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DISCOVERY SCIENTIFIC SOCIETY

Spatio-Temporal Patterns of Human–Leopard Conflict at the Urban–Forest Interface of Jaipur, India

Aishwarya Mahajan[1], Joy Gardner[2], Nikhil Sharma[3], Saurabh Kumar Gupta[4], Suraj Kumar Singh[5]*

ABSTRACT

Human and leopard conflicts are being reported more and more in the growing urban areas of India, but there are still relatively few studies that use spatial data to identify conflict hotspots which could then be used to direct management efforts. This study uses an exploratory, descriptive GIS-based hotspot analysis of human-leopard conflict in Jaipur city and its surroundings based on 81 conflict incident records during 2018–2025. Conflict records were obtained from the Rajasthan Forest Department, Jaipur Zoo and verified media reports and were analysed in QGIS and ArcGIS for annual trend, seasonal pattern, diurnal distribution, land-use / land cover (LULC) association and spatial clustering. The dataset is small (n = 81 over 8 years) and should be treated as a descriptive baseline of reported incidents rather than a complete count of human-leopard interactions. Reported incidents are subject to reporting bias since urban incidents are more likely to be reported than rural ones. There is also geolocation uncertainty when village or locality centroids were used instead of exact locations. With these caveats in mind, the analysis yielded the following descriptive findings. The annual mean was 10.13 ± 5.38 incidents with no significant monotonic trend (Kendall's $\tau = -0.265$, $p = 0.373$). The majority of the conflicts were urban in nature (47 cases, 58.0%), then came rescue operations (21, 25.9%), followed by livestock depredation (5, 6.2%), human injury (4, 4.9%) and road mortality (4, 4.9%); the distribution of conflict types was significantly different from what would be expected by chance ($\chi^2 = 86.10$, $df = 4$, $p < 0.001$). There was a significant concentration of conflicts in the winter season (37.0%) and in the post-monsoon season (32.1%) ($\chi^2 = 13.47$, $df = 3$, $p = 0.004$), as well as during the evening and early-night hours (41.6% of conflicts occurring between 18:00 and 23:59 h; two-sample Kolmogorov-Smirnov test comparing day and night: $D = 0.653$, $p < 0.001$). The locations of the conflicts were much more concentrated in built-up and urban areas (79.2% of the incidents compared with 62.3% of the mapped area; $p = 0.3730$, $p = 0.3731$, $p = 0.3732$; observed-to-expected ratio = 1.27), although this could partly be due to a higher probability of reporting in urban areas rather than indicating a real ecological preference for such areas. Kernel Density Estimation (KDE) indicated that the top 10% of density values accounted for 11.21 km² and included 59.0% of the incidents, and the Average Nearest Neighbour analysis confirmed that there was

significant clustering (NNI = 0.615, z = −6.41, p = 0.3733); however, these spatial statistics must be interpreted in view of the geolocation uncertainty and reporting bias noted above. There were only a small number of cases of human injuries (p = 0.3734) and leopard deaths on the roads (p = 0.3735), which meant that a formal trend analysis of the severity of conflicts was not necessary. Although the number of injury incidents after 2022 was more apparent, they still do not indicate a statistically significant increase in severity. The results as a whole suggest that a focused, landscape-wide strategy for achieving human-leopard coexistence should be adopted, this strategy including hotspot-based monitoring, outreach campaigns customised to season and time, rapid-response measures, and actions to reduce road mortality. In future studies it would be necessary to use larger datasets based on probability, independent data on leopard abundance, carry out a bandwidth-sensitivity analysis, and validate the findings against known leopard movement corridors in order to strengthen the conclusions.

Keywords: Human–leopard conflict; hotspot mapping; kernel density estimation; urban–forest interface; Jaipur; Jhalana Leopard Reserve; GIS; seasonal pattern; diurnal activity; wildlife–vehicle collision; reporting bias; exploratory spatial analysis.

1. INTRODUCTION

Large carnivores are keystone species of many ecosystems: they regulate herbivore abundance and feeding behavior, preventing overgrazing and promoting floral biomass accumulation and diversity (del Rio et al., 2001). Moreover, the biomass of large carnivores also provides an important resource for scavengers and helps recycle nutrients within ecosystems (Ripple et al., 2014). Large carnivores are threatened by several human activities, including habitat loss, poaching, loss of prey, and increased human encounters. Hunting for meat, trophies, or the killing of problem animals poses a major direct threat to large carnivores, even in protected areas (Ordiz et al., 2021). Changing habitats to use them for agriculture, for human settlements, and for the associated infrastructure such as roads, railways, and power lines can have a serious impact on large carnivores by fragmenting and degrading their habitats, in particular those of wide-ranging species (Ordiz et al., 2021; Almasieh et al., 2025). Furthermore, changes in land use can cause alterations in the spatial distribution and behaviour of carnivores as they respond to the altered landscape, with adverse effects on their ecological functions (Suraci et al., 2019; Almasieh et al., 2025). The overhunting and competition with livestock for wild herbivores have contributed substantially to prey depletion, an often-overlooked threat to large carnivores (Wolf & Ripple, 2016; Karanth & Chellam, 2009).

In India protected forests are generally small and lie adjacent to villages, farms and linear infrastructure; large carnivores (mainly leopards and tigers) tend to use the edges of these forests where people live and keep livestock (Athreya et al., 2013; Naha et al., 2021). Leopards are present in about 70% of all of India, and due to their abundance and proximity to humans, they are the wildlife species most prone to conflict (Naha et al., 2020). Conflict with leopards, bears, and tigers is not uncommon anywhere across the country; it takes several forms, with livestock predation among the most common (Naha et al., 2020; Ramesh et al., 2020). It is common for communities to poison, shoot, snare or electrocute leopards, wolves, bears and large cats, leading to a high level of direct death among large felids in ecosystems where humans are present (Naha et al., 2020; Ramesh et al., 2020; Bharti et al., 2025). When the areas where conflicts occur are identified, measures such as fencing, changes in grazing methods, the removal of attractive vegetation from farms and better protection of livestock can be implemented more effectively (Pant et al., 2023; Karanth et al., 2012). Analysis of conflict hotspots can help adapt strategies to reduce human-carnivore conflict in populated regions by pinpointing sensitive areas and directing responses where leopards are found (Miller, 2015; Naha et al., 2020).

Although human-leopard conflict is common, there has been no spatial analysis to pinpoint conflict hotspots to better comprehend the distribution of such incidents and guide local conflict-mitigation measures in the Jaipur landscape. Jaipur is an up-and-coming city in the semi-arid state of Rajasthan, which possesses several protected forests, including Nahargarh Wildlife Sanctuary (NWLS), Jhalana Leopard Reserve (JLR), and Amagarh Leopard Reserve (ALR), which are surrounded by or integrated into the metropolis. This produces a unique urban-wilderness matrix in which leopards' ranges, livestock grazing, traffic, and human activities intersect, necessitating an assessment of the spatio-temporal patterns of human-leopard conflict to develop context-specific adaptation measures for coexistence.

The main objectives of this study were (i) to collate and cross-verify human-leopard conflict incident records that have occurred in and around the Jaipur region between 2018 and 2025; (ii) to assess trends in the time series in terms of years, seasons, and time; (iii) to examine the relationship between the number of incidents and land-use / land-cover (LULC) types; (iv) to find spatial clusters of conflict incidents (hotspots) using kernel density estimation (KDE) and to analyze their average nearest neighbor (ANN) to understand

significant spatial clustering patterns; and (v) to discuss the results in the context of the coexistence of humans and leopards. This study must be considered a preliminary descriptive assessment because the number of incidents recorded is relatively low (n = 81 incidents over eight years). The data used in this study are based on reported incidents, which may not reflect all cases, with a potentially low number of incidents affecting the reliability of the results. Additionally, it is a multi-source analysis combining several databases, making it difficult to identify patterns that may exist within each dataset. Thus, the article will report the study's descriptive results and limitations and suggest future work, including a more extensive probability-based incident database, leopard abundance survey, bandwidth sensitivity analysis, and testing against leopard's movement corridors, that can improve ecological knowledge and inform management interventions.

2. STUDY AREA

The study area (Figure 1) is located in Jaipur District of Rajasthan, India, includes Jaipur city and 54 surrounding municipal areas, and extends within the coordinates of 26.76°-27.08°N and 75.68°-76.00°E. The study area consists of the protected forests of Nahargarh Wildlife Sanctuary (NWLS), Jhalana Leopard Reserve (JLR) and Amagarh Leopard Reserve (ALR), which are connected to Jamwaramgarh Wildlife Sanctuary in the north-east. These forests are part of the north-eastern range of the Aravalli Mountain range, which roughly divides the study area into two halves. The urban Jaipur is located on the western side of these hills, whereas the east side accommodates sub-urban and rural settlements. The forests in Jaipur are penetrated by villages and thick human settlements in the buffer/fringe areas. Jaipur's climate is semi-arid with long summers, low precipitation and mild winters with temperatures ranging from approximately 5 degrees Celsius in January to 47 degrees Celsius in June. The annual rainfall is 600-650 mm with the majority falling during the south-west monsoon season (July to September). The proximity of three protected leopard habitats to a quickly growing urban matrix makes the study area an interesting case for the investigation on human-leopard conflict at urban-forest interface in semi-arid western India.

