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ARTICLE

Disease Ecology

A decade under lens: Characterizing wildlife mortality from disease and infection in Chitwan National Park, Nepal

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Abstract

Mortality and health issues are becoming an emerging issue in the conservation and management of wildlife populations. Understanding the causes of mortality is necessary for proper management of wildlife and habitats. To address this, a mixed approach was employed: we conducted a longitudinal analysis of a decade (2010–2019) of observed mortality count data from Chitwan National Park, Nepal. These data are subject to inherent surveillance biases, and our results represent detected mortality patterns. Additionally, a focus group discussion was conducted to gain a deeper understanding of the causes and trends of mortality and conservation efforts. There was a total of 525 recorded cases, of which mortality causes were determined for 82%; for the remaining 18%, causes were unidentified. Herbivore mammals accounted for the highest mortality (61%), followed by carnivores (16%). Of determined mortality causes, anthropogenic causes were the leading contributors to mortality (33.14%), followed by natural causes (23.62%) and diseases and infections (13.33%). Generalized linear models (negative binomial/poisson) revealed a significant 15.3% annual increase in overall wildlife mortality counts, driven by significant increases in disease and infection by 25.8% per year and conflict/competition by 17.4% per year. Rhinoceros was the species suffering the highest mortality count (34%), which increased by 42.9% per year, followed by elephants, gharial, deer, and tigers. The health assessment revealed that wound and bacterial infections, tuberculosis, and parasitic diseases were the primary factors responsible for mortality. Furthermore, the research indicates a concerning increase in mortality counts due to disease and infections and highlights an urgency for the development of comprehensive conservation efforts, public awareness, and disease control strategies. Routine immunization for livestock and development of species-specific plans for disease diagnosis and treatment in well-equipped wildlife care hospitals are crucial. Additionally, regular research on wildlife health monitoring and research-based effective conservation should be prioritized.

KEYWORDS
bacterial infection, conservation, infectious diseases, threats, wildlife mortality

INTRODUCTION

Population dynamics are fundamentally shaped by natality, mortality patterns, and the quality of habitat available. Together, these factors determine the abundance, stability, and persistence of species in natural ecosystems. Wildlife populations have been threatened by multiple factors such as predation, illegal hunting, poaching, habitat loss, diseases and infections, and interspecific competition for resources (Pokhrel et al., 2019). Among these are direct anthropogenic threats such as poaching, vehicle collisions, electrocution, and forest fire, which remain critical drivers of mortality (Hamal et al., 2023; Koju et al., 2025). These threats are often visible and frequently documented, while disease- and infection-induced mortality has emerged as a less visible but equally serious challenge for wildlife conservation (Rhyan & Spraker, 2010). Declining wildlife health has broad ecological and socioeconomic consequences, including biodiversity loss, ecosystem disturbance, agricultural losses, and even risks to human health (USGS, 2019). Accordingly, conservationists and policy practitioners are alarmed by both infectious and noninfectious diseases and their cascading impacts (Deem et al., 2001). Furthermore, the interconnectedness of human, livestock, and wildlife health (one health approach) has been recognized as a critical framework for understanding disease dynamics (Becker et al., 2020). Nonetheless, both wild and domestic animals are at higher risk, leading to biodiversity loss and associated challenges (Wiethoelter et al., 2015).

Globally, infectious diseases are significant drivers of global biodiversity loss. Amphibian declines caused by chytridiomycosis, a fungal infection, provide one example (Fisher et al., 2009). Similarly, the spread of canine distemper virus (CDV) has threatened populations of the endangered Amur tiger (*Panthera tigris altaica*) in the Russian Far East (Gilbert et al., 2020). Unlike poaching or habitat degradation, disease can spread rapidly across species, often with devastating outcomes. Their ability to trigger mass mortality has positioned disease as an increasingly recognized major threat to the survival of wild fauna (Brand, 2013). These risks are further magnified by zoonotic dynamics; roughly 61% of human diseases originate from animals (Taylor et al., 2001). Recent pandemics have further underscored the role of wildlife as reservoirs for pathogens with cross-species transmission potential (Johnson et al., 2020). Spillover can occur through direct contact, vectors, shared resources, or contaminated environments (Fong, 2017). For instance, tularemia (*Francisella tularensis*) spreads from rabbits or rodents via ticks, biting flies, skin contact, and contaminated water (Kruse et al., 2004). Similarly, the Ebola virus is believed to spread through fruit sharing between bats and humans (WHO, 2020), while the origins of COVID-19 are linked to wildlife trade and consumption in Wuhan, China (Kimbrough, 2020). Additionally, cases of reverse transmission have also been documented, such as COVID-19 infections in Malayan tigers (*Panthera tigris jacksoni*) at the Bronx Zoo, New York (Daly, 2020). These highlight the bidirectional risks at the wildlife–human interface.

Climate change (CC) and habitat fragmentation further exacerbate the emergence and re-emergence of diseases, facilitating their spread from wildlife to livestock and humans (Daszak et al., 2000; Harvell et al., 2002; Olden et al., 2004). Recent studies have shown that climate-induced shifts in species ranges are enabling new host–parasite interactions and increasing disease risk (Carlson et al., 2022). Wildlife under stress become more prone to disease, compounding the impacts of habitat loss and poaching (Hing et al., 2016). As a result, rapidly spreading pathogens with high mortality rates can push vulnerable species toward extinction (Stuchin et al., 2018).

In Nepal, both anthropogenic and disease- and infection-related causes contribute to wildlife mortality. While poaching and retaliatory killings remain serious problems, emerging disease and infection pose a growing risk at the livestock–wildlife–human interface (Amin et al., 2018). Documented cases include CDV in domestic dogs (VIEW, 2017), foot-and-mouth disease (FMD) in cows (Kandel et al., 2018; Parajuli et al., 2020), and *Mycobacterium tuberculosis* in Asian elephants (*Elephas maximus*), blue bull (*Boselaphus tragocamelus*), spotted deer (*Axis axis*), and one-horned rhinoceros (*Rhinoceros unicornis*) (Thapa et al., 2017). In February 2015, for the first time, tuberculosis (*Mycobacterium orygis*) was diagnosed in a free-ranging female rhinoceros in Chitwan National Park (NP) (Peters et al., 2020). Earlier, in 2002, the disease had been reported in captive elephants (Gairhe, 2002). These events highlight how diseases once considered secondary are becoming central threats to Nepal's wildlife.

To address these challenges, Nepal has established a wildlife disease diagnostic molecular laboratory at the National Trust for Nature Conservation (NTNC), Biodiversity Conservation Center (BCC) in Sauraha, Chitwan, in collaboration with the Chitwan NP and Elephant Care International, USA (DNews, 2016). This laboratory facility verified the first case of tuberculosis in rhinoceros, marking progress in disease diagnosis (Peters et al., 2020). However, threats remain largely unquantified for many species. This gap is compounded by the complex ecological interaction among wildlife and domestic animals, including shared habitats, that obscure disease dynamics and transmission pathways (Amin et al., 2018). Nevertheless, the risk of transmission of diseases such as tuberculosis, FMD, and rabies is ever increasing. For instance, the rapid decline in vulture populations has led to a complicated situation: scavenging dogs congregate around carcasses, serving as reservoirs that may spill over to wild carnivores such as dhole (*Cuon alpinus*), bobcat (*Lynx rufus*), and golden jackal (*Canis aureus*) (Amin et al., 2018).

Despite these risks, systematic research on disease- and infection-related wildlife mortality remains low. Existing studies have primarily focused on poaching, illegal trade, and human–wildlife conflict while disease has often been treated as a secondary focus. Moreover, available studies are predominantly species-specific or event based, concentrating on charismatic megafauna. For instance, Bhandari et al. (2022) provide valuable insights into rhinoceros mortality but did not examine disease-related deaths across other species and time periods. Although some studies have assessed general wildlife mortality patterns (Ascensão et al., 2019), few have explicitly quantified disease-related causes or identified the most affected species within protected areas.

Consequently, Nepal lacks a long-term, quantitative, and cause-specific characterization of wildlife disease-related mortality that integrates institutional mortality records with expert knowledge. This knowledge gap is particularly evident in Chitwan NP. As Nepal's oldest protected area and a UNESCO World Heritage Site, it represents a critically important landscape for such investigation due to its high biodiversity, presence of flagship species, and close interface to wildlife, livestock, and human settlements. This study seeks to fill the gap of literature by focusing on wildlife mortality linked to diseases and infection in Chitwan NP. Specifically, this study aims to characterize major causes of wildlife mortality and mortality trends, identify affected wildlife species and their associated disease and infection, and highlight existing efforts for disease management and conservation planning. A robust understanding of disease-related mortality is crucial to advancing conservation strategies, improving health monitoring, and managing livestock–wildlife–human interactions in protected areas of Nepal.

