

Tree Biomass and Carbon Stock Variations Between Riparian and Terrestrial Forests in Central Himalaya

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Abstract

Riparian and terrestrial forests are vital components of tropical ecosystems, playing a key role in carbon sequestration and biodiversity conservation. This study assessed and compared tree biomass and carbon stock between riparian and adjacent terrestrial forests along the Sharda River in the Central Himalaya to understand structural and functional differences. Field surveys were conducted during 2023-2024 across three sites in each forest type using ten randomly placed 10 × 10 m quadrats per site. Vegetation parameters-frequency, abundance, density, and Importance Value Index (IVI)- were calculated utilizing standard ecological approaches. Tree basal area was derived from circumference at breast height (CBH), and biomass was estimated non-destructively for trees with CBH > 30 cm using species-specific and generalized allometric equations. Results showed higher tree density (350 ± 34.64 ind/ha), basal area (13.99 ± 0.51 m²/ha), species diversity (2.47 ± 0.11), biomass (95.81 ± 65.58 Mg/ha), and carbon stock (45.51 ± 3.13 Mg C/ha) in terrestrial forests compared to riparian forests. Riparian forests had 286.66 ± 50.33 ind/ha density, 6.31 ± 2.71 m²/ha basal area, 2.14 ± 0.06 diversity, 53.5 ± 25.14 Mg/ha biomass, and 23.79 ± 13.05 Mg C/ha carbon stock. These variations reflect differences in species composition and disturbance regimes. The findings offer valuable insights into the carbon dynamics of underexplored Himalayan riparian ecosystems, highlighting their importance in climate change mitigation and conservation planning.



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Introduction

Forest ecosystems are one of the most important types of ecosystems in terms of global carbon budget.¹⁻⁶ An essential ecological component in

evaluating carbon sequestration and the efficiency of carbon sinks is biomass, a basic quantitative characteristic of ecosystems. Riparian forests are vital components of terrestrial landscapes as

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they host both flood-tolerant species and species migrating from nearby uplands, making them key contributors to the region's overall plant biodiversity.⁷ The riparian forest vegetation is impacted by the species colonization process, stages of vegetation succession, and site disturbances.⁸ Seasonal variations in weather induce frequent disruptions like floods, which alter flow patterns locally and create a diverse mosaic of biological communities and landforms^{9,10}

Riparian forests along the rivers in the Himalayan region are predominantly composed of early- to mid-succession plant communities, reflecting their dynamic successional status and frequent exposure to natural and anthropogenic disturbances.^{11,12} The low water level during the winter and summer periods provides the time for regeneration of plant species that are eroded during the monsoon period, when huge amounts of water from the high water level create an early successional condition for vegetation growth. The Himalayan riverine/riparian forests consist of several plant communities encompassing *Drypetes roxburghii*–*Toona ciliata*, *Acacia catechu*, *Dalbergia sissoo* in Himalayan foothills, *Alnus nepalensis*, *Macaranga pustulata*, *Duabanga grandiflora*–*Terminalia myriocarpa* in the eastern part of Himalaya, *Debregeasia hypoleuca*, *Hippophae salicifolia*, *Populus ciliata*, and *Salix species*, etc, at higher elevations.¹³⁻¹⁵ Riparian forests preserve a lot of carbon since they develop quickly. Knowing how much carbon they preserve can help figure out how much bioenergy might be made in rural regions. The growing biomass sector is really making people throughout the world rethink the many natural sources of energy that exist. People are presently more interested in the biomass potential production from riparian forests than they were before, when it was mostly ignored since it was thought to be of inferior quality.¹⁶ Riparian forests play a vital role in carbon cycling, though their biomass and carbon stocks are often lower than adjacent terrestrial forests due to frequent disturbances and hydrological variability.¹⁷ In tropical regions, above-ground biomass in riparian forests can range from 40 to 80 Mg/ha, with corresponding carbon stocks typically comprising about 45–50% of total biomass.¹⁸ Large tree mortality rates, increased wind turbulence, and microclimatic changes all

affect the pattern of aboveground biomass (AGB) in fragmented forest patches, and forest edges, i.e., riparian zones, are especially susceptible to these effects. These edge-related disturbances have the potential to substantially alter carbon cycling processes, which may decrease the capacity to store carbon in these forested areas and overall sequestration potential.¹⁹

To measure biomass and carbon stocks in diverse Himalayan Forest zones, numerous studies have been carried out by different researchers.²⁰⁻²² However, there is very little or no information available on Himalayan riverine forest biomass, especially the riparian vegetation. So, this investigation was done to find out the biomass and carbon stock of the riparian and nearby land forests along the Sharda River in the Central Himalayan area.

