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Research Article

A Geospatial Analysis of Elephant Crop Damage in the Ommunities Adjacent to the Serengeti National Park and Grumeti Game Reserve, Tanzania

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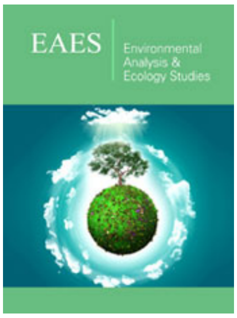

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Abstract

A study was conducted in the communities nearby the Serengeti National Park and Grumeti Game Reserve to investigate a spatial configuration of human-elephant interactions. Elephant crop damage was the most common adverse impact of the interactions. The researchers used geographic information systems to assess the distribution, hotspots, coldspots and relationships between elephant crop damage and environmental features in the Bunda District, Tanzania. The study unveiled six hotspots and three coldspots. Four hotspots occurred adjacent to Grumeti Game Reserve and two hotspots near the Serengeti National Park. Of all elephant crop damage incidents, 66% occurred in the village bordering Grumeti Game Reserve, 28% in the villages bordering the Serengeti National Park and 6% in the village the bordered none of the protected areas. There were significant hotspots of elephant crop damage in villages near Grumeti Game Reserve, and significant coldspots in the communities disconnected from protected areas. Trophy hunting in Grumeti Game Reserve is a probable factor for the presence of the significant hotspots as tourist hunting usually affects the movement and foraging behaviors of certain species. More importantly, unplanned hunting also affects the diversity of key ecological species that are habitat in the habitat manipulation and restoration. In addition, the geographical setting of the study might have contributed to the presence of many concentrations of crop damage incidents near Grumeti Game Reserve. As the majority, nine (75%) villages involved in the study are next to Grumeti Game Reserve and three (25%) villages border the Serengeti National Park. There was also a high concentration of elephant crop damage near rivers and protected areas, which decreased with increased geographical distance from the edge of these features.

Keywords: Bunda district; Cold spots; Conservation corridor; Crop damage; Elephant death; GIS; Grumeti game reserve; Hot spots; Human-elephant interactions; Kernel density; Serengeti national park; Trophy hunting

Introduction

Human-elephant interactions (HEI) cause various types of adverse impacts including human and elephant deaths, crop and house damages, and indirect impacts. Like other types of human-herbivores interactions, crop damage is the most common adverse impact that elephants (Loxodonta africana) inflict on communities bordering protected areas Desai [1]. At the local level, African elephants cause substantial and severe impacts to farmers Parker et al. [2] by raiding crops, damaging property, and, in some cases, causing death and injury. Elephants raid different types of crops, which make them, locally, the most destructive vertebrate pest [3,4]. Elephants have large appetites and lengthy feeding hours and may remain active for up to 18 hours in a day[5]. Crop damage is a common manifestation in communities surrounding protected areas, which elephants routinely visit for food and water. Other vertebrate species, such as eland, black rhino, baboon, wild boars, red-billed quelea, rodents, and hippos, also cause similar types of crop damage [6].

A GIS approach is useful for assessing the spatial distribution and concentration of patterns of elephant crop damage. However, technological, and financial constraints marginalise some parts of the world from adopting geographic information technology. Knowledge of the geographical configurations of crop damage is essential for decision-making and strategic planning for mitigation measures. Understanding the spatial patterns of elephant crop damage is important during planning, policy devising, and decision making because many decisions have spatial components [7]. GIS tracks events and entities. Two important ingredients of geographical data are spatial data (where is it?) and attributes (what is it?) (Einstein). Advancement and flexibility of GIS have enhanced spatiotemporal analysis of patterns for wildlife management Wilson et al. [8]. GIS enhances the understanding of causal mechanisms and processes of geographically referenced phenomena (Vanleeuwe). Consequently, GIS provides important tools for solving wildlife management problems. It simplifies the conservation and management of endangered species by understanding their conservation status, interactions, and movements. Ecologists use GIS to solve complex and dynamic geographical problems relating to wildlife managementdeployed GIS to understand spatial patterns of elephant poaching incidents in Tsavo East National Park in Kenya. Conservationists deploy a GIS approach to address different wildlife conservation issues. Mutanga [7] assessed eland crop damage by deploying GIS in Kwa-Zulu Natal, South Africa. In a similar study, the prediction of spatial aspects of HEI occurrences was made in an unprotected range of Maasai Mara National Reserve, Kenya Sitati et al. [9]. However, the spatial examination of elephant crop damage takes place with inadequate or no consideration of the areas of the density of crop damage occurrences (hotspots and coldspots). Because each elephant crop damage incident has spatial characteristics (Goodchild), a better understanding of its spatial configuration may provide elephant stakeholders with the necessary information required for developing proactive mitigation measures.