METHODS

Study area

The research was conducted in Chitwan NP, Nepal's first national park, established in 1973. It spans from 83°43′9.69″ E, 84°54′45.57″ E longitude to 27°51′34.15″ N, 27°13′27.02″ N latitude (Figure 1), encompassing subtropical Siwalik and inner Terai ecosystems in southern central Nepal. It connects India's Valmiki Tiger Reserve to Nepal's Mahabharat foothills via the Barandabhar biological corridor, vital for wildlife connectivity.

Initially covering 544 km^2, Chitwan NP expanded to 932 km^2 in 1977 and further to 952.63 km^2 in 2016. The park is internationally recognized as a UNESCO World Heritage Site, Ramsar Site, Important Bird Area and Biodiversity (IBA), and holds the Conservation Assured Tiger Standard (CATS) accreditation.

Chitwan NP comprises sal (*Shorea robusta*)-dominated forests (70%), grasslands (20%), riverine forests (7%), and wetlands (3%). It boasts diverse wildlife including 70 mammals, 546 birds, 47 reptiles, 55 amphibians, and 120 fish species. The park contains major habitat for the smallest mammal, pigmy shrew (*Sorex minutus*), to the largest mammal, the Asian elephant (*E. maximus*), and globally threatened species such as rhinoceros (*Rh. unicornis*), royal Bengal tigers (*Panthera tigris tigris*), gharials (*Gavialis gangeticus*), and Bengal florican (*Houbaropsis bengalensis*). The buffer zone (BZ) surrounding Chitwan NP covers 55% of the area with wildlife habitats, while the rest is used for agriculture and settlements. Over 80 BZ community forests are managed by local communities, overseen by BZ user groups, committees, and a BZ management committee. Indigenous tribes *tharu*, *bote*, *musahar*, *darai*, and migrant communities depend on subsistence agriculture, livestock, forest resources, and non-timber forest resources for livelihood.

Data collection

Data for this research covered the period from 2010 to 2019 and were specifically obtained from secondary sources related to wildlife mortality in Chitwan NP. These

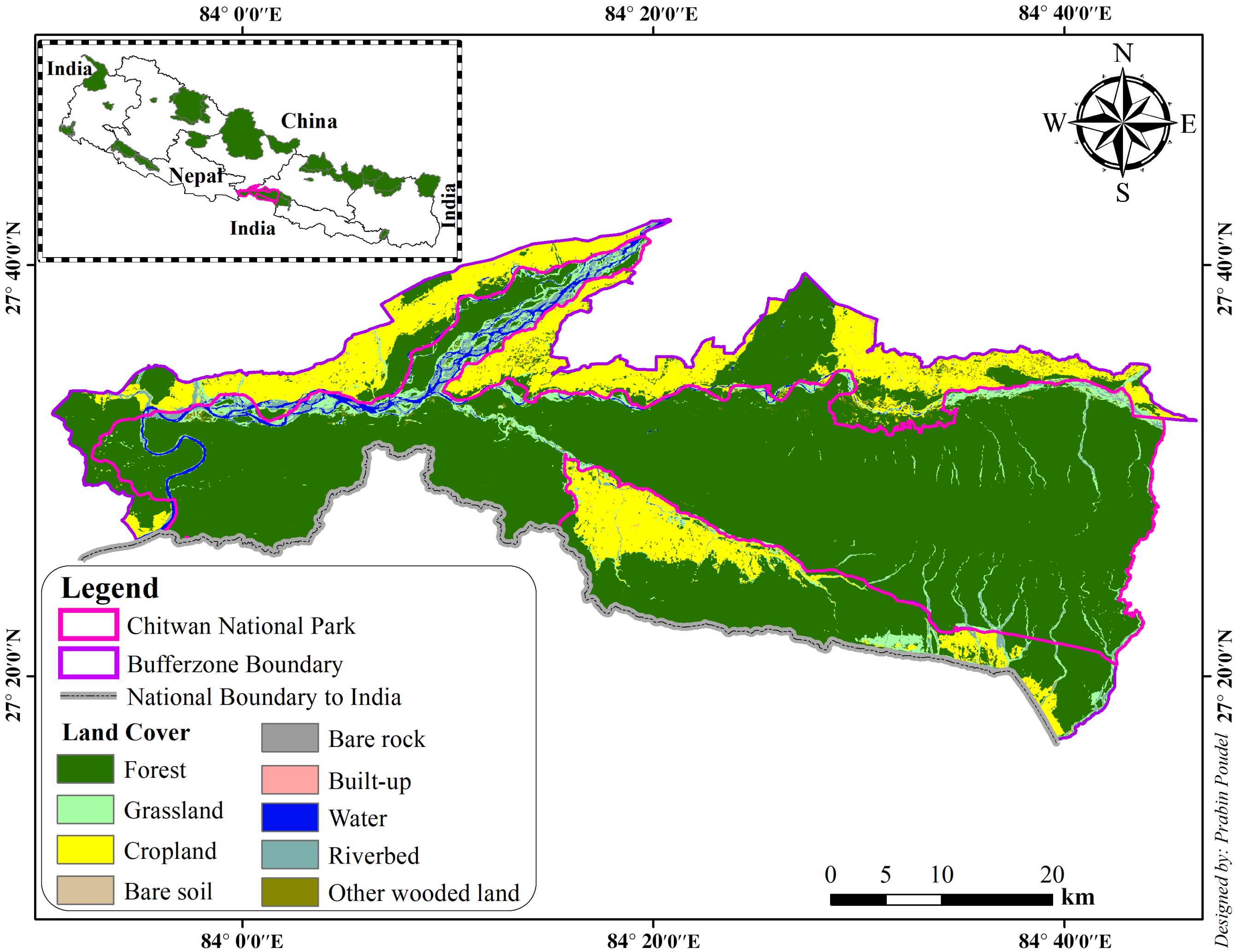

FIGURE 1 Land use land cover (LULC) map of Chitwan National Park. Map showing the protected areas of Nepal (inset).

sources include publicly accessible records such as annual reports, technical documents, and mortality logs maintained by Chitwan NP at www.chitwannationalpark.gov.np and the Department of National Parks and Wildlife Conservation (DNPWC) at https://dnpwc.gov.np. Additional data were obtained on species under captive management, specifically for elephant (*E. maximus*) and gharial (*Ga. gangeticus*) breeding centers (Table 1).

Chitwan NP has a substantial history of maintaining wildlife records for both captive and wild conditions. These records encompass flagship and endangered species such as the one-horned rhinoceros, elephants, tigers, gharials, vultures, and small mammals. Wildlife mortality detection is largely opportunistic discoveries made by park staff, security patrols, community forest users, tourists, and researchers, whereas mortality in captive facilities (elephants and gharial breeding centers) is routinely monitored by veterinary inspection and surveillance staff. These official records served as invaluable resources for gaining insights into patterns and determinants of wildlife mortality.

Mortality records were available for all years of the study period; however, the level of diagnostic detail varied across years. The data collected were reviewed and organized systematically by causes of death, species, and years. Causes of mortality were identified by veterinarians based on available post-mortem records, field observations, and incident reports and were categorized as anthropogenic, disease and infection, conflict/competition, natural, and unknown. If the cause of death was not conclusively revealed, it was labeled as unknown (Table 2). Of the 525 recorded mortality counts, 206 (39%), 101 (19%), and 218 (42%) were confirmed through veterinary post-mortem examination, field-based inference, and not recorded in the registry, respectively.

Additionally, the effort to gain a deeper understanding about the causes of mortality and to document the existing efforts to mitigate wildlife disease and challenges

TABLE 1 Secondary data sources for wildlife mortality.

Source	Details	Period covered	Source location
Annual progress report	Chitwan NP Annual Progress Report	2010–2019 (2067/68–2076/77 BS)	Hard copies available at Chitwan NP head office, Kasara, Nepal (www.chitwannationalpark.gov.np)
Official records	Chitwan NP Office Wildlife Mortality Event Records	2010–2019	Internal registry maintained by Chitwan NP office
Official records	Elephant Breeding Center, Khorsor, Chitwan NP	2010–2019	Internal records from the breeding center management
Official records	Crocodile Conservation and Breeding Center, Chitwan NP	2010–2019	Internal records from the conservation and breeding center management
Technical reports	Department of Wildlife and Conservation Management (DNPWC)	2010–2019	Soft copies available at DNPWC website (https://dnpwc.gov.np)

Abbreviations: BS, Bikram Sambat; NP, National Park.

