Spatial Ecology, Abundance and Threats to the Indian Pangolin (*Manis crassicaudata*) in Abbottabad District, Lesser Himalayas

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Research Article

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Abstract

This study examines the spatial distribution, abundance, and habitat associations of the endangered Indian pangolin (*Manis crassicaudata*) in Abbottabad District, Lesser Himalayas, Pakistan, from October 2024 to September 2025. A stratified random sampling design was implemented across four tehsils (Abbottabad, Havelian, Lora, and Lower Tanawal), covering approximately 110 km² of the district's total area (1,969 km²). Burrow-based surveys, combined with GPS mapping and GIS-supported spatial analyses, were conducted along elevational gradients ranging from 700 to 1,800 m. A total of 91 burrows were recorded, comprising 9 active, 55 feeding, and 27 inactive burrows. The mean burrow density was 0.83 ± 0.10 burrows km^{-2}, with higher densities observed in Lora (0.87 burrows km^{-2}) and Lower Tanawal (0.96 burrows km^{-2}). Statistical comparisons indicated moderate spatial variation across tehsils (mean ± SD = 0.16 ± 0.06 burrows km^{-2}), reflecting underlying habitat heterogeneity. Active burrows were primarily confined to low-to-moderate elevations (700–1,361 m) and were associated with scrub–pine ecotones and agricultural edges characterized by loamy soils and high termite abundance. No burrows were detected above 1,400 m, indicating a clear altitudinal limitation on species occurrence. The key threats identified included illegal hunting, habitat degradation associated with mining and road expansion, dog predation, and recurrent forest fires, particularly within *Pinus roxburghii* habitats. These findings provide the first quantitative baseline on the spatial ecology and relative abundance of *M. crassicaudata* in the western Himalayan region, with important implications for targeted conservation planning and habitat management.

1. Introduction

The Indian pangolin (*Manis crassicaudata* E. Geoffroy, 1803), commonly known as the thick-tailed pangolin, is one of four extant Asian pangolin species within the order Pholidota and family Manidae (Gray, 1821). It is a medium-sized insectivorous mammal that primarily feeds on ants and termites and exhibits specialized morphological and behavioural adaptations for this diet (Yang et al., 2007). Pangolins are nocturnal, solitary, and fossorial animals that are highly elusive and non-aggressive, making them among the least studied mammalian taxa in Asia (Lamichhane & Pokhrel, 2019; Yasmeen et al., 2021). The term "pangolin" originates from the Malay word *pengguling*, meaning "rolling ball," referring to their defensive behaviour of curling into a tight ball when threatened (Pearsall, 2002). Globally, eight extant pangolin species are recognized (Gu et al.,2023) comprising four African species (*Phataginus tricuspis*, *P. tetradactyla*, *Smutsia temminckii*, and *S. gigantea*) and four Asian species (*M. crassicaudata*, *M. pentadactyla*, *M. javanica*, and *M. culionensis*) (Hassanin et al., 2015; Gaubert et al., 2018,Gaubert & Antunes, 2005). All species are listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which prohibits international commercial trade (Bending 2015, CITES, 2019). Pangolins are often referred to as "scaly anteaters" due to their overlapping keratinised scales, which provide protection against predators, and their specialized myrmecophagous diet (Perera et al., 2017). The Indian pangolin is distributed across South Asia, ranging from Pakistan through India, Nepal, Bangladesh, and Sri Lanka (Dookia & Jakher,2004, Mohapatra et al., 2015). Within Pakistan, the species occurs in the Potohar Plateau, parts of Punjab and Sindh, and the

Himalayan foothills of Khyber Pakhtunkhwa, including Abbottabad District, where populations are increasingly threatened by habitat loss, poaching, and illegal trade.

In Pakistan, *M. crassicaudata* has been reported from localized areas across all four provinces and parts of Azad Jammu and Kashmir (Roberts, 2005; Akrim et al., 2017; Mahmood et al., 2019). The species is currently classified as Endangered on the IUCN Red List (Mahmood et al., 2019) and is protected under CITES Appendix I and national wildlife legislation (Molur, 2008). Its populations occur at low densities and are typically fragmented, largely confined to habitats that provide suitable foraging and burrowing conditions (Gaudin et al., 2006). The Indian pangolin occupies a wide range of habitats, including dry deciduous, moist, semi-evergreen, thorn forests, grasslands, and agricultural landscapes (Prater, 1980, Roberts, 1997; Zoological Survey of India, 2002; Perera et al., 2017). This ecological flexibility depends on prey availability, minimal human disturbance, and suitable soil conditions for burrowing (Perera & Karawita, 2020).The species constructs two primary types of burrows: resting burrows for shelter and reproduction, and feeding burrows used to access insect prey (Mehmood et al., 2012).

