Universidade de
Aveiro
2021

MARKUS SHIWEDA

CLIMATE CHANGE AND ANTHROPOGENIC FACTORS INFLUENCE ON HABITATS LOSS AND EMERGING ELEPHANT HUMAN CONFLICT IN NAMIBIA

INFLUÊNCIA DE ALTERAÇÕES CLIMÁTICAS E ANTROPOGÉNICA NA PERDA DE HABITATS E EMERGÊNCIA DE CONFLITO HOMEM ELEFANTE NA NAMÍBIA

Universidade de Aveiro
2021

MARKUS SHIWEDA

CLIMATE CHANGE AND ANTHROPOGENIC FACTORS INFLUENCE ON HABITATS LOSS AND EMERGING ELEPHANT HUMAN CONFLICT IN NAMIBIA

INFLUÊNCIA DE ALTERAÇÕES CLIMÁTICAS E ANTROPOGÉNICA NA PERDA DE HABITATS E EMERGÊNCIA DE CONFLITO HOMEM ELEFANTE NA NAMÍBIA

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia Aplicada, realizada sob a orientação científica do Doutor Mário Jorge Verde Pereira, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro

This research report is part of a research conducted in Namibia under the research permit of the National Council on Research, Science and Technology, research number RPIV01042040

I dedicate this work to my wife and daughter for offering me enough time to be in the field and office to conduct research work!

o júri

presidente

Prof. Doutora Maria Helena Abreu Silva
Professora Auxiliar, Departamento de Biologia, Universidade de Aveiro

Arguente

Prof. Doutora Edna Carla Janeiro Cabecinha da Câmara Sampaio
Professora Auxiliar, Departamento de Biologia e Ambiente, Escola de Ciências da Vida e Ambiente, Universidade de Trás-os-Montes e Alto Douro

Orientador

Prof. Doutor Mário Jorge Verde Pereira
Professor Auxiliar, Departamento de Biologia, Universidade de Aveiro

Agradecimentos/ Acknowledgements

I would like to thank my research supervisor, Professor Doctor Mario Pereira, for his guidance and commitment to always helping me with research design, scientific advice. Completing this research manuscript was crucial for establishing a foundation for future PhD research in Namibia and other Southern African countries.

The entire EHRA team is thanked for being supportive during my employment as a Field, Conservation and Research Manager and the Project Manager, which was made easy through the field team's daily support. EHRA has also offered me time off to attend classes in Portugal over two years, signing an agreement to host my future research and using the company data in my future research studies. On the other hand, this study report established research evidence-based solutions for NGOs like EHRA and the government involved in managing and preventing HEC in the two regions.

I would also like to thank, Fillipus Shivute whom I have known since our studies at NUST. Having been involved in underground water projects with GIZ and currently assisting the Ministry of Agriculture, Water and Land Reform, and Apex Geospatial-Intelligence Services, he has supported me with locating spatial science data in the field of natural resources.

I appreciate the Ministry of Environment, Forestry and Tourism, especially Mr Kenneth Uissed for sharing important information such as the Elephant Conservation Master Plan and Elephant Conservation documents in Namibia.
Finally, the local farmers and conservancy members and their community-based enterprises are thanked for helping establish a general picture of the situation using their substantial knowledge of the area. I look forward to working with them with my research team during our field visits, ultimately contributing primary data for future ecological preservation and sustainable community livelihood.

Keywords

Desert-dwelling elephants, remote sensing, biomass, home range, habitat loss, Human-Elephant Conflict, Namibia

Abstract

Human societies' growing concern about climate change, adverse effects on global biological systems, and the pace at which damage resolutions is taking place may prove insufficient, however slow, given the speed at which those changes are happening. Since some regions are more vulnerable than others, the need to act quickly before key species are lost is highly recommended. The International Union for Conservation of Nature (IUCN) reclassified in early 2021 the elephants of the African savannah *Loxodonta africana* and the elephant from the African forest *Loxodonta cyclotis* as endangered and critically endangered on the Red List. This study highlighted elephants among the species most affected by climate change and anthropogenic factors in the Namib Desert (Namibia), changes that put their survival at risk. Namibia is the driest country in Southern Africa, hence the high possibility of unfavourable impacts on wildlife habitats. Even though Namibia's elephant population has grown over the past three decades, multidimensional factors are potentially affecting the successes of elephant conservation and community-based natural resource management programs in the country. This study monitored, collected, and analyzed, over 3 years, between February and November 2018 to 2020 at fortnight intervals, the movement of elephants (N-29) downstream of the Ugab River Hydrographic Basin and elephants (N-52) of the Upper Ugab River Basin. Births, mortality, animal welfare, reproduction and migration were recorded. An analysis was performed, through interactive tools ArcGIS, QGIS and SPSS, to perceive patterns of movement in space and then time the historical movement, distribution area and patterns of habitat viability change. In addition, remote detection was used using NASA and European's Space Agency 2000 to 2020 Infrared Multispectral Satellite Imagery of Landsat 7 and 8 the to assess the loss and gain of vegetation and biomass through Normalized Difference Vegetation Index (NDVI). Ultimately, what can be inferred about the drivers of the new hotspots emerging from conflict between humans and elephants in the interior of the country is habitat loss and distribution area changes. Elephants in the study area lost 73% of historical habitats and established a new distribution area, 130.7% compared to the initial one. There was also, associated with this change, a loss of 16.3% of the viable vegetation for foraging in historical habitats, affecting the amount of biomass available to wildlife. These changes add to the need to anticipate and intervene in resource management and restoration of lost habitats.

palavras-chave

Elefantes que vivem no deserto, sensoriamento remoto, biomassa, área de vida, perda de habitat, conflito homem-elefante, Namibia

resumo

A crescente preocupação das sociedades humanas com as alterações climáticas, os efeitos adversos nos sistemas biológicos globais e o ritmo a que se estão a ocorrer resoluções de danos pode revelar-se insuficiente, por muito lenta que seja, dada a rapidez com que essas mudanças estão a ocorrer. Uma vez que algumas regiões são mais vulneráveis do que outras, a necessidade de agir rapidamente antes da perda de espécies-chave é altamente recomendada. A União Internacional para a Conservação da Natureza (UICN) reclassificou no início de 2021 os elefantes da savana africana Loxodonta africana e o elefante da floresta africana Loxodonta cyclotis como ameaçados e criticamente ameaçados na Lista Vermelha. Este estudo destacou os elefantes entre as espécies mais afetadas pelas alterações climáticas e os fatores antropogénicos no Deserto do Namibe (Namíbia), mudanças que colocam em risco a sua sobrevivência. A Namíbia é o país mais seco da África Austral, daí a elevada possibilidade de impactos desfavoráveis nos habitats da vida selvagem. Embora a população de elefantes da Namíbia tenha crescido nas últimas três décadas, os fatores multidimensionais estão potencialmente a afetar os sucessos da conservação de elefantes e programas de gestão de recursos naturais baseados na comunidade no país. Este estudo monitorizou, recolheu e analisou, ao longo de 3 anos, entre fevereiro e novembro de 2018 a 2020 em intervalos quinzenais, o movimento de elefantes (N-29) a jusante da Bacia Hidrográfica do Rio Ugab e elefantes (N-52) da Bacia hidrográfica do Alto Ugab. Foram registados nascimentos, mortalidade, bem-estar animal, reprodução e migração. Foi realizada uma análise, através de ferramentas interativas ArcGIS, QGIS e SPSS, para perceber padrões de movimento no espaço e, em seguida, tempo o movimento histórico, área de distribuição e padrões de mudança de viabilidade do habitat. Além disso, a deteção remota foi utilizada através da NASA e da Agência Espacial Europeia 2000-2020 Imagens de Satélite Multiespectra de Landsat 7 e 8 para avaliar a perda e ganho de vegetação e biomassa através do Índice Normalizado de Vegetação da Diferença (NDVI). Em última análise, o que se pode deduzir sobre os condutores dos novos hotspots que emergem do conflito entre humanos e elefantes no interior do país é a perda de habitat e as mudanças na área de distribuição. Os elefantes na área de estudo perderam 73% dos habitats históricos e estabeleceram uma nova área de distribuição, 130,7% em relação à inicial. Houve também, associada a esta alteração, uma perda de 16,3% da vegetação viável para a forragem em habitats históricos, afetando a quantidade de biomassa disponível para a vida selvagem. Estas alterações contribuem para a necessidade de antecipar e intervir na gestão e restauro de recursos de habitats perdidos.

Table of contents

Table of figures

CBNRM	Community-Based Natural Resources Management
DNA	Deoxyribonucleic acid
EHRA	Elephant-Human Relations Aid
ETM	Enhanced Thematic Mapper
GIS	Geographic Information System
HEC	Human-Elephants Conflict
HWC	Human Wildlife Conflict
IUCN	International Union for Conservation of Nature
LEAPS	Landsat Ecosystem Disturbance Adaptive Processing System
Ma	Mega annum
MEFT	Minister of Environment, Forestry and Tourism
NACSO	Community Based Natural Resources Management Support Organisation
NASA	Aeronautics and Space Administration
NDVI	Normalised Difference Vegetation Index
NECMP	National Elephant Conservation and Master Plan
NGOs	Nongovernmental organisations
NIR	Near-Infrared
NSA	Namibia Statistics Agency
OLI	Operational Land Imager
ULH	Ugab River Lower Catchment Herds
UUH	Ugab River Upper Catchment Herds

1. General introduction of the study

1.1. Introduction

The overall African elephants' population continue to decrease, a situation that might leave one of the world's charismatic species at a gulf of endangerment (Poole & Granli 2008). In Africa, poaching and Human-Elephants Conflict (HEC) linked to the Human-Wildlife Conflict (HWC) is one of the main contributors to elephant population decline (Osei-Owusu & Bakker 2008). Elephants were estimated to be over 1.3 million by 1979 (Douglas-Hamilton, 1987); however, the population decreased drastically over the last four decades. Chwalibog *et al.,* (2018) put it in numbers, illustrating that the elephant population in Africa was estimated at 470,000 to 690,000 in 2007. By no surprise, a decline by 144 000 elephants was recorded by 2014 (Chase *et al* 2016), with a population continuing to decline at a rate of 8% per year. Today, there is about 352 271 savannah elephants (Chase *et al.,* 2016) but only 16% roaming out of unprotected areas (Chase *et al* 2016., Pinnock and Bell 2019) that covers 80% of elephant home range, the larger portion compared to those within protected areas (Osei-Owusu & Bakker (2008). Such a decline divulges that the population could be much less today, as Pinnock and Bell (2019) further claimed that an elephant dies in Africa every 20 minutes.

In Namibia, many people continue to share the same ecological community with wildlife. As a result, the Community-Based Natural Resources Management (CBNRM) program was initiated to empower communal residents to look after free-roaming wildlife that is sharing the same resources with them (Jones & Weaver 2012, Brown & Bird 2010, Naidoo *et al.*, 2011, Namibia Association of Community Based Natural Resources Management Support Organisation - NACSO 2019). However, even though nearly half of the country's human population lives in urban areas, less developed regions as Kunene have 74% of the 86 856 people inhabitant rural areas (Namibia Statistics Agency, 2011). Yet, it is the most affected by drought (Hitila 2019), hence can contribute to the loss of wildlife habitats.

Hobbs (2012) and Brown (2003) weighed critical thresholds of conservation success and concluded that an integrated decision-making approach is vital for conservation success. Johnson *et al.,*(2003) suggested that meeting challenges facing the conservation industry requires an integrated approach that combines scientific methods with societal values. The idea for Johnson and co-authors validates the fundamental strategy for CBNRM on sustainable resources use in Namibia's communal areas that promote community and other stakeholders' involvement in natural resources management (van Schalkwyk *et al.* 2010). However, the prevailing HWC (and specifically HEC) still puts a significant responsibility on the shoulders of the CBNRM program as referred to by (Boudreaux, 2010), and still on the increase in new conflict hotspots such as Omatjete and Ugab River area.

This study estimated a home range of 12 237 km^2 for the Ugab River desert elephant population, which may change due to increasing migration instability. Viljoen (1989) Recorded home range sizes of 1763 to 2944 km^2 of the Namib desert elephants during his study. The elephant home range substantially expanded. The expansion can be attributed to the change in behaviour accompanied by habitat destruction and reduction, hence the need to understand the drivers. Elephants spend much time walking, covering a large area in a single day. Poole and Granli (2014) confirmed that elephants in the desert have the most extensive home ranges averaging 11 000 Km^2 compared to a maximum of 2 776 Km^2 in South Africa's Kruger National Park and 3 309 Km^2 in Northern Botswana. The largest habitat recorded of the desert elephants is 14 000 Km^2 (Garstang et al., 2014).

Climate change poses a risk to wildlife habitats in arid environments. Remote sensing is an emerging technique used in ecology to assess long-term landscape change patterns (Ibrahim and Al-Mashagbah 2016), including vegetation cover by using quality aerial images collected over the years by satellites (Islam *et al.,* 2016), a method used in achieving the objectives of this study. It is primarily known that healthy vegetation reflects light strongly in the near-infrared band and is less intense in the visible portion of the spectrum (Brown *et al.,* 2010; GIS Geography 2021). Therefore, it is essential for assessing the history and sustainability of wildlife habitats of the lower catchment, having preliminary observed deteriorating vegetation health, yet no recent study has been conducted regarding this problem in the Namib Desert. The only study done is that of Viljoen and Bothma (1990) that looked at 20 years of satellite, discovering that there were no vegetation and habitat loss 30 years ago. Nevertheless, a situation like this can lead to migration of wildlife species due to habitat loss, decreasing biomass. The decline in underground water aquifers was also indicated as a key enable (Jasechko & Perrone, 2021). This triggers migration to new areas, hence the possibility of emerging Human-Elephant Conflict hotspots at the new places.

1.2. Statement of the problem

Human-Elephant Conflict is a problem far from being resolved in Namibia (Enzerink 2017), despite a remarkable conservation effort that has been made over the past three years (MEFT, 2020). At the National Elephant Conservation Master Plan consultation workshop, the Minister of Environment, Forestry and Tourism, Pohamba Shifeta (Personal communication, 19 November 19), reiterated that Namibia's elephant population increased from 7500 to nearly 24 000 animals between 1995 and 2020, hence a parallel increase in Human Elephant Conflict (HEC) with both animals and humans affected. A report on the Revised National Strategy on Wildlife Protection and Law Enforcement 2021 – 2025 by (MEFT, 2020) has further revealed that 300 000 people living within registered 86 communal conservancies are experiencing HWC day by day, and HEC is one of the significant contributors.

Six conservancies within the Ugab River lower catchment benefit immensely from wildlife. Conservancy members benefit through tourism, trophy hunting and hunting for consumption (NACSO 2020), even though wildlife population sustainability may be affected. There are no registered conservancies at the Ugab River upper catchment. Despite one communal conservancy being established at the Okongue area, more information on wildlife movement is required to set up the proposed conservancy successfully. Many elephants are immigrating to the Okongue area, yet a lack of knowledge on the drivers, both in origin and emerging habitats, is unknown.

Much of the government and supporting organisations conservation efforts have been focusing on communal areas falling under communal conservancies. Nevertheless, most Omatjete communal land inhabitants and adjacent commercial farmers have been getting minimal support in the past. The community members have no direct economic incentives from wildlife, raising conflicts between communal farmers and migrating wildlife. Many commercial farms are not economically benefiting from wildlife on a commercial scale, except those that are game farming. The lack of direct benefit from wildlife and increasing damages to properties is thus contributing to the lack of farmers' willingness to co-exist with wildlife. In addition, farmers argued they have been getting less educational and infrastructure support from the government, mentioning that they have only started getting water infrastructure from the government and a few NGOs since 2019.

Since elephants play a significant role in tourism attraction for conservancies of the Ugab River lower catchment, habitat loss, biomass decline, HEC and events associated with climate change, and anthropogenic factors can be detrimental to conservancies income. Lodges and voluntourism organisations would be affected, and any possible future permanent home range shift may unsustainably affect their business models. During fieldwork, various habitat patches visited are characterised by large dead trees, mostly *Faidherbia albida*, which can contribute to the drivers of elephants' commuting and migration behaviour to the areas they are not known to make frequent visits before.

This phenomenon inspires that it was essential to assess the drivers of migrations, corridors, emerging habitats, and conflict hotspots. The resulting spatial contributing aspects were also vital to be studied to help inform the conservation policies for the study area and similar elephant population home ranges of the arid parts of Namibia. It also made it possible to project the system's future downstream and the escalation of HEC hotspots upstream.

1.3. Objectives of the study

1.3.1 Research objectives

The study is accomplished through the following objectives:

- Identify potential home range shift and habitat modification over time
- Assess if such shifts may lead to desert-dwelling elephants establishing permanent home ranges further inland
- To assess vegetation cover trends overtime for the historical habitats of the lower catchment
- Determine if habitats and home range changes relate to the rainfall and drought events
- Determine possible implications of climate change on natural springs of the lower catchment and deep-rooted vegetation that sustain livelihoods
- Provide an overview of future conflict hotspots resulting from home range expansions and habitat shifts

1.3.2. Research questions

- Are elephants abandoning their historic home ranges?
- Is there a possibility of permanent home ranges establishment at the upper catchment conflict hotspots?

- Will permanent migration have a negative economic impact on conservancies and communities in historically known home ranges of the lower catchment?
- Are there any historic habitat loss or gain for the Ugab River lower catchment?
- May habitat loss be attributed to climate change and anthropogenic activities?
- Are both natural and artificial water available contributing to the change in the behaviours of desert-dwelling elephants?
- How does declining biomass relate to the rest of the country's elephant habitats?
- Is the wildlife-livestock interface threatening arid ecosystems?

2. The background study on elephants

2.1. Elephant ancestry and evolutional hierarchy

Ageing elephant evolutional lineage requires an inclusive comparison of several findings cited in different publications. Elephants evolved with the other live-bearing mammals (Theria) from the Cynodonts (mammal-like reptiles) (Martin, 2005) of the Triassic era, about 225-195 million years ago. The egg-laying mammals (Monotremes) were the first to diverge in the Jurassic age (MacDonald, 2001). A book by MacDonald (2001) further presented that about 130 million years ago, in the early Cretaceous era, the Theria diverged into two other major mammal groups, the Marsupials, and then placental mammals (Eutheria) (Martin 2005), that elephants belong.