TABLE 2 Details on wildlife mortality data categorization (identified [natural, anthropogenic, disease and infections, competition] and unidentified).

Categories	Sub-categories
Identified (diagnosed deaths causes)	1. Natural (aging, flooding, mired in swamps, stress, orphan) 2. Anthropogenic (poaching, vehicle collisions, poisoning, electric shock, retaliation) 3. Diseases and infections 4. Conflicts/species competition (intra-specific and inter-specific)
Unidentified (non-diagnosed causes)	All the mortality of species whose cause of deaths are unknown

was crucial. We collected qualitative data using one focus group discussion (FGD) and a purposive sampling approach, selecting nine ($n = 9$) participants based on professional experience with wildlife. The group was comprised of park staff, a wildlife veterinarian, BZ forest users, hotel operators, and local key persons. This composition ensured a triangulation of perspectives from technical, enforcement, community, and tourism sectors. We used an open-ended checklist to explore trends in wildlife mortality, existing conservation efforts, and challenges. During this study, we reported wildlife mortality counts rather than rates due to a lack of reliable population estimates for all species across a 10-year span. To ensure data accuracy and to reduce bias and verification, we collaborated closely with the official record-keeping entities and rigorously cross-referenced our categorized data with annual reports published by the DNPWC.

In spite of our diligent efforts, limitations remained due to incomplete carcasses, late reporting, intra and interspecies predation, scavenging, and rapid decomposition that prevented conclusively diagnosed causes of death. Environmental factors such as adverse weather, forest fires, limited accessibility, and difficult terrain further complicated data collection. Moreover, detection probability varied across species and habitats: it was highest for large, charismatic species (like tiger, rhinoceros, leopards, elephants) and for mortalities near to settlements, roads, and tourist areas while lowest for small species near to dense forest and less accessible areas. Thus, the dataset represents minimum confirmed mortality counts and temporal trends that may partly reflect changes in surveillance. We acknowledge that species have different population sizes and detection probabilities; therefore, these results represent counts of reported causes of death across the wildlife community, not true species-specific mortality rates. Despite these different limitations, results offer valuable insights into mortality patterns and disease-related threats within Chitwan NP.

Critically, mortality detection was subject to systematic surveillance bias, varying significantly across three dimensions: (1) species size and charisma, with large, iconic fauna (e.g., tiger, rhinoceros, elephant) detected far more readily than small or cryptic species; (2) habitat accessibility, where deaths near roads, settlements, or open grasslands were reported more frequently than those in remote, dense forest; and (3) proximity to human activity, as events occurring near BZ communities, tourist routes, or agricultural fields benefited from higher observer presence and reporting rates.

Consequently, the dataset represents the minimum confirmed mortality: a spatially and taxonomically biased record of *detected* events. Observed temporal trends may therefore reflect changes in surveillance effort or accessibility as well as genuine ecological shifts. These results should be interpreted as patterns of *reported causes of* *death* across the observable wildlife community, not as true population-level mortality rates. Despite these inherent limitations, the analysis provides valuable, evidence-based insights into mortality dynamics and emerging disease-related threats within Chitwan NP.

Data analysis

Quantitative information from available records was carefully assessed and organized by year, sex, and age (if available), species name, and cause of mortality. To explore cause-specific patterns, percentages were calculated by dividing the number of cases in each cause of death category by the total number of mortality cases. To assess the association between the primary causes of wildlife mortality (anthropogenic, natural, disease/infection, conflict/competition, unidentified) and their observed frequencies, a Pearson's χ^2 test of independence was used. The null hypothesis was that the distribution of mortality cause was independent of its frequency. Only one test was performed while no correction was required for multiple tests.

Additionally, to analyze temporal trends in annual wildlife mortality counts over the study period, we used generalized linear models (GLMs) appropriate for count data. Based on the overdispersion test, we used a negative binomial (NB) regression for overdispersed data and poisson regression for data in which the mean and variance were approximately equal. The total annual mortality count was modeled as the dependent variable, with year (2010–2019) as the independent variable, to test whether mortality exhibited a significant temporal trend across the decade. Similarly, we performed separate NB or poisson regression models for each of the four primary cause-specific mortality categories (anthropogenic, natural, disease and infection, conflict/competition, and unidentified) and species-specific mortality categories (rhinoceros, elephant, tiger, deer, and other). This approach allowed the determination of whether the annual mortality count for each specific cause changed significantly over time, providing incidence rate ratios (IRR) and CIs as a measure of the annual percentage of change.

Qualitative data from the FGD was analyzed using thematic analysis (Braun & Clarke, 2006) to contextualize the quantitative mortality trends, resulting in ground-level insights into disease mitigation strategies and operational protocols. The session was systematically recorded, transcribed verbatim, and coded with the participants' consent. To ensure analytical rigor, two researchers independently conducted line-by-line coding of the transcripts to identify recurring patterns related to wildlife mortality, disease and infection mortality management, and existing challenges. Following the initial coding, the researchers compared codes, resolved discrepancies through discussions, and organized related concepts into primary themes. The validity of findings was further strengthened through a member-checking process in which findings were shared with a subset of participants to verify that preliminary themes reflected accurate representation. Representative verbatim quotations are used in the *Results* section to illustrate key themes, with all participant identifiers anonymized to ensure confidentiality. The final thematic framework was then used to triangulate and elaborate on the quantitative mortality analysis, offering a deeper understanding of the ecological and management factors influencing wildlife health in Chitwan NP.

In the realm of data analysis, we utilized Microsoft Excel to effectively visualize quantitative data through the creation of descriptive tables and figures. Statistical analysis was performed using the power of R version 4.6.0 (R Core Team, 2026), with a significance threshold set at 5% ($p < 0.05$). This comprehensive approach enabled us to thoroughly examine and comprehend the overall and cause-specific wildlife mortality patterns in Chitwan NP.

RESULTS

Causes and trends of wildlife mortality

Overall, 525 cases of wildlife mortality were recorded in captive and wild populations in and around Chitwan NP during the 10 years from 2010 to 2019 (Figure 1). Among these cases, 82.47% (433) were successfully diagnosed with causation of mortality, while 17.53% (92) remained unidentified. Among the identified cases, anthropogenic causes (33.14%, 174) accounted for the highest mortality, followed by natural causes (23.62%, 124), diseases and infections (13.33%, 70), and conflicts/competition (intra-specific and inter-specific) (12.38%, 65) (Figure 2). The highest share of anthropogenic causes of wildlife mortality is mostly attributed to illegal hunting, poaching, retaliatory killings, vehicle collision, forest fire, electrocution, and other human-induced factors. We found that wildlife mortality causes are significantly associated with their frequency ($\chi^2 = 77.29$, $\mathrm{df} = 4$, $N = 525$, $p < 0.001$). Notably, the cause of mortality due to diseases and infections was evident throughout the study period. However, a portion of recorded wildlife mortality cases could not be identified due to several challenges. Delays in reporting and unavailability of intact corpses for necropsies were common issues, often attributed to forest

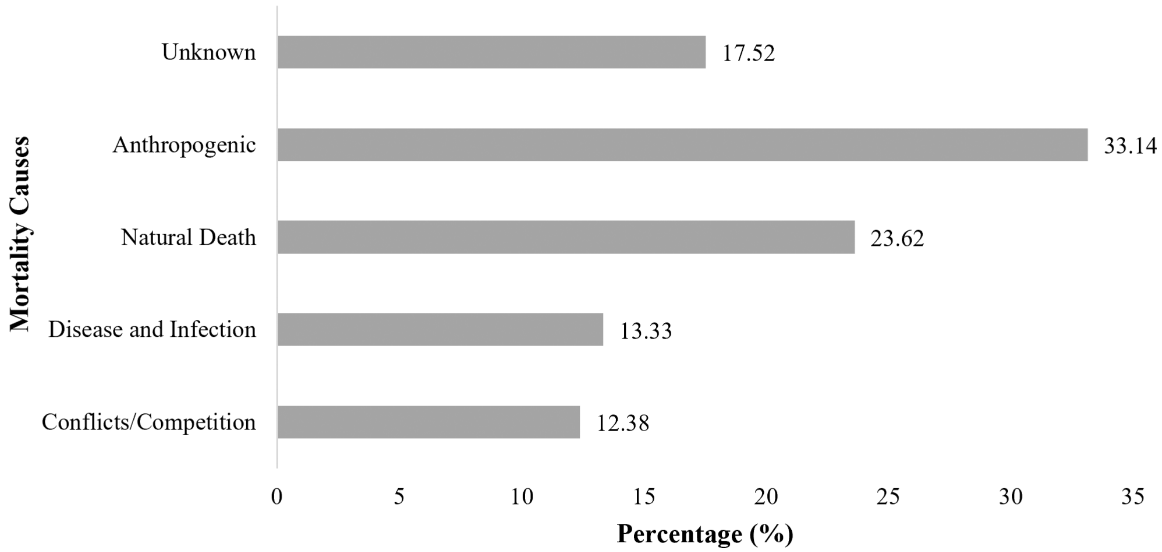

FIGURE 2 Percentage of overall wildlife mortality with respect to different causes.

