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Truncated Life: Patterns and Causes of Elephant Mortality in the state of Chhattisgarh, India

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Abstract

Human-elephant conflict (HEC) in Chhattisgarh, India, has intensified over the past two decades, threatening both elephant populations and rural livelihoods. This study analysed 218 elephant mortality incidents recorded between 2000 and 2023 to identify spatial, temporal, and ecological patterns underlying these deaths. Findings indicate electrocution as the leading anthropogenic cause, particularly affecting adult males, with mortality peaking during the monsoon season. Spatial analysis identified hotspots such as Dharamjaigarh, Chhal, and Jashpur, where the highest number of electrocution cases overlapped with key elephant corridors and movement routes. Land use and land cover (LULC) analysis (2000–2024) showed a -7.26% change in forest cover and a substantial increase in cropland and built-up areas, indicating habitat fragmentation as a key driver of conflict. Generalised linear- models identified proximity to croplands, elephant reserves, and edge density as significant predictors of mortality risk. Conservation measures must include monitoring distribution lines used in electric fencing, insulating power lines (selected locations), restoring habitat connectivity, and implementing AI-based monitoring tools. Additionally, community engagement through early warning systems and compensation schemes can reduce retaliation and foster coexistence. This study highlights the urgent need for integrated landscape-level planning and intersectoral coordination to mitigate HEC and secure the long-term survival of elephants in fragmented, human-dominated landscapes.

Keywords: Adult mortality, dharamjaigarh, electrocution, electric fencing, habitat fragmentation.

Introduction

Asian elephants have attracted global attention for conservation as their number has reduced by ~50% since the 1950s within a couple of elephant generations (considering about 60 to 75 years as the average lifespan of an elephant), along with rapid shrinkage of their habitat across the range countries (Sims *et al.*, 2015; de Silva *et al.*, 2023). The increase in human settlements and agricultural practices in Asia has led to widespread destruction of elephant habitats and reduced connectivity within the landscape (Jarungrattanapong & Olewiler, 2024; de Silva *et al.*, 2023; Shaffer *et al.*, 2019). Over the past decade, human–elephant conflict (HEC) has emerged as a major challenge across several Asian countries (Montez *et al.*, 2021; Shaffer *et al.*, 2019; Wilson *et al.*, 2015). These conflicts have resulted in economic costs and caused injuries and fatalities among both humans and elephants (Bhagat *et al.*, 2017; Köpke *et al.*, 2024). With human activities increasingly encroaching on elephant habitats, HEC poses a critical threat to their survival across their range (Billah *et al.*, 2021; Shameer *et al.*, 2024). Therefore, a deeper understanding of land-use dynamics and integrated management inside and outside PAs is vital for conserving elephants in HEC-prone landscapes. In Central India, elephant habitat covers about 21,000 km^2 across Jharkhand, Odisha, Chhattisgarh, and southern West Bengal, supporting nearly 10% of the country's elephant population (Menon *et al.*, 2017, Baskaran *et al.*, 2011) Although this landscape supports a relatively small elephant population, it records one of the highest human fatalities (Natarajan *et al.*, 2023a). Central Indian forests are severely fragmented and degraded by intensive agriculture, shifting cultivation, mining, and expanding infrastructure. Historically, elephants were distributed across southern Uttar Pradesh, Madhya Pradesh, to Chhattisgarh (Baskaran *et al.*, 2011). Chhattisgarh has a small population of elephants that initially travelled from Jharkhand and Odisha in the 1980s and 1990s. Over the past few decades, the forested areas in these two states have experienced degradation due to activities such as illicit logging, encroachments, industrialisation, and mining (Singh, 2002). Chhattisgarh serves as a corridor with this larger regional pattern of elephant range expansion driven by habitat degradation and fragmentation in the neighbouring states such as Jharkhand, Odisha and southern West Bengal (Debata *et al.*, 2013; Singh, 2002). According to Forsyth's historical account from 1889, elephants were once present in northern Chhattisgarh and experienced local extinction throughout the early years of the 20th century (Singh, 2002). However, in recent decades, increasing anthropogenic pressure in the adjoining states has forced elephant to venture into the state of Chhattisgarh (Natarajan *et al.*, 2023b). As reported, only 18 elephants moved into Chhattisgarh in 1988, but from 1998 onwards, the population gradually increased, reaching 247 individuals by 2017 (MoEF&CC, 2017). The incidence of human-elephant conflict has been on the rise since 2000 due to the steady increase in the number of migratory elephants entering Chhattisgarh (Singh, 2002). Presently, Chhattisgarh hosts an expanding metapopulation of 451 (Qureshi *et al.*, 2021–2025). Asian elephants, occurring across fragmented forest-agriculture mosaics in the northern districts like Surguja, Korba, Raigarh, Jashpur with individual elephant utilising annual home ranges of around 3,000km^2 (Natarajan *et al.*, 2023b).

The issue of human-elephant conflict presents a substantial hindrance to conservation endeavours and rural livelihoods in various regions of India, including Chhattisgarh. This conflict is marked by elephants inflicting damage to crops and property, resulting in human and elephant casualties (Natarajan *et al.*, 2025). Understanding the drivers of elephant mortality is critical for devising effective conservation and conflict-mitigation strategies, especially in regions where human–elephant interactions are intense. Chhattisgarh has emerged as one of the most challenging landscapes for elephant conservation in India, with consistently high rates of mortality recorded over the past two decades (Habib *et al.*, 2025). Despite the seriousness of the issue, a systematic evaluation of causes, spatial distribution, and demographic correlates of elephant deaths in this region remains lacking. First, investigating the temporal and spatial changes in mortality causes will help identify whether certain hazards, such as electrocution, poisoning, and other anthropogenic threats, have intensified or shifted geographically over time. This information is essential to target high-risk zones for mitigation measures. Second, analysing the association between age/demographic classes and specific mortality causes can provide insights into vulnerability patterns. For instance, calves and juveniles may be more susceptible to accidents or starvation, while adults may face higher risks from conflict-related electrocution or poisoning. Such demographic insights are vital for prioritising management interventions. Third, linking mortality data with landscape features and anthropogenic factors (e.g., habitat fragmentation, agriculture expansion, mining, power lines, or linear infrastructure) will help explain underlying drivers of mortality. This spatially explicit approach will not only clarify how human pressures shape mortality patterns but also guide landscape-level planning, such as corridor restoration, safe power infrastructure, and conflict-reduction strategies.

By addressing these three aspects, the study will provide a comprehensive, evidence-based framework to reduce elephant mortality in Chhattisgarh. The findings will be directly applicable to conservation policy, inform conflict mitigation programs, and support long-term coexistence between people and elephants in this high-conflict state.

Therefore, in the present study, we investigate the changes in elephant mortality causes and their spatial distribution in Chhattisgarh over the past two decades (2000-2023). The specific objectives are as follows: (i) How did the causes of elephant mortality and their spatial distribution in Chhattisgarh change over the past two (2000-2023) decades? (ii) Is there any significant association between the age and demography of deceased elephants and specific causes of mortality, particularly focusing on anthropogenic stressors? (iii) How do landscape and anthropogenic features over the same periods potentially influence these mortality patterns?