The first angulates, Condylarthra existed during Cretaceous 65 (Ma: Mega-annum) and the sub-ungulates during Paleocene (Rohland *et al.*, 2007). The study by (Rohland *et al.,* 2007) further stressed that the modern ungulates are currently classified under *Laurasiatheria*. Several scientists including (Dıaz & Barquez, 2002, Kuntner *et al.*, 2009), inferred from mitochondria DNA and phylogenetic analysis of fossils and agreed with (Martin, 2005) that Afrotheria had its root in Africa, then it deviated away from *Laurasiatheria* during the Paleocene period. Before that, the group had split into small orders of the sub-angulate Paenungulata dating from nearly the Eocene era of 54 Ma, including Order of Sirenia, Hyracoidea and Proboscidea.

Elephants belong to the Elephantidae family that arose in the late Miocene (Estes, 1991) of the Proboscidea order (van der Made 2010; Martin 2005; Jewell, Ashe & Krofta 2015). Proboscidea evolved as early as 60 million years ago (van der Made, 2010; Martin 2005), slightly different from an estimate by (Estes 1991). The first proboscidean was *Phosphatherium* (58 Ma) (Martin, 2005); hence the first small pig-like and sized Moeritherium evolved. Changotra (2018) clarified that *Moeritheriums* evolved during the Oligocene period, with elephant-like tusks at each side of its muzzle. In addition to the above, Martin (2005) informed that *Gomphotherium, Trilophodon, Platybelodon* and the *Mammuth* are all *Moeritheriums* subsequent divergent that got extinct only in recent years of Pleistocene era, 1.8 million before present.

Today, Proboscidea has only one extant family, Elephantidae, whose Elephas and Loxodonta are the only genus (Estes, 1991; Furstenburg, 2010). Until 2021 official reclassification of the African elephant into two species, there were only two species of elephant, *Eliphas maximus* (Asian elephant) and *Loxodonta africana* (African elephant) (Murata *et al.*, 2009) which is split into *L. africana* and *L. cyclotis* during recent discoveries (IUCN, 2021) despite recommendations by various authors over the past three decades. Previous studies already recognised two African elephant species, the forest elephant (*L. cyclotis*) and savanna elephant (*L. africana*) species are by (Shetty & Vidya, 2011; Poole & Moss 2014; Poole & Granli, 2014).

Thus far, the Hyraxes (Hyracoidea) and Dugongs (Sirenea) are the species and Order extant that is closer to the Elephantidae family (Shoshani 2000). However, these two are much closer to the *L. africana*. The *E. maximus* is closer to the recent extinct *Mammuth* (Changotra 2018). However, Furstenburg (2010) suggests other four potential subspecies if not local populations of *E. maximus* as *E. m. indicus* (the Indian elephant) *E. m. maximus* (the Sri Lankan elephant) *E. m. sumatrensis* (the Sumatran elephant) and *E. m. borneensis* (the Borneo elephant). Rohland et al. (2007) further endorsed that the mammoth had split from the African elephant 7.6 Ma and 6.7 Ma from the Asian elephant. An unsettled argument was raised between (Roca *et al*., 2001 cited in Murata *et al.*, 2009), stating that a considerable genetic divergence between the savanna elephant and the forest elephant took place at 2.8 Ma than 4.0 Ma confirmed by (Rohland *et al.*, 2007).

2.2. Anthropogenic elements threatening elephant existence

There are no old fossils (or quality DNA specimens) of *Loxodonta* extinct species that can help scientists closely understand the causes of *Loxodonta* families' extinction. A 0.8–0.2 Ma *Mammoth* fossil is estimated to be among the oldest found (Kalb & Mebrate, 1993), limiting the ability to comprehend the leading cause of extinction of *Loxodonta* species (Murata *et al.*, 2009). Okello *et al.*, (2008) ascertained drastic elephant population decline with poaching following human colonisation of the world. If humans can believably lead elephants to extinction even with so much conservation effort, may overkill theory justify how many animals have been pushed into extinction by humans? During the ice age, overkill theories and competitions were among the most debated cause of extinction. One of the crucial debates pointed out by scientists is that "man was in America in Mexico and Canada much earlier than accepted 12,000 B.P (Before Present)" (Lee and McIntyre quoted in Ginenthal, 2013). Such assumption undermines the theory of overkill, pending the human remain discovered that were predicted to be 18 000 to 33 000 years B.P.

Scientists may disagree on event timelines and human impact on various species extinction, but a few may prove a point. For example, some animals as camels, llamas, deer, pronghorn, stagmoose, shrub-oxen, mastodons, mammoths, and horses were all believed to be pushed into extinction because of an overkill hypothesis debated by (Ginenthal, 2013). However, the author further presented evidence-based recognition of other events such as Arctic Tundra - Mammoth Steppe or Velikovskian Pole shift, climate change, radiocarbon, ice age and the so-called catastrophes. Despite dissimilarities of the impacts each event posed to different species, various authors questioned why some species survived while others perished, believing that if some species made it through the Pleistocene period, each species would escape somehow. However, recognition should be made based on evidence that every species reacts differently to environmental conditions, hence the differences in the ability to survive or evolve morphologically to cope with changes, the study further reasoned.

Several factors are threatening elephant survival. Habitat loss and modification, habitat fragmentation, population isolation, and disturbance due to anthropogenic factors are all among the threats listed by the IUCN (2021). In Africa, poaching and HEC is one of the main contributors to elephant population decline (Osei-Owusu & Bakker, 2008). Combined severe impacts from climate change and anthropogenic activities today may pose much more deleterious effects that elephants may become extinct rapidly if appropriate preservation is not undertaken.

2.3. Historic elephant home ranges and distribution in Namibia

Elephants spend much time walking, covering a large area in a single day. Poole and Granli, (2014) confirmed that elephants in the desert have the largest home ranges averaging 11 000 km² compared to a maximum of 2 776 km² in South Africa's Kruger National Park and 3 309 Km² in Northern Botswana. The largest habitat recorded of the desert elephants is 14 000 Km² Garstang *et al.*, (2014). Viljoen, (1989) recorded home range sizes of 1763 to 2944 km² of the Namib desert elephants late 1980s. Current home range expansions can be attributed to the change in elephant behaviours, hence the need to understand the drivers. It is proven that factors such as rainfall pattern (Breine *et al.*, 2020, Garstang *et al*., 2014), available food - quality and abundance (Breine *et al*., 2020) plays a significant role in influencing such movements (Breine *et al.*, 2020, Viljoen 1989), which are analogous factors influencing the situation in Namibia.

Elephants are documented to have been distributed throughout Namibia 300 years ago (Martin, 2005). Drearily, elephants have declined significantly from most parts of Namibia in the 60s, and some local populations went extinct or declined to near-local extinction. For example, in the Namib desert's north-western part of Namibia, elephants declined to less than 100 at the time (Viljoen 1989). Not only did north-western Namibia experience extreme population decline, but elephants were also exploited from the Etosha National Park in 1881 (Fisher, 1914), with only 20 animals counted during the elephant survey at the time. A summary of a collection of studies read by (Martin, 2005) exposed two significant population declines in Namibia. Firstly, elephants have nearly gone locally extinct in the 1900s, picking up again by the mid-20th century before another drastic reduction in the late 20th century. During the two major events, populations of the Caprivi in the east and Kaokoveld area northwest have acted as the sink population that later recolonised current regional home ranges discussed below.

The figure below illustrates the historical home range of elephants. Even though elephants were not documented in the southwest part of Namibia, areas inhabited by elephants exceeded 56% of the country's total area of 823 000 Km². However, the distribution range declined drastically in the late 20th century (Figure 2) compared to the 1900s (Figure 1).

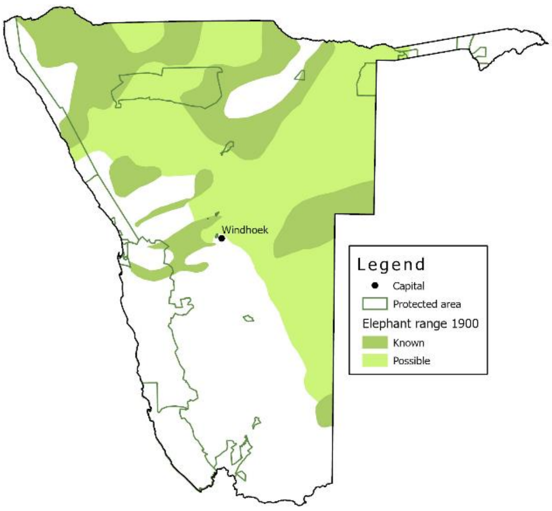


Figure 1. Estimated elephant distribution map before 1900 (Adopted with permission MEFT 2020) (26). The northwest and central north part of the country have the known distribution range. Swakop River (central west) and Gobabis area (central east) were among know ranges whose population that have gone locally extinct.

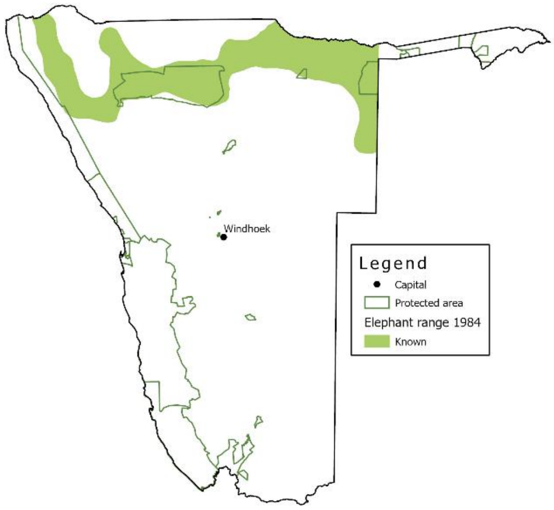


Figure 1. Estimated elephant distribution map by 1984 (Adopted with permission MEFT 2021).

2.4. The current elephant home ranges and distribution in Namibia

Elephant home ranges in Namibia are currently divided into five (5) main populations and two emerging populations. The current permanent population groups consist of Kunene desert-welling elephants, Etosha and surrounding areas, Mangeti, Katwitwi, Kaudum and surrounding areas in Omaheke, as well as the Bwabwata National Park and the entire northeast region. All current five home ranges are shown in the map below, adopted from the National distribution map for (MEFT, 2021). Based on the MEFT report on the distribution area estimates, the elephant home range declined by 62.5%, with only 21.3% (Figure 3) of Namibia's total area covered by their home range. This represents an increase in distribution from 4% in the 1990s to17.3% today. Therefore, according to the current study conducted by (MEFT, 2021), the "estimated rate of population increase p.a. for Namibia's elephants is 5.36% (between 4.20% & 6.53%)".

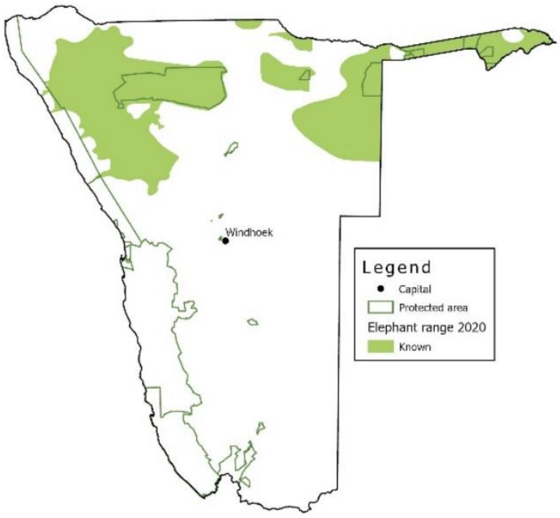


Figure 3. Estimated elephant distribution map by 2020 countrywide (Adopted with permission MEFT 2021) (26). The known population range have spread out mainly in the north-west and the northeast. The Ugab River is currently the river with permanent elephant distribution far south of the north-western distribution range. A huge difference from the distribution range that previously reached Swakop and Kuiseb Rivers in the central west of Namibia.

2.5. A case study on Desert-dwelling elephants, habitats, and Human Elephant Conflict

The Kunene and Erongo regions are home to desert elephants that roam freely in the communal areas of the ephemeral rivers' catchments (Viljoen, 1987; Viljoen, 1989; Leggett, 2009; Leggett, 2014), and the Ugab River, lower catchment population, is one of them. Desert elephants roam freely in the lower catchments of ephemeral rivers (Leggett, 2014), where annual rainfall range from 20 mm to 200 mm. The ephemeral rivers are the Ugab, Huab, Hoanib, Houarusid and Uniab Rivers. There are two populations of desert-dwelling savanna elephants in the world, the other found in Mali (Canney, 2019, Brown et al. 2020). Various authors have argued that desert-dwelling elephants are different from the African savannah elephant (Rohland et al. 2010, Ishida *et al.,* 2016), but recent genetic studies have shown that they are African savanna elephants.

An agreeable conclusion was made by (Martin, 2005; Ishida *et al*., 2016) that desert-dwelling elephants are the same African savannah elephant found in the country's interior. However, their ability to survive extreme arid environments enabled them to dwell in the desert (Garstang *et al*., 2014, Ishida et al. 2016); hence they are simply an ecotype (Brown *et al*., 2020). Being an ecotype, (Ramey *et al*., 2013) supported that elephants often dig in ephemeral rivers for water during dry seasons, a character unique for desert adaptation. However, it is not clear how genetically they are close to the adjacent elephant population further inland. No study revealed whether there is still reasonable cross-breeding with the population inland due to isolation in the past. This study counted 64 elephants living in Ugab and Huab Rivers, while a study by (Brown, 2020) presented that more than 200 animals live further north, mainly residents to ephemeral rivers Hoanib, Hoarusib and Uniab Rivers, as well as Palmwag area.

Viljoen (1987) summarised the study of von Moltke (1945) who revealed that before 1900, elephants were hunted in the Kunene area from 1880 up to 1908. Adding that during that time, about 2500 to 3500 elephants were hunted to an extend that elephants nearly went extinct in the area by the 1900s. Another study by Viljoen (1987) discovered that a total of 357 individual elephants was counted in Kunene in 1980. During the same period, 123 elephant carcasses were found, of which 107 showed positive signs of having been shot. The Ministry of Environment, Forestry and Tourism (2014) cited in a press release that elephants increased from less than 70 in the 1990s in Kunene and northern Erongo to nearly a thousand today (including both desert-dwelling and inland elephants). Local community members believe elephants had once escaped the war by fleeing to north Angola while others were killed.

The current population of desert-dwelling elephants from the early 60s can be identified as a population restoration. Despite desert-dwelling elephants having depended on finite resources – water and vegetation within such an arid environment for a long time, (Viljoen & Bothma 1990) noted no negative impact on vegetation until 30 years ago. The population was believed to be below caring capacity. The increase in human population creation of farms in the early 1900s and communal farms mid-1960s increased pressure on natural springs, while more boreholes were drilled for farms. Leased communal farms are found in communal land; they are not privately owned and cannot be fenced (Naidoo et al. 2011). As a result, more unoccupied communal land is used for grazing while acting as a wildlife habitat.

Currently, elephants, livestock, and people must compete for the same resource, water, food, or space (Garstang *et al*., 2014). For that reason, excessive water abstraction is required. However, (Jasechko and Perrone 2021) discovered an increasing lowering of the underground water table that may pose a risk to the future of the aquifers in arid environments. Over abstraction of water may contribute to changing habitats, reduced carrying capacity, drying of natural springs, and migrating desert elephants today. During this study, desert-dwelling elephants have been observed encroaching into commercial farms within the upper catchment areas of northern Erongo and Kunene regions (Figure 6, 7, 10, 11 and 12), a piece of evidence supported by (MEFT, 2020), which is historically not part of their home range according to the information provided by (Viljoen, 1987; Viljoen, 1989).

Despite the rivers stretching much further inland (Figure 4), desert-dwelling elephants found in the lower part of the river only cover about a third of the entire river catchments. During this study, the elephants roaming in the upper catchments are not considered desert elephants since those elephants never entered the outer part of the desert.

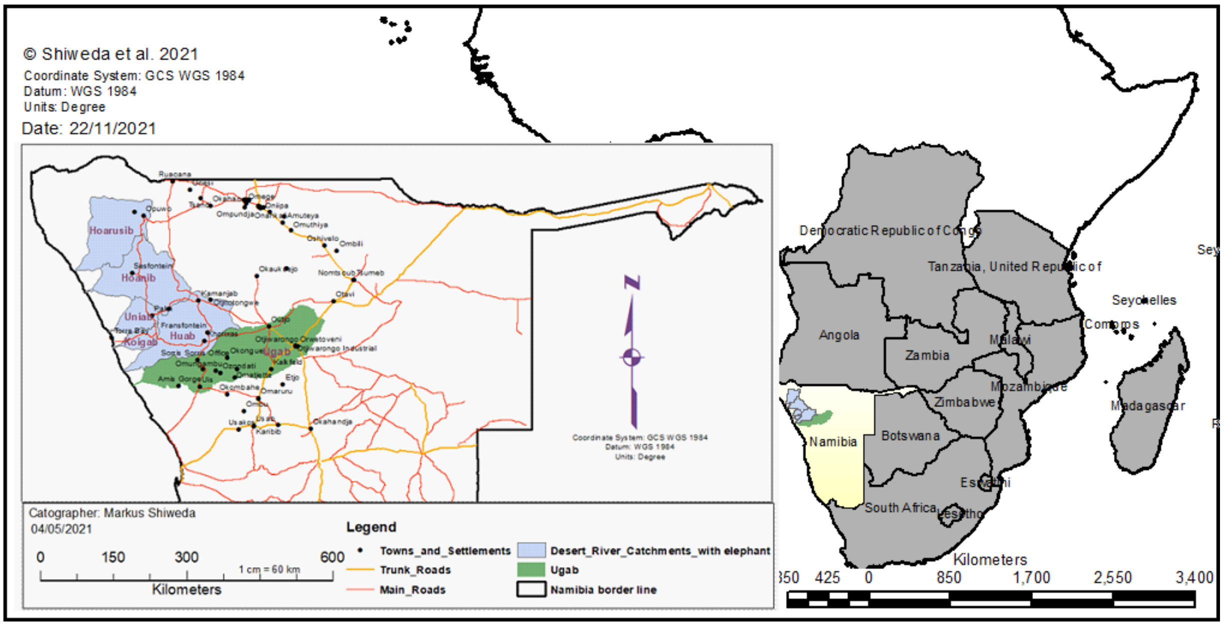


Figure 4. The Ugab and other Namib Desert ephemeral river catchments with elephants' local population. The ephemeral rivers of the Namib Desert with resident elephants are found in the north-west part of Namibia.