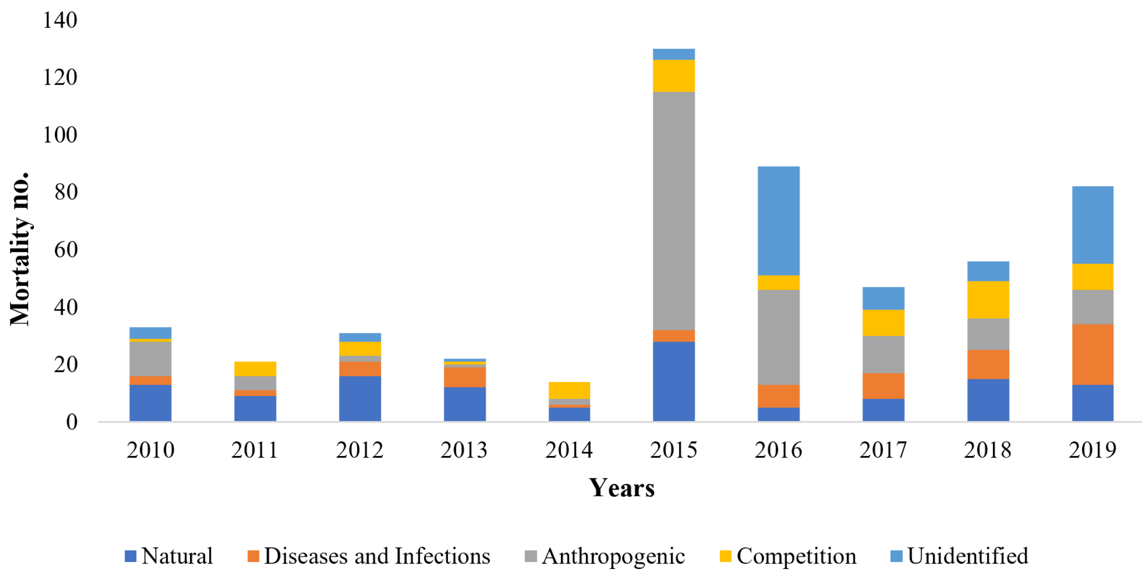

FIGURE 3 Overall annual wildlife mortality for 2010 to 2019. Different colors represent distinct causes of wildlife mortality for each year.

fire, carcasses consumed by other species, and rapid decay of carcasses.

Temporal trend analysis (Figures 3 and 4; Table 3) indicated that the overall annual wildlife mortality counts increased significantly with 15.3% (IRR = 1.153, 95% CI: 1.020–1.302, $p = 0.017$). Cause-specific trend analysis showed distinct patterns. Mortality counts due to diseases and infection increased sharply by 25.8% (IRR = 1.258, 95% CI: 1.150–1.384, $p < 0.001$). Similarly, conflict/competition mortality increased by 17.4% (IRR = 1.174, 95% CI: 1.075–1.288, $p < 0.001$), and mortality attributed to unknown causes increased by 36.6% (IRR = 1.366, 95% CI: 1.074–1.754, $p = 0.012$). In contrast, the models found no significant temporal trend in mortality counts attributed to anthropogenic causes (IRR = 1.165, $p = 0.210$) and natural causes (IRR = 1.002, $p = 0.971$).

Nature of mortality due to disease and infections

Over the span of a decade, from 2010 to 2019, Chitwan NP witnessed a total of 70 wildlife mortality cases, averaging 7 cases per year, primarily attributed to 19 distinct types of disease and infections (Table 4). Notably, wound

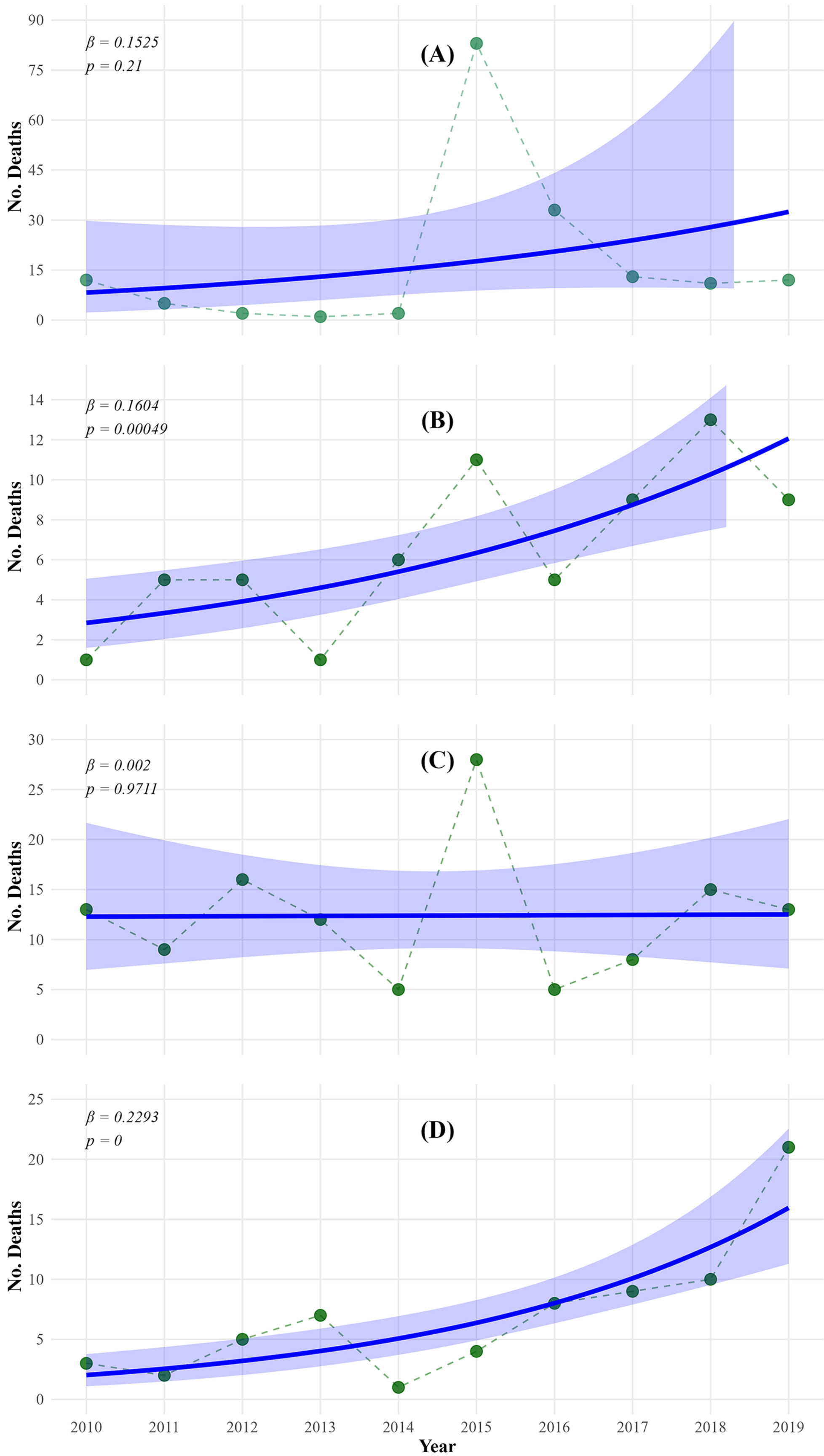

FIGURE 4 Cause specific annual wildlife mortality trends: (A) anthropogenic, (B) conflict/competition, (C) natural, and (D) disease and infection.

