [10].

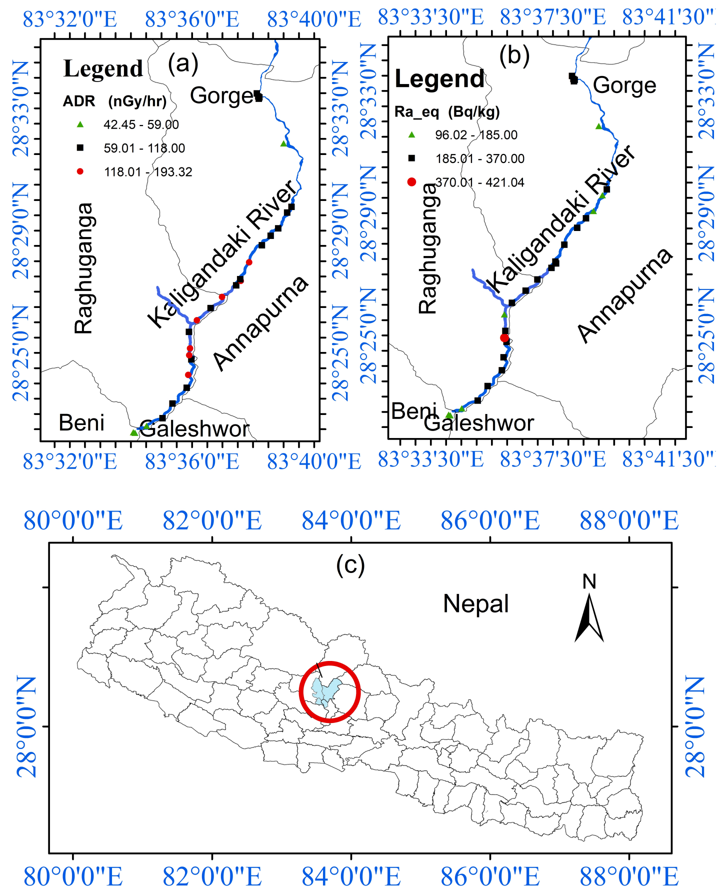

FIGURE 1: Map showing (a) Distribution of ADR, green triangle shows value within world average, black square shows value between world average and double to world average and red circle shows value greater than double to world average (b) Distribution of Ra_{eq}, green triangle shows value below half of recommended value, black square shows value between half to recommended value and red circle shows value greater than the recommended value (c) Study location

TABLE I: Radiological parameters for study area

S.N.	Radiological parameter	Units	Formula	World average	References
1	Radium equivalent activity	Bq kg^{-1}	$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K$	≤ 370	[12, 13, 14]
2	Absorbed dose rate	nGy hr^{-1}	ADR=$0.462A_{Ra} + 0.604A_{Th} + 0.0432A_K$	≤ 59	[13, 15]
3	Outdoor annual effective dose rate	mSv yr^{-1}	$AEDR_o = D_R(\text{nSv hr}^{-1}) \times 8760\ (\text{hr yr}^{-1}) \times 0.7(\text{Sv Gy}^{-1}) \times 0.2 \times 10^{-6}$	≤ 0.07	[13, 14]
4	Indoor annual effective dose rate	mSv yr^{-1}	$AEDR_{in} = \text{ADR}(\text{nGy hr}^{-1}) \times 8760\ (\text{hr yr}^{-1}) \times 0.7(\text{Sv Gy}^{-1}) \times 0.8 \times 10^{-6}$	≤ 0.41	[13, 14]
5	Internal hazard index	-	$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}$	≤ 1	[13, 14]
6	External hazard index	-	$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}$	≤ 1	[13, 14]