Material & Methods

Study Area

The present investigation area is located at 29°06'58" N–29°06'59" N Latitude and 80°09'33"–80°09'37" E longitude at an elevation of 260–290 m asl. The study area was divided into two vegetation types, Riparian Forest (along the river bank) and terrestrial forests (away from the river bank), based on distance from the active river channel.

The climate of study area varies from Sub-tropical monsoon type (hot summer followed by summer monsoon and mild winter) to tropical type (mild and dry winter, warm, dry, and wet summer). The lower Sharda Basin experiences an extremely humid subtropical climate with dry winters, with temperatures reaching up to 40 °C during summers. The winter season (mid-October to mid-March), temperatures generally range between 20 °C and 30 °C, accompanied by prevailing western winds. The region receives approximately 1000 mm of annual rainfall, with nearly 90% occurring during monsoon season, which extends from mid-June to September NASA official website.²³ (Fig. 1). The climatic data was obtained through NASA official website.²³ Geologically, the riparian forest is poor in soil quality because it washed away during monsoon flooding, and the stone and boulder remain on the edge of the river.

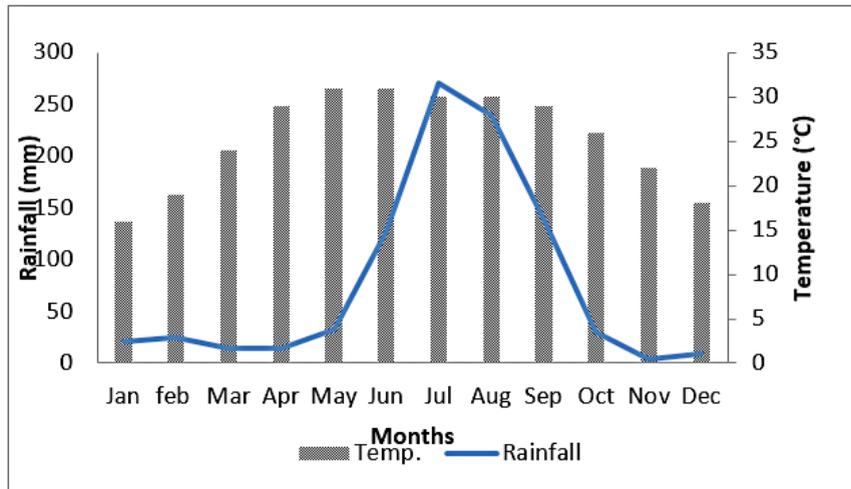


Fig. 1: Monthly variation in Temperature (0C) and Rainfall (mm)

Sampling Design

After thorough reconnaissance of the area in the riparian and adjacent terrestrial forest, 3 sites were selected in each forest for the analysis of vegetation and biomass. The study was conducted during 2023-2024 in both forests. Ten randomly placed samples of 10 × 10 m were established at each site. Tree vegetation was assessed in the 10 × 10 m quadrats following Mishra²⁴ and Saxena and Singh.²⁵ The vegetation Characteristics were analysed for density, frequency, and abundance following Curtis and McIntosh.²⁶ The distribution pattern of the species was figured out by looking at the proportion of abundance to frequency. The Abundance-frequency (A/F) ratio was figured out following Whitford.²⁷ Circumference at breast height (cbh) was taken to determine total tree basal area (TBA) and measured as πr^2 , here r is radius. Vegetation cover was taken for the determination of dominance for shrubs and herbs. The total TBA was measured by multiplying mean basal area and density of the species. The Importance Value Index (IVI) was found by adding together the relative density, relative frequency, and relative abundance.²⁸

Vegetation Analysis

Species richness (SR) has been denoted by total number of species present in each community or number of species per unit area.²⁹ Margalef's species richness index is determined following Margalef's.³⁰

$$SR = (S-1) / \log(N)$$

Here, "S" denotes total no. of species, & "N" is total no. of individuals of all species.

