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IMPACTS OF LANDSCAPE FRAGMENTATION ON HUMAN-ELEPHANT INTERACTION IN THE CHOBE ENCLAVE

by

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Abstract

Change in land use and land cover (LULC) is an area of interest in landscape ecology due to its adverse environmental impacts on wildlife habitats. At local, regional, and global scales, the fragmentation and obstruction of wildlife corridors has considerably increased over time as a result of factors connected to land use and climate variables. These environmental changes are a threat to wildlife and biodiversity conservation, particularly in places where large iconic mammals are supposed to roam freely. This study was carried out in North-Western Botswana, in the Chobe enclave, a communally managed area. The enclave is surrounded in the west by the Chobe National Park, the Namibian border (Cuando-Linyanti River) to the north and east and the Chobe Forest Reserve in the south. Seasonal flooding of the Cuando-Linyanti River system creates regular transitions between mesic and the local semi-arid climate, making this floodplain a haven for wildlife including the big games. Botswana has the highest freely roaming African savannah elephants' population in Africa, estimated at 126 000 in 2018 and largest concentrations are found in the northern part of the country.

There is dearth of knowledge about the impacts of landscape fragmentation on human elephant interactions in Botswana Particularly in Chobe enclave. Chobe enclave is experiencing increasing human population and large concentrations of freely roaming elephants. This have created competition between humans and elephants for space and other resources. It is vital to comprehend how landscape fragmentation and processes influences elephant's movements and ultimately human-elephants conflict especially in ecologically valued areas such as the Chobe enclave. With knowledge on how LULC dynamics, fragmentation and elephant movements and

distribution influences one another, possible and informed measures can be proposed to abate adverse human elephant interaction.

The aim of the study was to characterize and quantify LULC change using Landsat time series and to assess the influence of landscape fragmentation on human-elephant interaction (HEI) in the Chobe enclave over a period of 20 years from 2000 until 2020 using landscape metrics and field evidence information. Multi-temporal satellite imageries for all the study periods were ordered and downloaded from the USGS webpage at Landsat scene 174/072 and 174/073. Landsat imageries were radiometrically and geometrically corrected for best classification results. A classification scheme consisting of five LULC classes was established. The maximum likelihood classifier was employed for supervised classification. Classified maps accuracy was measured and change detection were performed on classified maps. In accordance with the purpose of this study, five (5) indices were selected for spatial characterization of the study area at class and landscape level. Selection of which landscape metrics to use was based on their ability to act as indicators of landscape change and also on their ability to quantify and assess landscape fragmentation. Selected indices, class area (CA), number of patches (NP), largest patch density (LPI), landscape splitting index (LSI) and aggregation (AI) were computed in a software called FRASTATS. Semi-structured interviews were administered to a total of 57 purposely selected key informants to seek knowledge and validation on LULC and HEI. High resolution images in Google Earth Pro together with indigenous knowledge were used to identify and delineate elephant migratory routes in the study area. Human elephant conflict hotspots (HECH) for the study period 2000, 2020 and indigenous knowledge were derived from the kernel density estimation.

Abstract

Results from LULC analysis shows that in 2000 the study area was dominated by Shrubland, 70 383 ha (45.2%) while in 2010 and 2020 LULC dominance shifted to grassland, 44 270 ha (29.5%) and 56 935 ha (31.2%) respectively. Change in the share of land in the study area is attributed to land use intensification, wild fires, over browsing and vegetation destruction by elephants and droughts. Landscape fragmentation within elephant habitats and migratory corridors is a result of land use encroachment thus creating land use conflicts scenarios between local communities and elephants. Landscape metrics reveals that the study period 2020 has the most fragmented landscapes with high cases of HEC. The fragmented landscape is characterized by subdivisions or landscape patches, low aggregation index and high landscape splitting index. Human elephant conflict hotspots positively correlate with landscape fragmentation. Socio economic impacts associated with HEIs in the study area includes negative attitude towards elephants by the enclave residents, indirect financial loss due to elephant crop raiding and property destruction. The study proposes that wildlife migratory routes in the Chobe enclave be marked and incorporated in land use plans and zones to avoid further habitat fragmentation and expansion of land use into them. This could enhance peaceful coexistence between people and elephants as conflicts would be minimized.

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Chapter 1 Introduction and Rationale

Drylands cover about a third of the world's land surface and host nearly one third of its human population (Dong et al., 2016). They are water limited, non-equilibrium systems, characterized by high temporal and spatial variability and low levels of human development (Nyberg et al., 2015). Across Southern Africa, an estimated 150 million rural and urban residents support their livelihoods through extracting natural resources from semi-arid savannahs, including firewood, food, fresh water, traditional medicine, thatching grass, reeds, poles, and other materials for building and crafts (Esterhuizen, 2015). Important land uses that support dry land livelihoods include pastoralism, agriculture, tourism (often relating to wildlife) and mining. Scarcity of surface water and high rainfall variability make these systems particularly vulnerable to land degradation resulting in the potential loss and fragmentation of ecosystem services, with rural and impoverished communities being disproportionately impacted (Galvin et al., 2008). Elsewhere in drylands, conflicts pitting agro-pastoralists, rural communities and conservation authorities have been on the rise (Turner et al., 2022). Persistent human-wildlife conflicts experienced around conservation areas is at the center of political-economic dynamics, where resource inequalities and contesting desires for land use have resulted in a complex group of wildlife-tolerant and wildlife intolerant factions of stakeholders (Kieti et al., 2020). As it stands, current policies related to grasslands do not provide incentives for wildlife and biodiversity conservation. Thus, reduced mobility resulting from prevailing land use policies is contributing to lower species diversity. There has been a growing appreciation of wildlife conservation as a social and political process with special emphasis on the need to incorporate local communities in sustainable use of natural resources (Kieti et al., 2020). Wildlife tourism is portrayed as a means for rural communities in sub-Saharan Africa to diversify, generate revenues and improve wellbeing (Esterhuizen, 2015). In principle, these competing forces are meant to be integrated at local level through community-based natural resource management (CBNRM), allowing communities and households to develop socially, economically and environmentally sustainable compromises. CBNRM further seeks to give natural resources a meaningful use-value to rural communities who bear the cost of human-wildlife conflicts and habitat conservation (Kieti et al., 2020).

In this study, we define landscape fragmentation as a landscape-scale process involving both habitat loss and the breaking apart of habitat and wildlife migratory corridors. Habitat loss or conversion is a direct change in the composition and configuration of the elements of a landscape, which changes a suitable habitat so that it is entirely unsuitable for the original user, although it may be quite suited to new users. Habitat fragmentation and loss are caused by several underlying factors: demographic, economic, institutional, technological, policy, climatic and biological factors (Wilson et al., 2016). In sub-Saharan Africa, change in property rights is a particularly important cause of habitat fragmentation (Joireman, 2008). Fragmentation can be caused bio-physically by a change in the availability of forage or water, due to seasonal variations. Savannah fires, when caused by lightning strikes, are a bio-physically derived cause of the modification and fragmentation of forage resources. However, most of the causes of wildlife habitat loss and fragmentation fall into the social realm, because humans dominate the forces of land change in range lands (Joireman, 2008).

The delineation and protection of wildlife migratory corridors are increasingly seen as critical to maintain wildlife mobility in wildlife dominated areas to allow wildlife passage in areas of increasing crop pressure (Walker & Craighead, 1997). Greater understanding in this area is required to allow better-informed design and implementation of human-wildlife conflict resolution and biodiversity conservation initiatives.

1.1 Problem Statement

Every living organism depends on the natural environment to survive, thus any changes to the ecosystem brought on by natural disasters or anthropogenic activities (Khan et al., 2016; Reis, 2008) have an impact on animals, plants, and other species (Dipesh et al., 2014). Land use-land cover changes such as transformation to agricultural and urbanization causes destruction and fragmentation of wildlife habitat (Dipesh et al., 2014) and obstruction of wildlife movement corridors (Okello et al., 2011). Human population increase is one of the major drivers of land use land cover change (Akinyemi, 2017). Some biological living organisms are at stake as their source of habitat and food are destroyed. In the process of habitat destruction, some animals migrate, and some plant species go extinct (Mas et al., 2004; Sala et al., 2000). Reduction in the availability of natural habitats and obstruction of wildlife migratory corridors has led to wild animals seeking alternate sources hence elephant crop raiding and livestock predation (BOPA, 2019; Gupta, 2011). The impacts brought by land use-land cover changes such as elephant habitat destruction are associated with human-elephant conflicts (Hoare & Du Toit, 1999; Naughton-Treves, 1998). Human-elephant conflict is common in places where people live in proximity to protected areas, because in these areas' human-elephant interaction is common (Mbaiwa, 2005). This is the case in the Chobe Enclave, Botswana (Gupta, 2011).

Botswana is a landlocked country with a semi-arid climate and a relatively small human population of approximately 2 346 179 million (Statistics Botswana, 2022). Despite the small size of the population, the country competes with a high concentration of elephant population for space, food, and limited water resources (Adams, 2020). This problem is more pronounced in the northern part of the country including the Chobe enclave. Botswana has the highest freely roaming African savannah elephant population in the world, which has increased from 120, 000 in 1995 to 230, 176 in 2012 and largest concentrations are found in the northern part of the country (World Bank, 2016). Due to increasing human population and large concentrations of elephants within the small area of the Chobe enclave (Table 2), humans find themselves in competition with elephants for space and other resources.

Table 1.1: Chobe enclave demographics

Human population		Elephants' population	Study area
2001 (3632 Pop.)	**2022** (4446 Pop.)	8800	1577.4 km^2

Source: Human population (Statistics Botswana, 2022); Elephants' population (Adams, 2020); Study area (Fox et al., 2017)

Chobe enclave is situated between the continuous river system and the unfenced Chobe national park, which is a home to about 70 000 freely roaming elephants, thus facilitating the movement of elephants into surrounding areas (Adams, 2020). Although the Chobe enclave is labeled as a hub for human elephant conflicts (Adams, 2020), most of its land users sustain people's livelihoods through arable agricultural practices and pastoralism. Subsistence agriculture is practiced along the floodplains of the Cuando-Linyanti River leaving the landscape fragmented and elephant migratory routes obstructed (Bearak, 2019; Naughton-Treves, 1998). From time-to-time elephants pass through fragmented landscapes while enroute from the Chobe national park towards the Cuando-Linyanti River to access the river and fertile grasses of the floodplain (Blanc et al., 2007; Chase, 2012) thus creating a land use conflict (Gupta, 2011; van Aarde & Jackson, 2007). The land use conflict has brought a lot of damage to farmers such as crop-raiding, property destruction, injuries, and intimidation to people and sometimes death (Lee & Graham, 2006; van Aarde & Jackson, 2007). The impacts threaten land user's food security and make them more vulnerable (BOPA, 2019; Mbaiwa, 2005). Some farmers have abandoned growing crops on their larger arable land in fear of elephant crop raiding (BOPA, 2019; Gupta, 2011).

Much is known about land use-land cover change (Akinyemi, 2017; Dwivedi et al 2005; Fox et al 2017 and Liping et al 2018), landscape fragmentation (Muhammed & Elias, 2021), human elephant interaction (Hariohay et al., 2020; Muboko et al., 2016; Parker et al., 2007; Zarestky & Ruyle, 2016) as independent variables. Some studies have investigated the impacts of land use-land cover change on human elephant interaction (Billah et al., 2021; Kusena, 2009) without incorporating the aspect of landscape fragmentation. Both studies have revealed that a land parcel consisting of agricultural land, human settlement and human-elephant shared water sources are human elephant conflict prone areas. Studies that has been carried in the study area in the context of human elephant interaction assessed the movement of elephants in human dominated area (Adams et al., 2020) and human wildlife conflict (Adams, 2020). Fox et al (2017) investigated causes of land use and land cover in the Chobe region. According to Nyaligu & Weeks (2019) to adequately analyze the ecological impacts of landscape change on human elephant interaction, landscape fragmentation ought to be assessed. There is dearth of knowledge about the impacts of landscape fragmentation on HEI in Chobe enclave, hence the need to fill that gap. This research applies landscape metrics in the context of landscape ecology to characterize and quantify landscape fragmentation and identification of human elephant conflict hotspots. Contemporary researchers in the field recommend others to study the mitigation of human elephant interactions as elephants are becoming habituated to the traditional mitigation techniques (Adams, 2020). This includes the understanding of human-wildlife conflict and its drivers (Dipesh et al., 2014). Adams (2020) further indicated that implantation of some traditional mitigation techniques such as use of guard dogs and bee fences does not work in the Chobe enclave hence an urge for new research.

1.1.1 Research Aim

To characterize and quantify land use and land cover change using satellite imagery and landscape metrics, and assess the influence of landscape fragmentation on human-elephant interaction in the Chobe Enclave over a period of 20 years from 2000 to 2020.

Table 1.2: Specific objectives in accordance with research questions

Specific Objectives	Research Questions
1. To assess and quantify land use-land cover change and landscape fragmentation in the Chobe Enclave using Landsat time series and Landscape metrics.	▪ How is the status of the landscape in Chobe enclave between 2000 and 2020? ▪ What are the driving factors of land use-land cover change and fragmentation in Chobe enclave?
2. To analyse the extent to which land use and landscape fragmentation influences human elephant interaction in the Chobe enclave.	▪ How does land use-land cover change and landscape fragmentation influence human-elephant interaction? ▪ Where are human elephant conflict hotspots located in the study area?

3. To investigate the socio-economic impacts associated with human elephant interaction in the Chobe enclave.	▪ What are the impacts associated with land use conflict between humans and elephants in Chobe enclave?

1.2 Significance of the Study

This study offers a different approach on assessment of human-elephant interaction in the context of landscape ecology to provide us with a clear and concise idea on how landscape fragmentation influences the location of human elephant conflict hotspots zones for better planning and land use conflict resolution. The motivation of assessing land use-land cover change and fragmentation is to better understand landscape composition, configuration, and processes (Lambin et al., 2003). It is also vital to comprehend how landscape fragmentation and processes influences elephant's movements and ultimately human-elephants conflict especially in ecologically valued areas (Jaafari et al., 2016) such as the Chobe enclave. With knowledge on how LULC dynamics, fragmentation and elephant movements and distribution influences one another, possible and informed measures can be proposed to abate adverse human elephant interaction (Singh et al., 2017).

To tackle challenges such as human-elephant conflict, climate change, food security and health in dry land such as Botswana, landscape fragmentation and its consequences such as habitat loss ought to be adequately addressed. This study intends to map and analyse landscape fragmentation in the Chobe Enclave. Such information is essential in efficient land use planning, mitigation, and development of adaptation measures to minimise human-elephant conflict. The information can be very useful to governmental organisations (mostly the Department of Wildlife and National Parks, Land authority, Department of Forestry and Chobe District Council), Kasane community, various NGOs intending to build and maintain coexistence between elephants and humans. The data is also vital in conservation of natural resources and land use planning. The information can also be used for monitoring purposes, making informed decisions, and coming up with ways to abate human-elephant conflict in the Chobe Enclave.

1.3 Land use Change and Human Wildlife Conflict: Driving Factors and Regulatory Frameworks

Land use involves the management and alteration of the natural environment into agricultural lands, and managed game reserves among others. Land use as a major factor through which humans alter the natural environment (Dipesh et al., 2014), differs from one place to another and it changes with period due to climate variability. Land use-land cover (LULC) change is an issue of great significance (Liu & Yang, 2015; Singh et al., 2017), due to its adverse impacts on ecosystem processes, biodiversity and natural resources at local and regional scales (Basommi et al., 2016; Jaafari et al., 2016). The terms land use and land cover are used interchangeably (Rawat & Kumar, 2015) though they are not of the same meaning (Dipesh et al., 2014). Land use refers to how land is used by humans (FAO, 2001). In contrast, land cover is defined as the biological and physical structures covering the land surface (Liping et al., 2018) such as vegetation, waterbody and soils among others (Matsushita et al., 2006).

