Environmental Challenges 7 (2022) 100458

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

Landscape predictors of human elephant conflicts in Chure Terai Madhesh Landscape of Nepal

Ashok Kumar Ram[a,b,*], Nabin Kumar Yadav[c], Naresh Subedi[d], Bivash Pandav[a], Samrat Mondol[a], Binita Khanal[e], Deepak Kumar Kharal[b], Hari Bhadra Acharya[b], Bed Kumar Dhakal[b], Krishna Prasad Acharya[f], Hem Sagar Baral[g], Bhagawan Raj Dahal[g], Rama Mishra[h], Dipanjan Naha[i], Narendra Man Babu Pradhan[j], Lakshminarayanan Natarajan[a], Babu Ram Lamihhane[d,*]

[a] Wildlife Institute of India, Dehradun, India
[b] Department of National Parks and Wildlife Conservation, Nepal
[c] Ministry of Industry Tourism Forest and Environment, Province 2, Janakpur
[d] National Trust for Nature Conservation, Lalitpur
[e] Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, Netherlands
[f] Ministry of Agriculture and Livestock development, Government of Nepal
[g] Zoological Society of London, Nepal
[h] Evolutionary Ecology Group, University of Antwerp, Belgium
[i] University of Georgia, Athens, USA
[j] IUCN Nepal, Kathmandu, Nepal

ARTICLE INFO

Keywords:
Asian elephant
Habitat fragmentation
Conflict prediction
Chure terai madhesh landscape

ABSTRACT

Human elephant conflict (HEC) is rapidly increasing throughout the Asian elephant range countries including Nepal. HEC occurs in the form of human deaths and injuries, and crop as well as property losses. We compiled 10,798 incidents of HEC including attacks on humans, crop and property losses caused by elephants in the Chure Terai Madhesh Landscape, Nepal, between January 2001 and June 2020. We interviewed 10.3% of the total households affected by HEC using structured questionnaire. We used multivariate analysis to identify landscape predictors associated with HEC. The intensity of HEC was high in the areas with higher forest fragmentation, vicinity to forests, protected areas, and larger coverage of seasonal surface water. Landscape heterogeneity, effective mesh size and altitude also contributed in HEC. Socio-economically marginalized communities living close to forests are more vulnerable to HEC. The spatial risk map of HEC identified Jhapa and Koshi in the eastern region; Parsa and Chitwan in the central region, Bardiya and Kanchanpur in the western region as HEC hotspots. Restoration of forests and corridor functionality in these hotspots could reduce HEC. The comprehensive understanding of HEC from this study provides important insights to devise strategies and actions for mitigating the HEC at the landscape level.

1. Introduction

Habitat loss, fragmentation, overexploitation of resources, and climate change are major anthropogenic drivers causing the purported 6th mass extinction on the earth (Mishra et al., 2020; Reid et al., 2005; Wagler, 2017). Over a million species face threat of extinction due to human impacts (Bongaarts, 2019). Because of high mobility, large resource requirements and highly prized body parts, large mammals are particularly vulnerable to local and regional extinctions (Hoare, 1999; Liu et al., 2017; Sukumar, 1989). In addition to species extinctions, paradoxically, pervasive human impacts on the planet had also have also triggered human-wildlife conflict (HWC). Human–wildlife conflict (HWC) is disproportionately higher in fragmentated landscape (Daskin and Pringle, 2016; Gubbi, 2012; Naha et al., 2020a; Tilman et al., 2017).

Asian Elephant (*Elephas maximus* Linnaeus. 1958; hereafter referred to as "elephant") is an umbrella species native to mainland Asia (Sukumar, 2003). Once distributed widely across Asia, the elephants are now confined to ~5% of their historical range (Leimgruber et al., 2003) within 13 countries with an estimated population of <50,000 (Williams et al., 2020). While elephants have cultural reverence in parts

* Corresponding authors.
E-mail addresses: elephas.maximus@yahoo.com (A.K. Ram), baburaml@gmail.com (B.R. Lamihhane).

https://doi.org/10.1016/j.envc.2022.100458
Received 2 November 2021; Received in revised form 18 January 2022; Accepted 21 January 2022

of South Asia, they are hunted for ivory and meat in Southeast Asia (Sukumar, 2003). Despite their essential natural and cultural role, elephants face high extinction risk and are categorized as endangered in the IUCN Red List (Williams et al., 2020).

The intensity of human-elephant conflicts (HEC) varies widely across Africa and Asia due to various ecological and socioeconomic factors, including food availability, size of protected areas, agricultural practices, human density, seasonal variations of climate and socio-cultural beliefs (de Boer et al., 2015; Shaffer et al., 2019). Nevertheless, human-elephant conflict (HEC) is a pervasive threat to human-elephant coexistence within shared landscapes (Acharya et al., 2017; Lamichhane et al., 2018; Naha et al., 2020b). Crop, property damage and occasional attacks on humans might reduce societal tolerance and provoke retaliatory killings impacting the elephant populations (Karanth et al., 2013).

Human elephant conflict (HEC) leads to a large number of human deaths and injuries, threatening the survival of Asian elephant throughout its range (Fernando et al., 2005; Sukumar, 2003, 1989). The nature and extent of HEC varied among ethnic groups, cultural practices, type of crops, season of cropping, habitat characteristics (availability of water and food), elephant population size, environmental conditions along with individual elephant behavior and the peoples' willingness to protect elephants (Dickman, 2010; Ram and Acharya, 2020; Shaffer et al., 2019). Nepal has a small population of wild Asian elephants estimated to be ~230 individuals (Ram and Acharya, 2020). These individuals form a part of the meta-population network of elephants across the *Terai* region encompassing the neighboring countries of India, Bhutan, Bangladesh and Myanmar (MoFSC, 2015). The Chure Terai Madhesh Landscape (CTML) comprises of the entire elephant range in Nepal and provides connectivity for the meta-population across the Terai region (Ram et al., 2021a).

Forest cover is a primary determinant of elephant distribution, thus, understanding impact of forest loss and fragmentation is crucial for elephant conservation (Padalia et al., 2019). About 22% of elephant habitat was lost between 1930 and 2020, with a larger proportion i.e., (12.3%) forest cover loss between 1930 and 1975 (Ram et al., 2021b). At present, only 19,000 km^2 forest cover is available as an elephant habitat in Nepal which has been gradually reduced at an annual rate of 0.27%. The continued fragmentation had fragmented elephant populations during the last century and escalated human-elephant conflict (HEC) (Ram et al., 2021b).

Presently, there is considerable movement of large mammals within the Chure Terai Madhesh Landscape (CTML) including the elephant, tiger (*Panthera tigris*), one-horned rhinoceros (*Rhinoceros unicornis*), and others (Acharya and Ram, 2017; Service, 2021; Sharma et al., 2019). The CTML covers both the Gangetic flood plains and the Siwalik Mountain range of Nepal. CTML is also a remnant elephant habitat with highly diverse flora and fauna, gradually experiencing elephant poaching and ivory trade (CTML) (Singh et al., 2019). The elephant habitat in CTML is interspersed with humans and thus, the negative interactions between the two species are frequent (Acharya et al., 2016; Lamichhane et al., 2019; Ruda et al., 2018). HEC has resulted in ~20 human deaths with large amount of crop, property damages along with the deaths of ~5 elephants due to retaliation each year in Nepal (Ram et al., 2021a).

Elephants are one of the less researched megaherbivore species in the CTML, Nepal with a large knowledge gap particularly with respect to HEC. The HEC situations are dynamic, and periodic assessments should be conducted to develop appropriate management strategies. In this study, we examined a) the landscape features associated with the HEC, and b) mapped conflict hotspots by modeling the probability of HEC. We examined three hypotheses; a) HEC is associated with demography (ethnicity, education, family size) of the respondent and the season, b) Fragmentation intensify HEC in the landscape, c) Water availability is associated with increased probability of HEC in the landscape.