To better understand the location, distribution and concentration of crop damage in Bunda District, Tanzania, the location of elephant crop damage incidents (X, Y coordinates) were collected and analysed. The Bunda district is one of the areas in Tanzania with frequent HEI occurrences Mduma [10]. A spatial understanding of elephant crop raiding is lacking, particularly in the communities that border the Serengeti National Park (SENAPA) and Grumeti Game Reserve (GGR). The communities, in the district, experience numerous events of elephant crop damage. In this study, researchers collected data from 12 villages nearby the Serengeti National Park and Grumeti Game Reserve in Bunda district.

Materials and Methods

Data collection

In Tanzania, a village is a small community in a rural area made up by inhabitants, infrastructure, forests, farms and geographical features, governed by a legally established local authority [11]. Collection of spatial data took place in Bukore, Balili, Hunyari, Kihumbu, Kyandege, Kunzugu, Mihale, Mcharo, Mugeta, Mariwanda, Nyamatoke and Nyangere (Figure 1). Proximity to protected areas and the high number of incidents of crop damage were the main criteria for the selection of the villages. The study adopted adaptive purposive sampling technique to identify and record the farms and households that experienced elephant crop damage. The researchers visited most of the farms with elephant crop damage for identification and documentation of crop damage patterns. Formal village meetings were also used to identify household representatives whose farms had suffered elephant crop damage. Historical patterns of elephant crop damage were identified and collected. The study was only interested in the identification of the geographical location of each incident not in the extent of crop damage.

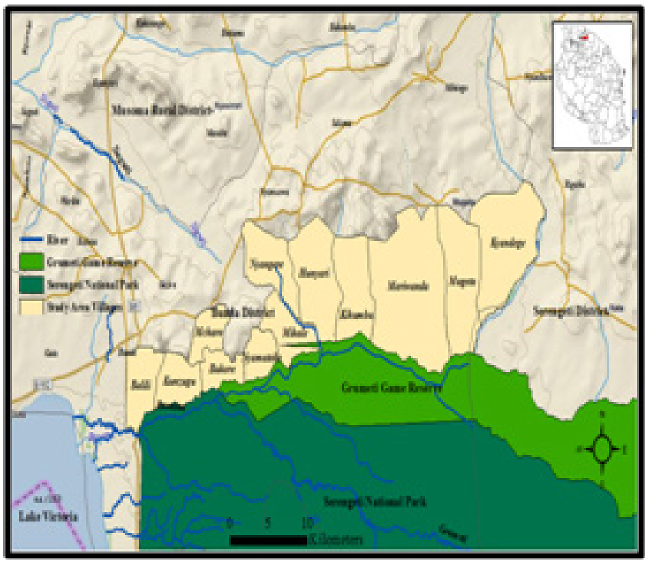

Figure 1: A map of the study area villages and their authorities bordering the Serengeti National Park and Grumeti Game Reserve.

Household representatives, elephant dung, distinctive feeding characteristics of elephants and elephant tracks were the main identification and verification criteria for the presence or absence of elephant crop damage. Elephant crop damage is the destruction of at least a portion of a crop by elephants. Due to the complex nature of crop damage, experts were consulted for clarification and confirmation of the damage. Experts consisted of wildlife officers, agricultural officers, and community development officers. In addition, villagers and their leaders participated in the identification and description of elephant crop damage for each village before entering an incident into the geodatabase [12]. A handheld Garmin GPS receiver recorded the locations (X, Y coordinate) of verified current and previous signs (within one year) of elephant crop damage. The data were collected for six months. From the collected information, it was possible to create a crop damage layer in ArcGIS 10.5.

