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Original Research Article

# Assessment of human–elephant conflicts in multifunctional landscapes of Taita Taveta County, Kenya

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## ABSTRACT

People and wildlife have co-occurred, sharing resources for thousands of years, however, over the last four decades records of human–wildlife conflict have increasingly emerged. Human–elephant conflict is a form of such conflict, resulting from negative interactions between people and elephants. Human–elephant conflict affects local community livelihood and the success of elephant conservation. Tsavo East and Tsavo West National Parks, which cover about 60% of the Taita Taveta County land area, host the single largest elephant population in Kenya. We analysed human–elephant conflict incident data over 15 years (2004–2018) in Taita Taveta County, which forms part of the Tsavo ecosystem in south-eastern Kenya. We identified eight forms of human–elephant conflict comprising elephant threat, crop raiding, property damage, injury to people, human death, elephant death, elephant injury, and livestock death. Three forms of conflict accounted for 97% of the reported incidents, namely elephant threat to humans, constituting the highest number of incidents (62.46%), followed by crop raiding (32.46%) and property damage (2.33%). Conflicts occurred throughout the year, with June to July having the highest number of incidents. Rainfall, distance from the Tsavo national parks, and human population density were used as covariates to explain HEC patterns. This study seeks to provide a detailed evaluation of the spatial–temporal patterns of human–elephant conflict in Taita Taveta County and to yield information useful for human–elephant conflict mitigation and elephant conservation.

## 1. Introduction

People and wildlife have shared the same space since the beginning of their co-existence on Earth. Human–wildlife conflict (HWC) occurs when the needs of people encroach on those of wildlife or the habitat needs of wildlife impinge on those of humans (Nyhus, 2016). HWC is as old as human civilization (Anand and Radhakrishna, 2017) and is extremely widespread in conservation areas that are under high anthropogenic threat, such as the demand for natural resources

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necessary for human livelihood (Barua et al., 2013; Rakshya, 2016; Githiru et al., 2017). Globally diverse animal taxa ranging from mammals to reptiles are associated with HWC. The elephant is one wildlife species that is an obstinate culprit for HWC within its range. The elephant is a mega-herbivore with high nutritional requirements and consumes large amounts of browse, grasses, tree bark, roots, and fruits (Valeix et al., 2011). In addition, the elephant is also highly water-dependent (Williams et al., 2018; Wato et al., 2018), requiring large quantities of water for drinking and wallowing (Dunkin et al., 2013; Mole et al., 2016). To meet these huge ecological requirements, elephants are facultative migrants moving in search of water, forage availability, and mates (Ngene, 2010; Purdon et al., 2018).

The migration behaviour of elephants is facilitated by the existence of functional ecosystem connectivity between habitat patches. In Africa, elephant range decline is attributed to habitat loss and fragmentation due to population growth and expansion in agriculture (Mbau, 2013b; Nellemann et al., 2013). Most land use changes have taken place in areas that were previously wildlife dispersal areas and buffer zones to the protected areas. This has resulted in interference of elephant migratory patterns, thus increasing potential adverse people–elephant encounters and conflicts across the elephant range (Parker et al., 2007). These factors, among others, threaten the continued conservation of this charismatic species, which is ecologically and aesthetically valued. Despite the elephant having cultural, aesthetic, and economic benefits, the elephant is also associated with most of the HWCs (Mbau, 2013a; Mukeka et al., 2019; Long et al., 2020) across its range.

Globally, elephant conservation is under threat from human–elephant conflict (HEC), poaching, habitat fragmentation, and loss (Campos-Arceiz et al., 2009; Chartier et al., 2011; Webber et al., 2011). HEC occurs when people and elephants interact negatively (Smith and Kasiki, 2000; Sitati et al., 2003; Kioko et al., 2008). The main documented types of HEC are crop raiding, property destruction, injuries, and deaths to both people and elephants (Hoare, 2000; Choudhury, 2004; Chiyo et al., 2005). HEC has social, economic, and conservation consequences at both the local and regional scales (Campaore et al., 2020). According to Sitati et al. (2003), the presence of elephants within human settlements affects normal activities, for example disrupts commuting to work and school.

In the Taita Taveta County (TTC), human activities have reduced the sizes of habitat patches that elephants use as stepping stones during their seasonal migration between conservation areas (Ojwang' et al., 2017; Williams et al., 2018). Elephant conservation in TTC mainly takes place within the Tsavo East and Tsavo West National Parks, which are separated by an agrarian landscape characterized by settlements, farms, and rangeland. Recently, elephant use and movement have been disrupted by the changing land use and land tenure system, including subdivision of community group ranches into smaller private parcels, which has triggered an increase in human settlements and croplands in previous dispersal areas (Ojwang' et al., 2017). Such settlements that lie within elephant movement routes are more likely to experience higher HEC incidents than those located far away (Ngene and Omondi, 2008; Chen et al., 2016). The growth of linear infrastructure development has led to habitat loss and fragmentation, leading to further disturbance of elephant movement within the landscape (Okita-Ouma et al., 2017). Conflict between people and elephants in the county is considered one of the key factors contributing to the negative perceptions that the local people have of wildlife (Kamau, 2017). Information on the nature of HEC is of great significance as a first step in identifying mitigation strategies (Von Hagen et al., 2019) to ensure a sustainable co-existence. Although HEC studies have been conducted in many countries with elephants, site-specific studies are vital since the conditions and HEC dynamics vary from site to site. In addition, conservation of elephants is at the top of the agenda of the Kenya Government based on stiff penalties for wildlife crimes (Government of Kenya, 2013) and large investments in conservation. Therefore, information on threats encountered by the species is a priority. Furthermore, although a solid legal framework and political goodwill exist to support elephant conservation in Kenya, inquiries on the HEC are insufficient. Additionally, the Kenya elephant conservation and management strategy highlights the need to improve the understanding of HEC dynamics at each of the conservation sites (Kenya Wildlife Service, 2012). Hence, while HEC is known to occur in TTC, detailed spatial evaluation has not been done. This study aims at addressing this gap by analysing HEC spatio-temporal patterns in TTC between 2004 and 2018 through three research questions:

i. What is the nature of HEC in TTC?
ii. What are the temporal patterns of HEC in TTC? We hypothesize that HEC is higher during the dry seasons than in the wet seasons. We expected that as resources become limited in the dry season then the rate of human-elephant encounters increases. To answer this question, we investigate whether there is association between rainfall and HEC occurrence in TTC.
iii. What are the spatial patterns of HEC in TTC? We expect that areas near the national park experience higher HEC than others. In addition, we anticipate that human-elephant encounters are higher in areas with high human population density. In this study, we investigate HEC spatial patterns using human population density and distance from the two Tsavo national parks.

## 2. Materials and methods

### 2.1. Study area

The study was carried out in Taita Taveta County in south-eastern Kenya (Fig. 1). The county covers an area of 17 071 km$^2$, has 340 670 inhabitants (Kenya National Bureau of Statistics, 2019), and is administratively divided into four sub-counties of Mwatate, Taveta, Voi, and Wundanyi (Fig. 2). Most of Mwatate (650–2000 m a.s.l.) and Voi (230–1600 m a.s.l.) are topographically flat and belong to savannah ecotype vegetation dominated by *Acacia-Commiphora* bushlands; and comprise of majority of the Taita ranches between Tsavo East and West National Parks. However, Mwatate includes part of the rough and

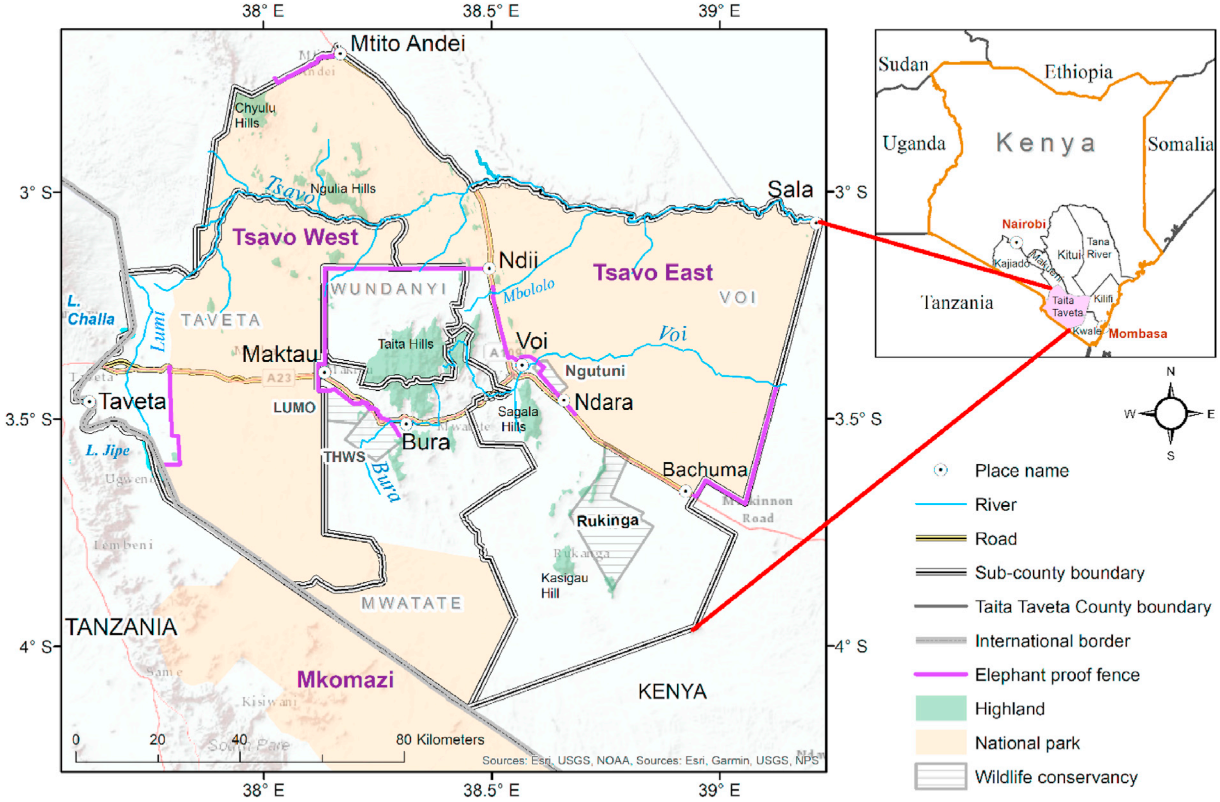

**Fig. 1.** Map of Taita Taveta County in south-eastern Kenya. The conservation areas include Tsavo East and West National Parks, community and private conservancies.