Study Area

The study was conducted in Chhattisgarh, India (Fig. 1), which lies between 17°46′N and 24°05′N latitude and 80°15′E and 84°20′E longitude. Chhattisgarh has a total geographical area of 135,192 km^2, of which 55,547 km2 (41.09%) is under forest cover. It has a hot and humid tropical climate with three distinct seasons: summer (March to May), rainy (June to October), and winter (November to February). Summer temperatures range from 30 ∘ C to 45 ∘ C, while winter temperatures range from 8 ∘ C to 25 ∘ C. The region receives an average of 1,292 mm of rainfall each year, with the most precipitation happening in July and August months. Chhattisgarh can be geographically divided into three main zones: Northern Hills, Bastar Plateau, and Chhattisgarh Plains. The Northern Hills and Bastar Plateau areas are covered with natural forests, while Chhattisgarh Plains are primarily used for agriculture. The steep southwest sections of the Bastar Plateau are part of Central India's Satpura hills, specifically the Maikal Range. Chhattisgarh's forest cover comprises 12 distinct forest types, predominantly classified into two major categories: tropical moist deciduous forests and tropical dry deciduous forests (Champion & Seth, 1968). These forest types form the ecological backbone of the region, influencing biodiversity patterns, habitat availability, and ecosystem functions.

Methods

Data Analysis

The data of 218 elephant mortality cases over 23 years were collected from 19 divisional forest offices in Chhattisgarh, detailing incident locations, division name, date of the incidents, human fatalities and injuries (with gender). Surveys were conducted in conflict-affected villages, in collaboration with forest officials, to gather more precise and detailed information on incidents. For each mortality incidence, we standardised the categories of the data for: (1) the cause of death, (2) time of incident (year, month and season: monsoon, post-monsoon, summer and winter); (3) division-wise list; (4) age and demography of the dead elephant. The details of the causes of death were further recorded with additional classification (see Table 1). Elephant deaths brought by natural calamities and unprecedented accidents like drowning, lightning strikes, and falls from hills were included in accidental deaths. Age groups were categorised as calf (0-1 year), juveniles/yearlings (1-5 years), sub-adults male and female (6-15 years), and adult male and female (16+ years) (Arivazhagan & Sukumar, 2008).

Land use land cover change, and factors influencing elephant mortality

The satellite data spanned from 2000 to 2024 and were divided into five intervals: 2000–2005, 2005–2010, 2010–2015, 2015–2020, and 2020–2024. Land Use Land Cover (LULC) change analysis was performed using Landsat 5 TM and Landsat 8 OLI imagery, each with a spatial resolution of 30 m (Figure 2). Chhattisgarh falls within UTM Zone 46. Six bands (blue, green, red, NIR, and two SWIR) were used for classification, while the QA band was applied for cloud and shadow masking. We collected 1,250 random points for RF classifier training and validation, with 70% used for training and 30% for validation in each iteration. Accuracy assessment quantified classification effectiveness. Google Earth Engine (GEE) handled image

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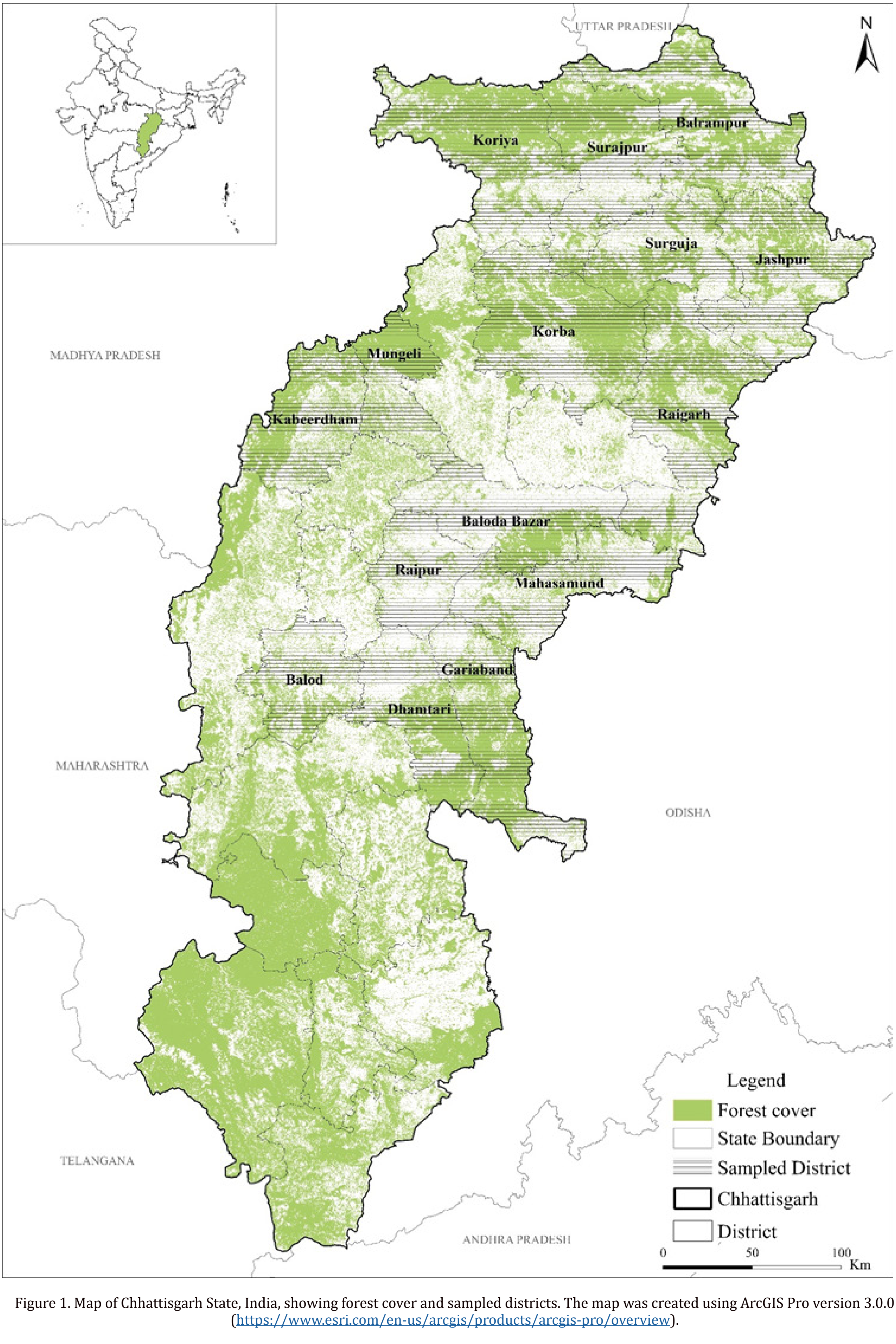

Figure 1. Map of Chhattisgarh State, India, showing forest cover and sampled districts. The map was created using ArcGIS Pro version 3.0.0 (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview).

