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Research paper

Assessing Wildlife Mortality Causes and Temporal Patterns: Insights from MaxEnt Modeling in Banke and Bardiya National Parks, Nepal

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ABSTRACT

Anthropogenic pressures significantly impact wildlife mortality in human-dominated areas. This study examined the risk areas, patterns, and causes of animal mortality within Nepal's Banke and Bardiya National Parks, analyzing 1,068 reported events using the Maximum Entropy (MaxEnt) model. In Banke, 449 mortality incidents were recorded, with 87% (390) attributed to anthropogenic causes, while in Bardiya, 619 incidents were documented, with 59% (367) attributed to anthropogenic factors and the remaining 41% (252) categorized as non-anthropogenic. Although both parks recorded varying patterns of mortality, statistical tests ($p > 0.05$) suggest no significant differences in mortality, despite seasonal variations. In Banke, anthropogenic mortality exhibited significant seasonality ($p = 0.001$), while in Bardiya, anthropogenic mortality lacked significant seasonal variation ($p = 0.121$), though non-anthropogenic mortality showed significant seasonality ($p = 9.841e^{-13}$). Major causes of mortality in Banke include roadkill, feral dog attacks, natural mortality, and electric wire incidents, while in Bardiya, roadkill is the leading cause, followed by irrigation canal accidents, illegal hunting, and electric wire incidents. Both parks also experience non-anthropogenic mortality, including a significant number of dog attacks. In Banke, road kills primarily affect *Sus scrofa* (wild boar, $n = 85$ instances) and *Axis axis* (spotted deer, $n = 54$ instances), while in Bardiya, spotted deer face high mortality due to dog attacks (103 cases) and road fatalities (125 incidents), with 63 related to irrigation canals. In Bardiya, wildlife mortality is concentrated near Motipur-Amerni-Bhurigaun and Chispani-Karanali, while in Banke, incidents are widespread, particularly around Shiva Khola village and along the Obary-Thorai-Kharikhola. These findings underscore the importance for policymakers and the scientific community to adopt holistic conservation strategies.

Keywords: human-wildlife conflict, mortality, MaxEnt model, vehicular collisions

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研究報告

評估野生動物死亡原因和時間格局：來自尼泊爾班克和巴迪亞國家公園物種分布模式MaxEnt建模見解

Shishilal Baniya,[1] Sewak Bhatta,[1] Santosh Ghimire,[2] Sudip Pandey[3]

摘　要

本研究採用最大熵模型(MaxEnt)分析尼泊爾班克(Banke)與巴迪亞(Bardiya)國家公園內1,068起野生動物死亡事件，以評估其死亡率、風險區域、時間模式及成因。於班克國家公園，共記錄449起死亡事件，其中87% (n =390)歸因於人為因素；而在巴迪亞國家公園，記錄619起事件，其中59% (n =367)與人為因素相關，其餘41% (n =252)則歸類為非人為因素。儘管兩個國家公園的野生動物死亡模式各異，但經統計檢定($p > 0.05$)顯示，死亡率在季節變化下並無顯著差異。於季節性模式分析顯示，班克國家公園內因人為活動導致的死亡率具有顯著的季節變化($p = 0.001$)，而巴迪亞國家公園則未呈現顯著的季節性變異($p = 0.121$)，但巴迪亞的非人為死亡率則表現出顯著的季節變異($p = 9.841\ e^{-13}$)。兩個國家公園內因人為因素導致野生動物死亡原因各異。在班克，主要死因包括：路殺、野狗襲擊、自然死亡及電線桿等事故；而在巴迪亞，路殺為主要死亡因素，其次依序為灌溉渠道事故、非法狩獵及電線桿等事故。此外，兩個公園皆觀察到大量野狗襲擊事件。在班克，路殺致死事件主要影響野豬(*Sus scrofa*，n = 85)及斑點鹿(*Axis axis*，n = 54)；而在巴迪亞，鹿類因野狗襲擊(n =103)與路殺(n =125)致死的比例較高，另有63起事件與灌溉管線有關。而空間分析結果顯示，在巴迪亞，野生動物死亡事件主要集中於Motipur-Amerni-Bhurigaun及Chispani-Karanali地區；而在班克，死亡事件分布較廣，尤以Shiva Khola村莊周圍及Obary-Thorai-Kharikhola沿線發生的機率較高。本研究結果顯示政策制定者和科學界需採取整體保保護策略的重要性。

關鍵詞：人類與野生動物衝突、死亡率、最大熵物種分布模式、車輛碰撞

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INTRODUCTION

Maintaining ecological balance through wildlife conservation is crucial, especially as the human population increasingly threatens wildlife, particularly vulnerable species (Gottert & Starik 2022). In response, numerous legal frameworks and instruments have emerged globally to protect wild species. Notable examples include the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the International Union for Conservation of Nature (IUCN) Red List, the Ramsar Wetlands Convention, and the Convention on Biological Diversity (CBD) (Trouwborst 2015). The CBD, in particular, has been instrumental in shaping modern legal policies that aim to balance ecological preservation with human interests (Cretois et al. 2019), reflecting an evolving recognition of the need to conserve global biodiversity while accounting for societal needs.

Human-wildlife conflict (HWC) is a significant challenge that arises from the complex interactions between human and wildlife populations (Pandey & Bajracharya 2016, Sharma et al. 2020) When humans and wildlife come into proximity, the likelihood of conflicts increases exponentially, posing a severe threat to species already facing habitat loss, climate change and other challenges that push them towards extinction (Carter et al. 2012). One of the significant concerns related to HWC is unnatural wildlife mortality resulting from anthropogenic activities (Joshi & Agarwal 2012). This type of mortality not only jeopardizes biodiversity but also affects ecosystem health, contributing to the global loss of species. Hill et al. (2020) found that approximately 28% of global wildlife mortality incidents are directly attributable to human activities, with larger animals and adult individuals disproportionally impacted compared to smaller species and juveniles. Understanding and addressing the causes of wildlife mortality is thus critical for effective conservation management and policy planning.

