Geocarto International

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tgei20

Vulnerability of land use/cover associated with human-wildlife conflicts in Mullaitivu District, Sri Lanka

P. Bharathy, S. Wijeyamohan, K. Suthakar & S. N. Surendran

To cite this article: P. Bharathy, S. Wijeyamohan, K. Suthakar & S. N. Surendran (2022): Vulnerability of land use/cover associated with human-wildlife conflicts in Mullaitivu District, Sri Lanka, Geocarto International, DOI: 10.1080/10106049.2022.2097480

To link to this article: https://doi.org/10.1080/10106049.2022.2097480

Published online: 15 Jul 2022.

GEOCARTO INTERNATIONAL
https://doi.org/10.1080/10106049.2022.2097480

Vulnerability of land use/cover associated with human-wildlife conflicts in Mullaitivu District, Sri Lanka

P. Bharathy[a], S. Wijeyamohan[b,c], K. Suthakar[a] and S. N. Surendran[d]

[a]Department of Geography, University of Jaffna, Jaffna, Northern Province, Sri Lanka; [b]Department of BioScience, Faculty of Applied Science, University of Vavuniya, Northern Province, Sri Lanka; [c]The William H. Darr School of Agriculture, Missouri State University, Springfield; [d]Department of Zoology, University of Jaffna, Jaffna, Northern Province, Sri Lanka

ABSTRACT

Human-wildlife conflict has increased over the decades and is now considered one of the most severe challenges to the survival of threatened species and the livelihood of communities worldwide. In Sri Lanka, population growth, fragmentation of land, and conversion of natural wildlife habitats into settlement and agricultural areas are the leading causes of human-wildlife conflict. This study seeks to characterise the conflict pattern in the Mullaitivu District by identifying land use/cover changes and assessing the vulnerability of land use/cover. Primary data were collected through a field survey using a structured questionnaire and direct observation methods, and secondary data on land use/cover changes were obtained from remote sensing images. These data were analysed statistically and on the Geographic Information System (GIS) platform. The study reveals land use/cover vulnerability status over the twenty-six years. Dense forests are on the decline, and wild animals migrate into human settlements and agricultural sites, resulting in different types of human-wildlife conflict such as crop damage, livestock depredation, and loss of life and/or injuries to both people and wildlife in the Mullaitivu district. People employ various wildlife mitigation strategies. However, they cannot safeguard their crops or livestock from these animals. By implementing appropriate management measures to avoid wildlife infiltration into human settlements, the human-wildlife conflict in the Mullaitivu district can be minimised.

ARTICLE HISTORY
Received 20 September 2021
Accepted 29 June 2022

KEYWORDS
Remote sensing and GIS; human-wildlife conflict; land use/cover change; mullaitivu district

Introduction

There has been an escalation of human-wildlife conflict, which is regarded as one of the critical threats to the survival of many global species (World Wildlife Fund (WWF) 2005). Human-wildlife conflict is any interaction between human and wildlife that negatively impacts both humans and wildlife. It can disrupt the social, economic, or cultural lives of humans and wildlife and environmental conservation (Hoare 2001; Conover 2002; Graham et al. 2005; Roy 2017). Wildlife movement and ranging patterns are shaped essentially by the availability of food, water and mates (Mace et al. 1996) and, of course,

CONTACT P. Bharathy bharathyp@univ.jfn.ac.lk

disturbance caused by humans. When these factors are not favourable for wild animals to stay within their natural habitats, they are forced to move into human settlements, causing several forms of conflicts (Mishra et al. 2014; Ogra and Badola 2008). Human-wildlife conflict patterns can be challenging to identify because of the intricacy of wildlife behaviour and ecology, human behaviour, seasonality, cropping and husbandry behaviour, and resource availability (Sapkota et al. 2014; Marchal and Hill 2009).

Furthermore, human-wildlife conflict was exacerbated by global human population growth and its consequences, such as land use/cover changes, wildlife habitat loss, land degradation, and forest fragmentation, as well as growing interest in mass and unmanaged tourism, increased access to nature reserves, and rising livestock populations (Distefano 2005). Fragmentation and conversion of natural habitats of wildlife, such as dense forests and scrub, are considered the leading causes of human-wildlife conflict (Vitousek 1992; Turner and Meyer 1994; Brandon 2001; Geist and Lambin 2002; Fernando et al. 2011). Such causes can be identified through spatial and temporal land use/cover surveys (Muchoney and Strahler 2002; Vitousek 1992; Turner and Meyer 1994; Brandon 2001; Geist and Lambin 2002). Settlement development and agricultural expansion contribute significantly to forest cover reduction and fragmentation, leading to land use/cover changes (Alves et al. 1999; Guild et al. 2004; Lopez 1997).

Sri Lanka is no exception to these trends. Human-wildlife conflict is one of the significant threatening issues in recent years that contribute to people's socio-economic vulnerability and intimidate human morbidity and mortality (Cynthia Castaldo-Walsh 2019; Santiapillai et al. 2010; Bandara and Tisdell 2003; Jayewardene 2004). In the past, such conflicts were mainly reported only from the North Western, Eastern, North Central and Southern Provinces of Sri Lanka (Jayewardene 1994; Jayewardene 2004; Perera et al. 2007; Pranjit et al. 2008; Santiapillai et al. 2010; Mathotaarachchi et al. 2021; Kopke et al. 2021). After a long civil war in 2009, human-wildlife conflicts have increased in Northern Province. Collectively, this poses a massive threat to Sri Lanka's wildlife survival. Such conflict opens utmost attention to protecting the people from the wildlife and safeguarding wildlife from human exploitation. In recent years, decreasing forest covers and wildlife habitats have been one of the primary reasons for increasing conflicts between humans and wildlife (Mombauer 2020). Evidently, according to the forest cover assessment made by the Forest Department of Sri Lanka in 2009, the forest cover was 29.6% in Sri Lanka (Food and Agriculture Organization (FAO) 2009), and by 2019 it had been reduced to 16.5% (Food and Agriculture Organization (FAO) 2020). The Forest Department conducted a systematic study to assess the forest cover in the Northern Province and identify essential forest areas for environmental conservation in 1999. Accordingly, the Northern Province had 44% of the forest in the total forested area of Sri Lanka (Mallawatantri et al. 2014). Arguably, there is quite a large extent of forest in the Northern Province compared to other provinces in Sri Lanka (Food and Agriculture Organization (FAO) 2009), although, in 2019, it was estimated at 24% (Ranagalage et al. 2020).