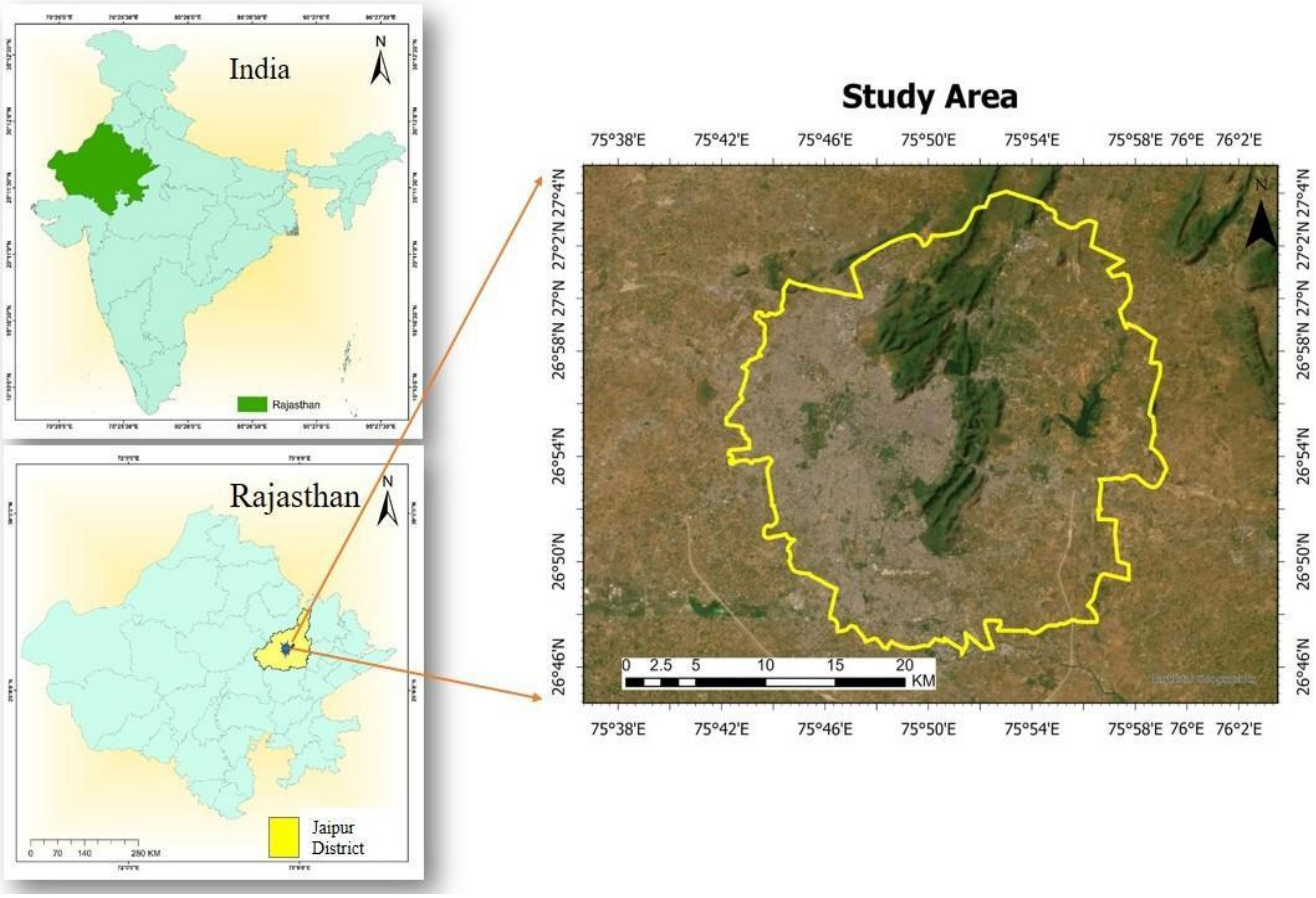


Figure 1. Map of the study area in Jaipur District, Rajasthan, India.

Jaipur is a clear example of an urban–forest interface because urban development expands directly alongside the scattered forest regions of the Aravalli hill range. The Jhalana Reserve Forest is located in the urban section of Jaipur. Its western and southern boundaries border the densely populated areas of Jawahar Nagar, Malviya Nagar and Jagatpura. The villages and recently developing settlements lie to its east and north. The Jhalana forest extends over an area of about 29 km². The Amagarh forest block, which is situated to the east of Jaipur, is likewise a significant leopard habitat in the urban–forest interface and has an area of approximately 15.24 km² (Rajasthan Environment, 2023). The area covered by the Nahargarh Wildlife Sanctuary is about 52.4 km² and is also a vast wooded region situated next to the northern urban boundary of Jaipur (Rajasthan Forest Department, 2020; Kumbhojkar et al., 2024). The forests surrounding Jaipur mostly consist of tropical dry deciduous and tropical thorn vegetation linked to the Aravalli hills. The Nahargarh Wildlife Sanctuary has dry deciduous and thorn forest ecosystems with species like Boswellia serrata, Anogeissus pendula, Butea monosperma, and Acacia spp. Jhalana is a semi-arid tropical dry deciduous forest with Acacia tortilis, Acacia senegal, and other native plants. This environment hosts various mammals, including the nilgai (Boselaphus tragocamelus), chital (Axis axis), sambar (Rusa unicolor), wild boar (Sus scrofa), hare, and gray langur. In the urban forest area of Jhalana, domestic animals—especially dogs, goats, cats and cattle—also make up a significant part of the leopard's diet (Kumbhojkar et al., 2020; Kumbhojkar et al., 2024).

3. METHODOLOGY

3.1. Data Sources and Reporting Bias

The leopard conflict records for 2018 to 2025 were obtained from Rajasthan Forest Department, Jaipur Zoo and other sources such as urban sightings, rescue operations, livestock predation, human injury, and leopard road mortality. In addition to the Rajasthan Forest Department and Jaipur Zoo sources, media reports of leopard sightings, attacks, and rescues were also used to supplement the leopard conflict records. The media sources were looked up using keywords such as "leopard sighting Jaipur", "leopard attack Jaipur", and "leopard rescue Jaipur". The media reports were used to evaluate and compare the information to the leopard conflict records of Rajasthan Forest Department, Jaipur Zoo and other sources. The media information gathered was merged with the Rajasthan Forest Department and Jaipur Zoo records to form the leopard conflict dataset with date, conflict type, location and outcome. In case of conflicting reports of the same leopard conflict incident, the Rajasthan Forest Department, Jaipur Zoo or official sources of information were prioritized since they were deemed to be more reliable. Each conflict record is thus reported once.

The dataset on leopards is made up of official data acquired from the Rajasthan Forest Department, the Jaipur Zoo, and media accounts of leopard sightings, attacks, and rescues. Since the method used to collect the data relies on these sources, it may have potential reporting biases. The leopard sightings, attacks, and rescues that take place in more populated regions have a higher likelihood of being reported by the general public and covered by the news media as compared to similar incidents that occur in sparsely populated regions. The leopard conflict dataset therefore contains a higher number of entries for urban regions compared to rural ones due to the differences in reporting rates and accessibility of Rajasthan Forest Department and Jaipur Zoo. The leopard conflict dataset does not contain an independent measurement of the differential reporting rates for urban and rural regions as a potential confounding variable. Section 5.6 discusses this limitation in detail.

3.2. Coordinate Accuracy and Geolocation Protocol

The leopard conflict dataset includes GPS coordinates for each leopard conflict incident reported and assigned according to the following Geolocation Protocol:

1. When the leopard conflict incident report included GPS coordinates (Rajasthan Forest Department rescue records, Jaipur Zoo intake records, road mortality reports), the recorded coordinates were used (Accuracy: +/-10-50 meters).
2. When the leopard conflict incident report did not include GPS coordinates, but instead specified a particular locality, road junction or village, the coordinates were estimated using GPS coordinates recorded in Google Earth Pro for the specified location (Accuracy: +/-100-500 meters depending on the size of the specified location).
3. When the leopard conflict incident report only specified a village or locality, the coordinates for the centroid of that village or locality were used (Accuracy: +/-500-2000 meters depending on the size of the specified location).

The inaccuracy of the geolocation method impacts the accuracy of the Kernel Density Estimate (KDE) and Average Nearest Neighbor (ANN) analyses: KDE bandwidth selection and hotspot boundary identification are affected by the choice of the point location within a multi-point centroid category, and ANN clustering statistics can be artificially inflated when multiple points share the same centroid. The KDE and ANN values cited in this study represent the entire leopard conflict dataset, including entries that were

assigned to a centroid category. A sensitivity analysis that excludes entries with estimated coordinates (categories 2 and 3) is recommended for the follow-up research as it would indicate how much the KDE and ANN values change for the subset of leopard conflict incidents with precise coordinates.

3.3. Sample-Size Justification and Study Framing

This study uses the data from leopard conflicts from Rajasthan Forest Department, Jaipur Zoo, and the media reports, as an exploratory and descriptive analysis of human-leopard conflict in the area, for the timeframe of 2018-2025. The dataset of leopard conflict contains eight years of data with an average of 10.13 +/-5.38 conflicts per year, constrained by the number of human-leopard conflict incidents reported by Rajasthan Forest Department, Jaipur Zoo, and the media in the area. A probability sampling framework was not used in this study as it would require a sampling frame with all the potential incidents of human-leopard conflict in Jaipur, which would be extremely resource intensive. This study does not assume that the dataset of leopard conflict is a sample from a more substantial population of potential incidents of human-leopard conflict, but uses the dataset as a descriptive basis for the analysis. A formal power analysis was not performed as this was a descriptive rather than inferential study. The effect sizes were not defined before performing the analysis as this was a descriptive rather than inferential study. The chi-square goodness-of-fit tests described in section 3.6 are descriptive rather than inferential. There are several categories with very small or zero expected values (livestock predation n = 5; human injury n = 4; road mortality n = 4), and the chi-square goodness-of-fit test on the types of conflict is dominated by the urban sightings category (n = 47), so that the results should be treated as descriptive rather than inferential. A substantially larger dataset that could be achieved with an extensive probability sample of incidents of human-leopard conflict reported by Rajasthan Forest Department and Jaipur Zoo is recommended for future work.