3. Materials and methods

3.1. The general study area and status of climate change

Namibia is the driest country in southern Africa and the most affected by droughts (Hitila 2019) and climate change (Midgley *et al.*, 2005) in the southern Africa. The maximum temperature exceeds 40°C in the northwest part of the country (Viljoen, 1992), and it is also the part hit mainly by drought over the past eight years (Hitila, 2019). A national average rainfall of 340 mm per annum is received (Mannerheim & Curtis 2009). The average rainfall across the country ranges from 0 (zero) mm in the desert in the west to more than 600 mm in the northeast (Mannheimer, Curtis, Le Roux, Müller, Müller 2019). Namibia is projected to experience a temperature increase of 2-6 °C across the country by 2050, 10% and 20% rainfall north-south and central respectively by 2050, which will rise to 20% and 30% by 2080 (Turpie *et al.*, 2010). A different study predicted an increase in temperatures of between 1°C and 3,5°C in summer and 1°C and 4°C in winter in the period 2046 – 2065, and a reduced number of days with temperature less than 5°C (Dirkx *et al* 2008).

Leggett (2010) speculated that "north-western Namibia is a scenically spectacular and incredibly arid area that appears impossible for any living organism to live there but let alone an animal the size of an elephant". However, the country's vulnerability to climate change is expected to affect the biodiversity with 10% of endemic plants expected to extinct by 2050 (Turpei *et al.* 2010). Namibia's aridness is characterised by only ephemeral rivers found in the interior (Jackobson *et* *al.*, 1995). The ephemeral rivers are cutting through igneous rocks formed by intrusive volcanoes during the Gondwana continental split (Trumbull *et al.*, 2000), flowing across the Namib Desert in the west, in the south and central east eastward across the Kalahari Desert. Even though the country's geographical boundaries are partly demarcated by perennial rivers (Orange, Kunene, Kavango, Zambezi, Kwando, Linyanti and Chobe rivers), none is found in the interior (Jackobson *et al.*, 1995). On a different note, over 40% and 30% with or without migration of the plants modelled pessimistically by (Midgley *et al.*, 2005) are projected to become Critically Endangered or Extinct in Namibia because of Climate change. How will the said climate change paired with anthropogenic impacts affect wildlife habitats and their survival? This is one of the questions attempted by this research study to measure how certain habitats are impacted.

3.2. The study area: a case study on Ugab River Catchment elephant population

The study will classify desert-dwelling elephants as those roaming below 200 mm isohyet of each ephemeral river where they mainly depend for survival. The ephemeral rivers of Erongo and Kunene are flowing from east to the west (Figure 4). The rivers are cutting through igneous rocks formed by intrusive volcanoes during the Gondwana continental split (Trumbull *et al.*, 2000), and they have got exposed over time. The ephemeral rivers may flow during the rainy season, depending on the amount of rainfall between January and April. There are few perennial springs available (Figure 13, Appendix A, B, and C) that are the primary water source for the wildlife and evergreen riparian vegetation along the rivers. The forest that formed a line on each bank attracts elephants during dry seasons for food and shade (Leggett, 2014). The focus is thus given to an ephemeral Ugab River lower and upper catchment where the main activities were observed. The river has a catchment area of 28 000 Km^2 (Figure 5) and a length of over 540 Km. It flows east to west into the Atlantic Ocean. The desert-dwelling elephants historically roam within the lower catchment between S20.6° - 21.1° and E13.9° - 15.2. The upper catchment elephants roam between S20.2 – 21.1 and E15.0 – 15.8.

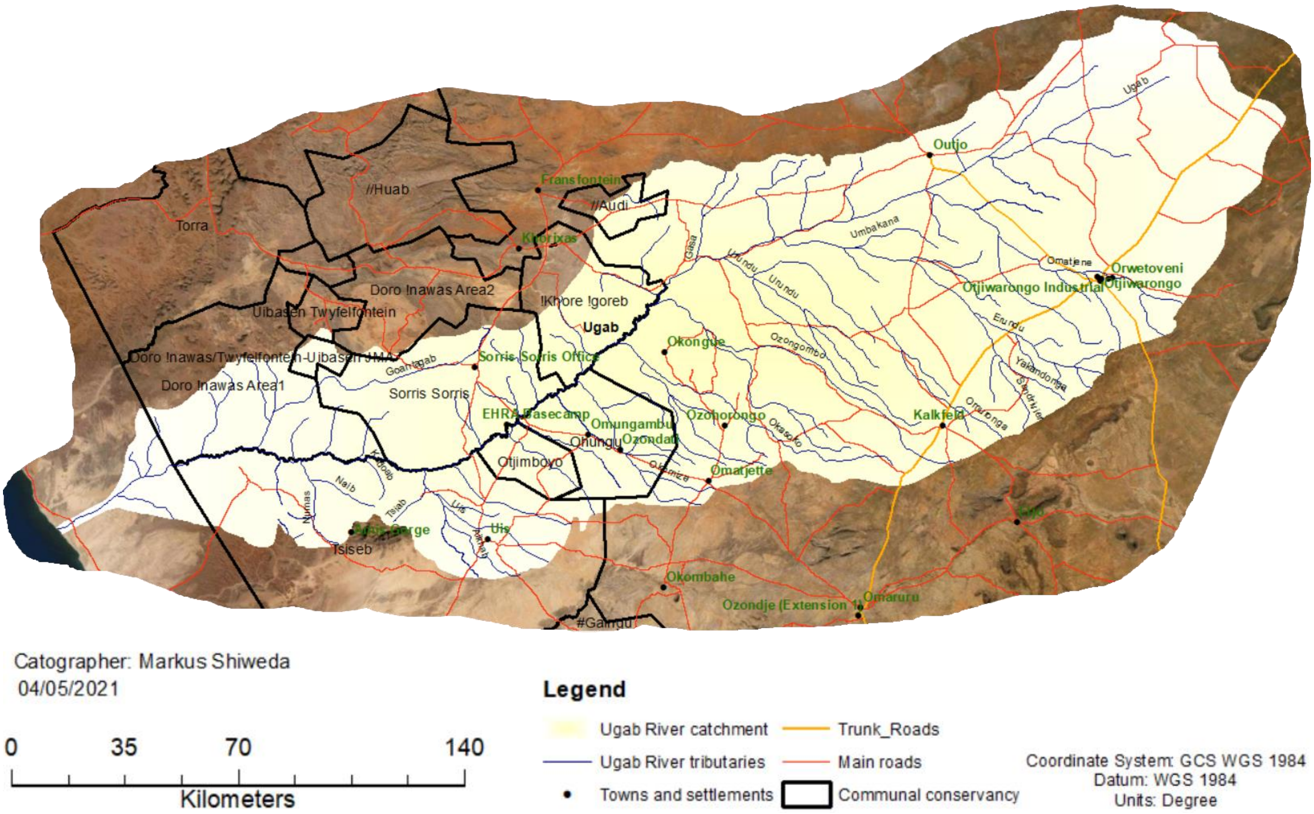


Figure 2. The Ugab River catchments and its tributaries. The case study on elephant's habitat loss and home range shift was conducted at this catchment.

3.3. Data collection

3.3.1. Limitations on data collection design

External factors highly influenced the design of the study data collection, one being an employee simultaneously collecting employers' data when in the field, secondly by having to travel to the university for exams and end of season classes that take place during essential data collection seasons. Since the study requires much-existing data from local institutions and the field data, various collaborations and research cooperation were needed. However, it was not possible to meet collaborators due to Covid-19 restrictive measures. Covid-19 has also affected work schedules; hence it was impossible to stick to the specific field data collection timeframe. On the other hand, wild elephants are challenging to locate by foot or car, especially during the wet season when they are out of the rivers.

None of the elephants in a lower catchment is collared. Tracking depends on traditional footprints reading techniques. When elephants are resting in densely vegetated areas, it is a risk to come close to identifying every individual; hence spending two hours with a group is possible, as long as no elephant notices you are among them. However, when desert-dwelling elephants are found at the lower catchment, they are usually in open areas, relaxed and can be approached easily with a vehicle as close as 40 metres, while they can also approach a parked vehicle and walk around it if everyone is silent. The elephants inland at the upper catchment are shy. They cannot accept to hear an approaching car and seeing a human on foot. Due to varying behaviours and different tolerance of human presence for each population, the data collection rules vary significantly. As a result, three weeks were also spent tracking elephants continuously since elephants moved to an area outside of the known home range. Elephants were not seen for 12 days throughout three weeks due to limiting mountainous trains and dense bushy vegetation even if tracking was done every day for eight to nine hours.

3.3.2. Field data collection

Field data were collected from February to November every year, 2018 to 2019 and February to September 30, 2020, every 2nd Monday to Thursday. This pattern was changed from April 1, 2020, to September 30, 2020, due to Covid-19. Tracking time remained the same throughout, starting 08h00 to 17h00, with a lunch break of 1 to 2 hours from 12h00 every day when is hot, +-35 ºC. Tracking was done both by foot and a car depending on vegetation density of each catchment that increases towards the upper catchment (Figure 6, 7, 10, 11 and 12). We drive on small tracks from farm to farm, usually 3 to 5 Km apart. While driving, checking for the elephant tracks is the priority, even though it is crucial to avoid getting a tyre punch. Tracking is done using traditional indigenous knowledge and guiding tracking methods of ageing animal ground imprints, dungs, footprint, the softness of leaves fed on and dropped to the ground and air smell. The method modified the guidelines of (Curtis 1995) of Princeton University. Non-invasive methods and distance restrictions were set up based on animals' behaviours and reactions to avoid disturbance, following MEFT guidelines.

On patrol weeks, elephant location is recorded with a Garmin GPS in degrees, minutes, and seconds or GPS coordinate mobile application. The coordinates are recorded in a notebook and transferred on excel sheets in the evenings and weekends. Individual animals were counted for every herd spotted, and an age estimate is being done following the method of (MEFT, nd; Shrader, 2006; Jachmann, 2008). Elephants ID Photos are captured for future identification and verification if not done onsite for every individual. Additional information is also recorded to identify family herds, with each head and individual animal assigned a unique code (i.e ULH1 for Ugab Lower-catchment Herd 1 and UUH1 for Ugab River Upper Catchment Head 1). For scientific reasons and data collections standards set by the researchers, individuals and herds identification, ageing, kinship structuring, and herds close parenthesis or relatedness were done independently. An individual or herd that historically spends 75% of their time annually to either the upper or lower catchment of the Ugab River is classified as a resident individual or herd to that catchment section.

In addition, the general health condition (physical fitness, body shape and illness signs) and behavioural wellbeing (level of shyness, aggressiveness and body language towards group members and presence of data collectors is recorded. Sightings of males were recorded for breeding assessment purposes to assess the chances of genetic flow in the and adjacent populations. Mortalities and new births are recorded.

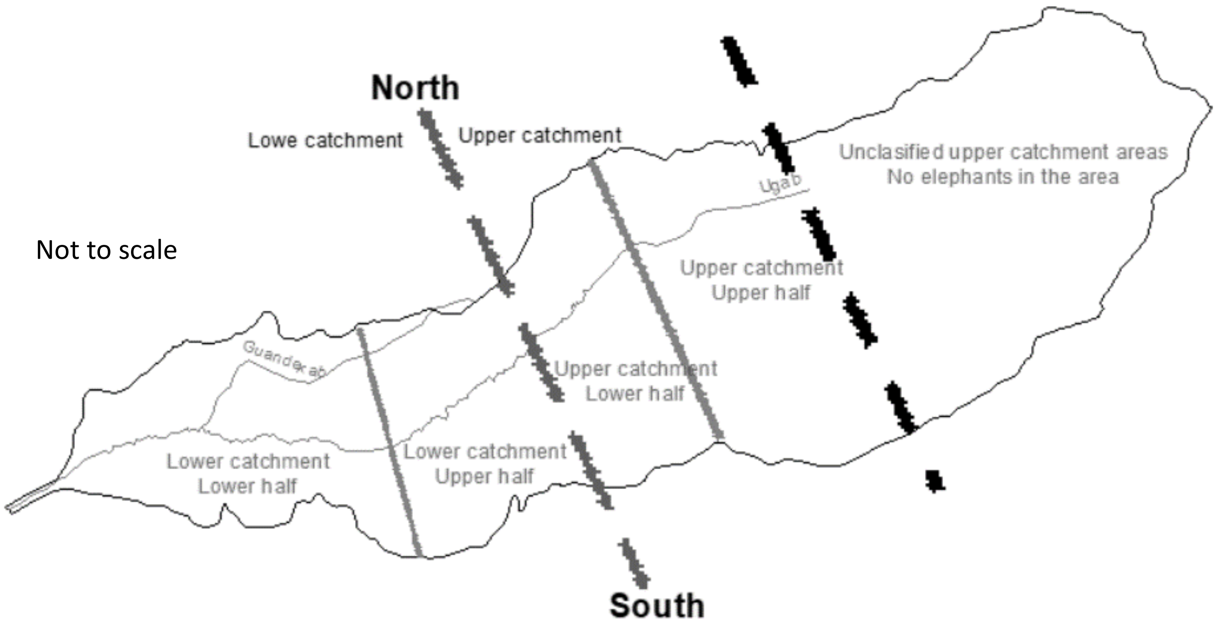


Figure 3. The Ugab River catchment and the division of sections inhabited by elephants.

3.3.3. Human Elephant Conflict

Human-Elephant Conflict events were also recorded and transferred into excel sheets. Conflict event records include a type of Conflict, types of damaged infrastructure, frequency to the farm or water point, seasonally and annually, and recording waterpoints where animals can drink. Incidents are recorded for both direct reporting at the farm or when reported via phone calls. Coordinates were also recorded onsite as well as using ArcGIS by overlaying farm locations with aerial images.

3.4. Analytical methods

3.4.1. Spatiotemporal and ecological analysis

Spatial analysis has been lauded for analysing the natural phenomenon, helping nature conservators, environmental managers, and planners pursue appropriate approaches for nature conservation. Carter et *al.,* (2020) demonstrated that projects aimed at promoting human-wildlife co-existence and conservation could be achieved through integrated spatial planning. Thus, spatial analysis can play a significant role to guide spatial planning and environmental projects implementation. To accomplish the objectives, a spatiotemporal analysis was conducted applying a model for (Long *et al*., 2015) of a simplified explanation of deer sightings concerning preferred canopy cover. The fact that free-roaming *L. Africana* prefers open woodland and grassland savanna (Furstenburg, 2010), "wild" elephants are behaviourally shy animals and prefer spending daytime far from human settlements.

Given that perspective, the assumption of (*Long et al*., 2015) on deer on habitat choices can be readjusted to fit wild elephants. During preliminary field observations so far, a matching situation noted by (Hunninck *et al.* 2018) is that elephants commute to farms during the night and revert to safe habitats with good vegetation cover. Gaynor *et al.*, (2018) maintained that "animals may adjust their spatiotemporal activity, using areas of an anthropogenic disturbance at night when people are less active", surely moving away in daylight.

It was observed that elephants commute to waterpoints at a few farms where people are elephant-friendly, an assumption supported by local farmers during informal discussions. However, since the elephants still commute back to the remote habitat patches from the farms, with a good vegetation cover for shade and food, such patches have been considered in mapping out habitats and corridors. Curiously, their field records show that elephants prefer to ephemeral rivers during the day. However, elephant tracks commute through major tributaries to the open plains at night as they feed on their way to the farms and may relate to a pattern worth mapping out as commuting and migration corridors. Hence these major tributaries link potential habitat patches with sufficient vegetation cover and farms with water points or natural springs.

3.4.2. Spatial and statistical analysis of movement data to trace altitudinal shift patterns, core areas and habitat expansion

Due to the increasing use of GIS in ecology for landscape and species conservation (Siedel *et al*., 2018), analysis movement data is one of the GIS tools that ecologists are increasingly using to analyse movement patterns (Wade *et al*., 2015). Various software was used to execute analysis to identify how desert-dwelling elephant's movement may affect the emerging HEC hotspot of Omatjete and Ugab River Upper catchment and potential conflict hotspot in the adjacent areas that may be affected by future home range shift and expansion. Such an analysis should help this study detect any relationship between home range shift, commuting, and migration patterns. GIS is recommended by (Graser & Dragaschnig, 2018) and ArcGIS and QGIS were preferred for the analysis, complemented with SPSS. GIS statistical tools were used to measure the Kernel density and the Weighted Optimised Hotspot Analysis of the population movements compared to the known core areas of the population and the generation of annual overall population centre using a mean Euclidean distance.

The weighted mean was used to determine the population centroid of sightings every year and between wet and dry seasons. Ultimately, it allows for a population shift patterns analysis in relation to the elevation and rainfall gradients. The distance between different time-bound centroids was measured to interpolate any possible population shift over time and relate it to the rainfall and altitude gradients to analyse the relationship between elephant habitat core-areas and home range shift pattern that may trigger HEC in emerging conflict hotspots.

3.5. Identification of current vegetation cover appropriate for habitats preferred by elephants

Multispectral satellite imagery from the United States Geological Survey's Earth Explorer's Landsat images were analysed. Ibrahim and Al-Mashagbah, (2016) suggested that image processing and geometric rectification techniques used in GIS can help to trace changes in vegetation density in different areas that may translate into preferable habitats. It makes sense for north-western Namibia where human activities increased over the last 60 years following a colonial period of tribal land demarcation. Many indigenous people concentrate in a small tribal land such as Damara Land, increasing pressure on finite resources. With communal farming set up in the area, (Rudnick *et al.*, 2012) believes it can reduce habitat space and compel resources available for wildlife. Human activities accompanied by livestock farming may influence changes in habitats (McLaughlin & Mineau 1995, Alkemade *et al.*, 2011; Greenpeace, 2012; FAO, 2019), justifying the choice of data analysed. The results from different layers were compared to choose satellite imagery that provides the best resolution, making a combination of images from a different time of the day. Vegetation covers imagery was analysed in ArcMap

10.7.1 and ArcGIS Pro, adapting and modifying the method of (Islam *et al.*, 2016), following the pathways set out by (GISGeography, 2021).