Data preparation and analysis

A shapefile of the Serengeti National Park, Grumeti Game Reserve, with rivers and administrative villages, was obtained from the Lincoln University GIS server and Serengeti National Park office. The village GIS layer consisted of a set of contiguous polygons representing the areas over which villages had responsibility rather than just the spatial extent of each individual village. A kernel density analysis identified the clusters of elephant crop damage in the district (Gibin). This study uses a 5000 m buffer zone around Serengeti National Park and Grumeti Game Reserve as the bandwidth (Biodiversitya-z, 2015). The Spatial Joint tool combined each village's map and the locations (X, Y coordinate) of crop damage in ArcMap. The resulting map contained a new field with the number of crop damage incidents for each village. The hotspot analysis used the new map to identify villages with a significant concentration of crop damage incidents. In this study, 'hotspots' are significantly high concentrations of elephant crop damage, and 'coldspots' is a significantly low concentration of crop damage Harris [12]. The Gedis-Ord G algorithm was used to identify crop damage hot and cold spots (Getis). A high Z score and lower P-value indicated significant hotspots. A high negative Z score and small P-value indicated cold spots. Hotspot analysis scrutinises whether high or low values of crop damage incidents were spatially clustered. In addition, proximity analysis assessed the geographical distance for each elephant crop incident to the edge of SENAPA and GGR.

Result

Impacts of environmental features on crop damage

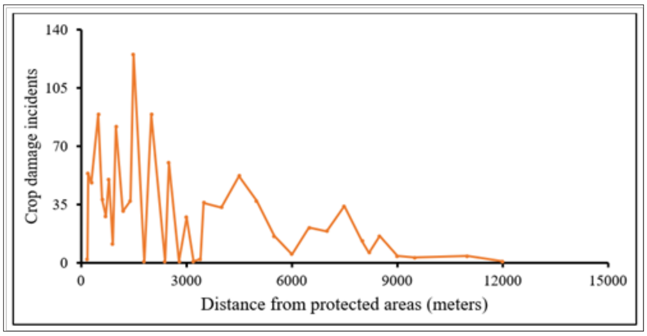

Figure 2: Crop damage incidents with increasing distance from Serengeti National Park and Grumeti Game Reserve.

The study recorded 1033 incidents of elephant crop damage from 12 villages for one year. The highest number, 147 (14.23%), of incidents occurred in Mihale village, and the lowest number, 18(1.74%), of incidents occurred in Nyangere village. Based on proximity analysis, the majority of crop damage events (554 or 51.5%) occurred within 2,000 meters of rivers and streams. There were no incidents of crop damage beyond 10,000 meters from the rivers and streams. The majority of incidents 574(53.3%) occurred between 0 and 2,000 meters from the boundary of protected areas (SENAPA and GGR), while, the lowest number of incidents happened between 10,000 and 12,000 meters from the boundaries of the protected areas (Figure 2). In comparison, the numbers and proximity of crop damage incidents to rivers and protected areas were similar. In other words, the number of incidents recorded at a certain distance from rivers resembled the number of incidents recorded at a similar distance from the boundary of SENAPA and GGR, probably because, SENAPA and GGR used rivers such as Ruwana River, in some parts, as their physical boundaries. The chi-square test at a 0.05 significance level, showed no significant differences between the number of incidents recorded at the certain distance from rivers and the number of incidents recorded at the same distance from the boundary of SENAPA and GGR (n=6 Value=30, P=0.224).

Kernel density analysis

Kernel Density estimated four major concentrations of crop damage in Kunzugu, Mihale, and Kihumbu and Hunyari villages (Figure 3) (Gibin). The largest concentration of crop damage incidents was between Hunyari and Mihale.