Despite its adaptability, (*M. crassicaudata)* faces increasing threats from habitat degradation, human–wildlife conflict, and illegal hunting driven by demand for meat and keratinized scales (Challender, 2011; Mahmood et al., 2012; Irshad et al., 2015; Challender et al., 2015; Heinrich et al., 2016). Pangolin meat is consumed in some regions, while scales are traded for traditional medicinal uses and other purposes (CITES, 2000). These pressures, combined with low reproductive rates and terrestrial habits, make the species highly vulnerable to overexploitation (Lim & Ng, 2007).

In Pakistan, limited field observations and the absence of long-term monitoring data indicate a decline in local populations (Irshad et al., 2015; Akrim et al., 2017). The species' secretive and nocturnal behaviour further complicates population assessments, resulting in significant gaps in knowledge regarding its distribution and abundance. Understanding spatial patterns and ecological drivers is therefore essential for developing effective conservation strategies and management interventions (Gaudin et al., 2006; Challender, 2009). Globally, reliable population estimates for *M. crassicaudata* remain scarce, particularly in South and Southeast Asia, limiting evidence-based conservation planning (IUCN, 2012, Government of Khyber Pakhtunkhwa, 2020). In Pakistan, inadequate law enforcement, weak monitoring systems, and the absence of baseline ecological data further constrain conservation efforts (Ahmad et al., 2025). The Abbottabad District, located in the Lesser Himalayas, represents a critical yet understudied portion of the species' range. Its diverse topography and vegetation mosaics provide potentially suitable habitats; however, systematic data on pangolin distribution, habitat associations, and threats are lacking.

Therefore, this study aims to investigate the spatial distribution, population status, habitat associations, and threats to *M. crassicaudata* in Abbottabad District. By addressing these knowledge gaps, the study provides essential baseline information to support targeted conservation planning, strengthen enforcement strategies, and inform long-term management of this endangered species.

2. Material and Methods

2.1. Study Area

The district Abbottabad located in the Lesser Himalayas of northern Khyber Pakhtunkhwa (KP), Pakistan, lies between 34°14'47" N, 73°11'56" E and 34°07'46" N, 73°16'56" E. It serves as the administrative headquarters of the Hazara Division and is historically known as *"the city of the maple trees"*. The district, founded in 1853 and named after Major James Abbott, is an important hill station and gateway to northern Pakistan via the Karakoram Highway. It is located approximately 125 km north of Islamabad. Covering an area of 1,969 km², Abbottabad comprises four tehsils: Abbottabad, Havelian, Lora, and Lower Tanawal. The district is confined by Mansehra to the north, Muzaffarabad (AJK) to the east, Rawalpindi to the south, and Haripur to the west. The elevations range from 600 to 2,800 m above sea level, with the city itself situated at approximately 1,260 m. The terrain is predominantly rugged and mountainous, featuring a mosaic of valleys, forests, and cultivated areas (Shahzad et al., 2020). The district has a cool temperate climate, averaging 23°C maximum and 11°C minimum annually, with about 1,366 mm of rainfall concentrated in the July–September monsoon and a subsequent two-month dry period. Winter snowfall usually occurs above 900 m, especially in areas such as Galyat, Barian, and occasionally in Abbottabad city. Seasonal changes in temperature and rainfall are seriously affected by the elevation and terrain. Ecologically, Abbottabad features a variety of forests, from subtropical scrub at lower altitudes to moist temperate forests at higher altitudes. The district hosts an estimated 1,300 plant species and at least 18 mammalian species, reflecting its position in a key transitional zone of the Western Himalayas. Despite this biological richness, only approximately 6% of the district's total area is formally protected. Communities residing near forest margins rely heavily on natural resources for timber, fuelwood, fodder, and agricultural expansion, leading to pressures such as deforestation, soil erosion, and habitat fragmentation. Agriculture remains the primary source of livelihood, while tourism and seasonal trade provide supplementary income, especially during summer (Chaudhry & Barkati, 2010).

