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GEOMORPHIC IMPACTS OF *LOXODONTA AFRICANA* (AFRICAN ELEPHANTS) IN TEMBE ELEPHANT PARK

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DECLARATION

I, the undersigned herby declare that this dissertation, submitted for the degree of Master of Arts in the Department of Geography, Geoinformatics and Meteorology at the University of Pretoria, is my own and original work, except where acknowledged. This work has not been submitted for a degree at any other tertiary academic institution.

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When you are privileged to view the earth from afar, when you can hold out your thumb and cover it with your thumbnail, you realize that we are really, all of us around the World, crewmembers on the space station Earth. Of all the accomplishments of technology, perhaps the most significant one was the picture of the Earth over the lunar horizon. If nothing else, it should impress our fellow man with the absolute fact that our environment is bounded, that our resources are limited, and that our life support system is a closed cycle. And of course, when this space station Earth is viewed from 240 000 miles away, only its beauty, its minuteness, and its isolation in the blackness of space, are apparent. A traveller from some far planet would not know that the size of the crew is already too large and threatening to expand, that the breathing system is rapidly becoming polluted, and that the water supply is in danger of contamination with everything from DDT to raw sewage. The only real recourse is for each of us to realize that the elements we have are not inexhaustible. We're all in the same spaceship. (Frank Borman, Astronaut) (Clark, 2004;IV).

Humankind is standing between a dwelling heap of usable natural resources and increasing heap of unusable natural recourses that have been abused and neglected in the landscape and it is up to us to change this fact. To change we need to understand how the environment functions as a system so that management of the natural environment may be improved to save our precious earth (Clarke, 2004).

ABSTRACT

Humans are modifying animal populations, indirectly accelerating or reducing the geomorphic alterations caused by animals. Species have been monitored and studied with focus on domesticated animals but little research has been undertaken on wild animals. This study analyses the geomorphic impact of elephants on Tembe Elephant Park, so that the changes they cause to the landscape may be quantified. To conduct this research four sites were chosen: an area where elephants had been excluded for twenty-five years, where excluded for five years, where elephants exist at present and where elephants mud wallow. Three of the four study sites were classed as sand forest (twenty-five-years exclusion, five-years exclusion and where elephants exist) and were analysed and compared to determine the similarities and differences in climate, microclimate, vegetation and the soil's physical and chemical properties. The wallow site was not compared to any other study site, but was observed and mapped to quantify the geomorphic impact of elephants wallowing. When the sand forest sites were compared the climate, vegetation type and soil were found to be similar. Where elephants were present: the vegetation was inconsistent in basil cover, canopy height, structure and class. Soils were more compacted with a low infiltration rate, higher temperature, lower soil moisture, higher pH and a lower electric conductivity and air relative humidity was the highest. Where elephants have been excluded for twenty-five years, the opposite trends arose from the data analysis. The vegetation was consistent in basil cover, canopy height, structure and class, and the soils were less compacted with a high infiltration rate, low temperature, higher soil moisture, lower pH and a higher electric conductivity. The microclimate showed a trend where the air relative humidity was the lowest. At the elephant wallow site data showed that the wallows were in general circular in shape, 52.5m^3 of soil was removed per month for the last nine months and the surface area of the wallows increased by 165.5m^2 per month for nine months from April to December 2008. All the results from this study show that the elephant activity in Tembe Elephant Park has geomorphic consequences. From the results, it is possible to conclude that the geomorphic impacts of elephants on Tembe Elephant Park are contributing to a nutrient cycle shift in the sand forest biome, as they change aspects of the vegetation, microclimate, soil and landscape, which are the foundation of the cycle.

Key words: Zoogeomorphology, Elephants, Geomorphology, Tembe Elephant Park, Sand Forest, Maputaland, pH, Electric conductivity, Wallow, Soil.

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INTRODUCTION

1.1 BACKGROUND

On the earth's surface there is an interaction and relationship between vegetation, aspect, slope, climate, soil properties, and the geomorphic role of animals and humans in the development of the landscape. Interactions between abiotic and biotic elements are highly complex at every geographic location but are simplified in Figure 1.1. With increasing demands of sustainable agriculture and tourism, it has become imperative to understand these interactions as it could help recognise human influences on the environment and avoid loss of land (Evans, 1998; Hall & Lamont, 2003). Living organisms are part of the surface of the earth but geomorphologists and other scientists who study the physical and chemical properties of the living, have rarely studied their geomorphic impact (Govers & Poesen, 1998; Hall *et al.*, 1999; Corenblit *et al.*, 2007). This study will develop from understanding the linkages between the earth's functions to identify and quantify some geomorphic and environmental alterations caused by African elephants in Tembe Elephant Park (TEP).

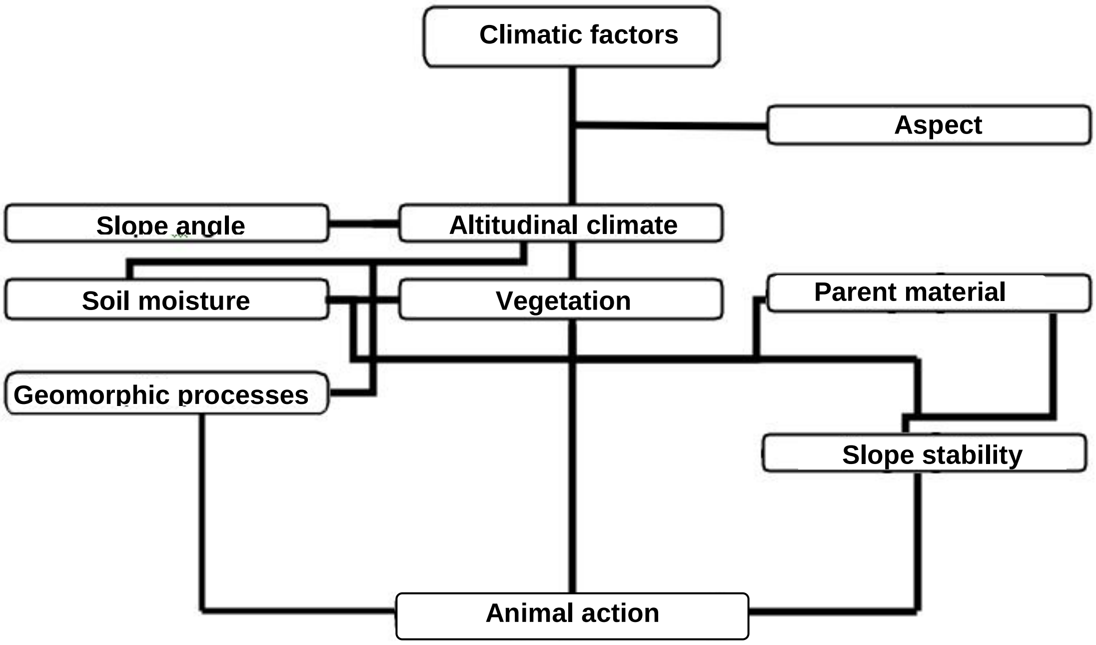

Figure 1.1 **Generalised climatic considerations for abiotic and biotic interactions**
(Modified from Hall & Lamont, 2003:222)

A combination of animals' role-playing as geomorphic agents and their actions being recorded by geomorphology, has initiated the field of zoo-geomorphology (the study of how animals change or alter the landscape). Prior to discovering the interaction between animals and the landscape, the progression to study this under geomorphology has been slow. As a consequence, the geomorphic impact of animals has been considered in other disciplines, making zoo-geomorphology indirectly the reason for multidisciplinary studies (Renschler *et al*., 2006). There are many different disciplines studying the geomorphic impact of animals, causing the fundamental focus (geomorphology) to be neglected and understanding relationships between abiotic and biotic elements on the earth function as a system to be incomplete. Consequently, in order to understand the importance of the geomorphic role of animals, it is imperative to understand the progression of geomorphology to date.

1.2 A BRIEF HISTORY OF GEOMORPHOLOGY IN A SOUTH AFRICAN CONTEXT

Geologists and geographers devised the term geomorphology in the late 19th century but the idea of studying the landscape has existed for over 2000 years. Several commonly termed geomorphic themes have been analysed since the beginning of this period, indicating geomorphology's existence before the term "geomorphology" was derived. As time progressed and the 20th century dawned, geomorphology became dominated by positivist scientific approaches causing the discipline to join the quantitative revolution.