elevated Taita Hills, and Voi includes also hilly areas, such as Mt. Kasigau and Ngulia hills. Owing to their location and ideal conditions, the Taita ranches support large numbers of wildlife and livestock (County Government of Taita Taveta, 2018). The Taita Hills with high and rough relief reaching highest peaks at Vuria at 2228 m a.s.l make up most of the Wundanyi sub-county and are agriculturally among the most productive and densely populated areas in TTC (Fig. 13). However, the northern and western parts of Wundanyi are flat lowland but are disjointed from the Tsavo West National Park by an elephant proof fence (Maktau-Ndii), and thus, large wild mammals are rare. Taveta sub-county, on the other hand, forms the western edge of TTC, bordering Mkomazi National Park in the south and Kajiado County to the north (Fig. 1), both of which are rich in wildlife. This mostly topographically flat sub-county lying near the foot of Mt. Kilimanjaro at an elevation between 600 and 1160 m a.s.l. is endowed with perennial rivers such as Lumi which feeds Lake Jipe and several streams that feed to the Tsavo river, hence Taveta has large areas of land under cultivation.

TTC has a bimodal rainfall regime with two distinct dry and wet seasons each year, namely a long dry season from June to October, a short wet season from November to December, a short dry season from January to February, and a long wet season from March to May (Pellikka et al., 2018). Seasonal and annual rainfall is mostly influenced by altitude, with the Taita Hills receiving annually over 1200 mm, while the lowlands in most of Mwatate, Taveta, and Voi have on average 500 mm per annum. For instance, average yearly rainfall recorded at Maktau weather station managed by Taita Research Station of University of Helsinki at 1060 m a.s.l. was 483 mm in 2014–2016 (Tuure et al., 2020), while at the Kenya Meteorological Department station in Voi at 580 m a.s.l. an annual average of 563 mm is recorded during 2000–2018. Significant drought in the TTC occurred between 2007 and 2010 during which, the lowest annual rainfall, 241 mm, was recorded in 2008 and the highest, 553 mm, in 2009. The short rains in November–December 2008 resulted only to 35 mm of precipitation, so practically the rains were missing (Amara et al., 2020). Temperature is influenced by altitude, with highlands having temperatures ranging between 18 °C and 27 °C, and the lowlands between 23 °C and 35 °C or even higher. The effects of climate variability in the recent past are evident, and seasons are no longer predictable, and this is already reported to impact primary productivity of ecosystems and agriculture (Mandela, 2017) in many parts of the world, TTC included.

The TTC is part of the Tsavo ecosystem, where the vast conservation areas host diverse wildlife species and unique wildlife habitats. The ecosystem is a known elephant stronghold, hosting about a 33% of elephants in Kenya (Ngene et al., 2013) and about 3% of Africa's population. Land use practices vary across the TTC, with the major type being conservation, which covers 62% of the county's land area, about 22% is under agriculture and settlements, and the remaining is rangeland mainly used for cattle ranches and pastoralism (County Government of Taita Taveta, 2018). Wildlife conservation is mainly in the Tsavo East

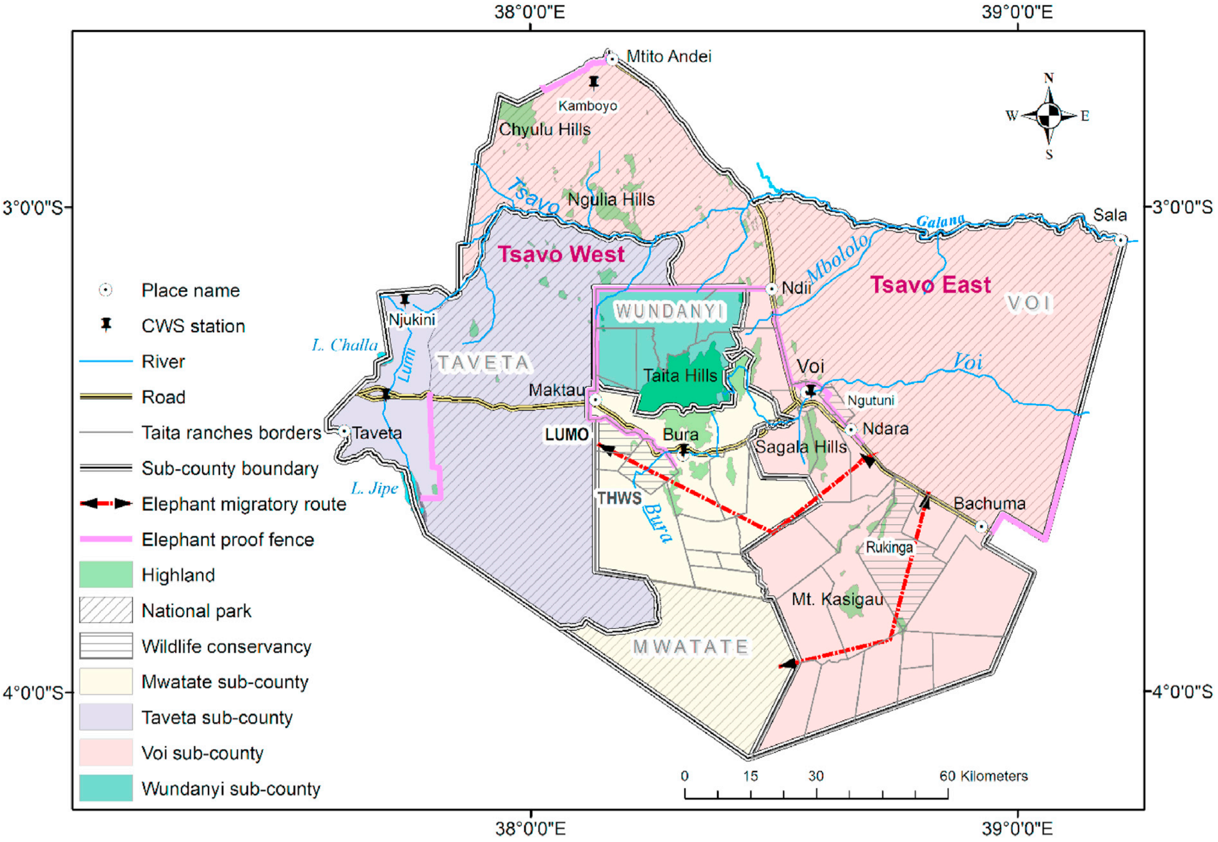

**Fig. 2.** Administrative division of Taita Taveta County into four sub-counties. Tsavo West and East National Parks also fall within the county administrative units. Elephant migratory routes were adapted and edited from Smith and Kasiki (2000) and Okita-Ouma et al. (2017).

and Tsavo West National Parks, Taita Hills Wildlife Sanctuary (THWS), Ngutuni, Rukinga and LUMO community conservancy (Fig. A2). In addition, the world's largest sisal (*Agave sisalana*) plantations are in Mwatate, Taveta and Voi (Wachiye et al., submitted). Agriculture is the main source of livelihood, contributing to approximately 95% of household income and 80% of employment in TTC (Ministry of Agriculture, Livestock and Fisheries, 2016). Agriculture is mainly rain-fed, except in parts of Taveta sub-county, where irrigation farming is common. Both small- and large-scale intensive crop farming is practised in TTC. Increase in human population and demand for food has led to increase in area under agriculture in TTC especially in the lowlands on the cost of bushlands, which are the natural habitats for elephants (Pellikka et al., 2018). These changes in land use have led to construction of elephant proof fences (wildlife barriers) where human activities are incompatible with wildlife conservation; there are currently six such fences (Fig. 1) with plans to extent and cover more areas (Kenya Wildlife Service, 2008). In addition, TTC landscape is also crossed by two major roads, the Mombasa–Nairobi highway and the Voi–Taveta road. Two railway lines from Mombasa to Nairobi run next to the Mombasa–Nairobi highway.

### 2.2. Data collection

HEC incident records over 15 years (2004–2018) were acquired from the Kenya Wildlife Service (KWS). The dataset is based on HWC incidents reported from different locations in TTC by the Community Wildlife Service (CWS) department of KWS, which manages wildlife outside protected areas. This department in addition to managing problematic animals is also involved in different community outreach projects. CWS has specialized units of well-trained and equipped ranger force that responds to HWC issues across the county. The CWS units in TTC fall under the Tsavo Conservation Area and have stations in Voi, Bura, Taveta, Njukini, and Kamboyo (Fig. 2). HWC incident reporting by the local community is done through telephone hotlines maintained by each of the CWS stations. The reporting lines are open 24 h a day, seven days a week. The call line is widely circulated to area leaders, including area chiefs, village elders, and community members. Communication within the CWS units is through comprehensive VHF radio communication network with links to other KWS operation areas across the county. Once a HWC report is received by the CWS unit, it is recorded as an incident in the occurrence log and a team is dispatched to respond accordingly. The HWC details recorded in the occurrence log comprise the date the conflict occurred, the conflict site, the species involved in the conflict, the nature of the conflict, and the action taken. Due to the good distribution of CWS stations across TTC and the dedicated communication network, these records provide the best and up-to-date dataset on HWC in TTC.

HEC records for TTC were filtered from the main database containing all HWC incidents caused by different species. The variables used for analysis were date of conflict, the sub-county the incident occurred, type of HEC incident, and any additional notes associated with the data. HEC data were subjected to further cleaning by confirming the conflicts with the team involved in the actual response to HWC incidents. A total of 8913 HEC incident records were validated and used to answer the research questions. In addition to the HEC dataset, precipitation data from the Voi weather station located in the central part of TTC was used to predict HEC since elephant food supply is dependent on the primary production, which relies on rainfall. Further, 107 spatial points were generated by georeferencing the HEC incident sites from the Survey of Kenya 1: 50 000 scale topographic map sheet for Voi and Google Earth Pro. Other datasets used were human population data for TTC and distance from the Tsavo national parks. Fig. 3 shows the methodological flowchart highlighting the HEC landscape level interactions. This flowchart draws from past studies that have identified underlying factors of HEC (Ngene and Omondi, 2008; Mariki et al., 2015).