2. Methods and materials

2.1. Study area

The study was carried out throughout the elephant range in Nepal's Chure-Terai-Madhesh landscape (CTML), which spreads across 24 districts of six provinces in Nepal (26.4154° to 29.1134°N and 80.1259° to 88.0849° E, area – 42,456 Km^2) (Fig. 1). The CMTL, extending from east to west in southern Nepal, has rich biological diversity and provides important ecological services (especially groundwater recharge) for more than half of the country's population (~15 million) (CBS, 2014; Chaudhary and Subedi, 2019; Hamilton and Radford, 2007). CTML comprises of 48% agriculture and settlement; 47.16% forest, shrub-land and grassland; and the rest 4.65% river and riverbed (GoN/PCTMCDB, 2017). Vegetation types in CTML include a) Himalayan subtropical broadleaved forest, b) Gangetic plains and moist deciduous forest, and c) *Terai-duar* savannas (Chaudhary and Subedi, 2019). The study area has a sub-tropical monsoonal climate with four distinct seasons defined here as winter (mid-December/mid-March), pre-monsoon (mid-March/mid-June), monsoon (mid-June/mid-September), and autumn (mid-September/mid-December) (Lamichhane et al., 2017). The maximum temperature varies from 35 to 40 °C during summer and 14–16 °C in winter (Jackson, 1994). Because of fragmented landscape, elephant occurs in four isolated populations (Pradhan et al., 2011; Ram, 2014; Ram et al., 2021b). The annual rainfall ranges between 1138 and 2680 mm, with over 80% of the rain occurring during monsoon months (DFRS, 2015). The altitudinal range varies between 60 and 1500 m (Chaudhary et al., 2016). CTML is densely populated with an average human density of 390 persons/km^2 (CBS, 2014), with sixty percent of the people depending on subsistence agriculture (Chaudhary and Subedi, 2019) (Fig. 1).

2.2. Data collection

2.2.1. Human elephant conflict (HEC) data

The farmers who experienced elephant-related losses, started reporting HEC incidents after implementation of Buffer Zone programs (1998 or later), which used to provide relief to victims in the form of ex-gratia. As a part of this program, human-wildlife conflict data are maintained systematically by the wildlife management authorities (Lamichhane et al., 2018). In 2009, goverment endorsed the directives on relief payment for wildlife damge including elephants (Acharya, Paudel, Neupane and Köhl, 2016). We compiled all such data of HEC (Human death, injury, crop, and property damage) from the Divisional Forest Offices (DFO) and Protected Area (PA) offices across the CTML for twenty years (July 2001 to June 2020). We collected a comprehensive dataset for our study but it is not the complete census of HEC incidents. Some of the HEC incidents remain undocumented as victim families do not report it. All reported HEC incidents were verified by the wildlife staff prior to compensation. We verified all HEC data from the annual reports of PAs, divisional forest offices, Department of National Parks & Wildlife conservation (DNPWC), and stakeholder consultation meetings ($n = 30$)(Ram et al., 2021a). The information transcribed from the data includes the victim's name and address, date of incident, type of loss, species of wildlife causing the loss, amount claimed and received.

2.2.2. Victim household questionnaire survey

We identified five major HEC hotspots in the stakeholder consultation meetings and surveyed randomly 10.3% of HEC victim's households ($n = 1116$ HH), using structured questionnaires. We interviewed either the head of the household or another adult member (age >18 years) upon receiving their consent. The interviews were also recorded electronically, along with filling the questionnaire. The wildlife officials who were present during ex-gratia payments for HEC related losses also accompanied the research team during questionnaire surveys. The

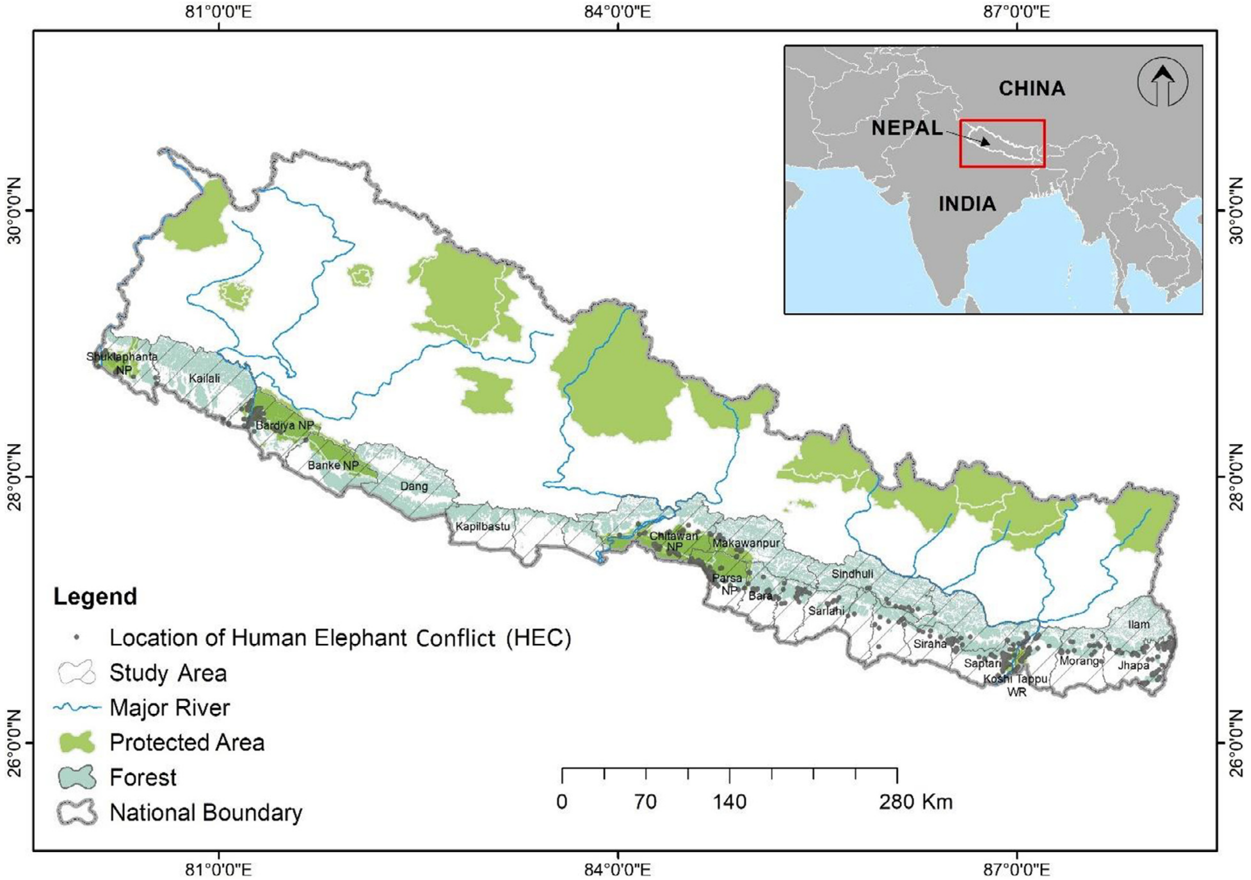

Fig. 1. Geographical location of Nepal, Study area along with human elephant conflict locations.

Table 1
Landscape predictor variables.

Types of variables	Predictor variables	Codes	Units	Range	Source /Description of data
Habitat (Fragmentation metrics)	Mean Perimeter Area Ratio	MPAR	Meter/hectare	0 – 0.34	Classified satellite images of 2020 (Landsat 8, 30 m resolution)
	Effective mesh size	MESH	Hectare	0 – 2500	„
	Landscape Heterogeneity	SHDI	Numeric (ratio)	0 – 0.6900	„
Habitat (Landscape variables)	Area of Open Forest	AOF	m^2	0 – 8231,400	„
	Distance to Protected areas	DPA	meter (m)	0 – 107,477	„
	Distance to Forest Area	DFA	meter (m)	0 – 30,953.8	„
	Digital Elevation Model	DEM	M	100 – 3602	SRTM Digital Elevation Data Version 4
	Area of seasonal water	ASW	m^2	0 – 11,849,442	EC JRC/ Google Earth Engine
	Area of permanent water	APW	m^2	0 – 1937,874	EC JRC/ Google Earth Engine
	Length of the Stream	LS	M	0 – 197,724	Department of Survey, Nepal, digital topographic map
Human footprint	Length of the road	LR	Km	0 – 99.87	Open street map
	Population density	PD	persons per km^2	0 – 12,389.8	GPWv411: Population Density (resolution – 1 km2)

questionnaire included demographic details of the respondent, spatial and temporal information of the incidents, age, sex, literacy, address with GPS location, date/time of incidents, type of incident, socioeconomic status, and habitat characteristics (Karanth et al., 2013; Lamichhane et al., 2018; Mukeka et al., 2019) (Supplementary information S4).