Modeling approaches, such as MaxEnt, play a key role in identifying areas with a high probability of wildlife mortality and highlighting the underlying drivers of human-wildlife conflict. MaxEnt, a machine learning algorithm, uses the principle of maximum entropy to predict species distribution based on environmental variables, contrasting background location data against presence location data to estimate potential occurrence zones (Phillips et al. 2006). While primarily used for species distribution, MaxEnt has also proven valuable in conservation scenarios where data may be incomplete or scarce (Phillips & Dudík 2008). This model is effective in pinpointing conflict hotspots and guiding conservation strategies where human-wildlife conflict is prevalent (Constant et al. 2015).

In Nepal, Banke and Bardiya National Parks face multiple threats beyond the well-known issues of deforestation, habitat loss, forest degradation, livestock grazing, illegal hunting, and poaching. Additional challenges arise from human migration, settlement, and the expansion of development projects in regions south of the parks (Chaudhary & Subedi. 2019). Furthermore, large-scale infrastructure projects, such as roads and railways cutting through protected areas and critical forest corridors, pose significant risks. Research indicates that these projects could degrade habitat quality by as much as 40% in some areas within and around the national parks (Sharma et al. 2018). As Nepal strives to achieve middle-income status by 2030, the Government of Nepal (GoN) has prioritized infrastructure development, resulting in the construction of highways, expressways, railways, and large irrigation canals aimed at stimulating economic growth. However, it is vital to recognize the risks that these large-scale projects pose to biodiversity (Thapa & Tuladhar 2021).

Wildlife mortality, particularly when driven by human activities, has significant consequences for both ecosystem functioning and species conservation. Without comprehensive evaluation of wildlife mortality, the detrimental impacts of human development may be overlooked (Fernando. 2015). While land use changes have been increasingly recognized as significant contributors to wildlife mortality, they have received limited attention in conservation efforts (Powers &

Jetz 2019). In Nepal, Adhikari et al. (2022) employed MaxEnt modeling to identify areas at heightened risk of wildlife mortality due to anthropogenic activities. These models generate risk maps that identify areas with a greater likelihood of wildlife mortality, providing essential tools for prioritizing conservation efforts and guiding land use planning.

In this study, MaxEnt modelling was used to map potential risk zones for wildlife mortality in the vicinity of Banke and Bardiya National Parks. The inclusion of temporal trends further aids in identifying the causes of mortality and helps pinpoint high-risk areas for wildlife within and around these national parks. This approach provides critical insights that can inform conservation strategies and improve the broader management of human-wildlife interactions in the region.

MATERIALS AND METHODS

Study area

The study was conducted in two national parks in Nepal, Banke National Park (BaNP) and Bardiya National Park (BNP) (Table 1). The core area of BaNP is delineated by the Chisapani-Obary section of the east-west highway and cultivated land to the south, the Churia ridge to the north, Shiva Khola to the east, and Kohalpur-Surkhet road in the west. BNP, the largest national park in Nepal, is bordered to north by the Siwalik Range and to the south by Karnali River and its tributaries. The park includes forests, cultivated land, small villages, and the Mahendra Highway to the south and east (Fig. 1). BNP was established to protect the representative ecosystems and conserve the habitat of tigers and their prey species.

Banke and Bardiya National Parks serve as critical habitats for a diverse array of wildlife. Banke National Park, with eight distinct ecosystems, harbors 124 woody plant species, 34 mammals, over 300 birds, 24 reptiles, 7 amphibians, and 58 fish species (https://dnpwc.gov.np/en/conservation-area-detail/79/). Notably, protected species such as tigers, striped hyenas, giant hornbills, black storks, gharial crocodiles, and pythons find sanctuary within the park's boundaries. Conservation efforts prioritize key habitats including floodplains and foothills to safeguard flagship species such as the Royal Bengal tiger and Asiatic wild elephant. The Rapti and Babai Rivers are lifelines for the park's inhabitants. Meanwhile, Bardiya National Park offers a diverse wilderness experience, with 70% of its forest comprised of Sal trees. Endangered species including the Royal Bengal tiger, wild elephant, and Bengal florican find refuge here, along with over 30 mammal species, 230 bird species, and various reptiles, lizards, and fish, making both parks pivotal for biodiversity conservation (https://dnpwc.gov.np/en/conservation-area-detail/80/).

Data collection

Data for the study were collected using primary and secondary sources. Primary data were collected using a set of questionnaires and interviews conducted at different levels. Field visits were conducted to collect mortality data and to conduct informant interviews. A total of 10 key informant interviews were conducted to verify the geographic locations of prerecorded mortality incidents.

Secondary data included wildlife mortality data and environmental variables. The mortality data were collected from national park offices and online sources. A digital elevation model (DEM) with a resolution of 30 meters was sourced from the United States Geological Survey

Table 1. Key features of Banke and Bardiya National Parks, Nepal

Features	Banke National Park	Bardiya National Park
Latitude	27° 58' 13" to 28° 21' 26"	28° 48' 59.99"N
Longitude	81° 39' 29" to 82° 12' 19"	80° 28' 59.99" E
Elevation	153 to 1,247 m	152 m to 1441m
Total area	550 km^2	968 km^2
Buffer area	343 km^2	507 km^2
District(s)	Banke, Bardiya, Dang and Salyan	Bardiya

Buffer area - A buffer area is a zone surrounding a national park where specific legal and management restrictions are imposed to provide additional protection and preserve the park's ecological integrity