Species diversity was calculated following the Shannon–Wiener³¹ as

$$H = - \sum (n_i/n) \log_2 (n_i/n)$$

Here "n_i" denotes no. of individual species & "n" denotes total no. of all species in that forest.

Species evenness had measured after Pielou's³² as

$$J = H' / \log(S)$$

Here, "H" denotes Shannon Wiener diversity, & "S" denotes total no. of species in forest.

Concentration of Dominance was measured by following the Simpson³³ as

$$CD = \sum (n_i/N)^2$$

Here, "n_i" denotes no. of individuals of each species & "N" denotes total no. of all species

Biomass and Carbon Estimation

Tree biomass was measured using a non-harvesting method. All individual trees along a circumference greater than 30 cm were noted, and CBH (1.37 m above the ground) was recorded in the sampled quadrats. To estimate the biomass of various tree components

(bark, bole, leaves, branch twig, lateral root, stump root, and fine root), previously established allometric equations developed for species and interspecies ($Y=a+bX$ for *Dalbergia sissoo*; $Y=a+bY\ln X$: for inter-

species;) where, Y= dry weight of component (kg per tree), X= cbh (cm), a = the intercept and b = slope of regression $\ln =$ natural log) were used (table 1).^{34,35}

Table 1: Allometric relationship between the biomass of tree components (Y, kg tree- 1) and GBH (X, cm) for different species

Species	Component	a	B	Reference
<i>Dalbergia sissoo</i>	Bole	-11.0369	3.6005	Lodhiyal and Lodhiyal, 2003 ³⁴
	Branch	-2.2528	0.7201	
	Twig	-0.9702	0.3168	
	Leaf	-1.1037	0.36	
	Reproductive parts	-0.3088	0.1008	
	Stump roots	-2.1194	0.6914	
	lateral roots	-1.4529	0.475	
	fine roots	-0.612	0.2012	
Interspecies for Sal Forest	Bole	-5.03	2.33	Rana <i>et al</i> 1989 ³⁵
	Branch	-5.21	2.08	
	Twig	-4.63	1.68	
	Leaf	-4.96	1.68	

We figured out the carbon (C) by multiplying the biomass value of a forest component by the conversion ratio 0.475.^{36,37} We expected the C of the forest at each site to be the sum of the carbon values of all the tree parts. The data were statistically analysed for

ANOVA using MS Excel, PAST-4.0, and IBM-SPSS 16.0 version for vegetation characteristics and forest biomass between riparian and terrestrial forest. Standard error was also calculated for each studied parameter of both riparian and terrestrial forests.

Table 2: Vegetation characteristics and biomass in riparian and terrestrial forest

Parameter	Riparian Forest	Terrestrial Forest	F	p value
Tree Species richness	6	6.3+0.6	1	NS
MI	3.4+0.2	3.5+0.3	0.02	NS
E	.81+0.03	.92+0.01	34	0.004
D (ind/ha)	286.7+50.3	343.3+41.6	2.26	NS
TBA (m ² /ha)	6.3+2.71	13.9+0.6	22.53	0.01
H	2.2+0.07	2.5+0.13	12.42	0.02
Simpson Index (CD)	0.3+0.03	0.2+0.01	15.56	0.012
Biomass and Carbon stock				
Total tree biomass (Mg ha ⁻¹)	54.4+24.11	95.8+6.6	8.25	0.05
Total biomass Carbon (Mg ha ⁻¹)	23.30+13.5	45.5+3.1	7.65	0.05

(MI: Margalef’s Index; E: Evenness; D: Density; TBA: Tree Basal Area; H: Species diversity; CD: Concentration of Dominance)

Results

A total of 17 tree species were observed in both the forest sites, of which 5 tree species were restricted

to the riparian forest, while 7 species were restricted to the terrestrial forest. However, 5 tree species were common in both the riparian and the terrestrial forests.