2.2.3. Landscape and habitat metrics

We stratified the study area into 5 × 5 km^2 (i.e. 25 km^2) grids ($n = 1407$) using Arc GIS 10.5 to identify spatial factors at coarser scales (Naha et al., 2020a, 2019; Ram et al., 2021b). We compiled 12 landscape predictor variables for each cell for predicting human-elephant conflicts (HEC), in three different categories viz. a) fragmentation metrics viz. mean perimeter area ratio (MPAR), effective mesh size-(MESH), landscape heterogeneity (SHDI) measures forest fragmentation (S1, Table 1); b) habitat characteristics (area of open forest, distance to protected areas, distance to forest area, area of permanent water, area of seasonal water, stream length, elevation); and c) human footprint (population density, length of road) (Naha et al., 2020a) (Table 1). Mean perimeter area ration (MPAR) is a shape complexity parameter describing the shape of different patches based on the relation between perimeter and area. It is used as a substitute for shape index. At class level, it decreases irregularly with the increase of area percentage for one class. The effective mesh size (MESH) is constrained by the ratio of cell size to landscape area and achieved when the corresponding patch type consists of a single one-pixel patch. Shannon Diversity Index of land use categories is used as an index of landscape heterogeneity (SHDI). It is ‘0’ when the landscape contains only 1 patch (i.e., no diversity). The index increases as the number of different patch increases and/or the proportional distribution of area among patch types becomes more equitable (de Beer and van Aarde, 2008; Fahrig, 2003; Haines-Young and Chopping, 1996). Finally, we generated the binary and count statistic for the surveyed HEC events (treating each human fatality, injuries, crop, and property damage as a single event) within each grid cell (Naha et al., 2020b, 2020a, 2019).

2.2.4. Data analysis

We carried out data analyses in the R statistical package v. 4.0.2 (R Core Team, 2020). We used the Pearson Chi-square test of independence (statistical significance $\alpha = 0.05$) (Franke et al., 2012; Rao, 2002) to compare the association between frequency of elephant attacks and education of the respondent, ethnicity of the respondents, seasons of conflict, types of houses and family size. We used binary and count statistic data for HEC events to model the spatial spread and extent of human-elephant conflict (HEC) incidents obtained from the questionnaire survey as a response variable (Clark, 2020). For the binomial distribution, the HEC presence/absence (presence coded as '1′ and absence as '0′) within the grid cell (25 km^2) was used as a response variable and the other 12 landscape predictors as explanatory variables (Table 1). Similarly, for the Poisson distribution, the frequency of HEC events within the grid cells was used as the response variable with the same explanatory variables.

Multicollinearity test among these 12 explanatory variables (Table 1) was performed using VIF functions (vifcor function in package 'usdm') in R (Naimi, 2017). None of the variables were highly correlated (VIF value >5) (S2).Thus, we used all the variables for model building (Chatterjee and Hadi, 2012). We run two sets of Generalized Linear Models (GLM) (Zuur et al., 2010) with the binomial and Poisson error distribution respectively, to analyze the effect of landscape features and human presence on HEC . We performed Moran's Index test using ArcGIS Spatial Analyst tool to test spatial auto-correlation and found the z-value (11.992), Moran's Index (0.) and (p-value < 0.01), indicating that there is a less than 1% likelihood that the spatial clustering pattern of the HEC events was due to random chance (Bivand et al., 2013). We also found that the distance threshold between each neighboring HEC site was estimated to be 5000.5 m. Finally, we performed z-transformation of the variables, which allowed us to interpret the model coefficients and to compare effect sizes between alternative models (Graf, 2004).

Using the multi-model inference 'MuMIn' package in R version 1.43.17., we constructed all possible models with a combination of predictor variables and ranked them based on the small-sampled AIC (lower AICc value indicates higher model ranking) (Barton and Barton, 2020). We obtained the final model by averaging the top candidate models (delta AIC $\leq$ 2) (Burnham and Anderson, 2001). From the total data of 1407 grid cells, 80% of samples were randomly selected for model building (training sample) and 20% for validation of the model (test sample)

We checked the model's accuracy by comparing the predicted values and the actual value of the test samples. Predicted values of the model with the highest accuracy were reported. Further, we generated the ROC curve and AUC values to predict the reliability of the dominant models using package ROCR in R 4.0.3. We predicted the potential conflict hotspots based on the coefficients of the dominant models . We used ArcGis Pro (version 2.8.2) for preparing the HEC risk map (Naha et al., 2020a, 2019).

3. Results

3.1. HEC records and interview with the victims

A total of 10,798 records of human-elephant conflicts (HECs) events were recorded within 203 grids between January 2000 and June 2020. Out of which, 274 cases were human fatalities, 138 cases of human injuries, 6606 cases of crop damages, and 3757 cases of property damages (Table 2). The highest number of HEC incidents were recorded in 2017 and most of the people got the relief in the form of ex-gratia payment.

HEC was distributed across the 20 districts of the CTML (Table 2). Similarly, temporal pattern shows very less incidents before 2009 (probably underreported or less incident happened) and increased spontaneously reaching maximum in 2017. The number of reported incidents slightly decreased afterwards.

Out of 10,798 HEC incidents, we interviewed ~10.3% of total households ($n = 1116$), and their details are presented in Table 2. There was no significant difference between frequency of HEC and education of the respondents and seasons. However, HEC frequency differed significantly between ethnic groups, types of houses, and family size, which supported the first hypothesis i.e., HEC is associated with the demographic feature of the respondents (Table 3).

3.2. Landscape predictors of HEC

We run GLMs with the binomial distribution (presence of conflict −1, absence of conflict 0) and also with Poisson distribution (grid wise count of conflict incidences). The direction of influence of predictor variables on response was consistent across both response variables presence/absence of conflict (binary) and number of conflict incidences (count) (Table 4a,4b). The results of binomial GLMs are presented in table 4 a) and 5, and of Poisson GLMs result presented in Table 4b) and Table 6. The model with additive influence of Area of open forest (AOF), Area of permanent water (APW), Area of seasonal water (ASW), Altitude (DEM), Distance to forest area (DF), Length of the stream (LS), Effective mesh size (MESH), Mean perimeter area ration (MPAR), Population density (PD), and Landscape heterogeneity (SHDI) appeared as best model among the candidate set (Table 4a). However, there is high amount of model uncertainty among candidate set indicted by similar model weight (Table. 4a). And, since no single model appeared to explain the data substantially, we did full model averaging to compute effect size of the predictor variables (Table 5).

Results of the dominant model demonstrate that the probability of HEC increased with decreasing distance from the forest (DFA), protected area, elevation and area of permanent water. However, probability of HEC increased with increase in open forest area (AOF), area of seasonal water (ASW), mean perimeter areas ratio (MPAR) and landscape heterogeneity (SHDI) (Table 5). The fragmentation metrices viz. mean perimeter area ratio (MPAR) and landscape heterogeneity (SHDI) have increased the intensity of human elephant conflict, so it justified the second hypothesis. Similarly, the increaseof seasonal water area and decrease of permanent water area have also positive effect on the increasing HEC in the study area, which justified third hypothesis (Table 5)

3.3. HEC prediction in Chure Terai Madhesh Landscape

The receiver operating curves (ROC) values for the dominant model (GLM with binomial structure) were estimated at 0.86 (86.83% accuracy). The HEC probability maps were prepared based on best model coefficients, indicated that Jhapa and Koshi (eastern region), Parsa and Chitwan (central region), and Bardia and Shuklaphanta (far western region) areas were the highest HEC hotspots. We also found that HEC probabilities were higher near the forest boundary and in the proximity of protected areas. The binomial probability and Poisson prediction of Human elephant conflict (HEC) risk map showed that HEC is distributed throughout the Chure Terai Madhesh Landscape (CTML) (Fig. 3a, b). The HEC prediction map also showed that the probability of HEC will also be higher in Jhapa, Koshi, Chtwan-Parsa complex and Bardiya with highest expected numbers >8 events per grids. (Fig. 3b).

4. Discussion

This is a comprehensive study on landscape predictors of HEC in Nepal. We documented a high level of HEC, primarily crop and prop-

Table 2
Spatial extent (District wise) of HEC incidents reported from Nepal between January 2001-June 2020.

District	Crop damage	Human death	Human injury	Livestock loss	Property damage	Total
Banke	5	2	1			8
Bara		20	4			24
Bardiya	2006	40	26	10	958	3040
Chitwan	918	26	17	3	529	1493
Dhanusha		9	3			12
Ilam		4				4
Jhapa	1789	41	25	3	1314	3172
Kanchanpur	41	5	10		11	67
Mahottari		1				1
Makwanpur		5	4			9
Morang	1	8	4	6	15	34
Nawalparasi		1		1	3	5
Parsa	194	21	7	2	113	337
Rautahat		7	1			8
Saptari	403	23	11		276	713
Sarlahi		5	4			9
Sindhuli		9	3			12
Siraha		16	3			19
Sunsari	1227	15	15		532	1789
Udaypur	22	16			4	42
Total	6606	274	138	25	3755	10,798

Table 3
Socioeconomic characteristics of respondents interviewed (n = 1116). Frequency (count), percentage (proportion) of the respondents and chi-square test of independence among different categories (where relevant) is presented in separate columns.