King and Davis (Beckedahl *et al.,* 2002) were leaders in qualitative analysis under geomorphology as they used this analysis to describe and classify slopes created and the processes involved. The interest in slopes by King and Davis began a trend in geomorphic research, which initiated the study of landscape systems theories and which in turn led to the processes response to change being analysed. Thus the interest in landscape thresholds' concepts and mechanism approaches were initiated. Growth in geomorphology led to the first international congress on geomorphology (Manchester, England, 1987), which resulted in the first international association of geomorphologists. South Africa followed the geomorphological evolution with their own congress of the South African Association of Geomorphologists in Umtata in 1988 (Beckedahl *et al.*, 2002).

South Africa has been an interesting area to study geomorphology with its political and social diversity, diverse landscape and unusual development patterns which change the landscape. Before the 1940s geographers and geologists described and studied the landscape in South Africa, creating an interest in geomorphology. The new growing field of geomorphology was therefore based on the relevant studies prior to the 1940's therefore influencing geomorphology today such as King's studies (Beckedahl *et al.,* 2002) on macro scale landforms. Trends that arose in geomorphology through sub-divisions of geomorphology (Applied Geomorphology, Tectonic and Macro Geomorphology, Geomorphic Theory, Process Studies, Hydro Geomorphology, Erosion and Degradation, Coastal Geomorphology, Karst, Slopes, Weathering, Climatic Geomorphology) in South Africa were related to climatic conditions on slopes, fluvial systems, erosion and sediment transportation, coastal processes and periglacial phenomena.

Surveys on the progression of geomorphology were conducted from 1966 to 2000 and showed an increase in applied geomorphology studies and a decrease in theoretical research (Beckedahl *et al.*, 2002). This development in geomorphology caused the discipline to become more mathematically inclined with chemistry and statistics dominating. After 1985 it became apparent that climatic geomorphology was the new development within this sub-division of geomorphology. It focused on environmental change, arid and semi region geomorphology and periglacial research. All the new changes and shifts of geomorphological focus resulted in previous areas of study within geomorphology to be neglected, such as long and medium term research on human-environmental interaction (Beckedahl *et al.*, 2002, Smith & Leader-Williams, 2006). Humans, however, are not the only species that should be studied intently in geomorphology as many other living organisms interact with abiotic systems making them geomorphic agents. Living organisms as geomorphic agents have been mostly neglected, and consequently it is vital to study their impact on the landscape (Hall *et al.*, 1999).

1.3 LINKING GEOMORPHOLOGY AND LIVING ORGANISMS

Volcanic activities, wind, water, oceanic currents, glaciations and plate tectonics all change the landscape but so do living organisms. The earth is an open system with many elements that may alter its state and shape. Theoretically geomorphology examines current or resent processes (natural, unnatural, animate or inanimate) operating on the earth's surface that erode, transport and deposit material to create landforms (Butler, 1995; Jones *et al.,* 1997). Living organisms use landforms as homes (habitat) and these ranges where the organisms live together are known as ecosystems. Once an organism has chosen a home, the organism alters it or changes the habitat.

These changes may result in removal of vegetation, excavating, trampling, deposition of soil material, changing chemical composition of soil (thus changing its properties) and transporting material, which in effect alters the landscape, directly or indirectly (Jones *et al.,* 1997; Haynes & Fraser, 1998; Butler, 2006). There is thus a close link between landscape, habitat, inhabitants and ecosystems. Geomorphology, ecology, zoology, botany and many other sciences are all integrated to explain the surface of the earth (Systems Theory) (Corenblit *et al*., 2007; Viles *et al*., 2008).

1.4 LIVING ORGANISMS IN THE LANDSCAPE

Living organisms, which are landscape modifiers, have been and are a part of the surface of the earth. In the past, geomorphologists and other scientists who studied physical and chemical properties of the earth have been reluctant to study geomorphic impacts of living organisms (Govers & Poesen, 1998; Hall *et al*., 1999; Corenblit *et al*., 2007). In recent times natural scientists have directed their focus on humans modifying animal populations (by removal or reduction of indigenous populations, by introducing domestic species to areas and by restricting populations with fences or other unnatural restriction agents), thus the landscape alteration they cause is perceived as being unnatural (Butler, 2006). Agriculture and soil science in particular have realised the importance of studying the geomorphic impact of animals on the environment causing a shift in research topics in those disciplines (with particular interest in over-utilisation of area, for example overgrazing) (Hall *et al*., 1999).

1.5 SPECIES NEGLECTED AS GEOMORPHIC AGENTS

Through the progression of Geomorphology, geomorphologists did not recognise living organisms as contributing to landscape alterations. In pre-World War II (pre 1940), geomorphology and physical geography textbooks were written focusing on: landscape processes, diastrophic forces of folding and faulting, internal and surface volcanism, weathering, soil development, gravity and mass movement, works of running water (surface and sub surface), works of glacial ice and ground ice, wind, waves and current action, excluding the possibility that living organisms influenced the processes.

After World War II scientists shifted focus by studying the micro-scale changes of the landscape but geomorphologists did not follow the growing trend. Butler (1995) suggests that geomorphologists did not research geomorphic impact of living organisms as they are trained in physical sciences and not in biological sciences, they are foreign to concepts displaying geomorphic impact of organisms, they are sceptical of using literature and evidence to substantiate their argument outside of the earth sciences and they see bio-geomorphology or zoo-geomorphology as 'marginal' and not fundamental to the alteration of the landscape. This trend continued until the mid 1970's where publications began to appear in geomorphology and physical geography journals on living organisms being geomorphic agents, however, the articles were few.

Other academic disciplines recognised animals as geomorphic agents and explored the geomorphic impact of living organisms as geomorphologists did, but their focus was on ecological and ecological-behavioural impacts rather than true geomorphologic impacts (Butler & Malanson, 1994). Living organisms were not a focal point in geomorphology but other areas of physical geography made them the focus such as biogeography (a natural science that studies living organisms [plants and animals], spatial distribution, vicariance and species adaptation and transformation in geographical space, studied organisms) (Meadows & Hill, 2002).

1.6 THE HISTORY OF BIOGEOGRAPHY IN THIS CONTEXT: GEOMORPHIC VALUABLE SPECIES

Biogeography is broad and its research focuses on species distribution, species history, ecosystems, island biogeography, vicariance, conservation, environmental management and climate change (Meadows & Hill, 2002). However, species that are perfect models to study within geomorphology as they have geomorphic impact are overlooked for their geomorphic value as biogeographers focus on their areas of expertise and not on function of the organism on and in the landscape. For example, Edwards *et al*. (2004) models examples of landscape changers and recognised the potential for studies of earthworms within biogeography. He reiterated that the distribution patterning, their modifications and adoptions could reveal the secrets of the continents if it were to be studied in biogeography. He went on to explain that Darwin identified that earthworms were found globally and have adapted and altered their features to suite their environments (Butler & Malanson, 1994).

Earthworms are missing from volcanic mid-oceanic islands (suggesting they did not swim to the islands). Uplifted carbonate platforms caused a 'barrier' that earthworms would have had difficulty crossing salt water even if they could adhere to salt water. They were however found on some oceanic islands. All this research on earthworms suggests that they are indicators of continental movement or a split of continents and play a role in species spatial patterning, vicariance, Island Biogeography and species history (Edwards *et al*., 2004). Earthworms, like other invertebrates, are therefore a vital topic to study within biogeography and geomorphology but have been neglected for their geomorphic value. But fundamentally any living organism (vegetation, invertebrates and vertebrates) has the potential to change the landscape on a micro or macro scale.

1.7 LANDSCAPE ALTERING ABILITY OF VEGETATION

Vegetation growing in the soil has the ability to change the physical and chemical structure of the landscape. Throughout the history of science, researchers have considered vegetation's role in the landscape. Since the 1950's, geomorphologists altered their viewpoints on vegetation and began to quantify and study the changes in detail on hill slopes, but until 2000 the research had been multi directional (Viles *et al*., 2008; Marstone, 2010). The movement of understanding the geomorphic role of vegetation on the landscape began with landscape ecologists and botanists investigating how vegetation has responded to landscape change and not the changes vegetation has made on the landscape (how vegetation has responded to mass movement, hill slope features, landscape processes, rock debris and materials, elevation, aspect, gradient and slope angle, rock type, snow avalanches, land surface erosion and edaphically futures).