A study of human-wildlife conflict to minimise its socio-economic, psychological and physical consequences for the people and conserve the wildlife's biodiversity is, therefore, inevitable in the Northern Province. Even though several studies focus on human-wildlife conflict in the Southern and Eastern parts of Sri Lanka (Cynthia Castaldo-Walsh 2019; Horgan and Kudavidanage 2020; Jayewardene 1994; Santiapillai et al. 2010; Jayewardene 2004; Perera et al. 2007; De Silva and Attapattu 1997; Kopke et al. 2021; Fernando et al. 2011) are available, there is a significant gap in the study of human-wildlife conflicts in the Northern Province.

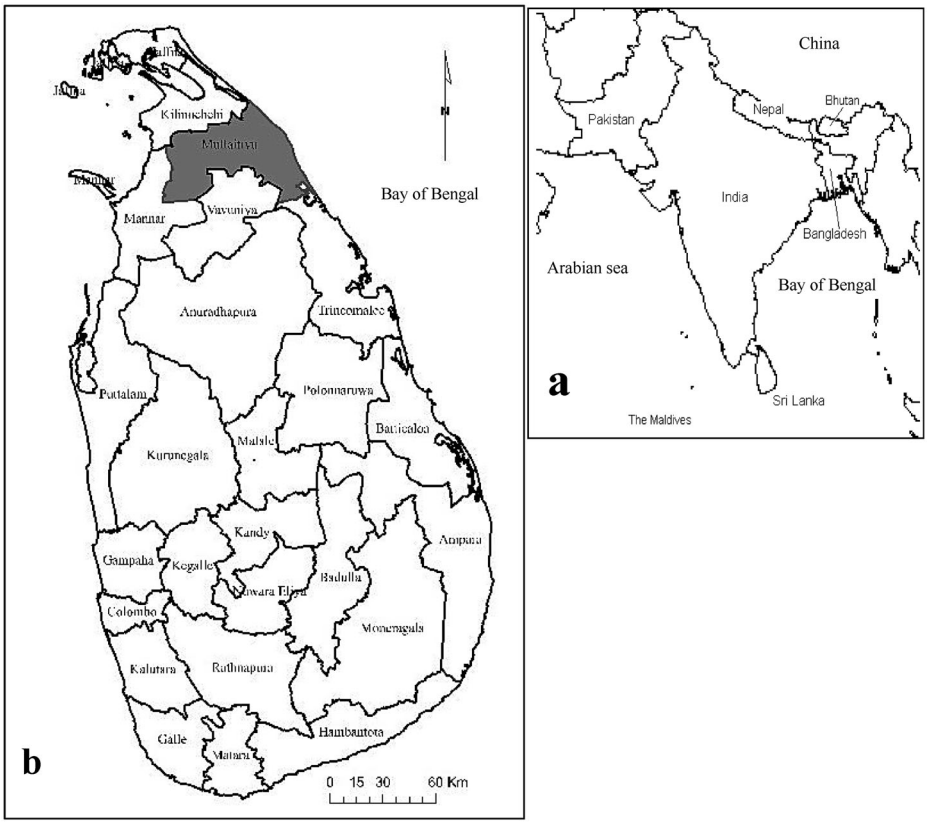

Figure 1. Study site: (a) Location of Sri Lanka in the Indian Ocean; (b) Mullaitivu district with bordering districts.

This study aims to identify changes in land use/cover in Mullaitivu District, assess the vulnerability of land use/cover, analyse the impact of the changes in land use/cover on human-wildlife conflicts, map the patterns of the conflict and discuss measures that can be taken to address this problem. After the cessation of the civil war, which was mainly confined to the Northern and Eastern parts of the country and lasted for nearly three decades and ended in early 2009, this study is the first attempt to assess the forest cover change and its impact on human-wildlife conflicts in the Mullaitivu district of Northern Sri Lanka.

Materials and methods

Study area

Sri Lanka is located in the Indian Ocean near South India (Figure 1a). The study area, Mullaitivu (1c), is one of the administrative districts in the Northern Province, which covers an area of 2617 km^2 and is located in the northeastern part of Sri Lanka. It lies between latitude 08° 56′ 41.28″N to 09° 27′ 33.38″N and longitude 80° 10'19.84″ E to 80° 37′ 17.65″ E. Mullaitivu District bordered by the districts of Kilinochchi and Jaffna in the north, Vavuniya and Trincomalee in the south and Mannar in the west, and the Bay of Bengal in the east (Figure 1b). This district accounts for 3.8% of the country's total area. The district has six administrative divisions and covers 136 Grama Niladhari Divisions

and 632 villages. The land use/cover of the district mainly includes agricultural lands (12.87%), home gardens (6.4%), forest lands (69%) and water bodies. Mullaitivu district has a total population of 136 623 in 2020. The district contains the most extensive forest cover in the Northern Province and is home to various postwar resettlement, development, and agricultural operations. These developments mainly impact the environment and shape some of the significant socio-economic issues prevalent in the district, including land encroachment, habitat loss, population increase, deforestation and human-wildlife conflict.

Data sets

Primary data for this study were collected through a field survey using a structured questionnaire and through direct observation of the landscape. Spatial samples have been designed based on 2.5 km x 2.5 km raster grids layer in the GIS environment. The grid layer originates from the Sri Lankan national grid of 200,000 m; 200,000 m at the peak of the Pithuruthalagala Mountain (Kandawala Datum). This raster grid layer was transposed onto the Mullaitivu district's base map to identify the spatial samples' location.