2.2 Methodology

A stratified, spatially explicit sampling design was employed, integrating field-based ecological surveys with community-based assessments. Within each tehsil, potential sampling sites were identified based on habitat suitability, accessibility, and consultations with the Wildlife and Forest Departments, as well as local communities. A 2 × 2 km GIS grid (n = 491 cells) was overlaid across the district, and a systematic random sampling approach was applied by selecting every third grid cell (n = 165) for field evaluation. This ensured proportional representation of elevation gradients and habitat types across the study area (Perera et al., 2022). Following reconnaissance surveys and stakeholder consultations, 20 representative sites (five per tehsil) were finalized. These included Salhad, Chamhad, Dahamtore, Kakul, and Banda Pir Khan in Abbottabad; Chamnaka, Sajikot, Dewal Manal, Rajjoia, and Khayala in Havelian; Gudai, Phallah, Ghamber, Suma, and Rakhala in Lora; and Sherwan, Shaheedabad, Jharral, Tandara, and Chamitti in Lower Tanawal. Field surveys were conducted between October 2024 and September 2025.

2.3 Data Collection Framework

Field data were collected using a combination of direct observations and indirect evidence to detect *Manis crassicaudata* and assess habitat characteristics. Recorded variables included vegetation type, canopy cover, undergrowth density, soil texture, terrain features, and anthropogenic disturbance. Geographic coordinates were recorded using a Garmin eTrex 10 GPS and validated using Digital Elevation Models (DEMs). All spatial data were processed and analysed using ArcGIS Pro for habitat and spatial analyses.

Standardized transect surveys were conducted using five transects per site, each measuring approximately 3 km in length, with a variable width of 30–50 m depending on terrain, vegetation density, and ground visibility. This variable-width approach was adopted to ensure consistent detectability of indirect signs across heterogeneous landscapes. In open and relatively flat terrain, the transect width extended up to 50 m, whereas in steep, rugged, or densely vegetated areas, the effective width was reduced accordingly. Based on these dimensions, each transect covered approximately 0.09–0.15 km^2, and the cumulative survey effort represented an effective coverage of approximately 110–120 km^2 across the study area, consistent with the sampling design described in the abstract. Surveys were conducted during dawn and dusk to align with peak pangolin activity. Both direct sightings and indirect signs, including burrows, feeding marks, tracks, and scats—were recorded in accordance with standardized wildlife monitoring protocols (Perera et al., 2022). Circular plots (100 m radius; ~0.0314 km^2) were established at selected locations to measure environmental covariates, following Waseem et al. (2020) and Karawita et al. (2018). Slope and aspect were recorded using a clinometer and compass; canopy cover was estimated using a densitometer and the Gap Light Analysis Mobile App (GLAMA); and distances to roads, water sources, and settlements were measured using GPS and rangefinders. Burrows were classified as active (fresh soil, claw marks, faeces, and insect remains) or inactive (vegetation-obstructed). Feeding burrows were identified as shallow excavations, whereas resting burrows were deeper and wider (Mahmood et al., 2019). Active burrows were used as proxies for individual presence, acknowledging potential limitations due to repeated use or multiple occupancy (Mohapatra & Panda, 2014). Population density (D; individuals km^{-2}) was estimated using the equation: $D = n / A$ where n represents the number of active burrows and A is the total surveyed area. The total population was then extrapolated to suitable habitat area using: Total population = D × total habitat area (km^2). Field observations also documented threats such as poaching, illegal trade, habitat degradation, agricultural expansion, dog predation, and road mortality. These observations were supplemented with official records from the Khyber Pakhtunkhwa Wildlife Department.

2.4 Threat Assessment and Community Perception

A semi-structured questionnaire survey was conducted to assess community perceptions, threats, and awareness of the Indian pangolin (*Manis crassicaudata*) across 25 villages (five per tehsil). In each village, 15 households were randomly selected, resulting in a total sample size of 375 respondents, of which 300 valid responses were included in the final analysis. Respondents included farmers, hunters, herders, students, and shopkeepers. Data collected included demographic characteristics, perceived population trends, conservation attitudes, and threats such as poaching and habitat degradation

(Newing, 2011). To ensure accurate species identification, respondents were shown standardized photographs of pangolins (Ali et al., 2021). Interviews were conducted in Urdu and Hindko to facilitate clear communication. Conservation attitudes were categorized as positive (protective), harmful (supporting killing or trade), or neutral/uncertain (Kansky et al., 2014). Community-reported information was triangulated with Wildlife Department records on seizures and poaching incidents during the study period. Statistical analyses were performed to assess demographic and spatial variation in perceptions, and independent t-tests were used to compare environmental variables across burrow types and elevation zones. Spatial analyses, including mapping of threat hotspots and human pangolin conflict zones, were conducted using ArcGIS Pro.

3. Results

3.1 Spatial Distribution of the Indian Pangolin

Across 20 surveyed sites in Abbottabad District, a total of 91 Indian pangolin (*Manis crassicaudata*) burrows were recorded, comprising 9 active, 55 feeding, and 27 inactive burrows. Active burrows represented 9.9% of total observations and were detected across all four tehsils. Burrow occurrence was concentrated within low- to moderate-elevation zones (700–1,361 m), with no evidence of presence recorded above 1,400 m as in Fig. 1.