### 2.3. Data analysis

Each HEC incident was considered once as a single observation and assigned to only one category. Analysis of HEC spatial patterns was performed using 107 spatial points georeferenced from the sites where HEC was reported. The analysis of annual patterns of HEC was based on monthly aggregates of the 15 years considered in the study. For descriptive statistics, mean (M) and standard deviation (SD) were used to show distribution and variation in incidents of HEC. These were used for analysis of variables, such as HEC incidents, across the defined range of years, monthly, and seasonal patterns. Proportion was also used to describe common forms of HEC. Frequency distribution was performed to show the distribution of HEC incidents among the seasons. One-way analysis of variance (ANOVA) was used in most of the variables to assess whether there was a significant difference in incidents of HEC among different groups. The groups subjected to ANOVA were range in years, seasons, and distance from the national park. Although all forms of HEC directly caused by the elephant can be termed as elephant threat, in this study, elephant threat refers to the state where elephants are found in areas of high human activity and where their presence leads to apprehension without resulting to any damage. Pearson correlation analysis was performed between elephant threat and other forms of HEC at the 0.05 significance level. Simple linear regression was also applied after Pearson correlation analysis where elephant threat predicted crop raiding at the 0.05 significance level. Multiple regression was used to investigate whether distance from the park and human population density could predict HEC. In order to examine the spatial patterns of HEC, all the 8913 incidents were manually assigned coordinates based on the site name (e.g. town, village, ranch, camp, and lodge) where the incident was recorded. A total of 107 sites were identified and assigned coordinates and GIS analyses were then performed. Firstly, to calculate human population density for each of those 107 sites, Thiessen polygons were created, and house points computed from Airborne Laser Scanning Data (ALS) see (Amara et al., 2020). For

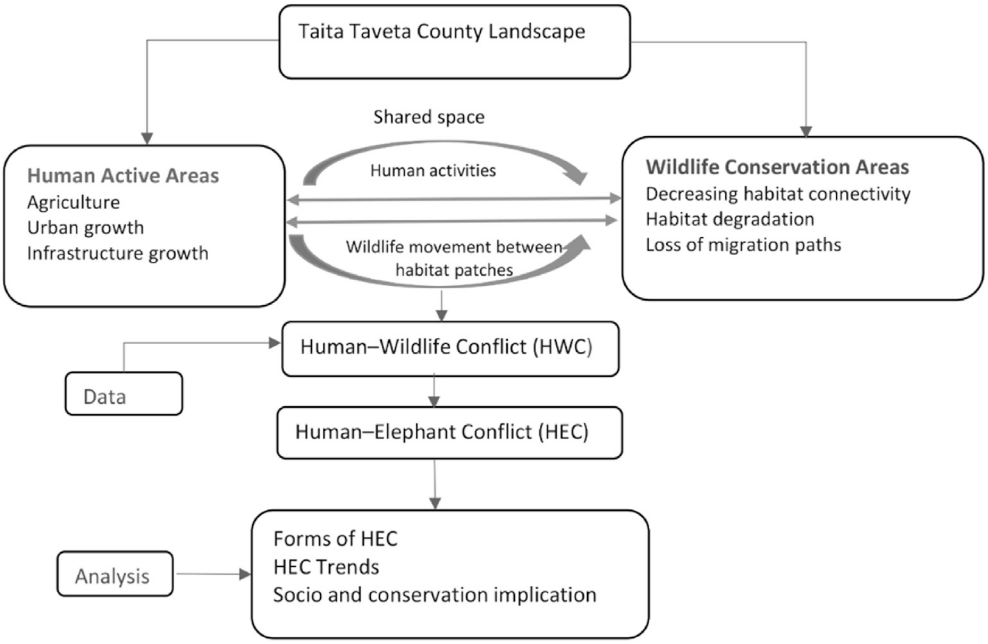

**Fig. 3.** Research flowchart for HEC dynamics in Taita Taveta County.

areas that were not covered by the ALS data, visual interpretation of very high-resolution images in Google Earth Pro and on-screen digitising was used to detect all the houses (N = 75 315) in the TTC. Each house point was set to four people and using Thiessen polygon areas (km$^2$), population density for each of the 107 sites was estimated. To calculate HEC distances from the Tsavo East and West national parks, the Euclidean Distance function in ArcGIS software was used and distance values extracted to the site points. Site points were also utilised to create graduated symbol maps for visualising spatial patterns of specific HEC types, HEC distances from the national park, and number of incidents for human death, elephant injury, crop raiding, property damage, human injury, elephant threat, livestock death, and elephant death in each of the sites (see Figs. 9, 10 and 13). Statistical data analysis was conducted using Statistical Program IBM SPSS Statistics for Windows, version 23 (IBM SPSS Statistics, 2015) and R software version 3.6.2 (R Core Team, 2019).

## 3. Results

### 3.1. Forms of human-elephant conflicts in TTC

The total number of HEC incidents were 8 913, with annual incident average of 594 (N = 15, SD = 255). We identified eight mutually exclusive forms of HEC in the period 2004–2018 (Fig. 4). In relation to forms of HEC, elephant threat which refers to the presence of elephants within human settlements that does not result to any of the other forms of HEC accounted for the highest number of incidents (62.46%), followed by crop raiding (32.46%), property damage (2.33%), human injury (0.83%), human death (0.79%), elephant death (0.57%), livestock death (0.53%), and elephant injury (0.03%).

### 3.2. Temporal patterns of HEC

#### 3.2.1. Inter-annual trend in HEC in 2004–2018

The HEC incident records over 15 years (2004–2018) were organized into five 3-year groupings arranged consecutively from the earliest to the most recent. The 3-year intervals were applied because total elephant counts are conducted every 3 years (Ngene et al., 2013), hence by using these intervals one census year was automatically included. Additionally, the 3-year interval was preferred to permit comparison of HEC incidents before and after building the new Standard Gauge Railway (SGR) 2014–2016, which is a major linear infrastructure in the area (Okita-Ouma et al., 2016).

The temporal analysis of annual HEC incidents (Fig. 5) indicated that the period 2010–2012 had the least number of incidents ($\overline{x}$ = 372±146.7), while the lowest year-to-year variation was observed in 2004–2006 ($\overline{x}$ = 491.3±12.6). The period 2016–2018 had the highest number of incidents ($\overline{x}$ = 837±310.8), while the highest variation within the three-year periods was seen in 2013–2015 ($\overline{x}$ = 688.7±329.7) and 2007–2009 ($\overline{x}$ = 602±201.0). One-way ANOVA indicated that there was no significant difference (F (4, 10) = 1.75, $p$ = 0.216) in HEC incidents among the defined year ranges. The line of best fit indicated a moderate increase in HEC incidents (R$^2$ = 0.46) between 2004 and 2018 as indicated in Fig. 5. The results showed that

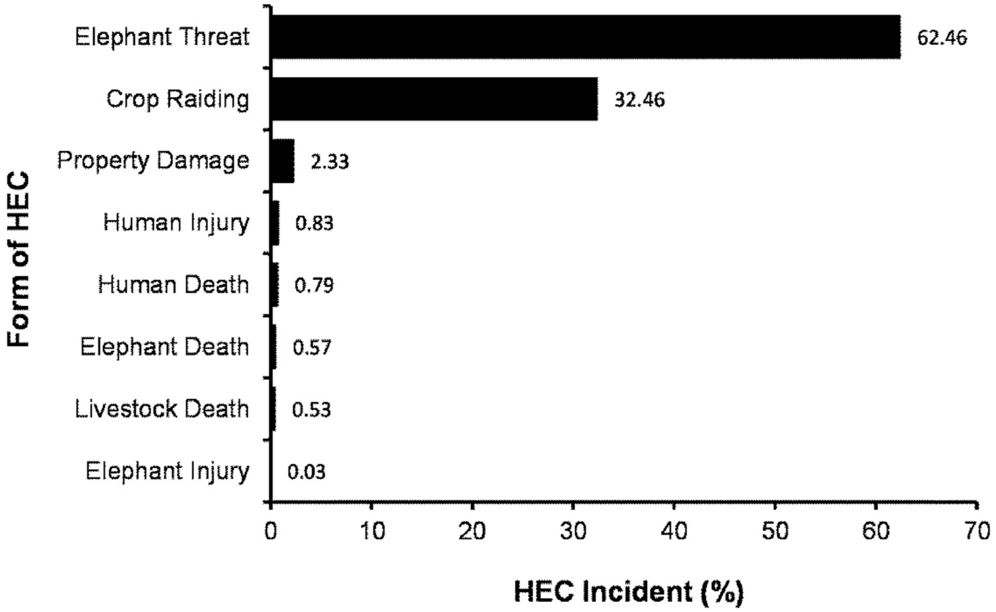

**Fig. 4.** Reported forms of HEC in Taita Taveta County between 2004 and 2018.

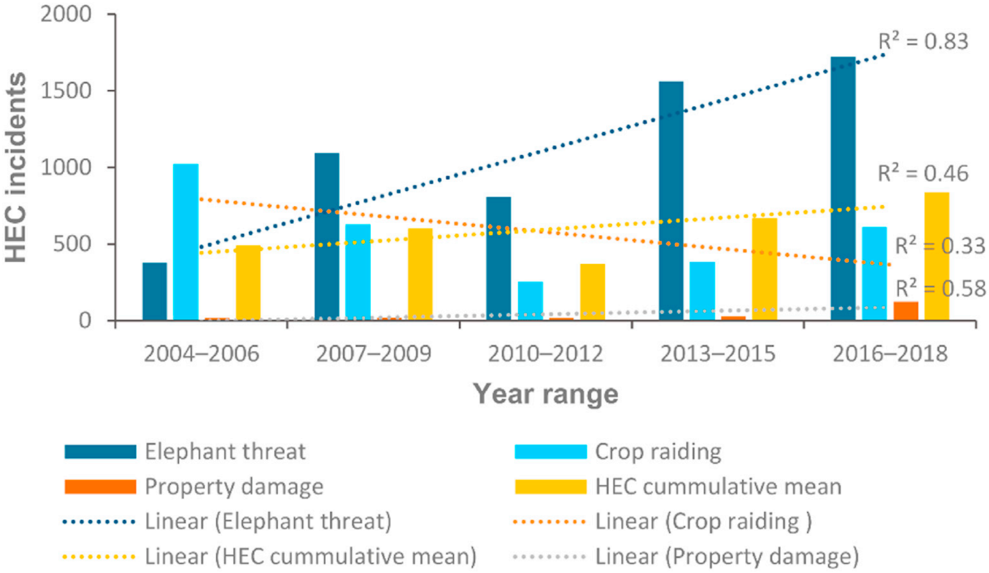

**Fig. 5.** Temporal trend of the three most common forms of reported human-elephant conflict incidents during the study period 2004–2018. For elephant threat, crop raiding and property damage the total count is used. The HEC cumulative mean accounts for all the eight forms of HEC.

elephant threat and property damage incidents also increased during the study period $R^2 = 0.83$ and $R^2 = 0.58$ respectively, while crop raiding incidents decreased $R^2 = 0.33$ in the same period.

