

**IMPACT OF TOURISM ON THE LANDSCAPE AND VEGETATION ALONG  
TOURIST ROADS IN ETOSHA NATIONAL PARK, NAMIBIA**

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## **ABSTRACT**

*Management of tourism-based protected areas often presents challenges in balancing biodiversity conservation and tourism development. Thus, understanding the interaction of related socio-ecological systems is essential for conservation. This study assessed how tourist roads, being part of tourism infrastructural development, impacts on the conservation efforts in the Etosha National Park, one of Namibia's hotspot for biodiversity conservation and visitor attractions.*

*For empirical data, stratified, randomly selected transects of 200m were conducted perpendicular to roads for vegetation assessment and soil analysis. This was complemented by the integration, manipulation and analysis of remote sensing and thematic data using Geographic Information Systems and Image Processing packages.*

*Results show that the Park has a tourist road density of 0.25 km / km<sup>2</sup>. Approximately 53% of these roads are situated on grasslands, a vegetation community which occupies 11% of the Park area. Moreover, gravel mining for roads constructions left behind at least 187 of un-rehabilitated gravel pits on the landscape. Kruskal-Wallis test showed that vegetation foliage cover and species abundance was not statistically related to distance from roads ( $p > 0.05$ ), whereas the General Linear Model revealed that the concentration of most soil chemical properties was not significantly related to distance from roads ( $p > 0.05$ ). However, cation exchange capacity, carbon and exchange calcium were significantly higher closer to roads.*

*Overall, impacts of tourist roads on the ecological landscape of the Etosha National Park are associated with vegetation clearance, habitat fragmentation and gravel quarrying. No conclusive evidence emerged to suggest that roads and vehicular emission have a significant impact on roadside vegetation and the concentration of soil chemical properties. The study recommends that siting of road infrastructures in the Park should be done considering various ecological factors, such as ecological sensitivity, endemism, species richness, and entrench a systematic rehabilitation policy of gravel pits.*

All maps, graphs and tables presented in this thesis were produced by the author, unless otherwise stated.

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**List of Acronyms**

CBD	Convention on Biological diversity
DPM	Disc Pasture meter
EI	Etosha Ecological Institute
EIA	Environmental Impacts Assessment
ENP	Etosha National Park
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Global Positioning System
ILWIS	Integrated Land and Water Information System
IUCN	International Union for Conservation of Nature
MET	Ministry of Environment and Tourism
NDP	National Development Plan
PAs	Protected Areas
SES	Socio-Ecological System
TSA	Tourism Satellite Account
UN	United Nation
USDA	United State Department of Agriculture
UTM	Universal Transverse Mercator
WTO	World Trade Organization

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***Dedication***

To my beloved family and friends

***Declarations***

I, Jesaya Nakanyala, declare hereby that this study is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education.

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## CHAPTER 1

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### 1. INTRODUCTION

#### 1.1. Background to the Study

Protected Areas hereafter referred to as PAs play an important role of global biological conservation in the world (Pauchard & Villarroel, 2004). PAs areas are defined as land or sea area dedicated to the protection and maintenance for biological diversity and cultural heritages, and managed by means of legal proclamations (Ching, Goh, & Yusoff, 2010). In Namibia, all PAs are proclaimed under the Nature Conservation Ordinance No 4 of 1975, which allows for the establishment of two types of major state-run PAs namely Game Park and Nature Reserve (MET, 2010).

Namibia's PAs cover approximately 17% of the land area, which is designated to preserve the biological diversity of fauna and flora (Ministry of Environment and Tourism, 2010). The history of PAs in the country dated back to the colonial era with the proclamation of game reserve 1, 2 and 3 as they were known at the time. The successive changes of boundaries of these reserves due to various reasons culminated into modern day Namib Naukluft Park and the Etosha National Park (ENP) (MET, 2010).

Before Namibia's independence in 1990, PAs were managed exclusively for wildlife management. The main objective for conservation was to protect wildlife from people who often hunted game for livelihood. Those who were caught hunting within

designated PAs were either fined or imprisoned or both (Hoole, 2008 ; Saarinen, Manwa, Becker, & Wilson, 2009). These restrictions were further extended to communal areas, whereas, commercial farmers were allowed to hunt games on their farms. This conservation strategy resulted in no immediate benefit to local communities, who instead turned hostile toward conservation efforts.

The proclamation of Namibia's PAs was accompanied by tourism and related recreational activities (Richardson, 1998). Namibia's PAs are rich in biodiversity which attract visitors especially nature-based tourists (Turpie, Lange, Martin, Davies, & Barnes, 2010). Also, Turpie et al. (2010) found that nature-based tourism activities such as game viewing, bird watching and attractive landscape attract over 73% of tourist to Namibia, who account for approximately 65 - 75% of all holiday expenditure in Namibia. Nature-based tourism is valued at an estimated amount of approximately N\$ 280 million per annum for the country (Turpie et al., 2010).

Following independence in 1990, the Namibia's tourism sector had grown rapidly due to increased political stability (Ashley, 2000 ; Hottola, 2009 and Saarinen et al., 2009). As a result, PAs started to contribute significantly to the economy through tourism revenue, employment creation and infrastructural development. The Namibian National Tourism Satellite Account (TSA) estimated that tourism sector contributed approximately 14.2% to the Namibia's Gross Domestic Product (GDP) in 2006 alone (Turpie et al., 2010). TSA are accounting methods developed by the United Nation (UN) and World Tourism Organization (WTO), and adopted by many countries including Namibia, to assess the economic values of tourism in destination countries. Statistics collected therefore indicated that tourism is the third largest

contributor of foreign currency to Namibian (GDP), following mining and fisheries (Hottola, 2009). In realizing the importance of the tourism sector in Namibia, MET has passed a National Policy on Tourism for Namibia in order to ensure that tourism developments are environmentally, economically and socially sustainable to meet the tourism development targets as stipulated in the National Development Plans (NDPs) and Vision 2030. The tourism policy therefore aims to guide tourism developments in the country in order to maximize tourism benefits within an acceptable environmental impact both in and outside PAs.

At times, tourism related activities may come in direct conflict with conservation and management efforts, however. While the presence of tourism activities in PAs is appreciated, conservation of biological diversity remains the highest priority (Blanco & Fedreheim, 2011). The Namibian legislation also recognizes conservation as a primary land use of local PAs, while tourism is considered as a secondary land use with its activities strictly limited to certain geographic zones within the PAs. Although financial benefits from tourism can be re-invested into conservation to manage PAs, an monitored tourism development may lead to unfavourable conditions, resulting in negative environmental impacts on natural habitats (Saarinen, 2006 as cited in Larson & Herr, 2008). In some instances, tourism and conservation are believed to lead to contradictory settings (Cheng & Zhang, 2005 ; Ferreira, 2004 ; Richardson, 1998). For instance, Lacitignola, Petrosillo, & Zurlini (2010) and Lindsay, Craig, & Low (2008) contend that tourism is a driving force which affect the environment through degrading natural resources such as landscape, natural

hydrologic systems, clean water, fresh air, and species diversity, thus reducing/altering their attractiveness. Contributing to the debate, Saarinen et al. (2009) argued that decision makers in the spatial planning of tourism development often strive to achieve monetary targets with low concern of environmental sustainability, by overlooking Planning instruments such as Environmental Impacts Assessment (EIA) in tourism development. Nature-based tourism is particularly vulnerable because it relies on the balance between conservation and tourism activities with the aforementioned contradictory relationship.

This study focused on the ENP, and assessed the impact of tourism on the Park's natural ecosystems. The ENP, one of Namibia's oldest and second largest Park in the country, is the leading nature-based tourist destination in Namibia (Hoole, 2008). In 2006, for example, out of approximately 900 000 international visitors to Namibia, 24.4 % visited the ENP (Turpie et al., 2010). At present, the Park occupies an area of approximately 22 270 km<sup>2</sup> (Berry, 1997), which was initially proclaimed as a game reserve in 1907, though it eventually received the status of a National Park through the Nature Conservation Ordinance No 4 of 1975 (MET, 2010).

Although the Park was initially dedicated to wildlife conservation, its rich biodiversity attracted numerous visitors which then necessitated tourism development in the Park. As a result, the ENP was opened to tourism in the 1950s (Berry, 1997 ; Dieckman, 2007). Since then, the development of infrastructure such as rest camps, roads and provision of potable water aimed at catering and enhancing

the comfort of visitors was promoted as a necessity. At the time of this research, the Park hosted five lodges, of which four are situated within a 10 km radius from the Etosha Pan, the most conspicuous geomorphological feature within the Park. The ENP is presently recognised as category II<sup>1</sup> National Parks under the International Union for Conservation of Nature (IUCN) (Dudley, 2008), while the Etosha Pan itself is classified as a wilderness area<sup>2</sup>. Although environmental impact assessments were conducted prior to the development and expansion of these facilities, monitoring the impact of tourism activities in the Park is lagging behind, which therefore necessitated this study.

## **1.2. Justification of the Study and Problem Statement Formulation**

The protection and management of ecological systems is of global and national importance in achieving conservation goals of the Convention on Biological Diversity (CBD) and the International Union for Conservation of Nature (IUCN), of which Namibia is signatory. These goals entail among others the conservation and sustainable use of biological diversity as well as equitable sharing of benefits arising from the uses of biodiversity (MET, 2010).

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<sup>1</sup> “Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities” (Dudley, 2008:16).

<sup>2</sup> “Wilderness areas are usually large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition” (Dudley, 2008:14)

In addition, the government of the Republic of Namibia has passed the National policy on tourism for Namibia (MET, 2008) and the Environmental Management Act of 2007 (GRN, 2007) as guiding documents toward sustainable tourism development both inside and outside PAs. These legislation are aimed at ensuring that tourism developments are economically, socially and environmentally sustainable through favourable tourism practice which would strive for a balance between minimal environmental impacts and a maximized quality visitor experience. Under the above-mentioned policy, Environmental Impacts assessments (EIA) and monitoring systems are required to identify significant impacts of tourism developments on socio ecological systems, thus informing relevant policies. Therefore, this study was designed to assess and evaluate the impact of tourism on the ecological landscape of ENP. The study limited itself to investigating the effects of tourist roads on adjacent ecological landscape. For the purpose of this study thereof “*impacts*” is used to refer to those developmental activities that may have a consequential qualitative or quantitative change on the environment, such as changes in ecological systems functions and degradation of landscapes.

As a result of tourism activities in the Park, a plethora of possible impacts may occur on the landscape. As such, impact emanating from road infrastructures was investigated in relation to vegetation and soil properties along tourist roads as well as the gravel pits created during construction of such roads in the Park. Results from this study will thus inform decision makers and protected area managers alike, about tourist’s related infrastructure and their implication on the management and utilization of PAs in Namibia.

### **1.3. Aims and Objectives of the Study**

The overall aim of this study was to determine the impact of tourist roads on the adjacent vegetation and soil properties in the ENP. In order to achieve this, the following objectives were formulated:

- Determine the road density for each vegetation community.
- Assess key vegetation parameters along tourist roads and compare it to that located at a predetermined distances away from roads.
- Measure and evaluate key soil properties along and at predetermined distances away from roads.
- Determine the density and areal size of gravel pits along tourist roads in the study area.
- Assess the ecological impact of such gravel pits on the natural landscape of the Park.

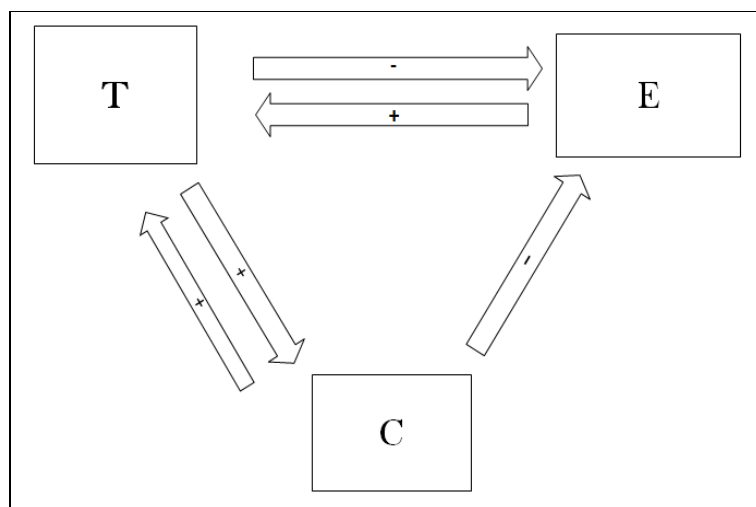
### **1.4. Research Questions**

In order to address the research objectives presented above, the study was directed by the following research questions:

- What is the level of roads density and coverage among vegetation communities of the ENP?
- Is there a change in vegetation structure in relation to proximity to roads?
- Is there a change in soil chemical properties with various distance away from and perpendicular to roads?
- What are the resulting ecological impacts of road construction in the Park?

### **1.5. Conceptual Foundation**

This study applied the Casagrandi and Rinaldi conceptual model (Casagrandi & Rinaldi, 2002 ; Lacitignola, Petrosillo, Cataldi, & Zurlini, 2007) of a tourism-based Socio-Ecological System (SES). A conceptual framework which was developed to assess the relationship between tourism development and quality of natural environment in PAs. Although this is a relatively new model in tourism management studies, it provides an appropriate framework for assessing the relationships among key tourist site variables, namely number of tourists visiting a protected area, infrastructural development for visitation purposes and changes in quality of natural environment. This model, also referred to as a minimal model, was deduced from a broader SES theory (Lacitignola et al., 2007). A SES is defined as an ecological system that is linked with and affected by one or more of the social systems (González, Montes, Rodriguez, & Tapia., 2008). A SES therefore involves the interaction between the natural and human environment. Asah (2008) ; Lacitignola et al. (2007) and Asah (2008) consider socio-ecological systems as complex systems whereby human's actions impact on the biophysical environment, while resulting consequences affect people in return. The interaction between tourists and nature is viewed as a socio-ecological system. For instance, Lacitignola et al. (2007) stated that the impacts of tourism on a destination results from a complex interaction among tourists activities and the natural landscape, therefore such interactions can be well understood in a SES context.



**Figure 1.1:** Conceptual model showing the interaction among the three major components of a tourism-based socio-ecological system. T=tourists, C= capital, E= quality of the environment, += positive interaction, - = Negative interaction. (Modified from Casagrandi & Rinaldi, 2002 ; Lacitignola et al., 2007)

Casagrandi & Rinaldi (2002) created this model to evaluate the relationship between three key pillars of a conceptual tourism-based socio-ecological system (Figure 1.1). For instance, (E) represents the quality of biophysical environment which serves as major tourist attraction, while (T) represents the number of tourists visiting a destination over a certain time period, and (C) represents capital which include accommodation, roads and other tangible facilities aimed for tourists activities. This model demonstrates that tourists (T) and physical facilities could have negative impacts on the environmental quality, which could potentially degrade attractiveness of the destination. But on the other hand, environmental quality (E) and facilities (C) attract tourists to a site. An increase in tourists (T) to a destination will create a demand for facilities and infrastructures (C). Meanwhile an expansion in facilities and infrastructures (C) has the potential to reduce the quality of the natural

environment (E). Additionally, if a tourist site loses its environmental quality which acts as a major attraction to visitor, it is likely to lead to a reduced visitation. While acknowledging the relationship between those three variables, this study specifically concentrated on the relationship between the growth and expansion of road infrastructures (C) and the quality of the environment (E). Lastly, this model was found to provide results which was in consistent with empirical studies (Lacitignola et al., 2007 ; Lacitignola et al., 2010).

## CHAPTER 2

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### 2. LITERATURE REVIEW

#### 2.1. Introduction

This chapter presents a synthesis of literature on the role of tourism in PAs. Firstly, two major contrasting views on the role of tourism in PAs are discussed. Secondly, in furthering the understanding of anthropogenic activities on natural ecosystems with a specific focus on roads infrastructure and related traffic activities, various findings from similar investigations are presented.

This section is portioned into three parts. The first part provides a general overview on the societal importance of roads infrastructural development and its relation with terrestrial ecosystems. While the subsequent parts deal with ecological effects of roads and related traffic pollutions, both during construction and vehicular traffic uses.

#### 2.2. Tourism and Biodiversity Conservation in PAs

In this study, the term “PAs” refers to those areas proclaimed and managed exclusively for conservation purpose, which also provide an opportunity for tourism, such as National Parks and Nature reserves. PAs are hubs of rich biodiversity of fauna and flora. As a result PAs represent a great conservation value in various countries.

The rich biodiversity found in PAs attract numerous nature-based tourists, creating business opportunities in tourism which contribute to socio-economic growth of local communities (Bushell & Eagles, 2007). Although the socio-economic benefits of

tourism are well documented, the role of tourism as a striving effort to ecological conservation in PAs is nevertheless still debated among conservationists. For instance, Li, Ge, & Liu (2005) and Li, Zhang, Liu, & Xue, (2006) argued in favour of tourism, by asserting that it brings positive influence in the environment through being used as an alternative livelihood source instead of other unsustainable methods of utilizing natural resources such as mining and agriculture, which degrade the natural landscape and disrupt ecological processes. These same studies, argued that nature-based tourism plays rather a big role in preserving ecological biodiversity in PAs compared to other forms of consumptive tourism such as hunting which mainly occur in private reserves. In defence of tourism, Bushell et al. (2007) also claimed that tourism gives visitors an opportunity to view nature which increases their interest in the protection and conservation of nature, as well as generating revenue for conservation work in PAs. Karim & Main (2009) argued that apart from financial benefits, tourism in PAs contributes to conservation through education and provides public awareness about environmental protection, thus achieving win-win goals with conservation.

Despite the positive environmental and socio-economic impacts of tourism presented in the aforementioned section, other studies have argued to the contrary. For instance, Bushell & McCool (2007) ; Cheng & Zhang (2005) and Ferreira (2004) argued that tourism and management of PAs are driven by conflicting interests, with destination developers striving to maximize visitors satisfaction and ensure profit, while on the other hand, protected area managers are trying to conserve and ensure the integrity of natural habitats. As a result, poorly planned tourism developments in

PAs often lead to the degradation of natural resources on which tourism itself as an industry depend (Bushell et al., 2007 ; Keyser, 2002).

The major challenge facing conservationists and destination developers is to find a balance between ensuring a high quality visitor experience and maintaining the integrity of ecosystems (Bushell & McCool, 2007 ; Moore & Polley, 2007). Visitors satisfaction depends up on the quality of activities and facilities available to tourists (Ching et al., 2010). In order to secure mutual benefits of tourism and conservation of biodiversity in PAs simultaneously, sustainability has increasingly become an important aspect of tourism development (Buckley, Pickering, & Weaver., 2003 ; Ferreira, 2004 ; Larson & Herr, 2008). Sustainable tourism is defined as:

*“tourism which is developed and maintained in an area in such a manner and at the scale at which it remains viable over an infinite period and does not degrade or alter the socio-ecological environment in which it exist to such a degree that it prohibits the successful development and well-being of other activities and process”* (Spenceley, 2008:02).

Some of the effects of tourism on PAs are related to infrastructural development such as roads, aimed at catering for tourist’s activities in Parks. Road infrastructure is used by visitors in PAs for activities such as game drive, sight seeing and scenery landscaping. As thus, their existence and expansion in tourism based PAs are a necessity. The following section deals with specific road related environmental effects.

### **2.3. General Overview on Ecological Effects of Roads**

Roads are linear conspicuous objects on the environment (Forman and Alexander, 1998). The presence of roads in a certain area forms part of the integral component of modern societies because they provide vital opportunity for transportation (Rentch et al., 2005 ; Van der Ree, Jaeger, Van der Grift, & Clevenger., 2011). Although the presence of road networks has enhanced connectivity within societies, it has nevertheless decreased connectivity among the remaining natural habitats of terrestrial and aquatic ecosystems (Roedenbeck et al., 2007). In support of this for instance, Coffin (2007:396) stated that “few forces have been more influential in modifying the earth than transportation”. In this context the linear structure of road networks is seen as a major modifier of the Earth environment as opposed to other anthropogenic activities.

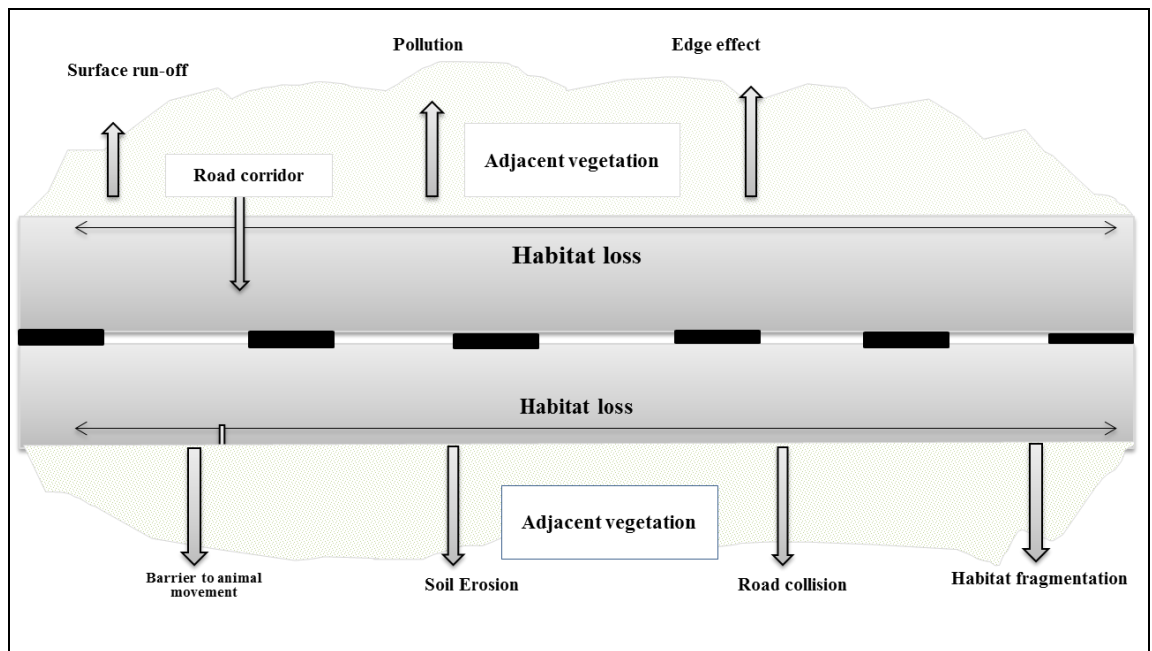
Moreover, authors such as Akay, Erdas, Reis, & Yuksel (2008) argued that road constructions in the past years were mainly planned with major consideration of economic and social factors, while overlooking environmental factors. As a result, many environmental losses have occurred due to road construction. Road networks facilitate the utilization of natural resources by providing access to resources extraction and recreational activities (Akay et al., 2008 ; Van der Ree et al., 2011). The effects of roads on terrestrial ecosystems have therefore become a major concern of environmental conservationists.