Table 1
Tehsil-wise distribution of burrows across the surveyed sites in Abbottabad.

Tehsil	**Survey Sites**	**Active Burrows**	**Feeding Burrows**	**Inactive Burrows**	**Total Burrows**
Abbottabad	Salhad, Chamhad, Dahamtore, Kakul, Banda Pir Khan	2	14	6	22
Havelian	Chamnaka, Sajikot, Dewal Manal, Rajjoia, Khayala	1	13	5	19
Lora	Gudai, Phallah, Ghamber, Suma, Rakhala	3	15	8	26
Lower Tanawal	Sherwan, Shaheedabad, Jharral, Tandara, Chammatti	3	13	8	24
Total	**20 sites**	**9**	**55**	**27**	**91**

Tehsil-wise variation in burrow abundance is presented in Table 1, with the highest counts in Lora (n = 26) and Lower Tanawal (n = 24), followed by Abbottabad (n = 22) and Havelian District (n = 19). Active burrows were primarily located within scrub–subtropical pine ecotones, while higher elevation zones dominated by *Pinus roxburghii* and *Quercus incana* showed no recent signs of pangolin presence.

3.2. Abundance and Activity Status of Burrows

Burrow density varied across tehsils (Table 2), with the highest density recorded in **Lower Tanawal (0.96 burrows km^{-2})**, followed by **Lora (0.87 burrows km^{-2})**, **Havelian (0.76 burrows km^{-2})**, and **Abbottabad (0.73 burrows km^{-2})**. Morphometric analysis of **nine active burrows** indicated consistent structural characteristics across sites. Burrow entrance ranged from **9.32 to 9.40 in**, and height from **9.01 to 9.08 in**, with Table 2.

Table 2
Significant ecological differences between resting and feeding burrows.

Tehsil	Survey Area (km²)	Active Burrows (n)	Feeding Burrows (n)	Inactive Burrows (n)	Total Burrows (n)	Density (burrows/km²)
Abbottabad	30.0	2	14	6	22	0.73
Havelian	25.0	1	13	5	19	0.76
Lora	30.0	3	15	8	26	0.87
Lower Tanawal	25.0	3	13	8	24	0.96
Total / Mean ± SD	**110.0**	**9**	**55**	**27**	**91**	**0.83 ± 0.10**

Within Abbottabad District, a total of nine active (living) burrows of the Indian pangolin were recorded across four tehsils, including Abbottabad, Havelian, Lora, and Lower Tanawal (Table 3). The distribution of active burrows was relatively balanced among tehsils, with slightly higher occurrences in Lora and Lower Tanawal (n = 3 each). Morphometric measurements of burrow entrances showed minimal variation across sites, with mean width and height recorded as 9.36 ± 0.05 inches and 9.04 ± 0.07 inches, respectively. Burrow depth exhibited moderate variation, with an overall mean of 48.62 ± 2.97 inches, indicating relatively consistent burrow structure across the district. These findings suggest uniformity in burrow architecture, likely reflecting similar soil conditions and habitat characteristics across the study area.

3.3 Temporal Patterns of Activity

Field observations indicated that pangolin activity was exclusively nocturnal. Two direct sightings were recorded at 19:15 h and 19:45 h during winter surveys in Gudai (Lora) and Chammatti (Lower Tanawal), respectively. No daytime activity was observed. Seasonal observations indicated relatively higher activity during winter, with reduced evidence of fresh burrow excavation during summer months. No statistically significant relationship between temperature and activity patterns was detected as shown in Fig. 2.

Table 3
Distribution and Measurements of Active Pangolin Burrows in the District Abbottabad

Tehsil	Active (Living) Burrows (n)	Mean Width (in)	Mean Height (in)	Mean Depth (in)
Abbottabad	2	9.32 ± 0.04	9.01 ± 0.06	47.30 ± 2.65
Havelian	1	9.40 ± 0.06	9.08 ± 0.08	49.10 ± 2.90
Lora	3	9.38 ± 0.07	9.05 ± 0.07	49.85 ± 3.10
Lower Tanawal	3	9.35 ± 0.05	9.02 ± 0.05	48.25 ± 2.60
Total / Mean ± SD	**9**	**9.36 ± 0.05**	**9.04 ± 0.07**	**48.62 ± 2.97**