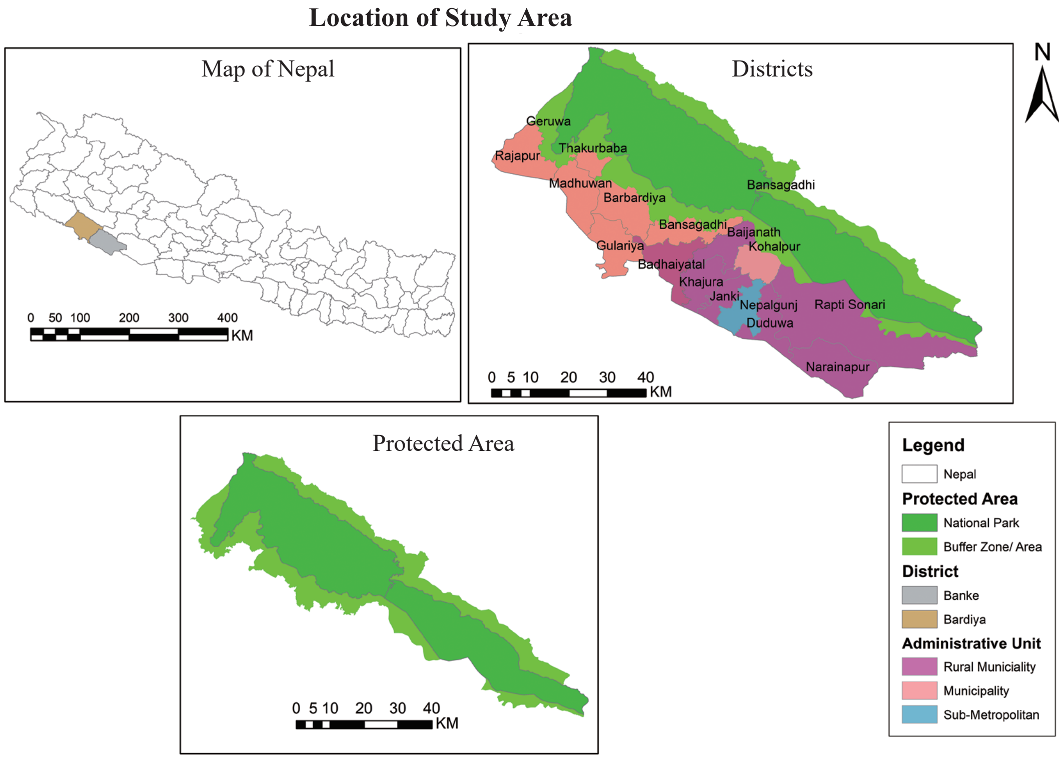

Fig. 1. Study area map

(https://earthexplorer.usgs.gov/). Slope and aspect were derived from the DEM using ArcGIS software. Land use change data was downloaded from the International Centre for Integrated Mountain Development (ICIMOD) with a resolution of 10 meters for 2021. The images obtained were used as background variables for the MaxEnt model. Similarly, bioclimatic data were obtained from World Clim (https://worldclim.org/). Climatic variables were used to identify the best-suited habitats for mortality data distribution. In this study, the best climatic conditions that matched the specific areas were taken into consideration. In addition to these variables anthropogenic variables related to water resources, and distance to the settlements were accessed through the Geofabrik website (https://www.geofabrik.de/). Climate and topographic factors are essential in predicting wildlife mortality events, as they influence habitat conditions and resource availability. Temperatures, precipitation, elevation, and slope affect survival and movement. Incorporating these factors into the MaxEnt model improves accuracy, enabling better identification of mortality patterns and guidance of conservation efforts.

Data analysis

The Shapiro-Wilk test was conducted to assess data normality, and the Kendell test analyzed the significance of trend direction. Kendall's tau coefficient measures the strength and direction of association between two variables, and is used to assess temporal trends, such as the wildlife mortality incidents in this study. Seasons were defined as divisions of the year characterized by specific climatic conditions that influence ecological processes and wildlife behavior. Mortality data were classified into four seasons: spring (March to May), summer (June to August), autumn (September to November), and winter (December to February). The association between season and cause of mortality was analyzed using a chi-square test. Understanding the causes behind seasonal mortality variations enables conservationists to design proactive, season-specific interventions that address the key risks faced by wildlife populations. MaxEnt modeling, a well-established method for species distribution modeling (SDM), was used to predict potential risk zones for wildlife mortality. This method compares sample background location data to mortality incident location data to determine areas where wildlife mortality is likely to occur. A 3 km buffer was created along both district administration boundaries to delineate the area for modeling mortality incidents. The MaxEnt model has been successfully applied in previous research to predict wildlife mortality hotspots (Nayeri et al. 2022). Integrating climate factors into the MaxEnt model enhances our understanding of how environmental conditions may influence anthropogenic mortality events. Predicting non-anthropogenic mortality events is essential for understanding natural mortality patterns and differentiating them from human-induced impacts. This comprehensive approach supports the development of more effective and targeted conservation strategies.

To mitigate multi-collinearity, highly correlated environmental layers, specifically digital elevation and temperature, were removed from the analysis. The correlation matrix revealed associations among the remaining variables, such as aspect, bio1 (Annual Mean Temperature), bio12 (Annual Precipitation), DEM, land use, river, settlement, and slope. Some variables exhibited positive correlations, while others showed negative associations. These adjustments were made to enhance the independence of the retained variables and reduce redundancy in the model.

RESULTS

Wildlife mortality

In the Banke district, 449 mortality incidents were recorded, with 390 attributed to anthropogenic causes and 59 classified as non-anthropogenic. In the Bardiya district, 619 incidents were documented, consisting of 367 cases caused by anthropogenic factors and 252 incidents categorized as non-anthropogenic (https://dnpwc.gov.np/en/reports/).

Temporal trends

In Banke, the daily range of wildlife mortality incidents due to anthropogenic factors varied from 1 to a maximum of 12. Similarly, in Bardiya, the peak for anthropogenic mortality incidents surged to 13 per day (Fig. 2). The highest instances of anthropogenic wildlife mortality were observed in January in Banke and in June in Bardiya. The highest number of incidents attributed to non-anthropogenic causes occurred in May, totaling 17 incidents. In the Banke region, a declining trend was evident in both anthropogenic and non-anthropogenic mortality incidents, as indicated by a negative tau coefficient. It's worth emphasizing that this trend did not reach statistical significance ($p > 0.05$). Conversely, Bardiya exhibited a different pattern, showing an increasing trend in mortality incidents for both anthropogenic and non-anthropogenic causes. Nonetheless, akin to Banke, this trend also did not attain statistical significance ($p > 0.05$) (Table 2).