Each band was downloaded separately into folders named according to the time of interest, April for the wet seasons and September for the dry seasons of 2000, 2005, 2010, 2005 and 2020. To render these raster datasets together to create a colour composite, each band contained within a single raster dataset is composted (ESRI, 2021). Thus, seven bands were composited using the ArcMap Composite tool. A band combination of 4, 3, 2, and 5, 4, 3 was preferred for Landsat 7 Enhanced Thematic Mapper (ETM +) and 8 Operational Land Imager (OLI) Surface Reflectance data through satellite images. The mentioned bands were chosen to drive the Normalised Difference Vegetation Index (NDVI) suitable for vegetation classification and quantification. The Landsat Ecosystem Disturbance Adaptive Processing System (LEAPS) at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Centre processes and releases Enhanced Thematic Mapper Plus surface reflectance scenes, providing 30-m resolution (Masek *et al*., 2006). The OLI reflectance is greater than the ETM reflectance for all bands as noted by (Roy et al. 2015), further alluding that the most remarkable differences are in the near-infrared (NIR) preferred during this study and the shortwave infrared bands due to the quite different spectral response functions between the sensors.

3.6. Analysis of vegetation cover and biomass in elephants historic home ranges in Ugab River lower catchment, a case study

As we built on a complex hypothesis, it is worrying that some vegetation was observed dead or with deteriorating health, especially large trees downstream. During preliminary observations, some vegetation patches of riverine forest in the Ugab lower catchment with many dead trees approximately cover areas larger than 500 m X 200 m (Figure 2). Water shortage is suspected of playing a role in vegetation loss. This situation may be driven by drought/declining average rainfall or an over-abstraction of water from boreholes, which depletes aquifers (Jasechko & Perrone, 2021). In addition, some natural springs known to flow annually have dried out over the last two years, yet this can be attributed to various traits associated with climate change and increasing pressure from anthropogenic activities such as farming over time. Mapping vegetation changes will help to predict a possible decline in biomass/vegetation cover (Adewumi *et al.*, 2016), which may apply to the lower catchment and may serve as a push factor for elephants wanting to expand their home range. A historic vegetation change detection analysis was done for the lower catchment to further interpret the data, comparing it with historical rainfall data.

To achieve the main goals, the health of vegetation was analysed by mapping out the major vegetation section that includes natural springs within the riverbed of the Ugab River's lower catchment (Figure 13 and 24, Appendix A, B and C). The site is also preferred by elephants, based on density analysis. The site is located at S-20.99446° and E14.46363° to S-20.99080° and E14.78905°, covering a riverbed length of 15.5 Km and a width of 1 Km across.

3.7. Identification and mapping corridors

Rivers are unique habitats for wildlife. Elephants in arid environments rely on ephemeral rivers for foraging, digging springs water, and commuting and migrating. Human development projects degrade riparian wildlife habitat and the adjacent terrestrial vegetation (Simon and Darby 2002 cited in Jeong *et al*. 2018), which leads to habitat connectivity reduction (Rudnick *et al* 2012, Pirnat & Hladnik 2016). In our study area, both humans and animals depend on rivers and their tributaries and food supply. No measurement was made to assess how settlement development affects elephants' habitats in the area. It was vital to map out appropriate commuting and migratory corridors and project those at risk and how that may contribute to elephant's habitat, commuting and migrating corridors blockage.

A combination of various approaches where considered, basing it on (Rudnick *et al* 2012) and modifications to their methods (Tuttle *et al* 2019). Layers generated using different GIS tools were overlayed to help us generate appropriate interpretations, applying criteria set out by Wade et al. (2015) for the Habitat and Corridor Cost Effective as adopted here to rank connectivity areas, supported with field experience of elephants. Anthropogenic obstructions and elephant resistant communities are considered as they can increase the cost of utilising specific corridors, no matter how suitable. The conservation biology model that considers cores, corridors, and buffers used by (Walker and Craighead 1997) was created based on the small island biogeography concept and the fragmentation of conducive habitats. Unlike Rudnick and co-authors (2012), that used watershed maps and riverine, linkage zone assessment criteria such as water sources within corridors and suitable vegetation that support natural surface springs or unexposed springs (where elephants can dig for water), as well as artificial water points and underground water flow for the tree line and clusters in the desert, are used. Satellite images are processed and classified based on a method discussed under topic 4.4 in ArcGIS, and mapping is modified based on water availability and farmers influence on community members. Refer to Appendix E for the list of artificial water points accessible by elephants.

4. Results

4.1. Elephant movement and population dynamics

Elephants' sightings were collected during all two major seasonal variations, the wet and dry seasons. About 60% of the dry/cold season elephant sightings were recorded at the lower half of the Ugab lower catchment from mid-July to the end of November of 2018-2019 (Figure 7 and 8). Wet season sightings at the Ugab upper half of the lower catchment mainly were done from March to May for the same years (Figure 7 and 8). In 2020, most of the dry season elephant sightings of the lower half of the lower catchment were in February and March for the upper half. Elephant's movements mainly were observed in the riverbed or within 5 Km next to the river, at the lower half of the lower catchment, and 27 Km and 22 Km north and south of the river at the upper half of the lower catchment. Few observations, less than 20%, were within the riverbed of the upper half of the lower catchment. Sightings of all elephants associated with the upper catchment home range were within 35 Km and 50 Km north and south of the river, while nearly 50% of the sightings were within 15 Km from the main Ugab River tributary. However, sightings outside the river are mainly along the tributaries of the Ugab river stretching through commercial farms, in mountainous areas and sandy to rocky plains. The figure below shows the distribution of the elephant movement sightings and annual rainfall distributions.

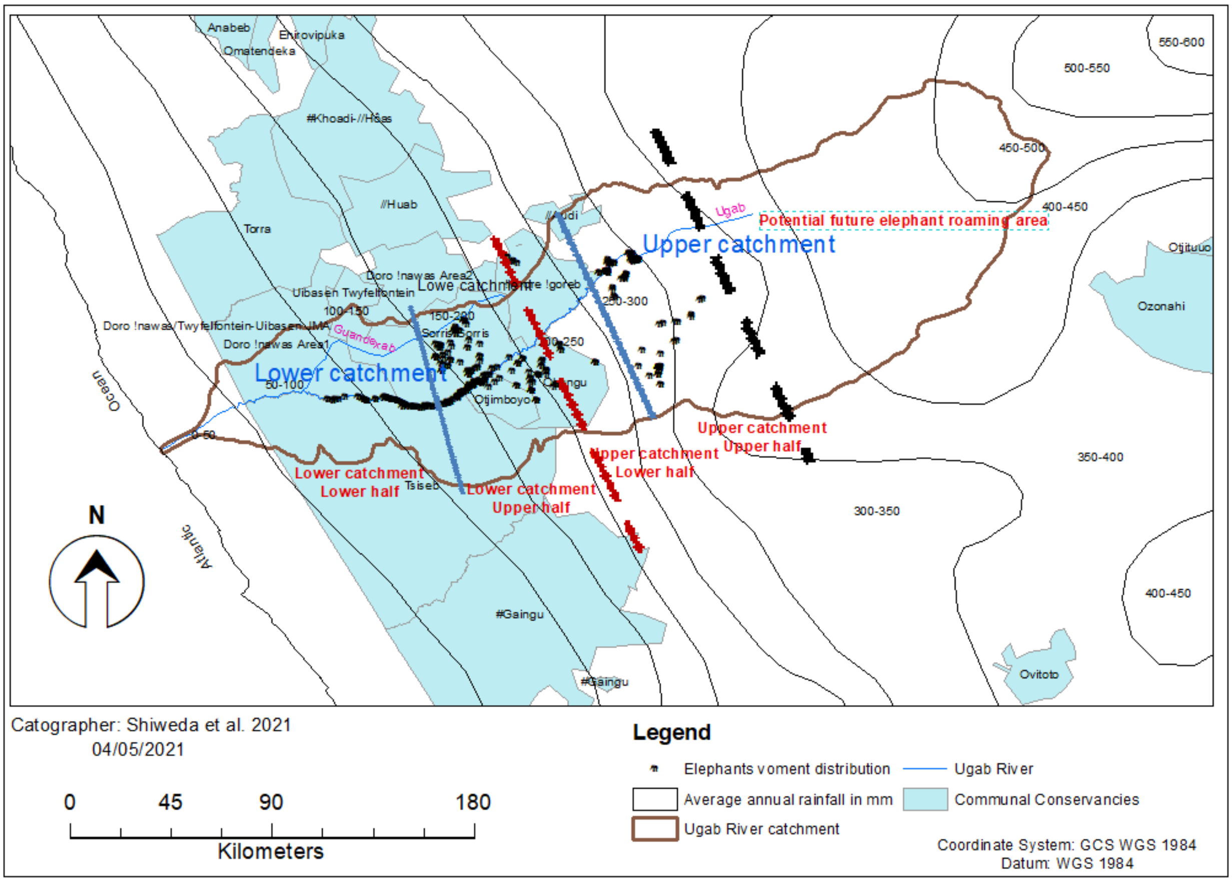


Figure 7. The distribution of elephants' movement sightings from February 2018 to September 2020. The main range fall within community conservation areas (conservancy with new expansions eastward. The blue, red and black lines are dividing different sections of the catchment as indicated with red letters.

The distribution shows the sightings made within communal conservancies and none-conservation areas. The amount of rainfall is also indicated in (mm), showing the amount of annual rainfall in each home range section. Desert elephant historic home range falls under <150 mm for the lower half of the lower catchment where they spend most of the time annually, while the lower catchment upper half receives <200 mm. Elephants spend less time at the upper catchment lower half (200 – 250 mm), and more time at the upper catchment upper half.

4.1.1. Weighted optimised hotspot Analysis

To map out the critical habitats and conflict hotspots, we weigh up the contribution of each sighting location to the predicted habitat core areas using Euclidean distance. The results are also overlaid with the water sources to observe the water points accessible by elephants. The waterpoints mostly accessible and close to major habitats have a high chance of being accessed by elephants. For the Ugab lower catchment, the closer the farms’ water points to the river, the higher the chance of elephants visiting to drink. On a different note, about 50% of the observations made at upper catchment water points within 15 Km from the Ugab River have equal chances of being visited by elephants as those within a 50 Km distance from the Ugab

River (Figure 8 and 9). The water points being visited by elephants that are away from the Ugab River at the upper catchment are considerably much more than those of the lower catchment (Figure 9 and Appendix E). Upper catchment waterpoints visited often are more located at the south of the river catchment compared to those of the lower catchment that are more at the north of the river catchment. Even if more water is available throughout the catchment, the number of water points being visited differs in spatial location. The number of boreholes distributed on each side of the river are almost the same, despite different visit incidents by elephants.

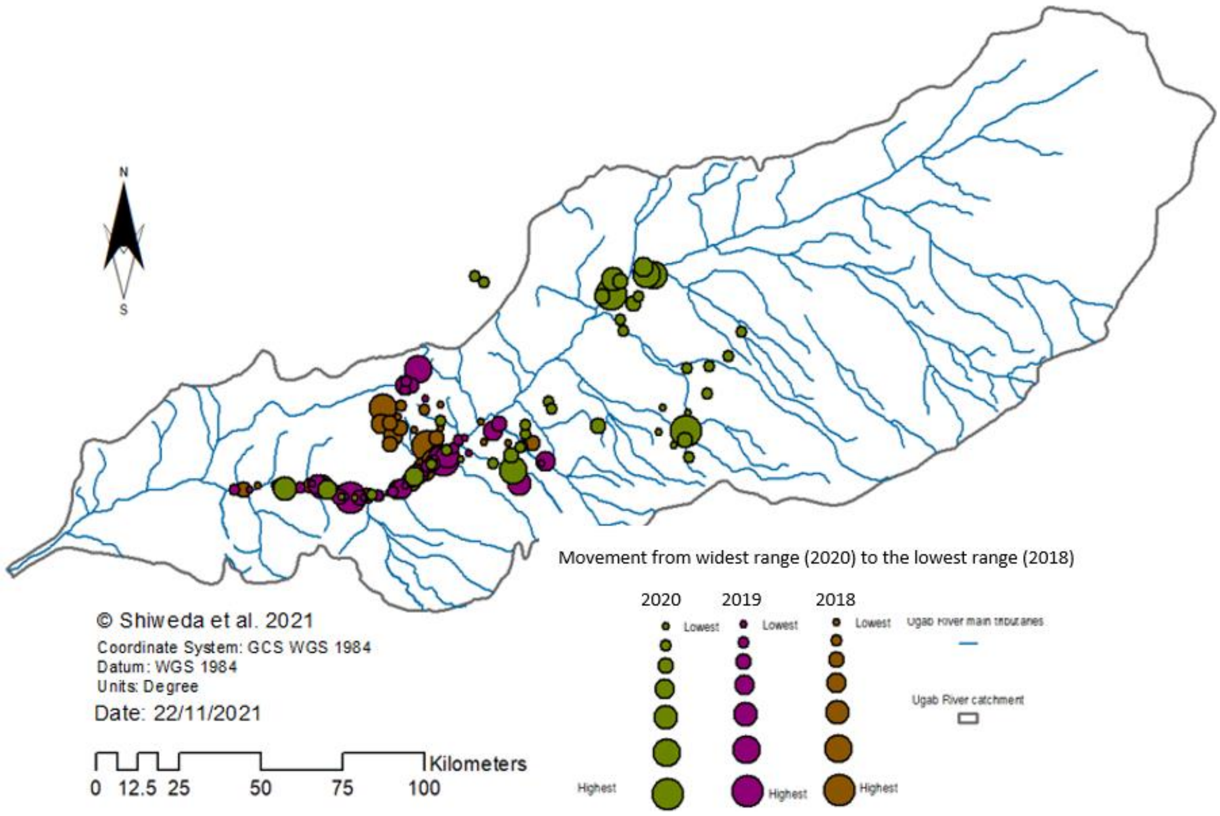


Figure 4. Elephants' sighting hotspots from largest hotspot range in 2020 to the smallest hotspot range in 2018.

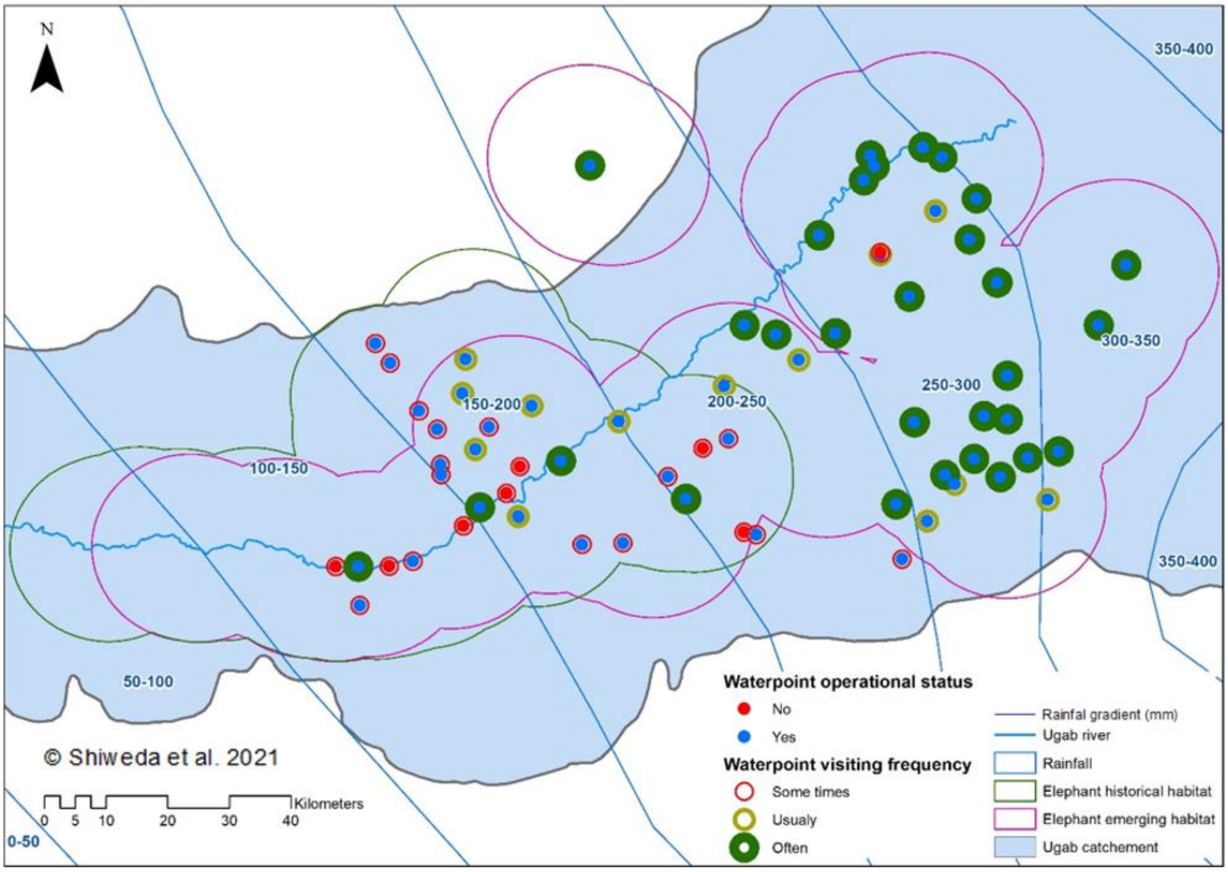


Figure 9. Location of waterpoints conflict. These are all drilled boreholes that access water at an average depth of 100 m (51).When comparing figure 2 and 3, there are more boreholes that are not functioning at the lower catchment along the riverbed. Elephants only live withing the proximity of the riverbed, thus can only access water from within and nearby waterpoints. Therefore a few water points are visited often, depicted with the size of the ring around them.

4.1.2. Home range expansion, shift and colonisation of new areas

The elephants are considerably changing the overall layout of their home range. The time spent at the lower catchment of the river is decreasing and increasing upstream. Less time is also spent within the transitional zone of the lower and the upper catchment. The transitional zone is between the lower and upper catchment, consisting of the lower catchment upper half and the upper catchment lower half. Elephants prefer to be at the lower half of the lower catchment or the upper half of the upper catchment home range. Elephants have spent more time at the lower catchment in 2018 and 2019 than in 2020 (Figure 8 and 10), but centrally shifting eastward. In 2020, elephants spent most of their time at the upper catchment, despite being seen there for the first time. The mean centre of the population shifted by 3.8 Km between 2018 and 2019 and 60.4 Km between 2018 and 2020 (Figure 10). The river length highly influences the shift direction, all moving eastward and spreading out wide at towards the upper catchments as more major tributaries.