After approximately 2000, geomorphologists recognised that the research conducted on the geomorphic impacts of vegetation was insubstantial, causing a shift to increase research in that field (60 percent of all articles on the geomorphic impact of vegetation were written after 2000). This shift brought about individual geomorphologies studying the geomorphic role of vegetation on many different landscape types and places (fluvial systems, mass movement, sedimentation and hill slope dynamics and other geomorphic processes) which has enhanced geomorphologists understanding of the interconnectivity between the landscape and vegetation (Marstone, 2010).

Many researchers aided in determining the geomorphic impact of vegetation. Carey (2006) recorded the ability, physically, vegetation growing in the soil causes the surface of the soil to become rougher (the roughness of the soil increases the infiltration potential of the soil as runoff is slower). Vegetation needs water to survive and as a result large amounts of vegetation growing in one area can have an effect on the water table causing a change in the physical properties of the soil. Lui *et al.* (2003) and Jacobsen (1987) analysed the subsurface changes of vegetation and found that the vegetation's intricate root system binds soil together causing the potential for erosion to be reduced and the water retention capacity to increase, thereby increasing percolation (increased pore spaces in the soil) and reducing runoff (Jacobsen, 1987; Liu *et al.*, 2003; Castellano & Valone, 2007).

Bochet *et al.* (1999) studied how topsoil islands within patchy Mediterranean vegetation in South East Spain is modified according to vegetation abundance, and found that if there is an increase of vegetation there is an increase in organic matter, a decrease in bulk density and an increase in infiltration. Frank and Groffman (1998) researched the carbon and nitrogen relationship in the soil between ungulates and the landscape in Yellow Stone National Park and discovered that soil moisture and temperature is influenced by vegetation (mulch, surface and subsurface vegetation). The study also showed that the rate of mineralisation is influenced by vegetation and the nitrogen and carbon cycles in the soil are driven by vegetation. If vegetation abundance is changed, mineralisation, carbon and nitrogen in the soil are altered (Frank & Groffman, 1998). In duplex soils, a high vegetation cover increases infiltration and causes subsurface erosion (soil pipes) (Bryan & Jones, 1997).

Chemically, in areas that are predominantly rock, the vegetation that grows on the rocky areas has the potential to extract minerals such as potassium and organic acids causing chemical weathering (Landeweert *et al.*, 2001). Chemical changes and pH in the soil are influenced by vegetation growing and organic matter (reduction of vegetation into the soil) decomposing in the soil (Li & Rengel, 2007). Hiernaux *et al.* (1999) discovered that when grazing is low in the sandy soils of Sahelian Rangelands, the acidity in the soils increases. Lewkowicz stated: “sands, partly containing small amounts of lignite and xylite fragments, are characterized by a highly acidic soil solution, higher organic carbon content, and higher electrical conductivity” (Lewkowicz, 2008:1977).

Therefore, the pH of the soil is related to electrical conductivity and organic matter content (vegetation) and as the pH changes, electrical conductivity is altered. Heirnaux *et al.* (1999) analysed the rate of vegetation cycling in the soil (from vegetation to organic matter to minerals) and found that soil texture influenced the rate of vegetation breakdown into the soil (the courser the soil, the faster the organic matter cycles through the soil). Research on the geomorphic impact of vegetation is an area where geomorphology could be strengthened as the geomorphic consequences of vegetation (indigenous or exotic) is evident but their exact ability to change the landscape (naturally or unnaturally as do animals) is understudied.

1.8 LANDSCAPE ALTERING ABILITY OF ANIMALS

Butler (1995) defines different actions animals undertake to describe the geomorphic processes, alterations and consequences animals have on the surface of the earth. Butler (1995) categorised all living biota into invertebrates, ectothermic vertebrates (consisting largely of birds) and mammals. In Figure 1.2, Butler (2006) illustrates how animal activities cause changes to landscapes through burrowing, tunnelling, denning, building, trampling, wallowing, geophagy, osteophagy, damming. The most remarkable outcome of Figure 1.2 displays that activity undertaken by animals result in changing the landscape, soils and drainage basins. If animal (vertebrates and invertebrates) and human activities geomorphic consequences are compared, it is evident that all geomorphic alterations ultimately have an influence on drainage systems and basins (Butler, 1995; Butler, 2006). These factors make it vital to understand the geomorphic impact of all living organisms to gain a holistic idea of how the landscape can be altered, naturally and unnaturally.

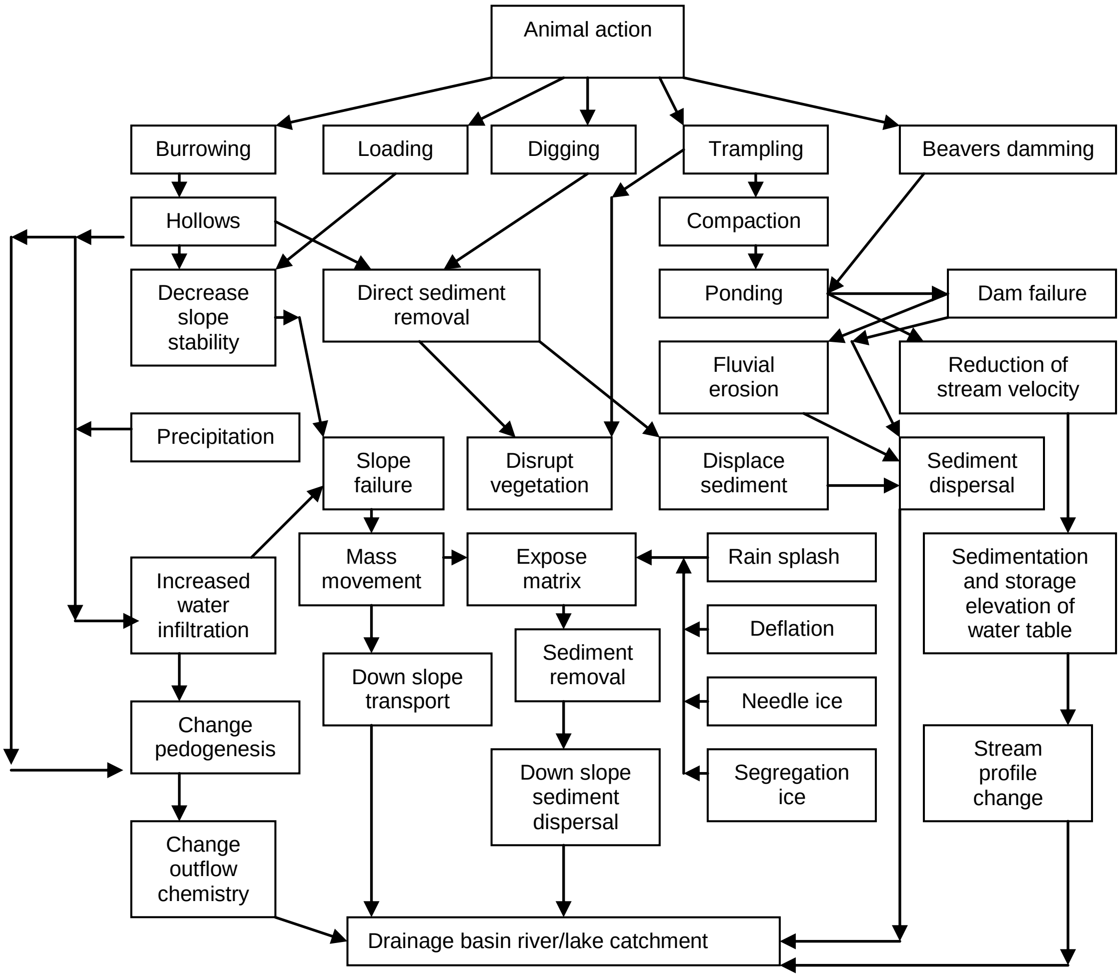

Figure 1.2 **The influence of animal activates on the drainage basins and hill slopes** (Butler, 2006:450)

1.9 LANDSCAPE ALTERING ABILITY OF INVERTEBRATES

Invertebrates have become pioneers in the formation of zoo-geomorphology as a sub-discipline research field. Terrestrial (land living) and aquatic invertebrates have been proven to have a dramatic landscape altering capability. Terrestrial invertebrates, such as earthworms, termites and ants, have a macro geomorphic altering capability but species such as arachnids, crustaceans and insects seem to have a micro geomorphic impact on the landscape. The changes species make to landscapes are dependent on the way in which species find food, live and reproduce. In a species with high geomorphic consequences the alterations may become dramatic and change the surface extensively. Geomorphic alteration caused by invertebrates have been more frequently studied than the impacts of vertebrates under a multitude of disciplines but there is still a great deal unknown about the exact rates of geomorphic change caused by animals, including invertebrates (Butler, 1995).