The study area covered 404 raster grids assigned unique serial numbers for identification purposes. From the grid layer, twenty-five per cent of the grids (101 sample grids) were randomly selected as sample grids which were later exported to Google Earth on a smartphone to identify the precise location of the sample points within the sampled grids. The field survey mainly focused on collecting primary data through direct observation and questionnaire survey from the households located at the central point of the selected sample grids. The nearest house to the central point was selected when no house falls on the grid's central point. Although field visit was carried out in all 101 samples, human inhabitants were found in only 56 samples. Therefore, a questionnaire survey was carried out from these 56 samples. Out of 101 samples, 45 are situated in the forest or areas not inhabited by animals where data were collected through observation and from people who lived in the nearest sites. The field survey was carried out from July to October 2019.

The questions were aimed to elicit information about the nature of human-wildlife conflict, the types and number of incidents that involved human-wildlife conflict in the area, the degree of damage to wildlife and humans, and human attitudes toward human-wildlife conflict, and measures taken by the community to mitigate human-wildlife conflicts.

Satellite images for 1994 and 2020 were downloaded from the **United States Geological Survey** (USGS) Earth Explorer. These images were acquired from Landsat – 7 TM and Landsat – 8 OLI sensors. Both images were obtained for the same season for the periods 11-10-1994 (Landsat TM) and 04-10-2020 (Landsat OLI) to minimise the illumination effect for change detection analysis. These images were subjected to necessary rectification processes with the ArcGIS Ver 10.3 (ESRI Inc, 2014). The supervised image classification method with the Maximum Likelihood Algorithm was applied to extract land use/cover information from the satellite images for the two periods. Kappa Coefficient was employed to calculate the accuracy assessment of the land use/cover maps. Accordingly, the kappa coefficients are 0.89, and 0.86 for 1994 and 2020, respectively. Finally, six land use/cover classes were delineated as dense forest, scrub, agriculture, homestead, barren land, and water bodies/wetland.

Table 1. Format of Land use/cover transition matrix.

Land use/cover types		Subsequent Period: Class 1	Class 2	Class 3	Class 4	Class 5	Total	Loss
Initial Period	Class 1	$P_{1,1}$	$P_{1,2}$	$P_{1,3}$	$P_{1,4}$	$P_{1,5}$	P_{1+}	$P_{1+}-P_{1,1}$
	Class 2	$P_{2,1}$	$P_{2,2}$	$P_{2,3}$	$P_{2,4}$	$P_{2,5}$	P_{2+}	$P_{2+}-P_{2,2}$
	Class 3	$P_{3,1}$	$P_{3,2}$	$P_{3,3}$	$P_{3,4}$	$P_{3,5}$	P_{3+}	$P_{3+}-P_{3,3}$
	Class 4	$P_{4,1}$	$P_{4,2}$	$P_{4,3}$	$P_{4,4}$	$P_{4,5}$	P_{4+}	$P_{4+}-P_{4,4}$
	Class 5	$P_{5,1}$	$P_{5,2}$	$P_{5,3}$	$P_{5,4}$	$P_{5,5}$	P_{5+}	$P_{5+}-P_{5,5}$
Total		P_{+1}	P_{+2}	P_{+3}	P_{+4}	P_{+5}	100	
Gain		$P_{+1}-P_{1,1}$	$P_{+2}-P_{2,2}$	$P_{+3}-P_{3,3}$	$P_{+4}-P_{4,4}$	$P_{+5}-P_{5,5}$		

Vulnerability analysis

Land use/cover maps show only the spatial pattern of land use/cover and the quantity of each land use/cover category. Vulnerability analysis of land use/cover shows how sensitivity to change particular land use into another land use. A transition matrix was used to identify land use/cover vulnerability. The transition matrix is a fundamental tool to analyse quantitative and qualitative data about land use/cover within the two prescribed years as calculated using equations 1a and 1b (Pontius et al. 2004; Ouedraogo et al. 2010). Accordingly, the transition matrix describes the percentage of land use/cover at the initial period change into other land use/cover in a subsequent period. The transition matrix follows a format such that the rows display the categories of an initial period (i.e. $P_{1,2}$, $P_{1,3}$, $P_{1,4}$, $P_{1,5}$) and the columns display the categories of a subsequent period (i.e. $P_{2,1}$, $P_{3,1}$, $P_{4,1}$, $P_{5,1}$) (Table 1). The main diagonal elements (i.e. $P_{1.1}$, $P_{2.2}$, $P_{3.3}$, $P_{4.4}$, $P_{5,5}$) designate the proportion of persistent land use/cover classes that show no changes. The gains and losses of land use/cover classes are calculated using the transition matrix diagonal elements (Pontius et al. 2004). The off-diagonal parts of the transition matrix depict the quantity of land use/cover that has been converted from one class to another between the initial and subsequent periods. The 'loss' column shows the amount of land use/cover that experienced a net loss of a particular class between the two periods. It is shown in the 'loss' column, whereas the 'gain' row reveals the amount of land use/cover that experienced a gross gain of other classes between the two periods.

$$P_{i+} = \sum_{i=1}^{n} P_{ij} \tag{1a}$$

$$P_{+j} = \sum_{i=1}^{n} P_{ij} \tag{1b}$$

where: n is the total number of classes, P_{ij} (where particular class to other class) designates the proportion of the landscape that experienced a transition from a particular class to another class between the initial period and the subsequent period. P_{i+} is the proportion of land-cover in the initial period and P_{+j} the proportion of land-cover in a subsequent period (Pontius et al. 2004*; Ouedraogo* et al. 2010*).*

The gain-to-persistence ratio Gp = (g/p), the loss-to-persistence ratio Lp = (l/p), and the net change to persistence (Np = Gp - Lp) was used to assess the vulnerability of each land use/cover class to the transition based on the gain and loss statistics. Gain, persistence (portions of a given category that stayed unaltered), and loss are represented by the letters g, p, and l, respectively. Gp and Lp values of more than one indicate that a given land-cover class has a higher chance of changing to another than remaining in its current state. If Np was negative, the land use/cover class would have a more significant chance

of losing area to other land use/cover classes than gaining from it (Pontius et al. 2004; Ouedraogo et al. 2010).