The tree density was varied from 286.67±50.33 to 343.33±41.63 ind/ha in riparian and terrestrial forest, respectively. The TBA was 6.31±2.71 m²/ha in riparian forest, while 13.9±0.57 m²/ha in terrestrial forest, and significantly higher for (p<0.05) terrestrial forest. The species diversity ranged between 2.16±0.07 and 2.46±0.13 in riparian and terrestrial forest, respectively, and was significantly higher (p<0.05) in terrestrial forest in comparison to riparian forest. In contrast to this, Concentration of dominance is significantly higher (p<0.05) in riparian forest (Table 2).

The tree biomass varied from 54.4±24.11 to 95.8±6.6 Mg ha⁻¹ in riparian and terrestrial forest, respectively, and it was significantly higher (p<0.05) in the terrestrial forest. The carbon stock varied from 23.30±13.5 to 45.5±3.1 Mg ha⁻¹ in riparian and terrestrial forest,

respectively, and was significantly higher (p<0.05) for the terrestrial forest as compared to riparian forests (Table 2).

In the riparian forest, total biomass was 157.47 Mg ha⁻¹, in which *Dalbergia sissoo* was the most dominant biomass-producing tree species with 82.75 Mg ha⁻¹ biomass, followed by *Acacia catechu* (24.63 Mg ha⁻¹) and *Terminalia elliptica* (21.11 Mg ha⁻¹), while other species aggregately 28.98 Mg ha⁻¹ biomass. Similarly, total carbon stock of trees in riparian forest was 71.65 Mg ha⁻¹ in which *Dalbergia sissoo* constituted maximum carbon stock (36.16 Mg ha⁻¹) followed by *Acacia catechu* (11.69 Mg ha⁻¹) and *Terminalia elliptica* (10.03 Mg ha⁻¹) while other species constituted a total of 13.77 Mg ha⁻¹ carbon stock (table: 3).

Table 3: Tree Biomass and carbon stock in riparian and terrestrial forests

Study sites	Species	AGB	BGB	Total tree Biomass	AGC	BGC	Total biomass carbon stock
Riparian Forest	<i>Dalbergia sissoo</i>	65.67	17.08	82.75	27.79	8.37	36.16
	<i>Acacia catechu</i>	17.78	6.85	24.63	8.45	3.24	11.69
	<i>Terminalia elliptica</i>	15.24	5.87	21.11	7.24	2.79	10.03
	Other species	20.91	8.07	28.98	9.95	3.82	13.77
	Total	119.6	37.87	157.47	53.43	18.22	71.65
Terrestrial Forest	<i>Mallotus philippensis</i>	55.89	19.87	75.76	26.54	9.5	36.04
	<i>Schleichera oleosa</i>	54.83	20.76	75.59	26.04	10.02	36.06
	<i>Cassia fistula</i>	26.58	10.24	36.82	12.63	4.87	17.5
	Other species	71.34	27.46	98.8	39.23	15.11	54.34
	Total	208.64	78.33	286.97	104.44	39.5	143.94

(AGB: Above ground Biomass; BGB: Below ground Biomass; all values are in Mg ha⁻¹)

In the terrestrial forest, the total biomass was 286.97 Mg ha⁻¹, in which *Mallotus philippensis* was observed to be the most dominant biomass-producing tree species with 75.76 Mg ha⁻¹ biomass, followed by *Schleichera oleosa* (75.59 Mg ha⁻¹) and *Cassia fistula* (36.82 Mg ha⁻¹), while other species contain a total of 98.8 Mg ha⁻¹ biomass. Similarly, total carbon stock of trees in terrestrial forest was 143.94 Mg ha⁻¹, in which *Schleichera oleosa* constituted maximum carbon stock of 36.06 Mg ha⁻¹ followed by *Mallotus philippensis* (36.04 Mg ha⁻¹) and *Cassia fistula* (17.5 Mg ha⁻¹) while other species constituted a total of 54.34 Mg ha⁻¹ carbon stock (table: 3).