The inventory and mapping of LULC are fundamental for sustainable land management and spatial planning. The main goal of mapping LULC is to essential understand the arrangement and distribution of landscapes (Lambin et al., 2003). LULC patterns have a greater influence on ecosystem functioning (Bain & Brush, 2004). It is better to accurately assess both the spatial and temporal characteristics of LULC to thoroughly understand the heterogeneity of the landscape, interaction of spatial patterns and their influence on ecological processes (Jianguo Wu et al., 2000). It is also imperative to study LULCC as it helps humans in anticipating and understanding some environmental problems such as habitat loss and landscape fragmentation. Remote sensing in conjunction with geographical information systems (GIS) are used to map and assess LULC change (Akinyemi, 2013; Reis, 2008). Other methods that can be used to analyse LULC change include landscape metrics (McGarigal & Marks, 1995; Mugiraneza et al., 2017).

1.3.1 Causes of Land Use-Land Cover Change

Land use-land cover change is brought about by anthropogenic activities (Briassoulis, 2000) such as evolution of road networks, agricultural intensification, increasing socio-economic necessities, land use planning (Reis, 2008) and natural factors such as population growth (Khan et al., 2016; Seto et al., 2002). Nonetheless LULCC is primarily determined by certain environmental factors such as soil type, and topography (Fasona & Omojola, 2005).

1.3.1.1 Anthropogenic Activities

According to Jaafari et al (2016) increasing population and economic development have rapidly modified the look and spatial location and extent of land parameters globally. Rapid population increase exerts pressure on land resources hence increasing the demand for food, construction material for shelter, wood and other necessities (Akinyemi & Mashame, 2018; Wubie et al., 2016). The increasing demand for food has resulted in expansion of agricultural lands, impervious surfaces and built-up areas to an extent of encroaching into natural forests, savannahs and wetlands (Akinyemi, 2013; Mengistu & Salami, 2007). This pressure has led to unplanned and unmanaged changes in the land use-land cover (Seto et al., 2002) alongside with consequences of deforestation and soil degradation.

Expansion of cropland and livestock production are some of the main drivers of land use-land cover change (Jaafari et al., 2016; Wubie et al., 2016). Forests and other vegetation cover are deforested and degraded in preparation for crop production and pastoral farming. About 129 million hectares (ha) of forests have been lost worldwide due to expansion in agricultural land (FAO & UNEP, 2020). Wubie et al., (2016) conducted a study to investigate the patterns, causes and consequences of land use/cover dynamics in the Gumara watershed of Lake Tana basin, North-western Ethiopia and the study revealed that human settlement and arable land increased by 22% within the Gumara watershed over a period of 48 years from 1957 until 2005. The study indicated that the reason for the increase in arable land was due to high demand for food therefore the government then introduced rice plantations hence the conversion of wetlands into farmlands.

It is vital to survey the socio-economic situation to identify the driving factors of land use land cover change of an area (Mengistu & Salami, 2007). A negatively affected economic system of a certain country/region puts the agricultural sector under pressure (Rufino et al., 2013). Moreover Satterthwaite (2009), Simon & Leck (2010) have labelled urbanization as a vital socio-economic need. Most cities worldwide are facing the impacts of urbanization on the local environment (Creutzig et al., 2015). Impacts posed by urbanization range from disturbance of the soil structure to loss of local tree species (Liu & Yang, 2015). Proper management of urbanization can result in economic development and poverty reduction.

1.3.1.2 Natural Factors

1.3.1.2.1 Climate

Apart from the noted anthropogenic activities, climate change also has a significant impact on land use-land cover change (Elias et al., 2015; Fasona & Omojola, 2005; Utuk & Daniel, 2015). According to Fasona & Omojola (2005) rainfall that was received in Nigeria around the 1980s was the least compared to the one received around the 1950s. The report further stated that as a result of climate change in Nigeria, changes in land use-land cover around 1976 and 1995 were witnessed to have experienced losses of prime arable land. On the other hand, new virgin lands were opened for growing crops towards the south of Nigeria. According to Akinyemi and Mashame (2018) dryland environments are prone to drought, land degradation, soil erosion and fertility loss due to climate variability. Land degradation is labeled as one of the causes of land cover change and habitat fragmentation (Jaafari et al., 2016). In this regard, land cover change in dryland environments has become a notable phenomenon as it challenges biodiversity (Reynolds et al., 2007).

1.4 Landscape Fragmentation

Human land use encroachment into wildlife habitats and migratory corridors is the main reason why ecosystems are getting deteriorated (Fahrig, 2002; Jianguo Wu, 2013). Biodiversity around the world is also declining due to landscape fragmentation (Haddad et al., 2015). Habitat loss and fragmentation are anthropogenic and naturally induced decline, loss and subdivision of vegetation patches into smaller ones. The above-mentioned ecological processes alter the composition and configuration of landscapes (Flowers & Huang, 2020). The expansion of land use is the primary factor influencing these effects (Jackson & Hobbs, 2009). It is important to test the landscape structure hypothesis to determine how habitat loss and fragmentation affect biota (McGarigal & Marks, 1995). Claims of the landscape structure hypothesis are that, a key element affecting species diversity and abundance is the organization of the entire landscape, not simply isolated patches (Ohmann, 1974).

Numerous studies have assessed habitat loss and landscape fragmentation at patch, class, landscape levels (Fischer & Lindenmayer, 2007; McAlpine & Eyre, 2002; Muhammed & Elias, 2021; Wilson et al., 2016). Landscape fragmentation is investigated for various reasons, which include, provisions of long-term effects of landscape fragmentation on ecological changes (Haddad et al., 2015). Also to understand the dynamics of landscape fragmentation, for formulation of well-informed biodiversity conservation policies (Flowers & Huang, 2020), and to provide a holistic view of the ecology of modified landscapes (Lindenmayer & Fischer, 2011). For this study, landscape fragmentation is assessed to understand its impacts on human elephant interaction in a semi-arid environment. In accordance with principles of landscape ecology, it is imperative to comprehend the heterogeneity of the landscape, driving factors, their interaction with the biota and lastly propose management plans if there are adverse environmental impacts (Wu, 2008).

1.5 Human-Wildlife Interaction

The interaction between humans and wildlife is common in places where human settlements are within and/or near protected areas such as National parks (Chomba, 2012; Mbaiwa, 2005). Humans-wildlife interaction can be negative or positive (Nyhus, 2016). The adverse impacts brought by the interaction between humans and wildlife are termed the human wildlife conflict (HWC). HWC conflict is defined as a threat resulting from a direct competition of natural resources between wild animals and rural communities and this sometimes entails loss of life and injuries on human beings, wild and domesticated animals (Woodroffe et al., 2005; World Conservation Union, 2003). The conflict between humans and wildlife is a universal matter affecting almost all nations and varies with the change in geography, human behaviour, land use patterns and wildlife habitat (Chomba, 2012). Human wildlife conflict is intense in developing countries practicing farming near protected areas (Dipesh et al., 2014). Human-wildlife conflict has recently become one of the fundamental aspects of wildlife conservation as it poses threats to biodiversity and wildlife species (Woodroffe et al., 2005), human populations (Dipesh et al., 2014), human and wildlife life (Conover, 2001) and the economy (Treves & Karanth, 2003).

In Botswana, human wildlife conflict is concentrated in the northern part of the country, especially in the Chobe District and North-West district (Darkoh & Mbaiwa, 2009). The intensity of the problem is increasing because of a number of factors such as increase in human populations, expansion of human settlement into wildlife habitats (Estes et al., 2012; Nyhus & Tilson, 2004). Research undertaken in Botswana in the context of human-wildlife conflict includes understanding human-large carnivore conflict (Mahupeleng, 2008), northern Botswana human wildlife coexistence project (DWNP, 2016), study of livelihoods and people-park relations around the Chobe National Park (Gupta, 2011) and human-wildlife conflict in the Okavango Delta (Mbaiwa, 2018). Different researchers have various findings and views about causes of HWC. Conflicts arise when the movement and activities of humans cross with those of wildlife (Treves, 2008). Human to human conflict over wildlife conservation, land use and resource consumption has influenced escalating human-wildlife conflict (Peterson et al., 2010; Redpath et al., 2002; Woodroffe et al., 2005). If there is a growing population and shared resources between humans and wildlife HWC cannot be avoided and will continue to occur in the present (Lamarque et al., 2009). Impacts on human-wildlife conflict can be direct and indirect (Nyhus, 2016). The impacts of HWC range from crop-raiding, disease transmission, destruction of property, loss of wildlife species, injuries and intimidation to people and sometimes death (Adams, 2020; Lee & Graham, 2006; van Aarde & Jackson, 2007). When assessing human-wildlife conflict of any type, it is vital to note the species involved and the level of damage caused (Chomba, 2012). Animals mostly involved in human-wildlife conflict include elephants, lions, buffalo, hippopotamus, and baboons (Chomba, 2012). Table 1.0 illustrates the statistics of human wildlife conflict in Botswana over a five-year period between 2015 and 2019. The statistics reveal that elephants are the most troublesome animals within the landscape of Botswana, as they experienced more HWC encounters compared to other animal species. Human elephant conflict increased from 2, 295 in 2015 to 3, 440 in 2019 and it is expected to continue increasing (Government of Botswana, 2022).

Table 1.0: Human wildlife conflict in Botswana between 2015 and 2019

Species	**2015**	**2016**	**2017**	**2018**	**2019**	**TOTAL**
Elephant	2 295	2 165	3 427	3 842	3 440	11 729
Lion	1 248	1 199	2 022	1 814	2 231	8 514
Leopard	1 381	1038	1 104	1 066	1 123	5 712
Wild dog	949	733	987	1 014	910	4 593
Hyena	240	192	185	158	140	915
Cheetah	89	70	111	75	96	441
TOTAL	6 202	5 397	7 836	7 969	7 940	**35 344**

Source: DWNP, 2020

1.5.1 Human Elephant Interaction

Human-elephant contact in areas adjacent to protected areas has increased due to alterations of the natural environment through conversion of woodland and savanna into arable land, urban land and livestock grazing (Nelson et al., 2003), hence the human-elephant conflict. Human-elephant conflict arises when humans pose threats to elephants and vice versa. Elephants in Africa particularly, African savannah elephants (*Laxodonta africana africana)* have not coexisted peacefully with humans through history (Nicole, 2019). The conflict between humans and elephants could be long term if humans and elephants share the same landscape and this could be worse when human settlement encroaches into elephant's habitat (Warner, 2008).

Most elephants in Africa live in southern Africa particularly in Botswana (DGEC, 2003). Botswana's elephant population has increased from 120 000 in 1995 to 230 176 in 2012 (DWNP, 2013) and it is ranked the world's leading elephant population (World Bank, 2016). Most elephants in Botswana live outside protected areas (World Bank, 2016) thus facilitating the movement of elephants into surrounding areas. Elephants compete with humans for food, land and water therefore whenever they coincide conflict arises (Hoare, 2015). Conflicts between elephants and humans have been extensively documented worldwide (Kusena, 2009; Lee & Graham, 2006; Nicole, 2019; Warner, 2008) including studies in Botswana (DWNP, 2013; Gupta, 2011; Jackson et al., 2008; Zarestky & Ruyle, 2016). The impacts of land use conflict between humans and elephants ranges between crop raiding, property destruction, injuries and sometimes loss of life (Muruthi, 2005). Elephants do most harm to subsistence farming and they are identified as the biggest threat to farmers in southern Africa (Parker et al., 2007).

Elephant crop raiding is much frequent towards the end of the rainy season especially at night (Graham et al., 2009; Jackson et al., 2008) even in Botswana (Adams, 2020). Elephants have been shown to raid farmers' crops for various reasons. Human settlements have obstructed traditional migratory routes of elephants (Kangwana, 1995) thereby, leading elephants to pass through by force hence fence and other property destruction, crop raiding (Naughton-Treves, 1999). Osborn (2004) has identified elephant's nutritional stress as the driving factor of crop raiding. Crop raiding is much likely to be undertaken by male elephants (Chiyo & Cochrane, 2005). The human-elephant interface, as it has shown to increase, has left small scale arable farmers with severe adverse impacts such as crop raiding hence some of the farmers have abandoned farming and others have left to urban areas (Adams, 2020; Warner, 2008). Small scale arable farming receives severe damage from elephants as compared to large scale arable farming, this is attributed to the "edge effect" as elephants are much likely to raid crops along the edge rather than deep into the heart of the cultivated crops (Warner, 2008). The contemporary socioeconomic conditions and damages brought by elephants have influenced humans to reduce tolerance to elephant's presence (Naughton-Treves, 1999).

1.6 Impacts of LULCC and Fragmentation on Human-Elephant Interaction

Land use-land cover dynamics and fragmentation have altered several environmental aspects and gave birth to many environmental problems such as land degradation (Utuk & Daniel, 2015), biodiversity loss (Sala et al., 2000), and desertification due to deforestation, and blockage of wildlife corridors (Debonnet & Nindi, 2017). Land degradation is among the major environmental crises the world is facing now, especially in semi-arid regions (Mashame & Akinyemi, 2016). Olagunju (2015) has indicated that poor land use practices such as deforestation, overgrazing and livestock overstocking accelerates land degradation in semi-arid regions. About 16-40% of the global agricultural land is already degraded (Chappell & LaValle, 2011). Continuous degradation of forest and mining of natural resources leads to disappearance of forest, wildlife habitat fragmentation, extinction of some plant and animal species, migration of animals and induce some earth processes such as erosion (Dwivedi et al., 2005; Zhao et al., 2004). The forest and vegetation cover protects the environment and provides food and shelter, thereby diversifying the ecosystem (UNEP, 2008).

In areas where human-elephant interaction is common, increase in land use within buffer zones has brought humans near to elephant habitat and movement corridors and has resulted in significant decline in elephant population and limited landscape connectivity (Shaffer et al., 2019). The introduction of land use in elephant habitat leaves the landscape fragmented and elephant movement corridors obstructed (Okello et al., 2011). Landscape fragmentation is characterized by subdivision, loss and reduction in habitat patches. Loibooki et al (2002) has revealed that a reduction in wildlife population and distribution is ascribed to human encroachment into wildlife habitat. Okello (2005) discussed the importance of wildlife corridors and indicated that lack of them may lead to wildlife population instability, loss in ecological integrity, possibility of extinction and human-wildlife conflict. Land use-land cover change and its impacts such as fragmentation and loss of elephant habitat, increased livestock population and farming within buffer zones and protected areas are described as sources of conflict between human and wildlife (Hoare & Du Toit, 1999; Naughton-Treves, 1998). Elephants are being driven into closer quarters with humans as their habitats get smaller, which lead to increasingly frequent and serious conflicts over territory and resources hence elephant crop raiding, property destruction and loss of life (Liu et al., 2017). Landscape fragmentation increases the likelihood of human-elephant conflict, as roads and agricultural lands surrounding elephant habitats are more likely to spark conflict (Fernando et al., 2005). Human elephant conflicts taking place across the globe are ranking among the main factors threatening biodiversity conservation (Muruthi, 2005)

1.7 Habitat, Movement and Behaviour of African Savannah Elephants

1.7.1 Elephants Habitat

The African elephant is the largest living iconic animal among all terrestrial animals, and it pursues mixed feeding strategy (Duffy et al., 2011). The elephant is found in 37 countries in the sub–Saharan Africa including west, east and southern Africa (Blanc, 2008). African elephants adapt well to a broad variety of habitats with annual rainfall lying between 150 mm to 1400mm. Their habitat ranges between, broken woodland, grassland, dense forest, closed savannah, deserts, bush veld, swamps and mashes (Adams et al., 2016; Duffy et al., 2011). Elephants tend to actively select a habitat based on availability of various resources such as water, food resources and shade (Shannon et al., 2006). Wiseman et al (2004) argued that habitat species are not of the same value and research about conservation strategies is being carried out to protect vital and endangered habitat species. Elephant habitats are being threatened by high human and elephant population densities (Loarie et al., 2009; Shannon et al., 2010). Their impacts can lead to irreversible changes in the structure and configuration of habitats and ultimately loss of biodiversity (Wiseman et al., 2004). Elephants can also threaten their habitats through their foraging behaviour (Duffy et al., 2002; Lombard et al., 2001).