Seasonal trends

In Banke, mortality incidents from anthropogenic causes consistently exceeded non-anthropogenic incidents in all seasons, with a slight overall decline. Rates were

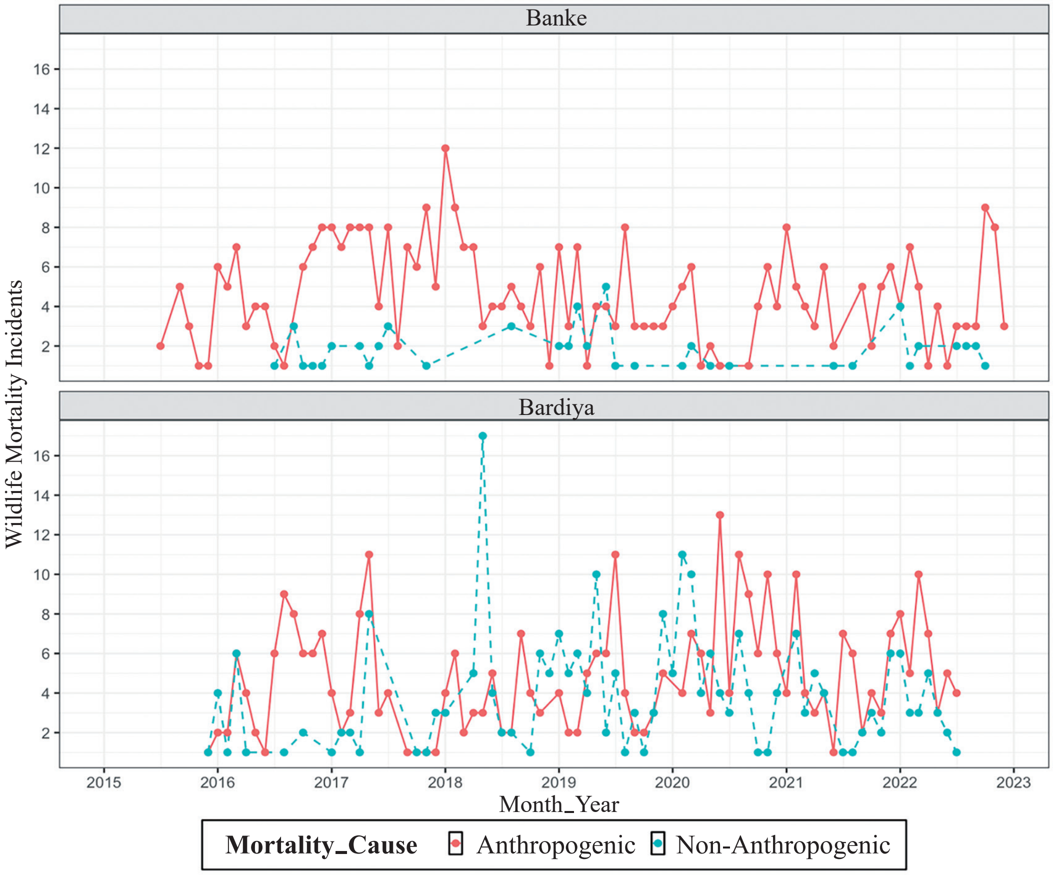

Fig 2. Temporal wildlife mortality trends

Table 2. Wildlife mortality trends in Banke and Bardiya National Parks, Nepal

Location	Mortality Cause	*Z*	*N*	*p*-value	*S*	Tau	Trend
Banke	Anthropogenic	-0.124	8	0.902	-2	-0.071	Decreasing
	Non-Anthropogenic	0	7	1	-1	-0.048	Decreasing
Bardiya	Anthropogenic	1.113	8	0.266	10	0.357	Increasing
	Non-Anthropogenic	1.608	8	0.108	14	0.500	Increasing

Note: Z = test statistic, N = year, p-value = probability value, S = Sample estimates, Tau = Kendall's tau coefficient

lower in summer but peaked in spring at 24 incidents, followed by autumn and winter with 22 incidents each. Non-anthropogenic incidents peaked in spring and summer 2019, with 6 cases (Fig. 3). In Bardiya National Park, autumn mortality incidents ranged from 2 to 25, summer from 7 to 28, spring from 8 to 22, and winter from 7 to 21, showing clear seasonal variation for both causes.

In Banke, anthropogenic causes were significantly associated with seasons ($\chi^2 = 20.7$, $df = 3$, $p < 0.001$), while non-anthropogenic causes showed no significant association ($\chi^2 = 5.34$, $df = 3$, $p > 0.149$). In Bardiya, anthropogenic causes showed no seasonal variation ($\chi^2 = 5.81$, $df = 3$, $p = 0.121$), but non-anthropogenic causes had strong seasonal variation ($\chi^2 = 59.0$, $df = 3$, $p < 0.001$) (Table 3).

Cause-specific mortality

In Banke, roadkill was identified as the primary anthropogenic cause of wildlife mortality, accounting for a significant majority of incidents at 84.9% ($n = 381$). Following roadkill, mortality due to feral dog attacks was the next significant cause, accounting for 7.35% ($n = 33$) of incidents. Feral dogs, independent of humans, pose risks to wildlife, especially near settlements where they prey on vulnerable species. Natural causes of death accounted for a smaller portion at 4.23% ($n = 19$). The frequency of roadkill incidents showed a consistent pattern over the years, with an increase from 12 incidents in 2015 to a peak of 80 incidents in 2017. Subsequently, there was a decline to 64 incidents in 2018, followed by fluctuations ranging from 34 to 46 incidents in the following years. Electric wire-related incidents were infrequent, with only four reported cases, and other anthropogenic factors including illegal hunting and irrigation canal incidents were less common (Fig. 4). In Bardiya, the recorded frequencies of roadkill incidents exhibited notable variations over the years. Only one incident was documented in 2015, followed by a significant increase to 56 incidents in 2016. The numbers decreased to 32 incidents in 2017, 30 in 2018, 28 in 2019, and then increased again to 48 in 2020. Subsequently, there were 33 incidents in 2021 and 30 incidents in 2022. Irrigation canal-related incidents emerged as the second most significant cause, occurring once in 2016 and then increasing to 6 in 2017, 9 in 2018, 18 in 2019, 21 in 2020, 13 in 2021, and 6 in 2022. Electric wire-related mortality incidents were minimal, with only a few cases documented in the respective years. Additionally, there were 6 cases of fence entanglement, with 2 incidents in 2021 and 4 incidents in 2022.