Hotspot analysis

Human-wildlife conflicts were identified in 56 sample locations through a structured questionnaire. The human-wildlife conflict sites are spatial phenomena depicted as points on a map that refer to events' locations. Hotspot analysis is a spatial analysis and mapping technique. This analysis was used to identify the clustering of human-wildlife conflict sites. Beyond assessing the density of points in a given area, hotspot analysis also measures the extent of point event interaction to understand spatial patterns. This study applied the spatial autocorrelation method for analysing spatial patterns and detecting hotspots. Spatial autocorrelation analysis looks at how similar those values are closer to each other. The Kernel Density Estimation (KDE) mapping technique was used to create a smooth, continuous surface map showing gradients of variations in the intensity of conflict risk across the study areas without being limited to thematic boundaries.

Furthermore, data from the questionnaire survey were summarised as descriptive statistics using SPSS® (statistical package for social science) version 25 to generate a general picture to arrive at conclusions under the categories of location, nature, and characteristics of human-wildlife conflict and to find out the solution for minimising the conflict.

Results and discussion

Land use/cover pattern

The spatial and temporal pattern of land use/cover in the Mullaitivu District from 1994 to 2020 is shown in Figure 2 and Table 2. Over the 26 years, the area of dense forest has decreased from approximately 57 per cent to 44 per cent, while the area of homestead and agriculture has increased by 5 per cent and 2 per cent, respectively. Consequently, a large extent of forest cover was cleared for agricultural and resettlement activities, destroying the wildlife habitat, which has caused an increase in human-wildlife conflict in the Mullaitivu district.

Vulnerability of land use/cover

Spatial and temporal land use/cover is meaningless as it only considers adding or deducting land use/cover areas. It is possible to know the changes in the spatial pattern of specific land use/cover and the quantitative value of land use/cover changes for 1994 and 2020 by overlay and transition matrix methods, respectively. The map of land use/cover changes, shown in Figure 3, makes it possible to understand the spatial pattern of the changes ('from to' change) to a particular land use/cover between 1994 and 2020. Accordingly, the dense forest has been largely converted into residential, agricultural and scrublands due to resettlement and development activities. Such a result emphasises the shrinking of wildlife habitats in the study area. The transition matrix assesses the continuous changes and helps identify the changes in land use/cover and their extent/degree during the 26 years (Table 2). Accordingly, the rows in Table 2 include the percentage of the land use/cover area in 1994, and the column denotes the percentage of land use/cover in 2020. The diagonal percentage of land use/cover area designates the proportion of persistent land use/cover classes from 1994 to 2020. It can be made out that the dense forest

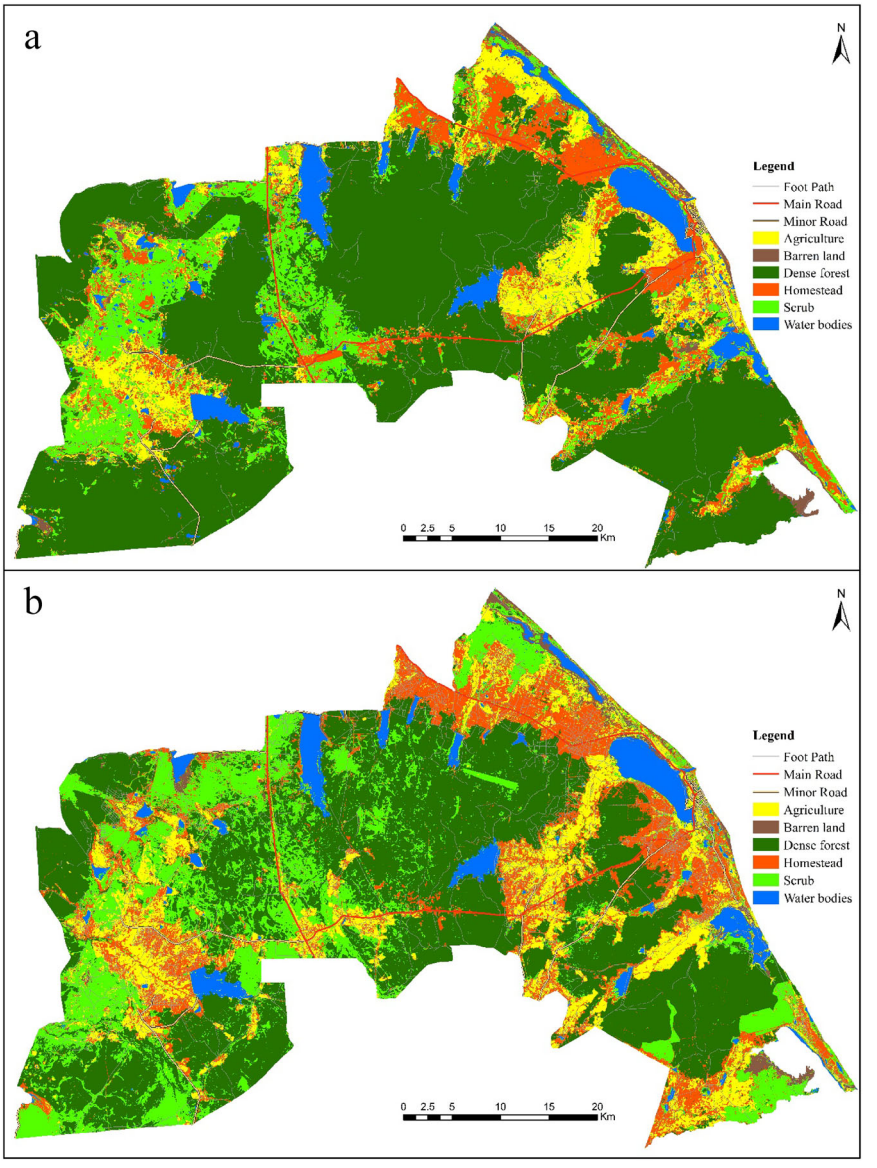

Figure 2. Land use/cover in Mullaitivu District in 1994 (a) and in 2020 (b).

has mainly changed into the scrub, homestead, and agriculture, and the scrub has changed to the barren land, agriculture, homestead, etc. The dense forest accounted for 57% area in 1994 and 44% in 2020, respectively. The extent of barren land, on the other hand, declined somewhat from 2.33% to 1.89%. Between 1994 and 2020, agricultural land and homestead percentages increased from 10.7%, 11% to 12.6%, and 15.4%, respectively. The loss of dense forest was the highest, representing over 13% of the total land use/cover.