TABLE 3 Results of regression (Poisson/negative binomial) analyses for temporal trends (2010–2019) in annual wildlife mortality count by causes in Chitwan National Park.

Mortality cause	Overdispersion test φ	z	p	Model	SE	IRR	CI	p	(+/−) Change (%)	Trend significance
Overall	17.81	1.54	0.061	NB	0.060	1.153	1.020–1.302	0.017	+15.3	Significant
Anthropogenic	30.9	1.29	0.099	NB	0.122	1.165	0.858–1.534	0.210	+16.5	Not significant
Competition/conflict	1.1	0.262	0.397	Poisson	0.046	1.174	1.075–1.288	0.001	+17.4	Significant
Disease and infection	0.98	0.044	0.518	Poisson	0.047	1.258	1.150–1.384	0.001	+25.84	Significant
Natural	3.26	1.267	0.103	NB	0.054	1.002	0.901–1.115	0.971	+0.2	Not significant
Unknown	10.06	1.291	0.095	NB	0.124	1.366	1.074–1.754	0.012	+36.6	Significant

Note: columns IRR, CI and p are grouped under the "IRR" heading.

Abbreviations: φ, dispersion parameter; +, increase; −, decrease; IRR, incidence rate ratio; NB, negative binomial; *p*, *p* value; *z*, *z* statistic.

TABLE 4 Categories of affected wildlife species caused by the respective disease and infections in Chitwan National Park from 2010 to 2019.

Disease and infection	Mammalia Herbivores	Mammalia Carnivores	Mammalia Omnivores	Aves Birds	Reptilia Reptiles	Total	Percentage
Anemia	0	1	0	0	0	1	**1.43**
Bloating	1	0	0	0	0	1	**1.43**
Cardiovascular disease	1	0	0	0	0	1	**1.43**
Dystocia	3	0	0	0	0	3	**4.29**
Foot and nail infection	0	1	0	0	0	1	**1.43**
Gastroenteritis infection	1	2	0	1	0	4	**5.71**
Helminthiasis	0	0	0	2	0	2	**2.86**
Hemorrhage	0	1	0	0	0	1	**1.43**
Herpes	3	0	0	0	0	3	**4.29**
Hip dislocation	1	0	0	0	0	1	**1.43**
Leptospirosis	1	0	0	0	0	1	**1.43**
Mites	0	1	0	0	0	1	**1.43**
Necrotic enteritis	0	0	0	1	0	1	**3.45**
Parasites	3	0	0	0	0	3	**4.29**
Pneumonia	2	2	0	0	0	4	**5.71**
Salmonella	1	0	0	3	0	4	**5.71**
Tracheitis	0	0	1	0	0	1	**1.43**
Tuberculosis	8	0	0	0	0	8	**11.43**
Wound and bacterial infections	18	3	1	2	5	29	**41.43**
Total	**43**	**11**	**2**	**9**	**5**	**70**	
Percentage	**61.43**	**15.71**	**2.86**	**12.86**	**7.14**	**100**	

and bacterial infections, tuberculosis, pneumonia, and parasites emerged as the most prominent diseases and infections. The impact of these diseases transcended across various species classes, including Mammalia, Aves, and Reptilia, encompassing herbivores, carnivores, omnivores, birds, and reptiles. Herbivore mammals accounted for the highest proportion of recorded cases (61.43%, 43), followed by carnivore mammals (15.71%, 11), and birds (12.86%, 9). Specifically, wound and bacterial infections constituted the majority of cases (41.4%, 29), followed by tuberculosis (11.4%, 8), pneumonia (5.71%, 4), and parasites (4.29%, 3). The remaining diseases, while present, affected only a limited number of wildlife mortality cases.

Wildlife mortality due to disease and infection

Disease and infection have affected both captive and wild species, in the categories of large herbivores, carnivores, prey species, reptiles, and birds (Table 5). Of the total mortality cases, 70 individuals from 15 different wildlife species listed on the International Union for Conservation of Nature (IUCN) Red list were affected by diseases and infections. These ranged from species of least concern to critically endangered. The one-horned rhinoceros (34.29%, 24) was the most affected species, followed by Asian elephant (20%, 14) and Bengal tiger (8.57%, 6). Rhinoceros were affected by seven types of different diseases and infections, followed by five types in elephants and four types in tigers (Appendix S1). Over the years, the incidence of wildlife mortality due to disease and infections showed a noticeable increase, with three cases reported in 2010, surging to 21 cases in 2019 (Table 5).

Patterns of disease and infection mortality in major fauna

The temporal trend analysis revealed that there are different trends in disease-related mortality among species (Figure 5). Specifically, rhinoceros exhibited the most pronounced and significant trend with a 42.9% annual increase in disease- and infection-related mortality counts (IRR = 1.429, 95% CI: 1.205–1.744, $p < 0.001$; Table 6). The aggregated other species showed a significant 45.6% annual increase (IRR = 1.456, 95% CI: 1.215–1.805, $p < 0.001$). In contrast, the models found no significant temporal trend in disease- and infection-related mortality for elephants (IRR = 0.907, $p = 0.377$) or tigers (IRR = 1.132, $p = 0.400$). While deer showed a large estimated increase of 63.5% annually, it was not statistically significant (IRR = 1.635, $p = 0.074$).

Conservation efforts and challenges

FGD with different key stakeholders revealed multiple existing efforts undertaken to address wildlife mortality caused by disease and infections in Chitwan NP. Thematic analysis revealed four themes: health monitoring and treatment, use of modern technology, institutional support and facilities, and challenges and biases in wildlife healthcare.

Health monitoring and treatment

Participants emphasized a strong collaboration between veterinary doctors from both Chitwan NP and the NTNC. Efforts were focused on the identification,

TABLE 5 Wildlife death cases with respect to identified diseases and infection during 2010–2019 (CNP, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019).

Wildlife species	Disease and infections	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total	Percentage
Axis axis	2	0	0	0	0	0	0	1	1	1	1	4	5.71
Bubo bubo	1	0	0	0	0	0	0	0	0	1	0	1	1.43
Canis aureus	1	0	0	0	0	0	1	0	0	0	0	1	1.43
Elephas maximas	5	3	0	1	5	0	1	2	0	0	2	14	20.00
Felis chaus	1	0	0	0	0	0	0	0	0	1	0	1	1.43
Gavialis gangeticus	1	0	0	0	0	0	0	1	1	0	3	5	7.14
Gyps bengalensis	2	0	0	0	2	0	1	0	0	1	0	4	5.71
Leptoptilos javanicus	2	0	0	0	0	0	0	0	0	0	3	3	4.29
Panthera pardus	2	0	1	0	0	0	0	1	0	0	0	2	2.86
Panthera tigris	4	0	0	2	0	0	1	1	0	0	2	6	8.57
Paradoxurus hermaphroditus	1	0	0	0	0	0	0	0	0	0	1	1	1.43
Pavo cristatus	1	0	0	0	0	0	0	0	0	1	0	1	1.43
Rhinoceros unicornis	7	0	1	2	0	2	0	1	6	3	9	24	34.29
Rusa unicolor	1	0	0	0	0	0	0	0	1	0	0	1	1.43
Sus scrofa	2	0	0	0	0	0	0	0	0	2	0	2	2.86
Total cases		**3**	**2**	**5**	**7**	**2**	**3**	**8**	**10**	**9**	**21**	**70**	**100**

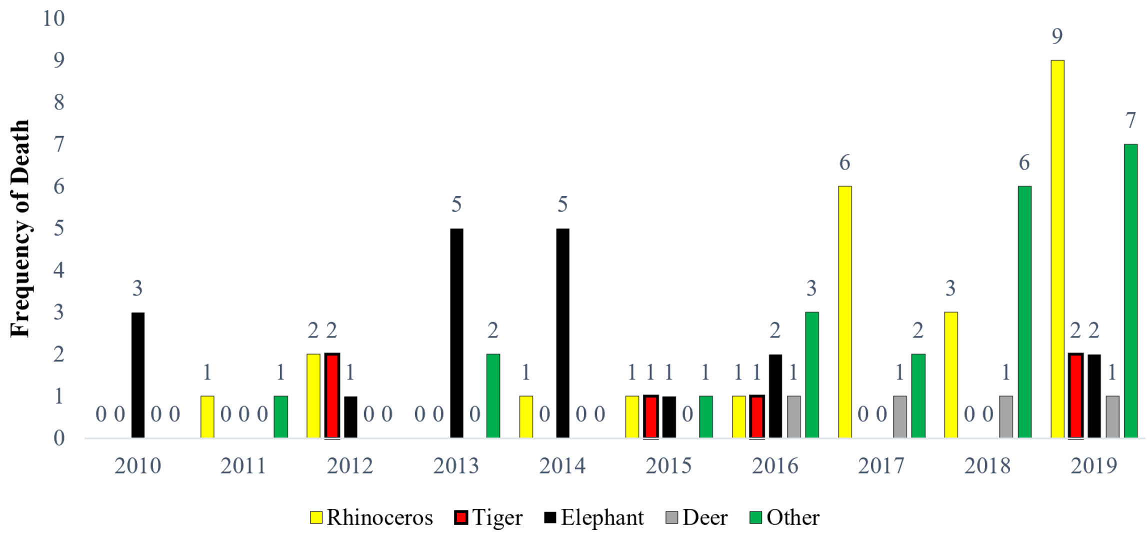

FIGURE 5 Mortality due to disease and infections among rhinoceros, elephants, tigers, deer, and others from 2010 to 2019.