Variables	Variable Components	Frequency	Percentage% of	
Household Head	Female	242	21.7	
	Male	874	78.3	
Education	higher education	5	0.4	
of	Illiterate	537	48.1	χ^2= 20.56, df = 12, p<0.06
respondent	Literate	201	18	
	Primary level	222	19.9	
	Secondary level	151	13.5	
Cast/Ethnicity	BCT	416	37.3	
	Dalit	147	13.2	χ^2= 43.78, df = 12, p<0.000
	Janjati	466	41.8	
	Madhesi	76	6.8	
	Muslim	12	1.1	
	Monsoon	416	37.3	χ^2=3.52,
Season of conflict	Spring	147	13.2	df = 9,
	Summer	466	41.8	p<0.94
	Winter	76	6.8	
Types	Cemented house	117	10.48%	χ^2=
of	GI roof house	441	39.52%	146.88,
houses	Thatch house	499	44.71%	df = 15,
	Thatch roof house	26	2.33%	p<0.001
	Tiled roof house	32	2.87%	
	Wooden house	1	0.09%	
Family	<5 person	499	44.71%	χ^2=
size	5–10 person	541	48.48%	21.10,
	10–15 persons	50	4.48%	df = 9,
	>16	26	2.33%	p<0.01
	Total	1116		

erty damage, clustered in four sites of CTML (Jhapa, Koshi, Chitwan, and Bardiya). The extent of conflict differed significantly among various communities based on their socioeconomic status and cropping patterns which support the first hypothesis (Table 3). Our results suggest that landscape features are significant predictors of HEC in CTML. Landscape structure, water availability, elevation, and human footprint were the significant factors associated with HEC which supports the second and third hypothesis (Table 5).

4.1. Spatio-temporal extent of HEC in the CTML

Although human elephant conflict (HEC) was recorded from the 20 districts of the CTML (Table 2), Bardiya, Chitwan, Parsa, Jhapa and Sunsari districts experienced the highest HEC (Neupane et al., 2017, 2013; Ram et al., 2021a). Our dataset is based on self-reported and it may have potential bias as some of the victims do not report for low-cost damages. However, with the recent provisions of relief payments for wildlife damages, most of the victim file for payments (Lamichhane et al., 2018). The highest number of HEC events occurred around protected areas (PAs) except in Jhapa district (Table 2). Elephant population is concentrated in and around protected areas (e.g. >100 in Bardia, 40–60 in Chitwan/Parsa) (Ram and Acharya 2020), thus, higher conflict probability close to these forests is expected (Gross et al., 2019). HEC incidents are relatively high in the eastern Nepal (Koshi and Jhapa) despite small population of elephant. The reason could be a) widespread forest fragmentation, loss of forest corridors in this region (Ram et al.,

Table 4
Second-order Akaike Information criterion scores (AICc, ΔAIC & AIC weight) of a generalized linear model with a) Binomial and b) Poisson structure predicting HEC using landscape predictors.

Component models*	df	AICc	ΔAIC	AIC weight	LogLik
Binomial distribution					
AOF + APW+ ASW+ DEM + DF + LS +MESH+ MPAR+ PD + SHDI	9	699.09	0	0.27	−340.46
AOF + APW+ ASW+ DEM + DF + MPAR+ SHDI	8	699.69	0.6	0.2	−341.78
AOF + APW + ASW + DEM + DF + LS+ MESH+ MPAR + SHDI	10	699.77	0.68	0.19	−339.79
AOF + APW + ASW + DEM+ DF MESH+ MPAR + SHDI	9	700.56	1.47	0.13	−341.2
AOF + APW + ASW + DEM + DF + DPA + LS + MPAR+ SHDI	10	700.66	1.57	0.12	−340.23
AOF + APW +ASW+ DEM+ DF+ LS + MPAR + PD + SHDI	10	701.05	1.96	0.1	−340.43
Poisson distribution					
AOF+ APW+ ASW +DEM+ DF+DPA+ LR+ MPAR + PD+ SHDI	11	4963.7	0	0.27	−2470.76
AOF+ APW+ ASW +DEM+ DF+DPA+ LR+LS+ MPAR + PD+ SHDI	12	4963.99	0.29	0.24	−2469.88
APW+ ASW +DEM+ DF+DPA+ LR+ MPAR + PD+ SHDI	10	4964.16	0.45	0.22	−2472

* *The variables used in the model are Area of Open Forest (AOF), Area of Permanent Water (APW), Area of Seasonal Water (ASW), Digital Elevation Model (DEM), Distance to Forest (DF), Distance to Protected Areas (DPA), Length of the Road (LR), Length of the Stream (LS), Effective Mesh Size (MESH), Mean Perimeter Area Ratio (MPAR), Landscape Shape Index (SHDI).*

Table 5
Coefficients of the best GLM model with binomial structure.

	Estimate	Std. Error	Adjusted SE	zvalue	Pr(>|z|)	Significance	CI (2.5% - 97.5%)	
(Intercept	−3.13	0.25	0.25	12.66	< 2e-16	***	−3.70	−2.71
AOF	0.29	0.10	0.10	2.74	0.01	**	0.07	0.48
APW	−0.62	0.23	0.23	2.77	0.01	**	−1.10	−0.23
ASW	0.77	0.21	0.21	3.68	0.00	***	0.39	1.20
DEM	−2.71	0.40	0.40	6.72	< 2e-16	***	−3.70	−2.08
DF	−1.44	0.42	0.42	3.45	0.00	***	−2.27	−0.58
LS	0.12	0.12	0.12	0.99	0.32		−0.02	0.40
MPAR	0.39	0.15	0.15	2.60	0.01	**	0.01	0.63
SHDI	0.32	0.14	0.14	2.28	0.02	*	0.07	0.65
MESH	0.05	0.11	0.11	0.46	0.64		−0.13	0.45
DPA	−0.01	0.04	0.04	0.20	0.84		−0.28	0.15
PD	0.00	0.06	0.06	0.08	0.93		−0.44	0.25

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Table 6
Coefficients of the best GLM model with Poisson structure.

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Significance	CI (2.5% - 97.5%)	
(Intercept)	−2.29471	0.11962	0.11972	19.167	< 2e-16	***	−2.5337	−2.06534
AOF	0.02481	0.0334	0.03341	0.743	0.458		−0.01967	0.107541
APW	−0.27476	0.03735	0.03738	7.35	< 2e-16	***	−3.53E-01	−2.07E-01
ASW	0.18952	0.02883	0.02885	6.569	< 2e-16	***	0.125463	0.240228
DEM	−3.07785	0.17765	0.1778	17.311	< 2e-16	***	−3.44E+00	−2.75E+00
DF	−0.88687	0.19693	0.1971	4.5	6.80E-06	***	−1.33384	−0.49423
DPA	−0.81414	0.05065	0.05069	16.06	< 2e-16	***	−9.30E-01	−7.29E-01
LR	−0.17987	0.04393	0.04397	4.091	4.30E-05	***	−0.26243	−0.09016
MPAR	0.1785	0.01822	0.01824	9.787	< 2e-16	***	0.137806	0.214669
PD	−0.34738	0.08095	0.08102	4.288	1.81E-05	***	−0.52036	−0.2005
SHDI	0.84876	0.05138	0.05142	16.505	< 2e-16	***	0.717825	0.9705
LS	0.02755	0.03877	0.03879	0.71	0.477		−0.02789	0.123817
NDVI	−0.01263	0.03118	0.0312	0.405	0.686		−0.12201	0.051404

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

2021b), and b) seasonal migration of elephants from nearby parks in India (Naha et al., 2019; Padalia et al., 2019). Studies from the other elephant range in India, Srilanka and Africa also shows similar findings with clustered pattern of HEC (Fernando et al., 2021; Gubbi, 2012).