1.7.2 Elephants Movement

Animal movement patterns provide a better understanding for ecologists to further understand the relationship between landscape heterogeneity and animal foraging behaviour (Bartumeus et al., 2005). Animal body size correlates positively with the size of the landscape with larger animal species such as larger mammals particularly African elephants requiring more space (Jetz et al., 2004; Tamburello et al., 2015; Tucker et al., 2014). Elephant's movement is noted to be determined by various environmental factors such as food resource, water and rainfall distribution (Boettiger et al., 2011; Shannon et al., 2010). Gadd (2005); Dai et al (2007) and van Aarde & Jackson (2007) further indicated that elephants move to a certain landscape for specific food resources. Elephants are natural migrants and move across vast areas during drought seasons and they tend to home on short ranges close to permanent water sources (Boettiger et al., 2011; Gadd, 2005). Shannon et al (2006) and Chamaillé-Jammes et al (2007) also added that elephants are highly attracted to habitats in close proximity to rivers as they provide not only water but abundance of palatable forage.

In a study that was carried by Duffy et al (2011) about movement patterns of elephants in different habitat types (woodland, grassland, floodplain, old farmland and riverine thicket) it was indicated that female elephants moved slow as compared to male elephants when in separate groups across all habitat types. The study further revealed that when both male and female elephants are together the movement speed of females increases across all habitat types due to the disturbance with individual mating. Benhamou (2004) elephant's movement patterns study is crucial in revealing paths used by elephants for food searching, spatial distribution and habitat utilization over time. Elephant's movement patterns data at patch level can provide valuable information about habitat preference (Dai et al., 2007; Shannon et al., 2010) and could be useful for conservation of both the habitat and elephants (Duffy et al., 2011).

(Adams et al., 2020) investigated how human presence and various land use influence elephant movement in the Chobe District over the course of 13 months. The study consisted of five elephants from two populations being the Chobe Enclave (three elephants) and Kasane/Kazungula area (two elephants). Elephant's movements were monitored through the employment of GPS collars fitted safely on elephant's necks. The study revealed that elephant movement patterns are determined by various environmental factors such as season, land use land cover and time of day. Moreover, elephant movements within the two elephant populations differed among individual elephants. Overall studied elephants had a smaller annual home range of approximately 400 km^2 to 1750 km^2 as compared to other researchers within southern Africa. In contrast to some previous research (Leggett, 2008; Loarie et al., 2009), elephants in the study area made larger diurnal movements than nocturnal movements. Adams et al (2020) indicated that movement patterns were significantly different across all land use-land cover types, suggesting that elephants have come up with ways to navigate through human dominated areas such as urban and agricultural land. In this regard elephants in urban areas displayed less seasonal home range as compared to the seasonal home range by elephants within agricultural land.

In a study that was carried out to investigate elephant movement patterns in various land use types, three Chobe Enclave elephants were designated names by the author (Adams et al., 2020) as follows CH62, CH65 and CH69. Individual elephant movement ranges were determined using the 95% Kernel method (Leggett, 2008) and it was revealed that two Chobe enclave elephants CH65 and CH69 had the largest annual home ranges of about 1453.2 km^2 and 1764.5 km^2 respectively. Chobe enclave elephants spend most of their time moving between communal land and protected areas. CH69 and CH65 spent most of their time around the Chobe enclave Community land while the CH62 spent greater time inside the protected area. They further revealed that elephants in the Chobe enclave moved faster when travelling through human dominated and unprotected areas. Chobe enclave elephants enter communal areas not only for crop raiding but also to access the river as settlement and agricultural land is located on or near the river (Gupta, 2011; Songhurst & Coulson, 2014).

1.8 Land use and wildlife conservation in Botswana: Policies and Regulatory framework

These are legal frameworks governing the study area's land use, wildlife conservation and natural resource management associated with human elephant interaction. Land use's legal frameworks consist of customary and formal laws. Customary are accepted and respected practices by members of a tribal community if they are not in contrast with written laws of Botswana (The Customary Laws Act, 1969) and formal laws are written legal systems and rules formed by institutions in accordance with certain processes.

1.8.1 The State Land Act, 1966

The act issues powers to both central and local governments to manage the state land and to allocate urban land to individuals and entities (Adams et al., 2003). The state land includes urban land, forest reserves and national parks.

1.8.2 The Tribal Land Act, 2018

Vests tribal land to the citizens of Botswana and grants administrative power that was formerly held by chiefs and headmen over the land to all Land Boards. Land Boards are given the power to allocate land, cancel customary rights, and rezone agricultural land for commercial, residential, and industrial uses. The Tribal Land Act also introduced certificates evidencing grants of rights to wells, borehole drilling, and individual residential plots, and allows people to apply for common-law leases of land, which they use to obtain mortgages (Adams et al., 2003; Government of Botswana, 2008).

1.8.3 The Town and Country Planning Act, 1977

Provides guidance for the management and development of rural and urban land (Adams et al., 2003) through vesting the local government with the authority to design land use plans and to monitor the public to abide by it.

1.8.4 The Sectional Titles Act, 1999

The act allows for the transfer of rights to sections of developments and properties, such as in condominium and industrial developments, upon approval of a sectional plan for the property. The Sectional Titles Act applies to all types and classifications of land (Government of Botswana, 2010; Taylor, 2007).

1.8.5 The Tourism Policy, 1990

The policy is of the view that game viewing and hunting are forms of tourism through which the country and local communities can benefit from. The aim of the policy is to promote development and encouragement of service provision in rural communities' especially remote areas. It further states that rural communities are to be sensitized on wildlife value and conservation.

1.8.6 Wildlife Conservation and National Parks Act, 1992

The act is administered by the Department of Wildlife and National Parks, and it repealed the Fauna Conservation Act of 1961 and National Parks Act of 1967. The legal framework seeks for conservation and management of wildlife species particularly endangered ones and protected areas.

1.8.7 CBNRM Policy, 2007

The policy seeks to promote involvement of local communities adjacent to protected areas in conservation of natural resources and biodiversity to minimize human elephant conflict. Socio economic activities of local communities are identified and linked with the management objectives of the adjacent protected area to improve their livelihoods and involve them in management of protected areas.

Chapter 2 Materials and Methods

2.1 Description of the Study Area

2.1.1 Geographic location and description

The study area (Chobe enclave) is in the Northern part of Botswana within the Northwest part of the Chobe District (Figure 2.0). The Chobe District with a total area of 22 560 km^2 shares international borders of the country with Zimbabwe in the East, Zambia in the north along Cuando, Linyanti and Chobe rivers and it also shares an 800m border with Zambia in the north along the Zambezi River (Chase, 2012). The Chobe enclave is enclosed by protected areas on the east, west, south and the Cuando-Linyanti River on the northern side, which forms an international border with Namibia (Jansen et al., 1990). The Chobe Forest Reserve (CH2-CFR) forms the Southern boundary while the Chobe National Park (CH3) forms the western and eastern boundaries (Jansen et al., 1990; Jones, 2002). The Chobe enclave lies at coordinates left; 23.922310, top; -17.933790, bottom; -18.350699, right; 24.722023. Most of the lands in the Chobe Enclave are liable to flooding (Jansen et al., 1990).

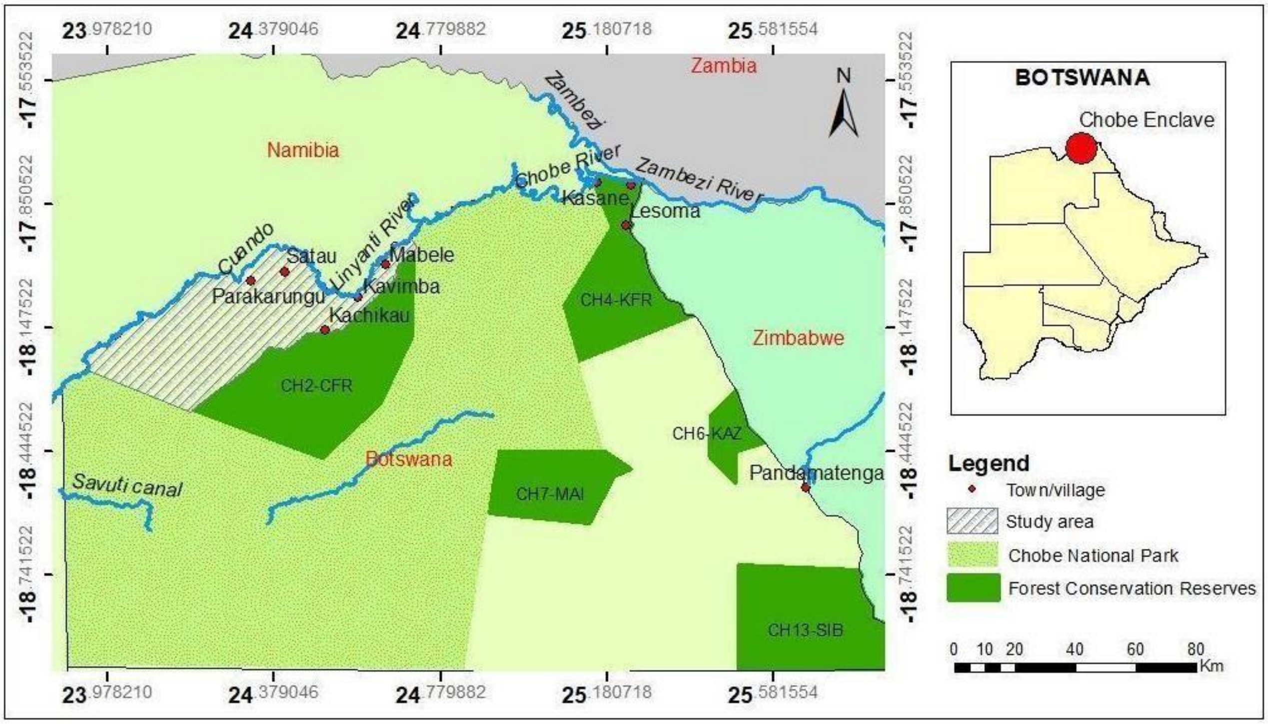

Figure 2.0: Study area map.

2.1.2 Biophysical Characteristics

The Chobe Enclave region lies within the semi-arid and sub humid climate (Jansen et al., 1990). Fluctuations of the inter-tropical convergence zone alters the climate hence high temperatures of about 30°C and heavy precipitation from November to March (wet season) while the dry season runs from April to October (Fynn et al., 2014). The area experiences a mean annual precipitation of 650 mm, and it is one of the regions receiving the highest rainfalls in Botswana (Burgess, 2006; Jones, 2002). The vegetation of the Chobe Enclave as any other vegetation found anywhere around the world is determined by climate, geomorphology, and moisture availability in the area. Vegetation of the area as studied by Sianga & Fynn (2017) includes mopane forests, acacia grasslands and sandvelds, Baikiaea forests along the southern edge, with riparian forests along the Linyanti and isolated dry floodplains and wetlands in the north-east.

The area is known for its diverse animal species of both land and water. There are large populations of big mammals such as elephants, Zebras and Buffaloes (Haynes, 2012).

2.1.3 Socio-economic Characteristics

The Chobe enclave's five main villages have a generally low human population of 4446 (Statistics Botswana, 2022) and approximately 30% of the Enclave's total population work outside the Enclave (Joos, 2015). More people resided in Kachikau with a population of 1214 and least in Kavimba with a population density of 567 (Statistics Botswana, 2022). The BaSubiya, BaTawana, and Xo people are the main ethnic inhabitants of the area where the BaSubiya are the majority (Northwest District Council, 1990). They make their living through arable agriculture, pastoralism, fishing and sometimes hunting (Jones, 2002). These are supplemented by smallscale businesses such as beer making and natural resources selling such as sand, baskets, thatching grass, game meat and firewood (Jones, 2002). Subsistence livestock and low intensity arable cultivation are practiced on communal lands in the Chobe enclave villages. State and tribal land are the chief land tenure systems in the Chobe District (Sluis et al., 2017).

Pastoral, arable farmers and the residents at large are facing a great threat from some free ranging wildlife such as elephants, lions, and buffaloes among others. Elephants raid their crops, and destroy their field fences (Adams, 2020); on the other hand, their livestock e.g., cattles are being threatened by lions and diseases such as foot and mouth disease (Mahupeleng, 2008). The disease is carried by buffaloes and has taken off many herds (Gumbo, 2018). In this regard, farmers and residents of the Chobe enclave have lost their ability to sell meat outside the region (Jones, 2002).

The human wildlife conflict in the enclave has caused residents to remain poor despite the

Government of Botswana trying so much to reimburse those affected even though the reimbursement allowance does not cover all the loss (Gupta, 2012). Widespread cultivation on flood plains exacerbates human elephant conflicts in the area (Adams et al., 2020). The enclave is also a trophy hunting concession area where the Chobe Enclave Conservation Trust (CECT) manages annually quota issued wildlife (Mbaiwa and Tlamelo, 2012). Almost all households in the area use natural resources for subsistence purposes (Jones, 2002).

2.2 Research Methodology

2.2.1 Data Acquisition

Cloud free and radiometrically corrected Level 2 multi-temporal satellite imageries for the study periods were acquired from Landsat satellite missions including Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI)/Thermal Infrared sensor (TIRS). Surface reflectance images at 30-meter spatial resolution (Table 2.0), were ordered and downloaded from the U.S geological survey (USGS) Earth Resources Observation and Science (EROS) Centre Science Processing Architecture (ESPA) webpage (http://earthexplorer.usgs.gov/). For each study period, two multi-temporal satellite imageries were acquired since the study area bounding polygon was lying between two Landsat scenes 174/072 and 174/073. Landsat satellite scenes for all the study periods were captured during the same season (dry season). They were selected for use in this study to minimize the seasonal influence on image classification results. The metadata of all the multi-temporal satellite imageries for all the study periods are well represented in (Table 2.0) respectively.

Table 2.0: Landsat images metadata

Satellite	Sensor	Landsat Scene	Spatial resolution (m)	Acquisition date
Landsat 7	ETM+	174/072	30	22-06-2000
Landsat 7	ETM+	174/073	30	22-06-2000
Landsat 5	TM	174/072	30	19-07-2010
Landsat 5	TM	174/073	30	19-07-2010
Landsat 8	OLI/TIRS	174/072	30	07-07-2020
Landsat 8	OLI/TIRS	174/073	30	07-07-2020

Table 2.1 below comprises of 2000 and 2010 ancillary land use-land cover maps of the study area. The maps were acquired to assist in generation of training and validation points for the historic study periods 2000 and 2010. The maps were also required to help as a guide during creation signature files that were used in supervised classification.