### *3.2.2. Seasonal patterns of HEC*

The temporal patterns indicate that HEC occurred throughout the year. July (12.1%) and June (10.4%) showed the highest proportions of incidents and March (6.9%) and November (6.2%) showing the least. January, February, June, and July recorded the highest variations in the numbers of HEC (Table 1). The highest proportion of HEC were during the harvest periods after the long and short wet seasons, while the lowest were during planting in the short wet season. The average count of incidents in the four seasons for the 15 years indicated the maximum mean in the long dry ($M = 822.6$, $SD = 24.9$) and short dry seasons ($M = 773$, $SD = 34.0$), while the long wet ($M = 672$, $SD = 19.2$) and short wet seasons ($M = 619$, $SD = 20.5$) had relatively lower number of incidents. One-way ANOVA conducted on the HEC incidents in the four seasons, showed the differences in the average seasonal totals were not statistically significant ($F(3, 56) = 0.897$, $p = 0.45$).

### *3.2.3. Influence of climate variability on HEC seasonal patterns*

We investigated whether rainfall could be used to predict HEC occurrence. A Pearson correlation analysis between average monthly rainfall and HEC incidences revealed negative correlations ($r(10) = -0.664$, $p < 0.05$). The mean monthly rainfall

**Table 1**
Monthly/seasonal calendar and HEC trend in Taita Taveta County. Activity is based on early warning bulletin (National Drought Management Authority, 2019).

| Month | Season | Activity | Count | % Proportion | Mean | SD | SE |
|---|---|---|---|---|---|---|---|
| January | Short Wet | Short rains harvests & land preparation | 788 | 8.8 | 52.53 | 33.59 | 1.5 |
| February | Short Wet | | 758 | 8.5 | 50.53 | 38.08 | 1.59 |
| March | Long Wet | Planting & weeding | 614 | 6.9 | 40.93 | 20.42 | 1.17 |
| April | Long Wet | | 643 | 7.2 | 42.87 | 21.9 | 1.21 |
| May | Long Wet | | 759 | 8.5 | 50.6 | 27.68 | 1.36 |
| June | Long Dry | Long rains harvests, land preparation | 927 | 10.4 | 61.8 | 34.09 | 1.51 |
| July | Long Dry | | 1082 | 12.1 | 72.13 | 38.54 | 1.6 |
| August | Long Dry | | 705 | 7.9 | 47 | 24.41 | 1.28 |
| September | Long Dry | | 733 | 8.2 | 48.87 | 27.53 | 1.35 |
| October | Long Dry | | 666 | 7.5 | 44.4 | 28.16 | 1.37 |
| November | Short Dry | Planting | 550 | 6.2 | 36.67 | 19.26 | 1.13 |
| December | Short Dry | & weeding | 688 | 7.7 | 45.87 | 28.1 | 1.37 |

ranged between 8.2 mm in June and 194.7 mm in December. A simple linear regression was calculated to predict HEC based on monthly rainfall. A significant regression equation revealed that rainfall explained a significant proportion of variance in HEC (F (1, 10) = 7.88, $p < 0.05$, with an $R^2$ value of 0.441). Our results show that every decrease in mm of rainfall is associated with a 0.096 increase in HEC incidents (Fig. 6).

### 3.2.4. Elephant threat seasonal pattern

We summarized elephant threat incidents according to the seasons. The results indicate that the threat of elephants was slightly higher in the long dry season (N = 5, $M = 519.4$, $SD = 78.4$) than in the short dry (N = 2, $M = 461$, $SD = 24.0$), short wet (N = 2, $M = 412$, $SD = 31.1$), and long wet (N = 3, $M = 408$, $SD = 21.6$) seasons (Fig. 7). Statistically, elephant threat was not significant between the seasons (F (3, 8) = 2.97, $p = 0.097$).

### 3.2.5. Crop raiding and property damage seasonal patterns

Crop raiding occurred throughout the 15 years of observation time (n = 2893, $M = 192.9$, $SD = 116.3$). Annually, the months of June ($M = 23.9$) and July ($M = 24.7$) recorded the highest number of incidents, while October ($M = 10.3$) and November ($M = 8.5$) had the lowest number (Fig. 8). The short dry (N = 2, $M = 285.5$, $SD = 57.3$) and long dry (N = 5, $M = 252$, $SD = 103.4$) seasons experienced more crop-raiding incidents than the long wet (N = 3, $M = 236.3$, $SD = 82.0$) and short wet (N = 2, $M = 175.5$, $SD = 67.2$) seasons. We used one-way ANOVA to test the hypothesis that there was no difference in crop raiding between seasons. One-way ANOVA based on the seasons averaged by months, showed that the number of crop raiding incidents was not significantly different between the seasons (F (3, 8) = 0.55, $p = 0.66$). However, one-way repeated measures ANOVA conducted on the 15 years of survey to examine the effect of the four different seasons on crop raiding, showed that crop raiding incidents were statistically significantly different between seasons (F (2,42) = 15.03, $p < 0.001$).

HEC in the form of property damage incidents (n = 208) occurred throughout the year (Fig. 8) and compared with crop raiding exhibited a peak in the months of July to October. The mean number of property damage incidents was 17.3 ($SD = 9.8$, $\delta^2 = 96.2$) and crop damage incidents 241 ($SD = 83.8$, $\delta^2 = 7027.4$). Seasonally, more incidents occurred during the long dry season (N = 5, $M = 26.6$, $SD = 7.3$) than during the short wet (N = 2, $M = 13$, $SD = 7.1$), long wet (N = 3, $M = 10.0$, $SD = 4.0$), or short dry (N = 2, $M = 9.5$, $SD = 3.5$) season. One-way ANOVA conducted to examine seasonal differences based on seasonal cumulative property damage incident values showed that there were statistically significant differences between seasons (F (3,8) = 2.97, $p < 0.05$). A one-way repeated measures ANOVA was conducted on the 15 years to examine the effect of seasonal differences on the number of property damage incidents. The results showed that there was statistically significant difference in property damage incidents between seasons (F (3, 42) = 13.15, $p < 0.001$. Fig. 14 shows photographs of some of the recorded damages by elephants in TTC.

### 3.2.6. All other forms of HEC

Human injury, human death, livestock death, elephant injury, and elephant death accounted for 2.75% of the 8913 HEC incidents. A total of 74 human injury and 70 human death incidents were reported between 2004 and 2018 in TTC. There were 47 incidents of elephants causing death to livestock between 2004 and 2018. The affected livestock were goats, donkeys, cattle, and camels. In the 15 years of the study, 51 elephant deaths and 3 elephant injuries associated with HEC were reported.

## 3.3. Spatial patterns of HEC in TTC

Analysis of spatial patterns were based on the 107 spatial points (Fig. 13). We show the spatial pattern in terms of the distance to the national park and secondly by human population density. High number of incidents per site were observed in most areas across the landscape. Figs. 9 and 10 show the spatial distribution of the four highest and four minor forms of HEC respectively. For elephant threat and crop raiding the overall spatial distribution of conflict sites appeared clustered in areas

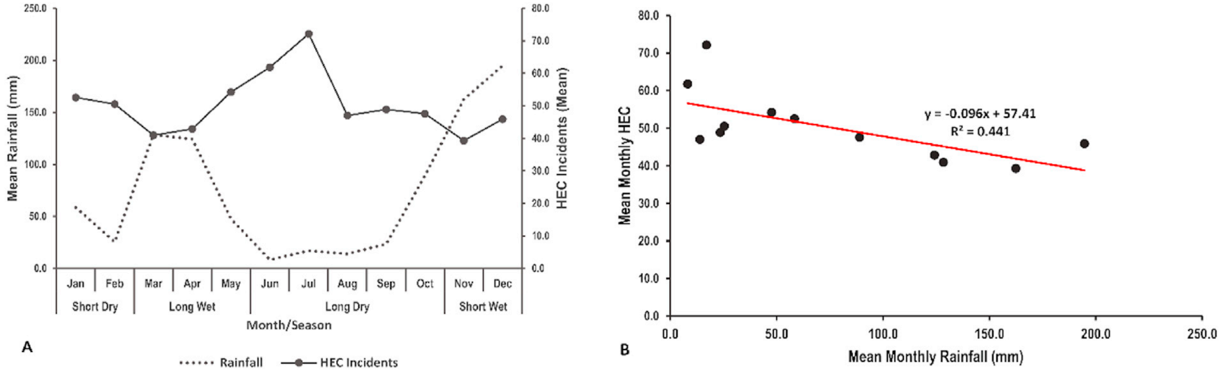

**Fig. 6.** (A) HEC incidents and rainfall presented as monthly averages in 2004–2018. (B) Scatter plot of monthly mean HEC incidents and rainfall for 2004–2018.