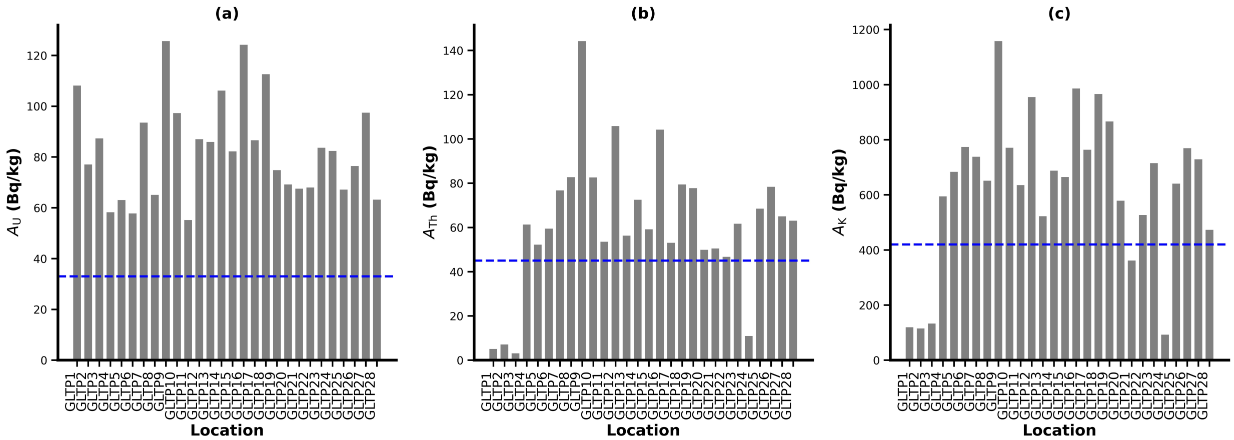

FIGURE 2: Location wise activity concentration of ^{238}U, ^{232}Th and ^{40}K for Study Area, blue dotted line shows world average value.

3. RESULTS AND DISCUSSION

The absorbed dose rate and the radium equivalent activity in the study area are presented in Fig. 1(a) and Fig. 1(b), respectively. The absorbed dose rate in air is observed to range between the world average value and approximately twice the global average. In the figure, the black squares represent ADR values ranging from 59 nGy hr^{-1} to 118 nGy hr^{-1}. Notably, near Beg Khola (GLTP11), the ADR value reaches about twice the world average. Radium equivalent activity for all locations (except GLTP9) are within world average value. Red circle in Fig. 1 (b) shows maximum value of Ra_{eq} for GLTP9.

TABLE II: Mean value of NORMs in study area

S.N.	Radionuclides	Mean value	Minimum value	Maximum value
1	A_U (Bq kg^{-1})	82.94 ± 19.55	55.17	125.63
2	A_{Th} (Bq kg^{-1})	61.79 ± 30.82	3.06	144.22
3	A_K (Bq kg^{-1})	631.03 ± 270.75	92.47	1158.06

Activity concentrations and range of ^{238}U, ^{232}Th and ^{40}K, are given in Table II. The activity concentrations of ^{238}U ranged from 55.17 to 125.63 Bq kg^{-1} (mean (± SD): 82.94 ± 19.55 Bq kg^{-1}), ^{232}Th ranged from 3.06 to 144.22 Bq kg^{-1} (mean: 61.79 ± 30.82 Bq kg^{-1}), and ^{40}K ranged from 92.48 to 1158.06 Bq kg^{-1} (mean: 631.03 ± 270.75 Bq kg^{-1}). The activity concentration of ^{238}U for most of the locations has values two times greater than the world average values Table 2. The activity concentration of ^{232}Th (except location 1,2,3,and 24) have values above world average values. For ^{40}K, except 5 locations (Locations 1,2,3,21 and 24), other values exceed world average.