Many ideas and research initiatives have been generated about earthworms due to their geomorphologic and biogeographic value. This has initiated earthworm studies under geomorphology, specifically their casting processes (Haynes & Fraser, 1998). Haynes and Fraser (1998) studied earthworms in a laboratory and monitored the changes and rate of soil alteration cause by the earthworm casting process. This study showed that the chemical composition of the soil was altered. Gabet *et al.* (2003) extended the research on earthworms by studying the effect of bioturbation and found that earthworms altered soil particle size and texture through the casting process (Gabet *et al.*, 2003). These multicellular invertebrates are not the only species changing the landscape. Butler (1995) describes the role of termites and ants in the alteration of the landscape as they create tunnels and build mounds or hills.

Holdo (2002) studied how woody plants are damaged by African elephants in relation to leaf nutrients in western Zimbabwe and found that termites play a role in landscape alterations. Holdo (2002) also observed that termites in the Karoo are clay experts and increase organic matter into the soil, which has caused a concentration of clay and organics around and in their mounds making the soils more fertile for plant growth. Klaus *et al.* (1998) researched geophagy of large mammals at natural licks in the rain forest of the Dzanga National Park, Central African Republic and found that termites move clay and nutrients from the deep subsurface to the topsoil, making the soil more fertile and mineral rich. Gabet *et al.* (2003) studied the effects of bioturbation on soil processes and sediment transportation and found that termites and ants increase air, increase organic matter (in the subsurface) and change the biochemistry of the soil.

1.10 LANDSCAPE ALTERING ABILITY OF VERTEBRATES

Mammals and ectothermic vertebrates play a significant role in changing the landscape, making it imperative to understand their geomorphic impacts on the landscape. Ectothermic vertebrates (avies, birds and reptiles) alter the landscape through lithophagy (eating clasts), gastroliths (digesting clasts), clast transfer (scat deposit), transporting material, building, burrowing, removing vegetation (expose soils) and nesting. Mammals change the landscape through, geophagy (eating soil), lithophage digging, feeding, trampling, burrowing, wallowing and building (Butler, 1995).

1.10.1 Ecothermic vertebrates (largely birds and reptiles)

Ecothermic vertebrates are animal such as birds and reptiles, which in this section are broken up into lithophagy (ingest rock material), gastophagy (this species requires rock material to digest food) and clast transferors (use clasts to digest food then excreta the clasts) (Butler, 1995*).*

1.10.1.1 Lithophagy, gastrophagy and clast transferors

Lithophagous, gastrophagous and clast transferors are closely linked as animals that eat clasts use them in their digestion process and eventually transfer and deposit the clasts in their scat. These three processes are common in large avies and reptiles such as ostriches and crocodiles. The species ingests the pebbles or clasts to aid in their digestion. Ostriches (*Struthionidae*) (Erasmus & Erasmus, 1997) and crocodiles (Dempsey, 2009) use the stones to grind the food in the stomach, as the stomach acids are too weak to conduct that task. This action causes clasts from the earth to be removed, resulting in a change to the landscape. In addition to this, the clasts are eroded through mechanical and chemical weathering in the stomach of the species. Once these clasts become too small to aid in digesting food they are deposited in the species scat (Erasmus & Erasmus, 1997; Dempsey, 2009). Dempsey (2009) discovered that many stone tools found were not stone tools at all; they were chemically and mechanically weathered stones from the belly of a crocodile. This discovery challenged previously held archaeological theories (Fowler *et al*., 2004).

1.10.1.2 Nest building material transporters and burrowing

Birds are experts at building nests to breed by transporting geomorphic materials into burrow holes banks. Maclean (1992) describes swallows (*Hirundinidae*) using mud to build nests and burrow holes into river banks to create nests (depending on swallow species). Ostriches scrape topsoil away from a site on the ground to build nests, while penguins (*Spheniscidae*) gather clasts or dig shallow burrows to nest and gannets (*Sulidae*) and boobies nest in burrows on the ground or in hollows on cliffs. All these families of avies have a geomorphic impact on landscapes through their nest building habits but so do reptiles (Butler, 1995).

Lizards, snakes, crocodiles, tortoises, terrapins and turtles all burrow holes to live in and lay eggs. In many reptile species, the individual digs a burrow then eggs are laid and covered with soil. Soil temperature then determines the sex of the hatchlings (Branch, 2007). This illustrates that reptiles, in addition to avies, excavate or transport material and burrow to build nests to breed, which changes the landscape. Mammals like birds and reptiles thus alter the landscape but for different reasons (Butler, 1995).

1.10.2 Mammals

Mammals are animals, which have a backbone, produce live young and lactate. These animals have the ability to change the landscape by ingesting the soil, grazing, digging, burrowing, trampling, wallowing and building (Butler, 1995).

1.10.2.1 Geophagy "earth eating"

Eating soil from selected sites across the globe has been observed since the 1960s. Much of the research conducted on geophagy has been related to the reasons for mammals eating the soil and where the favoured sites are but not on how the actions impact on the landscape (Klaus *et al*.,1998). Klaus *et al*. (1998) identified from past research conducted on geophagy that many omnivorous and herbivorous species eat or lick (place where animals lick soil is termed as a soil lick) soil for several reasons:

(1) A source of nutrients and minerals generally deficient in forage.

(2) To maintain the equilibrium between the major minerals in the body of the herbivore mammals after forage change in the early wet season, dry season or in early spring.

(3) Minerals in a soil lick may satisfy the seasonal demands of lactation, of calving, of growing of antlers and of growing of bones, horns or tusks.

(4) Minerals in a soil lick may help against faecal loss of minerals during times of diarrhoea.

(5) Clay minerals in a soil lick may help against lactic acidosis, they may absorb tannins and alkaloids, bacteria and toxins, and they may help to counteract gastrointestinal ailments.

(Klaus *et al.,* 1998:830).

Once all the reasons for animals being earth eaters was identified Klaus *et al.* (1998), researched geological features associated with lick sites and identified chemical and physical properties at licks in Dzanga National Park in the Central African Republic. His study identified that the average mineral lick sites in the rainforests were 12900m^2 in size, they were situated exclusively in areas of dolerite intrusions and there was high quantities of sodium, potassium, calcium, magnesium, phosphorous, manganese and clay in the soil. Mammals gather soil to eat by licking and digging up soil and, therefore, feeding is also responsible for other landscape or soil alterations (Butler, 1995).

1.10.2.2 Grazing

All families of mammals have their own way of feeding which may or may not have geomorphic impacts. Skinner and Smithers (1990) described how animals feed and suggested that antelopes are separated into two groups, namely browsers (eat off trees and shrubs) and grazers (eating grass); both groups have a geomorphic impact; and some grazers cut the grass off and some pull it out. Hiernaux *et al*. (1999) considered the effect of livestock grazing on physical and chemical properties of the soil in Sahelian rangelands in Nigeria and discovered that in areas of heavy grazing pressure, the acidity of soil and the organic matter content was much lower than the nine-year exclusion zone from intense mammal activity thus suggesting that grazing pressure from livestock changes soil chemistry. Many wild game grazers have been proved to have the same effect as the livestock in the Sahelian rangelands. Researchers have been observing the geomorphic changes of grazers and have found when areas have been overgrazed the erosion potential of an area increases as top soil is removed through grazing and the underlying soils are exposed to wind, water and rain (Butler, 1995; Evens, 2005a). It is clear that grazers feeding habits have geomorphic consequences. In addition to geophagy and grazers, other animals such as porcupines and mongooses dig and burrow to find bulbs, fungi and roots to eat and those actions also have geomorphic consequences (Butler, 1995).