Road impacts on ecosystems have been subjected to research in recent years. For instance, studies by Coffin (2007) ; Forman & Alexander (1998) ; Hussein & Elhaj (2004) ; Rentch et al. (2005) ; Shuangcheng, Qiaofu, & Lei, 2005 and Spellerberg

(1998) have addressed various aspects of roads related environmental impacts. These studies culminated in a general agreement that the interaction between a road, being an anthropogenic feature, and natural ecosystems results in alteration of such natural ecosystems. Key variables such as road corridor width, an area which is physically cleared for roads construction, roads connectivity and road usage are considered to be the main indicators of road impact on ecosystems (Forman & Alexander, 1998). Similarly, Angold (1997) and Rentch et al. (2005) found road infrastructure and vehicular traffic volume has a major and an increasing impact onto the environment. Such impacts range from habitat loss and disturbance during construction, to pollution from road dust, edge effects from road usage as well as wildlife mortality and barrier effects to wildlife movement. The following section thus deal with the aforementioned issues in more detail.

#### **2.4. Ecological Effects of Roads Emanating During Construction Process.**

The impacts from roads and vehicular traffic are classified into two major groups ; those that occur during the roads construction phase such as habitat loss, landscape fragmentation, and those effects that emerge following the utilization of roads and related vehicular activities such as pollution, soil erosion, and edge effects along the road verge, surface runoff, and vehicle-animal collision (Figure 2.1).



**Figure 2.1:** The conceptual model of primary ecological effects of road on ecosystems. (Re-drawn and modified from Seiler 2001 ; Müllerová, Vitkova, & Vitek , 2011).

#### 2.4.1. Landscape Fragmentation

Road constructions affect various aspects of terrestrial ecosystems. This section discusses ecological effects that occur on the ecological landscape during the process of road construction. Firstly, during construction process, there is a direct loss of natural habitats, by clearing vegetation and disturbing soil structure (Akay et al., 2008 ; Spellerberg, 1998). Similarly, Garci, Arevalo, & Palacios (2007) argued that transportation infrastructure is recognized as a main source of ecological fragmentation and disturbance in forest landscapes through loss of forest area, dividing ecosystems with artificial linear gaps, generate abrupt edges and shape landscape patterns, an ecological damaged referred to as fragmentation.

Ecological fragmentation is defined as the reduction in size and isolation of patches of natural environment by anthropogenic features (Alan, Franklin, & George, 2002). Similarly, Seiler (2001) defined fragmentation as splitting of contiguous areas into smaller and increasing dispersed fragments. Fragmentation reduces the amount of habitats available to wildlife. The construction of roads is particularly considered as the main agent of fragmentation of terrestrial ecosystems (Karim & Main, 2009 ; Seiler, 2001 and Van der Ree et al., 2011). Such process involves the breaking down of larger habitats into smaller habitats, which threaten biodiversity survival, as well as confining wildlife into small isolated habitats. According to Karim & Main (2009) isolation and declining patch size of forest habitat has been implicated in population declines of many species and may pose a threat to migratory species. Also, a study by Ament, Clevenger, Yu, & Hardy (2008) argued that road construction and usage leads to a direct wildlife mortality as well as road avoidance behaviours by wildlife. Indeed, landscape fragmentation alters vegetation structure and available habitats for many species (Cui et al., 2009). In an emerging discipline of “road ecology”, road density is considered as a convenient measure of landscape fragmentation (Forman & Alexander, 1998 ; Shuangcheng et al., 2005). Road density is defined as road length per unit area, mainly expressed in km/km<sup>2</sup> of road that passes through a certain vegetation community or habitat Forman & Alexander (1998). Therefore, Forman & Alexander (1998) proposed that a well-functioning landscape with a sustained population of wildlife such as wolves, lions and other mammals should have a maximum road density of approximately 0.6 km / km<sup>2</sup>. This road density threshold level was based on USA Minnesota wildland which is mainly dominated by coniferous, deciduous, brushland and scattered pasture. Thus this approach could

possibly not be directly applicable to other ecological systems such as semi-arid region of the Savannah ecosystems. Although Forman & Alexander (1998) acknowledged that this threshold level of road density is species specific, and its application will depend on landscape and infrastructure characteristics. This same study found that such a threshold level of road density is mainly applicable for managing impact of roads on wildlife such as road kill and road avoidance behaviours by wildlife than the ecosystems health itself. Moreover, the effects of road density are triggered mainly by other factors such as road width, traffic density and the network connectivity (Forman & Alexander, 1998).

In addition, the process of road construction is accompanied by major disturbances such as landscape excavation and quarrying that radically alter the ecological landscape (Takahashi & Miyajima, 2010). The quarrying process is done in order to excavate gravels for road construction, which may leave behind gravel/burrow pits on the landscape. Although Garlo (n.d.) and Santoul, Feguerola, & Green (2004) argued that gravel pits play an important role in conservation such as storing water for wildlife. Johnson & Lewis (2006) have argued contrary to that, emphasizing that during gravel excavation, the cut operation remove the area's top soil, leaving infertile material onto the surface which cannot support vegetation growth. Further, Pople & Page (2002) argued that gravel pits in PAs contribute to ecosystem degradation by promoting overgrazing and over browsing of vegetation as a result of these gravel pits being artificial water points, turning the landscape into piosphere systems. In addition, other construction materials imported from elsewhere in

different environments may bring along non-native seeds. Lastly, roads convert habitats into pavements and road verges that influence landscape quality.

#### **2.4.2.Road Networks and Sediment Transportation**

Soil is an essential engineering material for road construction and maintenance, a process that leads to the removal of soil as well as altering its biological and chemical properties (Biggs & Mahony, 2004). Also, foreign materials used in construction may introduce heavy metals and other chemicals in adjacent soil, thus altering its nutrients. Although, some heavy metals occur naturally in the environment, the extreme concentration of some soil heavy metals has been found along roadside soil as compared to distant localities (Forman & Alexander, 1998 ; Jaradat & Momani, 1999 ; Swaileh, Hussein, & Abu-Elhaj (2004). Foreign materials used in road construction may alter soil properties such as pH, EC organic content and other soil physico-chemical properties (Cui et al., 2009).

Moreover, roads affect different aspects of the hydrological systems and related variables such as soil erosion. For instance, Douglas (2003) found that roads account for over two-third of the soil erosion that occur in tropical forests. Road geometry, slope, road length, width, surface and frequency of maintenance are the major factors that influence the amount of sediment carried away from roads (Forman & Alexander, 1998). Sediments are transported from areas closer to road and then get deposited in nearby streams, thus affecting the hydrological system and water quality

(Coffin, 2007). Also, (Du Plessies, Bredenkamp, & Trollepe, 1998) the interaction between roads and hydrological systems depend on their locations relatively to the drainage networks. Meanwhile, Shi et al. (2008) found that the amount of soil erosion and severity decrease with an increase in distance from road. Likewise, roads are a major source of surface water runoff which triggers sediment removal (Coffin, 2007). The reduction in soil infiltration rate and increased soil compaction along road causes a higher surface runoff, which in turn leads to increased soil erosion.

In addition, surface water from roads is known to contain foreign pollutants from other habitats as well as tyre particles, fuel waste and other pollutants (Angold, 1997). During the road construction phase, a vast amount of vegetation cover is removed, which increase surface run-off, leading to a great loss of top soil and weakening soil physical properties (Cui et al., 2009). Therefore, roads have increasing impacts on hydrological systems and sediment transportation.

## **2.5. Ecological Impacts of Roads and Vehicular Traffic related Activities**

### **2.5.1. Impact of Roads and Vehicular Traffic on Adjacent Vegetation Communities**

Vegetation adjacent to roads often deteriorates due to various road-related factors. For instance, Flory & Clay (2006) found that solid particles from road pollution affect vegetation and cause changes in plant species composition. In addition, micro-habitats created alongside road networks affect the growth of various roadside plants (Takahashi & Miyajima, 2010). To confirm this, Angold (1997) and Cui et al., (2009) observed that species richness and diversity was significantly lower closer to

roads as compared to a distance further away, and, a higher dominance of grass cover mainly closer to road, while woody species increase with increased distance from road. Further, Angold (1997) speculated that road related traffic pollution is the probable major cause of this pattern, while Farrel & Milton (2006) observed that a decrease in woody vegetation with distance to roads was caused by clearing of vegetation during construction and maintenance of roads. Although clearing vegetation closer to roads might be necessary to increase visibility for motorists, it nevertheless compromises the survival of some vegetation species. Moreover, traffic density on a certain road was found to have a positive strong correlation with changes in vegetation condition, with emission as the major probable factor causing such changes.

### **2.5.2.Effect of Roads and Vehicular Traffic on Roadside Verges**

Road verge refers to the strip of land adjacent to road surface, usually dominated by herbaceous species such as grasses and herbs (Forman & Alexander, 1998 ; Jaradat & Momani, 1999 ; Swaileh et al., 2004). Road verges have been considered as areas of significant ecological value contributing to the conservation of various flora in the world (Farrel & Milton, 2006). As a result some road verges are designated as PAs. For instance in the United Kingdom and the European Union, some road verges are designated as PAs due to their botanical interests (Thomas, 2005). Despite such significant botanical interests attributed to road verges, they are nevertheless subjected to a variety of stresses from passing road traffic, which include oil spill, petrochemicals, lead and other air pollutants as well as effects of vehicle movement on the verge itself by off-road driving and tramping (Thomas, 2005). A study by

Takahashi & Miyajima (2010) found that road construction increase the relative cover of gravels and rocks on the edge of road which increase soil compaction as well as decreasing the ability of vegetation growth.

### **2.5.3. Vehicular Traffic Related Pollution and Roadside Soil Contamination**

Soil may be contaminated by pollutants from both natural and anthropogenic sources (Wang & Qin, 2007). Some of the anthropogenic sources of soil pollution are from roads and traffic related activities. Studies by Hussein & Abu-Elhaj (2004) and Jaradat & Momani (1999) found that motor vehicle release a large proportion of pollution into the environment which affect the roadside environment considerably. In addition, Coffin (2007) stated that toxic contaminant spread into the broad environment through storm water run-off from roads, thereby affecting interior environment. Park et al. (2010) found a statistical significant relationship between distances from roads and the concentration of soil chemical variables such as carbon (C), nitrogen (N), organic matter (OM), magnesium (Mg), soil cation exchange capacity (CEC), calcium (C) and soil pH along urban roadside environment in Ohio, USA. Also, Hussein & Abu-Elhaj (2004) detected a statistical significant relationship between the concentration of soil chemical variable such as lead (Pb), copper (Cu) and zinc (Zn) along a busy highway in the Palestinian's West Bank.

Soil pollution may become hazardous to vegetation. For example, Angold (1997) and Rentch et al. (2005) found that pollution emitted from road such as carbon, sulphur, nitrogen, lead and undistinguished dust affect plant growth. Similarly, Friedlova

(2010) argue that the contamination by soil chemicals has a significant problem which lead to negative influence on soil characteristics and limit productivity and environmental function.

However, there are other factors such as underlying geology and types of vegetation present at a certain site that influence soil properties (Cui et al., 2009). Thus, different localities which differ in underlying geology will differ in soil properties despite their distance from road.

## **2.6. Conclusion**

Land-use practice such as tourism and related-recreational activities in natural habitats require infrastructural development. In this context, the role and effects of road infrastructure was synthesized from a landscape ecology and conservation perspective. Results from this synthesis showed that road construction, maintenance and related traffic-vehicular activities results in ecological effects onto adjacent vegetation communities. Such effects are among others, landscape fragmentation, soil pollution, roadside erosion and surface run-off.

## CHAPTER 3

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### 3. THE GEOGRAPHICAL SETTING OF THE ENP AREA

#### 3.1. Introduction

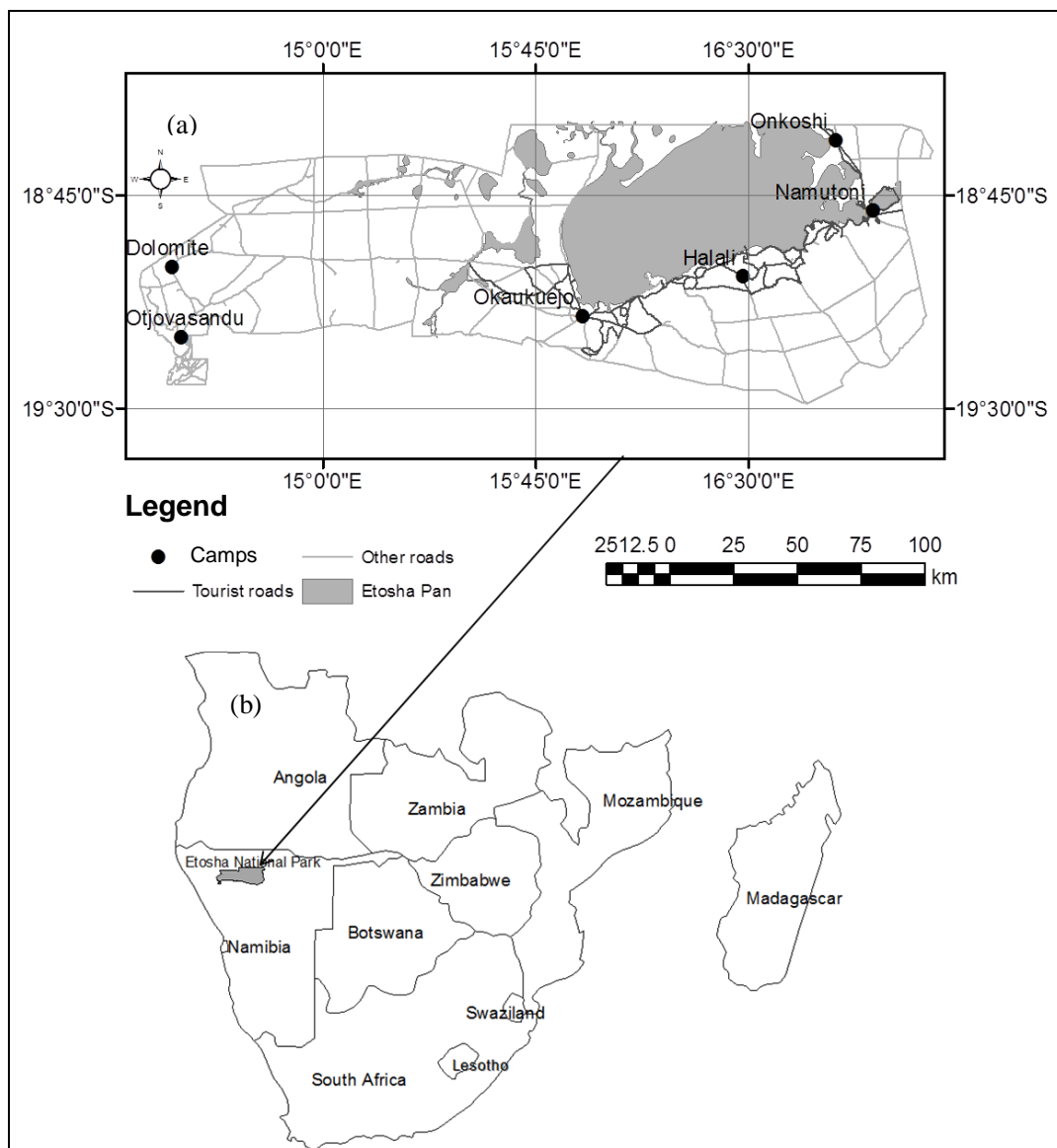
This chapter presents a brief description of the study area, focusing on the geographic location of the ENP, its climatic condition such as rainfall pattern, temperature and the prevailing wind direction. In furthering the understanding of the study area, a description of the fauna and flora, underlying geology of the sub-region and major soil types of ENP are highlighted. Lastly, this section provided a brief description of the Park's conservation and tourism land use history.

#### 3.2. Location

The ENP, one of the largest National Parks in the world and second largest in Namibia is found on the north-central part of Namibia, covering an area of approximately 22 270 km<sup>2</sup> (Berry 1997). Fig 3.1, shows the geographic location of the Park at local and regional scale. The ENP is elongated in an east-west direction, extending over a distance of approximately 300 km, while extending approximately 100 km in a north-south direction.

The main geographic feature of the Park is a conspicuous large, flat, saline depression known as the Etosha Pan, which is located on the southern edge of the Etosha / Owambo basin. The Pan itself covers an area of approximately 4760 km<sup>2</sup> (Lindeque & Archibald 1991) as cited in (Hipondoka, 2005), which occupy approximately 23% of the Park surface area. The Etosha Pan is classified as a wetland of international importance and is thus recognised as a Ramsar site (Cunningham & Jankowitz, 2011). Although this Pan is a seasonal wetland, it is

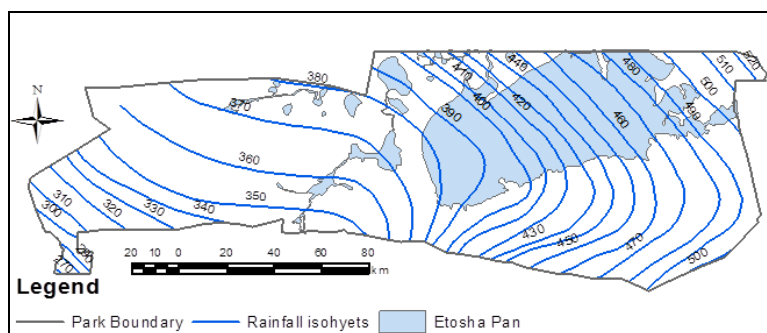
managed as a wilderness area, the highest category of conservation under the IUCN conservation of PAs categories.



**Figure 3.1:** Location of the study area at local (a) and regional (b) scale (Data source : EEI).

### 3.3. Climate

ENP is located in the semi-arid region of Namibia (Du Plessies, Bredenkamp, & Trollepe, 1998 ; Berry, Loutit, & Muller, 2006 ; Berry et al., 2007). Long term rainfall data recorded at Namutoni, Okaukuejo, Halali, Otjovazandu and areas in the interior of the Park shows that rainfall occurs mainly in summer months between November and April, with rainfall gradient decreasing from approximately 450 mm in the east to 300 mm per annum in the west (Engert, 1997 ; Le Roux, Grunow, Morris, Bredenkamp, & Scheepers, 1988 ; Le Roux et al., 1988), see Figure 3.2. Temperature at Okaukuejo near the centre of the Park range within an average maximum of 34.8 °C and average minimum of 17.7 °C in November to an average maximum of 25.0 °C and average minimum of 6.0 °C in July (Du Plessies et al., 1998). Meanwhile, the potential evapo-transpiration at Okaukuejo ranges between 2,600 mm and 2,800 mm per annum (Engert, 1997). The potential evapo-transpiration figures exceed average rainfall received in the Park, thus creating a water balance deficit, a condition which is usually associated with aridity. The prevailing wind direction is mainly north-easterly reaching up to 55.5 km / hour mainly during the dry seasons (Cunningham & Jankowitz, 2011).



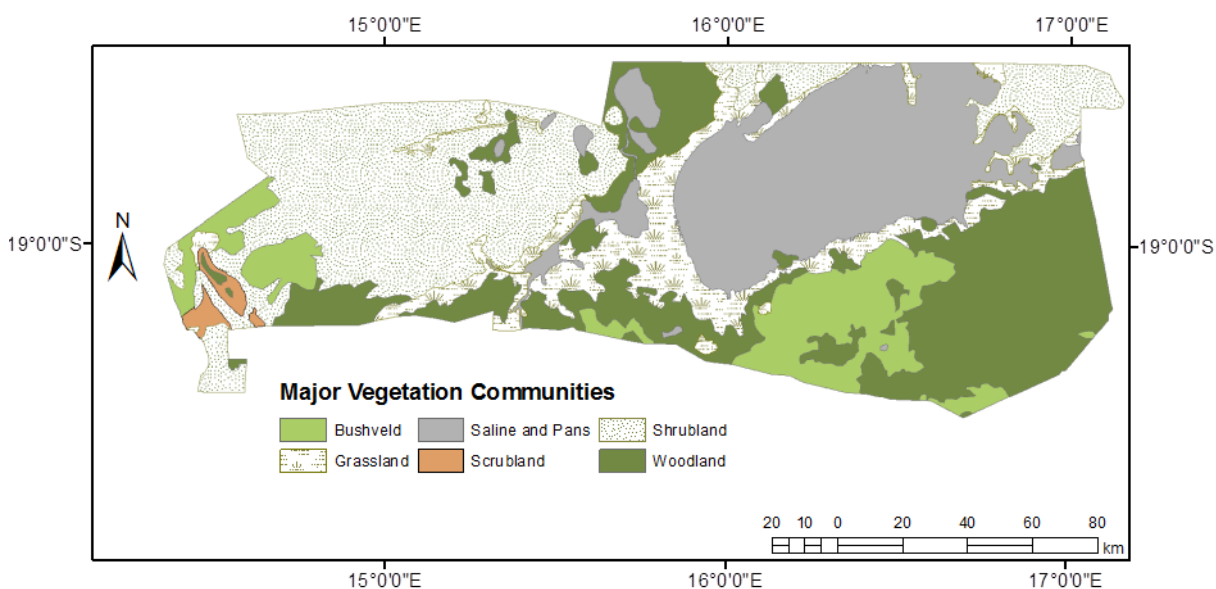
**Figure 3.2:** Spatial variation in long term average rainfall for ENP (Data source, EEI).