Conservation status of wild species

The majority of species mortality observed in the study belonged to the Least Concern category, accounting for approximately 70% of the cases in Banke.

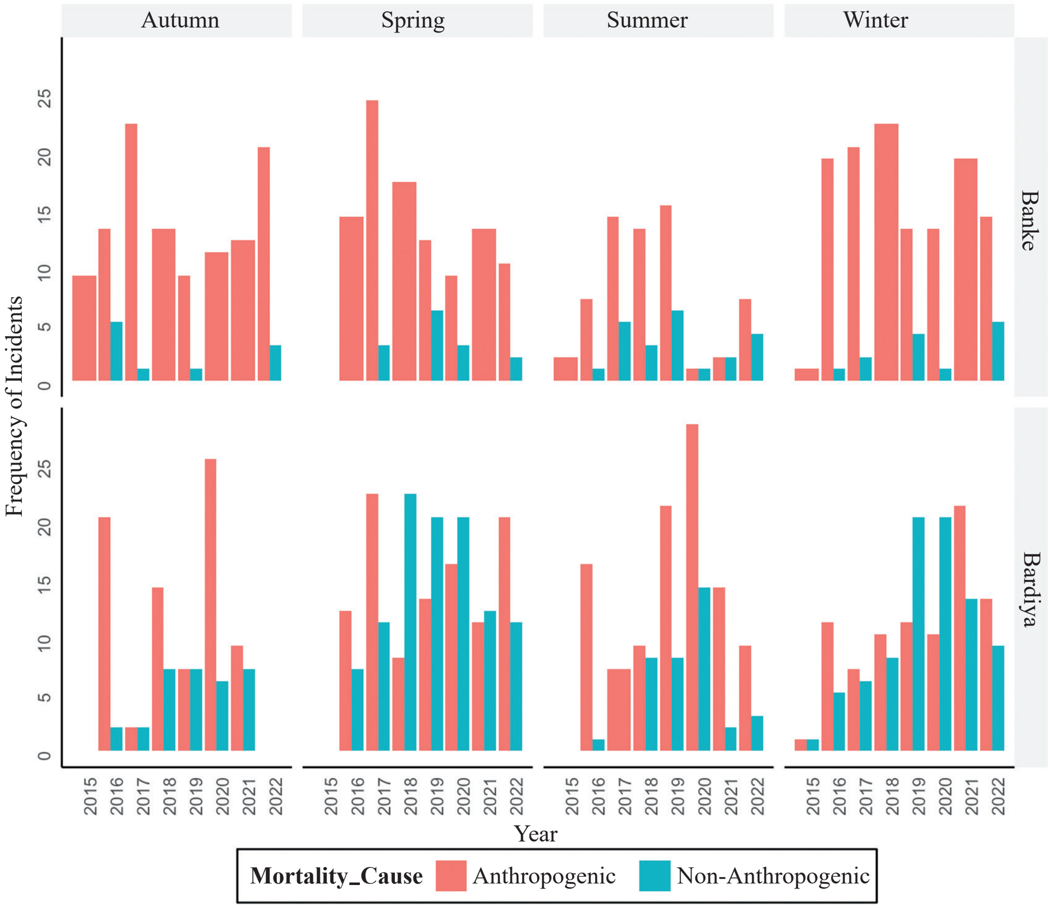

Fig. 3. Seasonal pattern of wildlife mortality

Table 3. Influence of seasonality on wildlife mortality incidents

Location	Mortality Cause	χ^2	*df*	*p*-value
Banke	Anthropogenic	20.708	3	0.0001211
	Non-Anthropogenic	5.339	3	0.1486
Bardiya	Anthropogenic	5.8065	3	0.1214
	Non-Anthropogenic	58.952	3	$9.841e^{-13}$

Note: χ^2 = Chi-square value, *df* = degree of freedom, *p* -value = probability value

This category included species such as the *Sus scrofa* (wild boar) and *Axis axis* (spotted deer). Endangered species accounted for about 7% of observed mortalities and included notable species like the golden monitor lizard and Indian crested porcupine. Near Threatened species, comprised around 1.11% of the cases, consisted mainly of the grey langur and striped hyena. Vulnerable species made up about 8.24% of the mortalities and included *Tetracerus quadricornis* (four-horned antelope), P*anthera pardus* (leopard),