Elephant population was small and confined in a few pockets in Jhapa, Parsa and Shuklaphanta in Nepal before 2000; and low level of HEC was reported (Shrestha et al., 1985; Smith and Mishra, 1992), HEC is gradually increasing after 2000 (Acharya et al., 2016; Ram et al., 2021a), along with increasing elephant population. There was no systematic recording of HEC incidents in Nepal before 2009, although buffer zone programs kept record of the relief payment for the loss from wildlife including elephants (Lamichhane et al., 2018). HEC events were recorded systematically after the endorsement of directives on relief for wildlife damage nationally by Government in 2009 (Acharya et al., 2016; Ram et al., 2021a). Initially, only human death and injuries on elephant attack were considered for relief, thus, crop and property damage events were not reported. The relief guideline was further amended in 2012 to include crop and property damage by elephants and payment procedure was clearly defined (Fig. 3). This resulted in continuous increase in registering HEC events with a peak in 2017 and slows down after 2017. The probable cause of reduction in the HEC incidents might be due to initiation of HEC mitigation measures and the initiation of participatory conservation approach viz. construction of active measures (solar fence ~500 km, GI piped fences, RCC walls, trenches etc.), and initiation of real time-based monitoring of problem elephants using satellite radio collars (Ram, 2021). In 2020, we have only included HEC

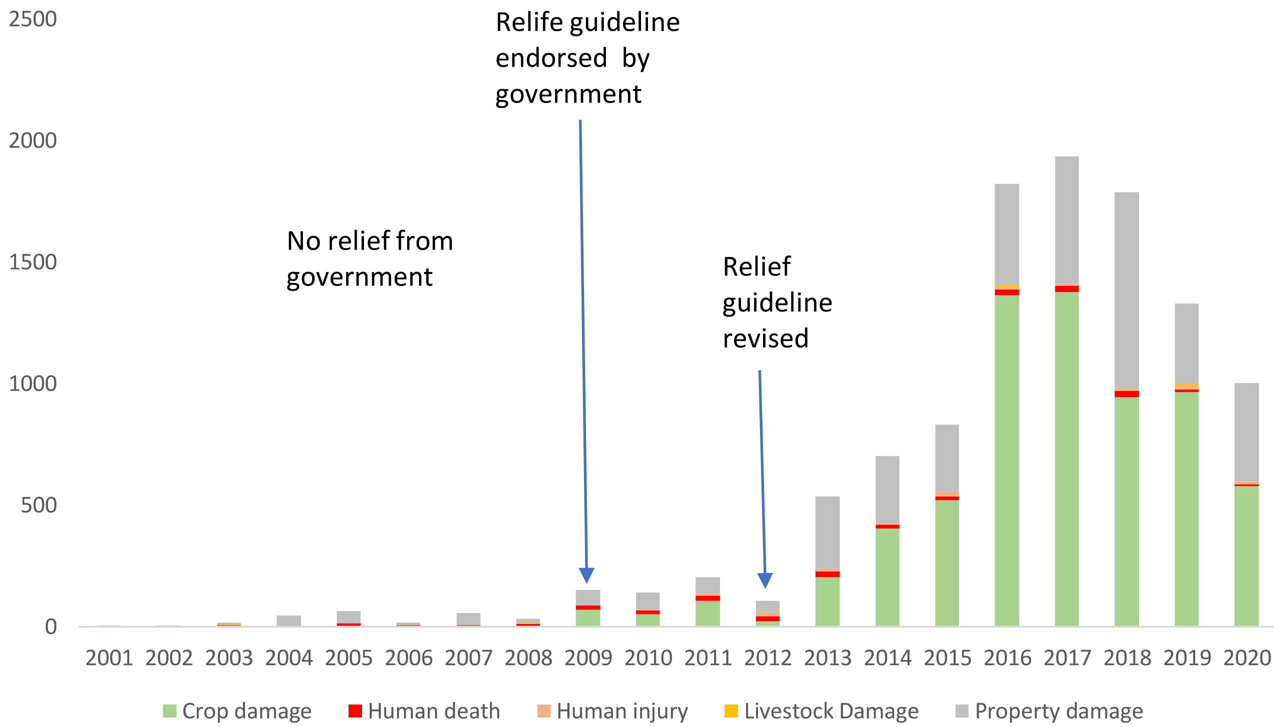

Fig. 2. Temporal extent of human elephant conflict (HEC).

incidents up to June, thus, the incidents seem comparatively less (Fig. 2). Increasing HEC incidents has been reported in other elephant range countries (e.g. India, Srilanka) (Karanth et al., 2013; Ranjeewa et al., 2017; Shaffer et al., 2019, 2014) .

4.2. Human elephant conflict (HEC) & Socioeconomic status of respondents

The HEC incidents were not evenly distributed among the socioeconomic classes of the respondents. socioeconomic features such as ethnicity, house types of respondents, and family size were associated with the conflict. The frequency of HEC was recorded higher in the Janajati (ethnic people). This community are socio-economically marginalized and have a high dependency on forest resources, increasing the chances of conflict. Moreover, they also use/produce alcohol in their locality which may attract elephants, increasing the extent of conflict. Ram et al. (2021a) also reported the increased threat of elephant attacks on humans when people are drunk. There was significant difference in the frequency of HEC incidents with the type of housing of the surveyed respondents with people living in Thatch house or GI roof house suffering more frequently compared to concrete or wooden. People living in thatch house are generally poor and marginalized with high dependency on forests for their livelihood (Ram et al., 2021a). Despite some seasonal variation in the frequency of HEC incidents, the difference was not significant statistically. Seasonality of HEC is observed in the other elephant range counties (Gross et al., 2018; Lakshminarayanan et al., 2016).

4.3. Landscape predictors and HEC

Our result shows that fragmentation indices viz. Landscape heterogeneity (SHDI), Mean Perimeter Area Ratio (MPAR), and Effective mesh size (MESH) are the major predictors of HEC in the landscape (Naha et al., 2019; Ram et al., 2021b). This is due to the higher rate of forest loss and fragmentation, especially in the forests outside of the protected areas. Forest fragmentation intensifies the challenges to the conservation of large-ranging species viz. elephants and tigers which require large areas beyond the protected areas for their survival. These animals came in to contact with humans while navigating through their migratory routes in fragmented landscapes, resulting in a large number of HEC incidents (Ram et al., 2021b). The forest fragmentation is likely to increase in coming days with expansion of linear infrastructure, degradation of forest and rapid expansion of settlements along the forest edge which could worsen the HEC (Acharya et al., 2017; König et al., 2020; Naha et al., 2019; Ram et al., 2021b).

Similarly, the HEC incidents increased with the decrease in coverage of permanent water but increase in area of seasonal water. Water is the crucial component of the habitat. Elephant frequently use the areas of seasonal water while passing through the migratory routes and often come in conflict with local communities (Naha et al., 2019). In the locations with larger areas of permanent water, elephant don't need to travel long distance to find water sources. This reduces the chances of elephant encounter with the local communities resulting the reduced HEC.

Our finding shows a high HEC risk in the proximity to forest, and decreased with increasing distance from the forest boundary which is similar to previous studies (Naha et al., 2019; Pant et al., 2015; Ram et al., 2021a). HEC decreased with increasing altitude, as elephant preferred flat lands, grasslands and low land forests. Our records of HEC include the locations with the altitude between 67 m (Prithiwinagar, Jhapa) and 587 m (Makwanpur & Sindhuli) and elephant presence signs were detected up to 885 m of Chure Hills.

4.4. Prediction of HEC risks in the CTML

Spatial risk zones analysis is used as a practical approach to devise mitigation measures for human-wildlife conflicts globally (Treves et al., 2011). The probability map shows the high HEC probability from Jhapa to Chitwan in the eastern landscape and Banke to Kanchanpur in western landscape (Fig. 3). In the eastern landscape, HEC incidents are high, despite relatively small resident elephant population. Majority of the elephants in eastern Nepal are males dispersed in different parts in smaller groups (Ram et al., 2021a). Males are more aggressive and, thus, come in confrontation with people frequently, increasing the chances of HEC. Be-