TABLE 6 Results of regression (Poisson/negative binomial) analyses for temporal trends (2010–2019) in annual wildlife mortality count by species.

	Overdispersion test					IRR				
Mortality cause	**φ**	***z***	***p***	**Model**	**SE**	**IRR**	**CI**	***p***	**(+/−) Change (%)**	**Trend significance**
Rhinoceros	0.84	−1.54	0.752	Poisson	0.093	1.429	1.205–1.744	0.001	+42.9	Significant
Elephant	1.6	1.311	0.095	NB	0.111	0.907	0.712–1.138	0.377	−9.3	Not significant
Tiger	1.09	0.288	0.387	Poisson	0.148	1.132	0.854–1.553	0.400	+13.2	Not significant
Deer	0.6	−1.799	0.964	Poisson	0.275	1.635	1.054–3.313	0.074	+63.5	Not significant
Other	3.26	1.267	0.103	NB	0.100	1.456	1.215–1.805	0.001	+45.6	Significant

Abbreviations: φ, dispersion parameter; +, increase; −, decrease; IRR, incidence rate ratio; NB, negative binomial; *p*, *p* value; *z*, *z* statistic.

control, and mitigation of wildlife diseases and infections. Regular health checkups were conducted for animals in captive and breeding centers (i.e., elephant, gharial, and vulture) and ensuring prompt healthcare for those showing abnormal behavior. Diseased or injured wildlife were isolated for necessary treatment and safely released back into their natural habitat after recovery.

A vigilant monitoring system was in place for suspected sick or wounded animals, with a specialized rescue team using tranquilizer darts when needed. Samples were collected for laboratory diagnosis, enabling appropriate medical treatments. Proper care and treatment were provided throughout the captive period, including food, shelter, and quarantine facilities, following animal welfare standards. This system only records what they can see: “Our system works well for the animal we see, but our data is a map of our attention, not a map of disease in the park.” This highlights that mortality counts likely missed many animals that died without being seen.

Use of modern technology

The adoption of modern technology, such as microchips implanted in captive elephants, facilitated continuous health monitoring and treatment assessment. Vaccination programs targeted specific diseases, with anti-rabies vaccines administered to approximately 500 dogs in the BZ and similar initiatives for diseases like FMD. A wildlife technician pointed out, “We vaccinate dogs for rabies because we know its there and it jumps to human and wildlife. But what about the pathogens we aren’t testing for? The lab can only find what we look for.” This insight suggests that cause-specific mortality data are constrained by diagnostic capacity and the underestimation of undiagnosed diseases.

Institutional support and services

Two facilities have been established to manage disease and infection among wildlife in Chitwan NP and the surrounding BZ.

1. *Diagnostic molecular laboratory*: The BCC at NTNC Sauraha, Chitwan, established a diagnostic molecular laboratory in 2016 with financial support from the USAID, Hariyo Ban Program of World Wide Fund for Nature (WWF), Nepal. This is the only government laboratory dedicated to diagnosing diseases in wildlife species. It analyzes samples from wild, captive, and domestic animals for disease and infection diagnosis. Notably, the laboratory achieved a significant milestone by identifying the first positive case of tuberculosis in rhinoceros. Additionally, a survey of domestic dogs revealed the presence of CDV.
2. *Chitwan wildlife hospital*: Construction of the Chitwan Wildlife Hospital began on March 4, 2015, and is the first of its kind in Nepal, specially targeting the medical treatment of injured and sick wildlife species. The hospital was completed in 2019 with financial support from the NTNC, World Wildlife Fund, and the Katie Adamson Conservation Fund (KACF), USA. The hospital formally began operation on December 11, 2020, under the Ministry of Forests and Environment of Nepal.

Challenges and biases in wildlife healthcare

1. *Systematic surveillance and detection biases*: Stakeholders reached a consensus that detection probability is not uniform. Monitoring is heavily skewed toward “flagship” species (e.g., rhinoceros and tigers) due to intensive daily patrols. Consequently, disease-related deaths in these species are recorded more frequently than those of smaller, less charismatic, or nocturnal mammals. A park official explained, “If a large species (rhino, elephant, tiger) dies, we find it within few days but if a deer dies only the vultures know.” Additionally, a geographic bias exists; mortality detection is highest in BZs and tourist corridors, while deaths in the dense core areas often go unrecorded due to inaccessible terrain. A hotel operators mentioned, “We report everything we see near settlements and BZ but deep inside the carcass is gone before any patrol reaches.” This confirms that the spatial distribution of mortality records likely reflects human accessibility rather than true mortality.
2. *Diagnostic and environmental constraints*: The characterization of disease is often hindered by the state of the carcass. Veterinarians noted that while poaching or conflict-related deaths are obvious, disease-related mortalities are frequently categorized as “natural” or “unknown” due to rapid decomposition, scavenging, or late reporting in the field. A veterinarian stated, “We list them as unknown but as a technician we missed the window to know if it was disease.” This explains many deaths in our data were marked unknown, but might have been due to knowable causes, had they been identified closer to the point of death.
3. *Operational and administrative hurdles*: Logistical gaps, like delays in importing medications due to government protocols, hinder proactive care. A local key person and park officials stated, “We confirm a disease outbreak, but by the time we get the specific vaccine or drug cleared through customs, the critical window for intervention has passed while our response is always playing catchup.” This insight explains potential temporal gaps in outbreak mitigation and the challenges of delivering timely wildlife healthcare.

DISCUSSION

Overall, the findings of this study must be interpreted with the critical context of its methodological limitations. Our analysis relies on observational data collected by Chitwan NP, a process inherently subject to surveillance bias. Through examining the wildlife mortality count, causes, patterns, and existing conservation efforts, our study elucidates a critical aspect of wildlife mortality over a decade. Overall, the study reveals an increasing trend in wildlife mortality, affecting both captive and wild species. The four major causes of wildlife mortality identified by this research are anthropogenic, natural death, diseases and infection, and conflict/competition. This study offers valuable insights into wildlife mortality caused by diseases and infections, which could emerge as significant contributors to wildlife loss. Regarding scanty research on characterizing disease and infection mortality, this study expects to cover the gap for a better understanding of trends of cause-specific, species-specific mortality and conservation efforts.

Understanding the causes of wildlife mortality

Our study distinctly identified that the causes of overall wildlife mortality were attributed highest to anthropogenic (~33%) followed by natural (~24%), disease and infections (~13%), and conflicts/competition (~12%) (Figure 2). However, we must pay close attention to the notable trends in disease and infections and competition, which increased significantly over the study period. It is crucial to note substantial interannual variation, like the pronounced peak in overall detected mortality observed in 2015 (Figure 3). This may be linked with catastrophe, that is, a 7.8 magnitude earthquake that struck Nepal in April 2015, which altered human–wildlife dynamics. Research reported that such catastrophic events can intensify human dependency on forest resources for basic needs, which could escalate poaching, retaliation, and habitat disturbance (Poudel et al., 2022). Later, post-disaster recovery-led intensified patrolling may have further increased detection and reporting, contributing to a higher wildlife mortality count.