Table 2.1: Ancillary data

Year	Name	Source
2000	Botswana_LandCover_2000_Scheme_II	http://geoportal.rcmrd.org/layers/servir%3Abotswana_landcover_2000_scheme_ii
2010	Botswana_LandCover_2010_scheme_I	http://geoportal.rcmrd.org/layers/servir%3Abotswana_landcover_2010_scheme_i

2.2.2 Land Use-Land Cover Classification

2.2.2.1 Classification Scheme

The first step in the process of image classification was to design a classification scheme for land use-land cover classes of the study area. Formation of the classification scheme included determination of which land use-land cover class to include. This was made easier due to being familiar with the environment of the study area together with the aid of previous studies conducted in the study area about the same and/or related matters. There are no agreed definitions of land cover classes due to the difference in climatic, economic and social conditions among various places (FAO, 2000). The Government of Botswana (2015) has adopted the FAO (Gregorio & Jansen, 2000) definition of land use-land cover classes. Description of land use/land cover classes listed in (Table 2.2) was based on an assessment which was undertaken in Botswana (Government of Botswana, 2015) and other previous studies on land use-land cover change (Akinyemi, 2013; Akinyemi & Mashame, 2018; Fox et al., 2017; Gashaw et al., 2014). Therefore, land use-land cover classes plus their description as listed in (Table 2.2) were proposed. These land use-land cover classes (Table 2.1) served as guide during collection of ground truth points used in image classification and validation. The classification scheme is also meant to help the reader understand and differentiate land use-land cover classes of the study area as suggested by the author.

Table 2.2: Land use-land covers Classification Scheme of the study area.

CODE	Land Use-Land Cover Classes	Description	Pictures
01	Water Body	Water bodies that hold water, could be ephemeral or perennial e.g. rivers, lakes, streams and reservoirs.	
02	Woodland	Land with trees higher than 5 meters and a canopy cover of 5 – 10 percent plus shrub bushes and trees above 10 percent.	
03	Shrubland	Land covered by small trees usually bushes, herbs and shrubs with less than 3 meters height, in some cases mixed with grass coverage not exceeding 10 percent of the total class cover.	

04	Grassland	Area of land predominated by grass with limited trees, shrubs and herbs in between.	
05	Bareland/impervious	Area of land covered mostly by buildings, roads, parking lots, crops with very limited trees and grasses. This includes an area of land covered by soil/rock outcrop with no vegetation.	

2.2.2.2 Image Pre-Processing

Spectral bands for all acquired Multi-temporal Satellite imageries were stacked into ArcGIS 10.7 in preparation for image composition. The Composite Landsat images for all the study periods were geometrically corrected to UTM WGS 1984 35S projection system and georegistered using the image-to-image registration technique. Since the study area bounding box was caught up between Landsat scenes 174/072 and 174/073, Landsat imageries were mosaicked together through the nearest neighbour algorithm. The study area bounding box was used to spatially subset the mosaicked Landsat images using the raster clip tool. False colour composite band combinations were employed for all Landsat imageries as shown in (Table 2.3). Band combinations were selected based on their ability to depict objects well on certain land use land cover classes.

Table 2.3: Band combination (RGB) per land use-land cover class

LULC Classes	Landsat 5 TM & Landsat 7 ETM+	Landsat 8 OLI/TIRS
Waterbody	7, 5, 3	5, 6, 4
Woodland	4, 3, 1	5, 4, 3
Shrubland	4, 3, 2	5, 4, 3
Grassland	4, 3, 2	5, 4, 3
Bareland/impervious	3, 2, 1 (Built-up)	7, 6, 4 (Built-up)
	7, 4, 2 (Agriculture)	6, 5, 2 (Agriculture)
	5, 4, 3 (Bare soils)	5, 6, 4 (Bare soils)

2.2.2.3 Training and Validation Samples Selection

For all the three study periods, a total number of 1711 of sampling points were generated to aid in image classification. Sampling points for the historic study periods (2000 and 2010) were stratified randomly selected using, “create accuracy assessment point” tool in ArcGIS. Sampling points for the historic periods were then edited independently per image to maintain fair distribution of points; points that were close to one another were separated and LULC classes that had less, or more sampling points led to points being added or removed respectively. For classification of the study period (2020) image a total of 511 sampling points was collected at the field in the Chobe enclave from 04th August 2020 until 18th August 2020 using eTrex 20x

Garmin handheld GPS for the five LULC classes. The ground truth points were selected more than 30m away from one another to minimize the confusion between LULC classes. For all the three study periods a total of 856 and 855 sampling points were used for training and validation respectively.

2.2.2.4 Image Classification

Among other image classification techniques, the maximum likelihood classification algorithm, even though it is difficult and time consuming, was adopted for use in this study since it was considered to yield accurate results in the context (Akinyemi, 2013; Wasige et al., 2012). For classification of Landsat surface reflectance images, maximum likelihood classifier (MLC) is the most widely used classification algorithm (Currit, 2005; Jensen, 2005; Weng, 2002). Maximum likelihood classification depends on the probability that various and well distributed pixels belong to different land classes (Shepherd et al., 2002). The accuracy of supervised classification such as maximum likelihood classification is affected by visual interpretation and standard interpretation keys such as colour, shape, tone, size, texture, pattern site, shadow and resolution. For each land use-land cover (LULC) class, training sites were only developed on homogeneously looking areas of the Landsat image to avoid confusion between land use-land cover classes on classification results.

2.3 Post Classification, Processing, Accuracy Assessment and Change Detection

There is the need for land use-land cover (LULC) map users to know how accurate the maps are in order to use the data efficiently without any doubt (Plourde & Congalton, 2003). The minimum interpretation accuracy in the identification of LULC from remote sensing data is expected to be at least 85% (Manandhar et al., 2009). For the historic periods 2000 and 2010 a total of 300 validation samples were generated through “create accuracy assessment point” tool in ArcGIS respectively with the guide of ancillary data in Table 2.1. For both study periods a total of 37, 113, 213, 162 and 75 validation samples were generated for waterbody, woodland, shrubland, grassland and bareland/impervious respectively. Whereas for the study period 2020 exactly 253 validation samples were collected in field at a distance of 30m away from one another to minimize confusion. For each class, waterbody, woodland, shrubland, grassland and bareland/impervious precisely 19, 12, 64, 53 and 105 were collected respectively. Study area classification maps were filtered using an 8x8 majority filter to reduce the noisy effects on the classified images. The accuracy assessment was then performed for all the study periods classified maps. Overall accuracy, producer and user's accuracy and Kappa statistics were all acquired through generation of the confusion matrix to find the accuracy and reliability of the maps produced. Senseman et al (1995) have argued that kappa coefficients of at least 0.8 are considered of good classification while those at most 0.4 are considered of poor classification. The LULC study area classified maps of (2000 & 2010) and (2010 & 2020) were independently combined using the combine function to detect persistence and changes in LULC.

2.4 Landscape Metrics

Landscape metrics (LM) were derived with FRAGSTATS Version 4.2.1, a spatial pattern analysis program for quantifying landscape structures (McGarigal et al., 2012). FRAGSTATS is a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns (McGarigal et al., 2002). The software is widely used nowadays by decision makers and experts in various fields of study including ecology, statistics and wildlife experts to describe and characterize the landscape structures including their spatial extent (Çakir et al., 2008; Ricketts, 2001).

According to McGarigal et al (2002) shape, aggregation, edge-area, core area, contrast, subdivision, isolation and diversity are metrics methods of which indices on land use-land cover maps are derived from. The landscape patterns are to be computed and analysed at class and landscape levels. Class metrics represent the spatial extent and pattern of patches of the same category whereas landscape metrics represent the spatial pattern of the entire landscape. Metrics are categorized in two general groups namely the composition and configuration metrics (McGarigal et al., 2002). Composition metrics measure the amount of different land use-land cover classes in a landscape and their relative share within the entire landscape. Configuration metrics measure the spatial behaviour and arrangement, position orientation and shape of land use-land cover patches within the entire landscape. It is always advisable to understand for each metric which aspect of landscape is being quantified since landscape configuration and composition can affect ecological processes independently and interactively. In addition (Li & Wu, 2004; Uuemaa et al., 2009) advised that when using landscape metrics caution should be taken at all times since some metrics are redundant and at times, they represent confounding information (Riitters et al., 1995). Researchers in the context have various reasons for selection and use of landscape metrics (Table 2.4).

Table 2.4: Landscape metrics review

Author	Assessment	Metrics used	Reason of choice
(Jackson et al., 2005)	Habitat use by Ocelots	NP, Shape, mean patch size, edge and nearest neighbor.	Based on their ability to measure the degree of fragmentation.
(Flowers & Huang, 2020)	Habitat fragmentation	CA, NP, mean patch size, edge density, class area, mean shape	Based on their ability to analyze change in landscape composition and configuration.

		index, area-weighted mean shape index	
(Mugiraneza et al., 2019)	Land cover dynamics	CA, NP, Patch density, LSI, Aggregation index, TECI and CWED	Quantification and arrangement of habitat.

There is no general agreement on the choice of which metric is the best alternative. A series of most common and least correlated metrics were selected to compute and analyse the spatial characteristics of the study area. In accordance with the purpose of this study, five (5) indices were selected for spatial characterization of the study area. Selection of which landscape metrics to use was based on their ability to act as indicators of landscape change and also on their ability to quantify and assess landscape fragmentation. The five (5) indices selected include class area (CA), number of patches (NP), largest patch density (LPI), landscape splitting index (LSI) and aggregation (AI) as listed and described in (Table 2.5). These indices were then subdivided under composition and configuration categories. Mugiraneza et al (2019) stated that CA, NP and LPI are useful at analysing landscape composition while indices such as LSI and AI can better assess landscape configuration.

Table 2.5: List of selected landscape metrics used in this study (McGarigal et al., 2002)

Landscape Metric	**Description**	**Units**	**Category**	**Range**
Class Area (CA)	The sums of all the patch areas of the same land use-land cover class.	Hectares (ha)	Area Metric	CA > 0, without limit

Largest Patch Index (LPI)	The percentage of the area of the corresponding LULC class type divided by the total landscape area.	Percent (%)	Area Metric	0 < LPI ≤ 100
Number of Patches (NP)	Total number of patches of the same LULC class type.	None	Subdivision Metric	NP ≥ 1, without limit
Landscape Splitting Index (LSI)	Number of patches one gets when dividing the total landscape into patches of equal size in such a way that this new configuration leads to the same degree of landscape division as obtained for the observed cumulative area distribution.	None	Subdivision Metric	LSI ≥ 0, without limit
Aggregation Index (AI)	The ratio of the observed number of like adjacencies to the maximum possible number of like adjacencies given the proportion of the landscape comprising each LULC class.	Percent (%)	Aggregation Metric	0 ≤ AI ≤ 100

2.5 Human Elephant Interaction

2.5.1 Perceptions of Land Users

Data collection methods are divided into quantitative and qualitative (Johnson & Onwuegbuzie, 2007; O'Cathain, 2019). Choosing the best and suitable research method to employ is based on the kind of research undertaken and the nature of the research problem (Noor, 2008). For this research, a qualitative data collection method was utilized as it was compatible with the requirements of the research problem statement. Qualitative research methods are utilized to gather various opinions and perceptions of respondents (Johnson & Onwuegbuzie, 2007; Moswete & Monare, 2015). There are many qualitative data collection research methods that exist in the context and the most common ones are observation and interview (Creswell & Oaks, 2007). The three kinds of interview data collection methods are structured, semi-structured and unstructured (Ritchie & Spencer, 1995). Semi-structured interview respondents are required to answer a set of open-ended questions (Adams, 2015) as administered by the interviewer. Under semi-structured data collection method, face to face key informant interview method was utilized for this research data collection. The method is best suitable for studies having individual persons as a unit of analysis (Maxfield and Babbie, 2016). This in-depth interview method is used particularly in gathering individuals or groups of people's perceptions (Jamshed, 2014). This type of interview method is normally conducted once in overall during a research period and it usually lasts for about 30 minutes to about more than 1 hour (DiCicco-Bloom & Crabtree, 2006). This data collection research method has been utilized by various researchers in different fields (Oladele, 2011; Anim and Chauke, 2014).

Human beings across all societies have developed adaptation methods (de Guchteneire et al., 2000) and knowledge about the environment they reside in (Nakashima et al., 2003; Nyong et al 2007). On the 17th of March 2021 until 31st March 2021 open ended questions were administered to a total of 57 purposively sampled key informants in the Chobe enclave. Key informants were community leaders, professionals in the community and residents affected by HEI. Respondents were questioned on land use-land cover change, human elephant interaction, elephant migratory routes and how human elephant conflict has affected them economically and their tolerance level for elephants. The interview consisted of planned and written open-depth questions to help guide and keep the interview on track (Cresswell and Oaks, 2007). English language Interview questions were written in a paper and administered orally in Setswana language, since this was the only common language between the respondents and the interviewer. Interview responses were collected through notes writing and recording only through respondent's consent.

2.6 Delineation of Elephant Migratory Routes

Elephants are great wanders and can travel long distances in search of food and water (Purdon et al., 2018). Elephant migration is the seasonal movement of elephants between separated habitats. Even though migration is an ecologically significant process it is endangered by climate change and landscape fragmentation (Harris et al., 2009). According to Thouless et al (2016) elephants in Botswana have a major home range of about with the aid of visual interpretation techniques, high resolution Google Earth pro imageries were used to delineate elephant migratory routes (EMR). The interpretation technique includes detection, identification, description, and assessment (Svatonova, 2016). Identification of EMR was based on certain parameters such as location, colour, texture, pattern, shape and size. Areas showing more than one linear wildlife path, limited vegetation especially grass and visible traces of elephant dung were identified as EMR. Key informants were asked to identify areas elephants use most often for movement and observations of the landscape were made. Data sought was used for validation of identified EMR.

2.7 Human Elephant Conflict (HEC) Hotspots

To delineate areas of land with high probability of HEC incidents certain criterion was put in place. The assumption of the criterion is that, from time-to-time elephants navigate through human dominated areas from the Chobe national park to access water sources on the other side. Moreover, wildlife movement corridors in the area are not fenced, hence free navigation of elephants to an extent whereby their navigation ends up overlapping with adjacent land use such as human settlement and arable land. Human elephant conflicts are deemed to be occurring in places where human land use and elephants' migratory routes overlap (Billah et al., 2021; Kusena, 2009) especially in places near water sources (Chamaillé-Jammes et al., 2007; de Beer & van Aarde, 2008). For this study, human-elephant conflict hotspots are specified as a landscape matrix consisting of human settlement in proximity to elephant migratory routes (Kusena, 2009). Since the land use class "bareland/impervious" consists of barren land and human settlement as defined by the classification scheme (Table 2), high resolution images from Google Earth Pro were used to collect arable land and kraals coordinates data for study periods 2000 and 2020. Data collected was treated as the human settlement when mapping the HEC hotspots. The human settlement data was overlaid with the land use-land cover map and 3 km buffered elephant migratory routes. Human settlement data found within the buffer zone of the elephant's migratory routes and those near ephemeral and perennial water sources were retained while the rest were discarded. The remaining human settlement data were used to feed the kernel density estimation tool for production of human elephant conflict hotspots for both study periods.