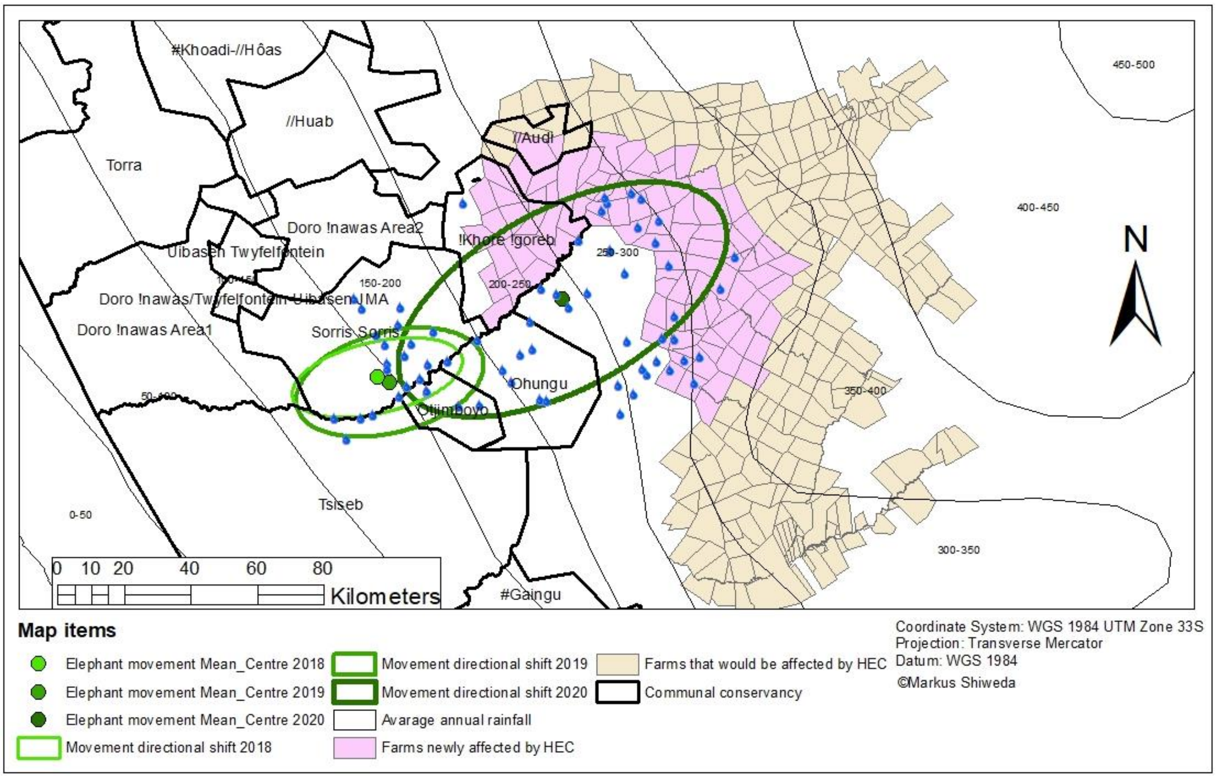


Figure 10. The population mean centre shift 2018 to 2020. The elephant's movement behaviour is shifting its entire population eastward (inland) to the commercial farms through communal land (open areas outside demarcated land east of Ohungu community conservancy)

4.1.3. Habitats lose, gain, connectivity, and corridors

The Ugab River desert-dwelling elephants overall home range is estimated over 12 237 Km² which expanded from <5 000 km². The home range covers over a third of the Ugab River's 29175.2 Km². Our analysis focused on viable habitat, with both lost and gained habitat estimated. A viable habitat in the context of the study population is narrowed due to other factors such as the nature of human interaction with elephants. A viable habit is where elephants have access to food and face less destruction from people and domestic animals such as dogs. In such an environment, an elephant can rest at least 90% of its preferred resting time without being distracted, that it should abort resting completely. Ugab River Lower Catchment Herds had a historic viable habitat of 2500 Km² of <5 000 km² overall home range (Figure 10 and 11), which has been reduced to 608.55 km² by 2018 (Figure 12) when much vegetation has significantly deteriorated (the vegetation started to decline measurably between 2013 and 2014)

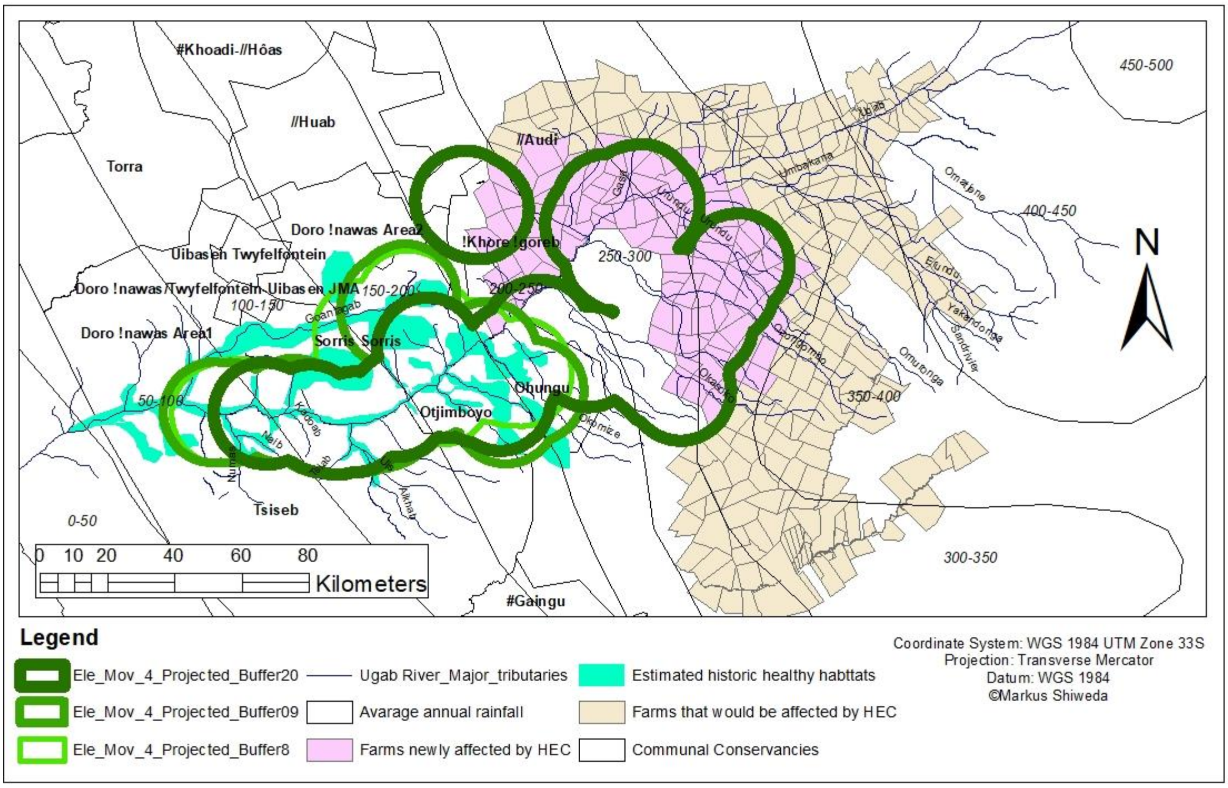


Figure 11. The buffer of the viable historical habitat of ULC elephants (green patches). The estimated historic viable habitat started 50 Km away from the ocean, and it is 150 Km long in the straight line. In the main riverbed that elephants often use for east-west-east migration, it is 155 Km.

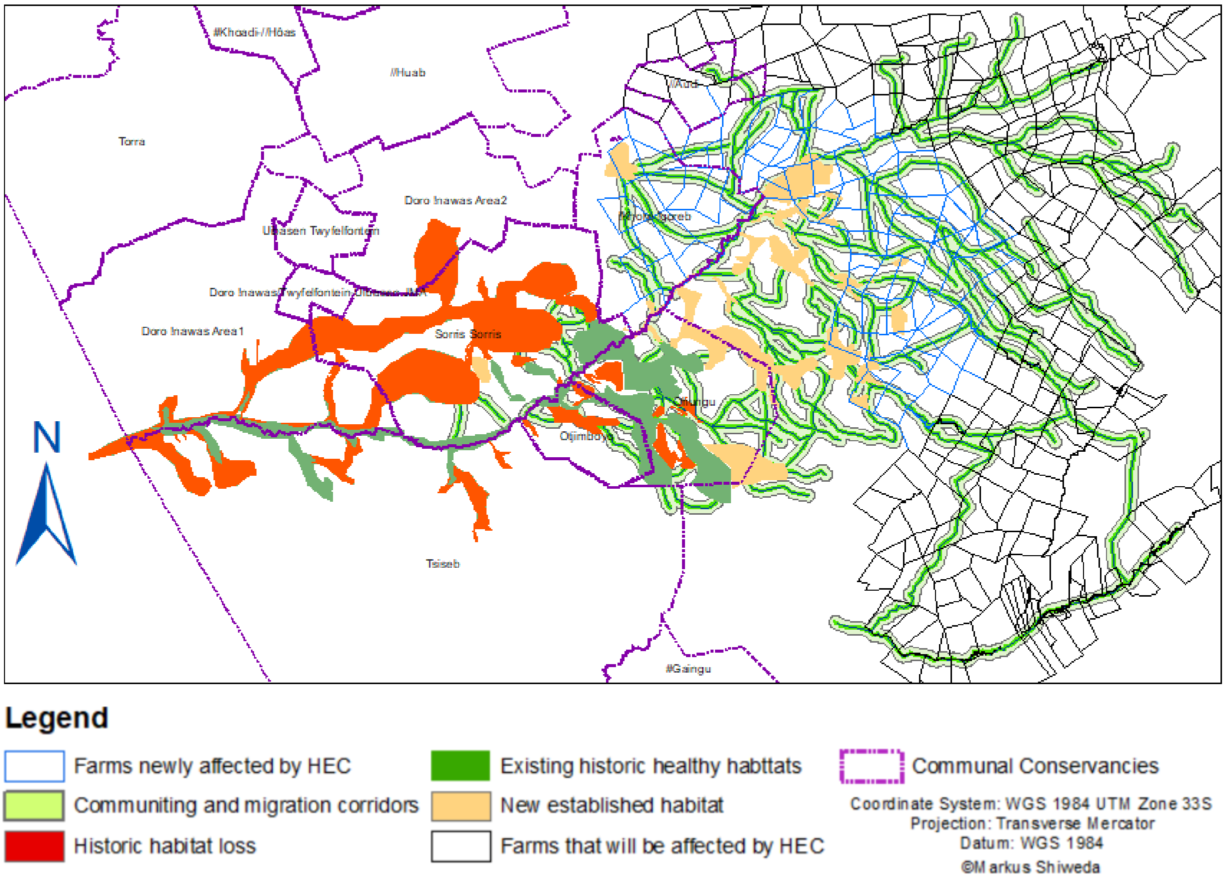


Figure 12. Habitat loss, gain and migration corridors. Historical habitat loss (red) reduced the available historical viable habitat (green).

The figure above shows a further extension of the elephant home range in 2020 with an additional 50 Km to 150 Km². The stretch in the main riverbed also increased by 53 Km, totalling a west-east movement of 207 Km of both viable historic and new home ranges. However, the viable historical habitat of 2243.33 Km² declined by 73% (habitat loss). The recent viable habitat expansion increased the existing viable habitat by 130.71% (habitat gain). Elephants are expected to continue moving further eastward temporarily in summer when they are upstream.

4.1.4. Habitat, vegetation, and biomass loss in the Ugab River lower catchment

A 16 446.94 hectares (ha) sample area was selected downstream (Figure 13), covering an east-west length of 38.5 Km. Areal images for the years 2000, 2005, 2010, 2015 and 2020 were analysed. However, there were no suitable images for 2005 due to cloud cover during the targeted months thus replaced with the satellite image of 2006. Other images collected during the same month also have the surface covered by mist and dust due to strong eastern wind. Thus the 2006 satellite image was considered for the same month. Over the last 20 years, the vegetation decreased cumulatively in the riverbed (Figure 13 and 14), living many healthy habitat patches barely vegetated. For detailed imagery view, refer to Appendix A, B and C.

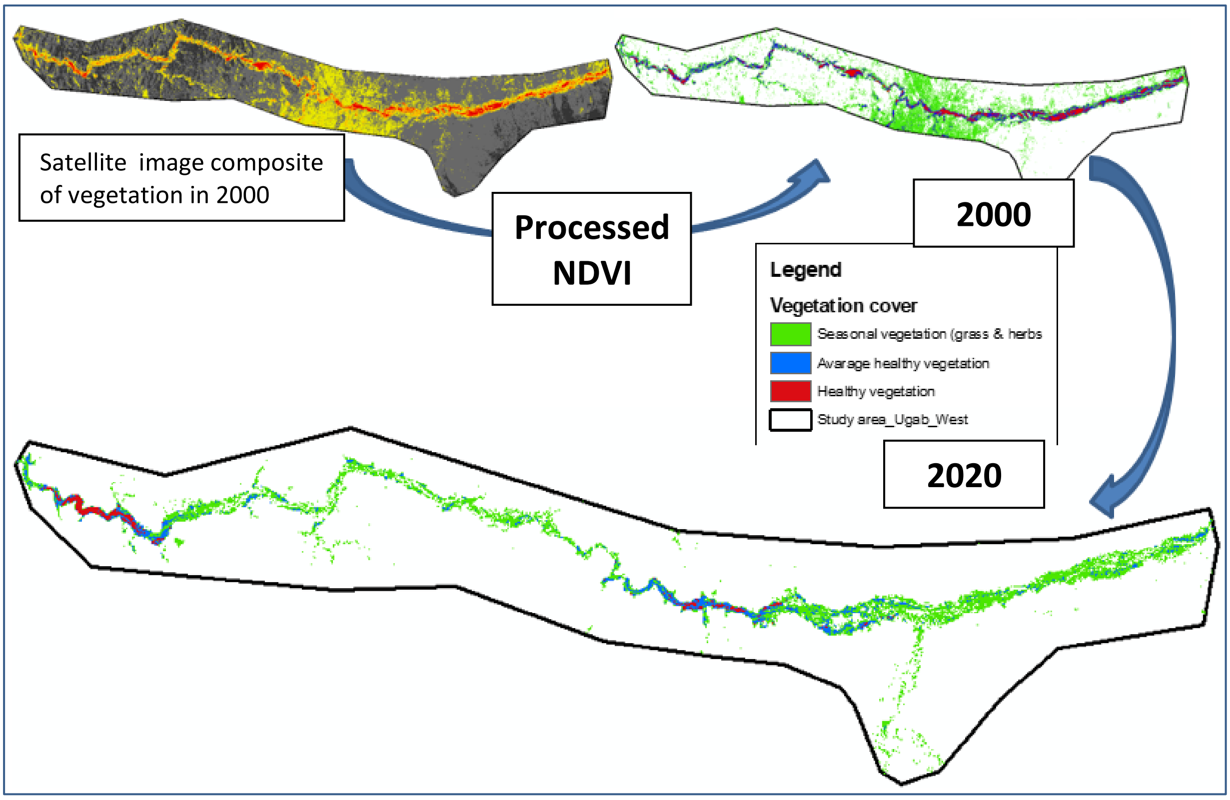


Figure 13. changes in vegetation in Ugab River lower catchment. The study area is at the lower half of the Ugab River lower catchment (north of Brandberg mountain), where desert elephants initially used to stay. Changes to vegetation available for foraging, resting, and hiding reduced lower catchment habitats suitability for elephants to continue living there.

The image was reduced from the overall area cover to show foliage only. A signature was created using a Training Sample Manager in ArcGIS to eliminate none-vegetation pixels. The classification was made based on the potential for the vegetation to reflect light, hence different vegetation categories. The categories of vegetation type were verified on site as well as using Google Earth images. For accuracy purposes, images from dry seasons with no seasonal vegetation were used, helping to differentiate seasonal and perennial foliage. However, the percentage cover of the none-vegetation pixels (rocky plains and mountainous areas) was considered in calculating vegetation percentage cover of the total area. The study area is at the lower half of the Ugab River lower catchment, where desert elephants initially used to stay. Changes to vegetation available for foraging, resting, and hiding reduced lower catchment habitats suitability for elephants to continue living there.

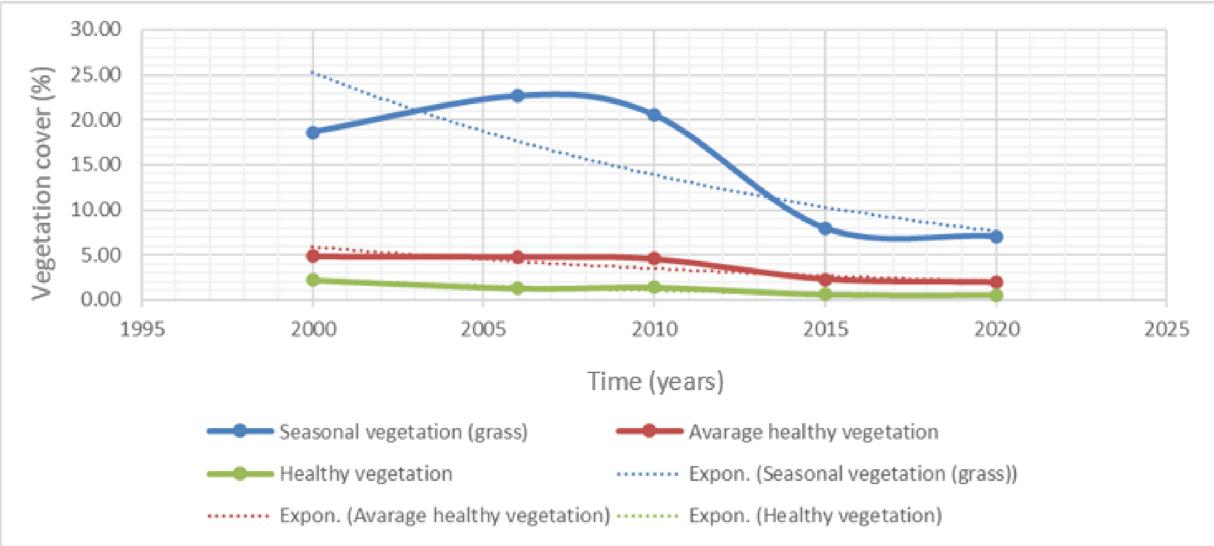


Figure 14. Gain and loss in vegetation cover and biomass from the Ugab River lower catchment.