The vulnerability of land use/cover is determined based on the values of the transition matrix. Table 3 shows the extracted values from the transition matrix, such as area, gain, loss, and persistence. The gain-to-persistence ratio (Gp) and the loss-to-persistence ratio

Table 2. Transition Matrix to assess the continuous changes of Land use/cover for Mullaitivu District (1994-2020).

Land use/ cover types		Area (%) – 2020							
		Agriculture	Barren land	Dense Forest	Homestead	Scrub	Water bodies	Grand Total	Loss
Area (%) – 1994	Agriculture	3.34	0.17	0.79	4.31	1.92	0.12	10.65	7.31
	Barren land	0.37	0.54	0.36	0.50	0.47	0.09	2.33	1.79
	Dense forest	2.46	0.26	39.99	3.48	10.54	0.24	56.97	16.98
	Homestead	3.14	0.21	0.95	4.97	1.40	0.28	10.95	9.55
	Scrub	3.05	0.42	1.77	1.92	6.13	0.23	13.52	13.29
	Water bodies	0.28	0.29	0.32	0.23	0.37	4.08	5.57	1.49
Grand Total		12.64	1.89	44.18	15.41	20.83	5.04	99.99	
Gain		9.30	1.35	4.19	10.44	14.70	0.96		

Note: The rows display the percentage of area for different categories of Land use/cover in 1994 and the columns display the percentage of area for different categories of Land use/cover in 2020. The elements of the main diagonal cells designate the persistent percentage of area for the Land use/cover between the 1994 -2020.

(Lp) are higher than one in agriculture, dense forest, scrub, and homestead. According to this result, these land use/cover have the highest probability of changing into other Land use/cover classes. The net change-to-persistence (Np) appears as negative for barren land, dense forests, and water bodies/wetlands. This means that these land use/cover classes would have a higher probability of losing their current area and converting to other land use/cover classes than gaining from them. Dense forests, barren land, and wetland change significantly because of anthropogenic activities such as land encroachment, resettlement, agricultural expansion, and urbanisation. Consequently, wildlife habitat decreases or degrades, and wild animals move into the human settlement and agricultural areas, which leads to human-wildlife conflict in the Mullaitivu district.

Human-wildlife conflict

Loss of wildlife habitat is the primary reason for the increasing human-wildlife conflict in the Mullaitivu district. According to the vulnerability of land use/cover and its role in wildlife intrusion into human settlements and agricultural areas, people face significant threats such as crop damage, injuries to and death of livestock, shelter destruction, income loss, and injured/killed people. It is essential to understand the socio-economic characteristics of the study area's households to understand the nature of the conflict and suggest measures for mitigation.

According to the questionnaire survey, it was observed that human-wildlife conflicts were found in all the 56 samples; however, conflict frequency varies spatially. A hotspot can be defined as an area with a higher concentration of conflicts than the expected number given a random distribution of conflicts. Figure 3 shows the relationship between the spatial pattern of the land use/cover changes and the distribution of hot and cold spots, along with their confidence levels. The hot spots are mostly found where land use/cover changes have occurred or are involved in the highest vulnerability to change, particularly conversion from the forest into agriculture and homestead and from scrub into agriculture and homestead. Figure 4 depicts the spatial pattern of the human-wildlife conflict risk based on the hot and cold spots. Cold spots are mainly distributed in the forest or non-human inhabitants, where minimum or no evidence is available to prove the human-wildlife interface, and hotspots represent the frequency of incidents involving human-wildlife conflict. Accordingly, very high and high-risk areas are concentrated in the eastern and western parts of the study area, where land use/cover changes have occurred significantly from 1994 to 2020 and larger settlement and agricultural areas are located close

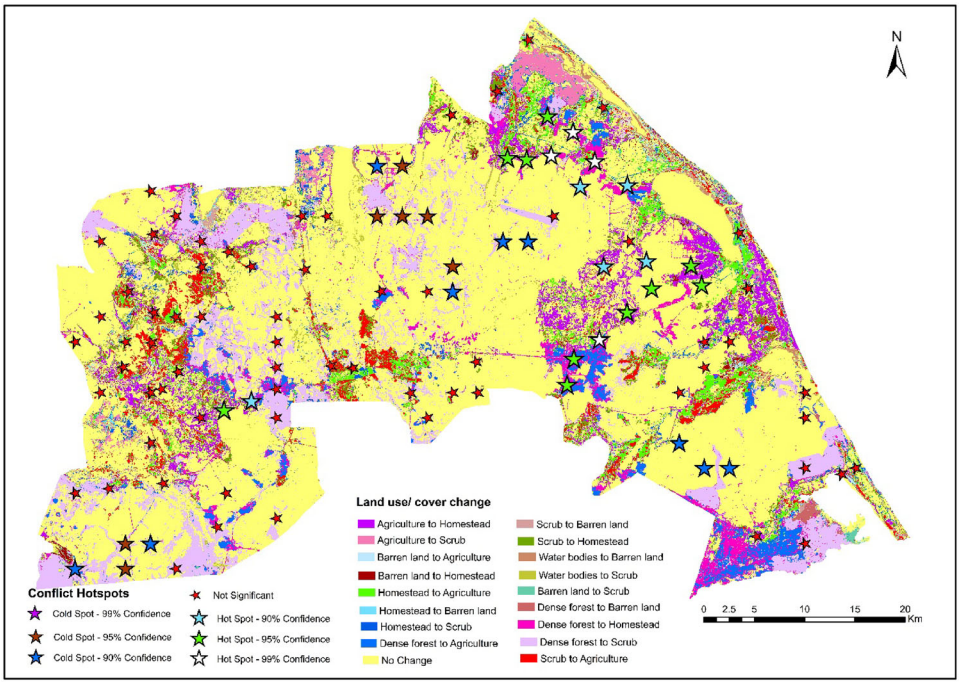

Figure 3. Land use/cover Changes in relation to Human – wildlife conflict hotspots (1994 – 2020).