3.4. Habitat Characteristics and Environmental Associations

Active burrows were predominantly recorded within low- to moderate-elevation habitats (700–1,361 m) associated with scrub–agriculture–forest ecotones. These habitats were characterized by moderate canopy cover (45–70%), dense undergrowth (50–85%), and loamy to clay soil textures. Vegetation composition was dominated by *inus roxburghii* (> 80%), along with *Eucalyptus camaldulensis*, *Quercus incana*, *Acacia modesta*, *Pistacia integerrima*, *Platanus orientalis*, and *Juglans regia*. The shrub layer included *Dodonaea viscosa*, *Justicia adhatoda*, *Berberis lyceum*, *Viburnum cotinifolium*, *Carissa spinarum*, *Ziziphus nummularia*, *Lantana camara*, and *Calotropis procera*. Burrows were most frequently observed on gentle slopes (< 20°) and in areas proximal to cropland and termite-rich substrates, whereas steep, rocky, and high-altitude sites showed no burrow presence. A comparative analysis of 82 burrows (27 resting and 55 feeding) revealed differences in environmental and structural attributes (Table 4). Resting burrows occurred at a relatively higher mean elevations (1,042.7 ± 152.6 m) and were associated with denser canopy (38.4 ± 10.7%) and understory cover (42.7 ± 12.5%). Feeding burrows were more frequently located at lower elevations (975.4 ± 128.3 m) and closer to cropland areas. Resting burrows exhibited greater dimensions, with mean depths exceeding 120 cm, and were commonly associated with boulders and north- to east-facing slopes. Table 04.

Table 04
Environmental and structural characteristics of resting and feeding burrows .

Habitat / Burrow Characteristic	Resting Burrows (n = 27)	Feeding Burrows (n = 55)	t-value	p-value
Elevation (m)	1,042.7 ± 152.6	975.4 ± 128.3	2.11	0.038 *
Slope (°)	24.8 ± 6.5	21.6 ± 5.9	1.92	0.059
Canopy Cover (%)	38.4 ± 10.7	29.2 ± 9.4	3.34	0.001 **
Undergrowth Density (%)	42.7 ± 12.5	34.9 ± 10.8	2.82	0.006 **
Distance to Water (m)	146.3 ± 38.5	173.9 ± 44.6	2.63	0.010 *
Distance to Settlement (m)	312.6 ± 81.4	285.5 ± 76.2	1.34	0.186
Burrow Opening Width (cm)	24.3 ± 3.5	21.7 ± 2.8	3.01	0.004 **
Burrow Opening Height (cm)	23.9 ± 2.9	21.4 ± 3.1	3.20	0.002 **
Burrow Depth (cm)	126.5 ± 22.3	103.7 ± 18.4	4.12	< 0.001 ***
Presence Near Boulders (%)	62.9 ± 7.2	47.1 ± 6.8	3.78	< 0.001 ***
Aspect (N & E facing, %)	74.0 ± 10.3	68.5 ± 9.5	1.92	0.058

3.5 Threats and Anthropogenic Pressures

Field surveys and community-based observations identified five primary threats to *M. crassicaudata*:

(i) poaching and illegal trade,
(ii) habitat loss due to deforestation,
(iii) agricultural expansion,
(iv) domestic dog predation, and
(v) road mortality.
The frequency of these threats varied across tehsils, with Lora and Havelian reporting higher incidences of hunting and dog predation. Spatial mapping indicated an overlap between poaching occurrences and areas of higher burrow density.

3.6 Community Perception

Among the 300 valid respondents across 25 villages, 63% reported sightings or indirect signs of pangolins within the past three years. Species recognition accuracy was high when standardized photographs were presented. Perceived population trends indicated a decline in 72% of responses, while awareness of legal protection remained low (27%). Spatial correspondence was observed between community-reported sightings and field-verified burrow locations.