1.10.2.3 Digging and burrowing

Digging and burrowing is direct sediment displacement. Mammals undertake digging to create burrows for them to live in and excavate roots and legumes to feed on. Skinner and Smithers (1990) described the habitats, breeding, behaviour and physiology of all mammals in Southern Africa. Skinner and Smithers (1990) described hyena’s (brown and spotted), ant bears, ant wolves, bat-eared foxes, rodents, hairs and mongooses as digging dens or burrows to breed and survive. Bragg *et al.* (2005) showed how the Cape porcupine turned over soil and effected ecosystem processes thereby linking the geomorphic impact of the Cape porcupine to their behaviour. In this study Bragg *et al.* (2005) firstly described how porcupines dig up roots and legumes to eat and, secondly, how the species live in rock crevices that they burrowed. As a result of their digging and burrowing in Nieuwoudtville on the Bokkeveld Plateau in the Northern Cape province of South Africa, Bragg *et al.* (2005) found that 0.34% of the surface per hectare was disturbed, $1.6m^3ha^{-1}yr^{-1}$ soil was dispersed, and across the landscape, 160-3463 holes were dug per ha, and $2.2m^3$ per ha per year of soil was displaced. It is evident that digging and burrowing change landscapes through excavation but animals' mere existence on the earth causes trampling which also has geomorphic consequences.

1.10.2.4 Trampling and wallowing

Trampling (walking, crawling, running and standing) and wallowing (animals rolling in muddy areas to rid themselves of parasites and pests) activities contribute to landscape change (Butler, 1995). Mammals trampling or wallowing in an area causes soils to become compacted, water repellent, have a low infiltration rate and a high erosion potential (Castellano & Valone, 2007). Boelhouwers and Scheepers (2004) studied the role of antelope trampling on scarp erosion in a hyper-arid environment on the Skeleton coast of Namibia and found that the animal paths along the scarp slopes caused scarp recess and initiated cutback of the slope causing an increase of slope processes. Bennett (1999) quantified the geomorphic impact of *Marsupialia: Macropodidea* in Queensland, Australia, and found that geomorphic impact of trampling is directly related to the foot size, weight of the species and number of species. In this study Bennett (1999:365) stated: "medium or large macropods are comparable to those of galloping ungulates". The findings support the commonly held belief in Australia that introducing grazing animals may cause greater mechanical disruption of soil surfaces than indigenous game, which may lead to increased rate of soil erosion. Wallowing studies have identified that animals with no fur (pigs, warthogs, rhinos, elephants and buffalo) wallow to keep themselves cool and parasite free in Southern Africa (Skinner & Smithers, 1990). Examples and research that has been conducted in Southern Africa on wallowing habits seems to be focused on elephants, as they are the most dramatic wallowers (see section 1.12.2).

1.10.2.5 Building

In Southern Africa there are few examples of mammals 'building', but in North America a mammal that alters river systems and watercourses significantly, namely beavers, has been studied (Butler, 1995). Butler (1995) described that dam building activity undertaken by this species causes a significant sediment build-up behind the dam, which enables ponds (small pools of water) to form. The sediment build-up gathered organic matter, which settled on the base of the watercourse where the pond was formed, which caused higher organic matter content in the river sediment where beavers existed than where they do not. It was thus determined that the beavers play a significant role in altering fluvial systems by changing the hydraulics of a watercourse (Butler & Malanson, 1994; Butler, 1995; Butler & Malanson, 2005).

Just as beavers change fluvial systems, so does every animal and mammal on the earth's surface have some geomorphic impact through one of their daily activities (Butler, 1995). The focal point of this research is the geomorphic impact of elephants on Tembe Elephant Park (TEP) making it vital to consider all the potential geomorphic changes as a result of elephant activity.

1.11 LANDSCAPE ALTERING ABILITY OF ELEPHANTS

Over the last 50 years the impact elephants have on the environment has been observed and recorded with the primary focus being on vegetation. Kerley *et al*. (1999) studied the effects that browsing of succulent plants by both elephants and goats have on the soils in Addo Elephant Park, South Africa. This study showed that when elephant population increased, runoff increased (a consequence of soil compaction and water repellent soils) and Johnson *et al*. (1999) and Lombard *et al*. (2001) acknowledged these findings as they noticed the same changes to the landscape from elephants. Laws (1970) recorded how elephants alter the landscape, Butler (2006) described the geomorphic impact of elephants' wallows, Cumming and Cumming (2003) quantified theoretical trampling impacts of elephants and Chamaillé-Jammes *et al*. (2007) evaluated the 'piosphere' effect of elephants on surrounding waterholes (in Hwange National Park, Zimbabwe) using vegetation cover as the indicator.

One recognises that quantifying elephant impact on the earth is important as overpopulation of any species may have severe negative effects both ecologically and botanically, as elephant impacts on vegetation is prominently recognised; but the geomorphic impact of these mammals has never been quantified. The geomorphic impacts of elephants are equally important to understanding the impact on the vegetation, as together, a more holistic deduction can be made on the rate of environmental changes caused by elephants.

1.12 IMPACTS OF ELEPHANTS ON THE LANDSCAPE

The geomorphic alterations associated with elephants are known and accepted but the quantification of their changes to the landscape remain largely unknown (Butler, 1995). Elephants are responsible for geomorphic alterations through macro (viable changes to the landscape) and micro (no visible changes such as physical and chemical property changes of soils in the landscape) geomorphic change uprooting vegetation, pushing over trees, using trees and rocks as rubbing posts, creating paths, geophagy, dust bathing and wallowing (Flint & Bond, 1968; Weir, 1969; Laws 1970; Pullan, 1979; Skinner & Smithers, 1990; Butler, 1995).

1.12.1 Uprooting and displacing vegetation

Elephants are mixed bulk grazers (eat grass, trees and shrubs in large quantities and are not selective in what they eat) and remove vegetation from the soil or off the host plant or pushing trees over causing them to be uprooted (Guldemound & Van Aarde, 2007). When vegetation is removed from the ground or trees are pushed over, the soil is disturbed, exposed and vulnerable to weathering and erosion (exposed soils are dried out by the sun and become water repellent, therefore runoff increases and infiltration is reduced; the roughness of the surface is, in addition, reduced which accelerates runoff, and the soils are exposed to wind erosion) (Skinner & Smithers, 1990; Butler, 1995).

1.12.2 Wallowing and dust bathing

Elephants dust bathe and wallow to keep them cool, protected from the sun and to reduce the parasites. The geomorphic impacts of wallowing cause clays to be compacted through trampling and deflation through the elephants removing the soil. Compaction seals the earth's surface, which causes impervious zones of depressions forming ponds. Flint and Bond (1968) estimated that an individual elephant displaced $0.31m^3$ of sediment every time they wallow. In Kenya, Thomas (1988) measured elephant wallows that range in size between $0.45km^2$ and $0.49\ km^2$ and were on average 200m in size in Ayeni, Zimbabwe (Flint & Bond, 1968; Butler, 1995). Deflation contributes to the size and extent of wallows but largely, trampling, drinking and geophagy cause pans to form (Flint & Bond 1968; Skinner & Smithers, 1990; Butler, 1995). Once an elephant has wallowed, it carries the soil with it and deposits it while conducting daily activities (Flint & Bond, 1968; Thomas 1988; Skinner & Smithers, 1990).

1.12.3 Path creation

Laws (1970) and Skinner and Smithers (1990) explained that elephants, like humans, make paths to walk on through the bush. These paths are created by elephants walking in single file on the same routes throughout their lives (elephants live to approximately 60 years) causing the soils on paths to be highly compacted and susceptible to erosion as soils become impervious, encouraging water to pool on the path, thus increasing run off along paths (Laws, 1970; Skinner & Smithers 1990).

1.12.4 Rubbing posts

In an Elephant's attempt to reduce the parasites on its body, it uses rocks or trees to scratch or rub itself on. As a result the mud and dust, which has been collected on the animal's body, become attached to the rubbing post or deposited in the area of the rubbing post. This causes a build up of sediment in the general area and on the object that the animal has rubbed itself (Skinner & Smithers, 1990). In 1972 Weir recorded elephants using termite mounds as rubbing posts in Botswana and this rubbing up against termite mounds broke up the mounds, causing a sediment disturbance in the area and an exposure of the subsurface (Pullan, 1979).