3.4. Spatial and Temporal Analysis

Spatial analyses were performed using QGIS and ArcGIS. The leopard conflict records were integrated with forest boundaries, LULC, roads, water bodies, settlements and administrative boundaries in a common projected coordinate reference system (UTM Zone 43N / WGS-84). Annual and seasonal summaries were prepared for 2018–2025. The leopard conflict records were categorized into four seasons: summer (March – June), monsoon (July – September), post-monsoon (October – November) and winter (December – February). For annual trends, Kendall's rank correlation analysis was applied, whereas for seasonal trends, a chi-square goodness-of-fit test was used to test whether incidents were uniformly distributed across seasons. Time-of-day trends were analyzed in 3-hour and 6-hour intervals. Two-sample Kolmogorov-Smirnov tests were used to assess differences between day-night and morning-evening distributions.

3.5. Spatial Clustering and Hotspot Mapping

The spatial clustering of leopard conflict records was evaluated using Average Nearest Neighbor (ANN) analysis as implemented in ArcGIS Spatial Statistics toolbox. Nearest Neighbor Index (NNI), z-score and p-value statistics were calculated using the study-area boundary polygon provided by Rajasthan Forest Department. NNI scores less than 1 indicate clustering; low NNI values indicate strong clustering; NNI scores greater than 1 indicate dispersion; high NNI values indicate strong dispersion; z-scores with absolute value above 2.58 are statistically significant at $p < 0.01$. ANN analysis assumes that the input points are unbiased sample of the underlying spatial processes, which might not be the case due to the factors discussed in Sections 3.1 – 3.2; thus the NNI statistics should be considered as descriptive evidence of clustering in the recorded leopard conflict dataset rather than unbiased assessment of clustering in general leopard conflict environment.

Kernel Density Estimation (KDE) was used to identify hotspots in the recorded leopard-conflict locations. The KDE bandwidth used the ArcGIS default based on the mean nearest-neighbour distance. The KDE raster was created using 20-meter cell size. The upper 10% of density values defined the high-density area and the percentage of incidents included within this area was used as a summary statistic for spatial concentration. KDE results are sensitive to bandwidth selection. Smaller bandwidths produce more compact high-density areas and can concentrate a larger share of incidents within them. Here, the analysis uses the KDE surface generated with the default bandwidth. Future work should test bandwidth sensitivity by varying the bandwidth (e.g., creating KDE surfaces for 50%, 75%, 125%, and 150% of the default bandwidth value) and comparing the results of hotspots and incident concentrations. Furthermore, the temporal stability of the hotspot could be examined by creating KDE surfaces for 2018–2021 and 2022–2025 and comparing the 10% highest density tail areas using the Intersection Over Union metric. These recommendations are discussed in Section 5.6.

3.6. LULC Analysis

The majority of records were categorized as urban leopards (47 of 81 records, 58.0%), followed by rescue (21 records; 25.9%), depredation of livestock (5 records; 6.2%), roadkill (4 records; 4.9%) and injury to humans (4 records; 4.9%; Table 1; Fig. 4a). Frequencies of conflict categories were significantly different from a distribution of equal frequencies ($\chi^2 = 86.10$, df = 4, $p < 0.001$), but this result is primarily a result of the overwhelming prevalence of urban sightings (n = 47) relative to the other four conflict categories, which each only occurred in 21 records: the chi-square statistic here should be interpreted as simply reflecting the preponderance of urban sightings in the records, rather than a meaningful comparison of all five conflict categories.

3.7. Statistical Analysis

Descriptive statistics were used to summarise the leopard-conflict records. All statistical tests were conducted at the $p < 0.05$ significance level. Spatial analysis methods (mapping, KDE, ANN) were used to examine spatial patterns in the recorded incidents. We used chi-square goodness-of-fit tests to determine whether the recorded incidents conform to the expected distributions with respect to season, time of day, or the different LULC classes. In order to look at how the number of recorded incidents changed from year to year, we applied Kendall's rank correlation coefficient. For the purpose of comparing the time-of-day distributions between day and night, the Kolmogorov-Smirnov test was employed.

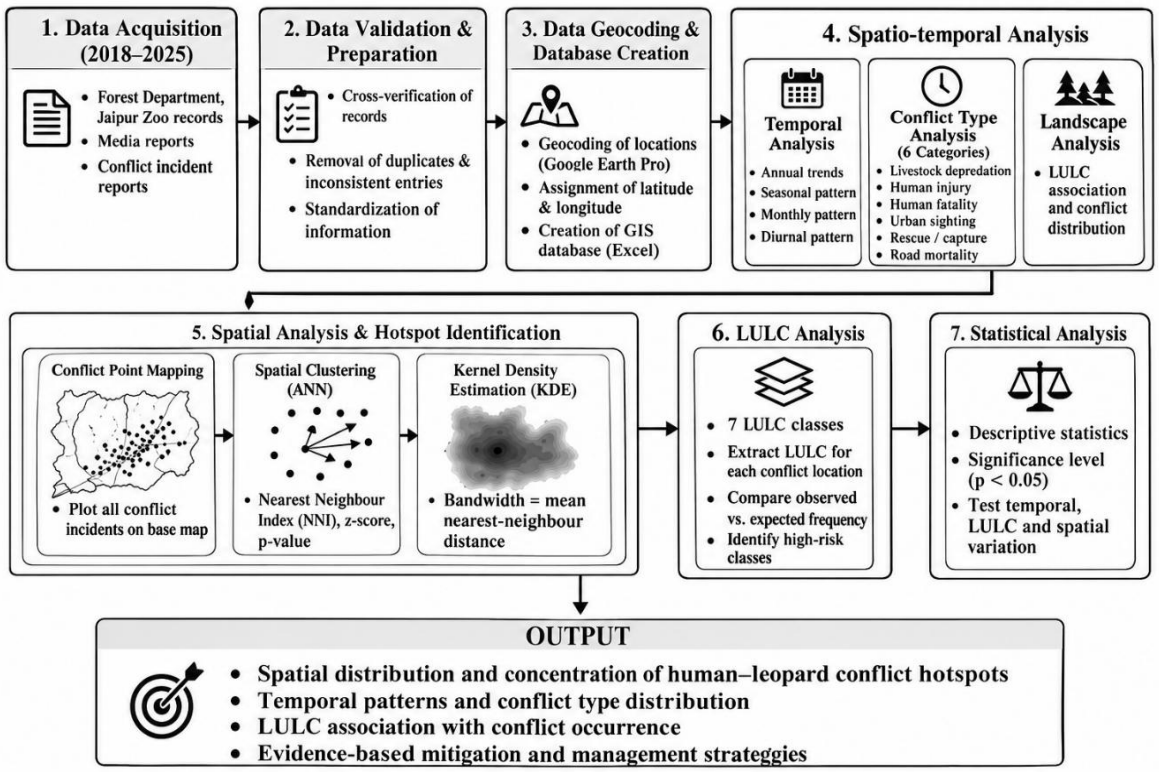


Figure 2. Methodological framework for human–leopard conflict hotspot mapping in Jaipur.

Every chi-square statistic mentioned in the Results section was additionally calculated using Python (scipy.stats, version 1.11) from the contingency tables described in the text to ensure correctness.

4. RESULTS

4.1. Annual Trend of Conflicts

During 2018–2025, 81 human–leopard conflict incidents were documented in Jaipur, with an annual mean of 10.13 ± 5.38 incidents (mean ± SD). Annual incidents varied between 3 incidents in 2023 and 20 incidents in 2019 (median = 10 incidents/year) indicating moderate interannual variability (Figure 3). Representative field photographs illustrating leopard sightings within urban areas and

rescue operations in the Jaipur landscape are presented in (Figure 4), providing visual examples of the two most frequently recorded forms of human–leopard interaction documented during the study period. The total number of annual conflict incidents showed no statistically significant increase or decrease over the study period (Kendall's $\tau = -0.265$, $p = 0.373$); however, with only 8 annual counts the Kendall's τ test has low power to detect weak temporal trends and the absence of a significant trend should be interpreted descriptively rather than as evidence of no underlying change. Urban leopard sightings dominated, comprising 47 of 81 incidents (58.0%), followed by rescue operations (21 incidents; 25.9%), livestock depredation (5 incidents; 6.2%), road mortality (4 incidents; 4.9%) and human injury (4 incidents; 4.9%) (Table 1; Figure 5a). Conflict category frequencies were significantly different from an equal distribution ($\chi^2 = 86.10$, df = 4, $p < 0.001$), but this is overwhelmingly driven by the dominance of urban sightings ($n = 47$) over the other four categories ($n \leq 21$ each): the chi-square statistic should be regarded as an indication of the dominance of urban sightings in the records rather than a balanced comparison of all five categories.

The number of urban sightings rose from 4 cases in 2018 to a maximum of 17 cases in 2019, after which it decreased slowly from 2020 to 2023 and stayed about the same during 2024 and 2025. The number of rescue operations was fairly steady over the study period, varying between 2 and 4 each year. Livestock depredation was uncommon and was only recorded in 2022 (3 cases), 2024 (1 case) and 2025 (1 case). There were no cases of human injury between 2018 and 2022, but four injury cases were noted during 2023 to 2025, two of which took place in 2024. Similarly, four leopard road mortalities were recorded during the study period, with two incidents occurring in 2018–2020 and two mortalities recorded during 2025. Because the human-injury category contains only 4 incidents and the road mortality category only 4 incidents, trend analysis of these two categories in the dataset is not statistically meaningful; the appearance of injury incidents after 2022 is noted descriptively, but cannot be interpreted as a statistically supported increase in conflict severity. This caveat is discussed further in Sections 5.1 and 5.6.