### 3.4. Flora and Fauna

The ENP presents a mosaic of different ecosystems and a diverse wildlife (Olivier & Olivier, 1993). A detailed classification of vegetation for ENP was done by Le Roux et al., (1988), who identified various plant communities and species falling within broader vegetation communities such as Shrubland, Woodland, Bushveld, Saline and Pans, Scrubland and Grassland (Figure 3.3). Major vegetation types include Dwarf Shrubland, Grassland, Thorn Bush Savanna, Mopane Savanna, Depressions and Turf Pans, Mixed Tree and Shrub Savanna, Dolomite Hills as well as Tamboti and Terminalia Woodland (Berry, Loutit, & Muller, 2006). Moreover, common woody plant species found in the ENP are *Acacia newbournii*, *Acacia reficiens*, *Acacia erioloba*, *Acacia mellifera*, *Albizia anthelmentica*, *Catophractes alexandri*, *Colophospermum mopane*, *Boscia foetida*, *Combretum apiculatum*, *Commiphora* spp., *Grewia* spp., *Terminalia prunioides*, *Terminalia sericea*, *Ziziphus mu cronata* and others (Berry et al., 2006 and Le Roux et al., 1988). Meanwhile, Grassland community mainly found on the Andoni Plain situated to the north east of the Pan and the Okondeka Grassland area is dominated by herbaceous species such as *Sporobolus spicatus*, *Eragostis biflora* and *Mariscus squarosa*, which support the survival of games such as Springbok, Zebras, Gemsbok, for instance.

The vegetation distribution patterns of ENP are mainly determined by soil type (Beugler-Bell & Buch, 1997 ; Du Plessies et al., 1998) and rainfall pattern (Le Roux et al., 1988). Tall Woodland vegetation communities are mainly dominant on the eastern and central part of the Park, while Shrubland and Grassland extend westward.

Due to its diverse vegetation communities and availability of water from natural springs and artificial waterholes, ENP houses a variety of wildlife that is dependent on such resources. Waterholes in particular play an important role by creating favourable viewpoint for tourists interested in viewing wildlife for activities such as photography. Such water points support a diversity of species in the Park. According to Olivier & Olivier (1993) the ENP is home to over 114 mammal species, 340 bird species, several reptiles, amphibians and at least one species of fish. Major wildlife commonly seen in the Park are such as Elephant, Black and White Rhino, Black-Faced Impala, Lion, Giraffe, Leopard, Eland, Burchell's Zebra, Springbok, Blue Wildebeest, Gemsbok, Damara Dik-Dik, among others (de Beer, Kilian, Versfeld, & van Aarde, 2006 ; Olivier & Olivier, 1993). Browsers particularly elephants have enormous impact on the survival of woody plants, mainly closer to water points (de Beer et al., 2006). There are also various species of vertebrates such as small mammals, as well as invertebrates which are often not seen by visitors.



**Figure 3.3:** Major vegetation communities of ENP (Data source: EEI).

### 3.5. Geology and Soil Types

The ENP is located within the Owambo Basin, of which Etosha pan is one of the lowest sections of the basin (Miller, Pickford, & Senut, 2010), following Lake Oponono. The Park lies within the geological formation of the Damara sub-group (Le Roux et al., 1988). The ENP area is relatively flat, with the exception of dolomite hills in the south and west of the Park.

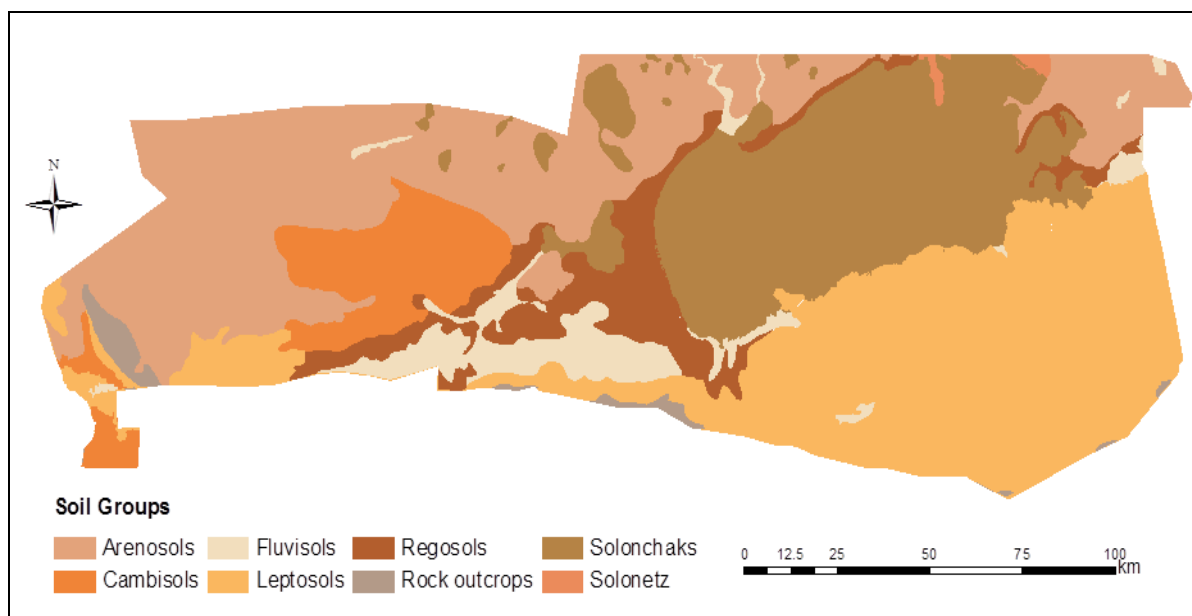
Soil types show a typical characteristic of arid and semi-arid environments, which is characterised by low organic matter, acidic to alkaline soil pH, low fertility and higher carbonate content, among others. A detailed mapping and description of soil in the Park was done by Beugler-Bell & Buch (1997), who mapped various soil units using a modified system of the Food and Agricultural Organisation (FAO).

This section thus provides a summary of Beugler-Bell & Buch (1997)'s work. Major soil units observed in ENP are such as *Arenosols*, *Regosols*, *Cambisols*, *Leptsols*, *Vertisols*, *para-Vertisols*, *Fluvisols*, *Solonchaks* and *Solonetz*s. The distribution of these soil units shows a clear relation to geomorphological processes and underlying geology. Aeolian and fluvial process particularly play a major role in soil formation for the Etosha region. For instance, Beugler-Bell & Buch (1997) observed that along the Etosha pan's western and north-western edge strong aeolian activity has led to the deposition of rich calcium carbonate rich sediments mainly from the Etosha limestone.

Meanwhile, *Fluvisol* attributed to fluvial process are commonly found along the river valleys, depressions and the omiramba of the ENP. In the western side of the Park,

large areas are covered with shallow to moderate deep Aeolian *Arenosols* sediments, with low nutrient status organic matter content. Meanwhile, *cambic* and *ferralic Arenosols* developed in sandy substrata of either aeolian or fluvial in origin cover most of the north-east part of the Park. Those carbon free soils are mainly characterized by fine to medium sandy texture. On the southern part of the Pan, soil association of *lithic/ eutric/ rendzic Leptosols* and *eutric Vertisols* in depressions are commonly found. The south east and west side of the ENP is relatively rocky, with its surface mainly covered by gravels. This pedological zone is also referred to as rock outcrops. The western side of Okaukuejo is primarily dominated by carbon free *eutric Fluvisols*. Lastly, the immediate area of the Etosha Pan is made up of a salt and sodium rich *solonchaz* soil, while the *solonetz* soil is found on the north eastern edge of the Pan.

Given that this study mainly concentrated on the eastern part of the ENP, sampling sites were dominated by soil groups such as *calcaric Regosols*, *lithic Leptosols*, *mollic Leptosols*, *eutric Fluvisols*, *ferralic Arenosols* and *sodic Solonchas*. The distribution of major soil groups for ENP is shown in (Figure 3.4). Wind and water process are recognised as main agents of soil erosion in ENP (Beugler-Bell & Buch, 1997). However, soil erosion in the Park is further accelerated by human activities such as the creation of artificial water points which has turned into piosphere systems, degrading both vegetation and soil at water points (Berry et al., 2007).



**Figure 3.4:** Major Soil groups of the ENP (Data source: Mendelsohn, Jarvis, Robert, & Robertson, 2002).

### 3.6. History of Conservation and Tourism in ENP

The area presently known as ENP was proclaimed as a game reserve (Wildschutzgebiet) in 1907 Berry (1997) under the German colonial government. Although ENP initially occupied a large area of approximately 80,000 km<sup>2</sup> in the past, which extended from the Kaokoland and Skeleton Coast to Namutoni, approximately 72% of such area size was de-proclaimed under the Odendaal Plan for South West Africa to its present size of 22 270 km<sup>2</sup>.

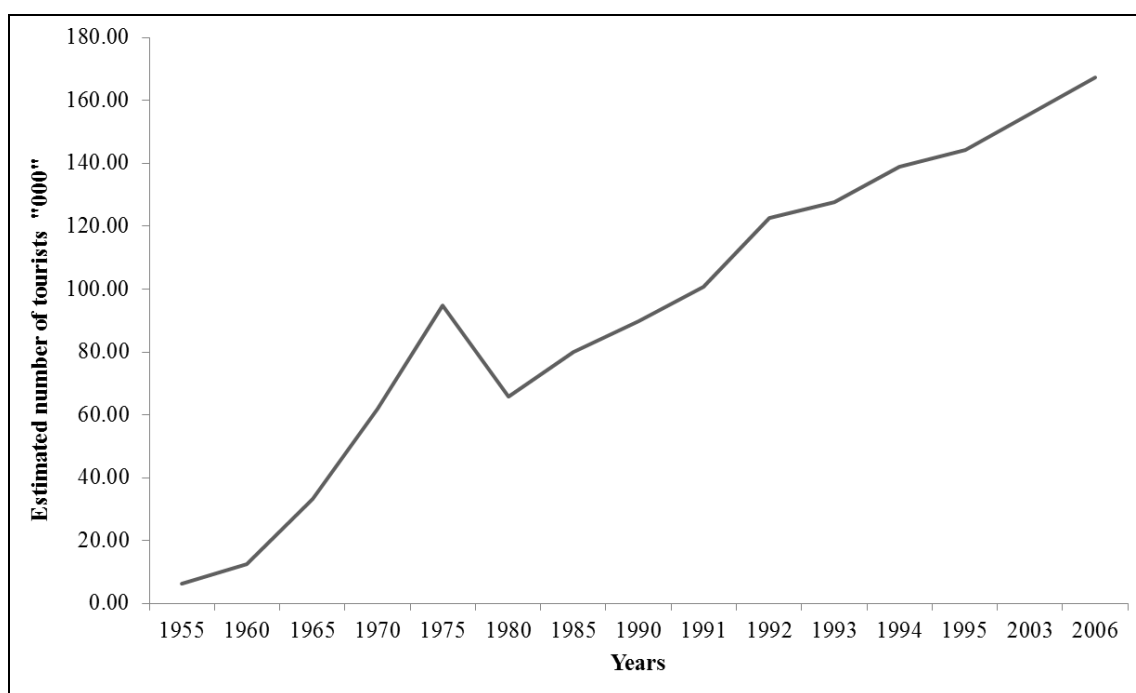
Prior to the proclamation, most of the Park area was occupied by the Hai//om inhabitants who survived from wild food, hunting and water supply from natural springs in the Etosha region. The Hai//om people are indigenous inhabitants that belong to the hunter-gathers of the Khoisan cultural groups, an ethnic group which lived in Southern Africa for many generations.

In the 1960s, the government of the day decided to remove this community from the ENP under the pretext of consolidating wildlife conservation (Berry, 1997). Specifically, their relocation from the area was justified by citing various factors such as hunting inside a protected nature reserve, disturbing tourists at water points, as well as disturbing wildlife at water points during tourist visitation (Dieckman, 2007). Prior to their displacement from the ENP, the Hai//om had been a main cultural tourism attraction to the Park, performing various traditional dances in their traditional dresses upon which they were compensated for by the Park authorities with game meat (Berry, 1997). In addition, Oshiwambo speaking farmers resided on the north-eastern part of the reserve (Berry, 1997). While the Otjiherero speaking pastoralists and their livestock occupied the Etosha grass plain on the western part of the Park (Hoole & Berkers, 2010). These communities were also removed from the Etosha area, losing access to valuable livelihood resources such grazing land and access to water.

Due to a great diversity of wildlife found in the Park, tourism was considered as a necessity to the Park. Park-based tourism was introduced to the Park in the 1950s to enable visitors view and experience the wildlife-based tourism, hence generating revenue. Prior to the establishment of permanent accommodation for visitors in the ENP, tourists slept in the open air, camping at the Okaukuejo fountain and were often required to seek protection in vehicles against wildlife particularly lions (Berry, 1997). Since then, numbers of visitors to ENP increased significantly. There was an increase in tourists arrival to ENP between 1955 and 2006 (Figure 3.6). Although there was a high fluctuation in tourist arrival to the ENP mainly in the 1970s, which could be attributed to political instabilities in the country at the time, a major increase

in tourists arrival increased significantly after independence in the 1990s (Figure 3.5).

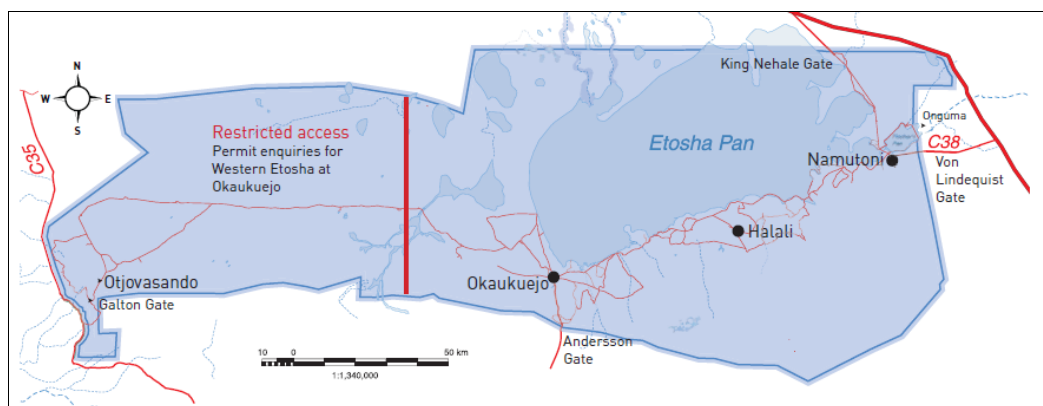
Conservation of wildlife was the main important land use in the ENP. However, earlier tourism management practices jeopardized conservation efforts. For instance Berry (1997 and Dieckman (2007) reported that one of the formerly fascinating tourists' attraction in the Park was the practice of the so- called "lion party", when game rangers visited specific area where either a zebra or wildebeest was hunted for feeding fit and free-ranging lions. Tourists were then invited by Park officials to watch lions devouring a carcass.



**Figure 3.5:** Trend in tourists arrival to ENP between 1955 and 2006 (Modified from Berry, 1997 and MET, 2010).

As a result of tourism activities and related infrastructure development, human influence increased considerably on the natural system of ENP (Berry, 1997. For

example, gravel burrow pits were created as either artificial water points or through road construction to facilitate game viewing for a growing number of visitors in the Park (Berry, 1997). In terms of accommodation facilities, Okaukuejo and Namutoni were the first two camps introduced to tourists. In order to provide accommodation for a growing number of visitors however, Halali camp was opened in the 1960s (Berry, 1997). Further, Onkoshi camp and Dolomite camp were introduced in the 2000s, with major emphasize on exclusivity, by targeting the upper segment of the market. As a result, ENP has become the main tourist attraction in Namibia, particularly in the north-central regions, with about two-third of visitors coming to Namibia including ENP in their trips (Mendelsohn et al., 2000). Nevertheless, not all parts of the Park are opened for tourism activities. According to MET (2010) the area zoned for tourism activities cover approximately 12-15 % of the Park, concentrated mainly on the eastern part of the Park in the vicinity of the Etosha Pan.



**Figure 3.6:** Map showing the eastern section of ENP which is open to tourists, while the western section is managed as a restricted area. Source: MET (2010).

Figure 3.6 shows the eastern side of the Park which is open to tourists. The western section is managed as a restricted area, upon which an entry permit is required. However, for tour operators in possession of a legal permit, those are allowed to travel via Otjovazandu<sup>3</sup> gate to a newly opened Dolomite Camp in the western part of ENP.

<sup>3</sup> Although portrayed as a “camp” in Figure 3.1, Otjovazandu is not utilized by tourist as a resort camp. Instead, it belongs to the Park authority, and used as a management camp. For mapping purpose however, it was portrayed as such.

## CHAPTER 4

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### 4. METHODS AND TECHNIQUES

#### 4.1. Introduction

This chapter introduces the methodological approaches used in the study. The sampling procedures and study design applied in this study are therefore highlighted. Fieldwork, existing spatial digital data acquired, remotely sensed data and soil laboratory analysis were the major sources of empirical data for this study. Lastly, statistical procedure and techniques used for analysis are also presented.

#### 4.2. Sampling Design and Fieldwork

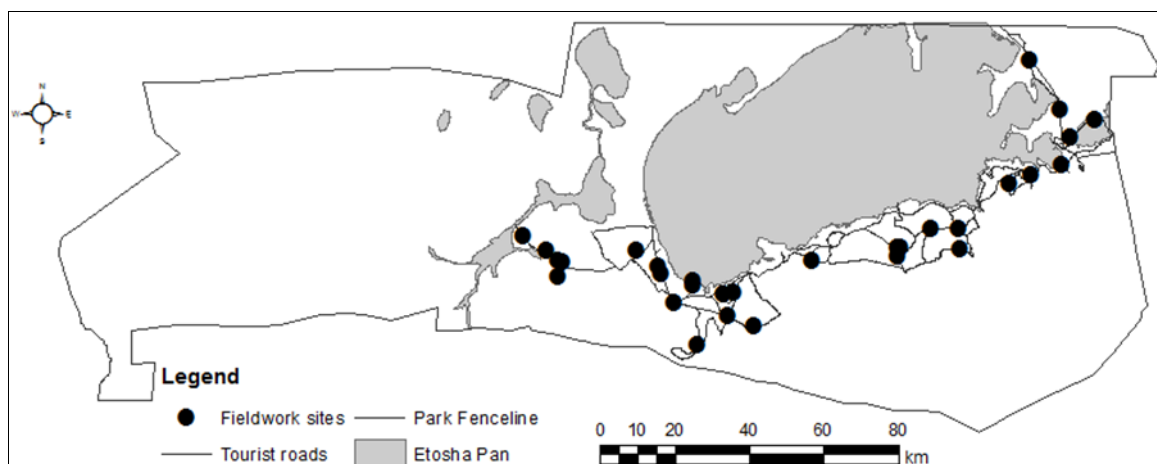
This study involved an analysis of roadside vegetation and soil properties at stratified, randomly selected transects along the tourist roads. Existing Geographic Information System (GIS) layers such as tourist roads and vegetation communities were acquired from the Etosha Ecological Institute (EEI) during the pilot field assessment.

In order to proportionally select sampling points among vegetation communities traversed by tourist roads, all spatial data was imported into Intergrated Land and Water Information System (ILWIS 3.3) ; ITC, the Netherlands) as vector layers. The tourist roads layer was then converted from polyline to points using an interval of 2 km. This resulted in numerous points along tourist roads, which were then intersected with the layer of vegetation communities based on Le Roux et al. (1988).

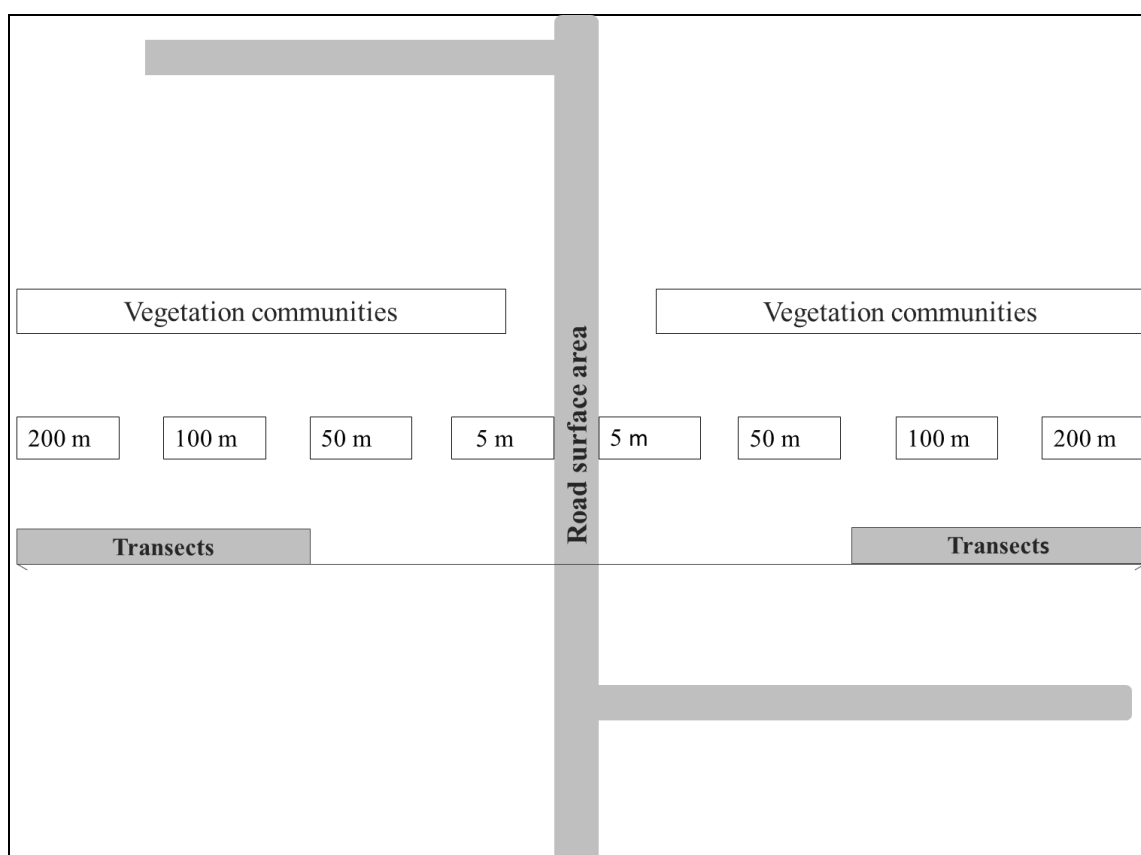
This process resulted in a new dataset containing attributes from both the points and vegetation communities' layers.