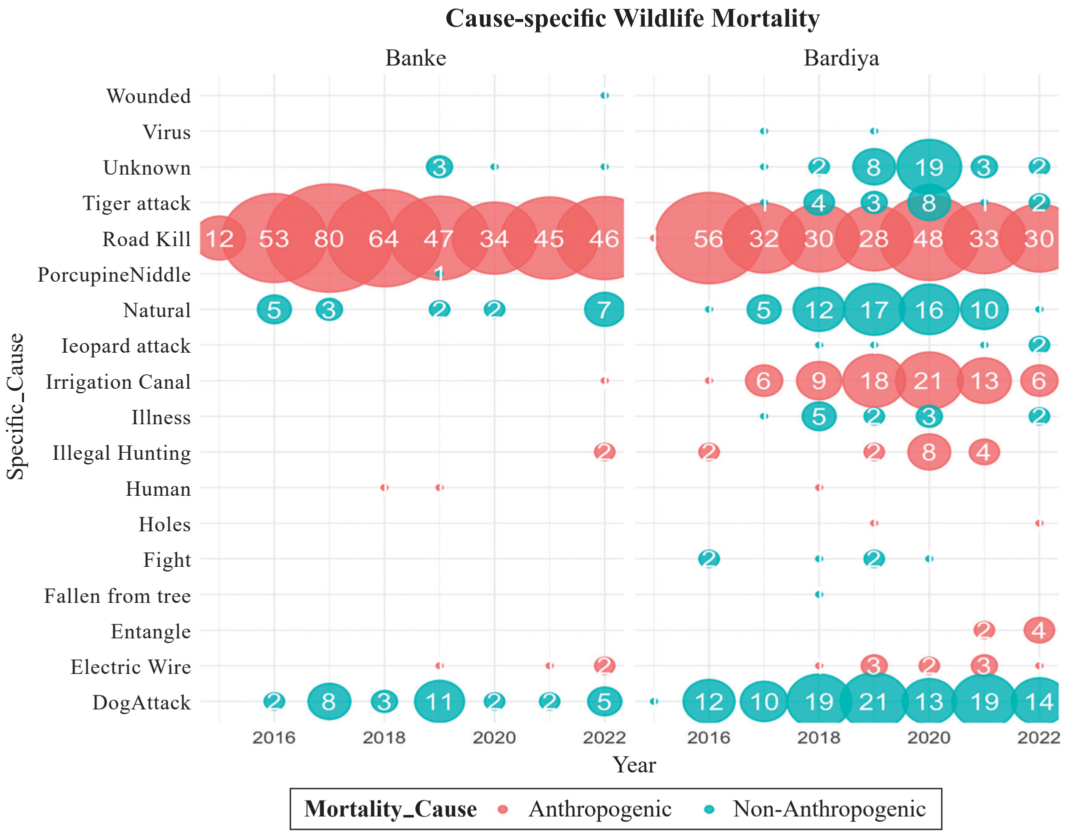

Fig. 4. Cause-specific mortality trends

Python molurus (python), *Rusa unicolor* (sambar deer), *Lutrogale perspicillata* (smooth otter) and *Crocodylus palustris* (mugger crocodile) (Appendix I). Among the anthropogenic causes of species mortality, 9.58%, 15.59%, and 16.93% of the cases involved species listed under CITES Appendices I, II, and III respectively. A total of 77.95% of species mortality fell under the non-protected status according to the National Park and Wildlife Conservation Act of Nepal, while 8.91% were species with protected status. Furthermore, for mortality caused by non-anthropogenic factors, the percentages were 11.58% for protected species and 1.56% for non-protected species (Fig. 5).

In Bardiya, Least Concern species accounted for 46.37% of mortalities, while endangered and near threatened species represented 4.52% each. Anthropogenic causes were responsible for 7.27% of critically endangered species deaths and 0.97% of near-threatened species deaths. CITES Appendices I, II, and III species accounted for 6.3%, 3.07%, and 9.05% of anthropogenic mortality, respectively. Non-protected species experienced 57.51% of anthropogenic mortality under the National Park and Wildlife Conservation Act, while protected species accounted for 1.78%. Non-anthropogenic causes resulted in 32.28% of mortalities for non-protected species and 7.43% for protected species. In both Banke and Bardiya, anthropogenic causes of

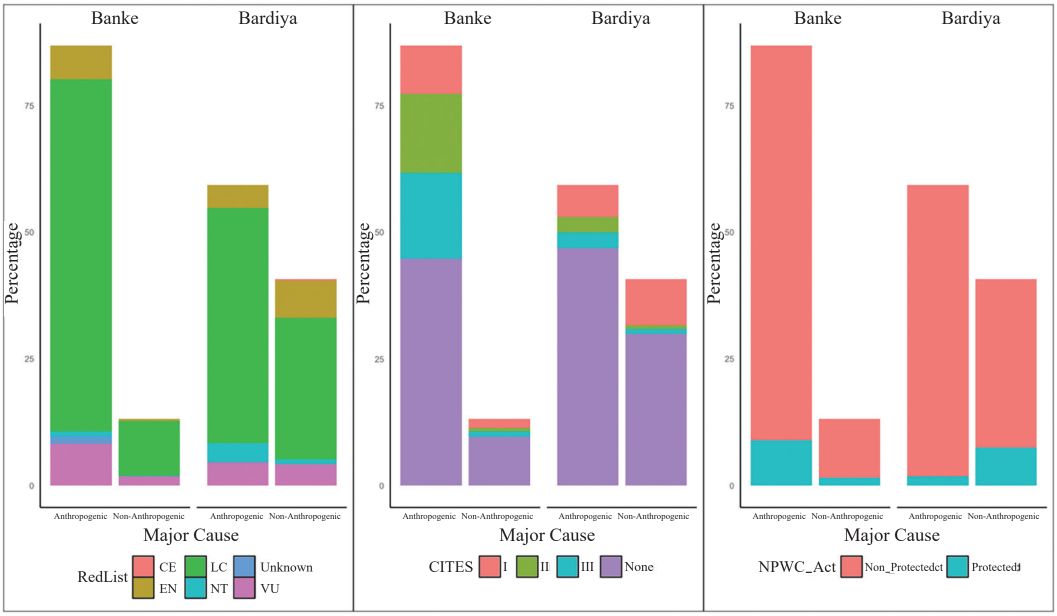

Fig. 5. Conservation status of wildlife

mortality were consistently higher than non-anthropogenic causes. There were seasonal variations in the occurrence of mortality incidents, with peaks observed in certain seasons. However, these trends were not statistically significant.

High-risk wildlife mortality areas and causes

Anthropogenic causes

Based on the MaxEnt model output, mortality incidents along the East-West Highway section displayed a notable prevalence, primarily attributed to roadkill. Specifically, in the Bardiya district, a significant concentration of wildlife fatalities was observed within the Motipur-Amerni-Bhurigaun Sainawar area, which falls under the jurisdiction of Thakurbaba municipality near the Babai River (Fig. 1). Additionally, the Chispani-Karanali area reported higher rates of wildlife mortality. Surrounding regions of these road sections exhibited a moderate level of susceptibility to anthropogenic factors contributing to wildlife mortality. In contrast, Banke district experienced high levels of wildlife mortality along roads, with a particularly prominent cluster of incidents noted in the Obary-Thorai-Kharikhola stretch within the Raptisonari municipality. This specific road section is intricately linked with the Kamdi corridor, adjacent forested areas, and the Sita irrigation canal, making it a notably high-risk zone for wildlife mortality resulting from anthropogenic factors. A notable increase in wildlife mortality was also observed near the settlement areas of Solari, Kusum, Bagkhor, and Lauti, all aligned along the Shiva Khola (Fig. 1). This geographical alignment further underscores the heightened susceptibility of this region to wildlife mortality resulting from anthropogenic influences.