1.12.5 Geophagy (ingesting soils)

Since the 1960s scientists have been recording elephants eating soil to obtain nutrients and minerals. Flint and Bond (1968) described how elephants have a preference for saline rich soils. In 1971 the reserve in the Tsavo National Park, Kenya experienced a decrease in termite mounds as the elephant population increased. Pullan (1979) observed that the elephants were eating the soils of termite mounds in addition to using mounds as rubbing posts (Pullan, 1979; Thomas 1988). Klaus *et al.* (1998) amalgamated all the reasons for elephants eating soil and identified the physical and chemical changes in the soil as a result of geophagy.

On the earth's surface interactions and relationships between vegetation, aspect, slope, climate, soil properties, and the geomorphic role of animals and humans in the development of the landscape, portraying the need to study and understand these changes within geomorphology. The geomorphic role of animals is becoming increasingly important as a spiralling global population creates increased pressure on natural resources. This makes the 'managing of nature' vital for the survival of all biotic systems (Hooke, 2000).

1.13 AIM OF THIS STUDY

Tembe Elephant Park (TEP) is an area where Ezemvelo KZN Wildlife is managing biodiversity and coordinating increased pressure from outside communities seeking resources, and carrying an overpopulation of the greatest geomorphic changers, elephants. The management on TEP therefore needs to understand the landscape altering abilities of elephants so that management of the area may be efficient through a greater understanding of the dynamics of the species on TEP (Matthews, 2005).

The aim of this study is to quantify the general geomorphic alterations caused by elephants by first understanding and quantifying macro geomorphic changes, namely elephant wallows through mapping and determining the rate of sediment removal from the wallows, and second, by measuring and interpreting the micro geomorphic changes (soil physical and chemical properties) in the sand forests as a result of elephant activity. These objectives can only be achieved if site environmental differences are also determined, namely climate, topography, soil and vegetation with the focused controlling factor being elephants so that the overall geomorphic role of elephants can be interpreted and thus incorporated into management decisions on TEP.

Thus the main purpose of this study was to quantify geomorphic and associated environmental impacts of African Elephants to the landscape of Tembe Elephant Park. The specific objectives were:

- To determine the rate of geomorphic alteration (macro geomorphic change) at the water points by mapping and measuring elephant wallows;
- To analyse the micro environments in sand forest (micro climate, air temperature and humidity and rainfall, vegetation and soil (soil type and soil micro climate) in the sand forest study areas with elephants being one variation between the sites;
- To identify soil property changes in sand forest (physical and chemical) caused by elephants.

Chapter 2

MAPUTALAND AND THE STUDY AREA

2.1 INTRODUCTION

In the last 20 years, scientists have discovered evidence of humans modifying animal populations (removing of indigenous populations, introducing domestic species to areas and restricting populations with fences or other human made structures [fences, railway lines, dams and roads] restriction agents) thereby causing an unnatural landscape alteration (Butler, 1995; Butler, 2006; Mackey *et al., 2*006; Post *et al.*, 2007). The result is that humans, as primary geomorphic and environmental agent, are indirectly accelerating the geomorphic impact of animals in restricted areas. If animal activities and geomorphic impacts were studied in retrospect to the impacts of humans on the land (example: game number management or carrying capacities), the landscape changes by animals might be understood and predicted more accurately. Consequently, protected wildlife areas and game populations would be better managed, improve preservation, protect areas and increase biodiversity (Van Schalkwyk, 1997; Hooke, 2000; Zhaoa *et al*., 2005). The focus of this research is on geomorphic modification caused by animals with specific attention to elephants on Tembe Elephant Park (TEP), as this species can cause the most dramatic alterations to the landscape (Butler, 1995).

2.2 STUDY AREA

The importance of studying the impact of elephants on Tembe Elephant Park (TEP) is imperative to the area as a whole (Maputaland) because it has the most endangered sub tropical forests in the world (sand forest), is classified as a global centre of endemnism (the area has an exceptionally high number of unique species of fauna and flora) and is ranked by the International Union for Conservation of Nature (IUCN) as one of eight biodiversity hotspots in the world. There are 2500 species of vascular plants (250 are endemic), 472 bird species, one species and 14 subspecies of mammals, 23 reptile species, three frog species, eight fresh water fish species and five bird species that are all endemic to the area. Three fundamental factors that rank high in this area for their uniqueness and endemic status are sand forest, elephants (subspecies) and suni (Matthews *et al.,* 2001; Matthews, 2005).

2.2.1 Status of sand forest in Maputaland

Sand forest, unique to Maputaland, comprises the western sand forest, sand forest thickets, eastern sand forest and licuati sand forest with its restricted ancient coastal dunes. This unique biome is home to many unique plants, such as *Dialium schlechteri, Cleistanthus schlechteri, Hymenocardia ulmoides, Newtonia hildebrantii, Balanites maughamii, Pteleopsis myrtifolia* and *Ptaeroxylon obliquum* and the shrubs include *Drypetes arguta, Croton pseudopulchellus, Cola greenwayi* and *Psydrax fragrantissima.* It is also home to animal species which has caused the forest to be declared as the Maputaland centre of endemics taxa. As a result of the uniqueness and rarity of the sand forest, this biome has been identified as a priority to conserve by Ezemvelo KZN Wildlife (EKZNW) (Matthews, 2005; Herd, 2009). The status of the sand forest competes with the status of the elephants in Maputaland as they are ranked as one of the top priority amongst mammal species in South Africa.

2.2.2 History of elephants in Maputaland

The Maputaland elephants have been recorded roaming the Eastern coastal plains from the White Umfolozi River in the South to Maputo Special Reserve in Mozambique in the north since the 1840's (Harris, 1852; Baldwin, 1895, Bulpin, 1966; Matthews, 2005). At present the elephant population is isolated and split up into Tembe Elephant Park (TEP), Futi Corridor and Maputo Special Reserve. These elephants, no longer free roaming, are bound in by electrical fences and socio-political barriers imposed by human activities. In the transition from free roaming elephants to captive elephants, the species experienced 30 years of extremely high poaching and harassment during the Mozambique civil war, causing the elephants to take refuge in the areas with the lowest human populations and activity and greatest vegetation cover. Although the elephants took refuge away from people (late 1980's to early 1990's during the Mozambique civil war), there was still a substantial amount of elephant-human conflict in Northern KwaZulu-Natal (Matthews, 2005).

2.2.3 Inhabitants

In the 1770's and 1780's the leader of Thongaland (the original name of Maputaland), Chief Mabhudu, was responsible for the region being called Maputaland. The Thonga (meaning 'dawn' in Zulu) tribe lived in the South of Mozambique and the northern reaches of KwaZulu-Natal (Mukuzi River in the South, Pongola River in the West, Maputo in the North and the Indian Ocean in the East). The Tembe tribe acquired their name from the founder of the clan, Mthembu, "who migrated from the Kalanga to settle near Maputo around 1554" (Matthews, 2005:11). Tembe people were seen by the Zulu people as slaves and different from the other nationalities in South Africa because they were not from the Nguni or Sotho origin. Portuguese sailors were the first Europeans who made contact with the Tembe people and called the area 'Terra de Fumo' due to the dramatic wild fires in the region.

Although the distribution of the Tembe clan was known throughout the region, when international boarders were designated, the clan was redistributed and split into two regions, namely Ingwavuma in South Africa and Matutuine district in Mozambique. Displacement and isolation of the Tembe's increased human elephant conflict placing natural resources under strain, as they could not keep cattle (the area is not suitable) and agriculture and subsistence farming was not an option due to the poor soils in the region (Kloppers, 2001; Matthews, 2005). Over utilisation and pressure on the natural resources in the area was extensive, therefore the people of the area were concerned and prioritised the preservation of biodiversity. These concerns for the biodiversity and the elephant conflicts with the people in the area initiated the establishment of TEP (Matthews, 2005).

2.2.4 Proclamation of Tembe Elephant Park

In 1983, TEP (30013 ha), on the Boundary of Mozambique and KwaZulu-Natal (South Africa) with its unique biomes and endemic species, was proclaimed a National Park to preserve the rich biodiversity, to keep people living in the area safe from elephants and to protect the last of the Maputaland elephants. In the establishment of the park, fences were erected on the perimeters of the park (the first fences erected in the area). This unique, species-diverse park now attracts many tourists and visitors to the area because of its natural wealth, untouched beauty and culture and historical significance, but if the ecosystem is altered negatively all this may be jeopardised (Matthews *et al.*, 2001).