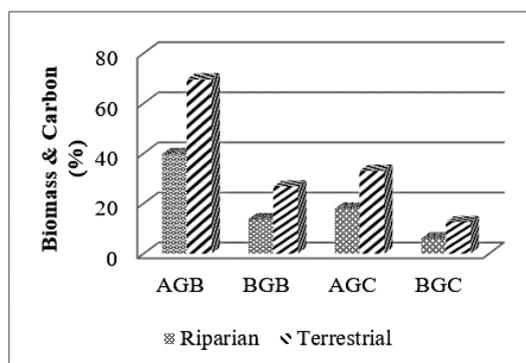


Fig. 2. Percent-wise accumulation of Biomass and carbon stock

In riparian forest, trees constitute 75.95% above-ground (AG) and 24.05% below-ground (BG) biomass, in which maximum biomass accumulation was shown by *Dalbergia sissoo* (52.55%), followed by *Acacia catechu* (15.64%) and *Terminalia elliptica* (13.41%). Similarly, in terrestrial forest, trees constitute 72.58% above-ground and 27.42% below-ground biomass, in which maximum biomass accumulation was shown by two species, *Schleichera oleosa* (26.41%) and *Mallotus philippensis* (26.41%), followed by *Cassia fistula* (12.81%) (fig: 2). A similar trend of Carbon stock was also observed in both terrestrial and riparian forests.

Discussion

The forest ecosystem can accumulate carbon in a variety of ways. Trees, bushes, herbs, forbs, roots, litter, and soil organic carbon stocks are examples of both aboveground and belowground biomass.³⁸ Approximately 80% and 40% of the total terrestrial aboveground and belowground carbon storage, respectively, is derived from forest ecosystems.³⁹ So, estimations of how much carbon is stored in forests might help with national carbon budget calculations.⁴⁰ Researchers have figured out the carbon budgets for many ecosystems, encompassing tropical, subtropical, temperate, and boreal forest ecosystems, at the local, regional, and national levels.⁴¹⁻⁴⁴ Tropical forests constitute a critical component of the terrestrial biosphere, accounting for approximately 40% of the global terrestrial biomass carbon stock.⁴⁵ Biomass production in riparian forest is shaped by multiple environmental

drivers, including climatic conditions, hydrological regimes (water availability), topographical features (e.g., slope, elevation), and the age structure of vegetation communities.⁴⁶

Comparative analysis of species richness for tree layers indicates that it was slightly higher in the terrestrial forest than in the riparian forest. In contrast to biological corridors, such as riparian forests, terrestrial zones also exhibit greater density & diversity, as shown by relatively higher Shannon index values and lower Simpson index values. The observed tree density was lower than reported by Sharma *et al.*⁴⁷ for Khair-sissoo mixed forest, Garhwal Himalaya, Iqbal *et al.*⁴⁸ for Khoh river, Garhwal Himalaya, and Aziem *et al.*⁴⁹ for Bhilangana valley, Garhwal Himalaya. The total tree basal area (TBA) was lower than that documented in previous studies in riparian forests Tripathi *et al.*⁵⁰ for Katerniaghat Wildlife Sanctuary, Iqbal *et al.*⁴⁸ for Khoh River. Species diversity was lower than reported by Aziem *et al.*⁴⁹ for Bhilangana valley, Sunil *et al.*⁵¹ for Cauvery River, South India. The higher vegetation characteristics reported in other studies are due to the large extent of vegetation area, as compared to the present study, as the area of riparian vegetation might vary from one river to another.

This may also be due to the periodic flooding and frequent anthropogenic pressure, which hinders the establishment and growth of trees, and insufficient nutrient availability may be the reason for lower vegetation characteristics in the riparian forest.