The model demonstrates robustness with an average test Area Under the Curve (AUC) of 0.859 and a low standard deviation of 0.024 across replicates (Fig. 6), indicating both predictive power and stability. This balance between fitting the training data and generalizing to new data ensures consistent and reliable predictions for the target variable (Table 4).

Non-anthropogenic causes

Predicting non-anthropogenic mortality is crucial for understanding natural causes of animal deaths, guiding effective wildlife management, and informing conservation efforts to maintain ecosystem balance (Fournier et al. 2017). Wildlife mortality in Banke and Bardiya districts reveals distinct spatial patterns. Bardiya exhibits a significantly higher concentration of wildlife mortality incidents ($p > 0.05$) when compared

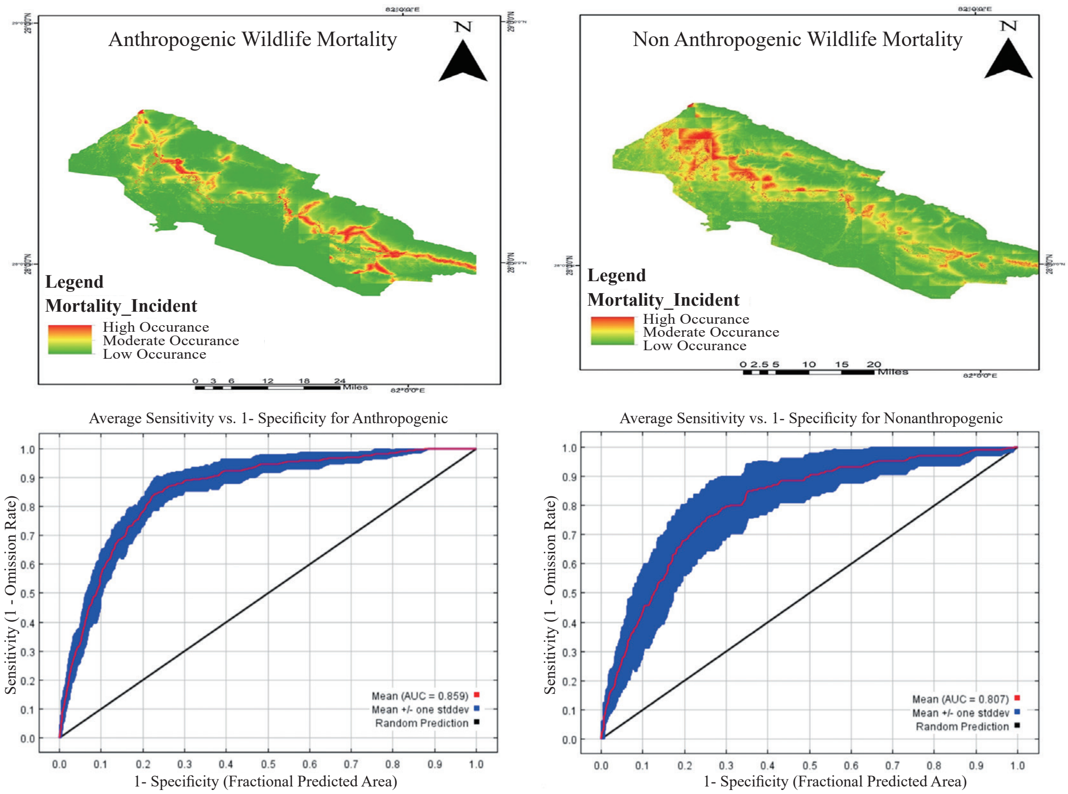

Fig. 6. Potential areas for wildlife mortality due to anthropogenic and non-anthropogenic cause and their model performance

Table 4. Contributing variables to anthropogenic mortality

Variable	Percent Contribution	Permutation Importance
Annual Precipitation	51.1	45.2
Distance to River	22.9	29.6
Land use	17.6	18.8
Distance to Settlement	5.3	2.6
Slope	4.4	5
Aspects	0.3	0.4

to Banke ($p < 0.05$). Within Bardiya, both anthropogenic and non-anthropogenic wildlife mortality incidents are prominently clustered within specific regions, notably Greuwa and Thakurbaba municipalities, encompassing areas with human settlements and forested parklands (Fig. 1). In contrast, Banke displays a more dispersed spatial distribution of incidents. However, a conspicuous aggregation of incidents is observed near the west Rapti River, particularly along the East-West Highway, notably within the Khasakusma region of Raptisonari municipality.

The model demonstrates robustness with an average test Area Under the Curve (AUC) of 0.807 and a low standard deviation of 0.063 across replicate runs (Fig. 6). This signifies both predictive power and stability. The model effectively balances fitting the training data with generalizing to new data, ensuring consistent and reliable predictions for the target variable (Table 5).

DISCUSSION

This study emphasizes the prevalence of human-related animal mortality incidents in Nepal's Banke and Bardiya districts. While a growing trend in Bardiya contrasts with a declining trend in Banke–potentially linked to conservation efforts–statistical significance remains elusive. Nonetheless, these results underscore the complexity of assessing animal mortality and the necessity for ongoing conservation initiatives. The downward trend in Banke suggests that conservation efforts may be effective there. For example, animals such as squirrels, foxes, monkeys, and mongooses have been observed using six canopy bridges in the area, indicating successful habitat preservation efforts, alongside the implementation of vehicle speed restrictions (Thapa & Tuladhar 2021).

In contrast, increasing mortality trends in Bardiya call for a heightened focus on conservation efforts. The complexity of wildlife mortality is further underscored by the lack of statistical significance in the data, emphasizing that effective measures to combat wildlife mortality must be adaptable and customized. Moreover, Hill et al. (2020), demonstrate that the growing body of research on this topic emphasizes the negative effects of human activity on animal populations. Our findings align with other studies conducted during the COVID-19 lockdown period, which similarly identified a rising trend in animal deaths but no change in the average number of injury incidents (Koju et al. 2021). Garriga et al. (2017), reported similar results, which support the findings of our study that death rates are higher in the spring, fall, and winter. In Banke, our analysis found that anthropogenic causes of death showed a

Table 5. Contributing variables to non-anthropogenic mortality

Variable	Percent Contribution	Permutation Importance
Annual Precipitation	42.9	49.1
Distance to River	22.2	10.8
Land use	15.8	14.5
Distance to Settlement	12.1	15.9
Slope	4.4	5
Aspects	2.7	4.8

seasonal correlation, but non-anthropogenic causes did not show seasonality.