TABLE III: Value of radiological parameters for study area

S.N.	Radiological parameter	Mean value	Minimum value	Maximum value
1	Ra_{eq} (Bq kg^{-1})	219.89 ± 72.89	96.02	421.04
2	ADR (nGy hr^{-1})	101.11 ± 34.01	42.45	193.32
3	$AEDR_{out}$ (mSv yr^{-1})	0.12 ± 0.04	0.05	0.24
4	$AEDR_{in}$ (mSv yr^{-1})	0.50 ± 0.17	0.20	0.94
5	H_{in}	0.81 ±0.23	0.46	1.47
6	H_{ex}	0.59 ± 0.19	0.26	1.13

Locations GLTP27 and GLTP28 are close to world's deepest gorge, where all ^{238}U, ^{232}Th and ^{40}K exceed world average values. GLTP9 has highest value of ^{238}U, ^{232}Th and ^{40}K. Higher activity concentration of ^{40}K in GLTP9 may be due to presence of fertilizer used in different agro-farm located in that region but in case of ^{238}U and ^{232}Th further study is required. The mean values of ^{238}U, ^{232}Th and ^{40}K concentrations in study region are 82.94± 19.55 Bq kg^{-1}, 61.79 ± 32.69 Bq kg^{-1} and 631.03 ± 270.75 Bq kg^{-1} respectively. All these values exceed world average values [16].

The Fig. 3 shows correlation between ADR and activity concentrations A_U, A_{Th} and A_K. ADR shows weak correlation with A_U (FIGURE 3(a)) but strong positive correlation (r=0.96) and (r= 0.93) with A_{Th} and A_K (FIGURE 3 (b) and (c)). This suggests that thorium and potassium are major contributors to the total radium equivalent activity.

The Fig. 4 demonstrates correlation between Ra_{eq} and activity concentrations. Ra_{eq} shows a strong and statis-

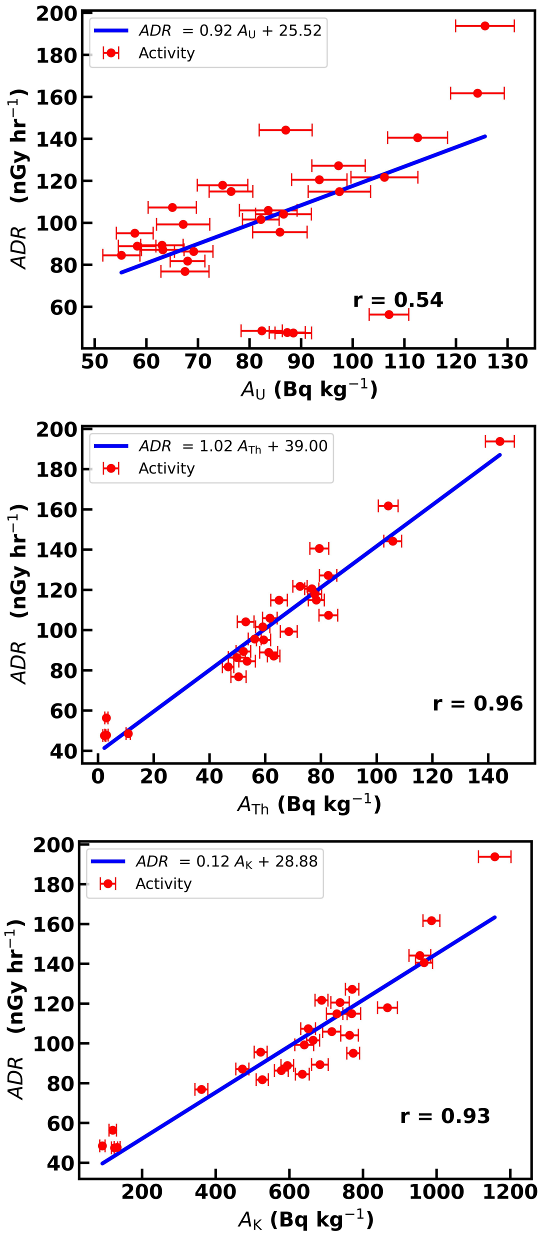

FIGURE 3: Correlation between Dose rates and activity concentrations ^{238}U, ^{232}Th and ^{40}K for Galeshwor Tatopani Region.