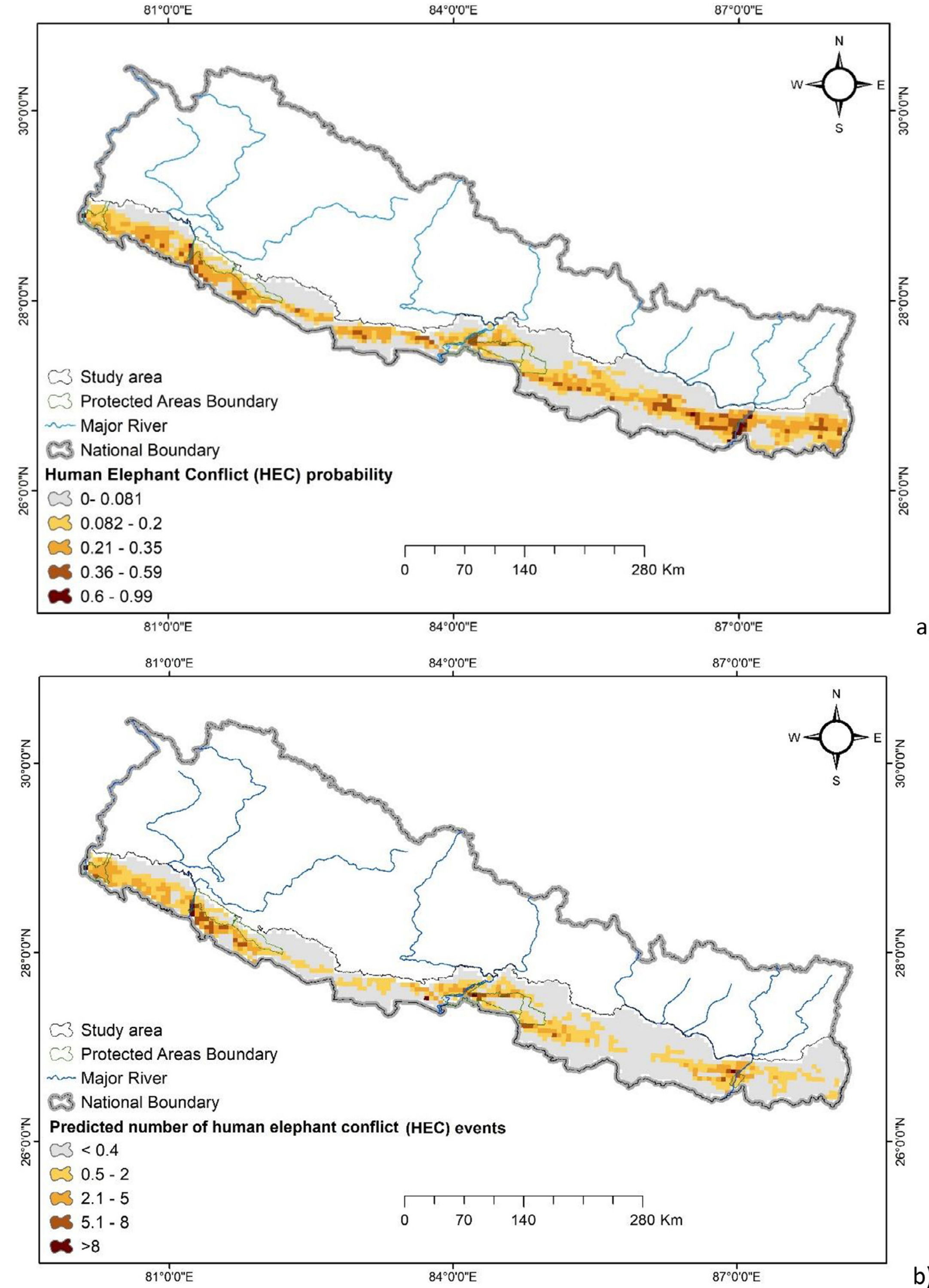

Fig. 3. a) HEC probability map using the binomial model results, darker areas indicate high risk areas, b) expected number of HEC risk map using the best model of Poisson structure. The darker color means the higher probability of conflict.

fore 2015, a heard of migratory elephants used to enter Nepal annually from Bahundangi area of Jhapa (eastern boarder). After installation of the electric offset fence, the large heard moved southward and only few risk-taker bulls entered Nepal breaking the fence. In the western landscape the elephant population is relatively large and cause damage while migrating Nepal-India or different forest patches in Nepal through the forest corridors and sometimes settlement areas. The government and conservation organizations should focus their HEC management effort, including awareness campaigns, fencing, and other HEC mitigation measures in the areas with a high probability of conflicts. At present, wildlife conservation is concentrated primarily inside the protected areas (PAs). However, most HEC incidents were recorded outside protected areas (Naha et al., 2020b; Ram et al., 2021b), and little effort has been made to protect elephants there.

Habitat fragmentation is likely to increase with ongoing and planned infrastructure development, many of them lie partly or fully in CTML. For instance, Nijgadh-Kathmandu fast track (under construction), Bardiwas-Simara electric railway line, additional electric transmission lines (under construction) have resulted in tremendous loss of forest and induced habitat fragmentation (Khatiwada, 2018; Mahat, 2020; Puri, 2021). In addition to these, forest encroachment for community purposes such as schools, colleges, temples, picnic spots, football grounds, Hat bazaars has also destroyed the forest in recent decades. Thus, fragmentation is continued in the CTML due to highest demand for land (by the hill migrants) and valuable timber (Aryal et al., 2020; Laudari et al., 2020).

5. Conclusion

Our results conclude that forest fragmentation and degradation, proximity to forest, altitude and availability of surface water were the major landscape predictors contributing to the HEC. Socio-economically marginalized communities living close to forests are more vulnerable to HEC. HEC is a multifaceted issue, not limited to the protected areas. Thus, it is necessary to extend our conservation priority beyond the boundary of the protected areas. A comprehensive HEC strategy and action plans to initiate HEC mitigation measures including alternative crop farming and initiating other income generating activities are recommended in the HEC risk zones.

6. Research Ethics statement

We obtained research permissions from the Department of National Parks and Wildlife Conservation Nepal (Ref no: 3066/073/74; June 02, 2017). We didn't carry out any experiments with live animals. We only carry out stakeholder consultation and questionnaire surveys by taking verbal consent from the participants for the ground verifications.

7. Data accessibility

Upon publication of the article, all the supporting data for obtaining the results will be made available via the dryad online data service.

8. Author contributions

AKR, NS, SM, & BP designed the study; AKR conducted the fieldwork; AKR, NKY, BRL, BK & BP analyzed the data; AKR, BRL, NKY, SM, BP & NS wrote the first draft of the manuscript; DK, HA, BKD, DN, RM, NLN, KPA, NMBP, HSB, BRD, BK and all authors revised the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We are thankful to Director General and Dean of Wildlife Institute of India (WII) Dehradun, Ministry of Forests and Environment (MOFE) Nepal, Director General, Dr. Ram Chandra Kandel, Department of National Parks and Wildlife Conservation (DNPWC), National Trust for Nature Conservation (NTNC), and Zoological Society of London (ZSL) Nepal office for support at different stages of the study. Dr. Shanta Raj Jnawali, Mr. Nawa Raj Chapagain, Ms. Carol Inskip, Mr. Man Bahadur Khadka, Mr. Shyam Bajimaya and Mr. Abdhesh Singh provided crucial feedback on the earlier version of the manuscript. We acknowledge the contribution of Mr. Gopal Prakash Bhattarai, Mr. Top Bahadur Khatri, Mr. Bishnu Prasad Shrestha, Mr. Gopal Khanal, Mr. Rishi Ranabhat, Mr. Hem Raj Acharya, field assistants Mr. Suman Acharya, Mr. Dinesh Ghimire, Mr. Badri Chaudhary, Mr. Anish Timsina, Mr. Ram Sahi, and Mr. Shankar Luitel. We are indebted to the support of the Director-General of DNPWC, National Park/Wildlife Reserve wardens, and Divisional Forest Officers of the Terai region during this study. The study would not be possible without the Rufford Small Grants Foundation (RSG), International Elephant Foundation (IEF), U.S. Fish and Wildlife Service through NTNC and ZSL Nepal. Finally, we like to thank anonymous reviewers and editors for their constructive comments to improve the manuscript

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2022.100458.

Reference

Acharya, H.., Ram, A.K., 2017. A Report on Extended Rhinoceros Unicornis Population, Habitat Monitoring and Rescue from Rautahat Districts of Central Nepal, Department of National Parks and Wildlife Conservation (DNPWC),Kathmandu, Nepal, 1–8.

Acharya, K.P., Paudel, P.K., Jnawali, S.R., Neupane, P.R., Köhl, M., 2017. Can forest fragmentation and configuration work as indicators of human–wildlife conflict? Evidences from human death and injury by wildlife attacks in Nepal. Ecol. Indic. 80, 74–83. doi:10.1016/j.ecolind.2017.04.037.

Acharya, K.P., Paudel, P.K., Neupane, P.R., Köhl, M., 2016. Human-wildlife conflicts in Nepal: patterns of human fatalities and injuries caused by large mammals. PLoS ONE 11, 1–18. doi:10.1371/journal.pone.0161717.

Aryal, K., Laudari, H.K., Ojha, H., 2020. To what extent is Nepal's community forestry contributing to the sustainable development goals? An institutional interaction perspective. Int. J. Sustain. Dev. World Ecol. 27.

Barton, K., Barton, M.K., 2020. MuMIn: multi-model inference. R package version 1.43.17. Version 1, 18.

Bivand, R.S., Pebesma, E., Gómez-Rubio, V., 2013. Applied Spatial Data Analysis with R, 2nd Edition Springer Applied Spatial Data Analysis with R: Second Edition doi:10.1007/978-1-4614-7618-4.

Bongaarts, J.IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Popul Dev Rev doi:10.1111/padr.12283.

Burnham, K.P., Anderson, D.R., 2001. Kullback-Leibler information as a basis for strong inference in ecological studies. Wildl. Res. 28, 111–119. doi:10.1071/WR99107.

CBS, 2014. National Population Census 2011, Central Bureau of Statistics. Central Bureau of Statistics Ramshah Path, Thapathali Kathmandu, Nepal.

Chatterjee, S., Hadi, A.S., 2012. Regression Analysis by Example. Wiley, New York, p. 98.

Chaudhary, R.P., Subedi, C.K., 2019. Chure-tarai madhesh landscape, Nepal from biodiversity research perspective. Plant Arch 19, 377–383.