The pattern of wildlife mortality in Bardiya contrasts with that of Banke, highlighting the unique effects of seasonality on various causes of death. The heterogeneous land use patterns along the Bardiya highway are major contributors to the growing number of wildlife mortality cases. Additionally, a significant drop in the Geruwa River's water flow–a branch of the Karnali River near Chisapani–due to siltation has adversely affected wildlife in western Bardiya National Park. To mitigate this, 180 waterholes and 50 ponds equipped with solar pumps have been constructed to provide drinking water for wildlife during the dry season.

Conversely, Banke National Park faces an extreme lack of water, especially from February through May, due to the arid environment of the Chure Bhabar region. This arid zone comprises around 53% of the park's total area and offers minimal water resources. As a result, wildlife is compelled to cross the East-West highway in search of water from the Rapti River, putting them at risk of fast-moving vehicles. While 26 artificial ponds have been created, these remain insufficient to meet the water demands of the wildlife, contributing to a rise in traffic-related deaths. Moreover, the lowlands of the park are inadequately protected, as highlighted by Paudel and Heinen (2015), forcing many species to adapt to and thrive in human-dominated wooded areas. This situation highlights the urgent need to intensify conservation efforts to effectively protect the park's wildlife populations and their ecosystems. Our findings align with previous studies that identify roadkill as a primary cause of wildlife mortality (Moore et al. 2023), supporting the strong correlation between urbanization and anthropogenic wildlife mortality first proposed by McCleery et al. (2008). The increased frequency of traffic accidents may be attributed to several factors, including the nighttime behaviour of animals and reduced visibility due to headlight glare from fast-moving vehicles, as observed in Chitwan National Park (Magar et al. 2022).

According to our research, the second most common anthropogenic cause of species mortality in Bardiya is related to irrigation (ILaM 2023), whereas only one case was reported in Banke. There is a need for more investigation into animal rescues and injuries for a comprehensive understanding of wildlife mortality (Adhikari et al. 2022, Pandey & Pant 2023). Mammals, particularly larger species, have recorded higher death rates due to landscape changes and direct exploitation, as seen in North America (Collins & Kays 2011). However, smaller species with restricted ranges are more vulnerable to landscape changes even without direct exploitation (Gonzalez-Suarez & Revilla 2014). Our study indicates that medium and smaller sized species face a heightened risk from human-related factors (Hill et al. 2020). Wild boar and spotted deer were particularly vulnerable to both natural and human-driven causes, aligning with findings from the Barandabhar Corridor Forest (Magar et al. 2022). Notably, tigers, a keystone species in the park, rely on these species as primary prey (Dinerstein 1980, Adhikari et al. 2016).

Remarkably, a study by Upadhaya et al. (2018) revealed no significant difference in the food choices of male and female tigers, both of whom primarily hunt spotted deer. However, there were differences in their preferences: males showed a stronger preference for sambar deer and wild boar, while females favoured wild boar and chital. This finding is significant, especially given the low sambar deer population in the study area.

Aryal et al. (2016) highlighted the challenges of maintaining the growing tiger population, pointing to the shortcomings of the current protected area system. To overcome this obstacle, it is essential to increase prey availability and provide sufficient habitat for tigers. The ratio of grassland to forest cover is one factor that affects prey populations, and the availability of water positively impacts the site utilization of barking deer (Lamichhane et al. 2020).

Adhikari et al. (2022) report that approximately 9% of affected species mortality is attributed to dogs and cats in settlements, accounting for 60% of overall mortality. These attacks, which contribute a significant mortality rate of 45%, notably impact native species in India, especially species already listed as threatened by the IUCN (Home et al. 2018). Studies have demonstrated that feral dogs negatively affect native animal populations, leading to local extinctions or reduced abundance and even altering activity patterns (Zapata-Rios & Branch 2016). Our investigation identified yearly precipitation and proximity to rivers as the two environmental factors most influential in defining wildlife mortality risk regions. However, it is important to acknowledge that other studies have identified additional contributing factors to wildlife mortality, including the cumulative impact of human-induced mortality, agricultural land extent, and district literacy rates (Pandey & Bajracharya 2010, Baral et al. 2022) Furthermore, temperature and humidity have also been shown to affect roadkill incidents involving animal species (Garriga et al. 2017). In our specific study location, we emphasize the significance of yearly precipitation and river proximity, while recognizing that wildlife mortality is a complex issue influenced by various environmental factors, as noted in other studies.

CONCLUSIONS

Our study highlights the significant impact of anthropogenic factors on wildlife mortality in the Banke and Bardiya districts. While conservation efforts in Banke show promise, the increasing mortality rates in Bardiya underscore the urgent need for intensified conservation actions. Roadkill emerges as a major concern, illustrating the link between urbanization and wildlife mortality. Seasonal variations in mortality patterns emphasize the necessity for tailored conservation strategies. Maintaining waterholes during dry seasons helps prevent wildlife from entering human settlements, while habitat restoration provides essential resources during periods of scarcity. Enhancing existing wildlife corridors ensures safe migration and reduces risks associated with seasonal movements. Particularly vulnerable species, such as spotted deer and wild boar, highlight the importance of habitat preservation and management of prey populations. Additionally, non-anthropogenic factors, such as dog predation, call for comprehensive population-level assessments. In light of our findings, we strongly advocate for the implementation of comprehensive road safety measures to reduce incidents of roadkill and public awareness campaigns focusing on wildlife conservation. In Bardiya, enhanced management and protection of irrigation canals are also crucial to mitigate threats to local wildlife. Establishing wildlife-friendly crossing structures can facilitate safe passage for animals and minimize human-wildlife conflicts. Together, these measures form a vital strategy for promoting harmonious coexistence between humans and wildlife in the Banke and Bardiya regions.

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