Table 3. Gain to persistence (G_p), Loss to persistence (L_p), and Net change to persistence (N_p) ratio of the Land use/ cover types in the Mullaitivu district.

Land use/ cover types	1994	2020	Gain	Loss	Persistence	G_p	L_p	N_p
Agriculture	10.65	12.64	9.30	7.31	3.34	2.78	2.19	0.59
Barren land	2.33	1.89	1.35	1.79	0.54	2.50	3.31	−0.81
Dense forest	56.97	44.18	4.19	16.98	39.99	0.10	0.42	−0.32
Homestead	10.95	15.41	10.44	9.55	4.97	2.10	1.92	0.18
Scrub	13.52	20.83	14.70	13.29	6.13	2.40	2.17	0.23
Water bodies	5.57	5.04	0.96	1.49	4.08	0.24	0.37	−0.13

Note: The 'loss' column indicates the percentage of the area of Land use/cover that decreased from 1994 to 2020, whereas the 'gain'column shows the percentage of the area of Land use/cover that increased from 1994 to 2020,'persistence' colomnshows the percentage of the area of Land use/cover that are not changed, Gp = (gain/persistance), Lp = (loss/persistance), and Np = Gp - Lp

to forested sites. Changes in wildlife routes, areas of wildlife habitat, and availability of feeding supplies for wildlife have intensified the risk of human-wildlife conflict.

Changes in land use/cover result in the loss of a wide range of wildlife habitats and harm to human property, such as homes, trees, agricultural fields, and even human death. People in the study area engage in different types of rural-based livelihood systems such as agro-pastoralism (65%), farming (90%), keeping livestock (50%), and small-level business (10%)(Statistical Handbook 2020). Households grow mainly paddy, subsidiary crops such as brinjal (eggplant), chilli, peanuts, beans, carrot, pumpkin, drumstick, and ladyfingers (okra) and perennial crops, particularly coconut, jack-fruit, banana, papaya, citrus, and mango. Most farmers cultivate paddy crops in two seasons per year, maha (North-East Monsoon period) and Yala (South-West Monsoon period), using rainfalls and irrigated water. People in the study area encounter two different scenarios of human-wildlife conflict. Firstly, conflicts arise when humans or their livestock enter the forest searching

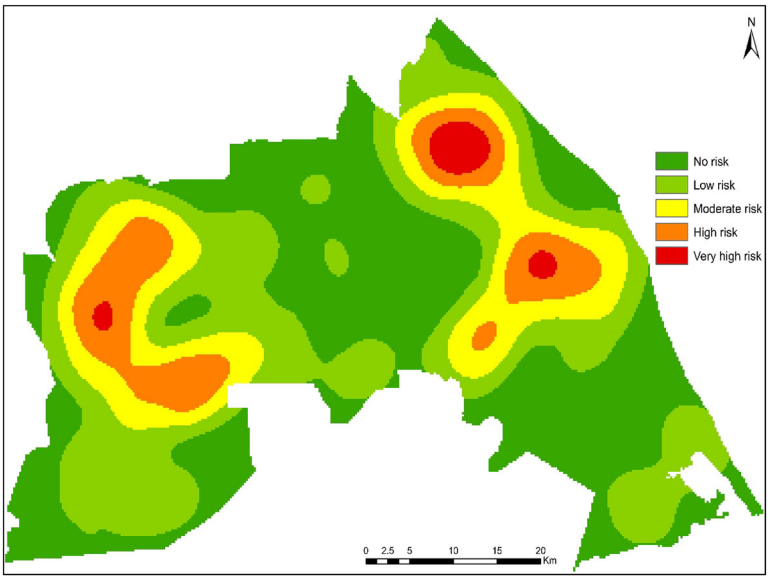

Figure 4. Human – wildlife conflict risk map in Mullaitivu district.

for resources for livelihood or grassing. Secondly, when wild animals trespass into the community land for feeding, crops and shelters are destroyed. People, livestock, and wildlife get injured or killed in both situations. Notably, 75% of the respondents report that they encountered crop damage when the wildlife trespassed into their field or residence.

Whenever wild animals move around through human settlements from one place to another to search for food, water and mates, they destroy the crops on their way. Up to 58% of the farmers report that searching for food is the main reason for the frequent visit of wild animals to the farms. In addition, due to the water scarcity during the dry season, wildlife moves into residential areas for water. Seventy-four per cent of households face frequent intrusions of wildlife per year, 20% report more than ten times per year, and 6% report a minimum of five times per year. As a result, the people's livelihoods, the economy, and even the quality of life of the people are threatened. Hence, the farmers spend a considerable amount of time and energy protecting their family members, crops and properties from wildlife during the daytime and at night.

The extent of crop damage varies depending upon the location of samples and the types of wildlife. Samples which are located closer to the forest reported more damage than other samples by elephants and peacocks. At the same time, damages caused by pigs and monkeys were reported in the samples far from the forest area. Most crops are damaged by mainly four raiders, including elephants, monkeys, wild pigs, and peacocks. Moreover, monkeys and elephants are the worst destroyers in the Mullaitivu district. Plenty of fruit trees in the villages and fields support monkeys by providing food and shelter for them to escape from the crop guards. Furthermore, the people in the area do not hurt monkeys except to chase them away from their crops. This has increased crop damage.

Elephants also cause severe damage to crops. The highest numbers of paddy raiding incidents that involved elephants were reported during the pre-and post-harvesting period. The Wild Pig is another essential crop raider. It destroys crops during the crop maturing time. Further, peacocks eat seedlings and the paddy seeds initially during the

sowing period. Of the respondents, 95 per cent (53 respondents) reported that monkeys destroy their crops, 85 per cent of respondents (48 respondents) blamed elephants and Peacocks destroy their crops, and 48 per cent of people (27respondents) charged the wild pigs. The monkeys frequently visit the farms throughout the year, while the Elephants and wild pigs mainly visit the farms during the harvesting season or just before it.