Key informants across all the 5 main villages of the study area had a positive impact in mapping of the indigenous knowledge HEC hotspots in the study area. Respondents were asked to locate areas within the study area mostly affected by human elephant conflict. Spatial coordinate points for such areas were recorded and the kernel density estimation was then executed to produce indigenous knowledge HEC hotspots map for the study area.

Chapter 3

Results

3.1 Land use-land cover

3.1.1 Image Classification Accuracy

A total of five land use-land cover classes were identified (waterbody, woodland, shrubland, grassland and bareland/impervious) to be used in image classification (Table 2.1). The overall classification accuracy and kappa coefficient for the study periods 2000, 2010 and 2020 are presented in Table 3.0 and the error matrix and accuracy are shown in Table 3.1. The 2000 classified map had the overall classification accuracy of 93.33 % while classified maps of 2010 and 2020 had 94.33% and 90.12% respectively Table 3.0. The kappa coefficient is 0.91 in 2000, 0.93 in 2010 and 0.86 in 2020 Table 3.0. Classified maps for the study periods 2000, 2010 and 2020 had the LULC classified categories producer and user's classification accuracy ranging between 87.5 % to 100 % in 2000, 88.9 % to 100 % in 2018 and 75 % to 100 % in 2020 (Table 3.1).

Table 3.0: Overall classification accuracies and kappa coefficient

Study Periods Maps	2000	2010	2020
Overall accuracy (%)	93.33	94.33	90.12
Kappa coefficient	0.91	0.93	0.86

Table 3.1: Error matrices and accuracy for LULC maps

LULC Categories	01	02	03	04	05	Total	Producer's Accuracy (%)	User's Accuracy (%)
2018								
Waterbody (01)	**11**	0	0	0	0	11	100	100.0
Woodland (02)	0	**75**	9	0	0	84	98.7	89.3
Shrubland (03)	0	1	**114**	1	0	116	89.1	98.3
Grassland (04)	0	0	5	**59**	3	67	96.7	88.1
Bareland/ Impervious (05)	0	0	0	1	**21**	22	87.5	95.5
Total	11	76	128	61	24	300		
2010								
Waterbody (01)	**25**	1	0	0	0	26	96.2	96.2
Woodland (02)	0	**33**	0	0	0	33	89.2	100.0
Shrubland (03)	0	2	**81**	3	1	87	95.3	93.1
Grassland (04)	0	1	1	**96**	2	100	95.0	96.0
Bareland/ Impervious (05)	1	0	3	2	**48**	54	94.1	88.9

Total	26	37	85	101	51	300		
2020								
Waterbody (01)	**19**	3	0	0	0	22	100.0	86.4
Woodland (02)	0	**9**	1	1	1	12	75	75
Shrubland (03)	0	0	**58**	1	3	62	90.6	93.6
Grassland (04)	0	0	3	**48**	7	58	90.6	82.8
Bareland/ Impervious (05)	0	0	2	3	**94**	99	89.5	95.0
Total	19	12	64	53	105	253		

Note: correctly classified validation samples are indicated in bold.

3.1.2 LULC Mapping and Change Detection (2000–2010 and 2010–2020)

LULC maps were produced using the supervised classification (maximum likelihood algorithm) for all the study periods. As indicated in Figure 3.0, 3.1, 3.2 and Table 3.2 land use land cover classes are experiencing a change in their spatial extent. An increase in one land use land cover class is a loss in another LULC class. The total surface area of the study area is 157842 ha. Figure 3.0 below shows a yield of image processing techniques that were carried out. On the right-hand side of (figure 3.0) are LULC maps showing the distribution and arrangement of land use-land cover within the landscape of the Chobe enclave.

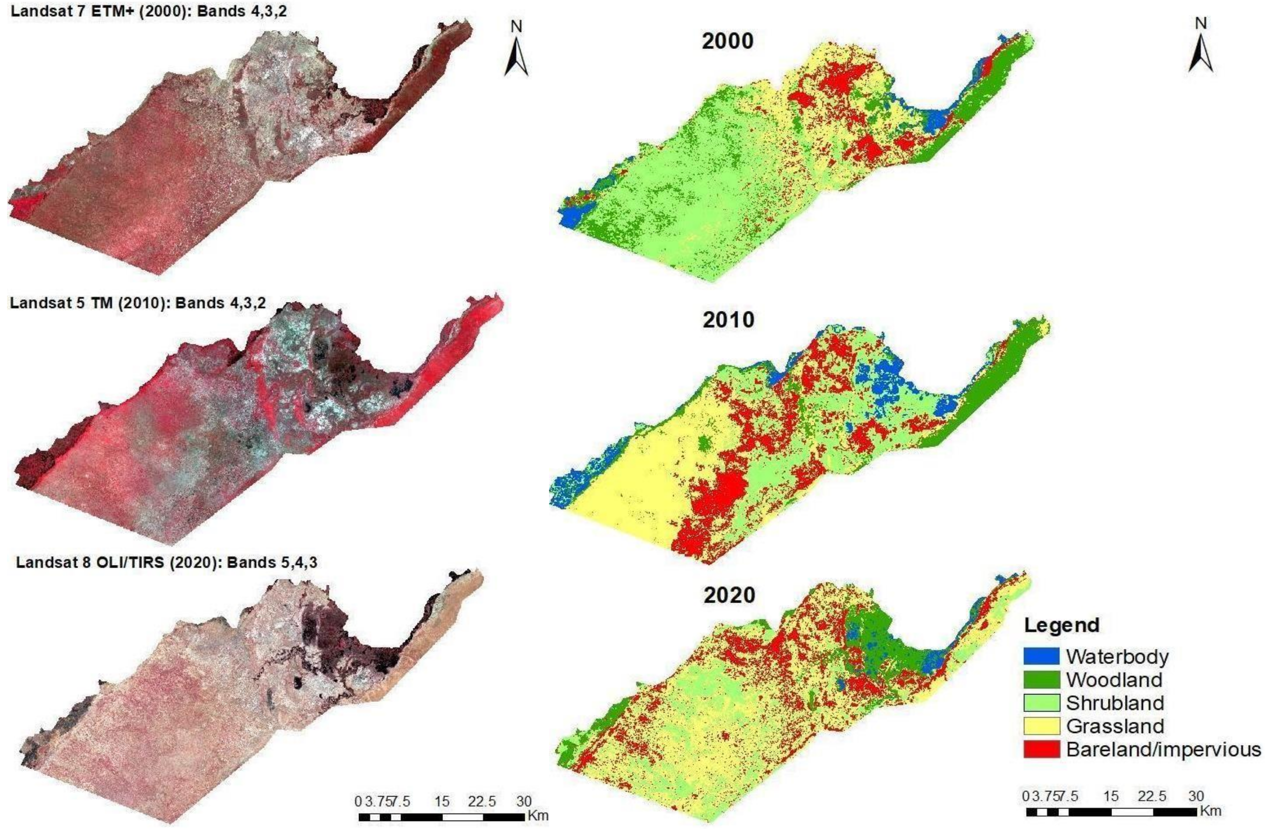

Figure 3.0: False colour composite images and land use-land cover maps.

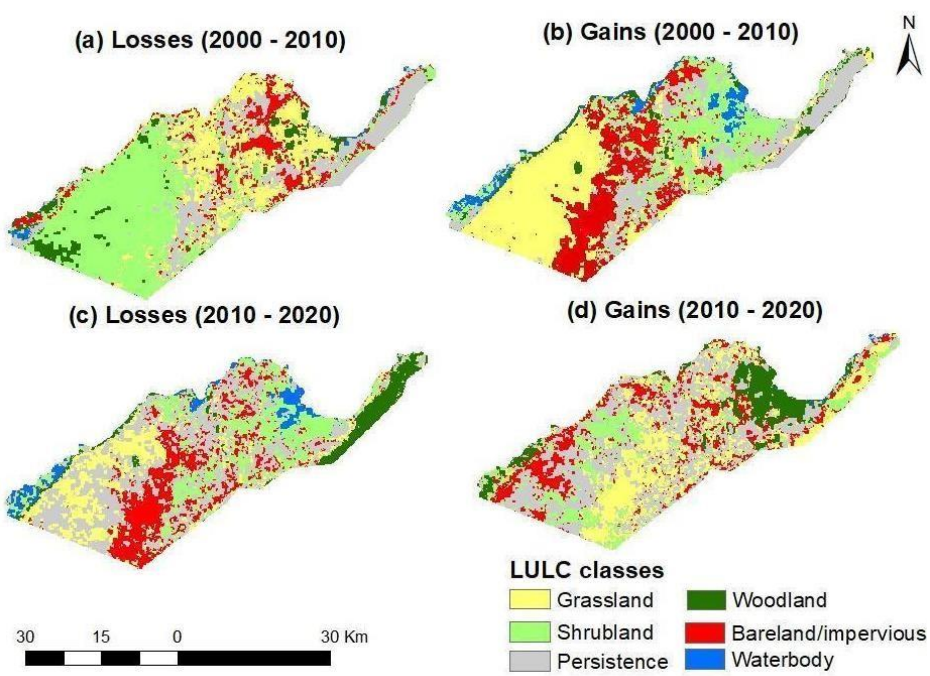

Figure 3.1: Maps of gains and losses among the five-land use-land cover classes.

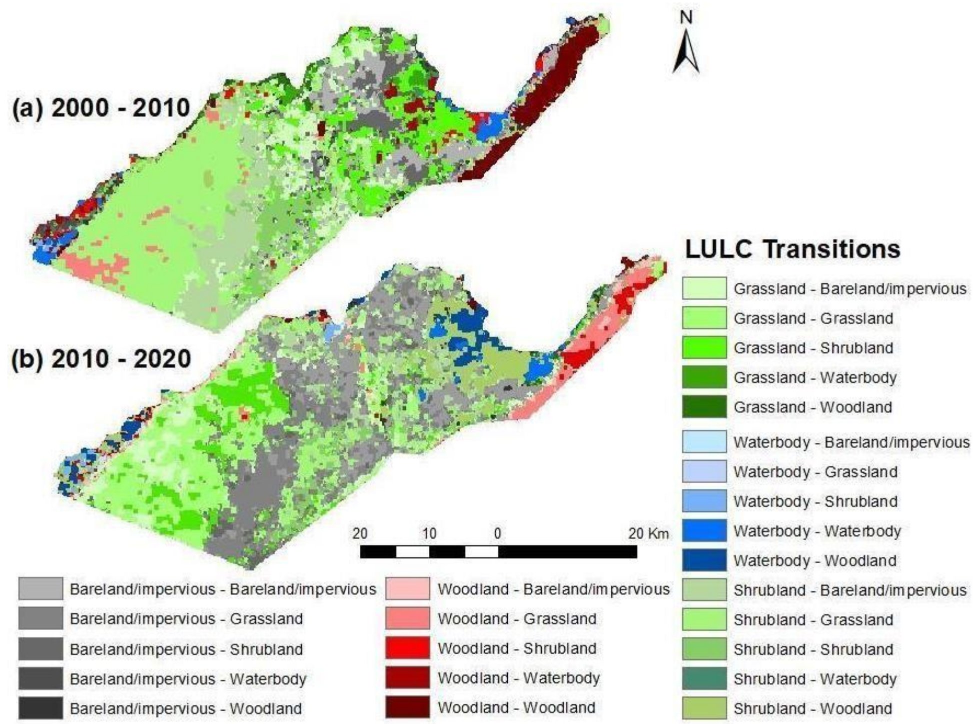

Figure 3.2: LULC transition map

Table 3.2: LULC change matrix for time interval 2000–2010 & 2010–2020.

	2010											
LULC Categories	**01**		**02**		**03**		**04**		**05**		**2000 total**	
2000	Area (km2)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)
Waterbody (01)	39.0	32.9	8.7	4.8	10.3	2.2	3.3	0.7	1.1	0.4	62.5	4.0
Woodland (02)	34.8	29.4	106.1	58.1	79.7	17.1	114.3	23.0	11.9	3.8	346.7	22.0
Shrubland (03)	18.7	15.8	48.1	26.3	159.3	34.2	345.2	69.4	142.2	45.4	713.2	45.2
Grassland (04)	19.5	16.5	11.9	6.5	150.6	32.3	21.9	4.4	91.3	29.2	295.2	18.7
Bareland/impervious (05)	6.8	5.7	7.9	4.3	66.0	14.2	12.8	2.6	66.4	21.2	159.8	10.1
2010 total area & %	118.5	7.5	182.7	11.6	465.9	29.5	497.4	31.5	312.9	19.8	1577.4	
	2020											

LULC Categories	01		02		03		04		05		2010 total	
2010	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)
Waterbody (01)	30.3	79.6	60.4	35.4	17.0	3.5	5.5	1.0	5.3	1.7	118.5	7.5
Woodland (02)	2.7	7.0	15.7	9.2	70.1	14.3	70.5	12.3	23.7	7.8	182.7	11.6
Shrubland (03)	4.1	10.9	86.5	50.7	162.1	33.0	134.1	23.4	79.1	25.9	465.9	29.5
Grassland (04)	0.7	1.9	3.9	2.3	186.4	37.9	219.6	38.4	86.7	28.4	497.4	31.5
Bareland/impervious (05)	0.2	0.6	4.1	2.4	55.7	11.3	142.8	24.9	110.1	36.1	312.9	19.8
2020 total area & %	38.1	2.4	170.6	10.8	491.4	31.2	572.5	36.3	304.8	19.3	1577.4	

3.2 Landscape Metrics

3.2.1 Class Area (CA)

As shown in class area (Figure 3.3) the study area was dominated by shrubland in 2000 with a class area of 70383 ha being the largest land cover the study area has ever had within the timeframe of this study. In 2010 and 2020 land cover dominance shifted to grassland with a respective land share of 44270 ha and 56935 ha. Although shrubland was dominating in 2000 it has suffered the greatest loss of -15.7% between 2000 & 2010. Moreover, shrubland loss is the greatest land cover loss the study area has experienced from 2000 to 2020. Despite the loss of shrubland between 2000 & 2010, it was witnessed to gain a land sum of 1.7% between 2010 & 2020. Grassland has turned out to be the only land cover to maintain its increasing trend between the two-time series 2000–2010 and 2010–2020 with a net gain of 12.8% and 4.8% respectively. Its net gain in 2000–2010 is the most land cover gains the study area has ever had. Woodland is observed to decrease in all study periods with a net loss of -10.4% and -0.8% in 2000–2010 and 2010–2020 respectively. Waterbody experienced a net gain of 3.5% between 2000 & 2010, though it remained the least dominant and declining land cover throughout all the study periods with a class area of 15304 ha, 16173 ha, and 3840 ha in 2000, 2010 and 2020 respectively. Bareland/impervious as the only land use class in the study area, had an increase in share of land between 2000 & 2010 with a net gain 9.7%. On the other hand, the land use class experienced a minor net loss of -0.5% between 2010 & 2020.