The entire vegetation cover at the study area represents 25.8% of the sample area. Based on remote sensing assessment of the satellite images, seasonal biomass increased steadily from 2000 to 2006 by 4%. On the contrary, perennial healthy vegetation and perennial above-average healthy vegetation have decreased at a low rate (perennial healthy vegetation 0.9% and perennial above-healthy vegetation 0.1%) since 2000 to 2006, before a significant decline from 2010 to 2015 of 0.8% and 2.3% respectively. Overall, 1.7%, 3.0% and 11.6% decreases are recorded for seasonal, perennial healthy and above-average healthy vegetation between 2000 and 2020. Unfortunately, the vegetation decreased in summer (April) from 25.8% in 2000 to <9.5%, covering only 1 562.5 ha of the total sample area of the sampled area of the lower catchment by 2020.

5. Discussion

5.1. Climate change impacts on elephant habitats loss in Namibia

The vegetation and biomass analysis shows a decrease for seasonal and perennial vegetation over the last 20 years, despite the finding by (Viljoen 1990) that elephants have made no change to the vegetation in the desert until 30 years ago. Agreeably, the current decline of vegetation in ephemeral rivers in the north-western part of the Namib desert is not driven by elephants, as it is observed they have minimally affected the plants. The decline is thus driven by anthropogenic activities and climate change, mostly starting 15 years after the study by (Viljoen and Bothma, 1990). The amount of healthy vegetation has also decreased drastically, posing a concern for the sustainability of viable vegetation and biomass availability. A significant decline in all vegetation experienced between 2010 and 2015 correspond with severe droughts indicated by (Hitila, 2019), experienced from 2011 to 2018. Most of the drought events were declared a state of emergency, either at the regional level for Kunene and/or the national level. During the five years of significant decline, 15.7% of vegetation loss is recorded.

Based on the vegetation study, there is an increase in *Phragmites australis* and *Tamarix usneoides* growing in the riverbed at natural springs depicted in dense dark-red sections of the areal images (Figure 13, Appendix A, B and E). The two species were the only indicators of vegetation gain at the lower catchment, given that the Ugab River is not yet affected mainly by common alien plant species i.e., *Prosopis glandulosa*. *Prosopis glandulosa* is one of the three *P. ssp* invasive alien plants in Namibia's ephemeral rivers (Mannheimer & Barbra, 2009). The invasive *Prosopis* can absorb much water from the ground, with the potential to deplete underground water, making it less available to deep-rooted indigenous tree species. Nevertheless, *Prosopis* are more prominent at Huab River, the next ephemeral river with desert-dwelling elephants at 65 km north of Ugab River. Furthermore, a few *Datura ssp.* of the only three species in Namibia are seen widely spread in the riverbed during the rainy season, even though they are still less abundant. These species can potentially take advantage of the current climate conditions to outcompete indigenous plants during wet seasons, leading to unfavourable succession and historic wildlife habitat loss and modification.

The natural springs have dried up and water is deeper than a metre (Appendix E); hence most of the springs previously occupied by water throughout the year are now occupied mainly by the two unpalatable plant species, *P. australis* and *T. usneoides* (Figure 13, Appendix A, B and D). Increasing annual rainfall below average will continue to minimise the rate of aquifer recharge, consequently reducing water available at Natural springs and artificially drilled wells. However, the springs are getting even more dryer, that *P. australis* will soon start to decrease before the wild *T. usneoides*. Elephants are often found at the springs as there are limited favourable shelters downstream due to dead *Faidherbia albida*, the most prevalent and abundant large trees but currently dying. The limited amount of rainfall affects the chances of new seed germination, thus very few young *F. albida, Acacia erioloba* were recorded. Elephants can no longer dig for water as the depth has gone beyond their ability to access it by digging (see appendix D). That is contrary to the findings by (Ramey *et al*., 2013), who informed that there was water readily available at the springs, and even if elephants preferred to dig, the wells shown in their study were less deep.

Figure 15. Dying of trees mostly for Faidherbia albida (own caption, September 23, 2020). The trees dying at the lower catchments of ephemeral rivers in the Kunene Region, even though this photo taken from the Ugab River. The trees are potentially dying due to a lack of accessible underground water.

Figure 14 above shows many trees dying at the lower catchments of ephemeral rivers in the Kunene Region, taken from the Ugab River. The trees are potentially dying due to a lack of accessible underground water, as discussed above. Even if only climate change-related arguments were provided above, another driver of water shortage is discussed in the following section on anthropogenic factors affecting the ephemeral rivers ecosystems. Figure 15 below further portrays the increase in dying reeds at Natural springs in Ugab River and other ephemeral rivers home to the desert-dwelling megafauna.

Figure 16. Drying natural springs (own caption, September 23, 2020).

5.2. Anthropogenic driven impacts on wild elephants' behaviour and habitats loss

Desert elephants were believed to live more within the extreme desert (Viljoen 1989), and HEC previously affected communal farms downstream at the Ugab river lower catchment. Organisations and the government ministries operating in the area have been focusing and protecting water points at the farms at which elephants go-to drink to prevent them from being damaged. Elephants drinking dams have been constructed at the farms existing water points, attracting elephants at the farms. HEC escalated in the past three years, with more reports and complaints from the Ugab River upper catchment areas. Elephants are establishing permanent home ranges at the upper catchment, stimulating HEC in Omatjete and Okongwe communal areas and adjacent commercial farms.

Habitat loss in the lower catchment is the primary driver of change in elephant behaviour. Habitats at the lower catchments of ephemeral rivers are becoming highly fragmented and degraded due to the increasing unsustainable human economic activities targeting wildlife. Firstly, increasing tourism development facilities exerts much pressure on underground water by drilling new boreholes for water abstraction. Secondly, the communal farms continue to expand, accompanied by the rise in human population and small and large livestock. However, the growing population relies on limited resources, including food, water, and space. The reliance on underground water lowers the water table, as discussed by (Jasechko & Perrone, 2021). In arid environments as Kunene and Erongo, relying on underground water is very unsustainable. Extreme droughts have become more prominent than annual rainfall, implying no sufficient aquifer recharge. Lack of water for the lower system flow reduces vegetation cover and biomass, triggering elephants to seek refuge at the two regions' upper catchments of ephemeral rivers. The lack of water available at natural water springs in ephemeral rivers and the inability of elephants to dig for water will continue to force them out of the area. These arguments further justify escalating HEC incidents at upper catchments such as the Kamanjab area of the ephemeral Huab River and Hoanib in the north.

5.3. The survival of the population and its structures

Like many other social animals, elephants form social groupings (herd) associated too many aspects of animal society's dynamics. To begin with, Ree (2012) explored elephant communities and have identified "fission-fusion" society concept. Moss and Lee (2011) condensed that elephant herds are more influenced by their environment and the population structure for survival. Elephants live in a matrilineal herd of females and calves (Williams, Carter, Hall & Bremner-Harison, 2019), each cow with offspring or siblings. Fernando and Lande (2000) believes that both African and Asian elephant forms similar social groups though it differs in complexity. A matriarch is generally an adult cow (female) also believed to be dominant. An elephant herd can be made up of cousins, sisters or close relatives and their babies who would then fill up all age gaps (Moss and Lee, 2011 cited in Ree 2012). Think of a human society where young people, youth and adults makes up a healthy society. Some novelists like Watson (2003) in his “Elephantoms” book compared elephants’ behaviour as close to that of humans.

An elephant herd can be made up of up to 40 individuals, however, such bigger herds are rarely seen today for free-roaming herds. Free-roaming elephants, especially in Namibia’s drier environment, form small herds that often walk long distances every day in search of food. Bigger herds split during food shortage where dominant cows will lead to few smaller herds that only come together to the main herd during summer when more food is available. Matriarchs often stay in one herd for their entire life until it dies for matriarchal succession to take place. Using modern technology for monitoring, it requires to collar a matriarch in a herd to trace the location of every individual in the herd.

The observed herds are closely related, with 30% of observations recording all herds from the lower catchment together. Even when herds were not together, they mainly roamed at the same section of the home range. For instance, all three herds from the lower catchment have spent three months, from May to July 2020, at the same farms – Aspro, Farm Moselle, Omburo West and Omburo Ost. However, four young males older than 12 years tend to leave the herd. Young males keep moving between adult males and the herd. There were only two prime males at the lower catchment (one died, while another immature male is promoted to a breeding male aged 25) and three prime males for the upper catchment, suggesting a limited gene pool and a high possibility of inbreeding. There were nine breeding females at the lower catchment, three of them dying because of HEC, while one died three days after it was collared. As a result, ULH1 has only four males left and one female for the ULH2. There are no females left for ULH3. None of the three calves born survived in three years of data collection, adding to five more that were born and died less than a week after birth since 2014 when the last calf survived (EHRA 2019). Despite the population recent home range overlaps, desert elephants may have been isolated from the main population inland, and the fact that there is less interaction between desert-dwelling herds from other river catchments may subject the population to a weak gene pool. The herds upstream have overlapping home ranges and have enough emerging males and adult males.

Lack of survival in calving can be associated with disturbance and loss of habitat. Inability to find sufficient food due to loss of vegetation and decreasing biomass can lead to poor fetal development, premature death. The loss in Anna trees that provide high nutritious seedpods is contributing to less protein intake. Elephants in the desert often rely on Anna tree seedpods as a source of nutrients, mostly available late in winter when there is limited palatable vegetation compared to summer. Elephants are often consuming the reeds and wild Tamarix, which is all less nutritious and contains a high amount of salt and mopane trees containing 8.7% of tannins (Mannerheim & Curtis 2009).

It was observed that conservation authorities keep pushing elephants back into the desert to minimise conflict with farmers upstream. It is thus unclear if the time elephants spend at the original habitats is entirely by choice or is influenced by conservation institutions, policies, and practices. Despite such efforts, the deteriorating resource base at the original home ranges will not sustain elephants. Moreover, the limited number of females and prime males and the growing retaliation killings by commercial farmers that led to a loss of 3 females in two months has may further exploit the population.

6. Conclusion and recommendations

It is part of elephant behaviours to move and migrate from place to place within their home ranges. Rainfall pattern (Breine *et al*., 2020, Garstang *et al*., 2014), available food - quality and abundance, plays a significant role in influencing such movements (Breine *et al*., 2020, Viljoen 1989). However, it is unjust to be relaxed about the status quo, given the intensity in elephants behavioural change as it suggests adequately that the drivers are eminent. Therefore, understanding the history of the Ugab River lower catchments habitat and vegetation change was crucial to predict the future of wildlife in the area under climate change and anthropogenic factors influences.

This study helped to understand the drivers of the emerging HEC. The results suggest that future expansions of elephants' home range further inland commercial farms as predicted (Martin 2005). Some farms will act as commuting and migration corridors, while others will serve as habitats. This will happen if elephants' movement is uncontrolled and if the habitats within historic home ranges remain unfavourable. While the current and the past conservation efforts were more reactive to the situation, proactive solutions should be taken for the farmers upstream before elephants expand their home range further east. One action is to sensitise the farmers of the arrival of elephants through the next 20 years and how to co-exist with them. Another is a restoration of the historic habitats downstream.

6.1. Farmers' education and habitable corridors co-existence

The existing and projected elephant corridors for the home range expansion (Figure 11) will affect commercial farmers. Many farmers interviewed or had a random conversation while tracking elephants suggested that they are willing to live with elephants if provided with educational support on elephant behaviour and property damages offset/compensation. However, the cost of farming practices is incompatible with elephants, and coexistence will only be possible if new farming strategies are taken.

Namibia has a high tourism potential as a way for locals to generate income, and many private game reserves have succeeded in transforming into game reserves. Commercial farms in Namibia have much wildlife, including antelopes, despite keeping livestock as the main source of income. Given stressful stochastic events such as drought, the environment will not cope with many livestock. Livestock requires much water and have low caring capacity compared to wild animals. With limited rainfall and over-abstraction of groundwater, food and water will be limited, that livestock farming will not be possible for some farms. Wildlife would thus be a better option, which is compatible with having elephants on a game reserve, even if they would not be there permanently. Most game farmers did not have a problem having elephants on the farms, but the concern was that they do not farm with wildlife and risk losing game when elephants break fences. That would be a different scenario if every farmer kept game as no one loss games through the process. Practically, areas such as Namibrand-Naukluft landscape have removed fences after everyone stopped farming with livestock, and the area has become the most tourist attraction featuring the presence of Sossusvlei.

Farmer's education should feature these sustainable opportunities and how community members can live with elephants without fear. The belief that elephants are a danger to the local people is part of perceived conflict. E.g., some people complain about elephants even when there are no damages to properties, just because they want to have a ranger at their property for safety.

6.2. Historic habitat restoration

"Can we repair some of the damage humans have done to ecosystems and biodiversity? Ecological restoration seeks to do just that, and restoration ecology is the science that underpins it" (Vaughn, 2014). For example, desert-welling elephants survived harsh conditions of the desert for so many years, but the growing human population has a severe negative impact on the megafauna habitats. As a unique population in the world with only two desert elephants' populations remaining, restoring their habitats is essential for elephants to recolonise lost historic home range. Restoration may sound an exciting concept, but an ecological restoration expert (Young 1999) emphasised that restoration should be regarded as a second option than conservation of nature, termed conservation biology. The idea for Young suggests that you require restoration when you have already destroyed the landscape, assuming that appropriate or sufficient care may not have been taken well enough for the ephemeral rivers' lower catchments despite measurable conservation efforts.

On the first hand, the need to restore the lower catchments in Namib is more complex than the initial restoration process. Various aspects are required for entirely functional ecosystem restoration (Perring *et al*. 2015). While repair is believed to occur with minimal human interference (rehabilitation), a combination of the two may suit the Ugab river system. Loss of vegetation will not restore on its own without ant support of planting indigenous tree species such as *F. albida* that is unique to the area. Reforestation will help recover lost vegetation, considering that the impact of climate change may not allow for easy natural restoration as many desert plants require much water for the seeds to germinate, a missing component due to the rainfall decline.

On the other hand, the dying of big trees due to a lower water table limiting both plants and animals from accessing water requires partly human and police intervention – then ecological restoration. The current pressure on underground water by drilling boreholes reduces the amount of water needed downstream for a functional ecosystem that would sufficiently support elephants, desert lions, rhinos, and all other species home to the desert. As the government is currently looking into plans to supply desalinated water to the central towns, the same will be required for all farms and settlements along the Namib desert. Limiting groundwater abstractions will help maintain a limited amount of groundwater flow feeding the lower catchment due to poor aquifer recharge and high evaporation rate. In addition, the number of lodges and tourism developments should employ appropriate water use practices, e.g., exempting them from operating swimming pools and a high number of guests per night to cut water demand. Most of the tourism development in the areas owns one or two swimming pools, yet they are kept open all day long. Swimming pools is inappropriate leisure for the driest regions in Namibia and entire southern Africa and pursuing it will lead to substantial economic losses and ecological destruction in the near future.

6.3. The impact of desert habitats and wildlife loss on community livelihoods

It is known that conservancies found along the desert and within the lower catchments of the Namib desert ephemeral rivers are the most successful income generation. However, wild animal tracking and viewing is the most activity attracting tourists, second to the landscapes. Loss of wildlife will thus affect the potential of desert-based conservancies to generate income. It is revealed in this study that elephants are expanding their home range upstream, which will reduce tourism income. The income from hunting will also be lost since the lack of water flow to the natural springs, and food downstream will mean that there won't be huntable games. To protect the efforts of the CBNRM in Namibia, these recommendations should be considered for a potential restoration of the lower catchments and their wildlife.