People living adjoining the forest frequently visit the forest to collect firewood, food and herbs and fodder for their livestock, in addition to opportunistic and deliberate hunting for food and sale, respectively. These people complain that when they visit the forest, they notice that encroachment of forest and land resources such as gravel mining (55%), timber cutting (50%), and building materials (65%) have occurred inside the forest. It is causing massive ecological degradation. Twenty-six per cent of respondents pointed out that lack of food in the forest is the main reason for wildlife movement into human-inhabited areas. During the dry season, wildlife entering the villages for water was reported by 19% of the respondents. Most people believe that human-wildlife conflict has increased significantly over the last ten years; however, they do not know the exact reason for the same.

Respondents report several mitigation measures used to protect property, livelihoods and lives from the wildlife. Accordingly, they practice easy and conventional mitigation measures such as guarding (45%), making fire (18%) and making noise (32%). These methods have limited use as a deterrent, usually only temporarily easing the problem initially or shifting it to a neighbouring area. The majority of the respondents (78%) felt that fencing off the wild animals is a very effective control measure, followed by educating the communities and creating awareness (21%) and translocation of animals (20%).

Conclusion

This study mainly focused on land use/cover vulnerability and its impact on increasing the human-wildlife conflict in Mullaitivu. According to the previous surveys, human-wildlife conflict was recorded significantly in the Eastern, Southern, Northwestern, and North-Central Provinces of Sri Lanka. However, this study reveals that the human-wildlife conflict is becoming a growing threat in the Mullaitivu District. Wildlife intrusion has affected people in various places in the Mullaitivu district. Wildlife such as elephants, monkeys, wild pigs, and peacocks mostly interface with humans and cause conflicts. The study shows that some land use and land covers, mainly forest and scrub, are more vulnerable than others. This vulnerability is caused by development activities such as agricultural expansion, resettlement and new settlement and illegal activities in Mullaitivu, particularly after the internal war. Increased human populations and resettlement programs after the end of the civil war demand cultivable lands that cause alteration of wildlife habitat to human habitation and cropland and result in severe human-wildlife conflict.

On the other hand, grazing excavations, deforestation and poaching are carried out by people from other districts and provinces, which also hamper the natural movement of wildlife. With the depletion of pond water during dry seasons, wildlife moves toward human habitat areas. This study identifies how the forest cover shrinks over time and predicts how it can affect the wildlife habitat and diversity and how the livelihoods of the people in the Mullaitivu district are affected by wildlife.

The Mullaitivu district is at risk of losing its forest cover, wildlife, and people's quality of life and livelihood. According to the National Policy on conservation and management of wild elephants in Sri Lanka and the results of this study, forest cover should be

conserved to sustain biodiversity and human livelihood and increase human-wildlife harmony. Such a situation needs to be addressed by various levels of management. Policies should be put forward to prevent the fragmentation of wildlife habitats. Forest corridors should be set up in fragmented places to accommodate the natural movement of wildlife. Electric fences should be set up along forest boundaries to prevent human-elephant conflict. Legal action should be taken to prevent human activities such as agriculture, new settlements, resettlement, and development activities from invading or encroaching on the forest. Illegal grazing, hunting, and timber poaching should be prohibited. In addition, awareness programs on human-wildlife conflict management should be practiced to safeguard people and their property from wildlife and promote the coexistence between humans and wildlife. This way, the growing human-wildlife conflict in the Mullaitivu district can be curbed. Taking management measures to prevent wildlife infiltration into human settlements and proposing strategies are necessary to prevent the encroachment of wildlife and sustain biodiversity.

Acknowledgements

All the sample household members from Mullaittivu District and the Wildlife Department are highly appreciated for their support during the fieldwork.

Disclosure statement

No potential conflict of interest was reported by the authors.

Ethical approval

Ethical approval to conduct the study was obtained from the Animal Ethics Review Committee, University of Jaffna (AERC/2021/04).

Funding

We are grateful to the University of Jaffna for giving financial assistance under the University Research Grant (URG/2019/DMCLSE/08).

References

Alves DS, Pereira JLG, De Sousa CL, Soares JV, Yamaguchi F. 1999. Characterising landscape changes in central Rondonia using Landsat TRANSITION MATRIX imagery. Int J Remote Sens. 20(14): 2877–2882.

Bandara R, Tisdell C. 2003. Comparison of rural and urban attitudes to the conservation of Asian elephants in Sri Lanka: empirical evidence. Biol Conserv. 110(3):327–342.

Brandon RB. 2001. Mapping rural land use and land cover change in Carroll County, Arkansas utilizing multi-temporal landsat thematic mapper satellite imagery. University of Arkansas. http://www.cast.uark.edu/local/brandon_thesis/index.htransition.matrixl.

Castaldo-Walsh C. 2019. Human-wildlife conflict and coexistence in a more-than-human world: A multiple case study exploring the human-elephant-conservation nexus in Namibia and Sri Lanka [Doctoral dissertation]. Nova Southeastern University.

Conover M. 2002. Resolving human-wildlife conflicts: the science of wildlife damage management. USA: Lewis Publishers CRC Press Company Boca Raton Florida.

De Silva M, Attapattu N. 1997. Alleviation of wild elephant– human conflict and conservation of elephants in the North-western region of Sri Lanka (Mimeo). Colombo: Department of Wildlife Conservation.