A total of 30 points were randomly selected for field sampling. Random selection function of a freeware, Quantum GIS version 1.5 was employed for selecting field sampling sites (Appendix A). The spatial distribution of these points is shown in Figure 4.1. Geographic Information System (GPS) coordinates of these points were then loaded onto a Garmin eTrex handheld Global Positioning System Receiver using Universal Transverse Mercator (UTM) projection, zone 33 south. The GPS device used in the field had a navigation accuracy of approximately  $\pm 10$  m. At each point, transects were then laid perpendicular to the tourist roads. A vegetation health assessment was carried out at predetermined distances of 5 m, 50 m, 100 m and 200 m from and on both sides of the tourist road (Appendix B).

Two periods of fieldwork were executed for this study. The first trip (February 2010) was intended to study the landscape during the wet season. The second which trip was aimed at assessing the landscape in the dry season took place in September 2010.



**Figure 4.1:** Location of Sampling points in ENP.



**Figure 4.2:** Design of transects used to sample vegetation and soil. A 100 m<sup>2</sup> plot was used to sample woody species, while 1 m<sup>2</sup> was used to sample herbaceous species.

In order to assess the status of roadside vegetation, the following procedures were applied. The percentage covers of herbaceous species was estimated using a 1 m<sup>2</sup> plot, whereas, woody species were assessed on a 100 m<sup>2</sup> plot. Figure 4.2 shows the experimental design used in the study. The plots sizes used are deemed appropriate after a scrutiny from similar studies, such as those carried out by Angold (1997) ; Rentch et al. (2005) and Takahashi & Miyajima (2010). For the purpose of this examination, vegetation percentage cover was defined as the percentage of quadrant/plot area covered by vegetation in relation to the bare ground. The assessment included variables such as species composition, vegetation vigour, plant height, and general rangeland condition. For vegetation vigour, indicators such as dead patches, vegetation stress, damage by browsers and level of recovery were used to rate the level of vegetation vigour.

#### **4.3. Estimating Herbaceous Biomass using Disc Pasture Meter**

While clipping is considered as the most accurate method of herbaceous biomass estimation, it is nevertheless time consuming and laborious (Harmony, Moore, Gorge, Brummer, & Russel, 1997 ; Sharrow, 1984). As an alternative, a Disc Pasture Meter (DPM), 46cm in diameter was used for the above-mentioned purpose. The Disc Pasture Meter is a falling plate-like equipment designed by Bransbay & Taintan (1977 as cited in Thrash 1998) specifically to estimate herbaceous biomass. Grass and herbs biomass was estimated by recording the height of a plate positioned on top of the herbaceous canopy. The following procedures were followed to ensure consistency and reliability of the process.

The Disc Pasture Meter plate was dropped from a consistent height onto each canopy of herbaceous vegetation at the sampling points to ensure that equal amount of force was applied at each point. If there were some bulk volume of herbaceous underneath, the resistance of the canopy would not allow the plate to rest on the ground, but would stop at the height where force from the herbaceous canopy is equal to force exerted by the Disc Pasture Meter. The height at which the plate stopped was then recorded from the standing pole. However, the accuracy of biomass estimation using a Disc Pasture Meter method relies on calibration equation using linear regression model derived from clipping and weighting forage from a known area (Samimi & Kraus, 2004 ; Sharrow, 1984). The Disc Pasture Meter calibration regression equation ( $y=379.79 x +247.76, R^2= 0.78, p < .05$ ) for Etosha area used in this study was adopted from Du Plessis (1997).

#### **4.4. Soil Sampling and Laboratory Analysis**

Soil sampling was done to a depth of approximately 30 cm using a 10 cm diameter soil auger (Eijkelkamp, Agrisearch equipment, The Netherlands). The 10 cm depth was necessary to allow detection of possible modification of the top soil which is the main supporting system for plants. In the field, soil was sealed in containers and labelled to allow proper identification in the laboratory. A total of 51 soil samples were collected during the wet season, but due to extreme variation found in the first dataset, the soil samples were increased to 82 during the dry season. Samples were then grouped into categories such as sandy loam, loam, clay loam, silt loam, sand, silt clay loam and loam sandy. These soil classes are based on the grain composition of sand, silt and loam. Approximately 350 grams of soil was collected from each site.

Samples were analysed by the soil laboratory of the Ministry of Agriculture, Water and Forestry in Windhoek.

Analytical procedures used at the laboratory are as follow. Soil samples were air-dried at temperature not exceeding 35 °C for over 24 hours and sieved using a 2 mm mesh to obtain the fine grain fraction for analysis. The remainder of the sample was considered as gravels, thus discarded.

Available phosphorus was extracted using the Olsen method (Kovor, 2009 ; Molina, 2011), and measured spectrophotometrically using the phosphomolybdate blue method. Exchangeable cations were extracted using 1 M ammonium acetate at pH 7 and atomic absorption spectroscopy was used to measure K, Ca, Mg, and Na concentrations in the extracted samples. Soil texture was determined by dispersion using sodium hexametaphosphate / sodium carbonate, and the pipette method was used to determine the silt and clay content. The sand fraction was determined by dry sieving and retention of particles > 53µm. The United States Department of Agriculture (USDA) classification system (Freddy, 2001) was used for texture classification. Organic carbon (Organic matter content) was estimated using the Walkely-Black method (Bafios & Sahrawat, 1982) and a 1.74 factor was included in calculations to account for incomplete oxidation.

Soil pH was determined by the 1:2.5, soil : water ratio suspension 57 on a mass to volume basis. Electrical conductivity was measured in the supernatant of the 1:2:5

soil : water suspension prior to measurement of soil pH ; unit of measurement are  $\text{mS/cm}=1000\mu\text{S}$ . High results indicating possible salinity hazards were repeated on the extract of saturated soil past. Total nitrogen was determined by acid digestion to convert organic-N into ammonium. Carbonate was determined by the reaction of soil with hydrochloric acid and estimation of acid consumed by titration with sodium hydroxide.

#### **4.5. Digital Spatial Data Acquisition and Analysis**

While Remote Sensing provides an aerial view of the landscape, GIS plays an important role in spatial data integration and manipulation. The landscape was assessed from Landsat Imagery with 30 m ground resolution, followed by a pilot field assessment. The GIS data that were acquired as mentioned in section 3.2.1 were then integrated and analysed in a GIS. Gravel pits were first identified from the Landsat image acquired on April 1997, through a visual assessment using band 7, 4 and 1 in Red, Green and Blue (RGB). However due to a finer spatial resolution required to digitize and quantify their area size, digital panchromatic aerial photographs at 1 m resolution taken in 2007 were used to supplement the latter approach. Those aerial photographs were acquired from the Directorate of Survey and Mapping, Ministry of Land and Resettlement in Namibia

GPS coordinates for gravel pits acquired from the EEI assisted in locating a number of randomly selected gravel pits for ground truthing and on-site assessment. All spatial data was thus integrated, analysed and summarised under a GIS environment, using ArcGIS 10 and ILWIS 3.4.

#### 4.6. Statistical Analysis

Statistical analyses were carried out using R.2.10 (R Development Core Team, 2009) and StatSoft STATISTICA version 7.0. Firstly, data was subjected to testing of normal distribution using the Shapiro test as a prerequisite for parametric analysis. Where necessary, data was transformed using a log transformation method to achieve normality. Where normality of distribution could not be achieved, non-parametric statistical techniques such as Kruskal-Wallis test and Chi square statistics were used accordingly. All analyses were considered significant at 0.05 alpha level.

In details, the effects of roads on adjacent soil chemical properties were modelled using general linear models. General Linear model (*GLM*) is a statistical technique which combines analysis of variances (ANOVA) and linear regression analysis, in which the independent variable can be either categorical or continuous.

The primary predictor in this model was distance from roads (m). However, in order to account for variances in the concentration of soil chemical properties that are not adequately explained by distance from roads alone, interacting variables such as soil texture, vegetation community type and change in seasons were incorporated in the model in order to account for interaction effects of distance and those other predicting variables. Prior to subjecting the soil chemical elements to statistical analysis, response variables such as soil pH, electrical conductivity, carbonate, phosphorus and exchange sodium were log transformed to achieve normality of distribution, results which were confirmed using Shapiro test and histograms ( $p > 0.05$ ).

Variable such as vegetation foliage cover, number of species for both herbaceous and woody species) did not achieve normal distribution. Therefore Kruskal-Wallis test, a non-parametric equivalent of ANOVA was used to determine whether the above-mentioned response variable were significantly different between localities from roads. Along transects, some plots were merely bare, while others had vegetation cover. A logistic regression model was thus built to predict whether distance from roads had significant effects on the probability of occurrence (presence/absence) of vegetation cover. As thus, absence / presence of vegetation cover was converted to 0/1 binary variables, and analysed with logistic regression, using binominal distribution.

Categorical variables such as vegetation vigour (high, low, medium etc.) were modelled using Chi square test to determine whether the occurrence of such pattern is independent of distance from roads.

## CHAPTER 5

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### 5. RESULTS

#### 5.1. Introduction

This chapter presents results on road density, gravel mining in the park, as well as the ecological effects of roads on adjacent herbaceous and woody vegetation communities foliage cover, species richness and herbaceous biomass yield, among others. The relationship between distance from roads and the concentration of soil chemical properties, and interaction with seasonal changes and soil texture are also presented.

#### 5.2. Road Density and Coverage in Major Vegetation Communities

Approximately 766 km length of road network was constructed in the park to facilitate tourism and recreational activities covering various vegetation communities (Table 5.1). This translates into a tourist road density of 0.25km per km for the entire park. More than half of this road network is constructed on Grassland, which covers only approximately 11% of the Park. Within this vegetation structure, these roads are mainly concentrated on the Grassveld located on plains to the south east and west of the Etosha Pan (Table 5.2). In addition, those roads are extended to the Duneveld covering part of the Okondeka Grassland on the western edge of the Etosha Pan and the Andoni Veld on the northern side of the Etosha Pan towards King Nehale gate. Grassland is followed by Woodland as a distant second vegetation community over which tourist roads are mainly built on the Mopane Treeveld located between Namutoni and Halali, as well as those found on the western side of Okaukuejo, extending over to *Terminalia prunioides* African Woodland in the Namutoni area, the south western strip of Ekuma Woodland, Marula Association and Marble

Hillocks vegetation patches. Shrubland which covers nearly a quarter of the park area, is the largest vegetation community in the Park. However, it has one of the lowest road densities, occupying approximately 4.9% of the entire recreational road network. Although, it is the largest vegetation community in the Park, the road length found on the Shrubland is nearly 10 times lower than those on the Grassland. These roads cover mainly the North Eastern Sandveld patches on the Andoni area. The spatial alignment of all tourist roads in relation to vegetation community types is illustrated in Figure 5.1.

Although Etosha Pan is zoned as wilderness area, various road segments are developed either to provide an outlook to the Pan or roads constructed passing the Pan edge leading to water holes where tourists could find games. For instance, Figure 5.2 shows the road section separating the Fishers Pan from the rest of the Etosha Pan, while another road segment was constructed at the eastern part of Fishers Pan. Approximately 1% of the tourist roads are associated with this geomorphologic feature.

**Table 5.1:** Tourist roads density in various vegetation communities of ENP.

<b>Vegetation structure</b>	<b>Area size of the Park (km<sup>2</sup>)</b>	<b>Cover in the Park (%)</b>	<b>Tourist Roads Length (km)</b>	<b>Tourist Road Cover (%)</b>	<b>Road density (Road length (km)/ Size of Vegetation Structure (km<sup>2</sup>))</b>
Bushveld	2375.24	10.67	103.5	13.5	0.044
Grassland	2465.76	11.07	402.61	52.51	0.163
Saline and Pan	5085.37	22.84	8.68	1.13	0.002
Scrubland	192.97	0.87	0	0	0
Shrubland	6226.84	27.96	38.04	4.96	0.006
Woodland	5923.81	26.6	213.92	27.9	0.036
<b>Total</b>	<b>22 270<sup>4</sup></b>	<b>100</b>	<b>766.75</b>	<b>100</b>	<b>0.25</b>

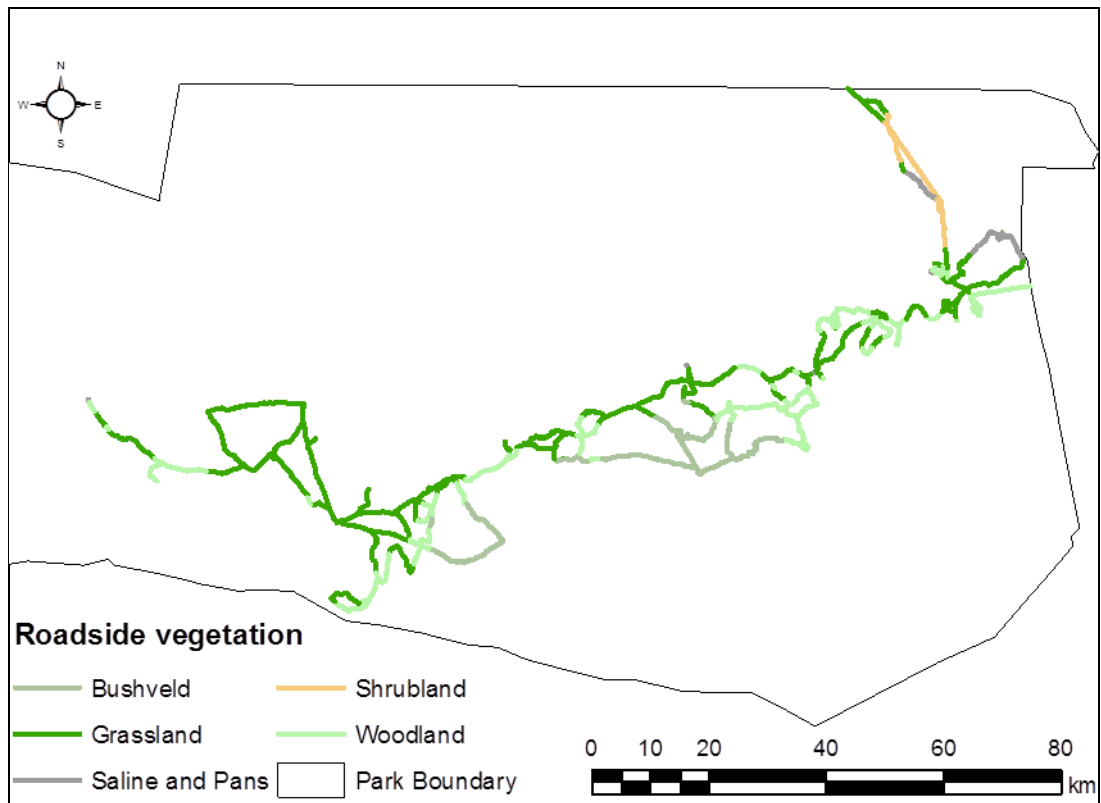
<sup>4</sup>Figures such as 22 935 km<sup>2</sup> or 22 915 km<sup>2</sup> are frequently cited in literatures since the emergence of GIS application in the Country from the 1990s to refer to the area size of Etosha National Park. However, the official figure for the Park is 22 270 km<sup>2</sup>.

**Table 5.2:** Tourist road lengths (km) in various plant communities of ENP.

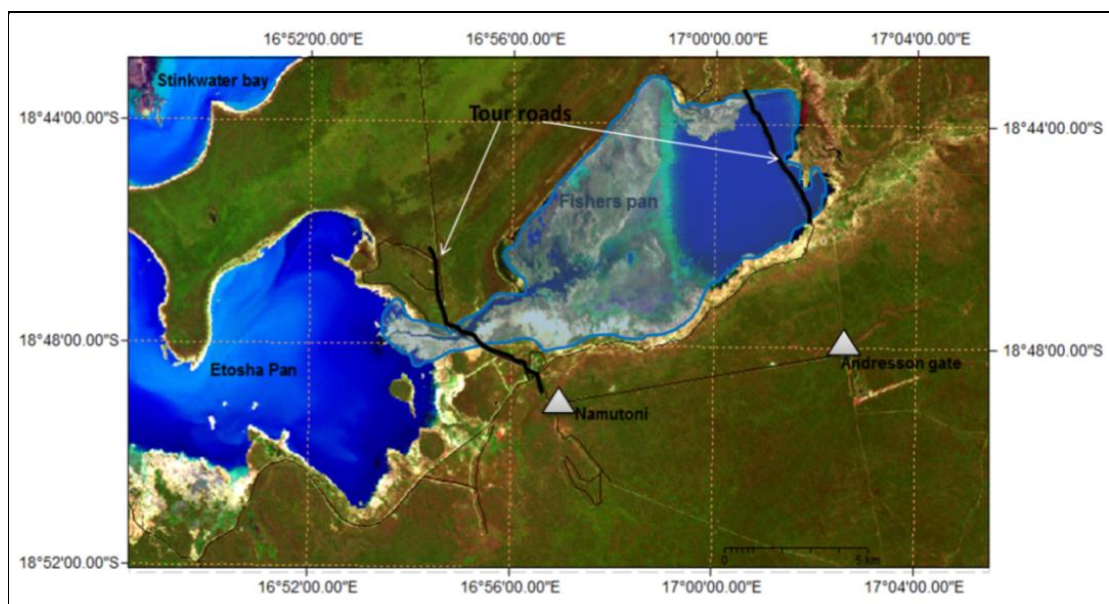
<b>Plant Communities<sup>5</sup></b>	<b>Tourist Road length (km)</b>	<b>Tourist road cover (%)</b>	<b>Vegetation structure</b>
Mixed Mopane Bushveld	103.5	13.50	<b>Bushveld</b>
Andoniveld	14.34	1.87	<b>Grassland</b>
Duneveld	26.86	3.50	
Grassveld	354.92	46.29	
Karstveld	6.49	0.85	
Pan	8.68	1.13	<b>Saline and Pans</b>
North Estern Sandveld	38.04	4.96	<b>Shrubland</b>
Ekuma Woodlands	2.38	0.31	<b>Woodland</b>
Marble Hillocks	4.99	0.65	
Marula Associations	2.49	0.32	
Mopane Treeveld	137.34	17.91	
Prunioides Woodland	66.72	8.70	
<b>Total</b>	<b>766.75</b>	<b>100</b>	

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<sup>5</sup>Plant communities, also referred to as mapping units presented here are part of the 31 plant communities/ mapping units as classified in Le Roux et al., (1988).



**Figure 5.1:** Roadside vegetation community structure of the ENP.



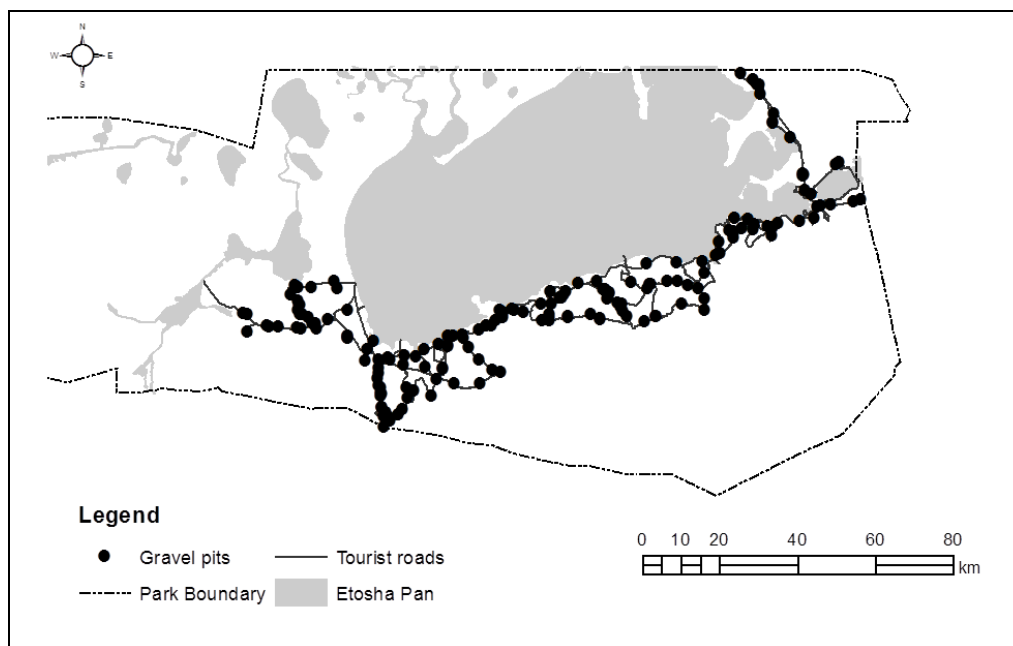
**Figure 5.2:** Landsat image using a false colour composite showing the eastern part of ENP with a tourist route constructed between Etosha Pan and Fishers Pan (Image acquired on April 1997: Band 7, 4 and 1).

Approximately 96.2% of roads constructed are made from gravel material mined in the Park, while 3.7% are made from tar materials. The only two tarmac roads are those connecting Okaukuejo and Namutoni resorts via Anderson and Von Lindequist gates, and are connected to the national road network. Road width varies among the major vegetation communities. For instance, road width of  $8.19 \pm 3.08$  m is found in the Bushveld,  $8.08 \pm 3.14$  m in the Grassland,  $11.76 \pm 5.31$  m in the Saline and Pans,  $7.68 \pm 1.87$  m in the Shrubland, and  $9.29 \pm 3.26$  m in the Woodland. This amounted to total average road width of  $8.56 \pm 3.26$  m for the Park. On average therefore, tourist roads occupy a mere surface area of  $6.5 \text{ km}^2$  or 0.03% of the Park.

### **5.3. Gravel Mining and Roadside Ecological Landscape Change.**

All unpaved roads were created using locally mined gravels within the Park.

Consequently, this process has led to creation of approximately 187 gravel pits along tourist roads (Figure 5.3).