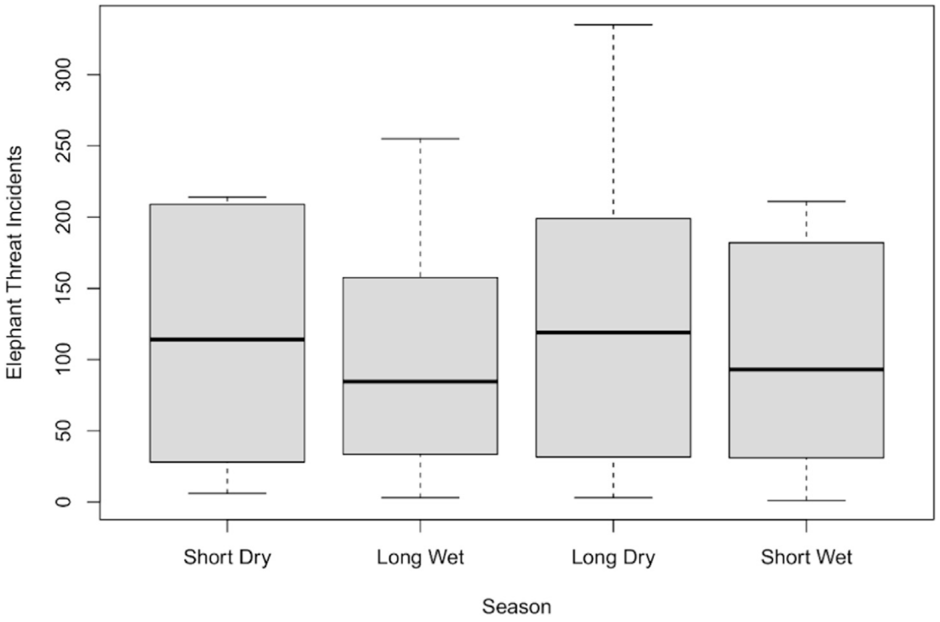

**Fig. 7.** Seasonal elephant threat to humans in Taita Taveta County in 2004–2018.

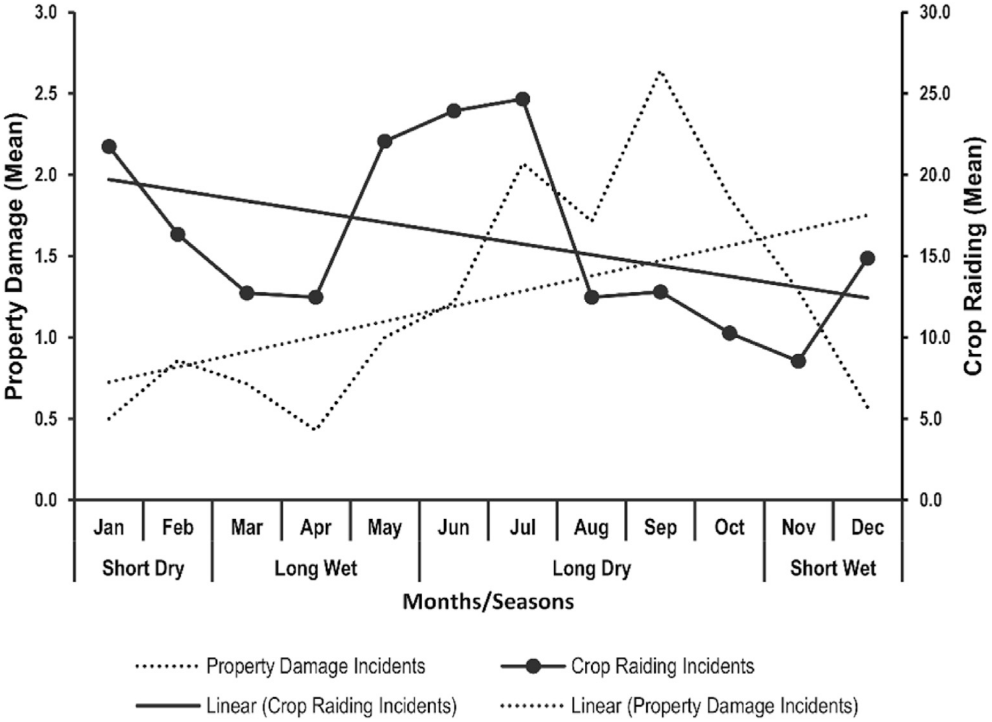

**Fig. 8.** Mean monthly counts of crop raiding and property damage in 2004–2018.

near highlands and close to wildlife conservancies, mainly the THWS which is located close to Tsavo West national park and Ngutuni ranch adjacent to the Tsavo East national park on the south west border. (Fig. 9).

### 3.3.1. *Spatial distribution of HEC with distance from Tsavo national parks*

We expected that HEC incidents would be highest close to the national park border. For purposes of this analysis we defined distance from the national park using six classes (Fig. 11). Distance from the national park ranged 0–27 km, with a

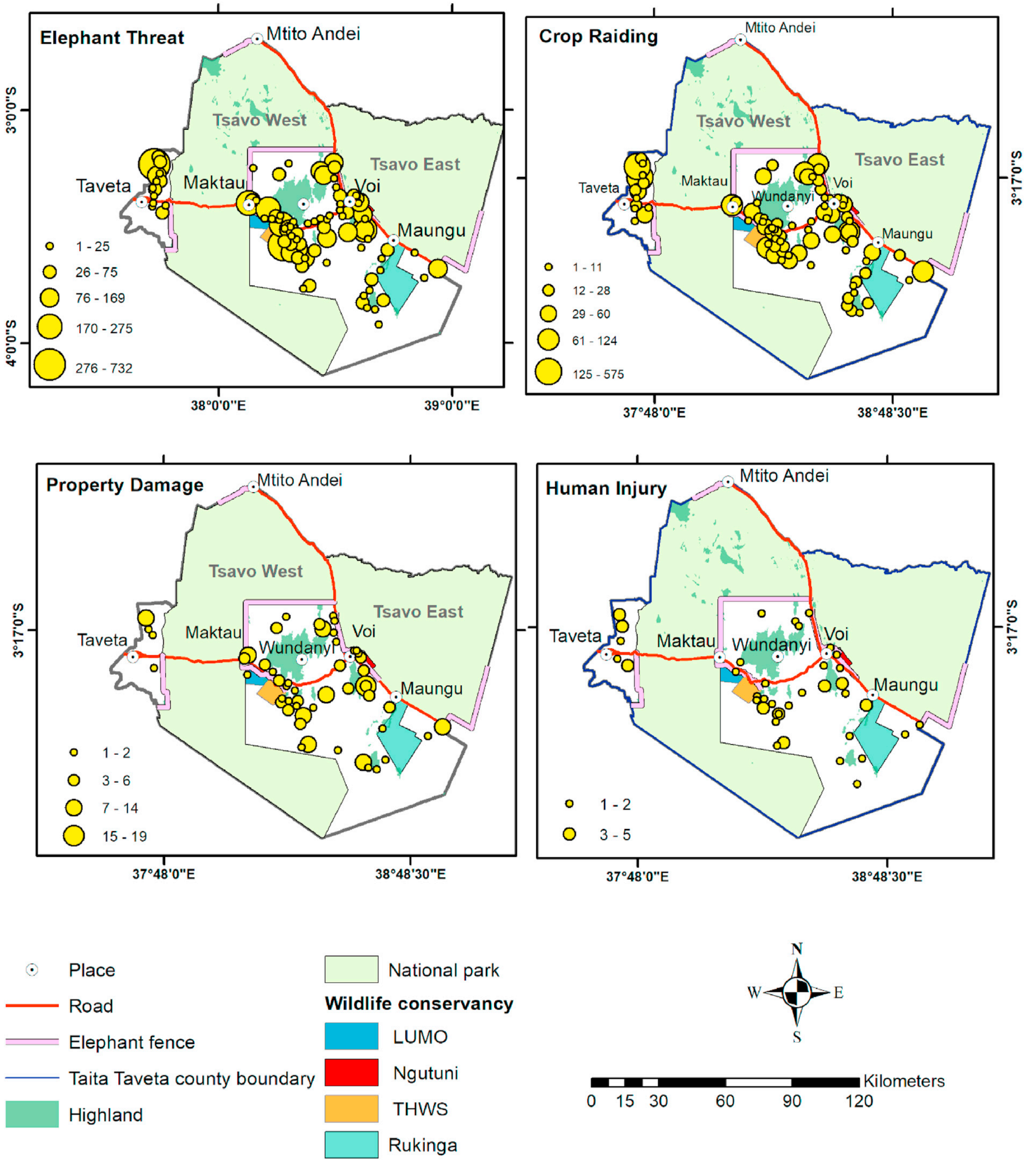

**Fig. 9.** Spatial pattern of the highest four forms of HEC. The points are based on identified 107 sites where HEC incidents were recorded in TTC. The size of the graduated symbols indicates the count per site in reference to the specific HEC type.

mean of 10.7 km. Overall the highest (38%, n = 3410 and 23%, n = 2054) proportion of all HEC incidents occurred at a distance of 5.1–10 km and 15.1–20 km respectively from the national park. One-way ANOVA showed that the differences within the group means were not statistically significant (F (5, 24) = 2.1, $p$ = 0.1. Further, we analysed the relationship of distance from the park and occurrence of crop raiding. The results showed the highest proportion (54%, n = 1559 and 18%, n = 527) of crop raiding incidents occurred at 5.1–10 km and 1.1–5.0 km respectively from the national park (Fig. 11), while the least incidents (1%, n = 28) were at less than 1 km from the national park. One-way ANOVA results revealed that the difference in crop raiding incidents between the six distance groups was statistically significant, (F (5, 24) = 3.56, $p$ = 0.014. In the case of