4. Discussion

This study provides the first comprehensive assessment of the spatial ecology, habitat associations, and anthropogenic pressures affecting the endangered Indian pangolin (*Manis crassicaudata*) in Abbottabad District, within the Western Himalayas. By integrating systematic field surveys with spatial and ecological analyses, the study addresses critical knowledge gaps in a region where baseline data on pangolin distribution and abundance have remained limited. The observed restriction of pangolin activity to low- and moderate-elevation zones (700–1,361 m), with no burrow records above 1,400 m, indicates a distinct altitudinal preference. This pattern is consistent with previous studies from the Himalayan foothills and subtropical regions of Pakistan (Mahmood et al., 2019; Akrim et al., 2017). The absence of burrows at higher elevations likely reflects environmental constraints, including reduced prey availability, lower temperatures, and unsuitable soil conditions for burrowing in areas dominated by *Pinus roxburghii* and *Quercus incana* (Perera, 2017). Comparable elevational limitations have been reported in Sri Lanka and northern India, where populations are concentrated in mixed scrub and agricultural–forest ecotones (Perera, 2017; Mahmood et al., 2021). Habitat associations observed in this study further emphasize the species' reliance on heterogeneous landscapes. Higher burrow densities in Lora and Lower Tanawal correspond to areas characterized by moderate canopy cover, dense understory vegetation, and termite-rich soils. The predominance of feeding burrows indicates active foraging within ecotonal habitats, supporting previous findings that prey availability is a key determinant of habitat selection (Karawita et al., 2018; Mahmood et al., 2021). The clear differentiation between resting and feeding burrows, reflected in variations in elevation, vegetation structure, and soil characteristics, indicates functional habitat partitioning. Resting burrows were associated with denser vegetation and more stable microhabitats, whereas feeding burrows occurred in relatively open areas with higher prey accessibility. Similar spatial and behavioural separation has been documented in Sri Lanka and Bangladesh (Perera, 2017; Yasmeen et al., 2021), suggesting consistent ecological strategies across the species' range.

Vegetation composition further highlights the importance of structurally diverse habitats. The dominance of *Pinus roxburghii*, *Acacia modesta*, and *Quercus incana*, along with shrub species such as *Dodonaea viscosa* and *Berberis lyceum*, indicates that pangolins preferentially occupy transitional vegetation zones that provide both shelter and foraging opportunities. This aligns with previous ecological studies from the Pothohar Plateau and Azad Jammu & Kashmir (Akrim et al., 2017; Mahmood et al., 2019). The relatively low proportion of active burrows (9.9%) and their dispersed distribution across tehsils suggest reduced population density and possible fragmentation. This observation is consistent with regional assessments reporting declining pangolin populations under increasing anthropogenic pressures (Mahmood et al., 2021). The consistent morphometric characteristics of burrows across sites indicate species-specific construction patterns, reflecting behavioural stability despite environmental variation. The exclusively nocturnal activity observed in this study is consistent with established pangolin behaviour (Challender et al., 2014). The limited number of direct sightings highlights the challenges associated with detecting this cryptic species and reinforces the importance of indirect survey methods. Seasonal variation in activity, with relatively higher observations during winter, may reflect changes in detectability or foraging behaviour; however, further long-term monitoring is required to confirm these trends.

Poaching and illegal trade were identified as the primary threats, followed by habitat degradation, agricultural expansion, and domestic dog predation. These findings are consistent with broader regional and global assessments (Challender et al., 2014; Mahmood et al., 2019). The spatial overlap between burrow distribution and human-dominated landscapes indicates an increasing interface between pangolin habitats and rural communities, which elevates the risk of exploitation. Similar patterns linking accessibility, human presence, and wildlife trade have been reported across South Asia (Perera, 2017; Mahmood et al., 2021). The integration of field observations with Wildlife Department records strengthens the reliability of these findings and suggests that exploitation pressures persist despite existing legal protection under the Khyber Pakhtunkhwa Wildlife and Biodiversity Act (2015).

Overall, this study establishes a critical ecological baseline for *M. crassicaudata* in the Lesser Himalayas. The species' restricted elevational range, dependence on ecotonal habitats, and exposure to localized anthropogenic pressures underscore the urgency of targeted conservation interventions. Strengthening habitat protection, improving enforcement against illegal trade, and enhancing community awareness in high-risk areas are essential for mitigating population decline. Long-term monitoring and genetic studies are recommended to assess population connectivity and support adaptive conservation planning.

5. Conclusion

This study presents the first comprehensive, district-level assessment of the spatial ecology, habitat associations, and burrow characteristics of the endangered Indian pangolin (*Manis crassicaudata*) in Abbottabad District, within Pakistan's Hazara Region. The findings demonstrate clear spatial structuring of habitat use, with higher burrow densities concentrated in low- to moderate-elevation zones characterized by heterogeneous vegetation and ecotonal landscapes. The observed ecological differentiation between resting and feeding burrows reflects functional habitat partitioning, indicating behavioural adaptations related to shelter, thermoregulation, and foraging efficiency. Significant associations between burrow occurrence and environmental variables, including vegetation structure, elevation, soil characteristics, and proximity to croplands and termite-rich areas, highlight the species' dependence on structurally diverse habitats that provide both refuge and food resources. The low proportion of active burrows and their fragmented distribution suggest potential population decline and localized pressures. Identified threats, particularly illegal hunting, habitat degradation, agricultural expansion, and human–wildlife interactions, further emphasize the vulnerability of the species in the region. These findings establish a critical ecological baseline for *M. crassicaudata* and provide a foundation for evidence-based conservation planning. Priority actions should include habitat protection and restoration, strengthening enforcement against illegal trade, and promoting community-based conservation initiatives. Integrating pangolin conservation into provincial wildlife management frameworks, alongside sustained monitoring and awareness programs, will be essential to ensure the long-term persistence of this species in the Lesser Himalayan landscape.