Chaudhary, R.P., Uprety, Y., Rimal, S.K., 2016. Deforestation in Nepal: causes, consequences, and responses. Biol. Environ. Hazards, Risk. Disasters doi:10.1016/B978-0-12-394847-2.00020-6.

Clark, D., 2020. Data Analysis with Pivot Tables and Charts. Beginning Microsoft Power BI. Apress, Berkeley, CA https://doi.org/ doi:10.1007/978-1-4842-5620-6_11.

Daskin, J.H., Pringle, R.M., 2016. Does primary productivity modulate the indirect effects of large herbivores? A global meta-analysis. J. Anim. Ecol. 85, 857–868. doi:10.1111/1365-2656.12522.

de Beer, Y., van Aarde, R.J., 2008. Do landscape heterogeneity and water distribution explain aspects of elephant home range in southern Africa's arid savannas? J. Arid Environ. 72, 2017–2025. doi:10.1016/j.jaridenv.2008.07.002.

de Boer, W.F., Van Oort, J.W.A., Grover, M., Peel, M.J.S., 2015. Elephant-mediated habitat modifications and changes in herbivore species assemblages in Sabi Sand, South Africa. Eur. J. Wildl. Res. doi:10.1007/s10344-015-0919-3.

DFRS, 2015. State of Nepal's Forests. Forest Resource Assessment (FRA) Nepal, Department of Forest Research and Survey (DFRS), Kathmandu, Nepal Ministry of Forest and Soil Conservation Nepalhttps://doi.org/978-9937-8896-3-6.

Dickman, A.J., 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. Anim. Conserv. 13, 458–466. doi:10.1111/j.1469-1795.2010.00368.x.

Fahrig, L., 2003. Effects of Habitat Fragmentation on Biodiversity. Annu. Rev. Ecol. Evol. Syst. 34, 487–515. doi:10.1146/annurev.ecolsys.34.011802.132419.

Fernando, P., De Silva, M.K.C.R., Jayasinghe, L.K.A., Janaka, H.K., Pastorini, J., 2021. First country-wide survey of the Endangered Asian elephant: towards better conservation and management in Sri Lanka. Oryx 55, 46–55. doi:10.1017/S0030605318001254.

Fernando, P., Wikramanayake, E., Weerakoon, D., Jayasinghe, L.K.A., Gunawardene, M., Janaka, H.K., 2005. Perceptions and patterns of human-elephant conflict in old and new settlements in Sri Lanka: insights for mitigation and management. Biodivers. Conserv. 14, 2465–2481. doi:10.1007/s10531-004-0216-z.

Franke, T.M., Ho, T., Christie, C.A., 2012. The Chi-Square Test: often Used and More Often Misinterpreted. Am. J. Eval. 33, 448–458. doi:10.1177/1098214011426594.

GoN/PCTMCDB, 2017. President Chure-Tarai Madhesh Conservation and Management Master Plan.

Graf, U., 2004. Z-Transformation, in: Applied Laplace Transforms and Z-Transforms For Scientists and Engineers. Birkhäuser, Basel, pp. 2–3. doi:10.1007/978-3-0348-7846-3_2 https://doi.org/.

Gross, E.M., Lahkar, B.P., Subedi, N., Nyirenda, V.R., Lichtenfeld, L.L., Jakoby, O., 2018. Seasonality, crop type and crop phenology influence crop damage by wildlife herbivores in Africa and Asia. Biodivers. Conserv. doi:10.1007/s10531-018-1523-0.

Gross, E.M., Lahkar, B.P., Subedi, N., Nyirenda, V.R., Lichtenfeld, L.L., Jakoby, O., et al., 2019. Does traditional and advanced guarding reduce crop losses due to wildlife? Acomparative analysis from Africa and Asia. Journal of Nature Conservation 50. doi:10.1016/j.jnc.2019.125712.

Gubbi, S., 2012. Patterns and correlates of human-elephant conflict around a south Indian reserve. Biol. Conserv. 148, 88–95. doi:10.1016/j.biocon.2012.01.046.

Haines-Young, R., Chopping, M., 1996. Quantifying landscape structure: a review of landscape indices and their application to forested landscapes. Prog. Phys. Geogr. 20, 418–445. doi:10.1177/030913339602000403.

Hamilton, A.C., Radford, E.a., 2007. Identification and Conservation of Impeortant Plant Areas for Medicinal Plants in the Himalaya, Project and Workshop Report. Plantlife International (Salisbury, UK) and Ethnobotanical Society of Nepal, KathmanduNepal.

Hoare, R.E., 1999. Determinants of human ± elephant con ¯ ict in a land-use mosaic. J. Appl. Ecol. 36, 689–700. doi:10.1046/j.1365-2664.1999.00437.x.

Jackson, J.K., 1994. Manual of Afforestation in Nepal Hardcover – .prn, 2nd edition Nepal-United Kingdom Forestry Research Project, Forest Survey and Research Office, Dept. of Forest January 1, 1994.

Karanth, K.K., Gopalaswamy, A.M., Prasad, P.K., Dasgupta, S., 2013. Patterns of human-wildlife conflicts and compensation: insights from Western Ghats protected areas. Biol. Conserv. 166, 175–185. doi:10.1016/j.biocon.2013.06.027.

Khatiwada, P., 2018. National pride project kathmandu-nijgadh fast track expedited.

König, H.J., Kiffner, C., Kramer-Schadt, S., Fürst, C., Keuling, O., Ford, A.T., 2020. Human–wildlife coexistence in a changing world. Conserv. Biol. doi:10.1111/cobi.13513.

Lakshminarayanan, N., Karanth, K.K., Goswami, V.R., Vaidyanathan, S., Karanth, K.U., 2016. Determinants of dry season habitat use by Asian elephants in the Western Ghats of India. J. Zool. 298, 169–177. doi:10.1111/jzo.12298.

Lamichhane, B.R., Persoon, G.A., Leirs, H., Poudel, S., Subedi, N., Pokheral, C.P., Bhattarai, S., Gotame, P., Mishra, R., de Iongh, H.H., 2019. Contribution of buffer zone programs to reduce human-wildlife impacts: the case of the Chitwan National Park, Nepal. Hum. Ecol. 47. doi:10.1007/s10745-019-0054-y.

Lamichhane, B.R., Persoon, G.A., Leirs, H., Poudel, S., Subedi, N., Pokheral, C.P., Bhattarai, S., Thapaliya, B.P., de Iongh, H.H., 2018. Spatio-temporal patterns of attacks on human and economic losses from wildlife in Chitwan National Park, Nepal. PLoS ONE 13, 1–18. doi:10.1371/journal.pone.0195373.

Lamichhane, B.R., Subedi, N., Pokheral, C.P., Dhakal, M., Acharya, K.P., Pradhan, N.M.B., Smith, J.L.D., Malla, S., Thakuri, B.S., Yackulic, C.B., 2017. Using interviews and biological sign surveys to infer seasonal use of forested and agricultural portions of a human-dominated landscape by Asian elephants in Nepal. Ethol. Ecol. Evol. 00, 1–17. doi:10.1080/03949370.2017.1405847.

Laudari, H.K., Aryal, K., Maraseni, T., 2020. A postmortem of forest policy dynamics of Nepal. Land Use Policy 91. doi:10.1016/j.landusepol.2019.104338.

Leimgruber, P., Gagnon, J.B., Wemmer, C., Kelly, D.S., Songer, M.A., Selig, E.R., 2003. Fragmentation of Asia's remaining wildlands: implications for Asian elephant conservation. Anim. Conserv. 6, 347–359. doi:10.1017/S1367943003003421.

Liu, F., McShea, W.J., Li, D., 2017. Correlating habitat suitability with landscape connectivity: a case study of Sichuan golden monkey in China. Ecol. Modell. 353, 37–46. doi:10.1016/j.ecolmodel.2016.09.004.

Mahat, S., 2020. Nijgadh International Airport debate: These are Key Arguments of Both Sides. Online Khabar, Nepal.

Mishra, S.P., Mishra, S., Siddique, M., 2020. The anthropocene dialogues on climate change to human health of Homosapiens in India. Curr. J. Appl. Sci. Technol. 13–30. doi:10.9734/cjast/2020/v39i2430869.

MoFSC, 2015. Strategy and action Plan 2015-2025 for Terai Arc landscape, Nepal.

Mukeka, J.M., Ogutu, J.O., Kanga, E., Røskaft, E., 2019. Human-wildlife conflicts and their correlates in Narok County. Kenya. Glob. Ecol. Conserv. 18. doi:10.1016/j.gecco.2019.e00620.

Naha, D., Dash, S.K., Chettri, A., Chaudhary, P., Sonker, G., Heurich, M., Rawat, G.S., Sathyakumar, S., 2020a. Landscape predictors of human–leopard conflicts within multi-use areas of the Himalayan region. Sci. Rep. 10. doi:10.1038/s41598-020-67980-w.