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Table 1. Causes of elephant deaths reported in the state of Chhattisgarh from 2000-2023

Causes of Elephant deaths	Indirect/ Direct sources	Categories
Still birth, old age, heart attacks, malnourishment, heat stroke, dehydration, illness	Natural	Natural
drowning, lightning strikes, fall from hills	Natural calamities, accidents	Accidental
Poisoning	Retaliation killing, HEC	Poisoning
Poaching	HEC	Poaching
Territorial fights	Natural behaviour, Interspecies conflict, decrease in territorial space	Territorial fights
falling into canals and wells, stuck in drains, electro-cution	Anthropogenic climate change, stress due to human infrastructures	Anthropogenic stressors

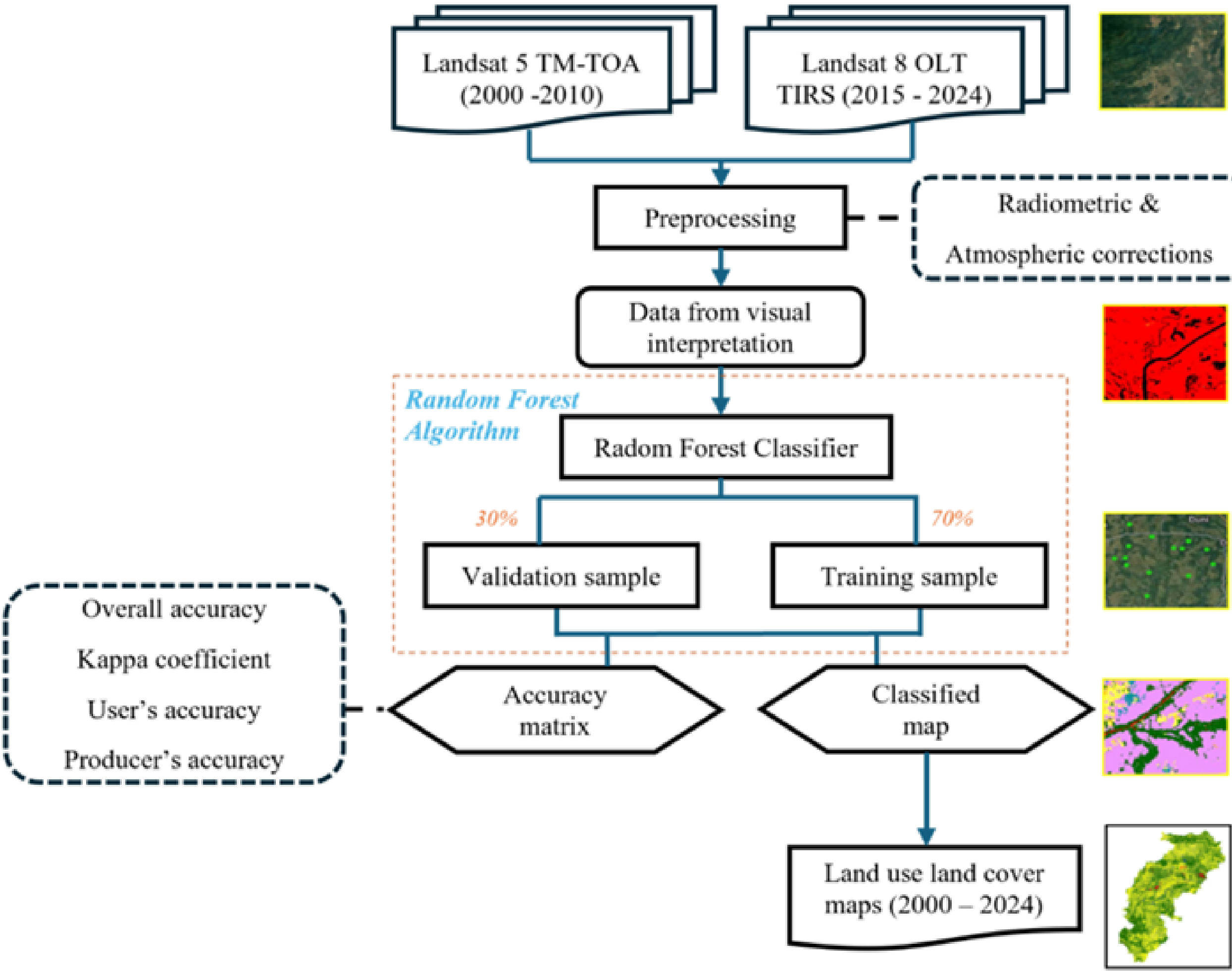

Figure 2. Flowchart of the methodology used to study the land use and land cover change pattern in the state of Chhattisgarh, India

processing and classification, while ArcGIS Pro was used for sub-setting, fragmentation analysis, distance calculations, and map preparation. A supervised pixel-based RF algorithm classified the Landsat dataset. The GEE was chosen for its robust accuracy and ability to handle large, high-dimensional datasets. RF classifiers applied to Landsat imagery in GEE effectively mapped five LULC categories: (1) forest, (2) water, (3) barren land, (4) agriculture, and (5) settlement. This study used the RF classifier from the "*smileRandomForest*" library. Using the forest cover class from the LULC maps, we extracted Patch Density (PD), Edge Density (ED), and Largest Patch Index (LPI) with FRAGSTATS v.4.2. A 7 km moving window analysis, based on the average movement of elephants (Hassan *et al.*, 2023), was used to generate a continuous surface, ensuring ecologically relevant outcomes. The forest cover and fragmentation analyses in this study are based on remote sensing classification techniques and have not been field-verified due to the absence of ground reference points. Elephant death distribution was analysed with kernel density estimation in ArcGIS to identify mortality patterns across divisions and villages. Generalised linear models (GLMs) with a binomial distribution in R (version 4.3.1) were employed to predict the influence of ecogeographical and anthropogenic variables on elephant mortality incidents (excluding natural deaths). The occurrences of mortality were

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coded as 1, while pseudoabsence locations (coded as 0) were generated using a two-step approach: (i) generating random points using the "Create Random Points" tool in ArcGIS Pro, and (ii) removing any points located within 1 km of a mortality incident to ensure they represented non-mortality zones. A total of 84 pseudoabsence points were retained after this filtering.

The GLM analysis included 12 explanatory variables: distances to forests, croplands, built-up areas, roads, railways, mines, waterways, protected areas, and elephant reserves, along with edge density, patch density, and largest patch index from *FRAGSTATS*, based on various hypotheses (Table 2). Model performance was evaluated using AIC, with models having ΔAIC ≤ 2 considered well-supported (Burnham & Anderson, 2002). Model selection was conducted through univariate analyses assessing the significance of each predictor, followed by collinearity checks to remove highly correlated variables (VIF > 5). We then developed multiple candidate models and evaluated them using the Akaike Information Criterion (AIC), retaining models with ΔAIC ≤ 2. Likelihood ratio tests were applied to compare nested models and assess predictor significance. The final model was selected based on the lowest AIC value and retained only significant predictors, ensuring an optimal balance between explanatory power and parsimony. The "*MuMIn*" package in R was used for model ranking.

Village categorisation for elephant mortality
To assess elephant mortality distribution in Chhattisgarh, we categorised villages into three groups: low (0–10 deaths), medium (11–20 deaths), and high (more than 20 deaths). This classification helped identify environmental factors influencing mortality, such as forest percentage, crop percentage, mines percentage, water density, built-up percentage, and road and railway density. Understanding these patterns shall allow targeted mitigation efforts, focusing on high-risk areas for habitat restoration, conflict management, and infrastructure improvements.