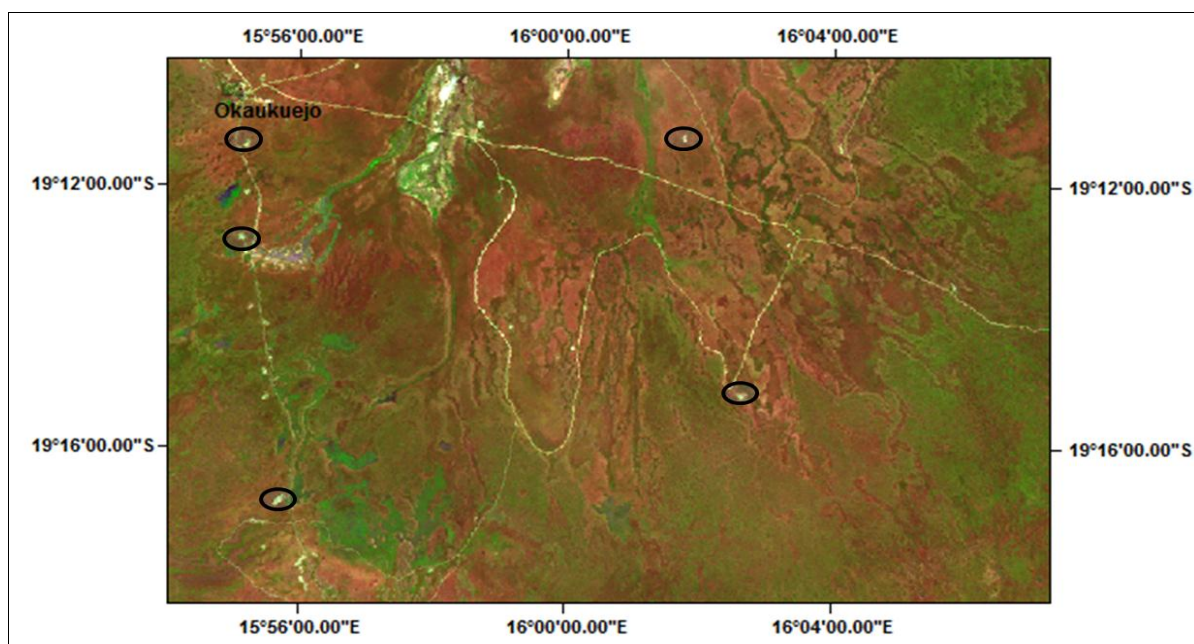


**Figure 5.3:** The distribution and density of gravel pits along tourist roads in ENP (Data source: EEI)

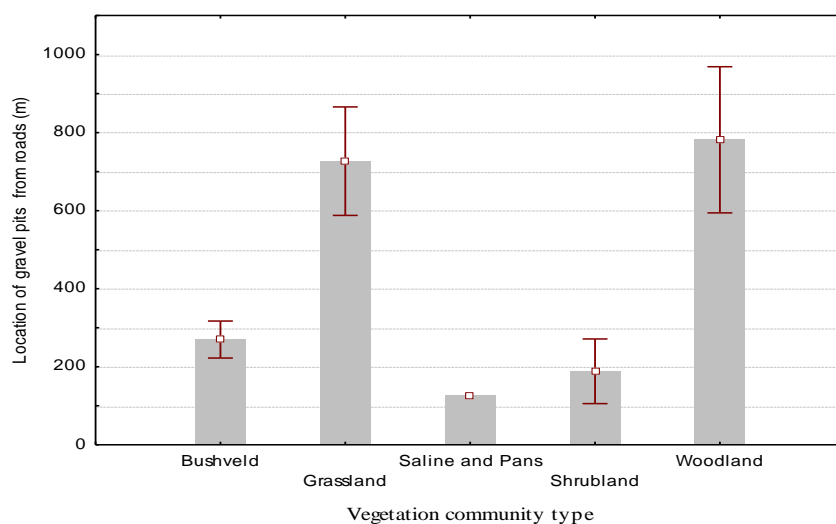
Although not clearly visible when driving along the tourist roads, the gravel pits are well noticeable on remotely sensed imagery, featuring as scars on the landscape (Figure 5.4). These gravel pits are located at a distance ranging between 41 m and 6.3 km from roads. However, distance location of those gravel pits from roads varies significantly ( $p < 0.05$ ) between different vegetation community types (Figure 5.5). For instance, in the open Plains (Grassland) and some low vegetated savanna areas, gravel quarrying was done at an average distance of approximately 700 m from roads, a distance which is nearly three times more from roads than the average distance found in bushy communities such as Bushveld and Shrubland. These gravel pits are approximately 121 m long and up to 78 m wide. Admittedly, no depth measurements were undertaken owing to a lack of relevant equipment. Located at a mean distance of  $4.9 \pm 3.33$  km

apart, these pits are estimated to cover a mean surface area of  $7263 \pm 691 \text{ m}^2$  each.

Typical examples of those gravel pits are presented in Figure 5.6.



**Figure 5.4:** Sample of gravel pits, depicted from a false colour composite of Landsat image, featuring as scars on the landscape. Some of those are circled, while others can be observed as white patches along roads on the landscape around Okaukuejo area.

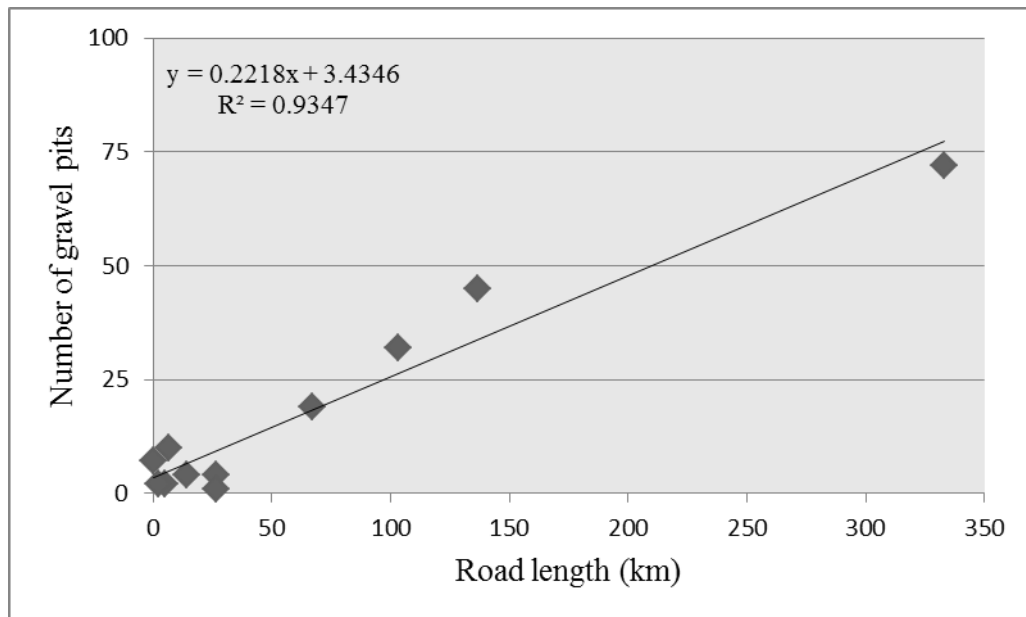


**Figure 5.5:** Mean  $\pm$  Standard error distance from roads to gravel pits in major vegetation communities.



**Figure 5.6:** Sample of Gravel pits sites assessed during fieldwork, (a and d) a pile of gravel excavated from a pit, (b) solid waste dumped on site, (c) vegetation re-growth in and around the pit.

The density and distribution of those gravel pits varied among the major vegetation communities. For instance, approximately 45.4% and 34% of those gravel pits are found on the Grassland and Woodland, respectively. This totals nearly 80% of all gravel pits along tourist roads. The remainder is spread in the Bushveld (16%), with Shrubland and Saline and Pans being the least affected with less than 3% of the gravel pits in each. A relationship was found between road length (km) and number of gravel pits created in various vegetation communities ( see Figure 5.7).



**Figure 5.7:** Relationship between road length (km) and number of gravel pits in various plant communities.

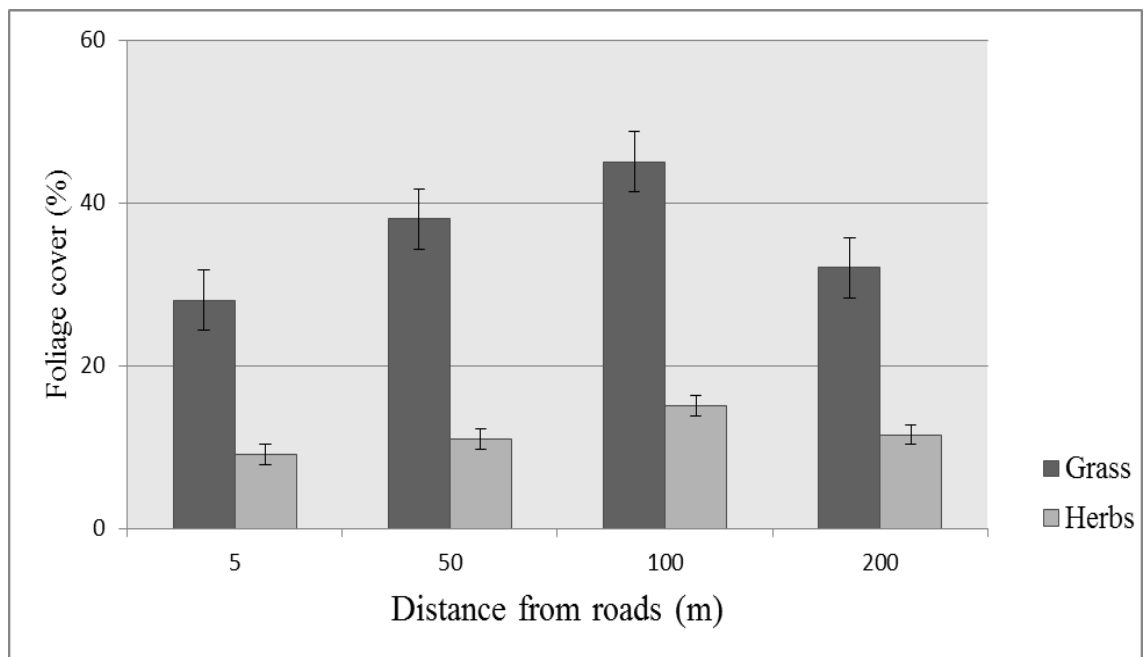
A total of 31 gravel pits were assessed in the field. About 55% of those were rated as having a low level of vegetation recovery. Whereas, only 25% of those gravel pits were rated as having a high level of vegetation recovery. Major factors that affect vegetation recovery process include age of the gravel pit, intensity of the damage and underlying parent materials. For instance, gravel pits located in rocky areas have shown a substantially low level of vegetation recovery compared to those located in sandy areas which easily allow grass species to regenerate. Using chi square test, a statistical significant association was found between level of stoniness and vegetation recovery ( $p < 0.05$ ). However, instead of the native vegetation to regenerate in those gravel pits, shrub species (*Pechuel-Loeschealeubuitziae*), locally known as bitterbush has particularly colonized the majority of these sites.

Many gravel pits have turned into seasonal water points. For example, 70% of the gravel pits assessed hold water seasonally. None of the gravel pits assessed showed a footprint of restoration or rehabilitation and help enable vegetation recovery. As a result, soil erosion, particularly sheet erosion was prominent at most of the gravel pits, with surface runoff as the major contributing factor.

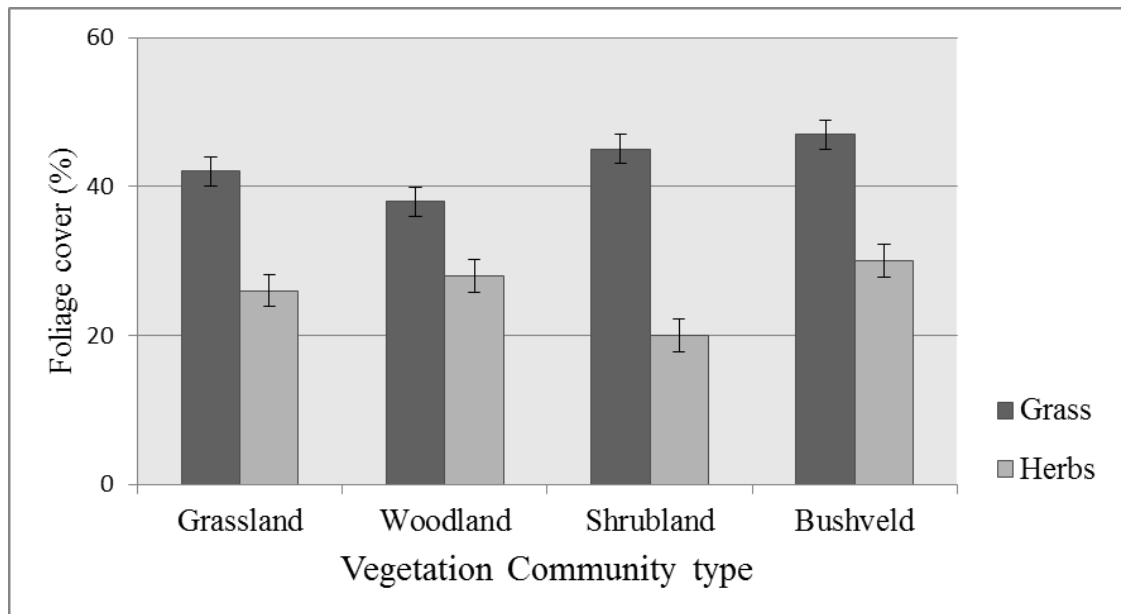
#### **5.4. Relationship between Distance from Roads and Adjacent Herbaceous Vegetation Communities.**

Herbaceous foliage cover was estimated based on plot percentage cover at fixed distances from roads. A total of 232 sites were surveyed (refer to section 4.2). Figure 5.8 shows mean foliage cover for dominant species for both grass and herb at differing localities from roads. Grass foliage cover was approximately (28%) at a distance of 5 m from roads. It then increased gradually to 38% at 50 m and 43% at 100 m, before dropping to just above 30% at 200 m distance from the road. This trend was observed in the Bushveld, Grassland, as well as Woodland. While in the Shrubland, a high grass foliage cover was found at 5 m, which decreased with increasing distance from roads. Herb foliage cover was lowest at a distance of 5 m approximately (10%), which increased gradually to 15% at 100, then decrease to approximately 11% at 200 m. This pattern was found particularly in the Woodland, Shrubland and Bushveld. Whereas in the Grassland, the highest average foliage cover was found at a distance of 50 from roads. Kruskal-Wallis test showed that grass foliage cover was not statistically significant between the assessed fixed distances from roads ( $H = 7.03$ ;  $P = 0.134$ ). The test results did not consider variation within the vegetation communities. On the other hand, a high statistical significant difference in grass foliage cover was found between the vegetation community types ( $H = 8.24$ ;  $P = 0.003$ ). For instance, a high grass foliage

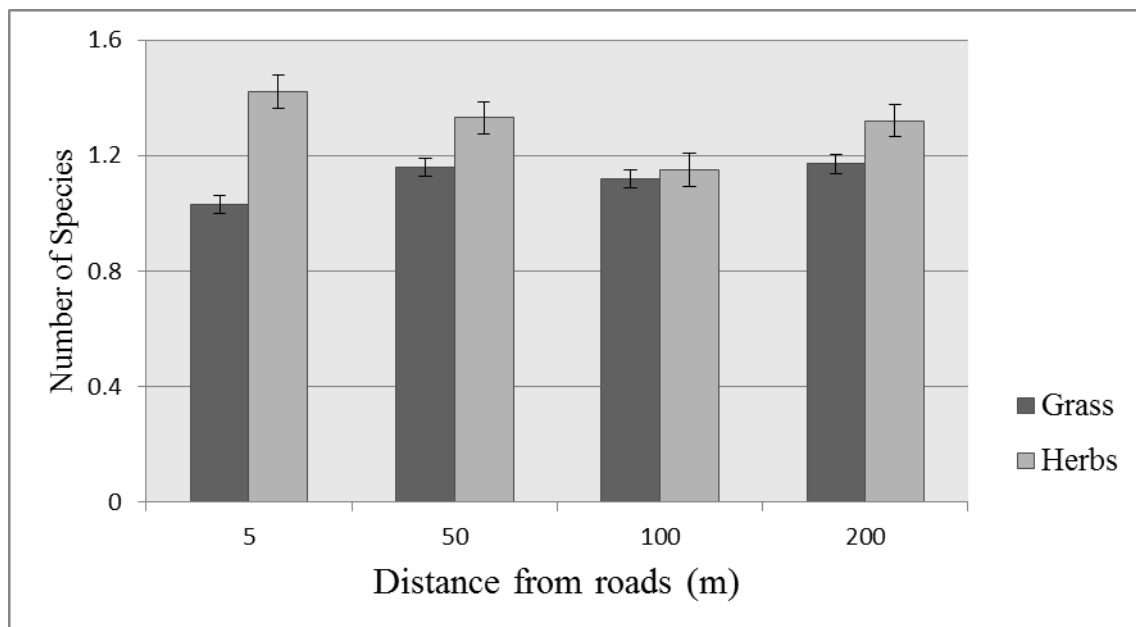
cover was found in the Bushveld and Shrubland as compared to Woodland. Whereas, grass foliage cover in the Grassland was falling in the intermediate range. Similarly, a high abundance of herb foliage cover was found in the Bushveld and the Woodland, as compared to other vegetation communities (Figure 5.9). On a broader scale, there was a significantly ( $P < 0.05$ ) high foliage cover for grass species as compared to herb species at differing localities and between the major vegetation communities.



**Figure 5.8:** Mean  $\pm$  Standard errors for grass and herbs foliage cover at various localities from roads.

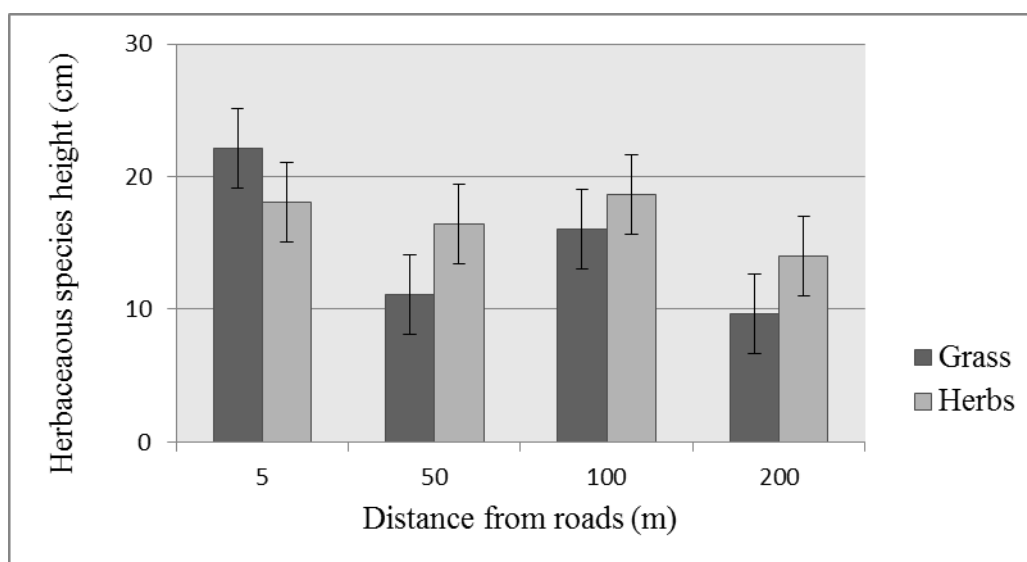


**Figure 5.9:** Mean  $\pm$  Standard error for herbs foliage cover in the major vegetation community of ENP.



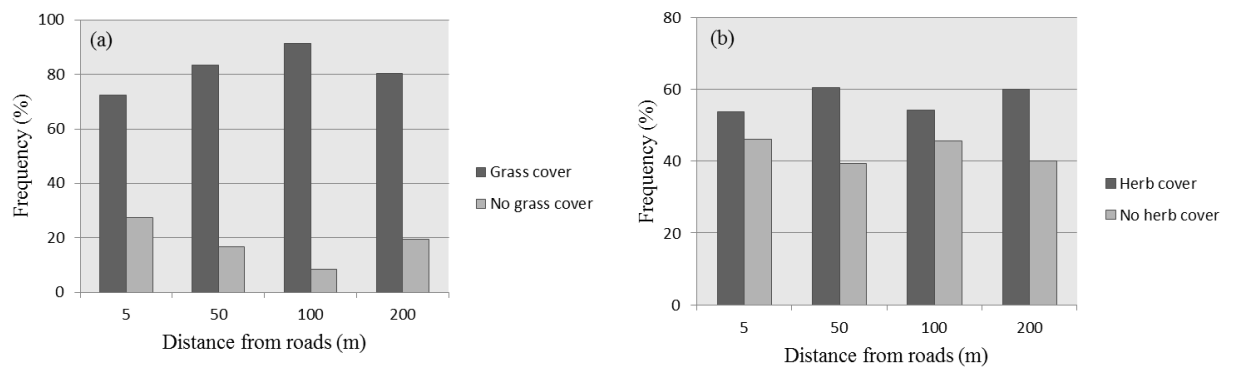
**Figure 5.10:** Mean  $\pm$  Standard error number of herbaceous species recorded at different proximity to roads in ENP.

Figure 5.10 shows mean  $\pm$  Standard error of number of grass and herb species recorded at various localities from roads. Although various types of grass and herbs were found in the study area, on average, one species of grass or herb was recorded per plot. Fewer grass species were recorded at a distance of 5 m from roads as compared to other localities, whereas, the highest herbs species were recorded at 5 m. On a whole, more herb species were recorded compared to grass species. Herb species showed increasing trend with distance to roads, while grass species decreased with distance to roads. Kruskal-Wallis test showed that distance from roads has no significant effects on the number of grass species found ( $H= 3.07$ ;  $P = 0.545$ ), as well as number herb species found ( $H= 1.22$  ;  $P = 0.873$ ). On the other hand, number of herb species found were significantly different between the vegetation communities ( $H = 9.09$  ;  $P = 0.048$ ). The variation in standing height for both grass and herb species recorded are presented in Figure 5.11.