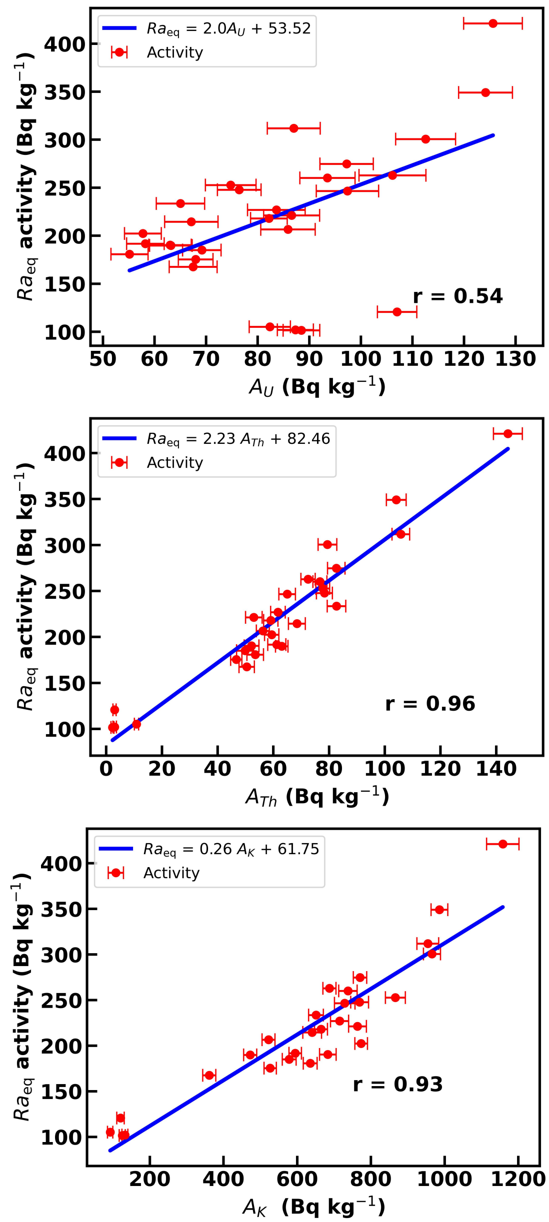

FIGURE 4: Correlation between Radium equivalent activity and activity concentrations ^{238}U, ^{232}Th and ^{40}K for Galeshwor Tatopani Region.

tically significant positive correlation (r=0.96) and (r= 0.93) between A_{Th} and A_{K} (FIGURE 4(b) and (c))but weak correlation with A_{U} (FIGURE 4(a)). In each case p-value is found to be less than 0.01 so the relation among parameters is statistically significant.This suggests that thorium and potassium are major contributors to the total radium equivalent activity.

4. CONCLUSION

An in-situ assessment of naturally occurring radioactive materials in the region of the world's deepest gorge along Kaligandaki River was carried out using a portable gamma-ray spectrometer (PGIS-2). The activity concentrations of radionuclides ^{238}U, ^{232}Th, ^{40}K were determined and compared with the world average. The results indicated that the concentration values in this region exceeded global average. Radiological parameters such as Ra_{eq}, $AEDR_{\text{o}}$, $AEDR_{\text{in}}$ and hazard indices were calculated. All radiological parameters were found to be below the recommended limits set by the ICRP. This study highlights the need for further investigations to better understand and evaluate the potential exposure to the public residing in that region.

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AUTHOR CONTRIBUTION

Bal V. Khatri: Conceptualization, Methodology, Validation, Data analysis, Visualization, Writing – Original Draft

Raju Khanal: Methodology, Resources, Writing – Review and Editing, Validation, Visualization, Supervision

EDITORS' NOTE

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