2.2.5 Reasons to study the geomorphic impact of elephants on Tembe Elephant Park (TEP)

If the earth's surface is altered to a point where abiotic factors on the land are adjusted to cause the destruction of biotic systems, parks will lose their species richness and unique biodiversity, causing the primary reason for a park's existence to be affected (Matthews, 2005). TEP would be a model area where an unbalanced ecosystem could have extensive consequences. If the biodiversity and ecology of the park is reduced, the local community will be adversely affected as they rely on the Park for economic stability based on tourists and visitors to the area. All naturally defined wildlife areas are examples of ecologically balanced zones (Matthews *et al.*, 2001). They should be assessed for zoogeomorphic changes and comparisons made, to understand the extent of geomorphic change caused by animals on TEP.

The preservation of the beauty and economic wealth of the park is a key reason for studying the geomorphic impact of elephants in the area, as the fences on the outskirts of the park have now placed limits on animals, including elephants, ranges and their habitats. In the Kruger National Park, Grainger *et al*. (2005) studied the landscape heterogeneity and how elephant use available space and discovered that the extent of the elephant population is related to the amount of accessible water and resource availability, but limits on water and resources determine elephant numbers and territory.

All the species and biomes are equally important to preserve, if one species, such as the elephants, overpopulates the area, it may alter habitats and change the landscape. Thus if the species balance becomes unstable, the landscape alteration from the instability may have negative effects on endemic species in the area (Butler, 2006). TEP is known for its biodiversity, species-richness and African elephants, therefore, to evaluate the impact the elephants have on the area, an understanding of the potential changes they have on the park must be established. One of the foundations to understanding the overall effects of the elephants on the park is to interpret their landscape changing ability.

2.2.6 Acquiring accurate data

For an accurate assessment of the geomorphic impacts of elephants in TEP, the area must be compared to areas with the same biotic and abiotic elements and cultural history. The area chosen in this study, as a comparison to TEP, is Tshanini Game Reserve (Tshanini) (25 years without elephants) situated to the South of TEP. This area was declared as a Game Reserve in 2000 but was managed by the Manquakulane tribe prior to Wildlands Trust's assistance with the management of Tshanini. The management of the area has simulated a Game Reserve since the establishment of TEP stating that TEP and Tshanini have similar histories and due to their locations, the Game reserves have similar ecological, geological, topographical and climatic patterns (Matthews *et al.*, 2001; Gaugris *et al.*, 2004). The only difference between Tshanini and TEP is that at present there are no elephants, rhinos, lions or buffalos on Tshanini. The two protected areas (Tshanini and TEP) had the same inhabitants and frequency of inhabitants until the final erection of the fence on TEP in 1989.

In this study a comparison will be drawn between some geomorphic and environmental characteristic changes as a result of African elephant frequency change across Tshanini and TEP (Tshanini having the lowest frequency of African elephants [25 year since African elephants roamed on the area] at present and TEP the highest). Knowledge of the geomorphic differences between the two areas may directly enable an accurate quantification to be made on the geomorphic impacts of elephants on the Tembe.

With the knowledge gained from this study, advancements in zoogeomorphology could be made in addition to improving elephant population management. If the objectives of this study are achieved, a more holistic park management may be achieved and zoogeomorphology may be incorporated into more animal population management strategies. If the geomorphic consequences of elephants can be quantified and used in conjunction with carrying capacity models, elephant impacts may be better understood and managed.

2.3 LOCALITY AND LAYOUT

TEP and Tshanini are both situated in the north of KwaZulu-Natal (Maputaland). TEP is 30013ha in extent with its northern boundary being the international border between South African and Mozambique, southern boundary (main tar road between Jozini and KwaNgwanase) eastern boundary (a security road) and western boundary (Mbangweni Corridor) (Matthews *et al.*, 2001; Van Eeden, 2005;). Tshanini is 2420 ha south of TEP (Gaugris *et al.*, 2004) (Figure 2.1).

In 1983 TEP Elephant Park was proclaimed (Gazette Notice Number 73 of 1983) and re-proclaimed in 1993 as a park (Gazette Notice Number 11 of 1993) by the local people, under Chief Mazimba Tembe. The park, therefore, belongs to the Tembe tribe but is managed by EKZNW. People that lived within the park boundaries were relocated to areas outside TEP in the proclamation but have been given rights to access some of the natural resources until the present (Matthews, 2005). TEP fences were erected on the Eastern, Western and Southern boundaries in 1983. When poaching of elephants from the North increased, a fence was erected on the Northern boundary in 1989. These fences fragmented elephant population in Maputaland and concentrated elephants on TEP (Morley, 2005).

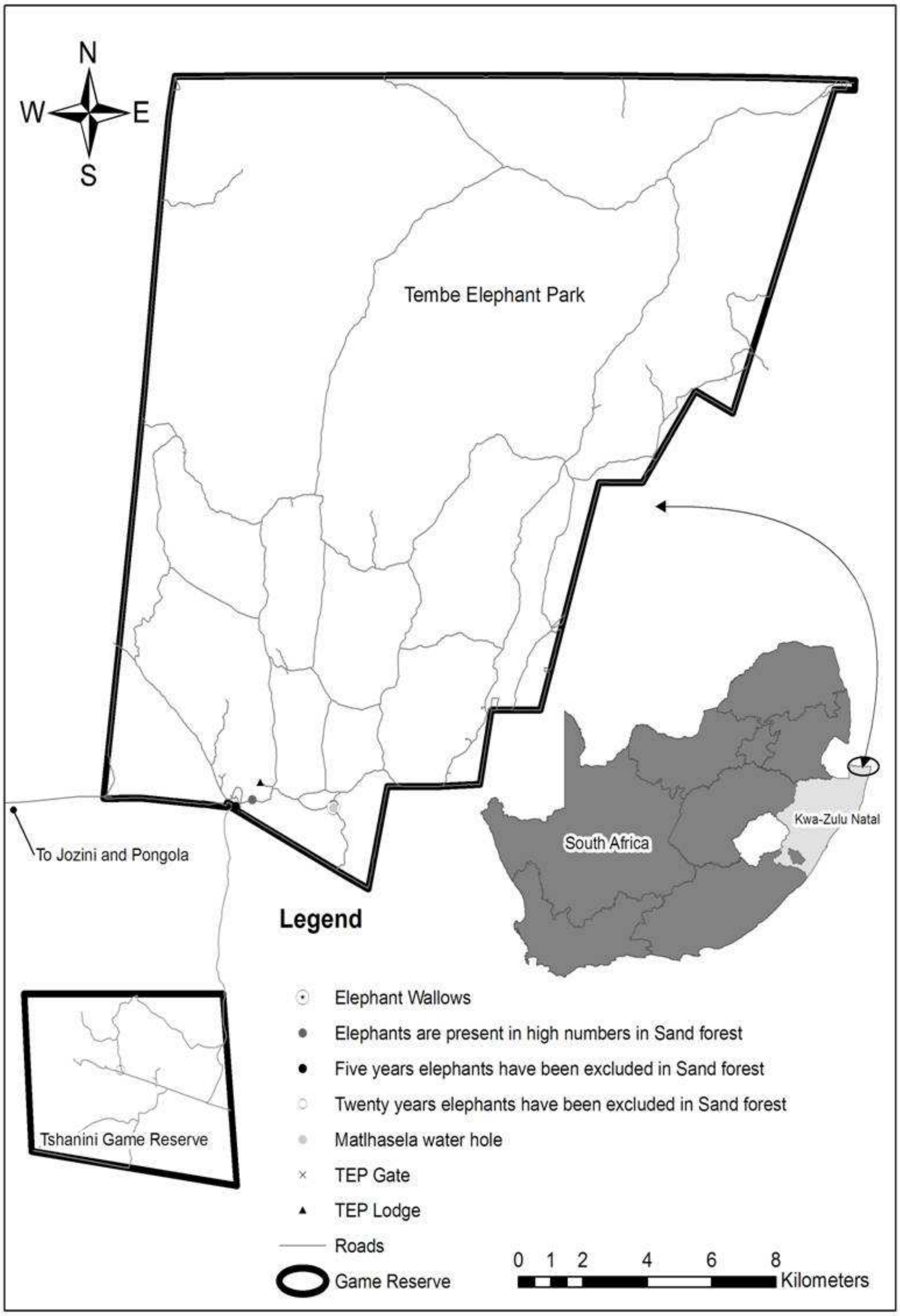

Figure 2.1 **Location map of the study area (WGS1984 datum projection)** (Data obtained from the University of Pretoria Cartographic unit). The wallows are located at Matlhasela water hole and the closest towns to TEP are Ingwavuma (approximately 70km West and Emanguzi 50km East)

These areas had little human interference prior to the parks declaration, making biological alterations and alterations of physical environments at present the result of reserve management. The primary reason for a low concentration of people on TEP was that there was and is little ground water available (Matthews *et al.*, 2001; Gaugris *et al.*, 2004; Van Eeden, 2005; Matthews, 2005).