Declarations

Ethical Statement

This study was conducted in accordance with the Declaration of Helsinki and standard ethical guidelines for human-participant and non-invasive wildlife research. It involved questionnaire-based community interviews and non-invasive field surveys, with no handling or disturbance of animals. Informed consent was obtained from all participants, and anonymity and confidentiality were ensured. Fieldwork permission was granted by the concerned District Wildlife Department, Khyber Pakhtunkhwa Pakistan. Formal ethics approval was not required for this study in accordance with the institutional guidelines of Universiti Sains Malaysia (USM).

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

M. Saad: Conceptualization, Methodology, Data collection, Validation, Writing original draft, Funding acquisition. Visualization, Resources, Data curation: Shahrul: Supervision, Methodology, Writing review & editing, Proofreading.

Availability of data and materials

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

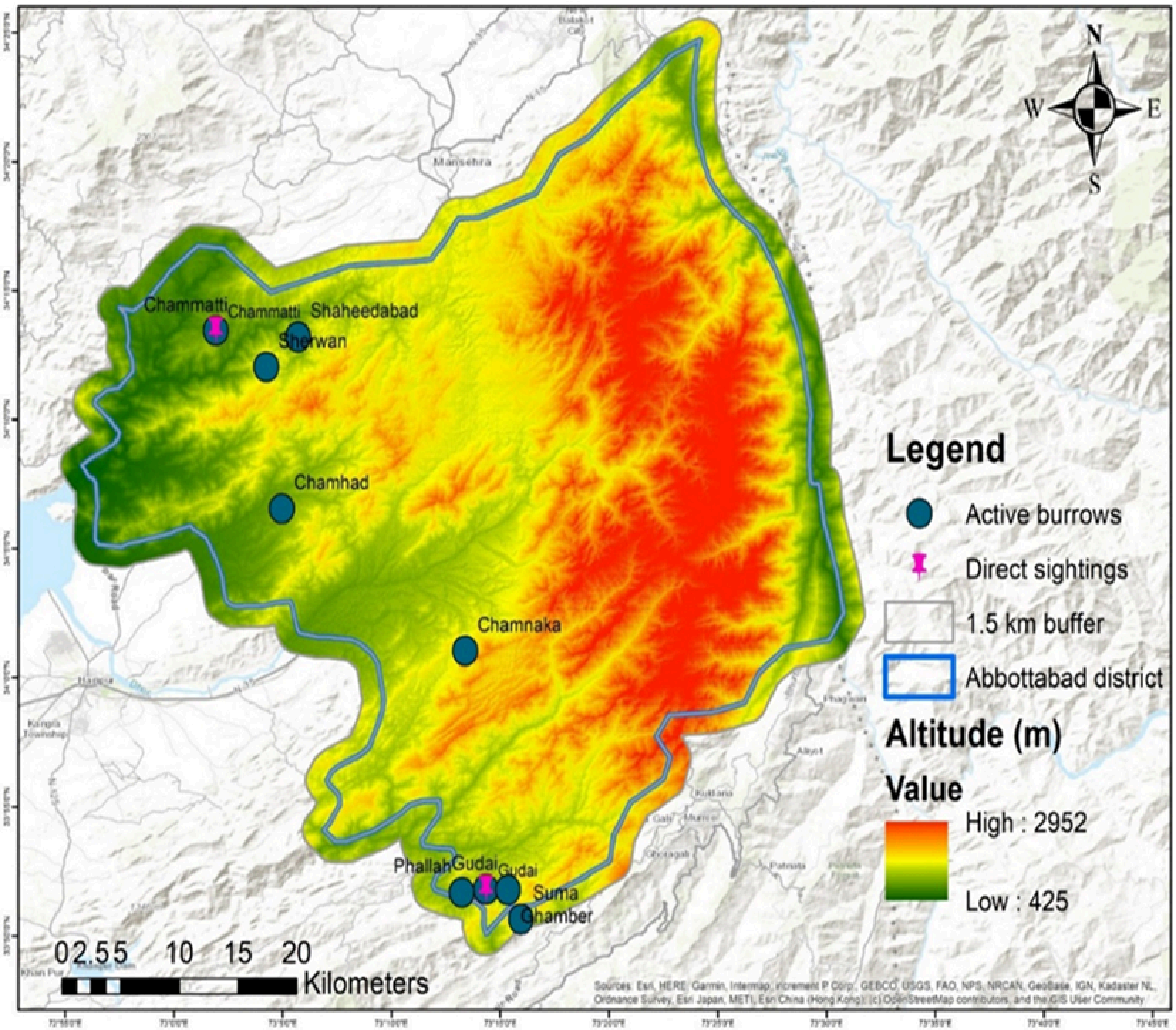

Figure 1

Distribution of Potential Sites, Direct Sightings and Active Burrows in the Study area.