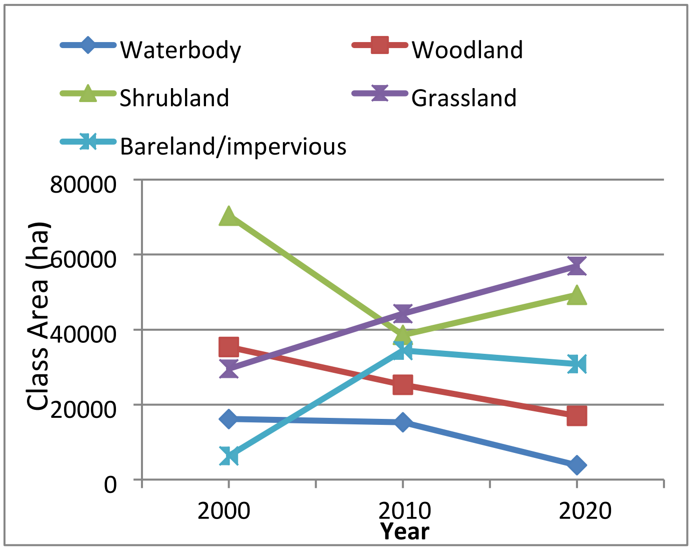

Figure 3.3: class area metric at class level

3.2.2 Number of Patches (NP)

During the first-time interval (2000-2010) only bareland/impervious experienced an increase in number of patches as it has gained 1769 patches from the initial of 4092 patches in 2000 and a final of 11261 patches 2010 (Figure 3.4). On the other hand, land cover classes such as waterbody, woodland, shrubland and grassland had a decrease in the number of patches during the same time interval. Woodland turned out to be the land cover class that has experienced the most decrease in number of patches as it has lost 12335 patches during the firsttime interval. Similarly, bareland/impervious has maintained its increasing trend in the number of patches. Woodland and waterbody maintained the decreasing trend in number of patches during the second time interval (2010-2020).

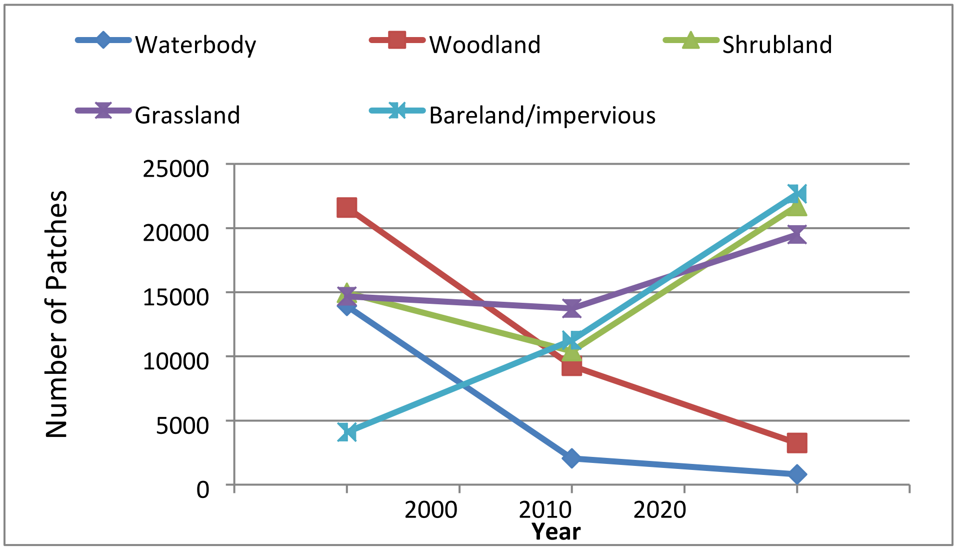

Figure 3.4: Number of patches metric at class level

3.2.3 Largest Patch Index (LPI)

In 2000 the largest patch index was found in shrubland with a percentage of 36.1 while in both 2010 and 2020 the largest patch index was found in grassland at a percentage of 20.7 and 13.8 respectively (Figure 3.5).

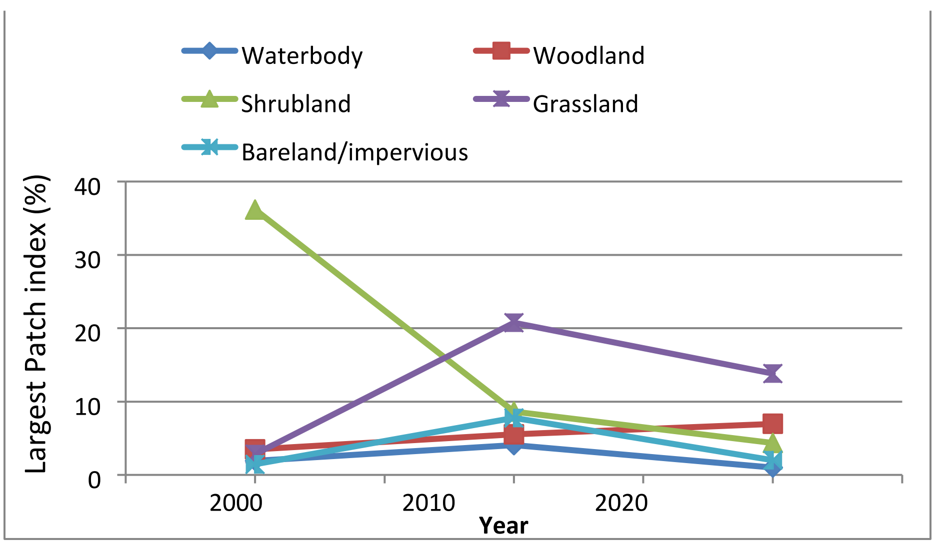

Figure 3.5: Largest patch index metric at class level

3.2.4 Aggregation Index (AI)

The study area landscape was evaluated to have been more aggregated in 2010 at a rate of 81.9% while in 2000 and 2020 the aggregation index was sitting at 74.6% and 71.7% respectively (Figure 3.6a). The final study period (2020) had the least aggregation index among other study periods.

3.2.5 Landscape Splitting Index (LSI)

The highest landscape splitting index is found in the final study period (2020) with a percentage of 33.3 while in 2000 and 2010 the landscape splitting index was sitting at 7.4 and 14.1 respectively (Figure 3.6b).

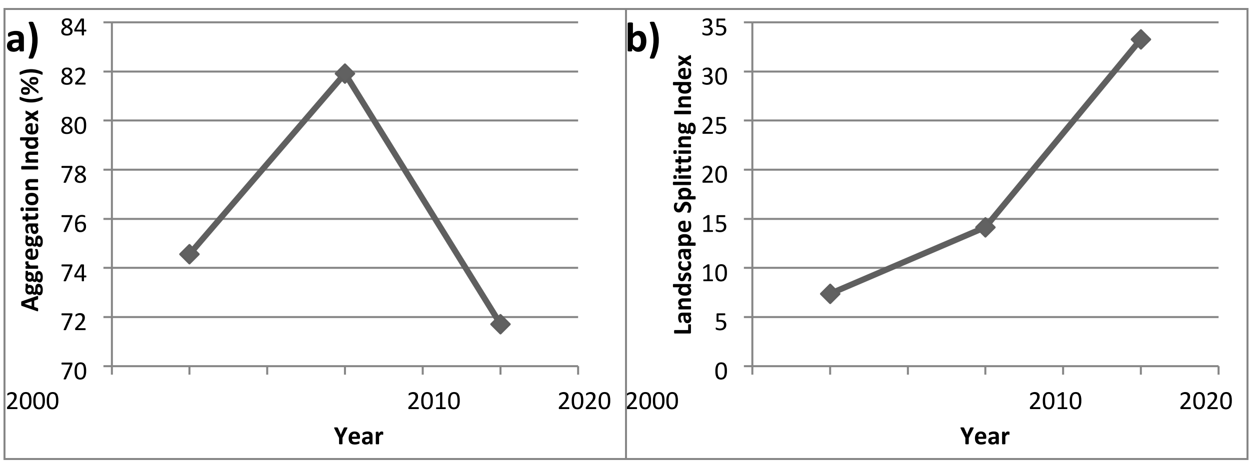

Figure 3.6: Landscape metrics; a) aggregation index and b) landscape splitting index at landscape level.

3.3 Human Elephant Interaction

The survey had a total of 57 respondents who were questioned on land use, human elephant interaction. Respondents had various education backgrounds, age structure, perception and their level of understating also differed. The survey has established three land use categories being settlement, arable farming and pastoral farming (Figure 3.7). All the respondents reside in the Chobe enclave's five main villages, Mabele, Kavimba, Kachikau, Satau and Parakarungu.

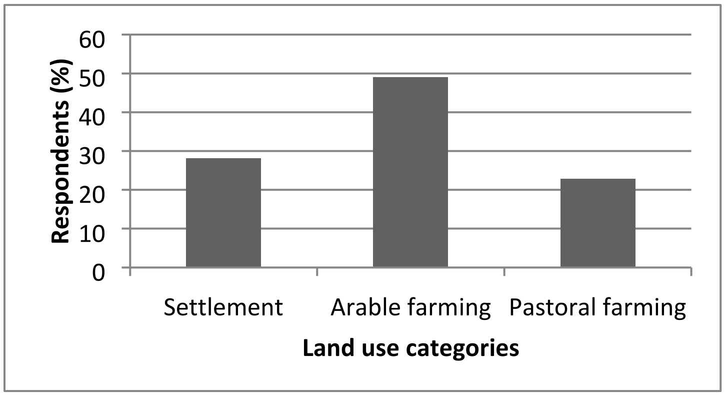

Figure 3.7: Land use by respondents

3.3.1 Chobe Enclave Key Informant's Perception on Land use Change

Land users' demographics such as sex, age structure, source of income and perception on land use change were sought and represented in (Table 3.3). The survey had more males (78.9%) than females (21.1%) who took part. Most of the respondents (61.4%) belong to the 45+ age group and the youngest person interviewed had 27 years while the oldest had 81 years. Respondents generated their income in various ways though most of them generated their income through subsistence farming (73.7%), particularly arable farming. Almost all (91.2%) of the respondents confirmed land use-land cover changes in the Chobe enclave since 2000 until 2020 while 8.8% were not certain about the change of LULC in the Chobe enclave. Most of the respondents believed the cause of change in LULC to be expansion in human settlement (54.4%).

Table 3.3: land users demographics and perception on land use change

Information sought	**Categories**	**Number of responses**
Sex	Male	n=45 (78.9%)
	Female	n=12 (21.1%)
Age	18 – 29	n=7 (12.3%)
	30 – 45	n=15 (26.3%)
	45+	n=35 (61.4%)
Source of income	Tourism/fishing	n=5 (8.8%)
	Subsistence farming	n=42 (73.7%)
	Commercial farming	n=3 (5.3%)
	Other	n=7 (12.3%)
Observed LULC dynamics	Yes	n=52 (91.2%)
	No	-
	Not sure	n=5 (8.8%)
Causes of LULC dynamics	Expansion In human settlement	n=31 (54.4%)
	Veld fires	n=17 (29.8%)
	Long Drought	n=9 (15.9%)

3.3.2 Socio-economic Impacts of Human Elephants Interaction

To adequately assess the socio-economic impacts of human elephant interaction in the study area, respondents were questioned on how HEI has affected them and, if they have received financial compensation from the government (Table 3.4). The survey has revealed among the 42 respondents affected by HEI, most of them were exposed to property destruction (38. 6%) and crop raiding (33.3%). The respondents believed human elephant conflict to be caused by increase in both land use and elephant population (50.9%). Even though almost all the respondents (89.5%) revealed that they are not free to roam around the study area in fear of elephant attacks, most of them had a positive attitude towards elephants, as they perceived them as a source of tourism (70.2%). About 36.8% of the affected respondents stated that they have received financial compensation from the government while 63.2% did not receive any form of financial compensation from the government.

Table 3.4: Human elephant conflicts and land users' perception towards elephants

Information sought	Categories	Number of responses
Affected by HEC (n=42)	Crop raiding	n=19 (33.3%)
	Property destruction	n=22 (38.6%)
	Injury	n=1 (1.8%)
	Death	-
	Not affected	n=15 (29.3%)
Causes of HEC	Increase in elephants' population	n=21 (36.8%)
	Increase in land use	n=7 (12.3%)

	Land use change & increase in elephant population	n=29 (50.9%)
Social Impacts of HEC	Fear of roaming freely	n=51 (89.5%)
	Hatred towards elephants	n=2 (10.5%)
	Calm	-
Perception towards elephants	Problem animals	n=17 (29.8%)
	Source of Tourism	n=40 (70.2%)
Financial compensation from Government (n=42)	Received	n=21 (36.8%)
	Did not receive	n=36 (63.2%)

The human elephant conflict annual frequency that was obtained from the Department of Wildlife and National Parks (DWNP) as secondary data is well represented in (Table 3.5 and Figure 3.6). Chobe enclave land users seem to have been adversely affected by human elephant interaction more in 2020 with 155 HEC reported cases while in 2010 there were 71 reported cases of human elephant conflict. The study area has experienced a 37% increase in human elephant conflicts reported cases between 2010 and 2020 with dominance in property destruction in 2010 (50.7%) and crop raiding in 2020 (54.8%) by elephants.

Table 3.5: Impacts of human elephant interaction annual frequency

	Frequency	
Impacts of HEI	**2010** (n=71)	**2020** (n=155)
Crop raiding	35 (49.3%)	85 (54.8%)
Property destruction	36 (50.7%)	70 (45.2%)

Figure 3.8 below depicts the monthly frequency of property destruction and crop raiding conflicts reported in 2010 and 2020. In accordance with HEI monthly frequency data, human elephant interaction took place throughout the year in both 2010 and 2020. The results were obtained as secondary data from the Department of wildlife and national parks (DWNP). For both study periods the human elephant conflicts reported cases took place more in the post wet season (April) and during the hot dry season (August – October). More cases were recorded during the hot dry season in 2010 (Figure 3.8a) while in 2020 more cases were recorded during the post wet season (Figure 3.8b).

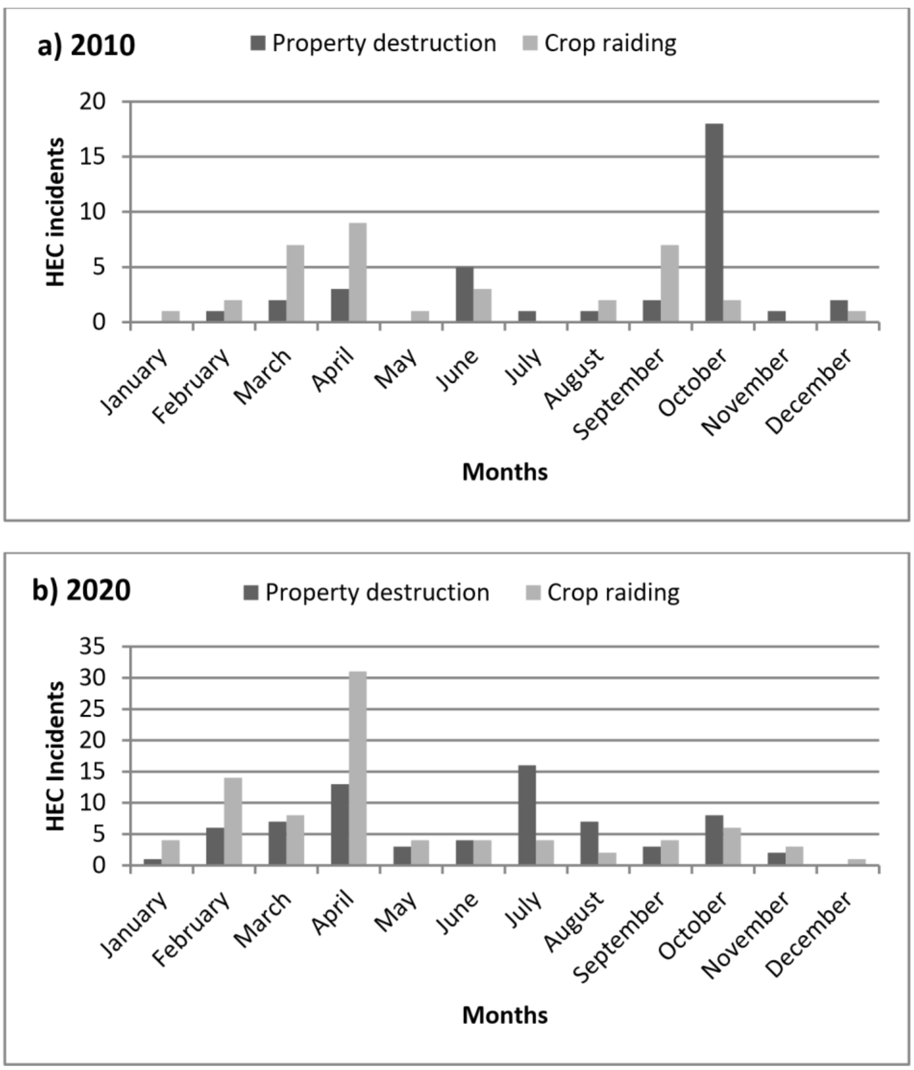

Figure 3.8: impacts of human elephant interaction monthly frequency

3.4 Elephant Migratory routes

A total of six elephant migratory routes namely A, B1, B2, C, D and E were identified to pass through the landscape of the Chobe enclave (Figure 3.9). The elephant migratory routes represent the movement of elephants between the Chobe national park and the Cuando-Linyanti River which forms an international border with Namibia. Human settlement is represented by arable land and kraals. The elephant population density data was collected as secondary data from the Department of Wildlife and National Parks. Elephant population densities depict the population of elephants per square kilometre. Most elephants were noted to be more concentrated within the elephant migratory route C.