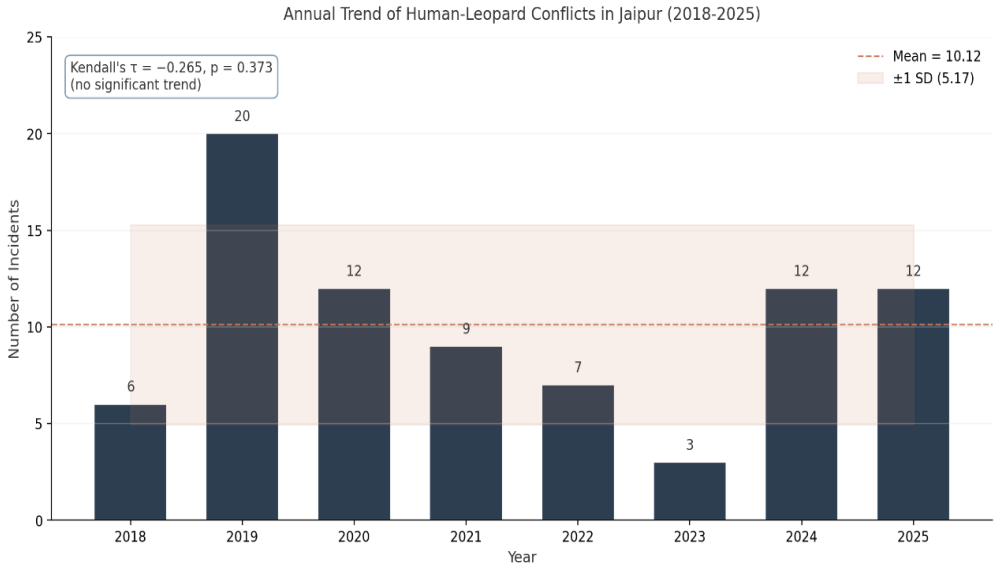


Figure 3. Annual trend of human–leopard conflicts in Jaipur (2018–2025).

Table 1. Distribution of recorded human–leopard conflict incidents by interaction type in Jaipur, 2018–2025.

Interaction type	Number (N)	% of all records
Urban sighting	47	58.0
Rescue / capture	21	25.9
Livestock depredation	5	6.2
Human injury	4	4.9
Road mortality	4	4.9
Total	81	100.0



Figure 4. Representative human–leopard interactions in Jaipur: (a–c) leopard sightings in urban and residential areas and (d–e) leopard rescue operations conducted at the urban–forest interface.

4.2. Seasonal and Monthly Patterns

There was a distinct seasonal pattern in the recorded human-leopard conflicts, the number of incidents differing from season to season (as shown in Figure 5b). Thirty incidents (37.0%) took place in the winter season (December–February), and 26 incidents (32.1%) occurred during the post-monsoon period (October–November). Conflict frequency remained low throughout the months of April to

August (0-3 incidents per month) but increased significantly from September onwards, reaching its peak in November (18 incidents) and December (22 incidents) (Figure 6). Seasonal variation was also seen among the different types of conflict, however, due the small category counts (livestock depredation n = 5, human injury n = 4, road mortality n = 4), it is not possible to make reliable seasonal cross-tabulations. Only urban sightings (n = 47) and rescue operations (n = 21) are described qualitatively. Urban leopard sightings and rescue operations were most frequent during the post-monsoon and winter months, while livestock depredation incidents (n = 5) were concentrated primarily during the summer and early monsoon period.

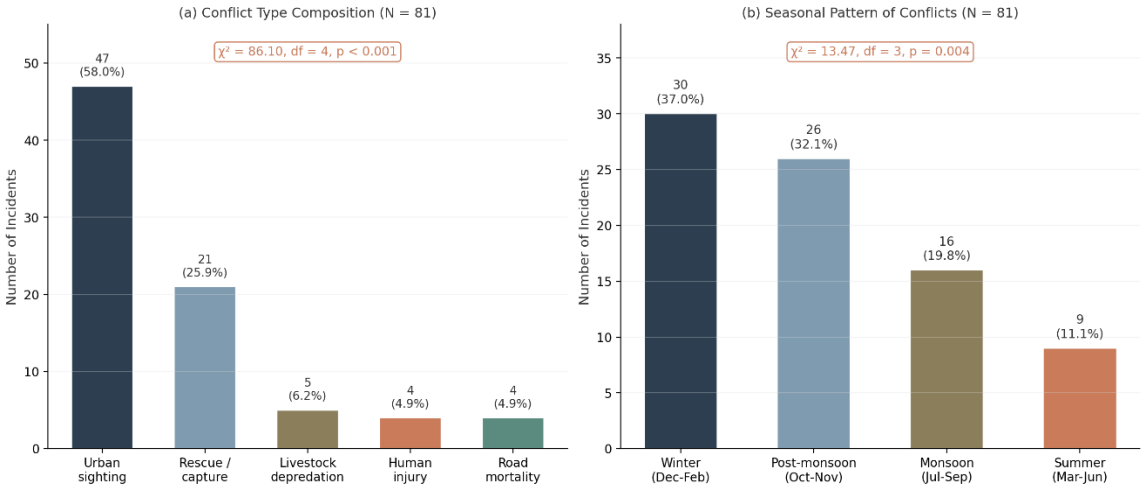


Figure 5. (a) Conflict type composition and (b) seasonal pattern of human–leopard conflicts in Jaipur (N = 81).

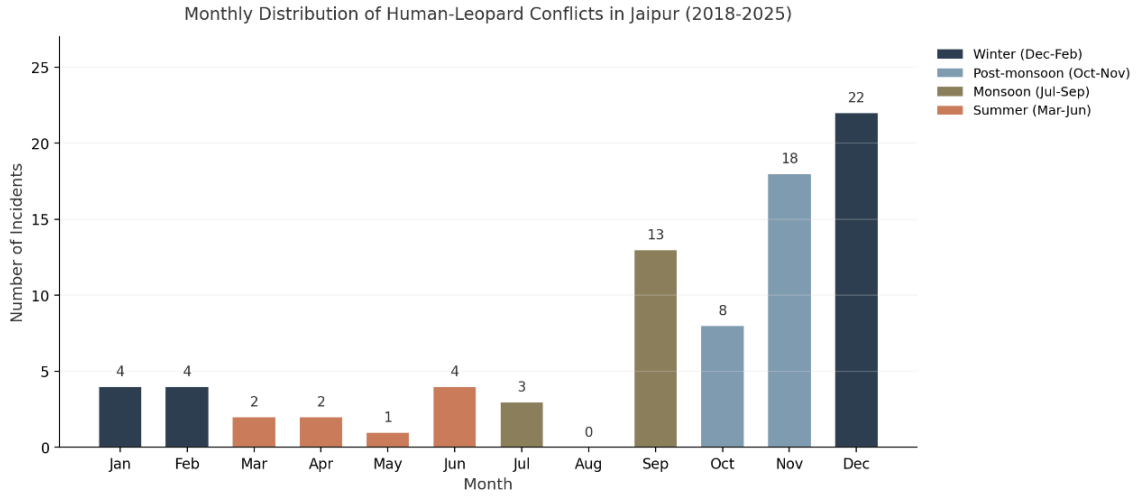


Figure 6. Monthly distribution of human–leopard conflicts in Jaipur (2018–2025).

4.3. Diurnal and Time-of-Day Patterns

A distinct diurnal pattern was exhibited by the recorded timing of human-leopard conflict incidents (Figure 7). Of the 81 records, valid time information had been recorded for 77 incidents. Conflicts were most frequently recorded after the evening and into the early-night (Figure 7). The six-hour temporal aggregation revealed that 18:00-23:59 h (32 incidents: 41.6%) followed by 06:00-11:59 h (19 incidents: 24.7%) and 00:00-05:59 h (17 incidents: 22.1%) and 12:00-17:59 h (9 incidents: 11.7%). Hence, nearly twice as many incidents were recorded in the evening/night period as compared to the afternoon period.

The three-hour interval distribution revealed that the majority of incidents occurred around 18:00-20:59 h (20 incidents) and 21:00-23:59 h (12 incidents). Indeed, urban observations were most concentrated during the evenings (12 incidents between 18:00-20:59 h; 7 more incidents between 21:00-23:59 h). Rescue events were relatively common during the evening/night period and, more specifically, during 21:00-23:59 h (5 incidents). Incidents involving human injury were comparatively rare (D = 36); nevertheless, they were concentrated mainly during 00:00-02:59 h (3 of 4 incidents); the noted distribution, however, is based on only 4 incidents and therefore cannot provide strong inference on the temporal distribution of human-injury incidents specifically. Road mortality incidents were predominantly recorded during 18:00-20:59 h (3 of 4 incidents); same caveat applies.

Comparison of the distributions of incident times between day (D = 37) and night (D= 38) indicated a significant difference in their temporal distributions (two-sample Kolmogorov-Smirnov test, D = 39, p = 0.0040). Similarly, the distributions of incidents during morning (06:00-11:59 h; p = 0.0041) and evening (18:00-23:59 h; p = 0.0042) differed significantly (p = 0.0043, p = 0.0044). The density distributions showed a distinctive evening peak whilst daytime incidents were more concentrated around the morning period. The hierarchical clustering of conflict types and three-hour time intervals showed that urban sightings formed the dominant temporal pattern with the highest frequencies occurring during the evening and early-night intervals. Rescue incidents demonstrated a similar but lesser concentration during evening hours, whilst the human-injury, livestock-depredation and road-mortality incidents were comparatively infrequent with more localised temporal distributions; the latter three categories are too small (p = 0.0045 each) to allow reliable cluster-level interpretation.