Results

Land use land cover
The land use and land cover (2000 - 2024) changed in forest cover, water bodies, barren land, cropland, and built-up areas (Fig.3). There has been a change of -7.26% in forest cover, with a change observed in 2005 (-2.47%), 2010 (-5.84%), 2020 (-1.02%), and 2024 (-1.76%). Urbanisation has shown an upward trend (Supplementary Table 1). The fragmentation analysis showed a high fragmentation in the northern and eastern regions of Chhattisgarh, with high edge density and patch density. Eastern areas have better forest connectivity with large continuous patches. The highly fragmented central part of Chhattisgarh faces a high risk of human elephant conflict (SF2).

Temporal and age demography
The long-term conflict records spanning over 23 years in Chhattisgarh resulted in a total of 218 elephant deaths attributed to multiple causes. Out of these, 134 were non-anthropogenic deaths, including natural cases (115 deaths), unknown (13 deaths), territorial fight (7 deaths) (SF1). While 84 anthropogenic causes included electrocution (76 deaths), poisoning (5 deaths), poaching (2 deaths), retaliatory killing (1 death), and vehicular accident (1 death). Electrocution emerged

Table 2. Factors Influencing Elephant Mortality in Chhattisgarh: A Priori Hypotheses

Feature	Variables	Source	A-priori Hypothesis
Landcover	Distance from Built-up (db)	Different landcover types (built-up, cropland, forest, waterbodies) are extracted from classified landcover data. Distance between conflict points and landcover were calculated using the Near Table tool (ArcPro 3.0.0).	Closer proximity to built-up areas may increase elephant mortality due to accidents, retaliatory killings, and habitat loss.
	Distance from Cropland (dc)		Higher elephant mortality is expected near croplands due to conflict arising from crop raiding and retaliatory actions.
	Distance from Forest (df)		Mortality may be lower near forests but increase at forest edges due to human-elephant interactions and habitat fragmentation.
	Distance from Waterbodies (dw)		Mortality risk may be higher near waterbodies, especially during dry seasons when elephants cluster around limited water sources, increasing human encounters.
Anthropogenic	Distance from Roads (dr)	Shapefile was obtained from OpenStreetMap and processed in GIS.	Proximity to roads may increase elephant mortality due to vehicle collisions and restricted movement corridors.
	Distance from Mines (dmn)	Mining areas were mapped using Google Earth Pro.	Mining areas may contribute to elephant mortality due to habitat destruction, pollution, and accidental falls into pits.
Protected Areas	Distance from Protected Areas (dpa)	Protected areas, Elephant Reserves were mapped using shapefiles from the Elephant Cell of WII.	Mortality may be higher at PA boundaries where elephants move into human-dominated landscapes, facing poaching or retaliation.
	Distance from Elephant Reserves (der)		Higher mortality may occur near reserves as elephants disperse into unprotected areas with human activity.

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Landscape Metrics	Edge Density (ED)	Calculated using landscape metrics in FRAGSTATS.	Increased edge density may elevate mortality due to fragmented habitats forcing elephants into high-risk areas.
	Patch Density (PD)		Higher patch density may correlate with increased mortality by restricting movement and increasing conflict zones.
	Largest Patch Index (LPI)		Larger continuous patches may reduce mortality by offering safer movement corridors, while fragmented areas may heighten risks.

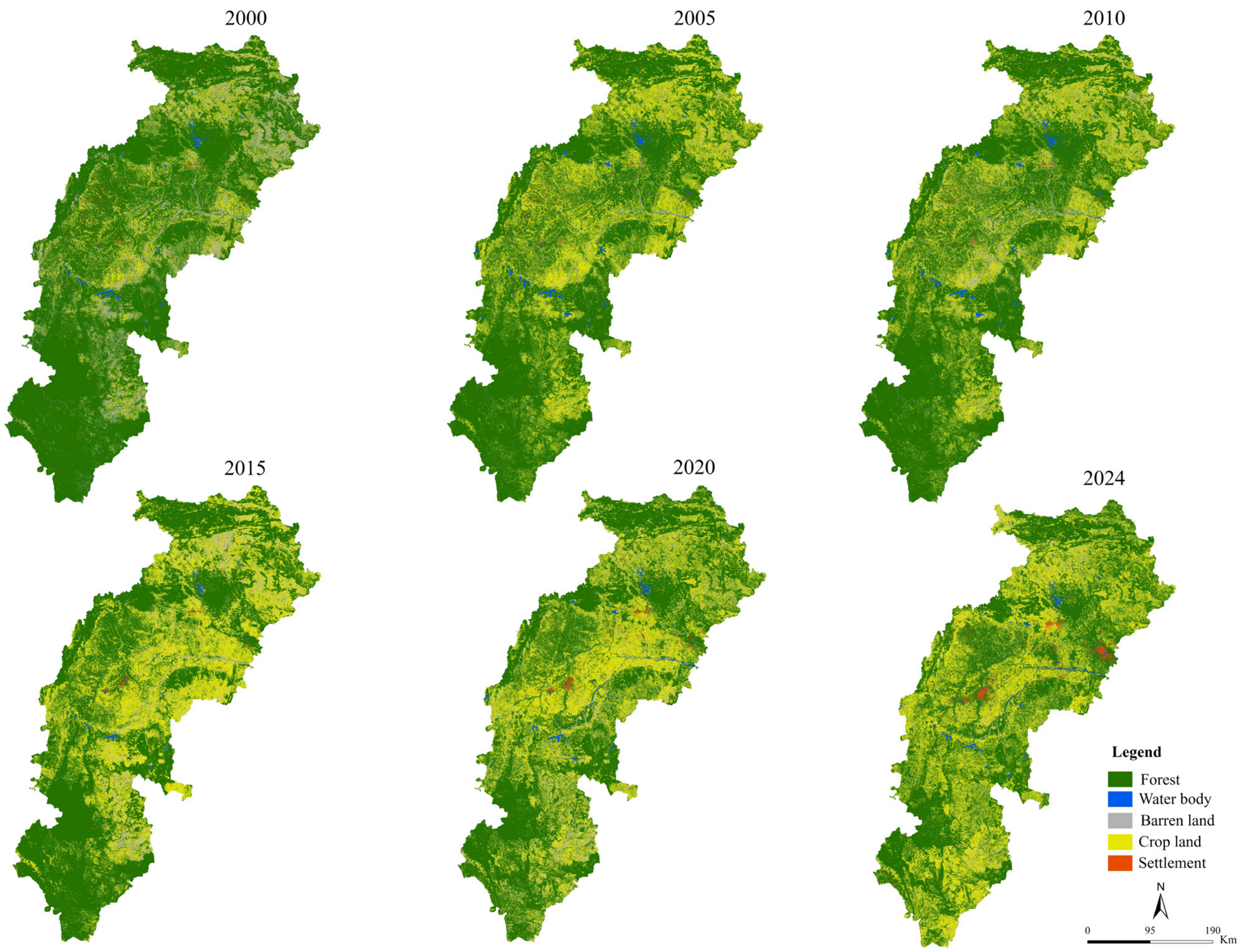

Figure 3. Land use land cover (LULC) maps of Chhattisgarh state, India, for the years 2000, 2005, 2010, 2015, 2020, and 2024. The maps were created using ArcGIS Pro version 3.0.0 (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview).

as the key reason for the elephant deaths, out of the anthropogenic causes (χ^2 = 11.468, df = 1, p-value = 0.001; Fig. 4). The number of death cases due to anthropogenic causes differed significantly across age and groups (χ^2 = 118.59, df = 5, p-value < 2.2e-16), with adult males having the highest numbers of deaths (35), followed by adult female (17), sub adult male (13), sub adult female (4), yearling (5) (Fig. 5). Among seasons, elephant deaths mostly occurred in monsoon season (26 deaths) (χ^2 = 5.101, df =3, p = 0.164), followed by post monsoon (20), winter (21) and the least deaths occurred in pre monsoon (12). Divisional variation showed that the highest elephant mortalities were observed in Dharamjaigarh (33 cases), with the most deaths occurring because of electrocution (33 cases), followed by Raigarh (11 cases; 8 electrocution cases), Jashpur (10; all electrocution cases), and Surajpur (9; all electrocution cases) (SF3). Kernel density estimation of the mortality represents the same (Fig.6).