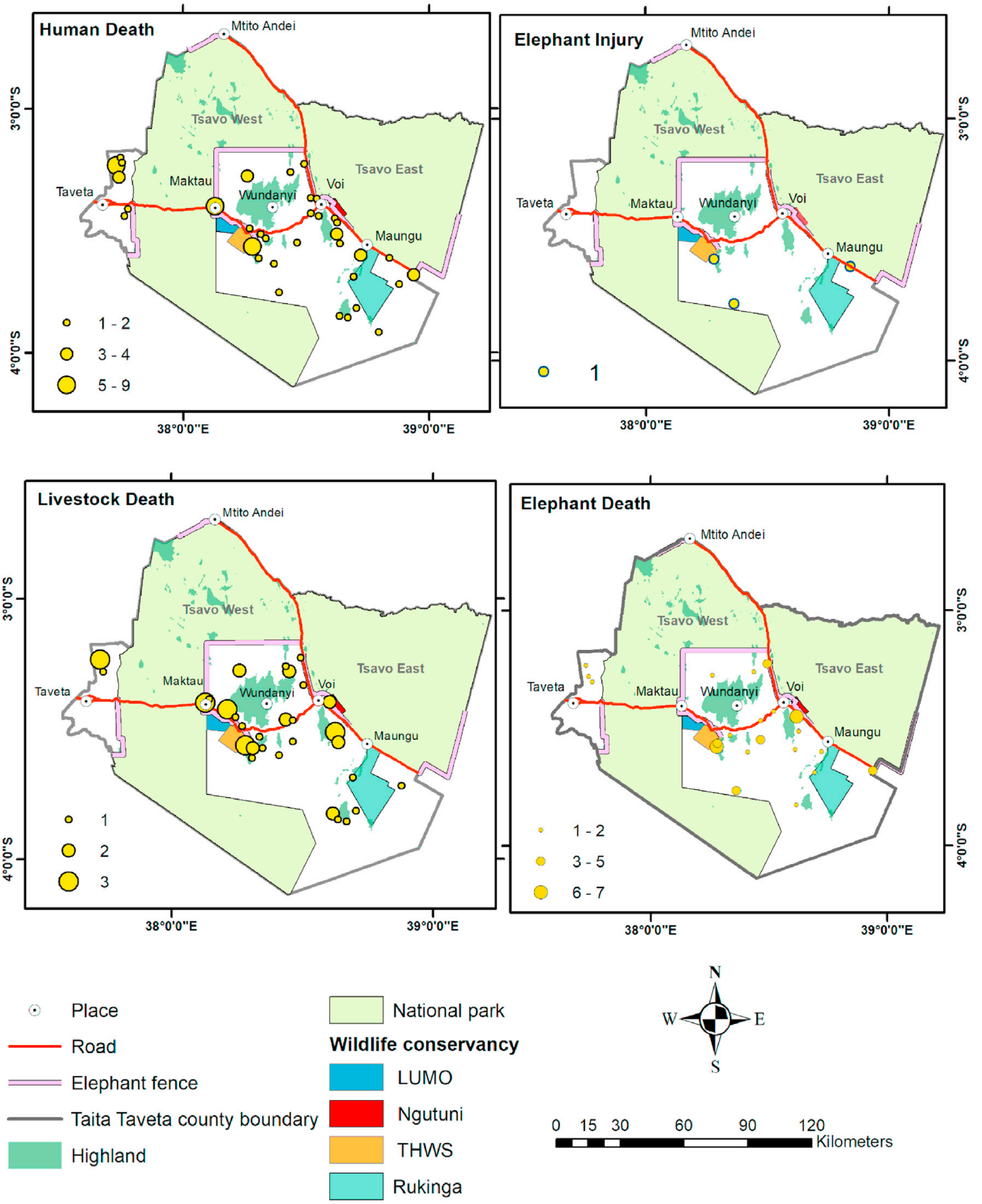

**Fig. 10.** Spatial distribution of HEC incidents for human death, elephant injury, livestock death, and elephant death in TTC 2004–2018. Spatial distribution of HEC with distance from Tsavo national parks.

property damage the highest proportion (34%, n = 70, and 29%, n = 60) occurred at 5.1–10.0 km and 1.1–5.0 km respectively, while the least (1%, n = 3) were at less than 1 km from the park. This difference was however not statistically significant (F (5, 24) = 0.99, $p = 0.44$. For elephant threat the highest proportion (31%, n = 1709 and 29%, n = 1618) occurred at 5.1–10 km and 15.1–20.0 km respectively, while the least (2%, n = 87) at less than 1 km. The difference in property damage incidents was however not statistically significant (F (5, 42) = 0.96, $p = 0.45$. The results indicate that no incidents of livestock and elephant death occurred at a distance of less than a kilometre from the national park.

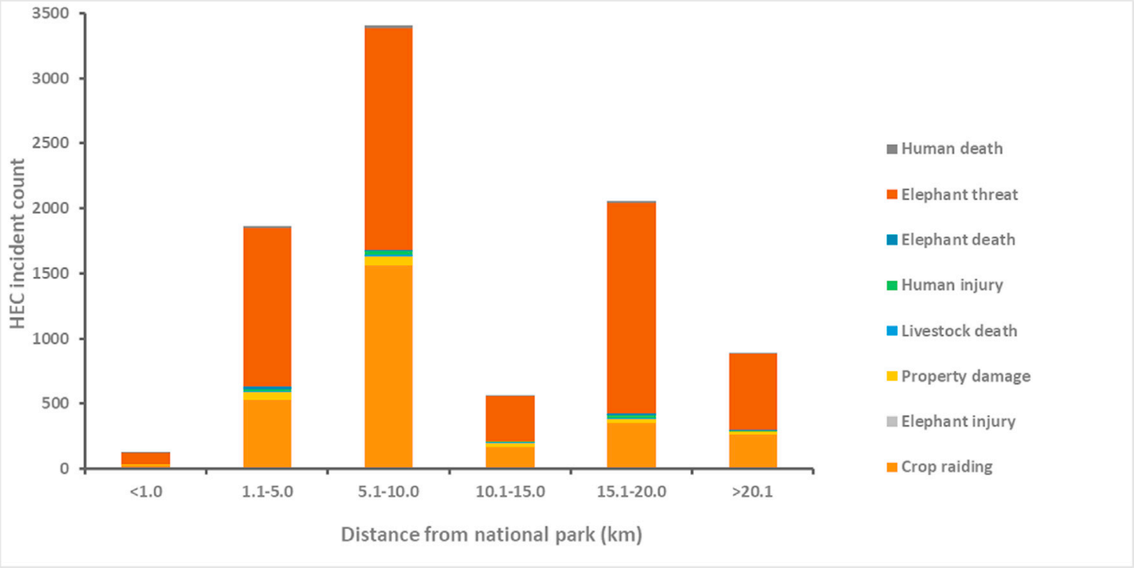

**Fig. 11.** Relationship of the eight forms of HEC with distance from the national park.

*3.3.2. Spatial patterns of HEC based on human population density*

Using Thiessen polygons human population density in TTC we analysed to establish the nature of relationship between HEC and human population. Frequency distribution results showed that the highest proportions (42%, mean = 85, *SD* = 145.2) of HEC incidents occurred at population density of 0–18 persons per kilometre square (Fig. 12, Table A1). A moderate proportion of HEC incidents occurred at 19–53.0 (21.6%, *M* = 77.1, *SD* = 86), 53.1–107.0 (18.6%, *M* = 110.7, *SD* = 188.5), and 107.1–239.0 (16%, *M* = 95.1, *SD* = 219.8) human population densities. The lowest proportion (1.7%, *M* = 19.1, *SD* = 17.9) was observed in high population density areas of 239.1–561 persons per km$^2$. This result shows that human population density strongly ($R^2 = 0.89$) explains the variation in HEC, indicating that HEC increased steadily with decrease in population density Fig. 12.

## 4. Discussion

Increasingly, the elephant habitat world-wide is undergoing a transformation that creates challenges for the continued human–elephant co-existence in multifunctional landscapes like TTC. Currently, limited literature exits on the temporal and