The significant increase in disease and infection wildlife mortality underscores a substantial health challenge for wildlife populations. A study by WWF also emphasized that disease and infections are the most frequent threats to wildlife vulnerability and risk of extinction (WWF, 2018b). Environmental changes and disturbances have been recognized as a potential catalyst for increased disease and infection prevalence among wildlife (Ellwanger et al., 2022). Alterations in climate patterns and land use and land cover may have created favorable conditions for disease and infection to thrive. In this context, an observed annual increase of 25.8% provides strong, localized empirical evidence of a global pattern, emphasizing wildlife disease and infection as an emerging concern. To address this challenge, collective efforts are required in developing disease control methods in wildlife and should be undertaken as a series of systematic steps toward well-organized disease control mechanisms (Carver et al., 2022).

The parallel significant increase in conflict/competition mortality, which rose by 17.4% annually, highlights the significance of resource dynamics. This trend aligns with the fundamental ecological principle that competition intensity escalates when resources become limited (Maziarz et al., 2023; Newton, 2007). It is exemplified by observations that elderly rhinoceros unable to compete for adequate forage inside the park are forced to move beyond its boundaries where they face a grim choice or risk either natural death or getting speared by humans (Martin & Vigne, 1996). Interspecific competition for resources is limited when the resources are abundant (Maziarz et al., 2023; Newton, 2007). Intraspecific competition seems likely to be intense because two members of the same species are likely to have very similar resource needs. However, competition intensity increases with the decline of ecological disturbances, further straining resource access among wildlife.

Contrastingly, the analysis indicates that natural ($IRR = 1.002$, $p = 0.971$) and anthropogenic ($IRR = 1.165$, $p = 0.210$) causes of mortality have remained relatively stable over the study period. Natural wildlife mortality seems to reflect the complex dynamics of the ecological processes. It is driven by aging, orphan, and environmental conditions (Bhandari et al., 2022). These deaths are induced by the multifactorial and integral part of broader ecological dynamics, serving as indicators of the complex web of survival in nature. This aligns with the findings of collaborative research efforts (Garcês et al., 2019) that emphasize the importance of intact ecosystems in maintaining ecological balance. Chitwan NP has a diverse range of species, including both predators and prey, and this highlights the complex ecological web that regulates population dynamics. Collaborative research efforts are crucial for a deeper understanding of the ecological factors contributing to natural mortality and their implications for wildlife management.

Similarly, anthropogenic causes continue to pose threats to wildlife as human-induced factors are directly responsible for more than a quarter of wildlife mortality on a global scale (Hill et al., 2019). Poaching, poisoning, retaliation, vehicle collision, habitat destruction, encroachment, and other human-induced activities put pressure on fauna in and around the protected landscapes, where human–wildlife interfaces are most active (Milda et al., 2020). Addressing these challenges requires a multifaceted approach: awareness campaigns, manpower, an effective management plan, and use of technology can collectively contribute to reducing the threats of anthropogenic-induced mortality.

Mortality across animal groups

Our study highlights the wildlife mortality due to disease and infection across major animal groups, including Mammalia, Aves, and Reptilia. This observation aligns with a global perspective that highlights "disease and infection" as one of the most common threats to wildlife survival and resilience (WWF, 2024). This threat extends its reach across diverse taxa, affecting mammals, aves, and reptiles on a global scale (WWF, 2018a). The most prominent diseases and infections were found to be wound and bacterial infections, tuberculosis, salmonella, pneumonia, parasites, gastroenteritis infection, and many others.

A particularly noteworthy trend appeared among different animal groups, where herbivorous species exhibited the highest mortality counts. This observation suggests that populations primarily feeding on green herbaceous vegetation face a heightened risk of mortality due to diseases and infections. Several ecological and anthropogenic factors may contribute to this vulnerability. Habitat shrinkage caused by the invasion of alien species, linear infrastructure development, encroachment, deforestation, and natural succession forces wildlife into increasingly fragmented and degraded landscapes. As habitats contract, wildlife species are compelled to share their living spaces with domestic cattle in BZs, fostering the exchange of diseases and infections between them.

Our analysis revealed the impact of diseases and infections on wildlife mortality, affecting species across the broad spectrum of IUCN conservation categories from "least concern" to "critically endangered." This indicates a large range of wildlife species were affected, which leads to declining populations and escalating risk of extinction. Brand (2013) reported that disease and infections pose significant barriers to the recovery of endangered species. Notably, species like rhinoceros, elephant, gharial, cheetal, and others were the highly affected wildlife species. This reinforces the urgency of integrating disease surveillance and management into conservation strategies.

Wildlife and their associated disease and infections

Mortality was observed in 15 different wildlife species over the period from 2010 to 2019, including those categorized as endangered (e.g., tiger, elephant, rhinoceros) and critically endangered (e.g., gharial, vulture). Mortality in those species has been noted as possibly a result of their behavior, such as, frequent forays outside of parks to fulfill their deficient habitat components (food, shelter, cover, and space arrangement) inside the park. The search for habitat components leads to interspecific and intraspecific competition, interaction with human-dominated landscapes, exchanges of diseases, and accidents caused by linear infrastructures. Historical records of disease and infection have been reported, such as tuberculosis (*M. orygis*) in Asian elephants, rhinoceros, spotted deer, and blue bull (Thapa et al., 2017) and the herpes virus in Asian elephants (Mandal & Khadka, 2013) which concur with our findings, highlighting persistent disease threats.

Our study underscores a noteworthy discrepancy in the mortality counts among different wildlife species, with rhinoceros, deer, and other species experiencing significantly higher mortality counts due to disease and infections when compared to remaining species such as tigers and elephants. Among rhinoceros, bacterial infection and tuberculosis are recognized as the primary causes of mortality (Table 5; Figure 2; Appendix S1). These results align with previous research, such as a study by Jonyo (1989), which highlighted physical wounds and bacterial infections as common contributors to wildlife mortality. Additionally, the emergence of tuberculosis in rhinoceros in Chitwan was reported for the first time in 2015 (Peters et al., 2020; Thapa et al., 2016). Similarly, Thapa et al. (2017) also emphasized the emerging threat that tuberculosis in wildlife poses to serious conservation efforts.

On the other hand, transmission of diseases often occurs through interaction between wildlife, livestock, and humans (Duffy et al., 2020). Although successful conservation efforts have enabled coexistence of rhinoceros, livestock, and humans (Martin, 2006), the coexistence in shared landscapes brings an increased risk of infectious disease cross-species transmission. This is exemplified by rhinoceros frequently entering croplands where they encounter domestic animals, creating opportunities for disease and infection exchange. These findings underscore the pressing need for strategies that not only safeguard wildlife health but also mitigate the risk of disease transmission between wildlife, humans, and livestock in areas of coexistence. Such efforts are pivotal for maintaining the delicate balance between conservation and public health concerns.

Species specific mortality

Except for translocation, the rhinoceros population is found in Parsa National Park, Chitwan NP, Bardia National Park, and Shuklaphanta National Park, among which Chitwan NP is the prime habitat. Chitwan NP provides a preferable riparian floodplain habitat for the highest number of rhinoceros (751) according to the census of 2021, which highlights the importance of Chitwan NP for this magnificent mammal. Our study explored the highest significant increase with 42.9% (IRR = 1.429, $p < 0.001$) in the rhino mortality counts due to disease and infections. A study by Bhandari et al. (2022) reported that disease, wounds, and injuries are not major risk factors, but our study revealed wound and bacterial infection, dystocia, tuberculosis, pneumonia, and others as contributors to rhino mortality. It could be because of intraspecific competition for resources and partners within this species. As the rhino population increases, competition for limited resources within the park intensifies. Ultimately, competition leads to wounds and injuries, which create opportunities for bacterial infections. Additionally, rhinoceros population expansion leads to the spread of the species out from the confined park; they raid farmlands in search of a proper quantity of food. This could increase human–wildlife interaction, escalating the risk of injuries and infection among the rhino population.

While these findings underscore the pressing issue of rhino mortality due to diseases and infections in Nepal's protected areas, they also highlight the complexity of the matter. It is imperative that further investigation be conducted to identify the underlying factors contributing to this trend and to develop targeted conservation strategies to ensure the continued well-being of Nepal's rhinoceros population. Addressing the challenges of intraspecific competition, habitat expansion, and human–wildlife interactions is crucial for the long-term conservation of this iconic species.

In contrast, for Asian elephants, the model indicated no statistically significant trend in disease- and infection-related mortality (IRR = 0.907, $p = 0.377$). This statistical finding likely reflects a critical surveillance gap rather than true absence of disease and infection risk. Asian elephants are migratory in nature and can cover large areas and travel longer distances in search of food and mating (Sukumar, 2003). While there were no death records in wild elephants due to disease and infection, captive elephants exhibited mortality from tuberculosis, wound and bacterial infection, herpes, and bloating. This disparity could be attributed to the limited attention given to the health of wild elephants, as they roam freely without regular medical checkups. Nevertheless, the frequent visits of wild male elephants to captive females for mating create clear opportunities for disease transmission.