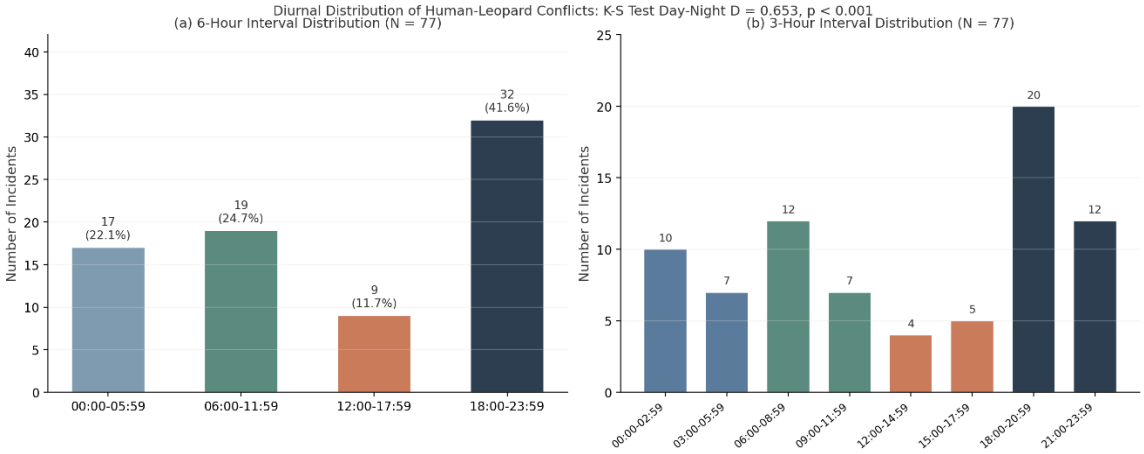


Figure 7. Diurnal distribution of human–leopard conflict incidents in Jaipur. Panel (a): 6-hour interval distribution (N = 77) showing the highest count in 18:00–23:59 h (41.6%). Panel (b): 3-hour interval distribution showing the peak at 18:00–20:59 h (20 incidents). Day–night distributions differ significantly (Kolmogorov–Smirnov D = 0.653, p < 0.001).

4.4. Spatial Distribution and LULC Association

Conflict locations showed a strong spatial association with the urban-forest interface **(**Figure 8; Table 2). Of the 77 conflict locations that coincided with the seven classified LULC categories, 61 (79.2%) were located in built-up/urban areas, followed by 14 (18.2%) in forest areas. Shrubland and cropland each only contained one conflict location (1.3%) and no conflict locations were recorded directly within fallowland, rocky/barrenland or waterbody classes. Built-up/urban areas comprised approximately 62.3% of the mapped LULC area whereas forest accounted for 17.1%. As discussed in Section 3.1, the observed concentration of incidents in built-up areas partly reflects higher urban reporting probability and the present dataset cannot disentangle the observed pattern into a reporting-probability component and a true-conflict component Figure 9.

When the frequencies that were observed were compared with those expected on the basis of LULC availability, there was a significant deviation from proportional abundance ($\chi^2 = 15.81$, df = 2, p < 0.001; the calculation was made by combining the five minor LULC classes into one category in order to meet the chi-square minimum expected cell requirement, as explained in Section 3.6). Built-up areas contained approximately 1.27 times the number of incidents that would be expected from their spatial availability, while the combined minor LULC categories (shrubland, cropland, fallowland, rocky/barrenland and waterbody) contained significantly fewer incidents than expected. Forest-associated incidents were approximately proportional to forest availability (observed-to-expected ratio

= 1.07). Spatially, conflict locations within the built-up matrix were found to be clustered around forest and shrubland patches, particularly in the southern and south-central portions of the study area. A few incidents were also recorded along narrow vegetated patches and drainage features crossing the urban landscape. Conflict locations were comparatively sparse over large areas of agriculture and bare ground; the low number of incidents in these LULC classes may reflect either lower leopard activity, lower reporting probability, or both, and the available data cannot distinguish between these explanations.

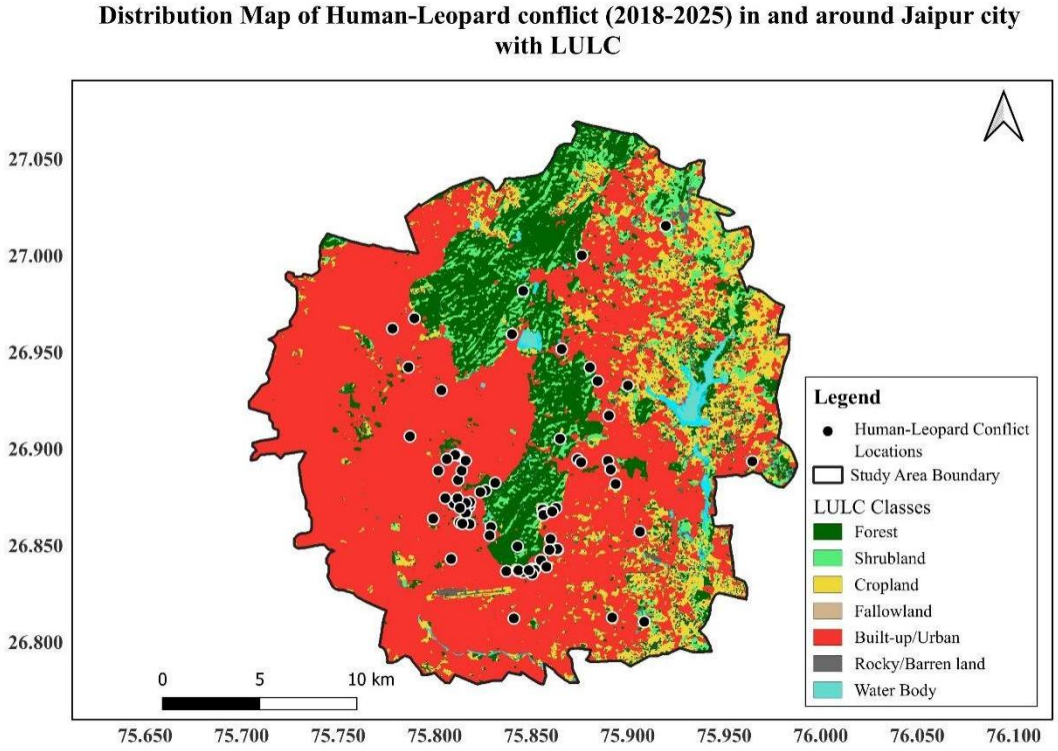


Figure 8. Human-leopard conflict distribution from 2018 to 2025 Over Land Use/Land Cover

Table 2. LULC association of human–leopard conflict incidents in Jaipur (N = 77 with valid LULC).

LULC class	Area (%)	Observed (N)	Observed (%)	Expected (N)	O/E ratio
Built-up / Urban	62.3	61	79.2	47.97	1.27
Forest	17.1	14	18.2	13.17	1.07
Shrubland	~4.1	1	1.3	3.17	0.32
Cropland	~4.1	1	1.3	3.17	0.32
Fallowland	~4.1	0	0.0	3.17	0.00
Rocky / Barren	~4.1	0	0.0	3.17	0.00
Waterbody	~4.1	0	0.0	3.17	0.00

Note: $\chi^2 = 15.81$, df = 2, $p < 0.001$ (calculated by combining the five minor LULC categories to satisfy the minimum expected cell size assumption for the chi-square test; the expected frequencies of the individual minor categories are less than 5 and are shown only for completion). The combined minor category reflects the residual departure from the expected proportional frequency. The observed-to-expected ratios of the individual minor categories are not statistically significant due to small frequencies.

Observed count of conflicts (warm bars) compared to the expected count given the LULC-area (cool bars) for each of the seven LULC categories. Built-up/urban areas contain more incidents than expected (O/E = 1.27), but minor categories contain less ($\chi^2 = 15.81$, df = 2, and $p < 0.001$). This discrepancy reflects a reporting bias (Section 3.1) and should not be taken as an indication of a true ecological preference for built-up land.