Village-level analysis of elephant mortality and its influencing factors

A total of 48 villages were identified where elephant mortality has occurred, with the most cases in Dharamjaigarh (15 deaths), followed by Chhal (10 deaths), Amandon and Goreapipar (4 deaths each), and Katghora and Raigarh (3 deaths each). High-incident villages had greater built-up density, while non-incident villages showed the lowest levels (Kruskal-Wallis Test: χ^2 = 8.8701, p = 0.0310). Water sources remained relatively stable across all village categories (χ^2 = 7.981, p = 0.0463). Cropland cover was substantially higher in high-fatality villages (χ^2 = 9.236, p = 0.02631; Figure 7). Post-hoc Dunn's test revealed specific pairwise differences (Table 3). The road density (χ^2 = 7.1148, p = 0.06833) approached significance, suggesting a potential trend but not meeting the conventional threshold.

Elephants' deaths were significantly influenced by habitat and human-induced factors, distance to cropland (β = -1.237, p = 0.016), and distance to elephant reserves (β = -1.357, p = 0.001).

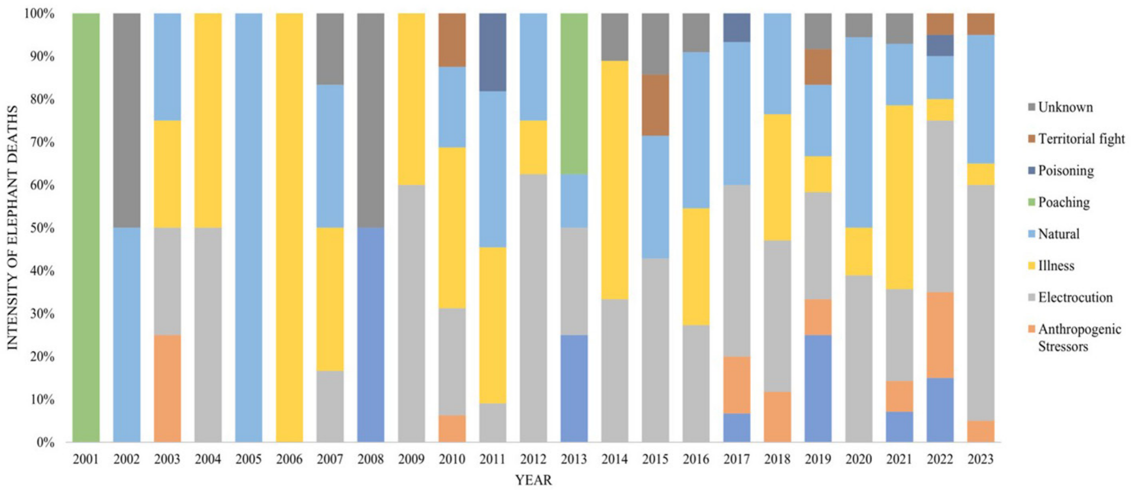

Figure 4. Temporal trends of elephant mortality 2000 to 2023 in Chhattisgarh, India

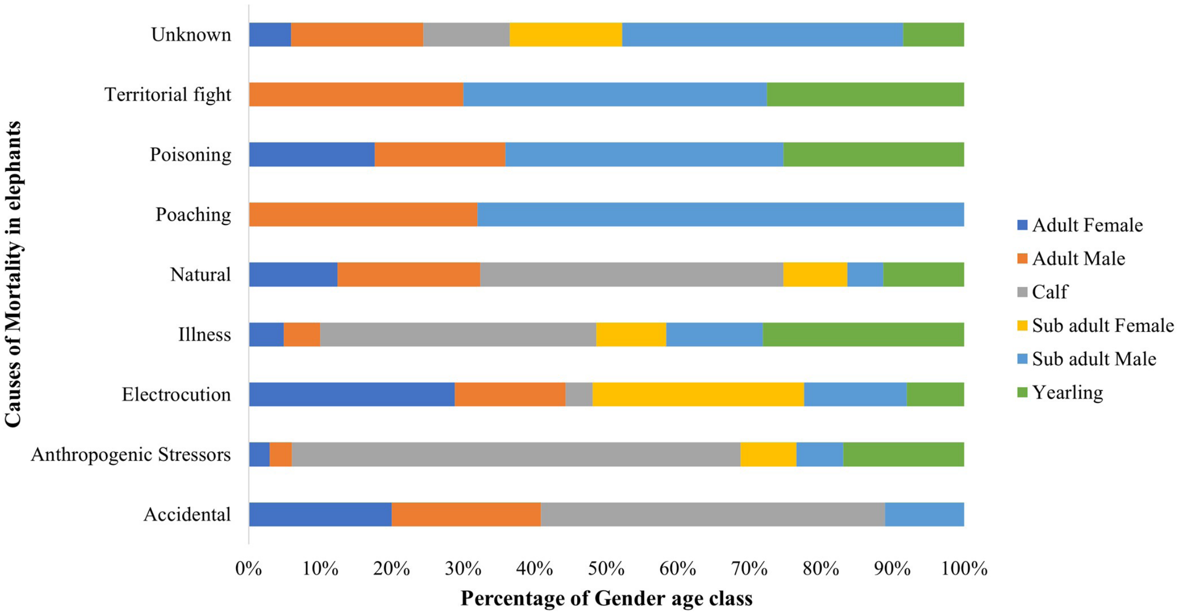

Figure 5. Age demography of elephants and its relation to different causes of mortality in Chhattisgarh, India (2000-2023)

Additionally, landscape features like the largest patch index (β = -0.984, p = 0.001) and edge density (β = -0.676, p = 0.009) showed significant negative relationships. Distance to built-up areas (β = -0.461, p = 0.074) and distance to mines (β = -0.510, p = 0.064) were marginally significant. Distance to forest (β = 0.487, p = 0.031), distance to protected areas (β = 0.364, p = 0.182) showed a positive trend. Distance to water (β = -0.607, p = 0.096), distance to roads (β = -0.133, p = 0.594) did not exhibit significant relationships with mortality risk (Table 4 & 5, Fig.8).

Discussion

Our study on land use land cover highlights that deforestation and conversion of cropland to built-up areas over the last two decades could be one of the drivers of rising HEC in Chhattisgarh. The rapid expansion of coal mining, urbanisation, and linear infrastructure has fragmented critical elephant habitats and disrupted elephant movement pathways (Khan *et al.*, 2016). The east-central region, particularly Chhattisgarh, has the highest number of identified elephant corridors in India, totalling 52 (Pandey *et al.*, 2024), highlighting the extensive fragmentation of this landscape.