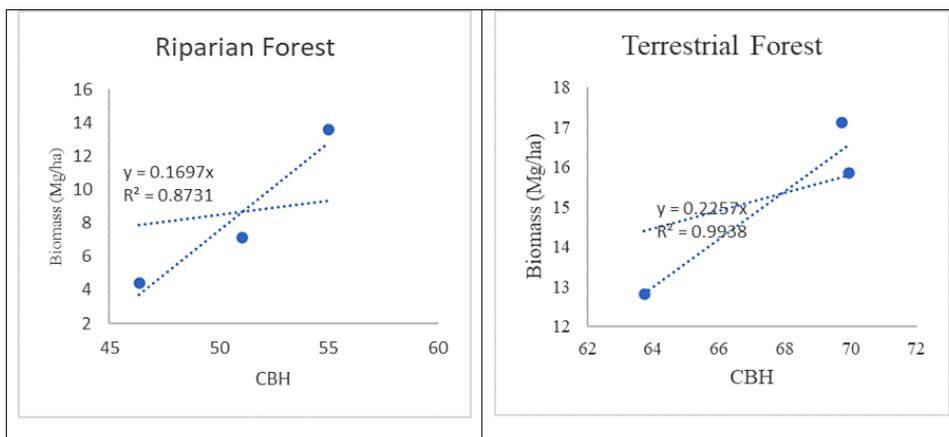


Fig. 3: Relationship between CBH, Biomass and carbon in study sites

The relationship between CBH, and Biomass in terrestrial forest depicts a strong relationship ($R^2=0.99$) while, in riparian forest biomass increases moderately with CBH ($R^2= 0.87$) (Fig: 3. A, B), this may be due to periodic disturbances and fragmented habitat, which hinders the growth of trees in riparian forests. This current investigation indicates that biomass and carbon stock in riparian forests are lower than those reported in previous studies, Rana *et al.*³⁵, Sundariyal *et al.*⁵², Ramchandran *et al.*⁵³, Lodhiyal *et al.*⁵⁴, and Shahid and Joshi⁵⁵ however, it slightly corresponds with Joshi *et al.*⁵⁵ in tropical forest ecosystems (table: 4). This disparity may be attributed to the structural characteristics of the riparian forests, which are typically characterized by more open

canopies and lower tree densities. Additionally, riparian forests are subject to periodic flooding, erosion, and sediment deposition, leading to spatial fragmentation and reduced forest continuity. These areas are also more frequently impacted by anthropogenic disturbances. In contrast, the adjacent terrestrial forests exhibited comparatively higher biomass and carbon stock, this higher biomass may be explained by the dominance of mid- to late successional species. The presence of more stable and nutrient-rich soils and reduced exposure to physical disturbances supports the high biomass and carbon stock in terrestrial forests relative to the riparian zones.

Table 4: Comparative analysis of Biomass and Carbon Stock

Forest types	Biomass (t ha ⁻¹)	Carbon stock (t ha ⁻¹)	References
Sal seedling coppice forest (Central Himalaya)	455+3.1	-	Rana <i>et al</i> 1989 ³⁴
Malay Watershed, Sikkim Himalaya	362.01+37.9	-	Sundariyal <i>et al</i> 1994 ⁵²
Deciduous and evergreen forest Central Himalaya Shisham Forest	251.7-307.3 50.3+2.46-122.7+3.14	125.8-153.7 -	Ramchandran <i>et al.</i> , 2007 ⁵³ Lodhiyal <i>et al</i> 2002 ⁵⁴
Moist deciduous forest, Doon Valley	338.4-438.2	169.7-219.1	Shahid and Joshi 2015 ⁵⁵
Community Forest, Nepal	163.07-347.06	76.64-163.12	Joshi <i>et al.</i> 2021 ⁵⁶
Tropical Riparian Forest & adjacent terrestrial mix forest, Central Himalaya	157.47-287.42	71.65-136.54	Present study

Riparian forests are particularly vulnerable due to their unique ecological conditions and the pressures from human activities like river regulation, land conversion, and unsustainable forestry practices. Effective conservation requires the integration of sustainable management approaches, legal protection, and the involvement of local communities and stakeholders.^{57,58}

Conclusion

There is a significant difference between riparian and terrestrial forests in tree diversity, biomass, and carbon stock. The terrestrial forest is conservative for all the vegetative parameters. These differences

are primarily driven by natural and anthropogenic disturbances in riparian forests, as well as site-specific environmental factors. Despite their lower biomass and carbon stocks, riparian forests remain ecologically significant, serving as vital biodiversity refugia and playing a crucial role in regional carbon dynamics. Recognizing the ecological and functional value of riparian forests is essential for effective conservation, land-use planning, and climate change mitigation. There is an urgent need to prioritize their conservation through improved management practices and the application of evidence-based, scientific interventions.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The data support the findings of this study is available from the corresponding author upon reasonable request.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Permission to Reproduce Material from other Sources

Not Applicable

Author Contributions

- **Kavita Joshi:** Conceptualization, Methodology, Writing – Original Draft, editing
- **Deepa Rana:** Data Collection, Analysis.
- **Jeet Ram:** Review, Visualization, Supervision

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