**Figure 5.11:** Mean  $\pm$  Standard Error herbaceous vegetation height change along differing localities to roads.

The presence or absence of grass and herbs foliage cover was also taken into account to determine whether distance from roads has an effect on the absence or presence of bare patches found. The frequency distribution of those is presented in Figure 5.12. For instance, at a distance of 5 m, 27% of the plots had no grass cover. This showed a declining trend with increasing distance from roads up to 100 m. A high frequency of plots without any herb cover was found at both localities with a steady decrease towards the 200 m distance.



**Figure 5.12:** Frequency distribution of presence or absence of grass species (a) and herb species (b) with relation to distance from roads.

Logistic regression analysis results revealed that the probability of occurrence (presence/absence) of both grass and herb species in plots was not significantly related to distance from roads ( $P > 0.05$ ; see Table 5.3). This model explained less than 1% of the variation in presence or absence of both grass and herb species with relation to distance from roads.

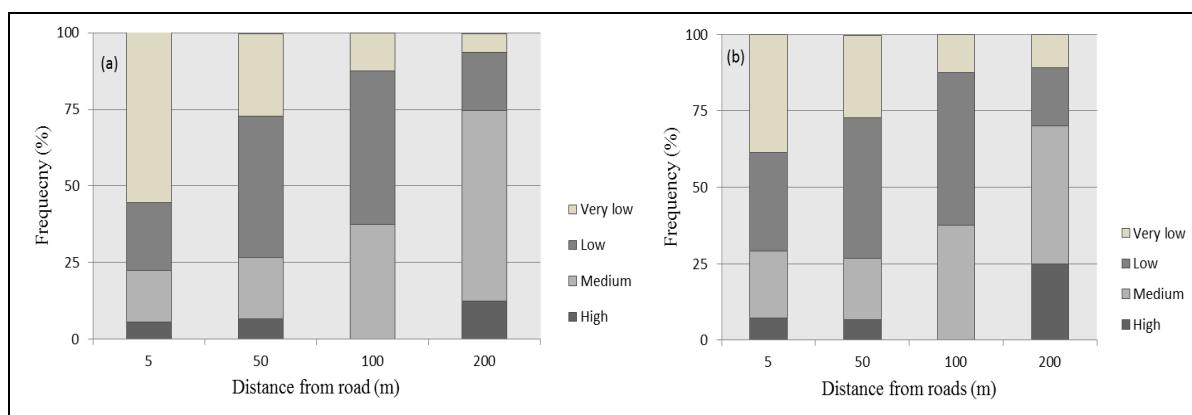
**Table 5.3:** Results of the logistic regression analysis showing the relationship between presence/absence<sup>6</sup> of herbaceous species with increasing distance from roads in ENP.

<b>Variables</b>	<b>Estimated coefficient</b>	<b>Standard Error</b>	<b>Z value</b>	<b>P value</b>
Grass	0.0021	0.0028	0.732	P > 0.05
Herbs	0.001	0.0022	0.489	P > 0.05

As part of vegetation health assessments along roads, herbaceous vegetation vigour was also estimated. The indicators used to rate vegetation vigour are presented in section 4.2. Results of vegetation vigour as rated at an ordinal scale are shown in Figure 5.13. Grass vigour was mainly rated as very low to low at a distance of 5 m and 50 m from roads. Whereas, at a distance of 100 m, grass vigour was mainly rated as medium to low, while grass vigour at 200 m was mainly rated as high. Chi square test revealed that grass vigour was not significantly related to distance from roads ( $\chi^2 = 13.10$  ; P = 0.158). Herb vigour was also rated mainly as very low to low at a distance of 5 m from roads. At 50 m and 100, 40% of the sites were rated as low. However, at 200 m from road herb vigour was mainly rated as medium to high. Indeed a significant relationship was found between distance from roads and level of herbs species vigour (H= 21.68; P = 0.001).

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<sup>6</sup>For analysis purpose presence / absence of species was coded 1/0, to predict the probability of occurrence using a binomial distribution.



**Figure 5.13:** Relationship between vegetation vigour and distance from roads (a) grass, and (b) herbs.

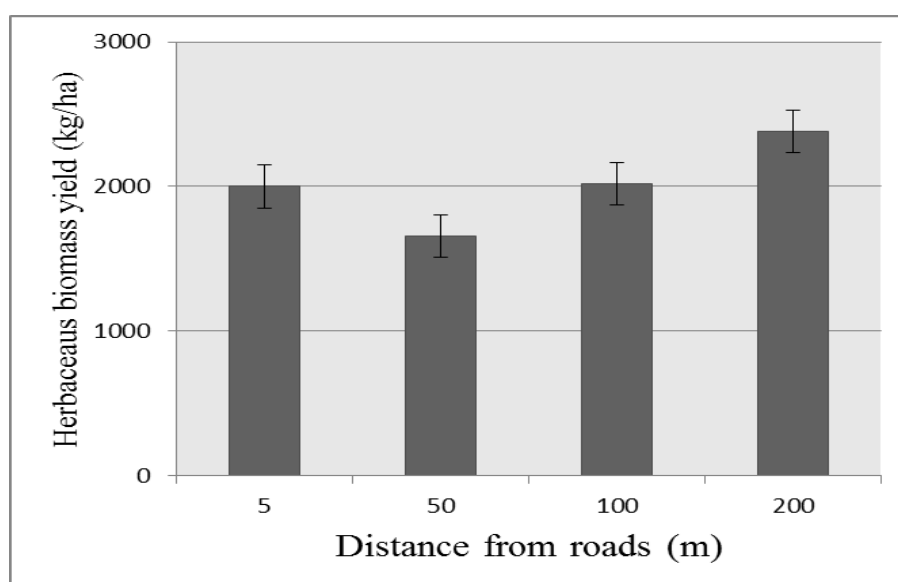
Herbaceous biomass was quantified using disc pasture meter (refer to section 4.3) at different localities from roads. General linear analysis results on the relationship between distance from roads, and the interaction of both distance and vegetation community types are shown in Table 5.4. Descriptive statistics (mean  $\pm$  Standard error) for herbaceous biomass yield at various localities are shown in Figure 5.14, while those of herbaceous biomass yield per vegetation community types are presented in Figure 5.15. Generally, there was a linear increase in herbaceous biomass yield with an increase in distance from roads. However, this pattern is further modified by vegetation community type. For instance, in the Bushveld and on the Grassland biomass yield was low at a distance of 5 m from roads, and was highest at 200 m from roads, a trend which is not found in the Shrubland and the Woodland. A statistical significant relationship was found between distance from roads and herbaceous biomass yield ( $P < 0.05$ ). Also, a statistical significant interaction effect of distance from roads and vegetation community types was found in communities such as Grassland and Woodland.

However, in the Shrubland biomass yield was not statistical significantly related to distance from roads ( $P > 0.05$ ).

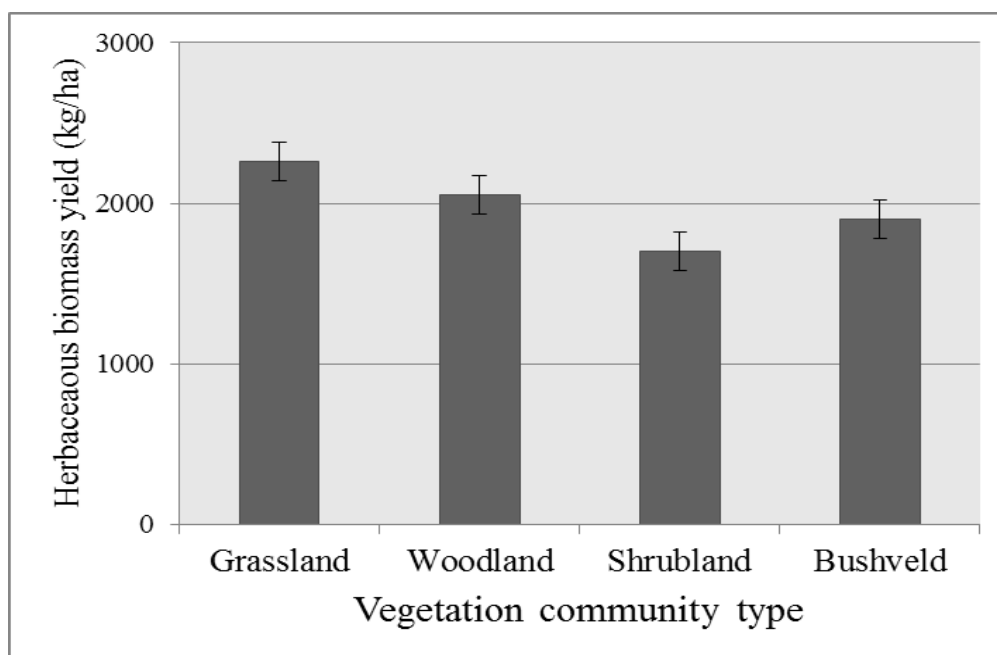
**Table 5.4:** Results of the linear model showing the main and interaction effect of distance from roads and vegetation communities on biomass yield of herbaceous vegetation species.

Predictors	Coefficient	Standard error	t statistic	P value
<b>Main effects</b>				
Distance (m)	0.006	0.002	2.23	0.027 *
Grassland	0.360	0.329	1.09	0.027 *
Shrubland	1.109	0.489	0.22	0.822
Woodland	0.865	0.427	2.02	0.045 *
<b>Interaction effects</b>				
Distance x Grassland	0.25	0.34	1.60	0.031 *
Distance x Shrubland	-0.006	0.004	-1.52	0.130
Distance x Woodland	-0.007	0.003	-2.08	0.038 *

\* Statistical significant at 0.05 alpha level



**Figure 5.14:** Mean  $\pm$  Standard error for herbaceous biomass yield at various localities from roads.



**Figure 5.15:** Mean  $\pm$  Standard error for herbaceous biomass yield in the major vegetation community types.

### 5.5. Relationship between Distance from Roads and Adjacent Woody Vegetation Communities

Woody vegetation was classified into shrubs and trees. As detailed in section 4.2, “shrub” in this study refers to those woody plants which grow on multiple stems, with standing height of approximately  $\leq 3$  m. While on the other hand, “trees” was used to refer to those woody plants with a single stem, multiple branches and a standing height of approximately  $\geq 3$  m. A total of 232 sites were surveyed (refer to section 4.2). For those woody species surveyed, shrubs height (m) was estimated to  $1.37 \pm 1.34$  m at 5 m,  $1.45 \pm 1.38$  m at 50 m,  $1.21 \pm 1.45$  m at 100 m and  $1.11 \pm 1.11$  m at 200 m. Meanwhile, estimated trees height (m) ranged from  $4.17 \pm 1.21$  m at 5 m distance,  $3.93 \pm 1.13$  m at 50 m,  $4.83 \pm 1.89$  at 100 m, and  $3.55 \pm 1.26$  m at 200 m from the roads.

There was a distinct variation in woody foliage cover with distance from roads. For example, shrubs cover was approximately 38% and 41% at 5 m and 50 m respectively.

While on the other hand, approximately 41% and 30% was found at 100 m and 200 m from roads. This, therefore shows an increase in shrubs foliage cover with distance from roads up to a distance of 100 m. On the contrary, trees foliage cover was lowest (23%) at a distance of 5 m, which linearly increased to approximately 40% at a distance of 200 m from roads. However, for both shrubs and trees, foliage cover was further modified by vegetation community type. For instance, in the Bushveld and the Woodland vegetation communities, the highest shrub cover was observed at a distance of 5 m, while in the Shrubland, the highest cover was found at a distance of 200 m. This pattern is further extended to the Grassland at a distance of 50, 100 m and 200 m. Furthermore, a low abundance of tree cover was observed at a distance of 5 m from roads mainly in the Bushveld. Although the lowest tree foliage cover was found at 5 m in the Grassland as well, this was nevertheless expected because little woody vegetation are found in grass plains. In the Shrubland and Woodland, a high abundance of cover was found at a distance of 200 m.

Shrubs cover was not significantly related to distance from roads ( $H=1.74$  ;  $P = 0.783$ , and trees foliage cover alike ( $H = 0.47$ ;  $P= 0.923$ ). Whereas, both shrub cover was significantly different between vegetation community type ( $P < 0.05$ ). Species richness for woody vegetation was determined based on number of different species per plot. The total average was then compared between various localities from the roads.

For both shrubs and tree species, the highest average was recorded at a distance of 200 m as compared to other localities. However, on average, less than two species were recorded at all localities, while a maximum of 6 shrub species was recorded in a plot at a distance of 200 m, whereas, a maximum of 4 shrub species was recorded in a plot at

other localities. Nevertheless, the declining pattern in shrub species richness was not significantly related to distance from roads ( $H= 1.28$  ;  $P= 0.8631$ ). On the other hand, a significant difference was found between number of shrub species and the predefined vegetation community types ( $H= 29.47$ ;  $P =0.000$ ). Similarly, number of tree species recorded was not significantly related to distance from roads ( $H= 3.33$ ;  $P = 0.343$ ).

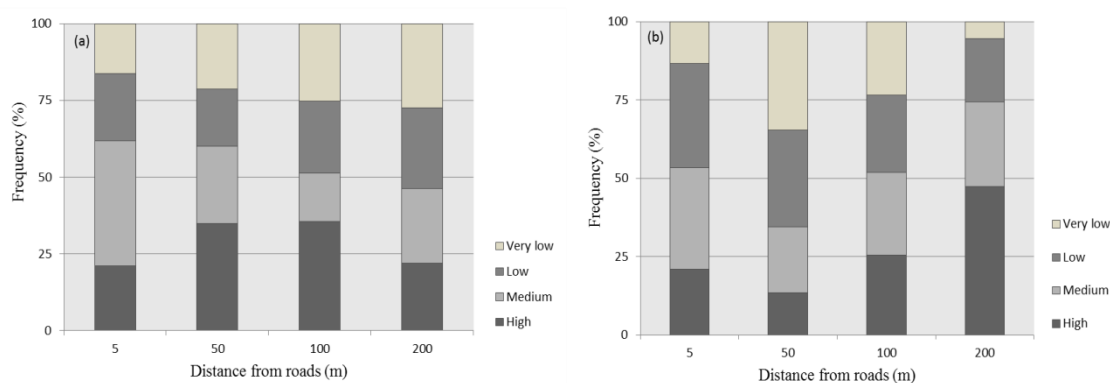
Approximately 43.7% of the plot had no shrubs species present, while 48.6% had no tree vegetation present. Although the absence of those woody species is relatively high in the plots, it is consistent with the fact that most roads in ENP are found on the grass plains as determined in section 5.2. Using presence/absence variables, in a logistic regression model, the probability of occurrences for these woody species was found to be independent of distance from roads. Those results are presented in Figure 5.15, of which both shrubs and trees were not significantly related to distance from roads ( $P > 0.05$ ).

**Table 5.16:** Results of the logistic regression analysis showing the relationship between presence/absence of woody species and distance from roads.

<b>Variables</b>	<b>Estimated coefficient</b>	<b>Std Error</b>	<b>Z value</b>	<b>P value</b>
Shrubs	-0.0009	0.002	-0.449	$p > 0.05$
Trees	0.003	0.0028	1.068	$p > 0.05$

For the woody vegetation found, vigour as an indication of vegetation health was rated using indicators as presented in (section 4.2). A low rating of vigour for shrubs was most frequent at 5 m, while the high rating of shrubs vigour was most frequent at 100 m distance from roads. Similarly, low rating for trees vigour was most frequent at the

distance of 5 m, while high rating for tree vigour was most frequently rated at distance of 200 m from roads (Figure 5.17). Chi square test showed that woody vegetation vigour was not significantly related to distance from roads, for both shrubs and tree species ( $P > 0.05$ ).



**Figure 5.17:** Changes in woody vegetation vigour with distance from roads. (a) shrub species, and (b) tree species.

#### 4.6. Relationship between Distance from Roads and the Concentration of Soil Chemical Properties

Soil samples were collected in various soil substrates along tourist roads. Dominant soil type was mainly *calcaric Regosols*, *lithic Arenosols* and *mollic Leptosols*. Other soil types found in the area were *eutric Fluvisol*, *ferralic Arenosols*, *sodic Fluvisols* and *sodic Solonchaks*. Refer to section 3.5 for details on the general description of soil types found in the study area.

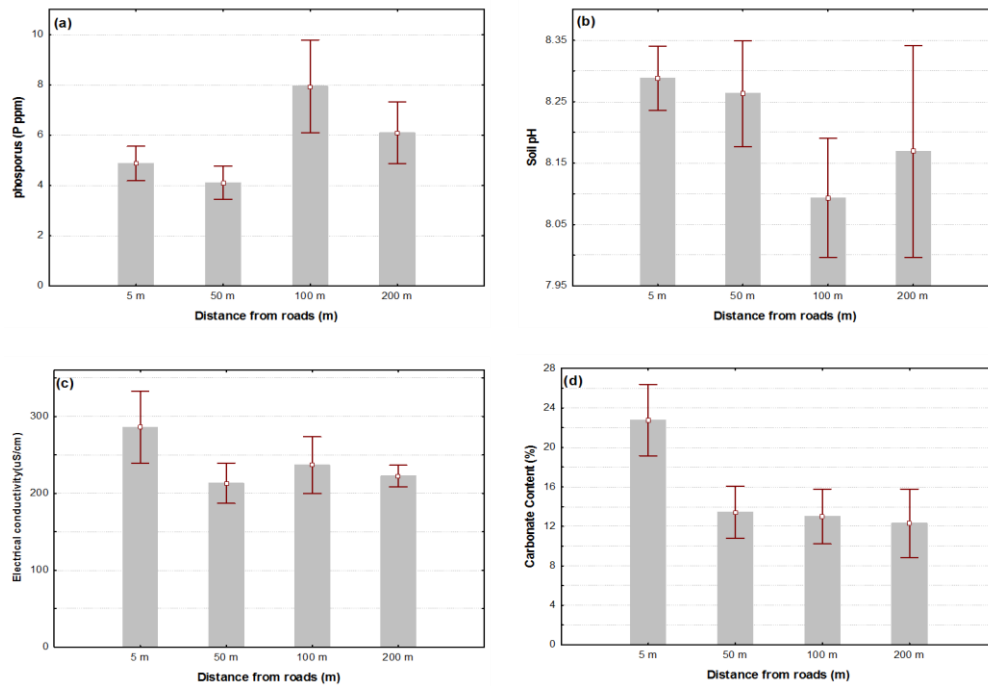
The chemical properties concentration in soil found at various localities followed distinct patterns with distance from the roads. For instance, soil pH, electrical (EC) conductivity, carbonate (C), exchange calcium (Ca), exchange magnesium (Mg), cation exchange capacity (CEC) and exchange sodium (Na) were highly concentrated at 5 m and 50 m, with a declining trend towards the 200 m distance from the roads. Whereas, soil chemical elements such as soil phosphorus (P), organic carbon (OC) and nitrogen

(N) showed an increasing trend with increasing distance from roads (Figure 5.18 ; 5.19 and 5.20).

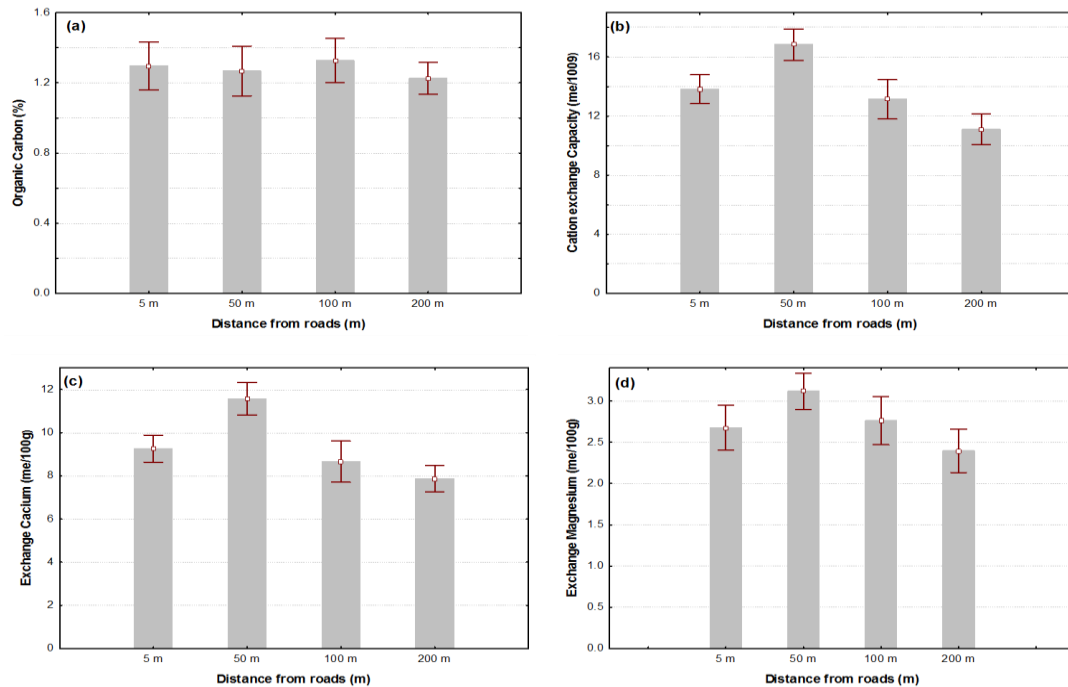
**Table 5.5:** Results of the linear model showing the relationship between distance to roads and the concentration of selected soil chemical properties.