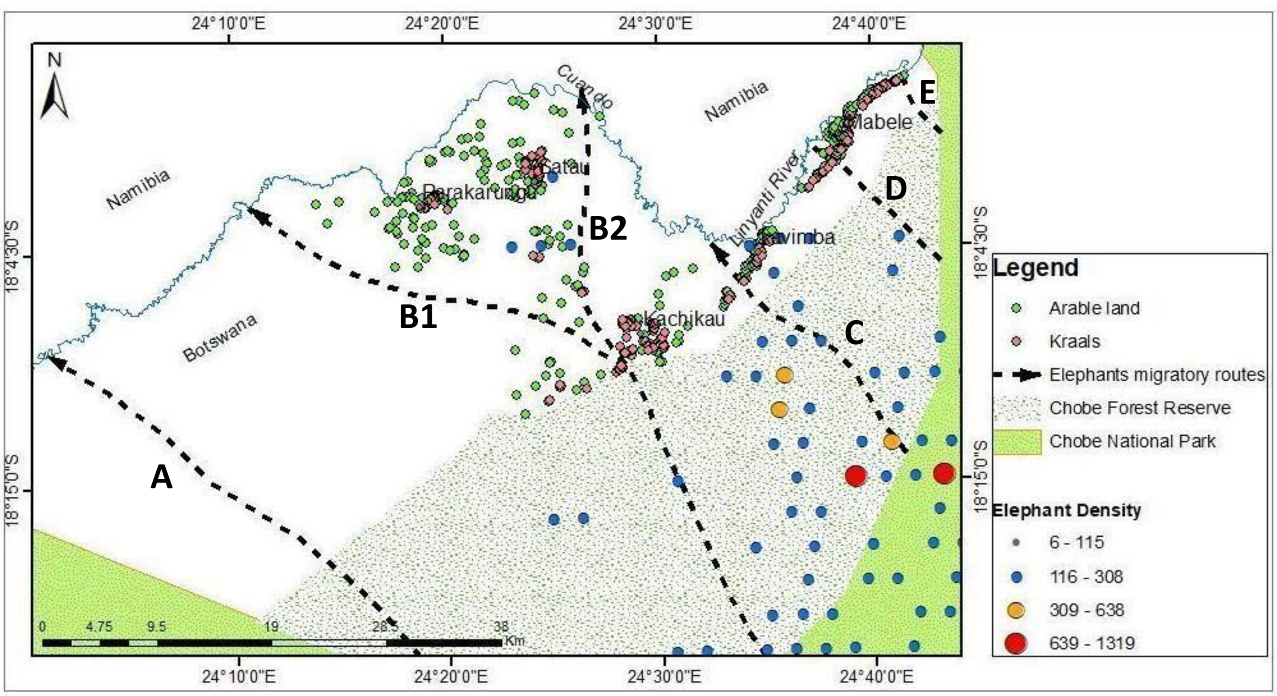

Figure 3.9: Elephants migratory routes.

3.5 Human Elephant Conflict Hotspots

The map below represents the land use derived human elephant conflict hotspots (HECH) in 2000 & 2020 and indigenous knowledge derived HEC hotspots (Figure 3.10). Rapid increase in HEC hotspots were noticed between 2000 & 2020 (Figure 3.10d) particularly in areas designated to arable land more especially in those proximate to water bodies. The indigenous knowledge derived HECH map (Figure 3.10f) represents confirmation of respondents to land use derived HECH and additional HEC hotspots along the (B2) elephant migratory routes passing near Kachikau towards wetlands not far from Satau.

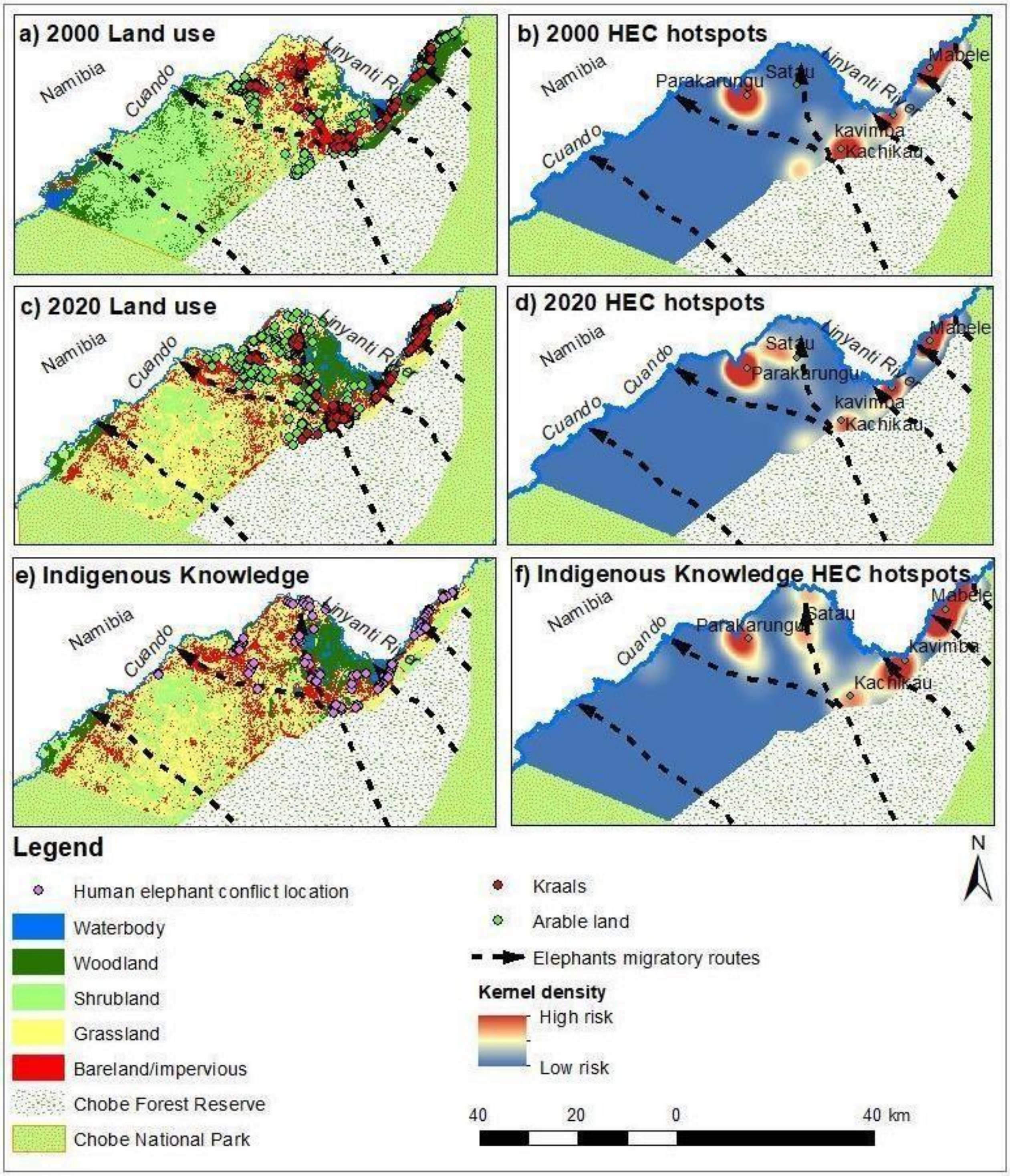

Figure 3.10: Human elephants' hotspots for the study period 2000, 2020 and indigenous knowledge represented in a), b) and c) respectively.

Chapter 4

Discussion

4.1 Land Use-Land Cover

4.1.1 LULC Time Interval Intensity

The study area was classified into two-time intervals with 2000-2010 being the first and 20102020 as the second time interval. The first-time interval experienced a rapid LULC change of about four times higher than the second time interval. Rapid LULC change is deduced to be due to natural environmental factors such as frequent veld fires, flooding, tree raiding by elephants, and human population growth (Fox et al., 2017). Grassland remained the dominant land cover in both the time intervals even though it has shown a decline during the second time interval. Reduction in grassland's land share during the second time interval is attributed to a shift in vegetation cover as a result of favorable climatic conditions hence shrubs, herbs and trees blooming. On the other hand, waterbody remained the least dominant land cover in all time intervals, and it experienced further decline in its share of land during the second time interval. The root of most transposes in land cover, more specifically water bodies in Botswana, is believed to be the aftermath of erratic rainfall patterns (Statistics Botswana, 2019).

4.1.2 Land use-land cover Change

Woodland and shrubland have experienced a great loss with shrubland being severely affected. The distribution of woodland is witnessed to be in riparian zones and along the area designated as forest reserve. Rodrigues et al (2018) argued that distribution of vegetation cover is influenced by the type of soil cover. The study area comprises chernozem and arenosols soil

(Romanens et al., 2019) and their distribution seems to correspond with the distribution of woodland in the study area. This was also validated by Hartemink & Huting (2008), who stated that most arenosols in southern Africa are dominated by woodland and forest. During the firsttime interval, woodland loss was mainly associated with over browsing and destruction brought by elephants in riparian zones especially during the dry season (Nichols et al., 2017). In dry areas of the study area, woodland and shrubland loss is mainly attributed to frequent veld fires that occur mostly during the dry season especially on the southwestern part of the study area (Fox et al., 2017). The other cause of vegetation loss in the study area is introduction/increase in agricultural land along the floodplains of the Cuando-Linyanti River and It adversely impacts the environment as trees are deforested in preparation for these farming lands. Alteration of the natural environment leads to a change in the structure and loss of habitats (Flowers & Huang, 2020). Despite loss of trees during the overall study period, shrubland has recovered during the second time interval at the expense of grassland. This is considered to have been due to improvements in climate variables, particularly an increase in rainfall (Akinyemi, 2017).

In the early 2000s, bareland/impervious was mostly distributed with human settlement and agricultural land on the northern side of the study area with low patches of bare degraded lands in the middle of the study area. To date, those human settlement areas are still dominated by human activities. Human beings in the Chobe enclave reside near the continuous river system of the Cuando-Linyanti River and some of their arable lands are situated along the floodplains of the river. Bare degraded lands exponentially increased (Figure 3.3) towards the southern side of the study area in 2010 and 2020 due to frequent floods causing runoff, soil erosion, land degradation (Burke et al., 2016) and frequent veld fires (Fox et al., 2017). Bareland/impervious has shown an increase in the study overall time interval (2000 – 2020), even though a slight decrease was noticed during the final study period (2020) of this study. Bareland/impervious net loss is explained as a response to regeneration of vegetation cover in bare degraded lands due to suitable climatic conditions of high precipitation (Akinyemi, 2017). The study area experienced an increase in human population within the time frame of the study (Statistics Botswana, 2022) and it comes with adverse environmental impacts such as loss of vegetation cover (Matlhodi et al., 2019) as new virgin shrubland/woodland are being opened to cater for human settlement and agricultural land. Farmers in the Chobe enclave deem the Cuando-Linyanti River floodplains as suitable land for farming as the land comprises high fertile alluvial soils and it is near the water source for irrigation of plants. Despite the floodplains being suitable for agricultural land, some farmers have fled to farm near their homesteads where elephant's movement is minimal, far away from the river plains in fear of elephant crop raiding (Gupta, 2011). Bareland/impervious patches situated along the CuandoLinyanti River floodplains are bare degraded land mostly from agricultural land on fallow period and retreatment of water bodies, thereby exposing the bare degraded land. Akinyemi & Mashame (2018) also found the same when they analysed land use change in dry land agricultural landscapes in an area situated about 661.1 km, southeast away from the Chobe enclave. Their study concluded that changes between waterbody and bareland are not permanent as these changes are affected by river flow and precipitation.

Waterbody has suffered a great loss in the floodplains of the Cuando-Linyanti River though an increase in its spatial extent was recorded in 2010 at the expense of other land cover, mainly the riparian woodland and grassland. Similarly, waterbody has lost its share of surface area mainly to woodland during the second time interval. Fluctuations in the spatial extent of water bodies are explained as a response to semi-arid climatic conditions such as inconsistent rainfall patterns (Statistics Botswana, 2019). Botswana has experienced a decrease in annual rainfall that has affected almost all parts of the country in recent years (FAO, 2015). Increase in water bodies is due to improvements of climate change, particularly above average rainfall that were recorded in the study area in January 2008 (Beilfuss, 2012). The above normal rainfall led to flooding, hence flood waters extending to places that had been dry for about four decades (Bosch, 2011). In support of the finding of this study, Burke et al (2016) argued that extensive flooding that occurred in 2009 and 2010 in the Chobe River basin had adversely impacted drylands around the Chobe enclave. These floods are associated with destruction of remote roads, crops and human habitat in the Chobe River basin.

4.2 Landscape Fragmentation

Land use-land cover change within the study area, during the periods of the study (20002020) shows that the landscape is characterized by massive fragmentation including loss and reduction of habitats. These results coincide with landscape metrics results. Quantification and characterization of landscape patterns at class and landscape level using landscape metrics has shown, increase in number of patches, landscape splitting index and decrease in class area, largest patch index, and aggregation index. According to Laurance et al (2010) and Leitao & Ahern (2001) the above stated trends of landscape distribution and configuration are indicators of a fragmented landscape.

Fragmentation is the breaking down of larger landscape patches into smaller and isolated patches (Midha & Mathur, 2010). Fischer & Lindenmayer (2007) have viewed landscape fragmentation and degradation as the leading factor of biodiversity loss. Landscape fragmentation is occurring almost in the entire Chobe enclave due to severe seasonal flooding, frequent veld fires, elephant tree raiding and human activities. Fragmentation and loss of habitat occurring between the Chobe national park and the Cuando-Linyanti River is induced by the growing human population (Statistics Botswana, 2022) hence the exploding demand for land to grow crops and rearing livestock (Semwal, 2005). The impacts of landscape fragmentation include but are not limited to habitat loss and disturbance in ecosystem services (Midha & Mathur, 2010).