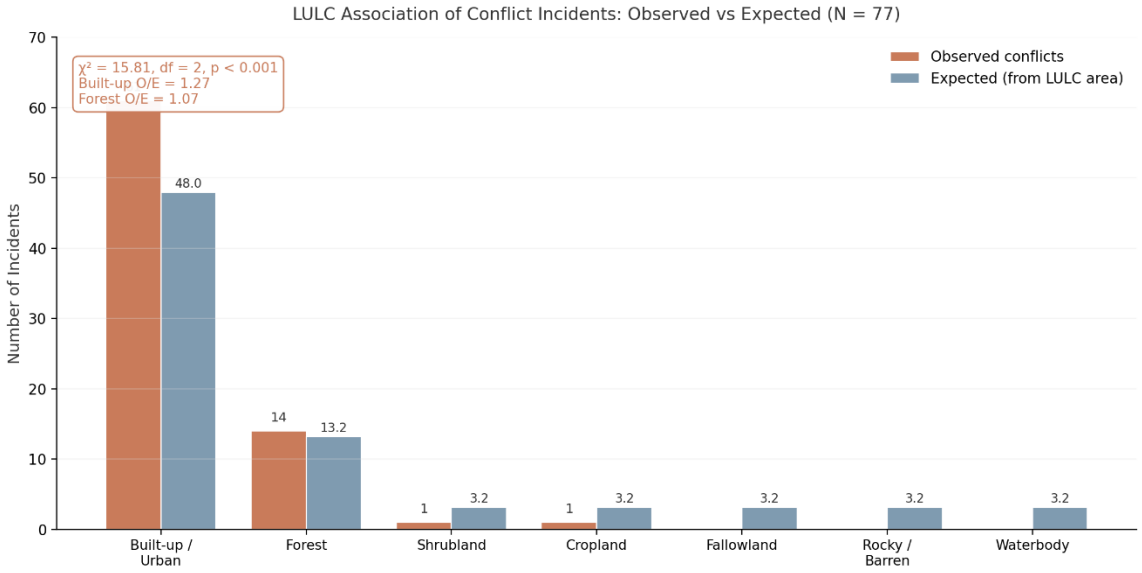


Figure 9. LULC association of conflict incidents: observed versus expected

4.5. Conflict Hotspot Analysis

Kernel density estimation (KDE) analysis revealed hotspots of human-leopard conflict in southern and south-central Jaipur, with the strongest concentrations over Malviya Nagar, Railway Colony and Kho Nagoriyan near Jhalana Leopard Reserve (Figure 10). Several less dense groupings were observed near Jamdoli and Jaisinghpura Khor around Amagarh Leopard Reserve, while the region of Nahargarh Wildlife Sanctuary was largely devoid of conflict. Since the KDE results, as discussed in Section 3.5, are very sensitive to the selection of kernel bandwidth and are affected by the uncertainties of the input points (Section 3.2), the cluster shown in Figure 10 should not be taken as an unbiased representation of leopard ecology, though it warrants further investigation.

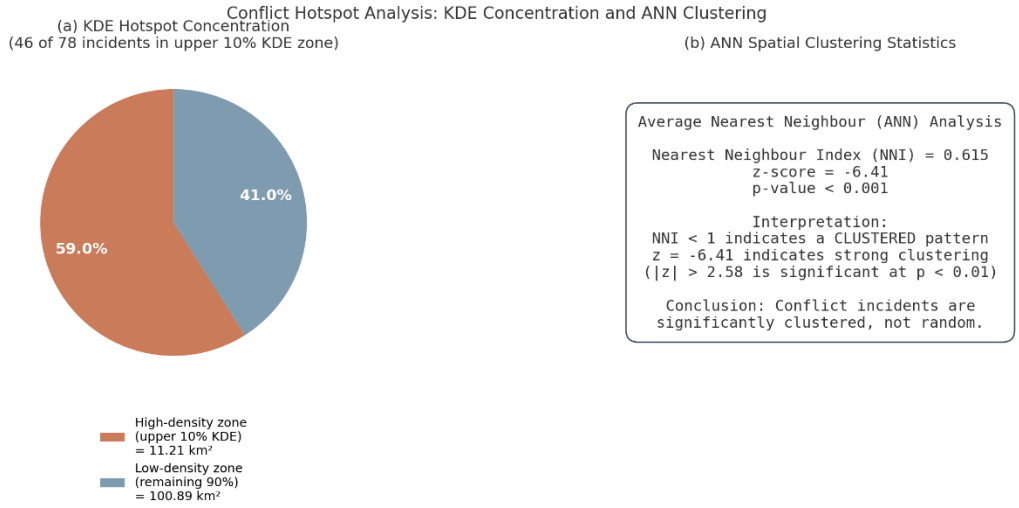


Figure 10. Conflict hotspot analysis: KDE concentration and ANN clustering statistics.

The top 10% of KDE density values covered an area of 11.21 km2 with 46 (59.0%) of all incidents, showing that recorded incidents were strongly concentrated within this area. The results of the Average Nearest Neighbor analysis supported this pattern, showing significant clustering of recorded conflict locations (NNI=0.615, z=-6.41, $p < 0.001$). The analysis assumes the input points represent an unbiased sample of a larger spatial process; the validity of this assumption depends on how strongly the sampling strategy that

generated the input points (described in Section 3.1) is biased, which is difficult to quantify due to the factors discussed in Section 3.2. As such, although the value of NNI indicates the recorded incidents are significantly clustered, it may not be an unbiased estimator of clustering for the leopard conflict in general. The regions of highest density were found to correspond to large clusters of developed land adjacent to forests. Of three leopards known to have died in 2023-2025, two (66.7%) were reported to have been hit by vehicles, mostly on the roads along the eastern edge of Nahargarh Wildlife Sanctuary, but the number of incidents is too small (n = 3) to draw any definite conclusions about the spatial distribution of leopard mortality. To sum up, the leopard conflict incidents recorded over the study period were found to be significantly clustered, with the densest concentrations occurring near the edges of the urbanized areas. Figure 11 shows the human-leopard conflict hotspots in Jaipur and the surrounding area.

In Figure 11, Panel (a) represents KDE hotspots; the top decile is 11.21 km² across, and 59.0% (46 of 78) of the incidents are inside of it. Panel (b) represents ANN statistics; NNI = 0.615 ($z = -6.41$; $p < 0.001$), indicating that the feature has a significantly clustered pattern according to the recorded data. The computation of ANN is presumed to work on an unbiased spatial sample, which is known to be violated, to an unknown extent, by reporting bias and geolocation imprecision (Sections 3.1-3.2). The fully detailed KDE surface will be provided by the authors, from the QGIS/ArcGIS export.

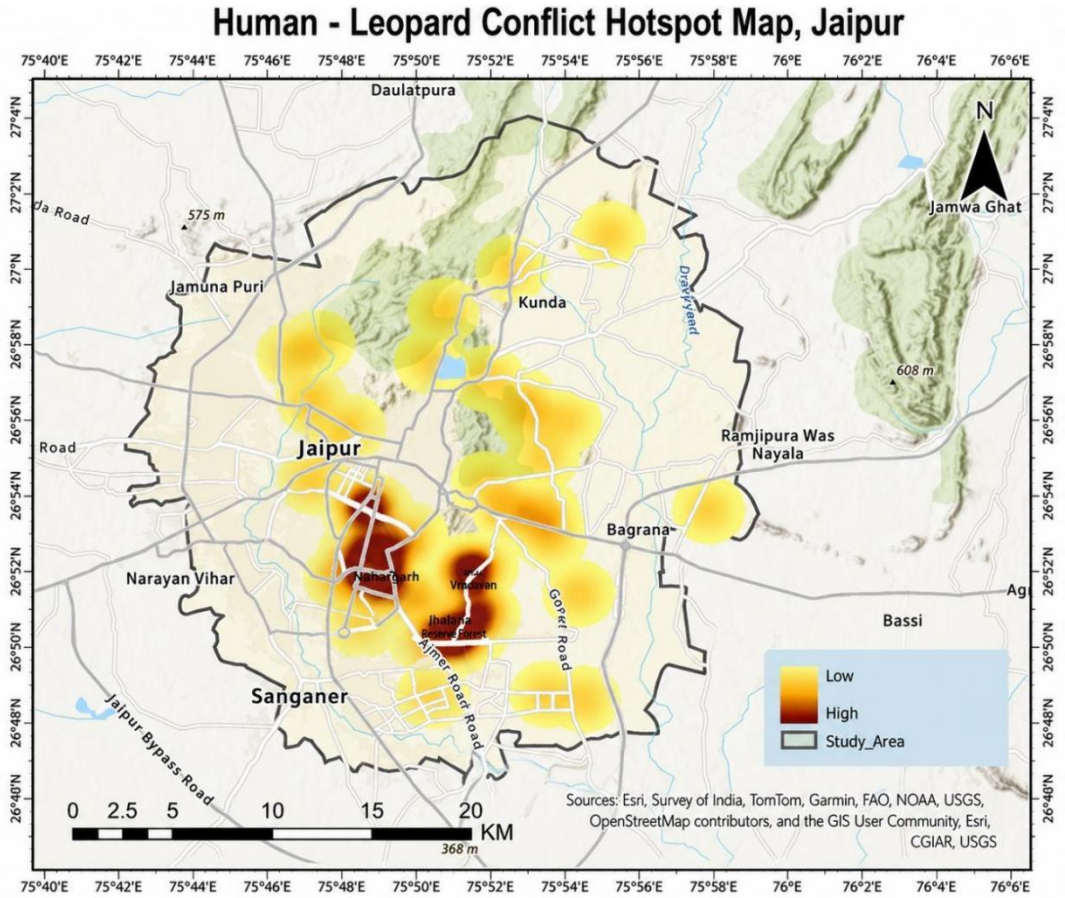


Figure 11. Human-leopard conflict hotspots in Jaipur and its surrounding areas

5. DISCUSSION

5.1. Temporal Dynamics of Human–Leopard Conflict

Absence of a major temporal trend in the annual number of recorded incidents suggests that the volume of recorded human–leopard interactions recorded in Jaipur has not increased consistently between 2018 and 2025. Instead, the composition of interactions recorded has varied throughout the study with urban sightings dominating the early years whilst human-injury incidents only appearing after 2022. Although this distinction between frequency of conflict and severity of conflict is significant, the tiny number of human-injury incidents (n = 4) and leopard road mortalities (n = 3) recorded during the study period prevents any formal inference of a change in conflict severity; whilst the appearance of injury incidents from 2022 is noted descriptively and could reflect either a genuine shift in

interaction severity or an artefact of improved recording of injury incidents in the later years of the study period. Leopards can exist within highly-modified landscapes with dense human populations, and human-dominated environments can offer appropriate resources and opportunities for movement (Athreya & Belsare, 2007; Kshettry et al., 2017).