Soil Elements	Adj R <sup>2</sup>	df	MS	F value	P value
Cation exchange capacity	0.082	1,50	106.38	5.56	< 0.05*
Calcium	0.058	1,50	36.97	4.18	< 0.05*
Carbon	0.048	1,50	533.85	3.62	< 0.05*
Sodium	0.019	1,50	0.39	2.00	0.164
Potassium	0.006	1,50	26.27	1.33	0.254
Magnesium	0.005	1,50	1.27	1.29	0.262
Electrical conductivity	0.002	1,50	14827.85	0.89	0.350
Soil pH	0.002	1,50	0.14	0.85	0.360
Phosphorus	0.004	1,50	0.31	0.80	0.376
Nitrogen	0.017	1,50	0.00	0.12	0.734
Organic Carbon	0.017	1,50	0.02	0.10	0.750

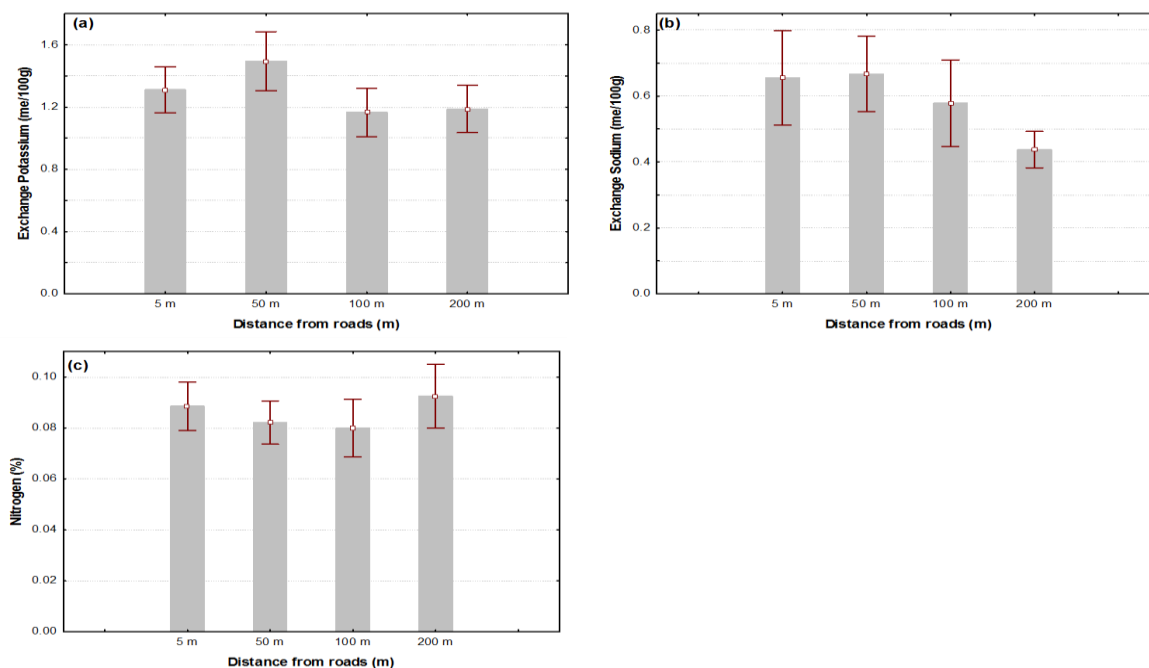
A significant statistical relationship was found between the concentration of cation exchange capacity, soil exchange calcium, and soil carbon concentration ( $P < 0.05$ ). Approximately distance from roads explained 8% of the variance in the concentration of cation exchange capacity, 5% soil exchange calcium and 4.8% of the variances in the concentration of soil carbonate. No statistical significant effects of distance from roads were found in the concentration of all other soil chemical properties as shown in (Table 5.5).



**Figure 5.18:** Mean  $\pm$  Standard error for the concentration of (a) phosphorus (b), Soil pH (c), electrical conductivity (d), and Carbonate content recorded in Soil at various proximity to roads.



**Figure 5.19:** Mean  $\pm$  Standard error for concentration of (a) Organic carbon ,(b) Cation exchange capacity (c), Exchange calcium (d) and exchange Magnesium is Soil at various proximity to roads .



**Figure 5.20:** Mean  $\pm$  Standard error for concentration of exchange (a) potassium (b), exchange Sodium (c) and (c) Nitrogen in Soil at various proximity to roads.

### 5.7. Relationship between Vegetation Structure and the Concentration of Roadside Soil Chemical Properties

Table 5.6 presents the results of the general linear model showing the relationship between community (herbaceous vs. woody) and the concentration of soil chemical properties. Out of the soil chemical properties tested, only the concentration of soil electrical conductivity was significantly different between herbaceous and woody communities ( $P < 0.05$ ), of which at least 9 % of the variance are shared between soil texture and the concentration of soil chemical properties. Although there was no statistical significant difference for various other chemical properties between the herbaceous and woody communities, mean concentration of chemical properties such as organic carbon, soil pH, phosphorus, sodium, cation exchange and potassium were

higher in the herbaceous communities as compared to the woody vegetation. However, vegetation community types shared less than 3% of the variances in the concentration of these both chemical properties.

**Table 5.6:** Descriptive statistics (Mean±Standard Deviation) of concentration of soil chemical properties, a comparison between herbaceous and woody communities<sup>7</sup>, and results of the general linear model analysis.

<b>Soil elements</b>	<b>Herbaceous</b>	<b>Woody</b>	<b>Adj R<sup>2</sup></b>	<b>MS</b>	<b>df</b>	<b>F value</b>	<b>P value</b>
Electrical conductivity	262.93 ± 133.50	155.91 ± 59.55	0.0995	99331	2,49	6.64	< 0.05*
Organic carbon	1.34 ± 0.46	1.06 ± 0.47	0.0382	0.65	2,49	3.03	<0.05 *
Soil pH	8.24 ± 0.42	8.11 ± 0.28	0.0028	0.14	2,49	0.86	0.358
Phosphorus	5.90 ± 4.73	4.75 ± 3.27	0.0086	11.28	2,49	0.56	0.456
Magnesium	2.70 ± 1.07	2.95 ± 0.66	0.0092	0.54	2,49	0.54	0.467
Sodium	0.60 ± 0.48	0.55 ± 0.31	0.0174	0.03	2,49	0.13	0.721
Cation exchange Capacity	13.97 ± 4.57	13.43 ± 4.73	0.0176	2.66	2,49	0.12	0.7317
Potassium	0.60 ± 0.48	0.55 ± 0.31	0.0187	0.02	2,49	0.06	0.8031
Calcium	9.37 ± 3.20	9.62 ± 2.60	0.0188	0.55	2,49	0.06	0.8119
Carbonate	15.51 ± 13.40	15.86 ± 8.46	0.0199	1.09	2,49	0.01	0.9343
Nitrogen	0.09 ± 0.04	0.09 ± 0.03	0.02	0.03	2,49	0.03	0.976

Statistical significant at 0.05 alpha level

<sup>7</sup>Herbaceous communities was used to refer to the vegetation communities covered by non woody vegetation such as grass and herbs. The woody communities was used to refer to vegetation communities such as Shrubland, Woodland, Bushveld

### **5.8. Relationship between Soil Texture and the Concentration of Selected Soil Chemical Properties**

Soil texture plays a significant role in determining the soil chemical properties and concentration. A high cation exchange capacity, exchange calcium, exchange magnesium, exchange potassium and organic carbon were mostly found in silt loam soil. Whereas, exchange sodium, soil pH, electrical conductivity and nitrogen was mostly concentrated in clay-loamy soil. The concentration of cation exchange capacity, exchange calcium, exchange potassium, organic carbon, soil pH and electrical conductivity was poorly concentrated in sandy soil texture. Exchange magnesium and exchange sodium were lowest in loamy sand, while phosphorus was lowest in Sandy loam, while nitrogen was lowest in loamy soil on the others side. To determine whether soil texture has a significant relationship with the concentration of selected soil chemical properties, a general linear model analysis was used. The results are presented in Table 5.8.

**Table 5.7:** Mean  $\pm$  SD for soil chemical properties concentration based on soil texture type.

<b>Soil texture</b>	<b>Sandy loam</b>	<b>Loamy sand</b>	<b>Loam</b>	<b>Clay loam</b>	<b>Silt loam</b>	<b>Sand</b>
Cation Exchange Capacity	12.56 $\pm$ 0.45	11.64 $\pm$ 1.73	14.53 $\pm$ 0.88	14.91 $\pm$ 1.56	19.83 $\pm$ 0.98	8.32 $\pm$ 3.52
Calcium	9.17 $\pm$ 0.37	9.40 $\pm$ 1.71	9.64 $\pm$ 0.54	9.00 $\pm$ 1.40	13.52 $\pm$ 0.89	5.87 $\pm$ 2.76
Magnesium	2.17 $\pm$ 0.11	1.87 $\pm$ 0.29	2.52 $\pm$ 0.15	1.98 $\pm$ 0.24	3.29 $\pm$ 0.21	2.16 $\pm$ 0.68
Potassium	0.91 $\pm$ 0.07	0.37 $\pm$ 0.06	1.07 $\pm$ 0.11	0.37 $\pm$ 0.09	1.25 $\pm$ 0.20	0.29 $\pm$ 0.10
Sodium	0.44 $\pm$ 0.12	0.08 $\pm$ 0.01	1.64 $\pm$ 0.57	3.67 $\pm$ 1.96	2.31 $\pm$ 0.70	0.12 $\pm$ 0.02
Phosporus	4.20 $\pm$ 0.59	6.60 $\pm$ 3.23	4.77 $\pm$ 0.50	8.87 $\pm$ 1.47	6.09 $\pm$ 0.72	9.33 $\pm$ 1.37
Organic Carbon	1.23 $\pm$ 0.06	0.97 $\pm$ 0.15	1.31 $\pm$ 0.08	1.05 $\pm$ 0.21	1.51 $\pm$ 0.08	0.37 $\pm$ 0.07
Soil pH	8.31 $\pm$ 0.06	8.15 $\pm$ 0.09	8.43 $\pm$ 0.06	9.11 $\pm$ 0.43	8.55 $\pm$ 0.05	7.91 $\pm$ 0.20
Electrical conductivity	464.49 $\pm$ 172.99	113.11 $\pm$ 13.77	754.02 $\pm$ 309.89	4745.97 $\pm$ 2340.44	601.46 $\pm$ 137.89	43.30 $\pm$ 10.65
Nitrogen	0.15 $\pm$ 0.045	0.06 $\pm$ 00	0.092 $\pm$ 0.03	0.42 $\pm$ 0.02	0.13 $\pm$ 0.03	0.04 $\pm$ 0.006

**Table 5.8:** Results of the general linear model analysis on effects of soil texture on the concentration of chemical properties.

Soil elements	Adj R <sup>2</sup>	MS	DF	F	P
Cation exchange capacity	0.27	159.30	7,126	8.05	< 0.001 **
Exchange Sodium	0.24	43.26	7,126	7.07	< 0.000 **
Soil pH	0.17	0.71	7,126	4.82	< 0.001 **
calcium	0.15	47.94	7,126	4.35	< 0.001 **
Magnesium	0.13	3.07	7,126	3.87	< 0.001 **
Electrical conductivity	0.13	9174886.47	7,126	3.83	< 0.001 **
Organic carbon	0.11	0.66	7,126	3.37	< 0.001 **
Potassium	0.10	1.24	7,126	3.08	< 0.001 **
Phosphorus	0.04	32.26	7,126	1.79	0.096
Nitrogen	0.07	0.002	4,47	2.02	0.1044

\*\* statistical significant at 0.01

Of the soil chemical properties presented in Table 5.8, a highly statistical significant relationship with soil texture was found, beside exchange phosphorus and nitrogen concentration. The concentration of various soil chemical properties is therefore well predicted by soil texture as compared to other predictor variables used in this study.

### 5.7. Interaction between Seasonal Changes and Distance from Roads on the Concentration of Roadside Soil Chemical Properties

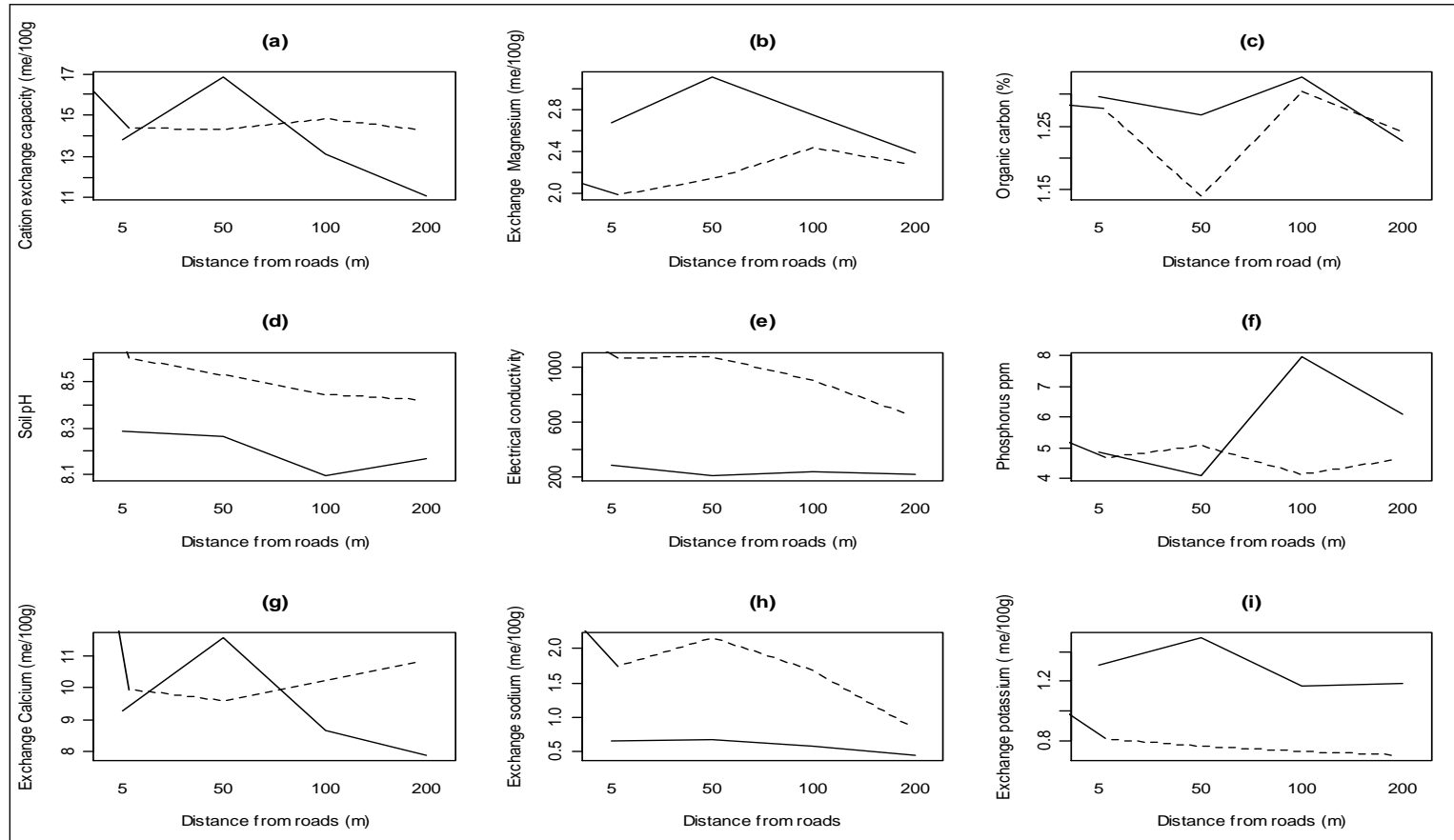
This study assumed that there will be a seasonal variation in roadside soil chemical properties concentrations which is modified by distance from roads. Descriptive statistics on roadside soil chemical properties are presented in Table 5.9, while the interaction of soil chemical properties with distance from roads and seasonal changes are shown in Figure 5.21. Linear model with interaction of seasons and distance from

roads showed that there was no statistically significant interaction in terms of cation exchange capacity ( $R^2 = 0.010$ ,  $F_{3,130} = 1.45$ ,  $P = 0.229$ ), electrical conductivity ( $R^2 = 0.006$ ,  $F_{1,130} = 0.73$ ,  $P = 0.534$ ), Organic carbon ( $R^2 = 0.02$ ,  $F_{3,130} = 0.10$ ,  $P = 0.94$ ), exchange sodium ( $R^2 = 0.006$ ,  $F_{3,130} = 0.695$ ,  $P = 0.55$ ), exchange calcium ( $R^2 = 0.005$ ,  $F_{3,130} = 1.26$ ,  $P = 0.289$ ), phosphorus ( $R^2 = 0.03$ ,  $F_{3,130} = 2.45$ ,  $P = 0.06$ ). A statistical significant interaction was found for exchange magnesium ( $R^2 = 0.07$ ,  $F_{3,130} = 4.51$ ,  $P = 0.004$ ), soil pH ( $R^2 = 0.11$ ,  $F_{3,130} = 6.97$ ,  $P = 0.002$ ), and exchange potassium ( $R^2 = 0.13$ ,  $F_{3,130} = 6.09$ ,  $P = 0.000$ ). The ecological implication of those results and conclusion drawn are discussed in subsequent chapters.

**Table 5.9:** Descriptive statistic (mean  $\pm$  Standard Deviation) for soil chemical properties during dry and wet season<sup>8</sup> at various distances from roads.

Distance from roads	5		50		100		200	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Cation exchange capacity	14.36 $\pm$ 3.26	13.82 $\pm$ 3.86	14.32 $\pm$ 7.08	16.85 $\pm$ 4.18	14.83 $\pm$ 5.94	13.14 $\pm$ 4.86	14.28 $\pm$ 5.47	11.11 $\pm$ 3.82
Electrical conductivity	1072.44 $\pm$ 2183.90	285.86 $\pm$ 183.44	1073.60 $\pm$ 2666.14	213.14 $\pm$ 103.49	901.97 $\pm$ 1897.26	236.67 $\pm$ 134.47	637.87 $\pm$ 1402.42	222.42 $\pm$ 51.14
Organic carbon	1.29 $\pm$ 0.51	1.30 $\pm$ 0.54	1.14 $\pm$ 0.44	1.27 $\pm$ 0.56	1.31 $\pm$ 0.36	1.33 $\pm$ 0.46	1.24 $\pm$ 0.56	1.23 $\pm$ 0.33
Soil pH	8.61 $\pm$ 0.26	8.29 $\pm$ 0.21	8.53 $\pm$ 0.36	8.26 $\pm$ 0.34	8.45 $\pm$ 0.51	8.09 $\pm$ 0.35	8.42 $\pm$ 0.41	8.17 $\pm$ 0.63
Sodium	1.72 $\pm$ 2.96	0.65 $\pm$ 0.56	2.17 $\pm$ 4.97	0.67 $\pm$ 0.45	1.68 $\pm$ 3.65	0.58 $\pm$ 0.48	0.83 $\pm$ 1.71	0.44 $\pm$ 0.20
Phosphorus	4.67 $\pm$ 3.55	4.87 $\pm$ 2.72	5.06 $\pm$ 5.68	4.10 $\pm$ 2.62	4.16 $\pm$ 3.30	7.94 $\pm$ 6.73	4.64 $\pm$ 4.01	6.09 $\pm$ 4.49
Exchange calcium	9.95 $\pm$ 3.04	9.26 $\pm$ 2.45	9.60 $\pm$ 4.33	11.57 $\pm$ 2.94	10.20 $\pm$ 3.66	8.66 $\pm$ 3.47	10.88 $\pm$ 4.46	7.87 $\pm$ 2.22
Magnesium	1.98 $\pm$ 0.76	2.67 $\pm$ 1.07	2.14 $\pm$ 0.97	3.12 $\pm$ 0.86	2.43 $\pm$ 0.90	2.76 $\pm$ 1.06	2.28 $\pm$ 0.83	2.39 $\pm$ 0.96
Potassium	0.81 $\pm$ 0.59	1.31 $\pm$ 0.59	0.77 $\pm$ 0.68	1.50 $\pm$ 0.75	0.73 $\pm$ 0.64	1.16 $\pm$ 0.57	0.70 $\pm$ 0.57	1.19 $\pm$ 0.56

<sup>8</sup> “Wet season” is used here to refer to data collected during peak of the rainy season, while the “dry season” refers to data collected in September late after the rainy season and before the onset of the rainy season.



**Figure 5.21:** Interaction plots showing the mean change in soil chemical concentration between the wet (-) and dry (--) season with distance from roads.

## CHAPTER 6

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### 6. DISCUSSION

#### 6.1. Introduction

This chapter is aimed at discussing the findings uncovered in this study in relation to the underlying research objectives as presented in section 1.3. Understanding the effects of tourism development in PAs is ultimately concerned with a complex assessment of the interaction of socio-ecological system in a nature-based tourist destination. This study specifically assessed how tourism, which is a human induced system, interacts with the biophysical environment, an ecological system in the ENP. Some of those human - nature interaction in tourism based PAs are embedded in infrastructural development such as roads. Therefore, this study investigated the effects of tourist road development on the ecological landscape of ENP, by assessing the density and spatial distribution of roads in the Park's major vegetation dynamics in roadside vegetation and soil properties as well as the ecological effects of gravel mining in the Park.

#### 6.2. Road Density and Landscape Fragmentation in ENP

The ENP has a mosaic of five major vegetation communities (Le Roux et al., 1988), over which tourism infrastructures are developed to enhance recreational activities. This study earlier hypothesized that the level of tourist road density will be relatively higher in vegetation communities which occupy a large surface area of the Park. However, it

was uncovered that nearly half of the tourist roads are found on Grasslands, which is one of the smallest vegetation communities in the Park, as compared to the woody vegetation communities. Grassland, being an open flat plain of the ENP provides a unique wildlife experience to tourists due to the abundance and enhanced observation of wildlife found roaming there.

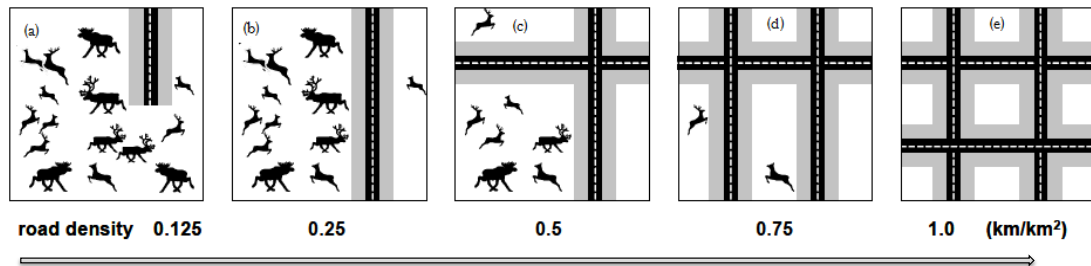
Indeed, the spatial alignments of road infrastructure in PAs could have an implication on nature-based visitor's satisfaction whose aim is to enjoy wildlife and scenery. For instance, visitors to PAs would prefer a closer view to wildlife mainly for photographic purposes. As a result, this could have probably influenced Park managers to develop roads mainly on the grass plains which give a clear view to plain ungulates such as Zebras, Wildebeests, and Springboks. However, there are other wildlife such as Rhinos and Elands which are hardly found on the open plains. This could have therefore led to the creation of other roads segments such as the Eland drive and Rhino drive which are found in the thick Bushveld east of Halali, where some of these wildlife are commonly found.