Expansion of bare degraded land and human settlement class area and number of patches between 2000 and 2020 has resulted in loss and fragmentation of vegetation covers such as grassland and shrubland. Landscape fragmentation has resulted in displacement of elephant habitat and obstruction of elephant migratory routes with arable land and cattle posts. Most of landscape fragmentation on the southern part of the study area is attributed to bare degraded lands as the land mass is mostly frequented by wild fires (Fox et al., 2017) with low human activities. While fragmentation on the northern side of the study area is a result of human activities as the area is dominated by human settlements and farming. Even though human activities had a minimal impact on the overall fragmentation of the landscape as compared to bare degraded areas, their impacts are significant especially in human-elephant interaction areas.

Despite habitat loss and landscape fragmentation, through increase in the largest patch index and class area, the study area's shrubland had dominance in the first study period. According to Sianga & Fynn (2017) the distribution of shrubland represents dominance of the *Colophospermum mopane* shrubs in the south-western part of the study area. This is an indication that the study area during that time experienced fewer disturbances as compared to the next two study periods where shrubland was witnessed to retreat due to severe environmental impact such as elephant tree raiding, veld fires and climate change. Land use-land cover results have shown reduction in the distribution of woodland and waterbody mostly in the floodplains and riparian zones of the Cuando-Linyanti River. Both land cover showed the same attributes of decreasing class area and number of patches. Tang et al (2006) observed a similar scenario in Daging city, China when analysing urban sprawl spatial fragmentation using multitemporal satellite images. They found that there was a decrease in both class area and number of patches of wetland and woodland thus indicating a gradual shrinkage of these landscapes. They concluded that most of the woodland and wetland fragmentation occurred in the wetland landscape.

Fragmentation of the overall landscape of the Chobe enclave is shown by the decrease in aggregation index and increase in landscape splitting index between 2000 and 2020. Aggregation index is used to measure the degree to which the landscape has brought together loosely separated patches (McGarigal et al., 2012) while the landscape splitting index measures the level to which patches and LULC classes have been fragmented (Plexida et al., 2014). The overall yield of landscape fragmentation is a collection of the LULC class heterogeneity and interactions that were taking place at patch and class level. Landscape metrics are dependent on class metrics, so in order to understand the landscape of a certain area class metrics ought to be adequately understood (Cushman et al., 2015). The results obtained at landscape level have corresponded well with those obtained at class level. Decrease that was recorded in aggregation index between 2000 and 2020 is characterised by increase in number of patches, landscape splitting index and a decrease in class area, largest patch index. According to Sertel et al (2018) a decline in aggregation index is a good indicator of fragmenting landscape. Fragmentation in the landscape is a result of increased population growth in a rural area where the livelihoods of residents are based on subsistence farming (Silitshena et al., 1998) and veld fires (Fox et al., 2017).

4.3 Human Elephant interaction

4.3.1 Key Informants Perception on Land use and Human-Elephant Interaction

Across all the Chobe enclave's five main villages, respondents pointed out land use-land cover change to be taking place. They also argued that the change in land use-land cover is mostly induced by humans through farming and settlement even though the area's land cover is sometimes affected by elephants and wild fires. Some key informants stated that they have witnessed elephants taking down trees and sometimes de-bark trees such that the tree will gradually dry out and eventually fall. These findings are in line with that of Fox et al (2017) and Chomba & Banda (2016).

About 90% of the respondents argued that human-elephant interaction is an ongoing activity in the Chobe enclave. According to Adams (2020) the Chobe enclave residents share space and resources with a total of about 8800 elephants and the area is described as a human elephant conflict hotspot. About 70% of respondents claimed that land use-land cover change has an influence on human-elephant interaction. Increase in the spatial extent of land use-land cover and landscape fragmentation escalates the probability of getting in contact with free roaming elephants as they move. Human activities in the Chobe enclave, particularly arable land on the floodplains of the Cuando-Linyanti River, found their place in elephant habitats and elephant migratory routes. Precisely 96% of respondents argued that the Chobe enclave and the surrounding areas have been the home for elephants' way before humans inhabited the area. One of the elders argued that human-elephant interaction has been a common phenomenon, even though it was not much common around the 1940s-1970s during their youth as compared to today. Those are times when most of the landscapes in Botswana were less fragmented with low human population.

Respondents further indicated that elephants visit their villages all the time, especially at night. According to Adams et al (2020) elephants move through human dominated landscapes of the Chobe enclave at night and more especially during the dry season to access the continuous river system. One of the key informants indicated that since Chobe enclave villages are situated between two eco-rich habitats, elephants are triggered to pass through villages as they connect between the Chobe National Park and the Cuando-Linyanti River. About 93.1% of respondents assumed that an increase in human-elephant interaction is due to the government's decision to ban trophy hunting in 2014. They also indicated that ever since then, HEI kept on increasing as elephant visits to human land use were becoming more frequent.

4.4 Impacts of Landscape Fragmentation on Human-Elephant Interaction

The presence of arable land, human settlement and cattle posts within the elephant home range are signs of habitat fragmentation. The northern part of the study area is dominated by human activities such as arable and pastoral farming. In the Chobe enclave it is common for elephants to share space and resources with humans (Garvin, 2017). Landscape fragmentation through human activities more especially within elephant habitats and in areas proximate to elephant migratory routes have led to increased human-elephant interaction. Availability of human activities within animal habitats is a major concern in ecology as it poses threat to biodiversity and ecosystem processes (Flowers & Huang, 2020). Landscape fragmentation in areas where HEI is common has brought about ecologically challenging problems such as obstruction of elephant migratory routes, loss of habitat through displacement by human homesteads and arable farms. Human-elephant interactions in local villages where most of the land users sustain their livelihoods through subsistence farming is a challenging case as human elephant conflict is inevitable. More especially in the northern Botswana where elephants are allowed to move freely for transboundary reasons and even distribution of elephants to avoid depletion of some resources (DWNP, 2016). The Chobe enclave is situated within the largest transfrontier conservation area in the world called the Kavango Zambezi Transfrontier Conservation Area (KAZA-TFCA). The conservation area is a partnership between five Southern Africa countries namely Botswana, Zimbabwe, Zambia, Namibia and Angola. KAZA-TFCA allows for elephants to access any ecologically significant area within the five countries (Stoldt et al., 2020).

Through elephant migratory routes, elephants pass through fragmented landscapes in the Chobe enclave on their way from the Chobe National Park towards the Cuando-Linyanti River to access the palatable grass on the floodplains of the river and permanent waters and some cross over into Namibia (van Aarde et al., 2021). While in movement, elephants are being lured into arable lands within their habitat and those adjacent to elephant migratory routes through smell and sight (Gross et al., 2017). Areas with high probability of human elephant conflict are designated as human elephant conflict hotspots. In the Chobe enclave most of the HEC hotspots are found within fragmented landscapes with high human-elephant interaction. The expansion of human elephant conflict hotspots is as a result of increase in landscape fragmentation and land use conflict between humans and elephants (Billah et al., 2021).

Delineation and marking of human elephant conflict hotspots is vital for alerting humans about the danger that has the ability to injure and take away life (Chen et al., 2016).

Discussion

According to the HEC secondary data obtained from the Department of Wildlife and National Parks, most of the reported cases took place within the fragmented landscapes. Almost all HEC reported cases took place in arable land and cattle posts through property destruction and crop raiding. For both study periods 2010 and 2020, the human elephant conflicts reported cases took place more in the post wet season (April) and during the hot dry season (August – October). More cases were recorded during the hot dry season in 2010 while in 2020 more cases were recorded during the post wet season. Frequent HEC incidents in the hot dry season are as a result of movement of elephants from the Chobe National Park to the river when most of ephemeral water bodies had died out within the park. On the other hand, a rise in HEC incidents during the wet season when plants are about to ripen, elephants are lured into arable lands (Gross et al., 2017) when on the way to the river and or Namibia. Despite the land use conflict risk the Chobe enclave farmers are exposed to, they are still involved in farming. Farmers are attracted by the fact that the study area is one of the areas in the country receiving high rainfalls and the Government of Botswana through the Integrated Support Programme for Arable Agriculture Development (ISPAAD) is assisting farmers with seeds, fertilizers, herbicides and ploughing (Motlhwa et al., 2019).

4.5 Impacts of HEC on Socio-economic welfare of local communities

Almost all the respondents stated that they interact with elephants regularly in the Chobe enclave and it has adversely affected them mentally, economically, and physically. They added that they live in a curfew as they are forced to be inside their homesteads during dark hours and fear resides in their hearts as they are ever afraid of being raided by elephants they live with. One of the affected farmers indicated that elephants' movement has brought about a wide range of damages such as property destruction, crop raiding, injury and sometimes death on both humans and domesticated animals. This finding is also shared by Adams et al (2016) and Garvin (2017). Respondents stated that crop raiding is very common between July to December especially when plants are about to ripen in most cases at night as elephants' rest under tree shadows during the day and seek food at night. Another affected farmer explained that sometimes elephants visit their villages not only to access the river but to raid their crops as they are much more palatable to what the natural environment is offering. One of the respondents in Parakarungu also added that elephants have destroyed his fishing nets to an extent that part of it was carried away by the river flow. Through human-elephant conflict, residents in the Chobe enclave are suffering from indirect financial losses (Jones, 2002).

A single parent in Satau indicated that women as heads of families such as herself are the most hit by the impacts of human-elephant interaction as they struggle the most. She expressed that, some farmers especially single parents' women have deserted their farms situated along the Cuando-Linyanti River and shifted to small scale farming behind their homes as they could not afford to live in their fields as practiced by most farmers in the Chobe enclave to deter elephants crop raiding at night. She further indicated that all her children went to work in town while some went to attend school away and she stays with kids less than 10 years of age hence making it difficult to practice large scale farming as it is time consuming and risky in the area. She added that she is using firewood to cook and warming up water for bathing therefore she is forced to hire someone to collect firewood for her as she is afraid of being raided by elephants in the woodland.

Despite all the adverse impacts brought by elephants to humans, a significant number of respondents still perceive elephants to be of good value to them as they are a source of tourism hence, they bring income for the community and the country at large. Farmers experiencing elephant crop raiding pointed out to report HEC incidents at the Department of Wildlife and Nationals Parks (DWNP). Based on the magnitude of the damage caused by the elephant, they receive compensation from the government. Farmers in the Chobe enclave have evolved ways to deter elephant crop raiding using firearms to scare elephants while others collide corrugated iron with any metal block to produce a disturbing sound for elephants. They have indicated that the methods tend to be working for them though they are tedious and time consuming.

Chapter 5 Conclusion

This study investigated the heterogeneity of LULC patterns, their interaction and later characterized and quantified landscape fragmentation in order to assess its impacts on human elephant interaction. The Chobe enclave has been subjected to land use-land cover change between 2000 and 2020 as a result of natural factors and anthropogenic activities. The first-time interval (2000 & 2010) experienced a rapid LULC change of about four times higher than the second time interval (2010 & 2020). Shift in LULC patterns is deduced to be due to natural environmental factors such as frequent veld fires, flooding, tree raiding by elephants, and human population growth. In overall there was significant decline in all land cover except for grassland which had a net gain of 27 730 ha (17.6%) while the decline in share of land for waterbody was sitting at -2 440 ha (-1.6%), woodland at -17 610 ha (-11.2%) and shrubland at -22 180 ha (14.0%). Bareland/impervious had a net gain of 14 500 (9.2%) due to emergence of bare degraded land as a result of frequent veld fires the study area is ever receiving and expansion in human activities. The above-mentioned factors are exactly what has led to the major decline in most vegetation cover and habitat fragmentation. Despite the LULC overall trend, shrubland dominated in 2000 by a land share amounting 70 383 ha (45.2%) while in 2010 and 2020 the landscape dominance was shifted to grassland 44 270 ha (29.5%) and 56 935 ha (31.2%) respectively. Shift in vegetation cover is attributed to climate change and land use intensification. The root of most transposes in land cover in Botswana, is believed to be the aftermath of erratic rainfall patterns (Statistics Botswana, 2019).

Conclusion

Expansion of arable, human settlement and cattle posts within the elephant home range are signs of habitat fragmentation and land use conflict. Human activities in the Chobe enclave expanded into elephant habitats and in areas proximate to elephant migratory routes leaving the landscape severely fragmented. Landscape fragmentation was characterized and quantified using landscape metrics at class and landscape level to measure the distribution and arrangement of landscape patterns. The Chobe enclave landscape resembles attributes of a fragmented landscape as there were increase in number of patches, landscape splitting index and decrease in class area, largest patch index, and aggregation index. Most of the landscape fragmentation on the southern part of the study area is attributed to bare degraded lands caused by veld fires and climate change While fragmentation on the northern side of the study area is as a result of human activities. Landscape fragmentation increased over years with land use-land cover change. The 2020 study period was proven to be more fragmented as compared to the 2000 study period. Through identification of elephant's migratory routes and observations, elephants were noticed to move to and fro the Chobe National Park through fragmented landscapes to Cuando-Linyanti River and Namibia. The land use expansion exposes Chobe enclave land users to indirect financial losses through property destruction by elephants, crop raiding, injuries and fear. Most human-elephant conflict encounters take place during the post wet season (April) and during the hot dry season (August-October) when most ephemeral water bodies have dried up in the Chobe National Park. Most human-elephant conflict encounters were recorded during the final study period 2020. Human elephant conflict hotspots positively correlate with landscape fragmentation; increase in landscape fragmentation gave rise to human elephant conflicts hotspots.

Conclusion

Landscape metrics based on classified images is a promising and cost-effective technique for characterizing and quantifying landscape fragmentation. Landscape metrics analysis method can aid in assessing landscapes in wildlife dominated areas such as northern Botswana for sustainable conservation strategies, management of habitats and human elephant conflicts resolution. There is a need for a new management approach in the Chobe enclave due to the increase of HEC incidents in fragmented landscapes. The study proposes that wildlife migratory routes in the Chobe enclave be marked and incorporated in land use plans and zones to avoid further habitat fragmentation and expansion of land use into them. Allocation of agricultural land in the Chobe enclave should be considered on areas far from the floodplains of the CuandoLinyanti River and elephant migratory routes. Agricultural land in the banks of the river should be reallocated to areas less affected by land use conflict between humans and elephants. Relevant institutions should continue to sensitize local community residents about human elephant coexistence strategies for human welfare and elephant conservation.

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Appendix

Interview questions

1. Who is the interviewee?
2. When was the interviewee born?
3. How long have the interviewee been living in the Chobe enclave?
4. How does the interviewee sustain his/her livelihoods?
5. Is the village experiencing human-elephant interaction?
6. How long has human-elephant interaction existed in the Chobe enclave?
7. How frequent do elephants visit/pass through human settlement?
8. Why are elephants visiting or passing through Chobe enclave human settlement?
9. Between the day, night and all the time, when do elephants visit/pass through human settlement?
10. Between the dry, wet season and all the time, when do elephants visit/pass through human settlement?
11. How is the relationship between elephants and humans?
12. What changes has humans brought to the natural habitat?
13. What changes has elephants brought to the environment?
14. How do elephants affect the human welfare?
15. How do human beings affect elephant's well-being?
16. Is there a trend in human movements among/through Chobe enclave villages?
17. What do you suggest could be done to reduce the human-elephant interaction in the

Chobe enclave?

Appendix

18. What do you suggest could be done to mitigate the human-elephant conflict in the Chobe enclave?

19. Where do people report incidents of human-elephant conflict?

20. How did the Chobe enclave land use-land cover change over the past 20 years from 2000 until 2020?

21. What are the main causes of the change in land use-land cover?

22. How does land use-land cover change influence human-elephant interaction.

23. How often do veld fires occur in the Chobe enclave?

24. Between humans, elephants and veld fires what are the main causes of the change in vegetation cover?