7. References

Alkemade, R., Reid, R. S., van den Berg, M., de Leeuw, J., & Jeuken, M. (2012). Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proceedings of the National Academy of Sciences*, 110(52), 20900–20905. https://doi.org/10.1073/pnas.1011013108

Adewumi, J. R., Akomolafe, J. K., Ajibade, F. O., & Fabeku, B. B. (1970). Application of GIS and Remote Sensing Technique to Change Detection in Land Use/Land Cover Mapping of Igbokoda, Ondo State, Nigeria. *Journal of Applied Science & Process Engineering*, *3*(1), 34-54. https://doi.org/10.33736/jaspe.173.2016

Beirne, C., Meier, A. C., Brumagin, G., Jasperse-Sjolander, L., Lewis, M., Masseloux, J., Myers, K., Fay, M., Okouyi, J., White, L. J. T., & Poulsen, J. R. (2020). Climatic and Resource Determinants of Forest Elephant Movements. *Frontiers in Ecology and Evolution*, 8, 90–96. https://doi.org/10.3389/fevo.2020.00096

Brown, M., Pinzon, J., & Tucker, C. (2010). ISLSCP II GIMMS monthly NDVI, 1981–2002. *ORNL Distributed Active Archive Centre*, NP. https://doi.org/10.3334/ornldaac/973

Brown, J., & Bird, N. (2010). Namibia's Story: Sustainable natural resource management in Namibia: Successful community-based wildlife conservation. Overseas Development Institute. 1-18. https://odi.org/en/publications/sustainable-natural-resource-management-in-namibia-successful-community-based-wildlife-conservation/

Brown, K. (2003). Integrating conservation and development: a case of institutional misfit. *Frontiers in Ecology and the Environment*, *1*(9), 479–487. https://doi.org/10.2307/3868115

Brown, L. M., Ramey, R. R., Vinjevold, R., Vinjevold, T., & Jauire, A. (2020). *Status and distribution of desert-dwelling elephants in the Hoarusib, Hoanib, and Uniab River drainages, Kunene Region, Namibia*. Desert Elephant Conservation. https://desertelephantconservation.org/about-desert-elephants

Canney, S. M. (2019). *The Mali Elephant Project: protecting elephants amidst Conflict and poverty*. *International Zoo Yearbook*, 53(1), 174–188. https://doi.org/10.1111/izy.12236

Carter, N., Williamson, M. A., Gilbert, S., Lischka, S. A., Prugh, L. R., Lawler, J. J., Metcalf, A. L., Jacob, A. L., Beltrán, B. J., Castro, A. J., Sage, A., & Burnham, M. (2020). Integrated spatial analysis for human-wildlife co-existence in the American West. *Environmental Research Letters*, *15*(2), 021001. https://doi.org/10.1088/1748-9326/ab60e1

Chase, M. J., Schlossberg, S., Griffin, C. R., Bouché, P. J., Djene, S. W., Elkan, P. W., Ferreira, S., Grossman, F., Kohi, E. M., Landen, K., Omondi, P., Peltier, A., Selier, S. J., & Sutcliffe, R. (2016). Continent-wide survey reveals massive decline in African savannah elephants. *PeerJ*, 4, e2354. https://doi.org/10.7717/peerj.2354

Chwalibog, A., Ngcobo, J. N., Nedambale, T. L., Nephawe, K. A., & Sawosz, E. (2018). The future survival of African elephants: implications for conservation. *International Journal of Avian & Wildlife Biology*, 3(5), 379-384. https://doi.org/10.15406/ijawb.2018.03.00123

Croal, P. (2014). Beauty and adaptation – the marvels of Namibia's dryland habitat. *Biodiversity*, 15(2–3), 229–230. https://doi.org/10.1080/14888386.2014.931250

Douglas-Hamilton, I. (1987). African elephants: Population trends and their causes. Oryx, 21(1), 11-24. https://doi.org/10.1017/S0030605300020433

Elephant-Human Relations Aid (2019). Annual Conservation Report. Swakopmund, Namibia: EHRA

Elephant-Human Relations Aid (2020). Annual Conservation Report. Swakopmund, Namibia: EHRA

Enzerink, R. J. V. (2017). *Co-existing with wildlife in Namibia's conservancies: A case study on the relationship between human-wildlife Conflict and attitudes of local communities and the influence of Community-based Natural Resource Management on this relationship* (No. 1). Radboud University, Nijmegen. https://theses.ubn.ru.nl/bitstream/handle/123456789/5389/Enzerink%2C_Roderick_1.pdf?sequence=1

FAO. (2020). Biodiversity and the livestock sector – Guidelines for quantitative assessment. FAO, Rome, Italy. https://doi.org/10.4060/ca9295en

Fernando, P., and Lande, R. (2000). Molecular Genetic and Behavioral Analysis of Social Organization in the Asian Elephant (Elephas maximus). Behavioral Ecology and Sociobiology 48(1), 84-91. https://www.jstor.org/stable/4601782

Furstenburg, D. (2010). *Focus on the African Elephant (Loxodonta africana)*. *South Africa Hunter*, 03038, 56-59. https://www.researchgate.net/publication/316165649_Focus_on_the_African_Elephant_Loxodonta_a

Garstang, M., Davis, R. E., Leggett, K., Frauenfeld, O. W., Greco, S., Zipser, E., & Peterson, M. (2014). Response of African Elephants (Loxodonta africana) to Seasonal Changes in Rainfall. *PLoS ONE*, 9(10), 1-13. https://doi.org/10.1371/journal.pone.0108736

Gaynor, K. M., Branco, P. S., Long, R. A., Gonçalves, D. D., Granli, P. K., & Poole, J. H. (2018). Effects of human settlement and roads on diel activity patterns of elephants (*Loxodonta africana*). *African Journal of Ecology*, 56(4), 872–881. https://doi.org/10.1111/aje.12552</div

GIS Geography. (2021). *NDVI Maps in ArcGIS*. https://gisgeography.com/how-to-ndvi-maps- arcgis/

Graser, A., & Dragaschnig, M. (2020). Open Geospatial Tools for Movement Data Exploration. *KN – Journal of Cartography and Geographic Information*, *70*(1), 3–10. https://doi.org/10.1007/s42489-020-00039-y

Greenpeace (2012). Ecological Livestock: Options for reducing livestock production and consumption to fit within ecological limits, with a focus on Europe. Greenpeace International: Amsterdam, The Netherlands. Accessed from: https://www.greenpeace.org/static/planet4-international-stateless/

Gunaryadi, D., Sugiyo, & Hedges, S. (2017). Community-based human-elephant conflict mitigation: The value of an evidence-based approach in promoting the uptake of effective methods. *PLoS ONE*, 12(5), e0173742. https://doi.org/10.1371/journal.pone.0173742

Hachfeld, B., & Jürgens, N. (2000). Climate patterns and their impact on the vegetation in a fog driven desert: The Central Namib Desert in Namibia. *Phytocoenologia*, 30(3–4), 567–589. https://doi.org/10.1127/phyto/30/2000/567

Hitila (2019). An assessment of the capacity of the Directorate of Disaster Risk Management of Namibia. (thesis). Namibia University of Science and Technology: Windhoek, Namibia.

Hobbs, S. J. (2012, January). *Community participation in Biodiversity monitoring*. The University of York. https://core.ac.uk/download/pdf/5225576.pdf

Hunninck, L., Ringstad, I. H., Jackson, C. R., May, R., Fossøy, F., Uiseb, K., Killian, W., Palme, R., & Røskaft, E. (2018). Being stressed outside the park—conservation of African elephants (Loxodonta africana) in Namibia. *Conservation Physiology*, *6*(1), cox067. https://doi.org/10.1093/conphys/cox080

Ibrahim, M., & Al-Mashagbah, A. (2016). Change Detection of Vegetation Cover Using Remote Sensing Data as a Case Study: Ajloun Area. *Civil and Environmental Research*, *8*(5), 1–5. https://core.ac.uk/download/pdf/234678357.pdf

Ishida, Y., Van Coeverden de Groot, P. J., Leggett, K. E. A., Putnam, A. S., Fox, V. E., Lai, J., Boag, P. T., Georgiadis, N. J., & Roca, A. L. (2016). Genetic connectivity across marginal habitats: the elephants of the Namib Desert. *Ecology and Evolution*, 6(17), 6189–6201. https://doi.org/10.1002/ece3.2352

Islam, K., Jashimuddin, M., Nath, B., & Nath, T. K. (2018). Land use classification and change detection by using multi-temporal remotely sensed imagery: The case of Chunati wildlife sanctuary, Bangladesh. *The Egyptian Journal of Remote Sensing and Space Science, 21*(1), 37–47. https://doi.org/10.1016/j.ejrs.2016.12.005

Jachmann, H. (1985). Estimating age in African elephants. *African Journal of Ecology*, 23(3), 199–202. https://doi.org/10.1111/j.1365-2028.1985.tb00948.x

Jasechko, S., & Perrone, D. (2021). Global groundwater wells at risk of running dry. *Science*, 372(6540), 418–421. https://doi.org/10.1126/science.abc2755

Jeong, S., Kim, H. G., Thorne, J. H., Lee, H., Cho, Y. H., Lee, D. K., Park, C. H., & Seo, C. (2018). Evaluating connectivity for two mid-sized mammals across modified riparian corridors with wildlife crossing monitoring and species distribution modelling. *Global Ecology and Conservation*, *16*, e00485. https://doi.org/10.1016/j.gecco.2018.e00485

Johnson, M. C., Poulin, M., & Graham, M. (2003). Towards an Integrated Approach to the Conservation and Sustainable Use of Biodiversity: Lessons Learned from the Rideau River Biodiversity Project. *Human Ecology Forum*, *10*(1), 40–55. https://www.jstor.org/stable/24707086?seq=1

Jones, B., & Weaver, L. C. (2012). CBNRM in Namibia: Growth, Trends, Lessons and Constraints. *Evolution and Innovation in Wildlife Conservation*, 241–260. https://doi.org/10.4324/9781849771283-24

Leggett, K. (2010). Daily and hourly movement of male desert-dwelling elephants. *African Journal of Ecology*, 48(1), 197–205. https://doi.org/10.1111/j.1365-2028.2009.01101.x

Leggett, K. (2009). Annual Report 2008 For the International Elephant Foundation (January 2008 – December 2008). *The International Elephant Foundation*. https://elephantconservation.org/leggett-annual-report-2008/

Mannheimer, C., & Barbra, C. (Eds). (2009). Le Roux and Muller's Field Guide to the Trees and Shrubs of Namibia. Windhoek: Macmillan Education Namibia

Masek, J. G., Vermote, E. F., Saleous, N. E., Wolfe, R., Hall, F. G., Huemmrich, K.F., Gao, F., Kutler, J., & Lim T. K. (2006). A Landsat surface reflectance dataset for North America, 1990-2000, *IEEE Geoscience and Remote Sensing Letters*, 3(1), 68-72. http://dx.doi.org/10.1109/LGRS.2005.857030

McLaughlin, A., & Mineau, P. (1995). The impact of agricultural practices on biodiversity. Agriculture, Ecosystems & Environment, 55(3), 201–212. https://doi.org/10.1016/0167-8809(95)00609-v

MEFT/NACSO. (2021, January). *The state of community conservation in Namibia* (*Annual Report 2019*). *http://www.nacso.org.na/sites/default/files/The%20State%20of%20Community%20Conservation%20Report%202019%20-%20book.pdf*

Ministry of Environment and Tourism (2014). Press release on Desert Elephants. http://www.met.gov.na/files/downloads/

Ministry of Environment, Forestry and Tourism. (2020, December). *Revised National Strategy on Wildlife Protection and Law Enforcement 2021 - 2025* (No. 1). MEFT. https://www.met.gov.na/files/downloads/072_National-Strategy_Wildlife-Protection&Law-Enforcement_F_re1_201209s%20(2).pdf

NACSO (2017). The state of community conservation in Namibia annual report. Windhoek, Namibia: NACSO. http://www.nacso.org.na/sites/default/files/State%20of%20Community%20Conservation%20book%20web%202017.pdf

Naidoo, R., Weaver, L. C., De Longcamp, M., & Du Plessis, P. (2011). Namibia's community based natural resource management programme: an unrecognised payments for ecosystem services scheme. Environmental Conservation, 38(4), 445–453. https://doi.org/10.1017/s0376892911000476

Nakale, A. (2018). Namibia's elephant population grow to more than 22 000. *Africa Sustainable Conservation News*. Accessed from: https://africasustainableconservation.com/2018/10/22/namibias-elephant-population-grows

Namibia Statistics Agency (2011). Namibia 2011 Population and Housing Census. https://cms.my.na/assets/documents/p19dmn58guram30ttun89rdrp1

Osei-Owusu, Y., & Bakker, L. (2008). *Human-wildlife Conflict: Elephant Technical Manual* (ed) (1). FAO. https://www.fao.org/3/ai576e/ai576e.pdf

Perring, M. P., Standish, R. J., Price, J. N., Craig, M. D., Erickson, T. E., Ruthrof, K. X., Whiteley, A. S., Valentine, L. E., & Hobbs, R. J. (2015). Advances in restoration ecology: rising to the challenges of the coming decades. *Ecosphere*, 6(8), 131. http://dx.doi.org/10.1890/ES15-00121.1

Pirnat, J., & Hladnik, D. (2016). Connectivity as a tool in the prioritisation and protection of sub-urban forest patches in landscape conservation planning. Landscape and Urban Planning, 153, 129–139. https://doi.org/10.1016/j.landurbplan.2016.05.013

Poole, J., & Granli, P. (2008). Mind and Movement: Meeting the Interests of Elephants. *Amboseli Trust for Elephants and ElephantVoices*, 1-15. https://www.elephantvoices.org/multimedia-resources/elephantvoices-publications.html

Ramey, M. E., Ramey, R. R., Brown, M. L., & Kelley, T. S. (2013). Desert-dwelling African elephants (*Loxodonta africana*) in Namibia dig wells to purify drinking water. *Pachyderm*, 53: 66–72. https://pachydermjournal.org/index.php/pachyderm/article/view/325

Ree, A. (2012). African elephant social structure: Visual, tactile, and acoustic communication that underlies social behaviour. *Concordia University of Edmonton*. NP. https://doi.org/10.7939/r3-y64v-te70

Rohland, N., Reich, D., Mallick, S., Meyer, M., Green, R. E., Georgiadis, N. J., Roca, A. L., & Hofreiter, M. (2010). Genomic DNA Sequences from Mastodon and Woolly Mammoth Reveal Deep Speciation of Forest and Savanna Elephants. PLoS Biology, 8(12), e1000564. https://doi.org/10.1371/journal.pbio.1000564

Rudnick, D., Beier, P., Cushman, S., Dieffenbach, F., Epps, C. W., Gerber, L., Hartter, J., Jenness, J., Kintsch, J., Merenlender, A. M., Perkle, R. M., Preziosi, D. V., Ryan, S. J., & Trombulak, S. C. (2012). The Role of Landscape Connectivity in Planning and Implementing Conservation and Restoration Priorities. *Issues in Ecology*, 1(16), 1–23. https://scholars.unh.edu/geog_facpub/19/

Schalkwyk, D. L. V., McMillin, K. W., Witthuhn, R. C., & Hoffman, L. C. (2010). The Contribution of Wildlife to Sustainable Natural Resource Utilization in Namibia: A Review. *Sustainability*, *2*(11), 3479–3499. https://doi.org/10.3390/su2113479

Shetty, N.R., Vidya, T.N.C.. 2011. To split or not to split: the case of the African elephant. *Current Science*, (00113891). 100(6):810-812. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=60525992&site=eds-live

Shrader, A. M., Ferreira, S. M., McElveen, M. E., Lee, P. C., Moss, C. J., & van Aarde, R. (2006). Growth and age determination of African savanna elephants. *Journal of Zoology*, 270(1), 40-48. https://doi.org/10.1111/j.1469-7998.2006.00108.x

Teshome, A., Sisay, E., Khare, D., Dananto, M., Singh, L., & Tadesse, D. (2018). Applications of Remote Sensing and GIS in Land Use/Land Cover Change Detection: A Case Study of Woreta Zuria Watershed, Ethiopia. *Applied Research Journal of Geographic Information System*, *1*(1), 1–9. se-j-arjgis-2018.0101001

Trumbull, Mingram, B., Schmitt, A., Volker, F. (2000)., B. R., Emmermannl, R., Bühn, B., Gerstenberger, H., Mingram, B., Schmitt, A., & Volker, F. (2000). Insights on the genesis of the Cretaceous Damaraland igneous complexes in Namibia from a Nd- and Sr-isotopic perspective. *Communs Geological Survey Namibia*, (12), 113-324. http://www.mme.gov.na/files/publications/c96_Trumbull%20et%20al_Damaraland%20Igneous%20Complexes.pdf

Tuttle, J., Massa, B., Munzer, O., Shaw, R., Childs, S., & Randall, J. (2019, December). *A landscape plan for wildlife habitat connectivity: in the Eno River and new hope creek watersheds, North Carolina* (No. 1). *North Carolina Botanical Garden Foundation*. https://ncbg.unc.edu/wp-content/uploads/sites/963/2019/12/EnoNewHopePlan_December_2019.pdf

Vaughn, K. J., Porensky, L. M., Wilkerson, M. L., Balachowski, J., Peffer, E., Riginos, C. & Young, T. P. (2010) Restoration Ecology. Nature Education Knowledge 3(10), 66. https://www.nature.com/scitable/knowledge/library/restoration-ecology-13339059/

Viljoen, P., & Bothma, J. D. P. (1990). The influence of desert-dwelling elephants on vegetation in the northern Namib Desert, South West Africa/Namibia. *Journal of Arid Environments*, 18(1), 85–96. https://doi.org/10.1016/s0140-1963(18)30874-7

Viljoen, P. J. (1987). Status and past and present distribution of elephants in the Kaokoveld, South West Africa/Namibia. *South African Journal of Zoology*, 22(4), 247–257. https://doi.org/10.1080/02541858.1987.11448054

Viljoen, P. J. (1989a). Habitat selection and preferred food plants of a desert-dwelling elephant population in the northern Namib Desert, South West Africa/Namibia. *African Journal of Ecology*, 27(3), 227–240. https://doi.org/10.1111/j.1365-2028.1989.tb01016.x

Viljoen, P. J. (1989b). Spatial distribution and movements of elephants (Loxodonta africana) in the northern Namib Desert region of the Kaokoveld, South West Africa/Namibia. *Journal of Zoology*, 219(1), 1–19. https://doi.org/10.1111/j.1469-7998.1989.tb02561.x

Wade, AA, KS McKelvey, and MK Schwartz. 2015. Resistance-surface-based wildlife conservation connectivity modelling: summary of efforts in the United States & guide for practitioners. General Technical Report RMRSGTR-333. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

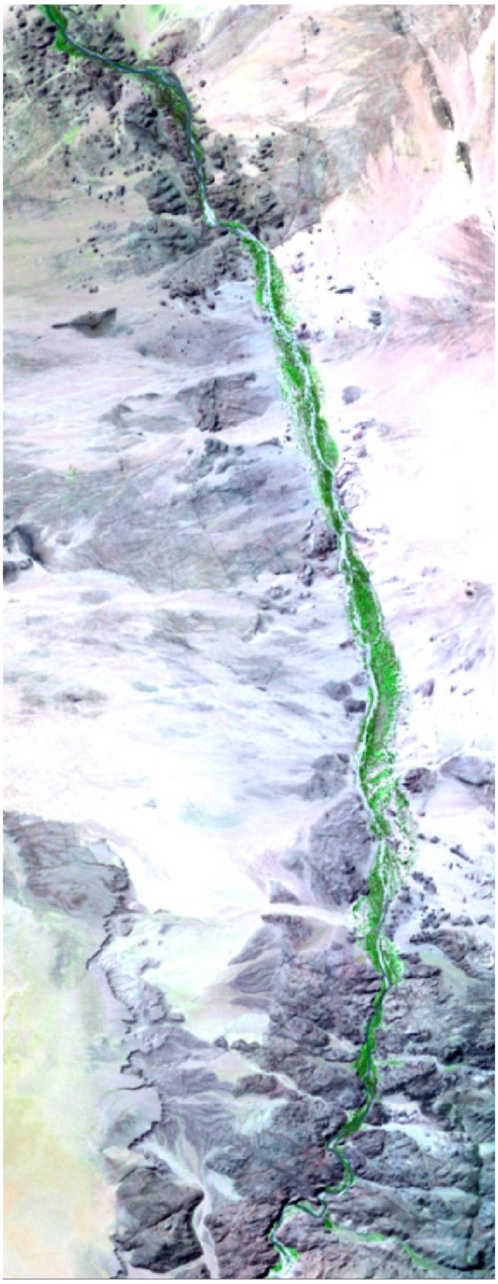
Watson, L. (2003). Elephantoms: Tracking the Elephant (Vol. 1). W. W. Norton & Company. ISBN:0393324591,9780393324594

Walker, RE, and FL Craighead. 1997. Analysing wildlife movement corridors in Montana using GIS. Proceedings of the 1997 ESRI User Conference. Available from http://proceedings.esri.com/library/userconf/proc97/proc97/to150/pap116/p116.htm.