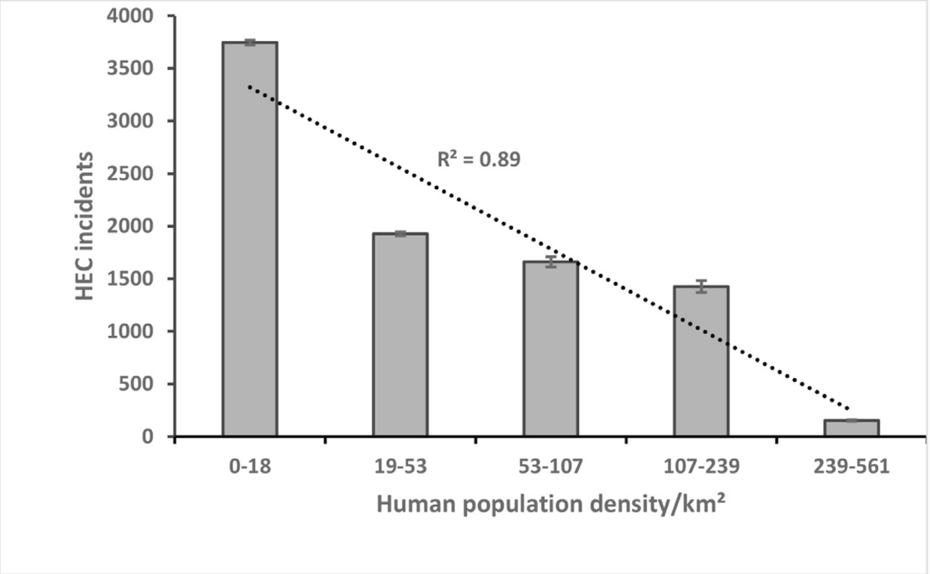

**Fig. 12.** HEC in different human population density categories with standard error of the mean.

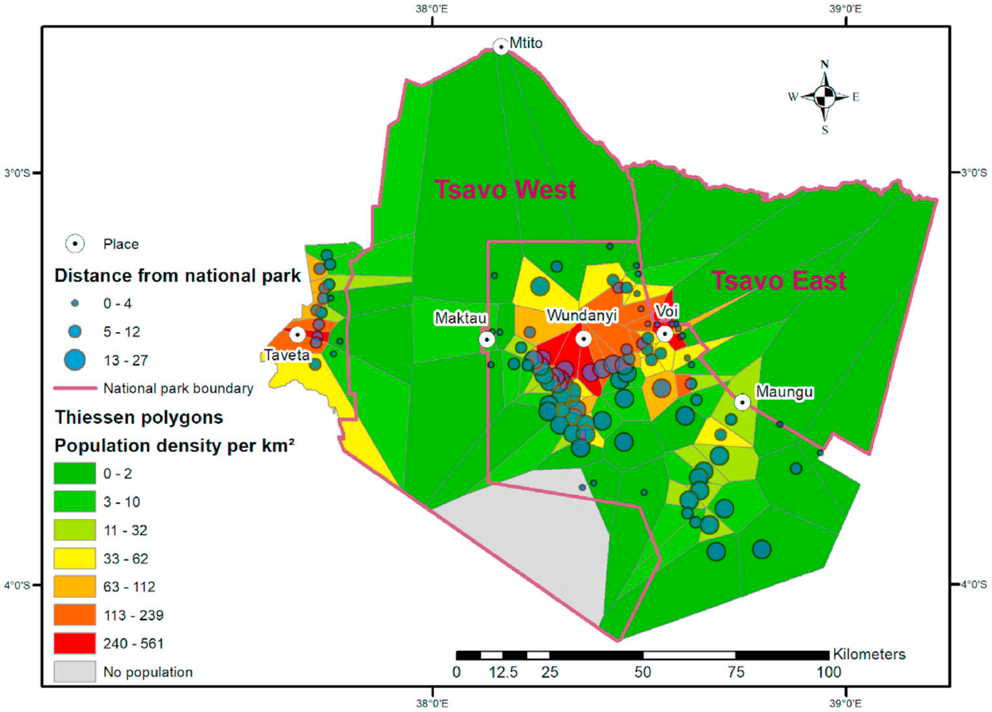

**Fig. 13.** Human population density in TTC based on Thiessen polygons and classification of distance from the national park.

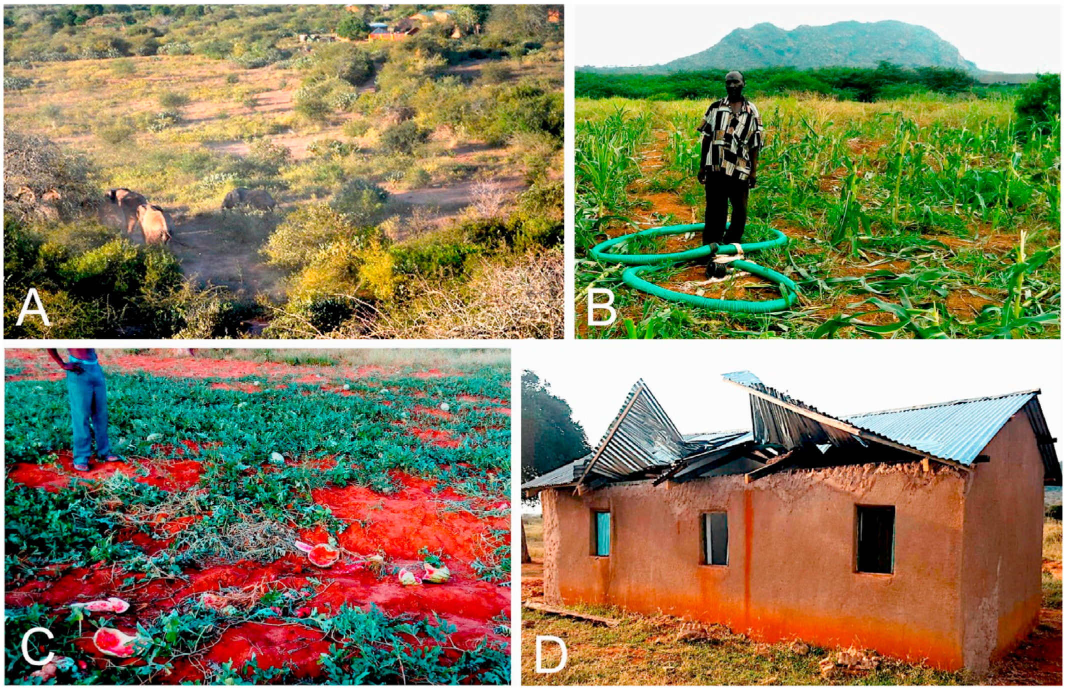

**Fig. 14.** Different forms of HEC in TTC. (A) Herd of elephants next to human settlements. (B) Maize (*Zea mays*) field raided by elephants. (C) Damaged field of watermelons (*Citrullus lanatus*). (D) House damaged by elephants (*Source: KWS*).

spatial trends of HEC in the TTC, as most studies have addressed HEC within the broad HWC context at the Tsavo ecosystem level or within a small zone of the county. In this study, we focused on the entire TTC and established eight forms of HEC; the three most common forms were elephant threat, crop raiding, and property damage. In the 15 years a moderate increase of

HEC was observed, with elephant threat indicating a sharp increase ($R^2 = 0.83$), while crop raiding declined in the same period. Rainfall moderately predicted monthly HEC incidents. HEC incidents were significantly higher during the dry season compared to the wet season. Spatially, the number of HEC incidents did not differ significantly with varying distance from the Tsavo national parks, however, incidents decreased with increasing human population density.

Our findings indicate that while no statistically significant difference existed between the five 3-year periods, 2007–2009, 2013–2015, and 2016–2018 stood out with higher proportions of HEC. The 2007–2009 period contains a severe drought in 2009 which afflicted the county following the failed rains in 2008 (Amara et al., 2020), resulting in the death of 366 elephants in the Tsavo ecosystem (Ngene et al., 2013; Wato et al., 2018). Our findings show a negative relationship between rainfall and HEC (Fig. 6) which agrees with other studies that have shown an increase in HEC when received rainfall is below normal (Mariki et al., 2015). In addition, the periods 2013–2015 and 2016–2018 fall within the construction period of the new railway line (SGR) which created permanent embankments causing substantial hindrance to elephant movements (Okita-Ouma et al., 2017). During the SGR construction elephants wandered into human settlements while finding their new path to national parks. The moderate increase in HEC incidents between 2004 and 2018 is mainly attributed to elephant threat which singly accounted for 62.46% of the reported incidents. This high proportion shows that elephant–human encounters in the landscape are significant despite most of them not having harmful outcomes. The demand to meet human needs of food, shelter, and quality life has led to transformation of areas that previously served as elephant refugium during their local and seasonal migrations. According to Githiru et al. (2017), the planning of multifunctional landscapes is complex and should consider the interlinkages of sustainability factors with indirect aspects like HEC, which if not addressed may become impediments. It is, therefore, important to evaluate HEC at a broad scope by examining human–elephant encounters whose outcome is not necessarily harmful as this can help map future conflict hot spots. Female elephants are highly defensive of their young and will attack if they feel threatened. The same aggressive behaviour is also seen in bull elephants during musth when sensing of being threatened (Fig. A1) may be responded with an attack.

Crop raiding by elephants was the most important form of HEC, with severe direct consequences on the local community. Our results indicate an escalation of crop raiding in January and July just as crops matured after the short and long wet seasons respectively as reported by Smith and Kasiki (2000), Chiyo et al. (2005) and King et al. (2017). Human encroachment and extension of cultivation activities to wildlife dispersal areas are attributed to increased crop raiding and HWC in general (Leta et al., 2016; Shaffer et al., 2019; Snyder et al., 2019). The findings show that the temporal patterns of crop raiding by elephants declined moderately during the study period. This decline in crop raids by elephants may suggest that the current interventions such as electric fences (Mukeka et al., 2018) and beehive fences (King et al., 2017) in parts of the county are effective. We argue this because elephant proof fences in wildlife areas neighbouring regions with high human activity or farmlands have been shown to be effective in minimizing HEC (Kioko et al., 2008; Neupane et al., 2017).

Property damage by elephants in the study area peaked in the dry season in the month of September. Both the African elephant (Sitati et al., 2003; Mukeka et al., 2018; Matseketsa et al., 2019) and the Asian elephant (Choudhury, 2004) have been associated with damaging of property. Although we found only 208 incidents of property damage in this study, this form of HEC is significant as in some cases the monetary investment on the destroyed items may be quite high. According to Long et al. (2020), between 2005 and 2016, 1152 property damage incidents were reported in Kenya of which 47% were water facility-related and 37% were fences. In this study property damage was associated with water facilities (pipes and tanks), fences, and houses among others. Damage to houses by elephants occurred mainly during the dry season, which is the period when farmers have harvested their crops and stored their food inside the houses (Fig. 14D). According to Parker et al. (2007) damage to the harvested produce is far more disruptive to the farmers than crop raiding itself as crops in the field can be replanted but destruction to stored food is irreversible.

Human injury and human death were the other severe forms of HEC identified in the study. These two forms of HEC often lead to negative perception of the importance of conservation by the distressed community. Aggressive actions to conflict-causing elephants is common within their range around the world (Choudhury, 2004; Shaffer et al., 2019), where communities express disapproval of inflicted damages by killing elephants thus resulting to another form of HEC. In addition to retaliatory killings, wildlife authorities also eliminate problematic animals as the last option to secure human lives. Thus, HWC is a threat to the conservation of problem species (Nyhus, 2016; Okello et al., 2016; Hazzah et al., 2017; Mmbaga, 2017; Hazarika and Dutta, 2018; Ontiri et al., 2019), and hence, understanding HEC dynamics is vital to protect people and elephants.

Deaths to livestock by elephants were also observed in the study area. Although large carnivores are the main culprits in livestock depredation (Patterson et al., 2004; Li et al., 2013), our findings are similar to other studies that have reported elephants as causing livestock killings (Mariki et al., 2015). Since elephants are herbivores, livestock killings by elephants in TTC can only be due to resource competition. In the studied landscape large scale livestock rearing is practised in the lowlands where elephants also freely roam. Illegal grazing in the national parks is also common as revealed in a recent survey that showed high livestock numbers in the Tsavo national parks (Ngene et al., 2017), hence the number of livestock killed by elephants could be higher than reported. We recommend specific studies to determine the temporal patterns for the five forms of HEC that accounted for less than 3%.