The fact that most of the recorded sightings and rescue operations have taken place in urban areas indicates that in Jaipur the leopards were generally present within the urban area rather than causing direct aggressive encounters. The same result has been found in other Indian cities where leopards live near human settlements but nevertheless avoid direct contact with people. For example, in Mumbai it has been noted that urban leopards are capable of adjusting their activity patterns with respect to humans and are able to remain largely nocturnal, allowing them to utilize human dominated environments while minimising interactions with people (Vikas et al., 2022). This could explain why Jaipur reported a large number of sightings and rescues but relatively few human injuries during the majority of the study period. The fact that human-injury incidents occurred after 2022 should therefore be regarded as a descriptive pattern which deserves to be kept under observation; yet since only four injury incidents were recorded in 2023, 2024 and 2025, the present dataset does not allow for a statistically defensible conclusion that conflict severity is increasing. An extended time-series and systematic reportage of injury incidents would be required to enable such a conclusion. Similar studies have noted that human–leopard conflict is significantly affected by the attributes of the shared landscape and human activities surrounding leopard habitat rather than simply the presence of leopards (Naha et al., 2018).

5.2. Seasonal and Diurnal Patterns

In Jaipur there is a clear seasonal pattern, with the majority of incidents taking place in winter and the period after the monsoon, which shows that recorded conflicts are distributed in a temporal pattern rather than being spread evenly throughout the year. A similar seasonal variation has also been reported in other studies on leopard-conflict in India, although the peak season differed in each case. For example, in Gir winter made up the largest proportion of the interactions (Zehra et al., 2022), while the studies carried out in the Himalayan region found considerable differences between sites and seasons (Naha et al., 2018).These geographic differences imply that seasonal differences in conflict are more likely to reflect local combinations of factors, such as prey abundance, vegetation cover, water availability, agricultural activity and human activity, rather than an overarching seasonal response of leopards.

In Jaipur, the concentration of incidents during post-monsoon and winter may also partially reflect heightened detectability of leopards in the urban setting as well as seasonal shifts in movement between forest patches and surrounding areas. The relatively low number of incidents reported during summer thus should not be assumed to indicate decreased leopard activity; reporting probability and human activity both vary seasonally. The high concentration of incidents during evening and nighttime provides further support that temporal overlap between leopard activity and human activity is an important driver of conflict risk. Nearly 42% of incidents with known time occurred between 18:00 and 24:00 h, and the difference between day and night distributions was statistically significant. This finding is in agreement with research on leopard movement in human-dominated Indian landscapes during night: GPS-collared leopards in Maharashtra and Himachal Pradesh increased their nocturnal movements near human settlements, with movements during the night being substantially greater than during the day (Kshettry et al., 2018), and urban leopards in Mumbai have similarly been described as predominantly nocturnal, possibly allowing them to exploit anthropogenic resources while avoiding people during daytime (Vikas et al., 2022). The concentration of sightings and rescues during evening hours suggests that the transition from day to night may be an important period for human–leopard encounters in Jaipur. From a management perspective, this means that awareness campaigns, rapid-response teams and public advisories could be particularly relevant during evening and early-night hours, around settlements adjoining leopard habitat.

5.3. Influence of Land Use and the Urban–Forest Interface

The spatial distribution of the conflict incidents is interesting to observe, as the recorded human-leopard interactions were concentrated on the interface between natural and built habitats. Built up land covered only 62.3% of the total LULC in the study area but had 79.2% of the conflict locations, and the distribution was not congruent with leopard's use of different LULC categories. It is also critical to note that it does not necessarily mean leopards have an affinity for built habitats, rather the recorded conflict hotspots were found to be disproportionately in-built habitats, especially when occurring near-forests and vegetated lands. As explained in section 3.1, the data used (Forest Department, Jaipur Zoo and validated media reports) could have overrepresented urban leopard incidents compared to rural ones; if people are more likely to report leopard sightings in urban than rural areas, then the proportion of leopard records from urban areas might be higher than their actual occurrence; the current dataset does not allow for distinguishing between reporting-probability effect and true leopard abundance.

This pattern is nevertheless consistent with evidence that leopards can exploit human-modified landscapes as habitats as long as there is sufficient cover, prey support and opportunities for movements. Leopards in Maharashtra and northeast India have been widely recorded in agricultural and human-inhabited landscapes and can have small home ranges in highly anthropogenic landscapes (Athreya et al., 2020; Kshettry et al., 2017). A recent study carried out on human-leopard conflicts in the Aravalli region of Rajasthan found that areas which had been built up or were composed of scrubland near villages were identified as important factors relating to such conflicts, the probability of conflict increasing as the distance from both sanctuaries and from human settlements grew (Koli et al., 2026). The juxtaposition of habitats within the study area, especially forests and built landscapes, creates a mosaic that allows for such interactions to happen with individuals using different resources within the same general area. The high concentration of conflict records around Jhalana Leopard Reserve is particularly noteworthy in this study as that reserve is located within an urban continuum; similar to how many protected areas within cities are surrounded by high-density human settlements (Vikas et al., 2022; Surve et al., 2022).

The low proportion of conflict incidents with croplands, barren lands and other minor LULC types should be taken with a pinch of salt, considering the dissimilarity in size of these categories and the chance of being recorded relative to build landscapes, let alone compared to forests. It must also be noted that the records reflect encounters and not the degree of habitat use; as such, the current analysis highlights locations of conflict records, not leopard preference.

5.4. Spatial Clustering and Conflict Hotspots

The Average Nearest Neighbour result (NNI = 0.615, $z = -6.41$, $p < 0.001$) indicates that recorded conflict locations were strongly clustered rather than randomly distributed, and the KDE analysis further showed that 59% of recorded incidents occurred within the upper 10% of the KDE density surface. Taken together, these results show that recorded conflict was concentrated within a relatively narrow portion of Jaipur rather than being evenly distributed throughout the city, with the greatest density being recorded around Malviya Nagar, Railway Colony and Kho Nagoriyan (adjacent to the Jhalana Leopard Reserve), and the JLR–urban interface is a clear priority for conflict management. The fact that sightings and rescues were concentrated in this area may be a reflection of frequent leopard excursions into the surrounding urban areas, it appears that leopards are capable of great flexibility in their habitat choice, and are able to navigate human dominated landscapes (which often, but not always have continuous forests or other natural vegetation) as long as they can find resources and cover (Athreya et al., 2013; Kshettry et al., 2018). The ANN statistic assumes that the input points are an unbiased sample of the underlying spatial process, which is violated to an unknown degree by the reporting bias and geolocation uncertainty described in Sections 3.1 and 3.2, and the resulting hotspot pattern should be regarded as a descriptive baseline of the recorded dataset rather than a validated ecological map of true conflict intensity.

The lower overall conflict density around Nahargarh Wildlife Sanctuary but occurrence of road-related leopard mortality illustrates an important distinction between conflict frequency and conservation impact. Two out of three recorded leopard deaths occurred because of road accidents, however, with only 3 leopard mortalities over the 8-year study period recorded, the data do not support a statistically defensible conclusion about the spatial distribution of leopard mortality. It is noted that conflict along roads and forest edges is in line with the current literature on linear infrastructure as a source of wildlife mortality (Athreya et al., 2013); a longer time series with systematic mortality recording would be needed for stronger inference. Linear infrastructure has the potential to fragment habitats and also present extra risks to the movement of wildlife, and earlier research into leopard habitats that are dominated by human activity has shown that landscape-level management is more important than management based solely on protected areas (Athreya et al., 2013).The clustering of conflict along roads and forest edges should be considered a management issue, with the spatial coincidence suggesting that roads located (or soon to be) at forest–urban interfaces may represent potential conflict and mortality zones. Targeted monitoring, road-safety measures and wildlife-sensitive infrastructure planning around these areas may therefore reduce mortality without unnecessarily restricting leopard movement.

5.5. Implications for Management and Coexistence

Taken together, the results indicate that the recorded instances of human–leopard conflict in Jaipur are characterised less by an overall annual increase in incidents than by spatial concentration, seasonal differences, nocturnal activity and a possible (but statistically unsupported) shift towards more severe interactions in recent years, which means that management focused only on the number of annual complaints or rescue operations may overlook incipient high-risk areas. The findings therefore emphasise a landscape-based approach to conflict management in contrast to management confined to protected area boundary definitions. Management should be focused on the JLR–urban interface with a specific focus on the Malviya Nagar–Railway Colony–Kho Nagoriyan zone while addressing

road mortality around the eastern periphery of NWLS. Evening and nighttime awareness programmes could be targeted at settlements surrounding forest patches where recorded encounters are most widespread. Rapid-response and rescue teams could similarly be focused on the areas identified by the KDE analysis. It is important that, since the number of sightings and rescues is so much higher than the number of injuries, the presence of leopards should not be automatically assumed to mean that there is severe conflict, and evidence from other parts of India shows that it is possible to live peacefully with leopards even in areas of high human density provided that leopards can make use of landscapes inhabited by people without having direct encounters with them (Athreya et al., 2011; Vikas et al., 2022). The aim of management therefore should be to reduce hazardous encounters and deaths while at the same time preserving the ecological connectivity needed for the long-term survival of leopards.

5.6. Limitations and Interpretation

When drawing conclusions from these findings, several limitations should be taken into account. The first of these is that the dataset includes only 81 cases over a period of eight years, a relatively small number for the kind of spatial and temporal analyses carried out in this study.