The situation is exacerbated by habitat mosaic complexity, mining expansion, and rapid infrastructure growth, leading to increased encounters and conflict-related mortalities (Natarajan *et al.*, 2023b). A significant portion of elephant range lies outside Protected Areas, in fragmented, human-dominated landscapes where the interspersion of forests and croplands heightens conflict intensity. Sustainable land-use planning is both an ecological and socio-political necessity to ensure the conservation of elephants and the safety and livelihoods of local communities (Pandey *et al.*, 2024). LULC changes in Chhattisgarh reflect significant human-driven transformations, with a decline in forest cover, particularly in Korba and Raigarh, driven by expanding coal mines and urbanisation (Bhagat *et al.*, 2024). Deforestation threatens biodiversity, disrupts carbon sequestration, and reduces water availability, while the conversion of cropland into built-up areas raises concerns about food security (Khan *et al.*, 2016). Urbanisation, driven by population and economic growth, demands better land-use planning to balance development and sustainability. Similar trends have been observed in the Mahanadi River basin, with projections indicating a decline in grassland and an increase in croplands (Sahu *et al.*, 2024). Rapid urban expansion in Raipur has further contributed to the conversion of agricultural and open lands into built-up areas (Khan *et al.*, 2016). Henceforth, implementing sustainable land management strategies remains critical to address these emerging challenges effectively.

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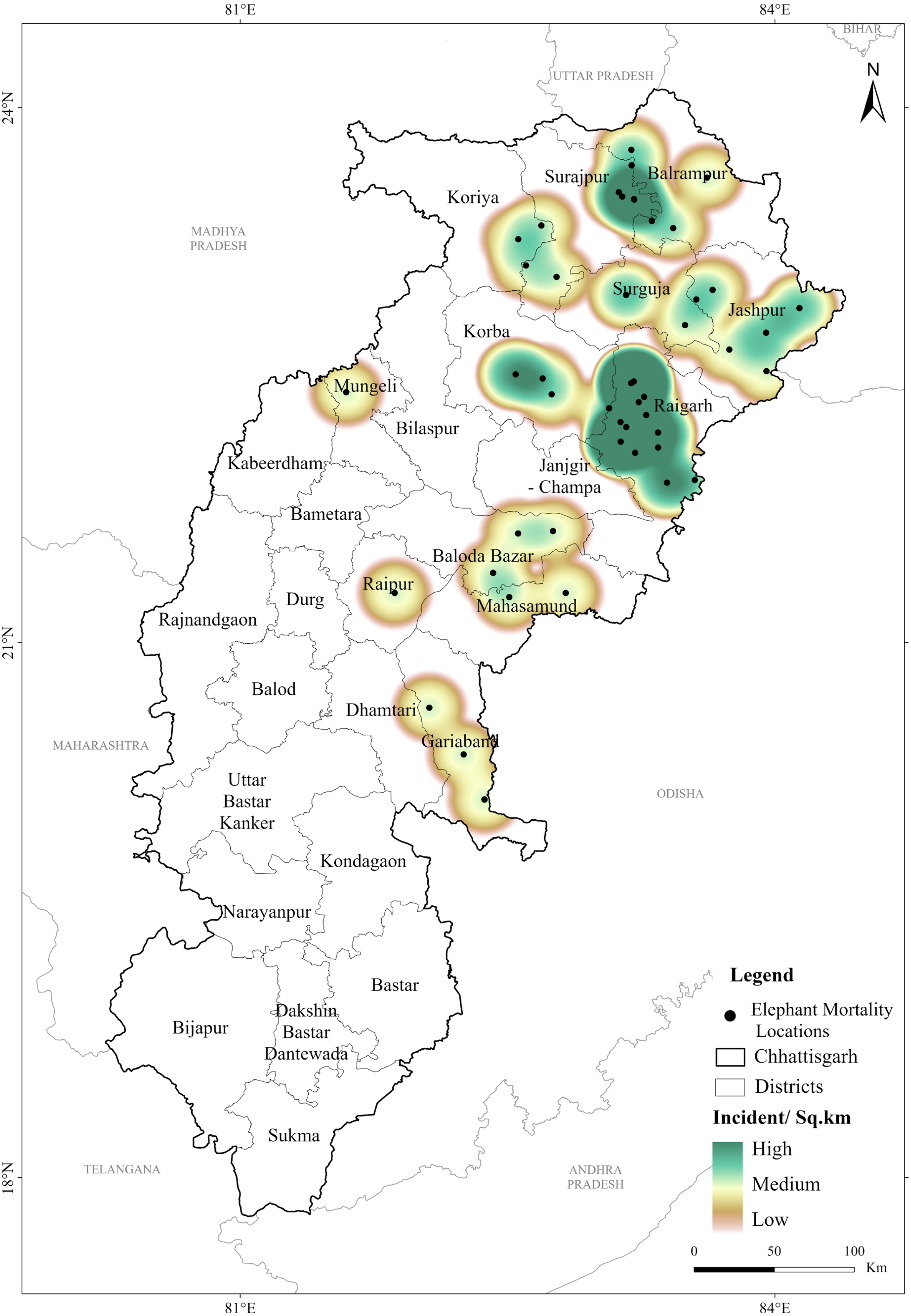

Figure 6. Hotspots of elephant deaths in Chhattisgarh State, India, from 2000 to 2023. The map was created using the kernel density tool in ArcGIS Pro version 3.0.0 (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview).

Table 3. Post hoc Dunn's Test for Significant Kruskal-Wallis Results

Variable	Comparison	p-value	Adjusted p-value
Water	Incident vs. Low Incident	0.0186	0.111
Built-up	Incident vs. Medium Incident	0.0146	0.0876
Crop	Incident vs. Medium Incident	0.0157	0.0944
Crop	Medium Incident vs. Low Incident	0.0245	0.147

Table 4. Summary statistics, log-likelihood (LogL), degrees of freedom (df), Akaike Information Criteria (AICc), relative support for hypothesis (Δ AICc), Akaike weights (Wi) of the candidate regression model explaining elephant mortality in Chhattisgarh.

Model	LogL	df	AICc	ΔAICc	Wi
dw + dr + df + dc + db + der + dpa + dmn + lpi + ed	-69.484	11	162.577	0.000	0.181
df + dc + db + der + dpa + dmn + lpi + ed	-71.842	9	162.767	0.190	0.165
dw + dr + df + dc + db + der + dpa + dmn + lpi + pd + ed	-68.857	12	163.629	1.052	0.107
df + dc + db + der + dpa + dmn + lpi + pd + ed	-71.363	10	164.060	1.483	0.086
dr + df + dc + db + der + dpa + dmn + lpi + ed	-71.435	10	164.204	1.627	0.080
df + dc + der + dmn + lpi + ed	-75.065	7	164.796	2.219	0.060
df + dc + der + dpa + dmn + lpi + ed	-74.024	8	164.910	2.333	0.056
dr + df + dc + db + der + dpa + dmn + lpi + pd + ed	-70.764	11	165.138	2.561	0.050
dc + db + der + dpa + dmn + lpi + pd + ed	-74.274	9	167.632	5.055	0.014
dw + dr + df + dc + db + der + dpa + dmn + lpi + pd	-73.023	11	169.655	7.078	0.005
df + dc + der + lpi + ed	-78.802	6	170.102	7.524	0.004
db + der + dpa + dmn + lpi + pd + ed	-77.028	8	170.918	8.340	0.003
der + lpi + ed + dmn	-80.811	5	171.976	9.399	0.002
der + dpa + dmn + lpi + pd + ed	-79.392	7	173.451	10.874	0.001
der + dpa + lpi + ed + dpa + dmn + pd	-79.392	7	173.451	10.874	0.001
null (Intercept only)	-121.983	1	245.988	83.411	0.000