Though research in these areas is not extensive, Mandal and Khadka (2013) used data from 2004 to 2009 in Nepal and reported that 14 captive elephants were infected with tuberculosis and 5 of them died. Tuberculosis has remained a significant cause of mortality among captive Asian elephants, although there has been a decreasing trend. This success in mitigation is attributed to the implementation of the Nepal Elephant Tuberculosis Management and Action Plan 2011–2015. The action plan involved collaboration among local, national, and international stakeholders and introduced innovative technology such as microchip installation and veterinary oversight in early diagnosis and treatment. These measures have proven invaluable in early disease diagnosis and isolation for proper medical care, saving elephants from untimely deaths.

Similarly, for tigers, this model indicated no statistically significant trend in disease- and infection-related mortality (IRR = 1.132, $p = 0.400$). This should not be interpreted as an absence of disease threat but rather as an indication that disease has not yet emerged as a dynamically increasing driver of mortality within the detectable dataset. Tigers are apex predators that coexist with humans in Nepal's Terai region and their nocturnal behavior brings them into frequent contact with domestic cattle (Acharya et al., 2016; Carter et al., 2012). Our study aligns with findings of disease and infections like pneumonia (Dharanesha et al., 2019), FMD, rabies (Amin et al., 2018), wound bacterial infection, tuberculosis, and canine distemper (Dudley, 2017) in tigers.

It is imperative that we recognize that the future holds potential challenges for tiger populations as their numbers have increased from 235 in 2018 to 355 in 2022. This dynamic population may lead to heightened competition, pushing weaker species to live in fringe areas, increasing interactions between tigers and domestic cattle (Silwal et al., 2017). In these fringe areas, big cats might prey on infected domestic cattle (dogs, buffalo, cows, etc.), serving as potential vectors for disease and infections such as foot and mouth infection and other bacterial infections. This is supported by the result of a study by Andheria et al. (2007): tigers fulfill 1%–12% of their diet from the consumption of livestock, imposing a higher probability of disease exchange. This alarming trend exemplifies a significant pathway for disease exchange.

Therefore, the current nonsignificant trend underscores the urgency of conservation efforts to protect wild cats from disease and infections. These efforts should include prompt identification of disease and infections, routine immunization of domestic cattle in the BZ and fringe areas, and improvement in habitat management. Furthermore, developing grassland management practices, effective movement management, and establishment of corridors and connectivity with a special focus on wild prey populations are highly recommended (Aryal et al., 2020; Ruda et al., 2020; Silwal et al., 2017).

For spotted deer, this model estimated a considerable 63.5% annual increase in mortality attributed to parasitic infections; however, this trend did not reach statistical significance (IRR = 1.635, $p = 0.074$). This high p value likely reflects substantial inter-annual variability and the limited sample size of recorded cases, which constrains statistical power. Despite the lack of a definitive trend, the observed pattern aligns with established ecological research. A study in Jabalpur, India, found approximately 80% of spotted deer afflicted by parasitic disease (Gupta et al., 2011), suggesting a species-level susceptibility. In the context of Chitwan NP, this vulnerability is likely exacerbated by resource overlap with domestic cattle in the BZ. Competition for grazing land may force deer to forage in marginal, swampy areas where parasite loads are higher and host-related behaviors such as feeding and movement patterns further mediate exposure (Kołodziej-Sobocińska, 2019). Thus, while our analysis cannot confirm a significant increasing trend, the consistent ecological evidence of high parasitic infection rates highlights a persistent health risk. This finding underscores the importance of proactive habitat management securing uncontaminated foraging areas and reducing livestock–wildlife overlap as a preventive measure to mitigate potential threats.

As it becomes operational, the recently built wildlife hospital in Chitwan NP shows a significant advancement towards sustaining healthy wildlife populations and maintaining healthy ecosystems. It enhances the role of identifying suspected cases, providing specialized treatment, and managing quarantine for orphaned and disabled individuals that is crucial for rehabilitation and release back to nature. However, its full potential hinges on addressing suspected cases of sickness and infections and preserving healthy ecosystems. Orphaned and disabled individuals receive special treatment at the hospital, including a well-managed quarantine, where individuals are treated under close supervision and a favorable environment, to be released back into their natural environment soon after recovery. However, realizing its full potential requires overcoming existing logistical and supply challenges.

CONCLUSIONS

In conclusion, our study sheds light on complex patterns and dynamic nature of detected wildlife mortality in Chitwan NP over the past decade, driven by four major causes: anthropogenic, natural, disease and infection, and conflict/competition. While anthropogenic causes were the most frequently recorded, our analysis revealed a significant trend: mortality attributed to disease and infection increased by 25.8% per year and conflict/competition mortality increased by 17.4% per year. This escalation is not uniform across species; rhinoceros experienced a 42.9% annual increase in disease and infection-related mortality, highlighting critical and specific health issues.

The findings, while not conclusive of true population level, are observational and subject to surveillance bias. Nevertheless, they suggest that diseases and infection are emerging as a significant contributor to wildlife loss. The pervasive presence of diseases like tuberculosis, pneumonia, FMD, and parasitic infections observed in different species including endangered to critically endangered species (tigers, elephants, rhinoceros, gharials, vultures) highlights a potential vulnerability. This threat is exacerbated by increasing human-dominated landscapes, habitat shrinkage, and intensified resource competition. The transmission of disease and infection between wildlife, livestock, and humans poses a multifaceted challenge to biodiversity conservation and public health. It underscores the urgency to investigate and develop comprehensive disease control efforts.

Successful disease management programs, such as the Nepal Elephant Tuberculosis Management and Action Plan, offer a blueprint for future interventions. These efforts are supported by case studies from other regions. For instance, the implementation of a mandatory annual vaccination for domestic dogs around Serengeti NP in Tanzania became a landmark example that successfully reduced CDV transmission to lions (*Panthera leo*) (Viana et al., 2015). Similarly, research in Kruger NP demonstrated tuberculosis transmitted from African buffalo to rhinoceros, highlighting the need for rapid response team (RRT) and mobile veterinary campaign during wildlife disease outbreaks (Dwyer et al., 2022). The full operationalization of Chitwan wildlife hospital and ongoing collaborative efforts are positive steps. However, addressing the identified challenges requires a more proactive, integrated and evidence-based approach to disease monitoring, habitat management, and human–wildlife coexistence. Although more rigorous, bias-corrected data are required to confirm these long-term population trends, the current evidence base strongly advocates for immediate, targeted conservation action to mitigate wildlife health risks.

To effectively address the emerging threat of wildlife disease-related mortality, a comprehensive and collaborative strategy is essential. Strengthening research on wildlife–human–livestock interactions is critical to understanding disease dynamics and safeguarding Nepal's biodiversity. Conservation efforts must move beyond pattern detection to confirm long-term trends through species-specific studies, spatiotemporal analyses of mortality, and systematic recording of surveillance effort data to correct for detection biases. A robust *One Health* approach should be central to such efforts, formalizing cross-sectoral collaboration among park authorities, veterinary services, universities, public health agencies, and local communities. This includes expanding annual vaccination programs for domestic animals in BZs, raising community awareness on biosecurity, and integrating wildlife and livestock health surveillance systems. Operationalizing the Chitwan Wildlife Hospital, fostering public–private partnerships, and expanding community-based monitoring networks will be vital for building cost-effective early warning systems. Technological integration, capacity building for field staff, and rapid response mechanisms must be prioritized to enhance disease detection and treatment. These proactive, evidence-based measures will guide park officials, conservationists, and policymakers toward resilient disease management and sustainable habitat conservation, ensuring a healthier future for Nepal's wildlife and protected ecosystems.

AUTHOR CONTRIBUTIONS

Prabin Poudel: Conceptualization; research design; methodology; data curation; data analysis; preparation of original draft. **Thakur Silwal:** Conceptualization; reviewing; draft preparation. **Kripa Pokhrel** and **Beeju Poudyal:** Conceptualization; methodology; draft preparation; review. **Abiral Acharya:** and **Sandeep Timilsina:** Data curation; review; editing. **Pushkar Pal:** Data analysis; review; editing. **Ganesh Prasad Tiwari:** Data curation; field visit. All authors have read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data (Poudel, 2026) are available from Zenodo: https://zenodo.org/records/18844251.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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