Overall, the number of HEC sites was conspicuously high in the areas near the four wildlife conservancies. These areas in Mwatate and Voi sub-counties occupy mostly the semi-arid lowlands between the Tsavo East and Tsavo West National Parks. This area consists mainly the Taita ranches and was originally used for livestock grazing. At the time when the ranches were actively managed, livestock and elephants co-existed, but during recent years agricultural expansion and population growth have fragmented the once homogeneous landscape and led to loss of habitat connectivity (Ojwang' et al., 2017), which has increased the potential for human–elephant encounters. Elephant-tracking information (Okita-Ouma et al., 2017) has demonstrated that elephants in the ecosystem move through almost defined migratory routes that continue to be lost to other land uses. In the area between Tsavo East and West national parks only a few areas, such as Rukinga, Ngutuni, THWS, and LUMO, have limited human activity, thus in the other areas elephants may encounter higher human presence during migration. Equally in some parts of TTC like the Taveta area, the availability of water for irrigation has attracted expansion of land under cultivation. According to Mbau (2013b), the land under cultivation in Taveta sub-county increased by 299.4%, while woodlands decreased by 58.2% between 2001 and 2011, thus leading to loss of elephant natural habitat. Similar land use change patterns have occurred around Taita Hills (Pellikka et al., 2018) and especially in Mwatate sub-county. The degradation and loss of elephant habitat is likely to lead to surge in HEC.

We anticipated that HEC would be higher close to the Tsavo national parks, as these constitute the core habitats for elephants in the landscape. On the contrary, the findings revealed that 5.1–10 km from the national park was the most significant distance where all forms of HEC intensified. The results showed that the least HEC incidents were within <1 km distance from the national park border which is contrary to what Sitati et al. (2003) established. Crop raiding by elephants was particularly highest (54%) in 5.1–10 km region. Most croplands and sisal plantations which maybe damaged by elephants are located around the highlands such as the Taita, Sagalla and Kasigau which are at least more than a kilometre from the national park. In the Taveta region a large area adjacent to the park is occupied largely by pastoral communities with most farming activities taking place along Lumi River. We suspect that the low number of HEC incidents close to the park maybe, due the fences that were constructed where land use is incompatible with conservation as earlier discussed, and thus elephant movement to these areas is restricted. Although fences could plausibly explain the observed pattern, still there are questions because the fences in this landscape were constructed at different periods and furthermore, these are partial fences hence elephants can circumvent the fences and cause HEC. Another explanation could be that the people living near wildlife areas are more cautious of potential attacks and thus they try to keep elephants away from their farms as stated in Kagwa (2011) and Musyoki (2014). Furthermore, we acknowledge limitations in the method that we used to generate the spatial points and thus we propose actual georeferencing of conflict sites and HEC incident records in order to sufficiently have best assessment for management application. In addition, we recommend further research to focus on the effectiveness of the fences in minimizing the HEC. Since HEC was exceptionally pronounced in locations more than 10 km from the core conservation areas, this highlights the significance of incorporating a broad perspective and stakeholder engagement during development of spatial plans in the county.

Our findings indicate a strong ($R^2 = 0.89$) negative relationship between human population density and HEC. The results of this study showed that the highest proportion of HEC incidents occurred in areas of low human population density. In the TTC landscape the areas with high population density are the urban centres such as Voi, Taveta, Mwatate, and the Taita Hills. In Voi area the 45 km long Ndii-Ndara fence was constructed in 1995 along the Tsavo East national park boundary to minimize HEC (Kenya Wildlife Service, 2008) in the densely populated area. Taita Hills in Wundanyi sub-county is densely populated due to the agricultural productivity, however conflict is low as it is buffered by Mwatate which has relatively high population density also. Furthermore, the highlands in TTC have high elevation and elephants are rarely found in such heights (Evans et al., 2018). It is, however, unclear why HEC is very high in areas with the lowest human population density where the expected human–elephant encounters theoretically would be low. These results may suggest growth of settlements in the lowlands which previously had few human structures (County Government of Taita Taveta, 2018). Furthermore, in the mining areas of Mkuki, Kasigau, Buguta, Alia, Kamtonga, Mwatate, and Kishushe, a large number of people reside with no permanent shelter (Anyona and Rop, 2015), hence the possibility of encountering elephants is high which explain the reason for elevated HEC in areas of low population density.

## 5. Conclusion

Detailed information on HEC at local scales are inconclusive to support mitigation strategies in most key sites. Our findings demonstrate the common forms and extent of HEC in the TTC landscape within the Tsavo ecosystem, a key elephant stronghold in Kenya. The results show moderate increase in HEC incidents in TTC despite the mitigation measures put in place. Rainfall appears to have great influence on the trends of HEC. Elephant threat and crop damage were the two most important forms of HEC in TTC. Proximity to the Tsavo national parks was not associated with increased HEC. On the other hand, human population density was negatively related with HEC. The high spatial distribution of HEC in Mwatate and Voi sub-counties, clearly shows the importance of maintaining connectivity or elephant migratory routes between Tsavo East and Tsavo West National Parks. These results show that elephant conservation in the two protected areas cannot be considered in isolation, without taking into account the human activities occurring in the larger landscape. Further, these findings highlight the urgency for rethinking the management of HEC in the County, as human activity is expected to increase and recent elephant population trends in the ecosystem indicate soaring numbers. Additionally, this study reveals the classic utility of long-term data collection in conservation, but also identifies a priority need to modernize and strengthen HEC data collection protocols to make them more valuable in addressing conservation challenges. For instance, if each incident in the 15 years dataset employed in this study had been georeferenced and was accompanied with complete metadata, the analysis would have been more dynamic. Although there were limitations in the extent of spatial analysis as incidents were fitted to only 107 sites and spatial data for human population in TTC was not available and had to be computed and approximated with Thiessen polygons, these findings present the first detailed spatial HEC outlook in TTC. Also, the findings set a useful baseline for future land use planning in the county and as well identify HEC hotspots that wildlife authorities can focus to promote elephant conservation initiatives in the landscape.

## CRediT authorship contribution statement

**Martha Munyao:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Mika Siljander:** Conceptualization, Methodology, Formal analysis, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Tino Johansson:** Writing - review & editing, Supervision, Funding acquisition. **Godfrey Makokha:** Methodology, Visualization, Writing - review & editing, Supervision. **Petri Pellikka:** Writing - review & editing, Project administration, Funding acquisition.

## 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.

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## Appendix A

**Fig. A1.** Elephant threatening to charge in Tsavo West National Park (*Source*: Petri Pellikka).

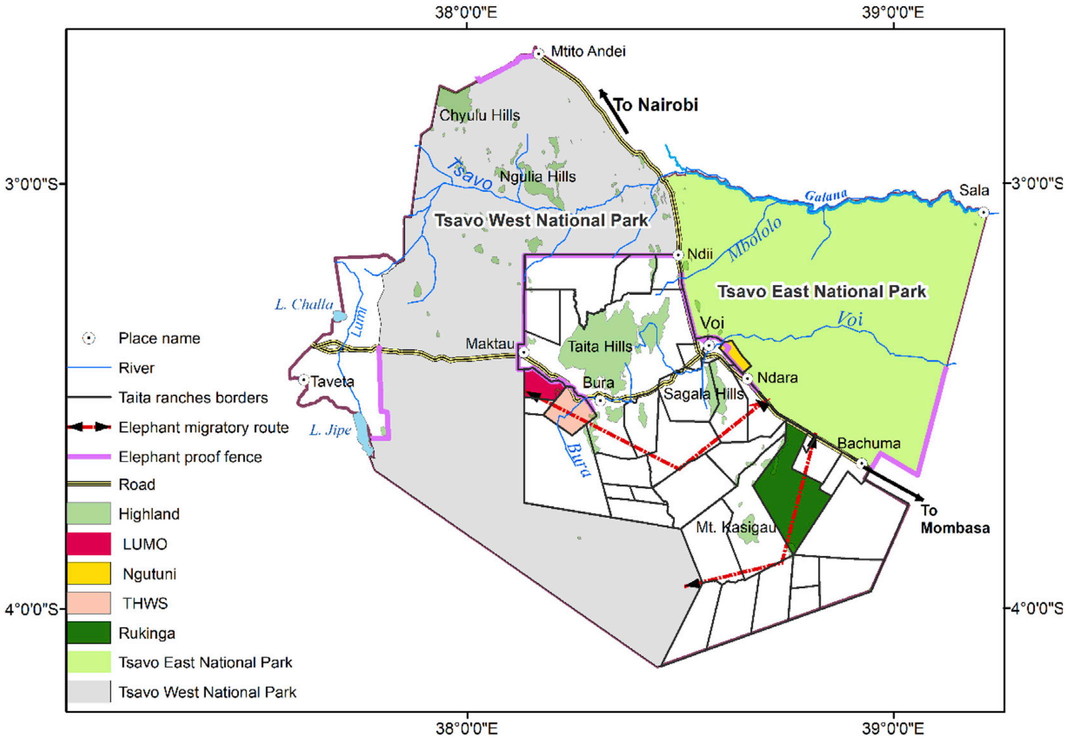

**Fig. A2.** Conservation areas in Taita Taveta County.

**Table A1**
Proportions of HEC by type among the stratified human population density groups.

| | Proportion of HEC incidents per population class | | | | | |
|---|---|---|---|---|---|---|
| Conflict description | 0–18 | 19–53 | 53.1–107.0 | 107.1–239.0 | 239.1–561 | HEC incident (N) |
| Elephant threat | 45.8 | 23.0 | 14.4 | 15.3 | 1.4 | 5567 |
| Crop raiding | 32.4 | 18.8 | 28.3 | 18.1 | 2.4 | 2893 |
| Property damage | 55.8 | 19.7 | 10.6 | 12.5 | 1.4 | 208 |
| Human injury | 52.7 | 10.8 | 24.3 | 1.4 | 10.8 | 74 |
| Human death | 57.1 | 24.3 | 5.7 | 11.4 | 1.4 | 70 |
| Elephant death | 66.7 | 23.5 | 3.9 | 5.9 | 0.0 | 51 |
| Elephant injury | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3 |
| Livestock death | 48.9 | 25.5 | 6.4 | 19.1 | 0.0 | 47 |
| HEC overall | 42.0 | 21.6 | 18.6 | 16.0 | 1.7 | 8913 |

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