Table 5. Parameter estimates effect (β) and probabilities of ecological and anthropogenic variables in determining the mortality of the Asian elephant due to various anthropogenic factors

Predictor	Beta	Z_value	P_value	Significance
(Intercept)	-0.378	-1.555	0.120	
Distance to waterbodies (dw)	-0.607	-1.663	0.096	.
Distance to roads (dr)	-0.133	-0.533	0.594	
Distance to forest (df)	0.487	2.152	0.031	*
Distance to croplands (dc)	-1.237	-2.413	0.016	*
Distance to built-up (db)	-0.461	-1.784	0.074	.
Distance to Elephant Reserves (der)	-1.357	-4.529	0.001	***
Distance to Protected Areas (dpa)	0.364	1.334	0.182	
Distance to mines (dmn)	-0.510	-1.852	0.064	.
Largest Patch Index (LPI)	-0.984	-3.616	0.001	***
Edge Density (ED)	-0.676	-2.599	0.009	**

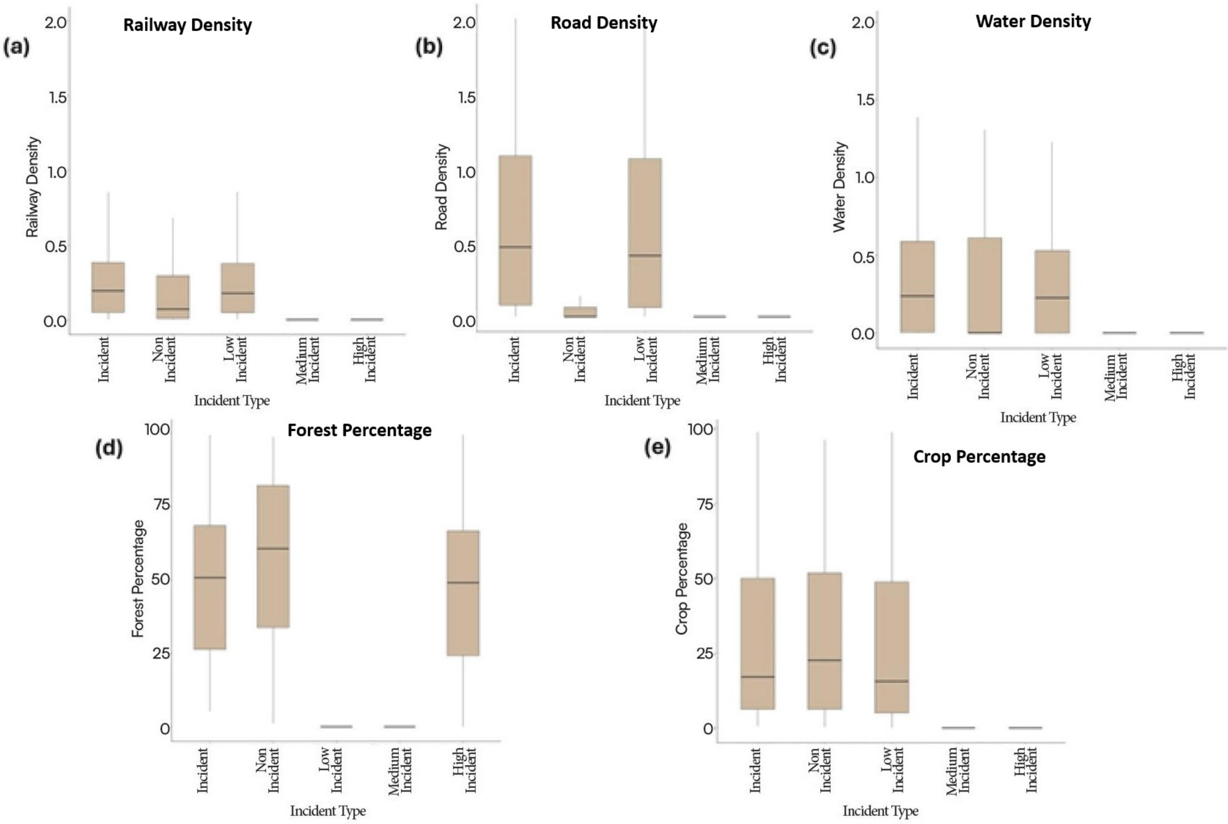

Figure 7. Box plot showing the built-up density, road density, railway density, crop percentage, forest percentage and mining percentage in non-incident, low-incident, medium-incident and high-incident villages in Chhattisgarh, India.

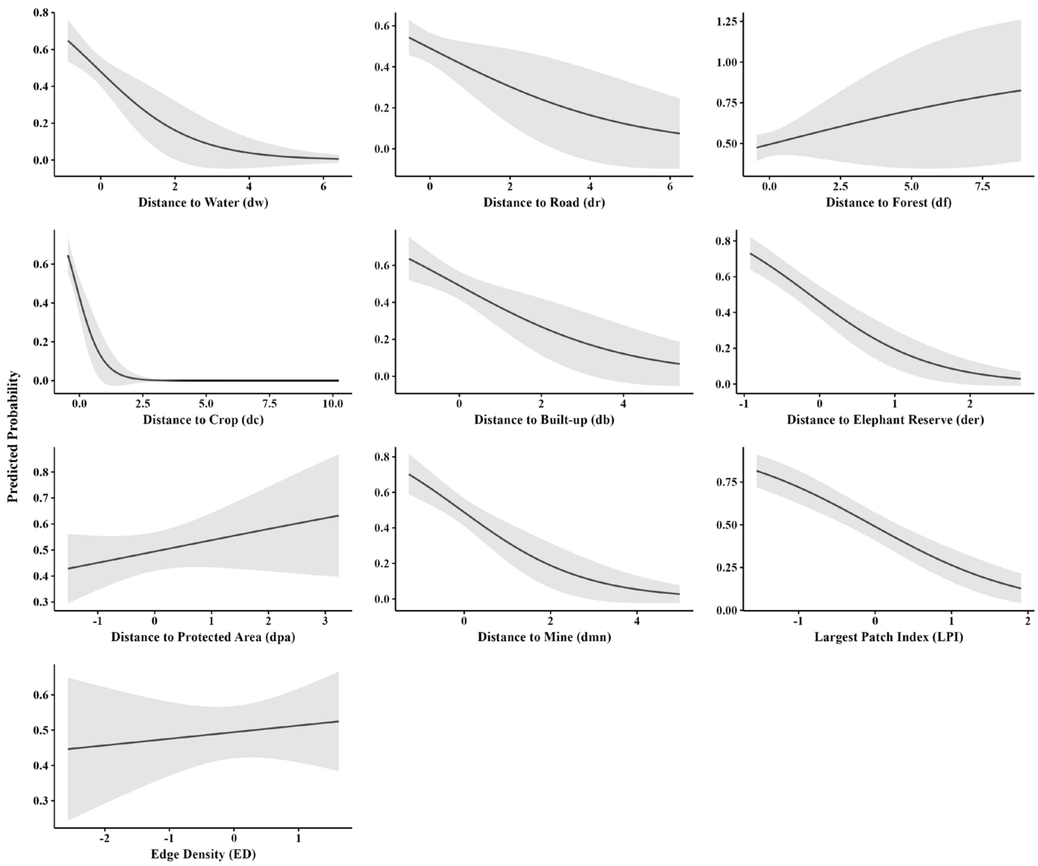

Figure 8. Graphs showing the probability prediction of elephant mortality in relation to the different selected variables in Chhattisgarh, India.