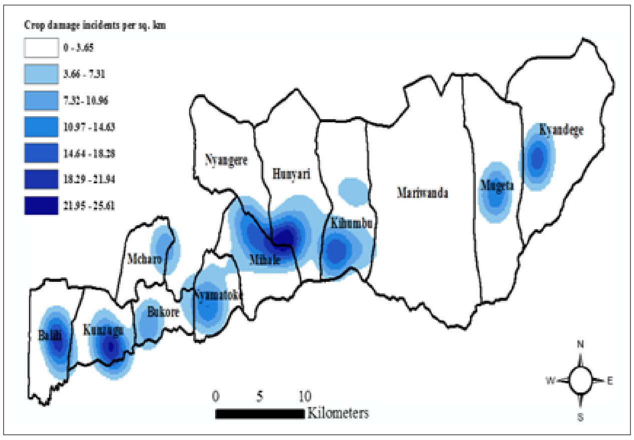

Figure 3: Crop damage incidents per square kilometre.

Hotspot analysis

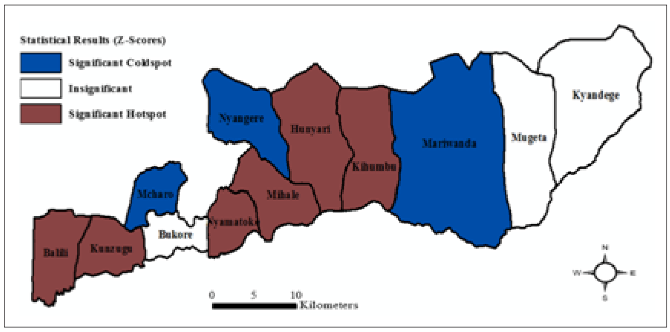

Figure 4: Statistical test for hotspots and coldspots of elephant crop damage.

A hotspot analysis identified statistically significant hotspots and coldspots of elephant crop damage in the study area. There were significant hotspots of elephant crop damage in Hunyari and Kihumbu villages and a cold spot in Nyangere village. The hotspots bordered Grumeti Game Reserve and SENAPA. The coldspots occurred in the village near GGR particularly in Mariwanda, and in the villages that have no borders onto any of the protected areas, Mcharo and Nyangere villages (Figure 4). The six villages, which are Balili, Hunyari, Mihale, Nyamatoke, Kihumbu and Kunzugu, had a statistically significant concentration of crop damage incidents. Bukore, Mugeta and Kyandege had an insignificant concentration of crop damage incidents.

Discussion

The degree and frequency of crop damage incidents varied between and within the villages bordering protected areas. For instance, all villages had varying rates of crop damage incidents throughout their administrative areas. Kihumbu, Mihale and Hunyari villages had the highest concentration of elephant crop damage compared to other villages. Crop damage incidents were more common in the villages near protected areas than villages that are more distant. For example, the low crop damage incidents in Nyangere village indicates that crop damage is unlikely to occur in communities disconnected from protected areas. Crop damage was more common in farms near rivers and SENAPA and GGR than farms that were distant from these features. In that context, the findings agree that the boundaries of the protected areas are the focal points of elephant crop damage, certainly for unfenced and unprotected farms Raihan [13]. Likewise, Nyirenda [14] asserted that protected areas, rivers, human presence and densities, and quality forage might influence the extent of elephant crop damage.

The proximity to water and certain species of forest trees increases the probability of elephant crop damage Hazarika [8]. Water quality and quantity inside the Serengeti National Park and Grumeti Game Reserve are unreliable. The elevated pH of greater than 10 and high fluctuations of dissolved oxygen (between 1% and 200%) make most of the water in the protected areas undrinkable to elephants Gereta [15]. Under these circumstances, elephants and other migratory species will move to unprotected habitats searching for water with satisfactory quality and quantity. The process of migration escalates the probability of elephant encroachment onto crop farms and water infrastructure. According to Nyirenda et al. [14], elephant crop damage near rivers is more intensive in dry seasons compared to the rainy seasons.

Human population densities and settlements may have caused a clumped spatial distribution of crop damage in certain areas of the district. Bunda District has a human density of nearly 200 people per km. Despite the high population density, some areas have remained untouched by agricultural and settlement encroachments as populations tend to grow in areas with a suitable level of soil nutrients, moisture content, social services and development infrastructures [16,17]. In that respect, crop farming becomes possible in the human-dominated landscape. The distribution of the human population coincides positively with the spatial distribution of elephant crop damage in the district. In the district, many residents usually have households surrounded by crop farms. Regardless of human presence, farmlands near conservation areas tend to attract elephant damage because the natural food of elephants usually decreases beyond the boundaries of protected areas.