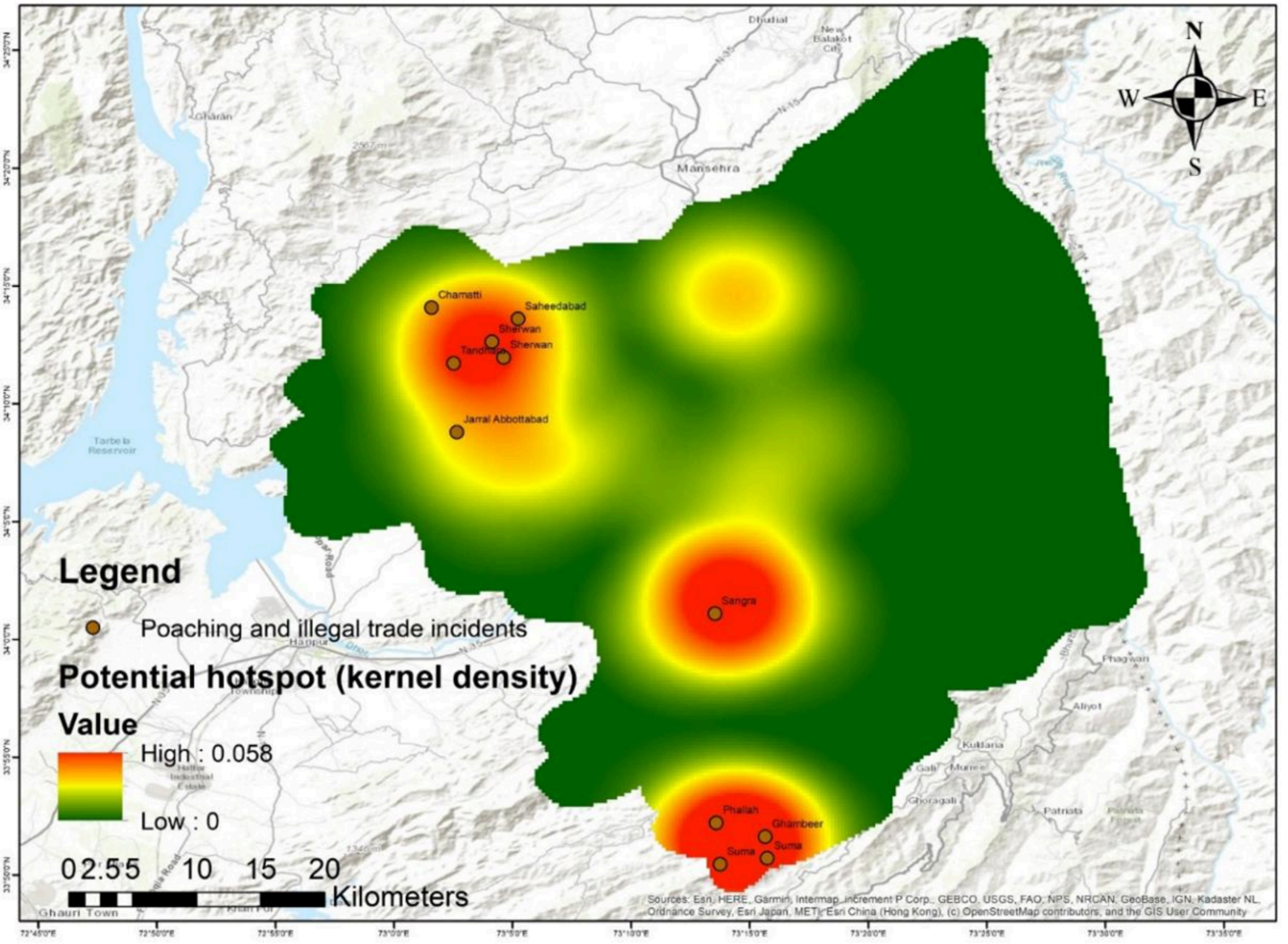

Figure 2

Spatial Distribution of Potential Hot spots of Pangolin in the Study Area.

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