 https://doi.org/10.63033/JWLS.WNKA3460

Furthermore, our findings highlight electrocution as the predominant cause of elephant mortality across divisions (in Chhattisgarh), particularly in areas with extensive electrical infrastructure. The concentration of fatalities in Dharamjaigarh, Raigarh, Jashpur, and Surajpur suggests a strong link between illegal fencing using distribution lines and, to some extent, sagging of power lines. Similar patterns have been reported elsewhere in India, where expanding settlements and poorly managed electrical networks heighten electrocution risk (Baskaran *et al.*, 2013; Gubbi *et al.*, 2014; LaDue *et al.*, 2012; Sangma *et al.* 2025). The highest number of elephant deaths due to electrocution reported from Dharamjaigargh could be linked to the widespread deployment of illegal electrical fencing surrounding agricultural fields in the area. A similar trend is also seen in other elephant landscapes in Tamil Nadu and Karnataka (Ladue *et al.*, 2012; Gubbi *et al.*, 2014).

Our study also showed that adult males experience the highest anthropogenic mortality, consistent with patterns observed in northern West Bengal (Roy *et al.*, 2017). This greater vulnerability is linked to male behaviour during musth, when they frequently enter human settlements or move along railway tracks, increasing the likelihood of fatal encounters. Habitat encroachment and expanding agriculture further compel elephants to forage in croplands, particularly during harvest seasons when raids peak (Pradhan *et al.*, 2013; Palei *et al.*, 2014). The loss of mature elephants, particularly socially dominant individuals such as matriarchs, can disrupt herd structure, cohesion, and decision-making (Douglas-Hamilton *et al.*, 2006). Adult elephants play a critical role in transmitting survival skills and guiding herd behaviour, and their absence can result in unpredictable behaviour, increased intra-herd aggression, and elevated human–elephant conflict. Studies have also shown that herds affected by culling or adult mortality exhibit social instability, whereas stable herds with intact social systems maintain cohesive interactions (Shannon *et al.*, 2013).

The current study showed that elephant mortality in Chhattisgarh was primarily influenced by both ecological and anthropogenic factors, consistent with earlier research on habitat fragmentation and human activity (Singh, 2002; Roy *et al.*, 2025). Across Asia and Africa, studies have linked habitat loss, fragmentation, and natural factors to increased elephant mortality and human-elephant conflict (Ladue *et al.*, 2021; Moeng *et al.*, 2022; Yu *et al.*, 2024). Agricultural expansion and urbanisation were key drivers of mortality, intensifying conflict as elephants were drawn to high-energy crops (Baskaran *et al.*, 2013; Shaffer *et al.*, 2019). Landscape metrics such as edge density (ED) and largest patch index (LPI) underscored the influence of habitat configuration, while distance to protected areas and water sources was less relevant due to elephants' wide-ranging movements. Infrastructure development, particularly mining and railways, posed emerging threats, with impacts varying by region (Chakraborty *et al.*, 2021). The near-significant link between road networks and mortality suggests that expanding infrastructure in elephant habitats could further elevate risks (Laurance *et al.*, 2009; Vanak *et al.*, 2010).

Conclusion

Over the past two decades, the elephant population in Chhattisgarh has increased, intensifying human–elephant conflicts driven by habitat loss, fragmentation, and electrocution. Major mortality hotspots such as Dharamjaigarh, Chhal, Amandon, Goreapipar, Katghora, Kunkri, and Raigarh highlight the urgent need to restore habitat connectivity and manage human activities. High-risk zones where elephants encounter power lines require immediate action, including insulation and elevation of lines to 6–7 meters and regular maintenance. Promoting solar power can further reduce dependence on high-voltage infrastructure.

Habitat restoration, corridor maintenance, and early warning systems are key to minimising conflict. Community initiatives such as "Elephant Watch Groups," compensation programs, and awareness campaigns can foster coexistence and reduce retaliation. Infrastructure measures like underpasses and overpasses, aligned with Wildlife Institute of India guidelines, ensure safe elephant movement across fragmented landscapes.

Technological innovations including AI-based predictive models, drones, satellite tracking, and smart collars with geofencing are transforming elephant management. Tools like the Gaj Sanket alert system, Elephant Tracking and Alert App, and Hathi Mitra Dal groups (Telegraph India, 2023; Down To Earth, 2022) have enabled real-time alerts and rapid response (The Hitavada 2022). Collaborative efforts with Kalpvaig app have generated over two million alerts across 14 divisions, engaging 20,000 villagers and 5,000 officials, contributing to zero human casualties in Udanti–Sitanadi TR (Times of India 2024; NDTV, 2024).

Overall, integrating scientific tools, community engagement, and policy support provides a robust framework for mitigating human–elephant conflict. Sustained research, adaptive management, and technology-driven conservation are essential to ensure long-term coexistence between people and elephants in Chhattisgarh.

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CONFLICT OF INTEREST

Bilal Habib & Parag Nigam hold editorial positions at the Journal of Wildlife Science. However, none of them participated in the peer review process of this article except as authors. The authors declare no other conflict of interest.

DATA AVAILABILITY

The data used in the study are available upon request from the corresponding author

AUTHOR CONTRIBUTIONS

Bilal Habib: Conceptualization (lead); Funding acquisition (lead); Investigation (lead); Methodology (lead); Project administration (lead); Resources (lead); Software (lead); Supervision (lead); Validation (lead); Visualization (lead); Writing-review & editing (lead). Ramesh Kumar Pandey: Conceptualization (lead); Funding acquisition (lead); Investigation (lead); Methodology (lead); Project administration (lead); Resources (lead); Supervision (lead); Validation (lead); Visualization (lead); Writing-review & editing (lead). Kalpana Roy: Data curation (equal); Formal analysis (equal); Methodology (equal); Writing-original draft (equal); Writing-review & editing (equal). Athira N. G: Data curation (equal); Formal analysis (equal); Methodology (equal); Writing-original draft (equal); Writing-review & editing (equal). Ananya Dutta: Data curation; Formal analysis; Methodology; Dheeraj Mittal: Data curation (equal); Investigation (equal); Methodology (equal); Resources (equal); Validation (equal); Writing-review & editing (equal). Parag Nigam: Data curation (equal); Investigation (equal); Methodology (equal); Resources (equal); Validation (equal); Writing-review & editing (equal). Anukul Nath: Data curation (equal); Investigation (equal); Formal analysis (lead), Methodology (equal); Resources (equal); Validation (equal); Writing-review & editing (equal).

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