Naha, D., Dash, S.K., Chettri, A., Roy, A., Sathyakumar, S., 2020b. Elephants in the neighborhood: patterns of crop-raiding by Asian elephants within a fragmented landscape of Eastern India. PeerJ 2020. doi:10.7717/peerj.9399.

Naha, D., Sathyakumar, S., Dash, S., Chettri, A., Rawat, G.S., 2019. Assessment and prediction of spatial patterns of human-elephant conflicts in changing land cover scenarios of a human-dominated landscape in North Bengal. PLoS ONE 14. doi:10.1371/journal.pone.0210580.

Naimi, B., 2017. Package "usdm". Uncertainty Analysis for Species Distribution Models. R- Cran 18.

Neupane, D., Johnson, R.L., Risch, T.S., 2013. Temporal and spatial patterns of human-elephant conflict in Nepal Temporal and spatial patterns of human-elephant conflict in Nepal. Int. Elephant Rhino Conserv. Res. Symp. Proc. 11.

Neupane, D., Kunwar, S., Bohara, A.K., Risch, T.S., Johnson, R.L., 2017. Willingness to pay for mitigating human-elephant conflict by residents of Nepal. J. Nat. Conserv. 36, 65–76. doi:10.1016/j.jnc.2017.02.004.

Padalia, H., Ghosh, S., Reddy, C.S., Nandy, S., Singh, S., Kumar, A.S., 2019. Assessment of historical forest cover loss and fragmentation in Asian elephant ranges in India. Environ. Monit. Assess. 191. doi:10.1007/s10661-019-7696-5.

Pant, G., Dhakal, M., Pradhan, N.M.B., Leverington, F., Hockings, M., 2015. Nature and extent of human–elephant Elephas maximus conflict in central Nepal. Oryx 50, 1–8. doi:10.1017/S0030605315000381.

Pradhan, N.M.B., Wegge, P., Williams, A.C., Dhakal, M., Wegge, P., Shrestha, R., Flagstad, Ø., 2011. Current status of asian elephants in Nepal. Gajah 35, 87–92. doi:10.2981/11-049.

Puri, S., 2021. Construction of Railway Track Worries Chandrapur residents. Kathmandu Post Nepal.

Core Team, R., 2020. R: A language and Environment For Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Ram, A.K., 2021. Real Time Monitoring of Problem Associated Elephants For Mitigation of Human Elephant Conflicts in Nepal. Prabhat Publ, pp. 23–29.

Ram, A.K., 2014. Geospatial Modeling to Assess Asian Elephant Habitat suitability, Migratory Routes and Human Elephant Interface in Eastern Nepal. Tribhuwan University, Institute of Forestry Pokhara.

Ram, A.K., Acharya, H., 2020. Status and Distribution of Asian Elephants in Nepal, in: A Compendium of Conservation News (Sanraxan Samachar Ko Sangalo in Nepali Version). Department of National Parksa and Wildlife Conservation, Babarmahal, Kathmandu, Nepal, pp. 146–151.

Ram, A.K., Mondol, S., Subedi, N., Lamichhane, B.R., Baral, H., Laxmiarayanan, N., Amin, R., Pandav, B., 2021a. Patterns and determinants of Elephant attacks on humans in Nepal. Ecol. Evol. 1–12. doi:10.22541/au.161491245.55390026/v1.

Ram, A.K., Yadav, N.K., Kandel, P.N., Mondol, S., Pandav, B., Natarajan, L., Subedi, N., Naha, D., Reddy, C.S., Lamichhane, B.R., 2021b. Tracking forest loss and fragmentation during 1930 –2020 in Asian elephant (Elephas Maximus) habitats in Nepal methods and materials. Sci. Rep. 1–14. doi:10.21203/rs.3.rs-717308/v1, https://doi.org/.

Ranjeewa, A.D.G., Pastorini, J., Isler, K., Weerakoon, D.K., Kottage, H.D., Fernando, P., 2017. Decreasing reservoir water levels improve habitat quality for Asian elephants. Mamm. Biol. 88, 130–137. doi:10.1016/j.mambio.2017.10.002.

Rao, C.R., 2002. Karl Pearson Chi-Square Test The Dawn. Springer Sci. Media, New York, pp. 9–24.

Reid, W.V., Moony, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, T., Pingali P, A.J., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennet, E., Kumar, P., Lee, M.J., Ciara, R.-H., Simons, H., Thonel, J., Zurek, M.B., 2005. Millennium Ecosystem Assessment, Ecosystems and Human well-beings, Synthesis. Island Press, Washington, DC.

Ruda, A., Kolejka, J., Silwal, T., 2018. GIS-assisted prediction and risk zonation of wildlife attacks in the Chitwan National Park in Nepal. ISPRS Int. J. Geo-Information 7, 1–21. doi:10.3390/ijgi7090369.

Service, H.N., 2021. Four adult tigers found in Rautahat. Himal. Times..

Shaffer, L.J., Khadka, K.K., Van Den Hoek, J., Naithani, K.J., 2019. Human-elephant conflict: a review of current management strategies and future directions. Front. Ecol. Evol. doi:10.3389/fevo.2018.00235.

Shaffer, L.J., Khadka, K.K., Van Den Hoek, J., Naithani, K.J., Thouless, C.R., Dublin, H.T., Blanc, J.J., Skinner, D.P., Daniel, T.E., Taylor, R.D., Maisels, F., Frederick, H.L., Bouché, P.J.C., Daskin, J.H., Pringle, R.M., Ims, R.A., Andreassen, H.P., Rangarajan, M., Desai, A.a., Sukumar, R., Easa, P.S., Vincent, S., Ganguly, S., Talukdar, B.K., Singh, B., Mudappa, D., Chowdhary, S., Prasad, A.N., Ogada, M.J., Muchai, D., Mwabu, G., Mathenge, M., Thomas, B., Holland, J.D., Minot, E.O., 2014. Warfare and wildlife declines in Africa's protected areas. Afr. J. Ecol. 68, 1065–1076. doi:10.1007/s10668-014-9513-1.

Sharma, P., Adhikari, H., Tripathi, S., Ram, A.K., Bhattarai, R., 2019. Habitat suitability modeling of Asian Elephant Elephas maximus (Mammalia: proboscidea: elephantidae) in Parsa National Park, Nepal and its buffer zone. J. Threat. Taxa 11, 14643–14654. doi:10.11609/jott.4467.11.13.14643-14654.

Shrestha, M.N., Shrestha, K., Dhakal, T.R., 1985. HMGN palace investigation centre, Principal Secretariat of His Majesty King, Royal Palace. Hatti Byabasthapan Yojana Tarujma Pratibedan (Report on Planning for Elephant Management). Kathmandu: Janchbujh kendra Bibhag Raj Durbar. Department Investigation Center, Nepali Royal Palace, Kathmandu, Nepal (in Nepali version)in Nepali version.

Singh, S.K., Jabin, G., Basumatary, T., Bhattarai, G.P., Chandra, K., Thakur, M., 2019. Resolving the trans-boundary dispute of elephant poaching between India and Nepal. Forensic Sci. Int. Synerg. 1, 146–150. doi:10.1016/j.fsisyn.2019.07.007.

Smith, J.L.D., Mishra, H.R., 1992. Status and distribution of Asian elephants in Central Nepal. Oryx 26, 10–14.

Sukumar, R., 2003. The Living Elephant evolutionary ecology, behavior and conservation.

Sukumar, R., 1989. The Asian elephant: ecology and managemen t 8, 254.

Tilman, D., Clark, M., Williams, D.R., Kimmel, K., Polasky, S., Packer, C., 2017. Future threats to biodiversity and pathways to their prevention. Nature 546, 73–81. doi:10.1038/nature22900.

Treves, A., Martin, K.A., Wydeven, A.P., Wiedenhoeft, J.E., 2011. Forecasting environmental hazards and the application of risk maps to predator attacks on livestock. Bioscience 61, 451–458. doi:10.1525/bio.2011.61.6.7.

Wagler, R., 2017. 6Th Mass Extinction, Encyclopedia of the Anthropocene. Elsevier Inc doi:10.1016/B978-0-12-809665-9.10477-X.

Williams, C., Tiwari, S.K., Goswami, V.R., S., de S., Kumar, A., Baskaran, N., Yoganand, K., Menon, V., 2020. Elephas maximus (Asian Elephant). The IUCN Red List of Threatened Species. Version 2020-1.

Zuur, A.F., Ieno, E.N., Elphick, C.S., 2010. A protocol for data exploration to avoid common statistical problems. Methods Ecol. Evol. 1, 3–14. doi:10.1111/j.2041-210x.2009.00001.x.