Environmental parameters influenced the distribution and concentration of elephant crop damage in the villages. Most of the crop damage occurred between 0 and 2,000 meters from the edge of rivers, Grumeti Game Reserve and Serengeti National Park, and there was no elephant damage recorded beyond 10,000 meters. The elephant is a water-dependent species, spending most of its time near streams and rivers Nyirenda et al. [14]. In that respect, crop farms that are closer to rivers and borders of conservation areas are more vulnerable to elephant crop damage than those at distant. Harris [12] asserted that elephants choose foraging near conservation areas and rivers because they prefer moving less, eating well, drinking easily and avoiding human encounters. In short, water availability in the savannah landscape affects the foraging patterns of elephants because animals travel long distances searching for water and food when resource scarcity prevails in the protected landscape Sitati [18]. In those situations, the proximity of planted crops to rivers and streams is one of the important factors influencing the concentration of elephant crop damage adjacent to rivers and streams.

The adaptive behavior of elephants reflects a cost-benefit analysis approach. Elephants prefer maximising the benefit from food and water and reproduction while minimising time and energy required to obtain them. Monney [19] suggested that elephants take into consideration the cost of energy before deciding where to graze and drink and that animals will avoid raiding farms located too far from park boundaries because they are expensive to visit in terms of energy. In respect to external factors, the absence of crop field guards, unfenced protected areas, and the presence of the most preferable natural plants at the edge of the parks, together with increase the susceptibility of neighbouring farms to elephant raiding[20,21]. The clustering of elephant damage at a particular distance from the edges of conservation areas was similar to the distribution around rivers. The protected area authorities regard rivers, including the Rubana River, as geographical boundaries for SENAPA and GGR. In that respect, the same river is also the physical boundary dividing the anthropogenic and protected landscape into two parts.

Kernel density analysis estimated elephant crop damage in the study area to produce a continuous map for establishing the actual concentration of the damage. The largest concentration of crop damage incidents was between Mihale and Hunyari villages. The villages are next to Grumeti Game Reserve. In addition, there were many concentrations of incidents in villages near GGR compared to SENAPA. Of all crop damage incidents, 66% occurred in the village bordering GGR, 28% in the villages bordering SENAPA and 6% in the village the bordered none of the protected areas.

The geographical setting of the study might have contributed to the presence of many concentrations of crop damage incidents near GGR as the majority, nine (75%) villages involved in the study are next to Grumeti Game Reserve and three (25%) villages border SENAPA. In addition, concession hunting may determine the largest concentration of crop damage incidents in the villages next to Grumeti Game Reserve. Protected areas in eastern Africa allow trophy hunting for eradicating problem elephants Burke [20]. In Tanzania, the Wildlife Conservation Act of 2009 allows trophy hunting in game reserves, while prohibiting any hunting activity in the Serengeti National Park. Hunting usually affects the movement and foraging behaviours of certain species. As an example, frequently hunted agricultural pests that escape concession hunting usually intensify the extent of crop damage Thurfjell [21]. The Tanzania Wildlife Authority (TAWA) and the District Game Office (DGO) has inadequate resources for managing problem elephants in the district. Tanzania National Parks (TANAPA) that manages the SENAPA has more human and logistical resources than TAWA, which may account for the lower incidence outside SENAPA. In that context, geographical challenges and inadequate resources overwhelm the competencies of TAWA to control problem animals outside all national parks[22-25].