Distefano E. 2005. Human – wildlife conflict worldwide: collection of case studies, analysis of management strategies and good practices. Available at http://www.fao.org/SARD/COMMON/ecg/1357/en/HUMAN-WILDLIFECONFLICT_final.pdf.
Fernando P, Jayewardene J, Prasad T, Hendavitharana W, Pastorini J. 2011. Current status of Asian elephants in Sri Lanka. Gajah. 35:93–103.
Food and Agriculture Organization of the United Nations. 2009. Human-wildlife conflict in Africa, causes, consequences and management strategies.
Food and Agriculture Organization of the United Nations. 2020. Global forest resource assessment report, Sri Lanka
Geist HJ, Lambin EF. 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience. 52:143–150.2.0.CO;2]
Graham K, Beckerman AP, Thirgood SJ. 2005. Human–predator-prey conflicts: ecological correlates, prey losses and patterns of management. Biol Conserv. 122(2):159–171.
Guild LS, Cohen WB, Kauffman JB. 2004. Detection of deforestation and land conversion in Rondonia, Brazil using change detection techniques. Int J Remote Sens. 25(4):731–750.
Hoare RE. 2001. A decision support system for managing human-elephant conflict situations in Africa. IUCN African Elephant Specialist Group Report.
Horgan FG, Kudavidanage EP. 2020. Use and avoidance of insecticides as responses by rice farmers to change impacts in southern Sri Lanka. Environ Manage (Provisionally Accepted). 65(6):787–803.
Jayewardene J. 1994. The elephant in Sri Lanka. In: The wildlife heritage trust of Sri Lanka. Rajagiriya: Biodiversity and Elephant Conservation Trust, Colombo, Sri Lanka.
Jayewardene J. 2004. Endangered elephants: past, present and future. Proceedings of the Symposium on Human-Elephant Relationships and Conflicts, Sri Lanka. Biodiversity & Elephant Conservation Trust, Colombo, Sri Lanka.
Kopke S, Withanachchi SS, Pathiranage R, Withanachchi CR, Gamage DU, Nissanka TS, Warapitiya CC, Nissanka BM, Ranasinghe NN, Senarathna CD, et al. 2021. Human–elephant conflict in Sri Lanka: a critical review of causal explanations. Sustainability. 13(15):8625..
Lopez R. 1997. Environmental externalities in traditional agriculture and the impact of trade liberalisation: the case of Ghana. J Dev Econ. 53:17–39.
Mace RD, Waller JS, Manley TL, Lyon LJ, Zuuring H. 1996. Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana. J Appl Ecol. 33(6):1395–1404.
Mallawatantri A, Marambe B, Skehan C. 2014. Integrated strategic environmental assessment of the northern province of Sri Lanka final report. Central Environmental Authority, Disaster Management Centre, Sri Lanka. https://www.iucn.org/sites/dev/files/content/documents/2017/isea_north_final_report.pdf.
Marchal V, Hill C. 2009. Primate crop-raiding: a study of local perceptions in four villages in North Sumatra, Indonesia. Primate Conserv. 24(1):107–116.
Mathotaarachchi KP, Godage WMCP, Thilakarathna KAAN. 2021. Conflict to coexistence: A critical look at issues related to human-wildlife interactions in Sri Lanka. Asian J Law and Governance. 3(1):47–59.
Mishra DK, Rathore SS, Pandey D. 2014. Human wildlife conflict and wildlife watershed management. Int J Bioassays. 3(08):3210–3213.
Mombauer D. 2020. Sri Lanka: Rich in biodiversity, and human-wildlife conflict. MONGABAY: News and Inspiration from nature front line.
Muchoney D, Strahler A. 2002. Regional vegetation mapping and direct land surface parametrisation from remotely sensed and site data. Remote Sens Environ. 23(6):1125–1142.
Ogra M, Badola R. 2008. Compensating human-wildlife conflict in protected area communities: ground-level perspectives from Uttarakhand. Hum Ecol. 36(5):717–729.
Ouedraogo I, Tigabu M, Savadogo P, Compaore H, Oden PC, Ouadba JM. 2010. Land cover change and its relation with population dynamics in Burkina Faso, West Africa. Land Degrad Dev. 21(5):453–462.
Perera BMAO, Abeygunawardena H, Abeygunawardena IS, Wanigasundera WADP, Gunatilake J, Jayasooriya AP. 2007. The human-elephant conflict (HEC): background and current situation in the northwestern wildlife region of Sri Lanka. Loris. 24:10–20.
Pontius RG, Shusas E, Mc Eachern M. 2004. Detecting important categorical land changes while accounting for persistence. Agric. Ecosyst. Environ. 101(2-3):251–268.
Pranjit KS, Bibhab KT, Jayanta KB, Bibhuti PL, Hazarika N. 2008. A geo-spatial assessment of habitat loss of asian elephants in Golaghat District of Assam. Gajah. 28:25–30.
Ranagalage M, Gunarathna MHJP, Surasinghe TD, Dissanayake D, Simwanda M, Murayama Y, Morimoto T, Phiri D, Nyirenda VR, Premakantha KT, et al. 2020. Multi-decadal forest-cover dynamics in the tropical realm: past trends and policy insights for forest conservation in dry zone of Sri Lanka. Forests. 11(8):836.

Roy M. 2017. A spatial and temporal analysis of elephant-human conflict at Gorumara and Jalpaiguri Forest Divisions of Northern West Bengal. J Wildlife Res. 05(3):41–49.
Santiapillai C, Wijeyamohan S, Bandara G, Athurupana R, Dissanayake N, Read B. 2010. An assessment of human-elephant conflict in Sri Lanka. Ceylon J. Sci. (Biol. Sci.). 39(1):21–33.
Sapkota S, Aryal A, Baral SR, Hayward MW, Raubenheimer D. 2014. Economic analysis of electric fencing for mitigating human-wildlife conflict in Nepal. J Res Ecol. 5(3):237–243.
Statistical Handbook. 2020. District Statistical Information: Mullaitivu. District Secretariat, Mullaitivu.
Turner BL, Meyer BL. 1994. Global land use and land cover change: an overview. In: Meyer WB, Turner BL II, editors Changes in land use and land cover: a global perspective. UK: Cambridge University Press; p. 3–10.
Vitousek PM. 1992. Global environmental change: an introduction. Annu Rev Ecol Syst. 23(1):1–14.
World Wildlife Fund (WWF). 2005. Human-wildlife conflict manual. Harare, Zimbabwe: WWF Southern African Regional Programme Office (SARPO).