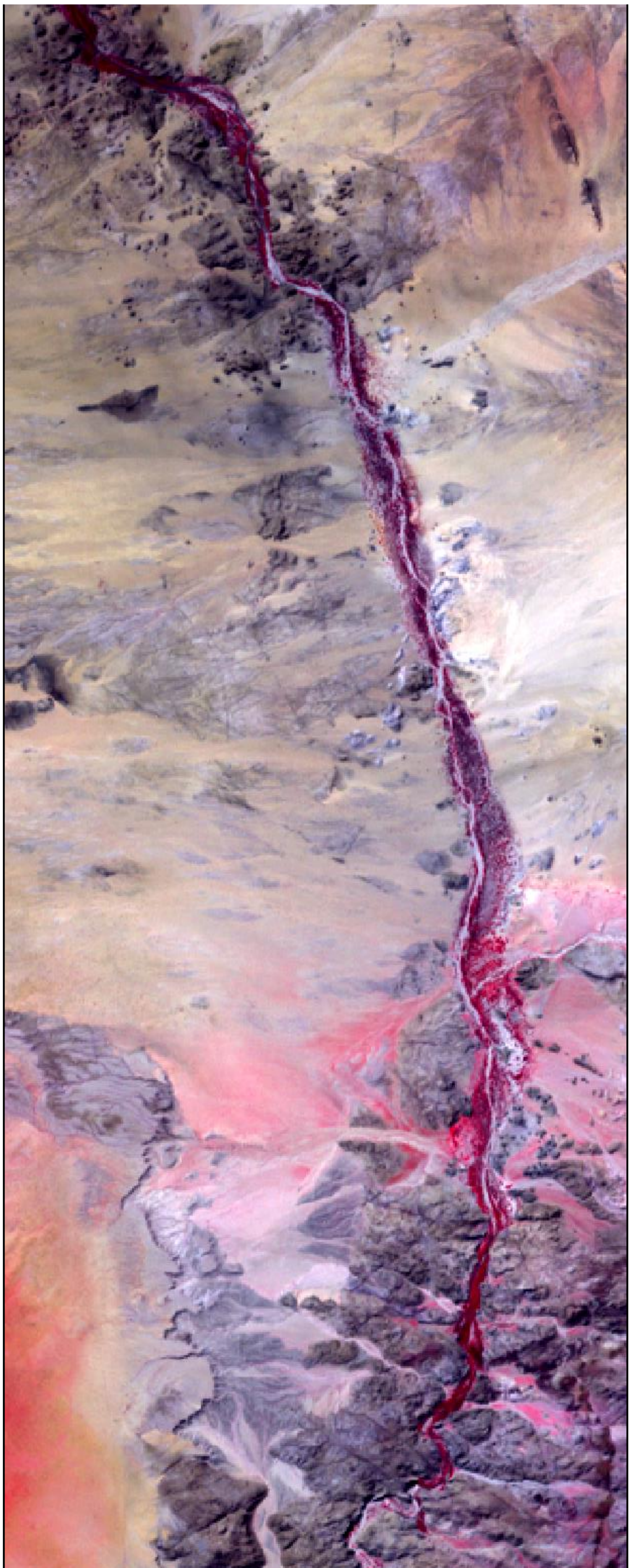
Williams, E., Carter, A., Hall, C., & Bremner-Harison, S. (2019). Social Interactions in Zoo-Housed Elephants: Factors Affecting Social Relationship. *Animals*, 9(10). 747; https://doi.org/10.3390/ani9100747

Young, P. T. (1999). Restoration ecology and conservation biology. Biological Conservation 92(1), 73-83. https://doi.org/10.1016/S0006-3207(99)00057-9

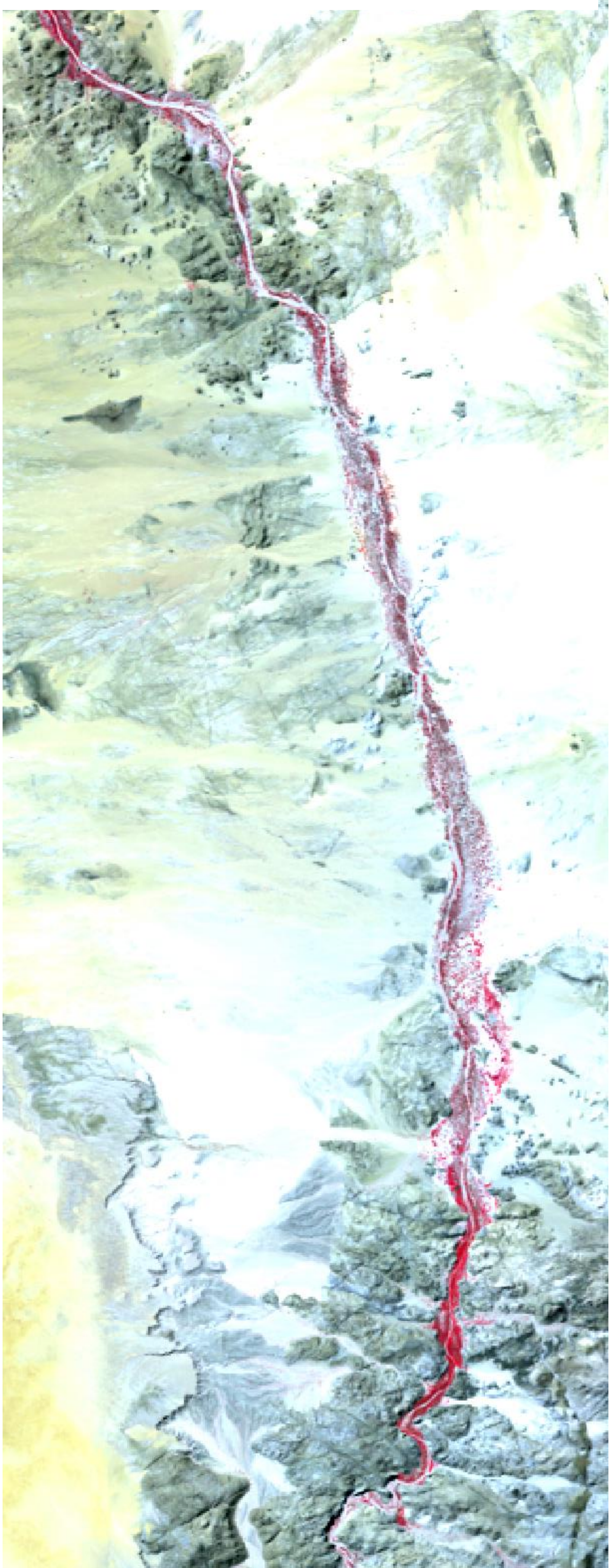
Appendix A: Composite image 2000



Appendix B: Composite image 2006



Appendix C: Composite Image 2000



Appendix D, A 1.1-meter depth to the water level at a dried-up natural spring downstream Ugab River

Appendix E. The list of manmade water points with water accessible to elephants

ID	Place_Name	Area	Region	Waterpoint_Vi	Waterpoint_Vi	Water_P_Oper	Damaged_by_E	Damaged_by_E	Water accessil	Lat	Lon	Avarag	Sum	Ava_flt
3	Alpha	Sori Soris	Kunene	Some times	1	No	No	2	0	-21.014	14.651	-3.1815	-6.363	3.1815
7	Brandberg Pos	Sori Soris	Erongo	Some times	1	Yes	Yes	1	1	-21.071	14.686	-3.1925	-6.385	3.1925
2	Aebeids Aarde	Sori Soris	Erongo	Some times	1	Yes	Yes	1	1	-20.688	14.709	-2.9895	-5.979	2.9895
1	!Gaus	Tsiseb	Erongo	Usualy	2	No	Yes	1	2	-21.01363889	14.729	-3.1423	-6.2846	3.14232
22	Loerkop	Sori Soris	Kunene	Some times	1	Yes	Yes	1	2	-20.71675	14.73041667	-2.9932	-5.9863	2.99317
23	Loerkop post	Sori Soris	Kunene	Some times	1	Yes	Yes	1	2	-20.7865	14.77269444	-3.0069	-6.0138	3.0069
15	Heinrich velde	Sori Soris	Kunene	Some times	1	Yes	Yes	1	2	-20.81327778	14.79930556	-3.007	-6.014	3.00699
19	Kairos	Sori Soris	Kunene	Some times	1	Yes	Yes	1	0	-20.86502778	14.80430556	-3.0304	-6.0607	3.03036
16	Houmoed	Sori Soris	Kunene	Usualy	2	Yes	Yes	1	2	-20.76094444	14.83613889	-2.9624	-5.9248	2.9624
4	Anixab	Tsiseb	Kunene	Usualy	2	No	No	2	0	-20.95433333	14.83791667	-3.0582	-6.1164	3.05821
67	Sori Soris Office	Sori Soris	Kunene	Usualy	2	Yes	No	2	0	-20.711	14.841	-2.935	-5.87	2.935
69	Uitsig post	Sori Soris	Kunene	Usualy	2	Yes	No	2	2	-20.843	14.85519444	-2.9939	-5.9878	2.9939
17	Irene	Sori Soris	Kunene	Some times	1	Yes	Yes	1	1	-20.80997222	14.87508333	-2.9674	-5.9349	2.96744
25	Manikams	Sori Soris	Kunene	Often	3	No	Yes	1	1	-20.90708333	14.90080556	-3.0031	-6.0063	3.00314
28	Okaepe	Sori Soris	Erongo	Usualy	2	Yes	Yes	1	1	-20.941	14.918	-3.0115	-6.023	3.0115
31	Okamahere	Sori Soris	Erongo	Usualy	2	Yes	Yes	1	0	-20.941	14.918	-3.0115	-6.023	3.0115
10	Eitaveree	Otjmboyo	Erongo	Some times	1	Yes	No	2	0	-20.94146	14.91843	-3.0115	-6.023	3.01152
65	Rooiport post	Sori Soris	Kunene	Some times	1	No	Yes	1	0	-20.86788889	14.92072222	-2.9736	-5.9472	2.97358
18	Irene post	Sori Soris	Kunene	Usualy	2	Yes	Yes	1	1	-20.77933333	14.93769444	-2.9208	-5.8416	2.92082
50	Otjikakaneno	Ohungu	Erongo	Often	3	Yes	Yes	1	1	-20.860064	14.980722	-2.9397	-5.8793	2.93967
46	Omihana	Sori Soris	Erongo	Some times	1	Yes	Yes	1	0	-20.982	15.011	-2.9855	-5.971	2.9855
64	Radyn Farm	Khorixas_Resettle	Kunene	Often	3	Yes	Yes	1	2	-20.428	15.023	-2.7025	-5.405	2.7025
61	Otuyapi	Otjmboyo	Erongo	Some times	1	Yes	No	2	0	-20.014283	15.03615	-2.4891	-4.9781	2.48907
51	Otjinduu	Ohungu	Erongo	Usualy	2	Yes	Yes	1	2	-20.802	15.065	-2.8685	-5.737	2.8685
54	Otjivero	Ohungu	Erongo	Some times	1	Yes	No	2	1	-20.8826	15.136641	-2.873	-5.746	2.87298
55	Otjiwapeke	Ohungu	Erongo	Some times	1	No	Yes	1	0	-20.841	15.188	-2.8265	-5.653	2.8265
12	Eura	Ohungu	Erongo	Usualy	2	Yes	Yes	1	1	-20.75	15.219	-2.7655	-5.531	2.7655
44	Omaozongaku	Ohungu	Erongo	Some times	1	Yes	No	2	0	-20.827	15.225	-2.801	-5.602	2.801
47	Omungambu	Ohungu	Erongo	Often	2	Yes	Yes	1	1	-20.950903	15.237208	-2.8568	-5.7137	2.85685
39	Okondomba	Ohungu	Erongo	Some times	1	No	Yes	1	0	-20.963591	15.247892	-2.8578	-5.7157	2.85785
43	Okotjoto	Ohungu	Erongo	Some times	1	No	Yes	1	0	-20.96355	15.24791	-2.8578	-5.7156	2.85782
33	Okapereke	Okongwe_Cons	Erongo	Often	3	Yes	Yes	1	0	-20.661	15.249	-2.706	-5.412	2.706
62	Ozondati	Ohungu	Erongo	Some times	1	Yes	Yes	1	1	-20.96749	15.26626	-2.8506	-5.7012	2.85062
42	Okotjize	Okongwe_Cons	Erongo	Often	3	Yes	Yes	1	1	-20.67527	15.2948	-2.6902	-5.3805	2.69024
52	Otjingore	Okongwe_Cons	Erongo	Usualy	2	Yes	Yes	1	0	-20.71197	15.32801	-2.692	-5.384	2.69198
37	Okavakua	Okongwe_Cons	Erongo	Often	3	Yes	No	2	1	-20.52969	15.35821	-2.5857	-5.1715	2.58574
38	Okavakwa_2	Okongwe_Cons	Erongo	Often	3	Yes	No	2	1	-20.52969444	15.35822222	-2.5857	-5.1715	2.58574
40	Okongwe	Okongwe_Cons	Erongo	Often	3	Yes	Yes	1	1	-20.673007	15.381771	-2.6456	-5.2912	2.64562
66	Rustig	Commecial farm	Kunene	Often	3	Yes	Yes	1	1	-20.449	15.423	-2.513	-5.026	2.513
68	Terrasse	Commecial farm	Kunene	Often	3	Yes	Yes	1	0	-20.413	15.433	-2.49	-4.98	2.49
45	Omburo_Ost	Commecial farm	Kunene	Often	3	Yes	Yes	1	1	-20.429	15.439	-2.495	-4.99	2.495
35	Okaserawe	Okongwe_Cons	Erongo	Usualy	3	Yes	No	2	1	-20.558	15.447	-2.5555	-5.111	2.5555
34	Okaserawe	Okongwe_Cons	Erongo	Some times	1	No	No	2	1	-20.55511111	15.44761111	-2.5538	-5.1075	2.55375
60	Otjozondjou	Zeraeue_TA	Erongo	Often	3	Yes	Yes	1	2	-20.923	15.471	-2.726	-5.452	2.726
59	Otjovatjimba	Zeraeue_TA	Erongo	Some times	1	Yes	Yes	1	2	-21.003	15.479	-2.762	-5.524	2.762
36	Okatjendjoura	Okongwe_Cons	Erongo	Often	3	Yes	Yes	1	1	-20.61921	15.48985	-2.5647	-5.1294	2.56468
48	Omutiuanduko	Okongwe_Cons	Erongo	Often	3	Yes	Yes	1	1	-20.80303	15.49705	-2.653	-5.306	2.65299
26	Moselle	Commecial farm	Kunene	Often	3	Yes	No	2	1	-20.401	15.51	-2.4455	-4.891	2.4455
32	Okanuanambuku	Zeraeue_TA	Erongo	Usualy	2	Yes	Yes	1	1	-20.948	15.516	-2.716	-5.432	2.716
8	Ehorongue	Commecial farm	Erongo	Usualy	2	Yes	Yes	2	0	-20.494	15.528	-2.483	-4.966	2.483
5	Aspro_Earth_dam	Commecial farm	Kunene	Often	3	Yes	No	2	1	-20.416	15.538	-2.439	-4.878	2.439
57	Otjomukona	Sori Soris	Kunene	Often	3	Yes	Yes	1	2	-20.88	15.542	-2.669	-5.338	2.669
56	Otjohorongo	Sori Soris	Erongo	Usualy	2	Yes	No	2	1	-20.89347222	15.55627778	-2.6686	-5.3372	2.6686
24	Madagascar	Commecial farm	Erongo	Often	3	Yes	Yes	2	1	-20.536	15.578	-2.479	-4.958	2.479
53	Otjiperongo	Sori Soris	Erongo	Often	3	Yes	No	2	2	-20.85658333	15.58438889	-2.6361	-5.2722	2.6361
27	Nuremberg	Commecial farm	Erongo	Often	3	Yes	Yes	1	1	-20.476	15.588	-2.444	-4.888	2.444
29	Okakombo	Commecial farm	Erongo	Often	3	Yes	Yes	1	2	-20.794	15.599	-2.5975	-5.195	2.5975
11	Epopo	Commecial farm	Erongo	Often	3	Yes	Yes	1	1	-20.599	15.618	-2.4905	-4.981	2.4905
58	Otjongoro	Commecial farm	Erongo	Often	3	Yes	Yes	1	1	-20.883	15.623	-2.63	-5.26	2.63
6	Boskloof	Commecial farm	Erongo	Often	1	Yes	Yes	1	1	-20.799	15.633	-2.583	-5.166	2.583
14	Gross_Omaoro	Commecial farm	Erongo	Often	2	Yes	Yes	1	1	-20.735	15.633	-2.551	-5.102	2.551
30	Okakombo Sud	Commecial farm	Erongo	Often	3	Yes	Yes	1	2	-20.855	15.663	-2.596	-5.192	2.596
20	Klein Okombahe	Commecial farm	Erongo	Usualy	2	Yes	Yes	1	1	-20.916	15.692	-2.612	-5.224	2.612
21	Klein Okombahe N	Commecial farm	Erongo	Often	3	Yes	Yes	1	2	-20.846	15.708	-2.569	-5.138	2.569
41	Okotjize	Okongwe_Cons	Erongo	Often	3	Yes	Yes	1	2	-20.661	15.76694444	-2.447	-4.8941	2.44703
9	Ehorongue_Earth	Commecial farm	Erongo	Often	3	Yes	No	2	1	-20.573362	15.806933	-2.3832	-4.7664	2.38321
70	Wolfa	Sori Soris	Kunene	Some times	1	yes	No	2	0	-20.87994444	16.13833333	-2.3708	-4.7416	2.37081
13	Gae-Aos	Sori Soris	Erongo	Some times	1	Yes	No	2	2	-20.98397222	16.14666667	-2.4187	-4.8373	2.41865
63	Quiti post	Sori Soris	Kunene	Often	3	Yes	Yes	1	1	-20.92736111	16.27833333	-2.3245	-4.649	2.32451
49	Omutiwanduko	Okongwe_Cons	Erongo	Often	3	Yes	Yes	1	1	-20.80336111	16.3025	-2.2504	-4.5009	2.25043