Understanding the significant crop-raiding hotspots and the influencing factors enhances the ability of conservationists to identify and map the areas with substantial clustering of elephant crop damage events for proactive mitigation measures. Graphical display of hotspots on maps aids policymakers to know where the damage occurs and the reasons for their clustering. In the study, there were six statistically significant hotspots, and three statistically significant coldspots and three insignificant areas. Four significant hotspots were adjacent to Grumeti Game Reserve. Significant coldspots occurred in the Nyangere and Mariwanda villages only. There were neither statistically significant hotspots nor coldspots near SENAPA. The presence of many significant hotspots identifies Kihumbu, Mihale, Nyamatoke, Kunzugu, Balili and Hunyari villages as highly predisposed areas to elephant crop raiding and therefore unsafe for crops farming in the district. In addition, the presence of significant coldspots in Mariwanda and Nyangere suggests that the villages are safe for farming. There were some issues with collecting and identifying evidence of elephant crop damage in the coldspots areas, such as reluctance to participate in the study and inadequate corporation from village governments. More importantly, the geographical setup of some villages, such as Mariwanda and Mugeta were difficult for data collection, the nature of the terrain made some farms in the villages inaccessible for data collection. Such challenges may have influenced the identification of hotspots and coldspots in this study.

The findings of this thesis might apply to other regions with active ranges of African elephants. The elephant stakeholders may use the findings to identify and document elephant distribution outside protected areas. Understanding the habitat utilisation and distribution outside protected areas is one of the major aspects of elephant management. Moreover, conservation authorities may use the findings to identify areas that are vulnerable to elephant crop damage when developing intervention measures. For example, it is likely that the distance from rivers and protected areas will be relevant to other areas in Africa[25-28].

Conclusion

A spatial approach advances understanding of the geographical configuration of direct and indirect adverse impacts of HEI. The findings of this spatial study became critical for understanding the current situation of elephant crop damage in the Bunda District and, by extension, other parts of the elephant range. Understanding the spatial configuration of crop damage helps conservation stakeholders envisage the context of spatial relationships of the human landscape in the Bunda District. The study exposed the spatial characteristics underpinning HEI, such as frequency and magnitude of elephant crop damage near protected areas and rivers. In particular, the study revealed a high incidence of crop damage near rivers and protected areas. It provided insightful information, such as where humans live and cultivate, where HEI occurs and how elephants use the areas outside the protected areas. As a result, conservationists may use the resultant maps to identify the elephant distribution and habitat utilization in the district. It is also possible to use the maps to identify, design and delimit elephant migratory routes. The government may use the maps for the identification of safe areas for relocating human settlements and agricultural farms. In short, the geospatial study serves as a powerful communication tool and activates discussions about HEI, elephant management plans, conservation policies and socio-economic development. Like many spatial studies, this one was influenced by data quality, quantity and geographical errors. The collection and analysis of spatial data were carried out in 12 administrative villages. The selection of participating villages in this thesis based on their proximity to SENAPA and GGR not on either frequency or magnitude of HEI. Such selection introduced some geographical issues. The Tanzania government defines village boundaries for administrative not conservation purposes. It was crucial to consider both geographical location and the magnitude of elephant crop damage for each participating village. In addition, time constraints, the willingness of participants to participate in the study, expertise on identifying elephant crop damage patterns and geographical challenges of the study area may have affected the quality and quantity of the geospatial data used for conclusion. As an example, elephant crop damage rectification experts on ecrop damage patterns. Moreover, some villagers needed incentives to participate in the surveys. Such challenges hindered the availability of reliable data used for spatial analysis. It is important to acknowledge that elephant crop damage happened in the margins of protected areas. Therefore, regional and landscape planning is essential to eradicate HEI incidents near protected areas. Prior to the comprehensive regional planning, the assessment of the spatial configuration of elephant crop damage is important, as it may disclose the spatial characteristics of the incidents in the human and elephant landscape. There are myriads of ways to analyse the expressions of elephant crop damage in the landscape. GIS efficiently connects the damage patterns directly to the regional landscape but computational modelling and simulation technique provides the dynamic nature of the incidents.

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Statement of Competing Interests

All authors have carefully read and understood the journal policy and therefore we declare that we had support from New Zealand Development Scholarship (NZDS), no financial and logistical support with political, apolitical, governmental and non-governmental organizations that might have interest in the submitted manuscript. We also confirm that no authors have any competing interest in the submitted work.

Author Contribution

We solemnly declare that this research has neither been submitted for consideration nor published elsewhere. We confirm that all authors have contributed substantially to this work, and all responsible organisations that technically and logistically contributed to this study have authorised its publication

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