The main direct impact of roads construction was the clearing of vegetation to create pathways for construction. Impact associated with clearing vegetation for road infrastructure construction was also recognized in other PAs such as in Australia (Pickering & Hill, 2007) and Kenya (Ikiara & Okech, 2002). The Etosha Pan, a saline seasonal wetland is an attractive geomorphological feature of the Park, which attracts

water birds, while springs and seepages along its margins act as water source for wildlife (Cunningham & Jankowitz, 2011). It is managed as a wilderness area, a conservation category which strictly prohibits human modification of the ecosystem (Dudley, 2008). Nevertheless, this study uncovered that at least approximately 1% of the tourist roads had come in direct contact with Etosha Pan, a seasonal wetland. For instance, Figure 5.3 showed a road segment which separates Fisher Pan from the main Etosha Pan. This road segment could exert negative impacts on the hydrological flow of water between Fisher's Pan and the Etosha Pan, which are naturally connected water bodies. On the other hand however, one of the benefits that arise from the existence of such road segments, for instance, is a pool of water at Fisher's Pan that often persist after the wet season, as the road segment act as an embankment. Unlike at Fisher's Pan, the Etosha Pan dries up much earlier, partly because of evaporation over a larger surface area with very shallow water. This water body thus benefits water birds, some of which often use the Pan for breeding purpose (Cunningham & Jankowitz, 2011).

Furthermore, the construction of road infrastructure has caused fragmentation of natural vegetation patches, translating them into a road density of 0.25 km per each square km area in the Park. Fragmentation of natural habitats is believed to pose a threat to the conservation of biodiversity (Karim & Main, 2009). For instance, with increasing traffic, as ENP experienced since the early 1990s, those roads could become barrier to wildlife movement in the Park as well as increased road mortality of small mammals (Seiler , 2001). The road traffic barrier effect has been observed in some other

ecosystems (Ament et al., 2008 ; Coffin, 2007 ; Karim & Main, 2009 and Spellerberg, 1998). Figure 6.1 demonstrate a scenario under which an increase in road density in a certain ecosystem could hinder the movement of wildlife, particularly big mammals. For ENP, a density of  $0.25 \text{ km} / \text{km}^2$  was found to be below the  $0.6 \text{ km}/\text{km}^2$  threshold proposed to guide to road construction in habitats dominated by big mammals (Forman & Alexander 1998). However, given that this threshold was developed in the USA wildland, its comparability to road infrastructure in semi-arid environments such as ENP is not well advanced. In addition, the presented road density for ENP might be an underestimate of the actual Park road density because it includes the vegetation patches found in the restricted access area which is not affected by tourist roads.



**Figure 6.1:** A hypothetical model illustrating how an increase in road density leads to landscape fragmentation, reduction in patches sizes and isolation of smaller patch. (a & b ) shows a relative low road density, (c & d) shows a relative high road density, while (e) shows extreme high road density. (Adopted from Seiler, 2001).

All unpaved tourist roads are made from locally mined gravel materials. This process has resulted in scars on the landscape known as gravel pits. Ideally, gravel mining in a protected area is not a desirable practice. The spatial distribution of these gravel pits

followed that of roads. This suggests that distance from the construction sites was valued as an important factor for locating gravel quarrying sites. As a result, there was a positive relationship between the road length (km) and number of gravel pits found in a certain vegetation patch. This therefore implies that if no intervention is taken on gravel quarrying in the Park, an increase and expansion of the road network will also yield an increased abundance of gravel pits on the landscape.

Significant differences in location of gravel pits from roads between the major vegetation communities could suggest that gravel mining in the open plains (Grassland) and some low vegetated communities was carried out at distant localities to minimize visual impacts with respect to visitors who would appreciate an aesthetic or near pristine environment. In other thicket vegetation communities, such as Shrubland and Bushveld, gravel pits are located closer to roads as a higher density of shrubs and trees can shield the visual impacts to visitors. Gravel mining in the vicinity of roads in woody vegetation communities helps limiting the scale and spatial extent of impacts. This is due to the fact that less access routes to quarrying sites would be required and that woody vegetation takes longer to recover, as compared to herbaceous layer.

On the other hand however, in many arid environments and other places, gravel pits play an important ecological role, making water available to wildlife longer after the wet season. This role was also recognized by Santoul et al., (2004) who highlighted the

importance of gravel pits for conserving water birds in south west France. Unfortunately, for ENP it is hypothesized that anthrax (*Bacillus anthracis*), which decimates plain ungulates and elephants in their numbers each year, tends to breed in those gravel pits (Berry, 1993 ; Lindeque, Nowell, Preisser, Brain, Turnbull, 1998 ; Herbert, Tomas, Geu, 2000). Gravel mining as a process itself has a consequential negative effect on the ecological integrity of a protected area. For instance, a pool of water found in these gravel pits could attract various browsers and grazers for watering, leading to a degradation of water point vegetation through overgrazing, over browsing and trampling on vegetation, thus turning them into piosphere systems. The ecological effects of those artificial water points in PAs are also well emphasized in (Pople & Page, 2002). Fortunately, this is not the case for ENP. This is because during the rainy season, water is available almost everywhere and as soon as the rains stop, gravel pits also dry up given the high evapo-tranpiration of up to 2800 mm per annum in the region. There are no systems of restoring these gravel pits in the Park, possibly because gravel mining is done without proper rehabilitation plans. As a result, most of the sites are colonized by *Pechuel-Loeschealeubuitziae* plants, a shrub species, which is well known for colonizing disturbed habitats.

### **6.3. Relationship between Distance from Roads and Adjacent Herbaceous Vegetation Communities**

In order to ascertain whether roads and traffic related activities has an effect on adjacent vegetation communities, the following changes to vegetation was anticipated: changes

in plant foliage cover, decreased vegetation productivity (vigour), changes in species composition and changes in biomass yield, at various localities from roads. This premise owes its origin to various roads and vehicular related effects on vegetation as reviewed in Chapter 2.

Results on herbaceous vegetation cover suggest that roadsides are dominated by a higher abundance of grass foliage cover as compared to herbs. This follows a general trend found in the Park whereby grass foliage cover is abundantly found as compared to herbs. Both grass and herb species foliage cover declined with increasing distance to roads, particularly at a distance of 5 m from roads. This can be related to the fact that a distance of 5 m from roads has a higher proximity to anthropogenic disturbances along roads such as off-road driving and increased soil compaction which could increase vegetation mortality through trampling. These results are supported by those of (Takahashi & Miyajima, 2010) who found a decrease in grass foliage cover with an increase in distance to roads on roads in Mount Norikura, central Japan. Takahashi & Miyajima (2010) and Makineci, Demir, Comez, & Yilmaz, (2007) further speculated that an increase in gravels and rocks at the edge of roads was responsible for the observed pattern because of the increase in soil compaction, which in turn decreased the ability of vegetation to grow. Also, Farrel & Milton (2006) noted that grading of roads for maintenance purpose was responsible for a decrease in the herbaceous cover of roadside vegetation. Results from this study also demonstrated that the variation in grass and herbs cover along roads was explained significantly by vegetation community types

than by distance from roads, of which a statistical significant difference was found between the major vegetation communities. Results on a lower abundance of herbaceous cover closer to roads, match with studies by (Angold, 1997 ; Cui et al., 2009).

A high number of herb species were recorded at a distance of 5 m from roads as compared to other localities. This pattern can be related to Farrel & Milton (2006) who found that disturbed roadside environment often attract weed species which are exotic in nature which adapt well to disturbed environments, of which most are frequently herbs. It is therefore likely that herbs species adapt to disturbed roadside area unlike grass species. The number of grass and herbs species were nevertheless not statistically significant between various distances from roads, thus rejecting the hypothesis that herbaceous species richness is related to distance from roads. Similarly, it was found that distance from roads was not related either to the presence or absence of herbaceous species along a distance gradient from roads, a pattern which is commonly found in savannah ecosystems. Other factors such as soil type, soil moisture content availability and overgrazing may be the main drivers behind the occurrence of bare patches. No statistical significant relationship was found between grass vigour and distance from roads. Nevertheless, a high frequent rating for low vigour was found at a distance of 5 m and 50 m from roads for both grass and herb species suggesting that there is an increase in vegetation vigour with distance from roads. This could be attributed to various vehicular related impacts such as trampling and highly disturbed environment closer to roads as discussed earlier. The herbs vegetation vigour was significantly related to

distance from roads as opposed to grass vegetation vigour, which imply that herbs are more vulnerable to road related pollution as compared to grass.

This study found a statistical significant relationship between distance from roads and herbaceous biomass yield, which suggest that roads and vehicular related effects have impacts on herbaceous biomass yield. However, biomass yield is further modified by what vegetation community type is found in the area. Generally, there was an increasing linear relationship between herbaceous biomass yield against distance from roads, mainly between 50 m and 200 m from roads. This suggests that distance from roads has an effect on herbaceous biomass, which could result from vehicular activities and road maintenance activities such as road grading. A high biomass yield correlated to a high abundance of herbs species particularly at a distance of 5 m. Such vegetation probable benefits from roads' water runoff, thus boasting biomass production. Although declined at 50 m, an increase in herbaceous biomass to nearly 2400 kg / ha at a distance of 200 m is evident that there is an increase in yield with distance from roads. The decline at 50 m from roads was rather unexpected. However, his study found that herbaceous biomass yield is mainly predicted by vegetation community type when compared to distance from roads.

#### **6.4. Relationship between Distance from Roads and Adjacent Woody Vegetation Communities**

Roadside woody vegetation are subjected to various disturbances. Disturbances such as clearing of roadside woody vegetation may be necessary in order to increase visibility for motorists, thus reducing animal-vehicle collision in most public road, including those found in PAs. But this happens with accompanying ecological impacts (Forman & Alexander, 1998). Although clearing of roadside vegetation is not common along tourist roads in ENP, the frequency of vehicles - wildlife along tourist roads is not documented to date. The findings from this study showed that shrub foliage cover increased with distance toward roads, particularly in the Bushveld and Woodland, while tree foliage cover increase with distance away from roads. These results were not statistically significant. Thus, it is speculated here that roads and vehicular activities has no effects on the growth of roadside vegetation. Our results are however contrary to those of Spooner, Lunt, Briggs, & Freudenberger (2004) who found that roadside areas are dominated by shrubs vegetation resulting from new recruitment after the disturbance of roadside areas as compared to distant localities which were less affected by landscape disturbances. Practically, during road construction phase, a piece of land which was cleared of woody vegetation extents further from the needed road path, resulting in what is referred to as road verge (Forman & Alexander, 1998). However, after construction, a regeneration process starts, increasing the abundance of shrub species along roads again. The disparities in (Spooner et al., 2004) findings and results from this study is perhaps

due to the fact that his study was conducted along national roads outside PAs, of which roadside vegetation were possibly managed differently during road construction. For instance, in a PAs, clearing of vegetation for road construction in a protected area is likely to be carried out with caution in order to minimize the ecological damage, considering the sensitivity of landscape.

Moreover, the change in shrubs and trees height as well as the abundance and distribution of those was not related to distance from the roads. Instead, the presence or absence of those woody species was related to the ecological vegetation community type in which they are found, which could further be determined by biophysical factors such as soil nutrient and rainfall pattern, among others (Sohrabi & Habashi, 2011).

Although no direct statistical significant relationship was found between woody vegetation vigour and distance from roads, results from the field showed that vegetation vigour was frequently rated as low at distance of 5 m compared to other localities, which evidently suggest that woody plants closer to roads are affected by road related pollution particularly dust from unpaved roads. The effect of road dust on adjacent vegetation was reviewed by Farmer (1993) who found that road dust may affect plant photosynthesis, respiration, transpiration and allow the penetration of toxic gaseous pollutants, thus decreasing productivity. However, this study could not statistically confirm that

vegetation vigour in the study area was related to distance from roads as hypothesized earlier.

### **6.5. The Relationship between Distance from Roads and The Concentration of Roadside Soil Chemical Properties**

In order to ascertain whether roads have an effect on the concentration of soil chemical properties, this study expected either decrease or an increase in soil chemical properties with increasing distance from roads. The soil chemical concentration was also related to other factors such as texture, vegetation community structure as well as seasonal changes.

Results showed that there was a significant increase in soil cation exchange capacity, exchange calcium and carbonate content with distance to roads. This suggests that the gravel materials used for construction of roads were mined from soil rich in calcium carbonate. This pattern is speculated here to have its origin from the Etosha limestone, which then accumulated in roadside soil. Indeed, calcrete that is usually sought after for roads construction in Etosha and elsewhere in Namibia is an accumulation of calcium carbonate and other alkaline minerals in the soil of layer.

This pattern was also observed by Barbosa, Feunandes, Carneiro, Junior (2010) who found that uses of limestone gravel, rich in calcium was responsible for increased calcium and carbonate rich soil along unpaved roads in Serra do Cipo´ Grassland,

Brazil. An increase in the concentration of soil pH, electrical conductivity, exchange magnesium, exchange sodium, with distance to road, though not statistical significant, suggest that traffic related emission could be a contributing factor.

However, given that distance from roads share nearly less than 1 % of the variance with the concentration of most of those soil properties, this study rejects the earlier premise that roads and vehicular traffic activities has a significant effect on the concentration of roadside soil in the ENP, with the exemption of soil cation exchange capacity, exchange calcium and carbonate concentration. However, these results are contrary to those of Park et al. (2010) who found a statistical significant relationship between distances from roads and the concentration of soil chemical variables such as carbon (C), nitrogen (N), organic matter (OM), magnesium (Mg), soil cation exchange capacity (CEC), calcium (C) and soil pH along urban roadside environment in Ohio, USA. A disparity which can also be attributed to the biophysical differences between the two environments as well as cumulative effects and traffic volume found.

Therefore this study uncovered no conclusive evidence to suggest that roads and vehicular related activates has an effect on the concentration of various soil chemical properties in roadside environment of the ENP. Instead, the concentration volume of those is attributed to underlying parent material. This is evident from the fact that approximately 80 % of the selected soil chemical properties was significantly related to soil texture as compared to distance from roads.

Overall, results from this study support the premise set in Casagrandi & Rinaldi (2002) tourism based SES conceptual model on the relationship between tourism development and quality of the natural environment. This study has demonstrated that expansion of road infrastructure to cater for tourism and recreational activities will yield a negative effect on quality of the environment such as habitat fragmentation, gravel quarrying and the disruption of wildlife habitats.

## CHAPTER 7

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### 7. CONCLUSIONS AND RECOMMENDATIONS

#### 7.1. Conclusions

ENP, one of the largest game sanctuary and a major tourist hotspot in Namibia was investigated for ecological impacts of tourism in this study. The main focus of this study was to investigate how tourism infrastructure development affects the ecological integrity of the ENP. To that effect, the integration of spatial data, fieldwork and laboratory analysis was analysed to achieve the study's objectives.

Evidence acquired suggests that the construction of tourist roads in the ENP has fragmented ecosystems in the tourism access area, with approximately 50 % of impact concentrated on the Grassland. This resulted in a road density of nearly 0.25 km / km<sup>2</sup> in the entire ENP.. Similarly, road construction and maintenance, as a process which is done with locally mined gravel materials, has resulted in a total of approximately 187 un-rehabilitated gravel pits on the landscape, of which nearly half are found on the Grassland. Some of these gravel pits, featuring as scars on the landscape, have so far turned into seasonal water points, which are believed to be breeding sites for anthrax, an endemic disease which severely affect wildlife in the ENP on an annual basis. Other old gravel pits have been turned into dumpsites (see Figure 5.6). Moreover, results showed that herbaceous vegetation communities are more vulnerable to road disturbance in

comparison to the woody vegetation, with a trend toward lower foliage cover and decreased biomass yield closer to roads. Results showed further that there was no conclusive evidence to suggest that roads and vehicular traffic related activities have caused a significant modification of roadside soil chemical properties. This, however came with an exemption of soil carbonate content, Cation exchange capacity and exchange calcium which were highly concentrated in roadside soil. The concentration of most selected soil chemical properties were found related to the underlying soil texture and geology.

## **7.2. Recommendation for Management**

Firstly, caution need to be taken when developing road infrastructure in the Park. For instance, various ecological zones based on factors such as ecological sensitivity, endemism, species richness can help Park managers to spatially align road infrastructure in the Park to minimize the short term and long term cumulative ecological effect emanating from roads. Moreover gravel mining should be done in a manner that does not compromise the ecological integrity of the Park. For instance, resources and rehabilitation plans need to be established prior to gravel excavation in the Park. Those plans need to be approved by relevant authorities, preceded by proper environmental impact assessments. This will help to ensure that gravel pits created for road construction are rehabilitated thereafter. The rehabilitation plans could involve activities such as landscaping and replacement of top soil, which carry the seed bank. This top soil can be sourced from similar substrates in order to ensure that vegetation re-growing is similar to their predecessor. This will allow native species to regenerate from the area

after they are rehabilitated, rather than turning some them (gravel pits) of those into dumping sites. This will help mitigate impacts caused during the construction phase. However, caution needs to be taken in order to prevent the introduction of new gravel pits when sourcing top soil. Secondly, this study suggest that there is a high abundance of tourist roads on the Grassland, therefore other vegetation communities could be considered, should there be a need to extend the road network in the Park.

### **7.3. Recommendation for further Investigation**

The assessment of how tourism impacts on the ecological integrity of the ENP is relatively unexploited, particularly with focus on infrastructure development. Therefore, this study suggests the following areas for further investigation: assess how tourist roads and traffic movement affect the movement of big mammals in the Park (i) assess factors leading to road mortality of small mammals, and the movement of ground dwelling invertebrates , (ii) and investigate whether tourist roads contribute to the spread of invasive species in the Park as it is happening in other ecosystems. Moreover, further studies could (iii) investigate effects of tourist roads on the hydrological systems, and how they impacts on vegetation, particularly on the Grassland and small saline Pans. Such studies could yield results that could help understand how tourist roads affect the landscape of the ENP and other PAs in Namibia and elsewhere.

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**APPENDICES**

## APPENDIX A

Universal transvers Mercator (UTM) GPS location of sampling sites

<b>Vegetation units</b>	<b>X-UTM</b>	<b>Y-UTM</b>	<b>Site Number</b>
Bushveld	618351.50	7872996.00	1
Bushveld	656851.50	7893996.00	2
Bushveld	657851.50	7893996.00	3
Bushveld	656851.50	7891496.00	4
Grassland	562851.50	7892996.00	5
Grassland	633851.50	7890496.00	6
Grassland	565851.50	7890496.00	7
Grassland	586851.50	7892996.00	8
Grassland	556351.50	7896996.00	9
Grassland	596851.50	7878996.00	10
Grassland	610351.50	7881496.00	11
Grassland	593351.50	7886996.00	12
Grassland	565851.50	7885996.00	13

Grassland	592851.50	7888996.00	14
Grassland	601851.50	7883996.00	15
Grassland	703351.50	7923496.00	16
Grassland	692851.50	7913496.00	17
Grassland	686851.50	7910996.00	18
Grassland	700851.50	7915996.00	19
Grassland	601851.50	7884996.00	20
Grassland	709851.50	7927996.00	21
Shrubland	700351.50	7930996.00	22
Shrubland	692351.50	7943996.00	23
Woodland	611351.50	7875496.00	24
Woodland	566851.50	7889996.00	25
Woodland	612851.50	7881996.00	26
Woodland	603351.50	7867996.00	27
Woodland	673851.50	7893496.00	28
Woodland	673351.50	7898996.00	29
Woodland	665851.50	7898996.00	30

**APPENDIX B:**

Field observation sheet used for data collection

**OBSERVATION FORM**

Date: \_\_\_\_\_ Observer(s): \_\_\_\_\_

Site No: \_\_\_\_\_ Sub-site: \_\_\_\_\_ Pre-Vegn Class: \_\_\_\_\_ Current Vegn Class: \_\_\_\_\_

Distance from the road: \_\_\_\_\_ Road Width: \_\_\_\_\_ Level of road utilization: \_\_\_\_\_

Easting \_\_\_\_\_ Northing \_\_\_\_\_ Topography: \_\_\_\_\_ Slope Steepness \_\_\_\_\_

**VEGETATION ASSESSMENT**

<b>Vegetation Structure</b>				<b>Vegetation vigor</b>		<b>Vegn Density</b>		<b>Abundance</b>	<b>No of Species</b>
<b>Dominant Grass</b>		<b>Height</b>		<b>Abundance</b>		<b>Others 1:</b> <b>Others 2:</b>			
<b>Dominant Herbs</b>		<b>Height</b>		<b>Abundance</b>		<b>Others 1:</b> <b>Others 2:</b>			
<b>Dominant Shrubs</b>		<b>Height</b>		<b>Abundance</b>		<b>Others 1:</b> <b>Others 2:</b>			
<b>Dominant</b>		<b>Height</b>		<b>Abundance</b>		<b>Others 1:</b>			

<b>Trees</b>						<b>Others 2:</b>			
<b>DPM Reading</b>					<b>Road footprint</b>				
<b>Invasive Type 1</b>				<b>Abundance</b>	<b>Invasive Type 2</b>		<b>Abundance</b>		
<b>Bush encroachment</b>					<b>Fire footprint</b>				
<b>Level of range utilization</b>					<b>Signs of plant utilization</b>				

**SOIL AND GROUND COVER**

<b>Soil Type</b>		<b>Ground Cover</b>		<b>Stoniness</b>	
<b>Erosion</b>		<b>Soil sample taken?</b>		<b>Depth of soils sample</b>	

**Remarks:**

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