The hotspot pattern, LULC association and diurnal distribution should therefore be treated as descriptive baselines rather than validated ecological inferences. Since the multi-source dataset (which includes the Forest Department, Jaipur Zoo, and media reports) is prone to reporting bias—urban incidents being more likely to be reported than rural ones—the fact that conflicts are observed to be concentrated in urban areas may in part be due to this reporting bias rather than indicating a real ecological pattern. Because reporting effort was not measured independently, the present analysis cannot quantitatively separate the observed pattern into a reporting-probability component and a true-conflict component.

The geolocation of the incidents is uncertain: when the exact coordinates were not available, the incidents were assigned to the centroid of the village or locality (this being Tier 3 geolocation, see Section 3.2), with an estimated precision of ±500 to 2000 m. The KDE and ANN are sensitive to the precision of the coordinates, and the hotspot pattern reported here may partly reflect the use of centroid-based geolocation for an unknown subset of incidents. A sensitivity analysis recomputing the KDE and ANN using only Tier 1 (direct GPS) incidents should be prioritised in future work. Since several of the conflict-type categories have very low frequencies (livestock depredation n = 5, human injury n = 4, road mortality n = 4, leopard mortality n = 3), the conclusions drawn from these categories can only be described and do not allow for strong statistical inference. In particular, the appearance of human-injury incidents after 2022 are noted descriptively but cannot be interpreted as a statistically-supported increase in conflict severity. The ANN statistic assumes a (spatial) unbiased sample, an assumption that is violated to an unknown extent by the reporting bias and geolocation uncertainty; the value of NNI = 0.615 reported here should be interpreted as descriptive evidence of clustering in the recorded dataset, rather than an unbiased estimate of clustering in the true (unobserved) conflicts process.

The KDE bandwidth was set to the default ArcGIS implementation (mean nearest neighbour distance) and the analysis did not include a bandwidth-sensitivity test: smaller bandwidths would generate smaller, more sharply-defined hotspots, and larger bandwidths would generate smoother, more diffuse surfaces. A bandwidth sensitivity analysis (re-running KDE at 50%, 75%, 125% and 150% of the default bandwidth and reporting the resulting area of hotspot and incident concentration) is recommended for future work. The temporal stability of hotspots across years has not been investigated; computing KDE separately for 2018–2021 and 2022–2025 and reporting the spatial overlap of the upper 10% density zones would provide a useful test of temporal stability in future work. The hotspot pattern has not been checked against independent data on known leopard movement corridors, leopard abundance or independent conflict records; such validation would greatly strengthen the inference.

The study is descriptive rather than predictive: it does incident mapping, KDE, ANN and LULC overlay, which are a standard GIS analyses. The novelty of the contribution is thus in the application of these methods to a previously under-studied urban-forest interface (Jaipur) and the descriptive baseline for future predictive work established, rather than the methods. Future work should bring in predictive modelling, risk mapping, machine learning classification or corridor analysis to add methodological contribution. The chi-square goodness-of-fit tests reported in Sections 4.1-4.4 are reported as descriptive tests of the recorded dataset, rather than as inferential tests generalizing to a larger population of unrecorded incidents; with the small sample size and multi-source reporting bias, the chi-square p-values should not be taken as evidence of statistically significant patterns in the underlying true (unobserved) conflict process. Finally, Kendall's tau trend test on 8 annual counts has low statistical power to detect weak temporal trends, and the absence of a significant trend should not be taken as evidence of no change.

Despite these limitations, the inclusion of time-analysis, association with LULC, nearest neighbour analysis and KDE in this study shows that recorded human-leopard conflict in Jaipur is spatially structured, and concentrated at the urban-forest interface. The results

provide a descriptive baseline of reported incidents against which future, more rigorous studies using larger probability-based datasets, independent leopard abundance data, bandwidth sensitivity analysis and validation against known leopard movement corridors can be benchmarked. The results further highlight the need to move beyond a simple analysis of annual conflict frequency, to site-specific, time-specific and landscape-level management of human-leopard interactions, while acknowledging the limits of inference available from a small, multi-source reported incident dataset.

6. CONCLUSION

This study provides an exploratory, descriptive baseline analysis of recorded human–leopard conflict in Jaipur for 2018–2025. The dataset is small (it includes 81 incidents that occurred over an 8-year period), having been compiled from a variety of sources (the Forest Department, the Jaipur Zoo, and verified media reports) and is influenced by reporting bias (incidents in urban areas are more likely to be reported than those in rural areas) and geolocation uncertainty (in the case of an unknown number of incidents, the locations have been assigned to the centroids of the villages or localities since the exact coordinates were not available). That said, several descriptive patterns did emerge. The annual average was 10.13 ± 5.38 incidents, and there was no significant monotonic trend (Kendall's $\tau = -0.265$, $p = 0.373$). The Kendall's τ test, which was based on eight annual counts, had limited statistical power. The majority of the recorded cases were urban sightings, 47 out of the 81 incidents (58.0%; $\chi^2 = 86.10$, $df = 4$, $p < 0.001$). This chi-square value indicates that urban cases were much more common than cases in the other four categories. Human-injury incidents only occurred after 2022, amounting to four cases in total. This is mentioned here for context, but it does not indicate a statistically significant increase in the severity of conflict.

Recorded incidents were strongly concentrated in the winter (37.0%) and post-monsoon (32.1%) periods ($\chi^2 = 13.47$, $df = 3$, $p = 0.004$) and during the evening and nighttime hours (41.6% in 18:00–23:59 h; K-S test for day vs night: $D = 0.653$, $p < 0.001$). A spatial analysis of the recorded dataset showed that there were significant clusters of incident locations, these clusters being mainly centred on the Jhalana Leopard Reserve and the adjacent urban areas, especially Malviya Nagar, Railway Colony and Kho Nagoriyan. The area making up the top 10% of the KDE density surface was 11.21 km² and included 59.0% of the recorded incidents, and the Average Nearest Neighbour index (NNI = 0.615, $z = -6.41$, $p < 0.001$) proved that a clustered pattern existed in the dataset; however, since the ANN statistic is based on the assumption of an unbiased spatial sample, this assumption had been violated to an unknown degree because of reporting bias and geolocation uncertainty, and the index therefore should be treated in a descriptive way only. The fact that so many incidents occurred in built-up areas ($\chi^2 = 15.81$, $df = 2$, $p < 0.001$; observed-to-expected ratio = 1.27) might in part be due to a higher probability of reporting in urban areas and must not be seen as proof of a real ecological preference for built-up land.

The results support a targeted, landscape-level approach to human-leopard coexistence in Jaipur that combines hotspot-based monitoring, community awareness of high-risk periods as well as rapid-response and mitigation measures relating to roads and mortality, while recognising that the analysis is descriptive and based on a modest, multi-source dataset of reported incidents. Rather than focusing mainly on annual conflict counts, management could prioritise where, when and how recorded interactions occur, directing limited resources toward places and periods with the greatest risk of harmful encounters.

Future studies could reinforce the inference by: (i) putting together a bigger (probability-based) incident dataset, using systematic procedures for reporting by the Forest Department; (ii) acquiring independent data on leopard numbers (for example, camera-trap densities); (iii) carrying out a bandwidth analysis in connection with KDE; and (iv) checking the validity of the hotspot pattern against known leopard movement corridors and independent conflict records; (v) performing a sensitivity analysis restricted to Tier 1 (direct GPS) incidents; and (vi) widening the temporal extent to enable an analysis of temporal stability of hotspots across years. The combination of GIS-based hotspot analysis with temporal and LULC analyses provides a transferable framework for descriptive baseline assessments in other rapidly expanding urban landscapes of semi-arid India where leopard populations persist in close proximity to dense human populations.

To reduce conflict between people and leopards in the urban areas surrounding Jaipur it is necessary to adopt a preventive, tailored and community-oriented strategy. Since the incidents reported in this study were concentrated in certain areas, the most attention should be paid to the parts next to Jhalana and Amagarh, where regular monitoring, quick response and public awareness programmes should be enhanced. Actions such as keeping livestock in enclosures that are resistant to predators, improving lighting in the areas where livestock are kept, decreasing the amount of unmanaged domestic prey and waste, and encouraging the community to be aware of the correct way to react when leopards are sighted could all help in reducing the chances of conflict. Earlier research carried out in Jhalana and Nahargarh has also pointed to better livestock management, protection of habitat, raising community

awareness and the implementation of specific mitigation measures as appropriate methods for reducing human-leopard interactions. Since domestic animals constitute an important source of prey for leopards in Jhalana, limiting access to easily available domestic prey may be particularly relevant when it comes to managing interactions in the areas where urban zones meet forests. The Rajasthan Forest Department should therefore support these measures by carrying out coordinated monitoring and offering timely intervention, particularly in those areas which have been identified as conflict hotspots.

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Author contributions

The first author, Aishwarya Mahajan, collected and compiled the human–leopard conflict data, performed the analysis, and prepared the initial manuscript. Joy Gardner and Nikhil Sharma contributed to data collection and verification. Saurabh Kumar Gupta contributed to the geospatial analysis and interpretation of the results. The senior author, Suraj Kumar Singh, conceptualized and supervised the study, cross-checked the analysis and relevant literature, and critically reviewed and edited the manuscript.

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Conflict of Interest

The authors declare that they have no conflicts of interest, competing financial interest or personal relationship that could have influenced the work reported in this paper.

Informed consent

Not applicable.

Ethical approval & declaration

Ethical approval was not applicable to this study, as it was based on secondary records, documented human–leopard conflict incidents, and geospatial data, and did not involve any experimental procedures on animals or human participants.

Data and materials availability

The anonymised dataset used in this study is available from the corresponding author on reasonable request.

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