2.4 GEOLOGY

TEP and Tshanini are situated on a Mesozoic and Cenozoic geological area that can be followed south and north along the Mozambican Coastal Plain (Matthews, 2005). The base material of the area is predominantly marine siltstone, which is a part of the St Lucia Formation (Figure 2.2). These deposits are not exposed on TEP as the siltstone is covered with the Maputaland Group (Uloa and Umkwelane Formations) and dune sands cover the Maputaland group (Figure 2.2 and Figure 2.3). The parent material of the dune sand is the Maputaland Group and are fossilised, making them the oldest dunes dating back to the early Pleistocene two million years ago). The youngest date back to late Pleistocene (30 000–10 000 years old), making them, therefore, some of the youngest marine formations in southern Africa (Matthews *et al.*, 2001; Gaugris *et al.*, 2004; Matthews, 2005).

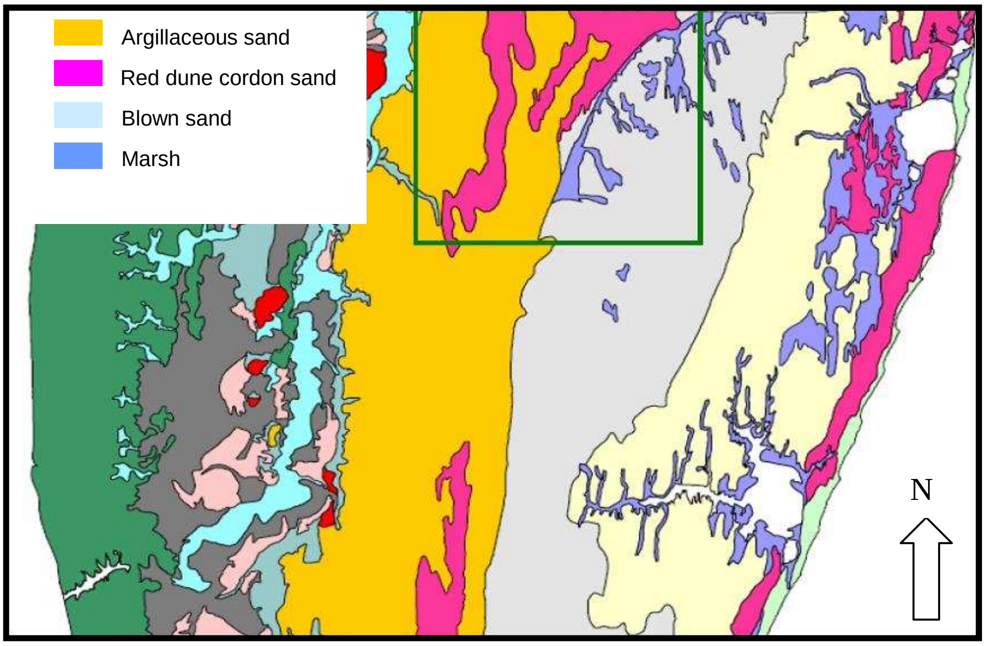

Figure 2.2 Schematic representation of the distribution of the geology on TEP (green block) and surrounding areas (Ezemvelo KZN Wildlife, 2007:43)

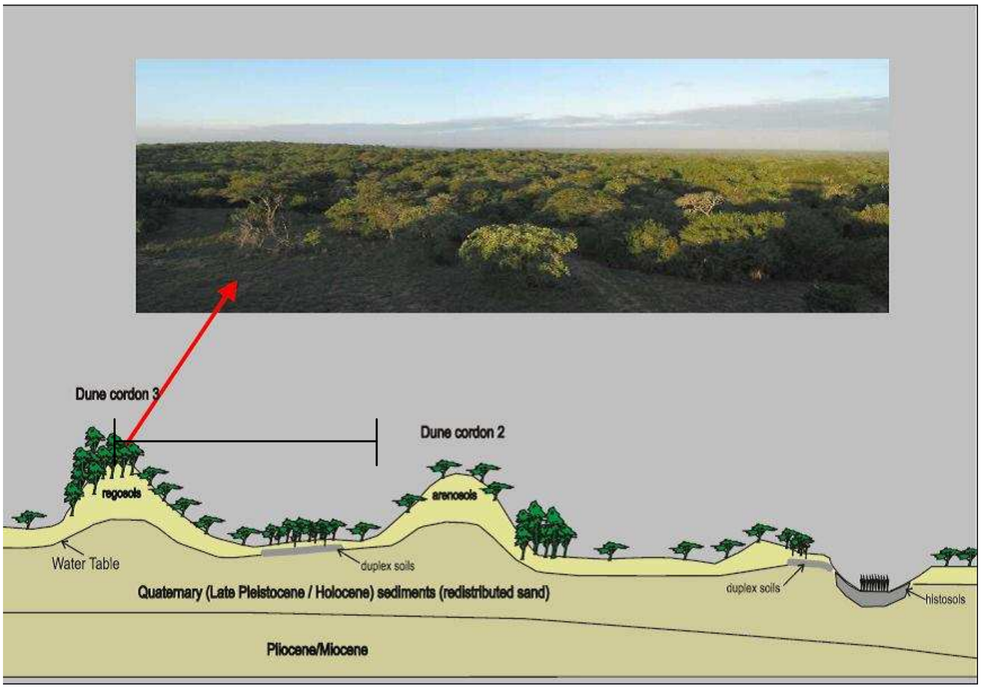

Figure 2.3 **Geology of the Northern *KwaZulu-Natal*** (WGS1984 datum projection) (Ezemvelo KZN Wildlife, 2007:48). The photo represents approximately one km illustrated on this figure.

2.5 TOPOGRAPHY

TEP and Tshanini are situated on flat low-level coastal plains, which were formed subsequently to the break-up of Gondwanaland. Since this event, sea levels have risen and fallen and increased deposition of marine sands and silts and accelerated erosion on the East African coastline (Matthews, 2005). The oldest rocks in the Maputaland region are found in the Lebombo Mountains to the west (Gaugris *et al.,* 2004; Matthews, 2005; Van Eeden, 2005) dating back to the Jurassic period. General geology of the area regresses in age towards the Indian Ocean to the east (Gaugris *et al.,* 2004; Matthews, 2005; Van Eeden, 2005). Quaternary sands, redistributed sands and alluvium from river systems, which cover the Tertiary, Cretaceous and Karoo formations, cover the Maputaland coastal plains (Morley, 2005). These sands have formed two fossilised linear dunes with dune streets running in a north-south direction on TEP and Tshanini. These undulated, relatively flat sand ridges rise to a maximum height of 129m above sea level, with the peak of the ridges being amongst some of the highest areas on the Maputaland coastal plains (Matthews *et al.,* 2001). The soils consist of low clay content, making it difficult for perennial pans to form as clay has a low permeability. The only natural ground water in the areas prior to the establishment of the TEP was the Muzi swamps and the water in the swamps is not suitable for humans, animals or plants as it is saline (0.5–5%). With the establishment of TEP, artificial water holes were made in areas with higher clay contents. These water holes were important to supply water to game in the park, as animals were now fenced in and as a result the game movement was restricted (Matthews *et al.*, 2001; Gaugris *et al.*, 2004).

2.6 SOILS

Soils on TEP and Tshanini are similar with the inter-dune depressions and dunes, being identified as inorganic (Matthews, 2005). The soils consist mainly of Quartz (silica oxide forming more than 94% of the soil content) with concentrations of ilmenite, rutile and zircon minerals and a thin organically rich A-horizon with a sandy subsurface (Matthews *et al.,* 2001). Clay minerals are minimal (less than 5%) within the matrix of the soil but are present as a result of weathered labile minerals. Soils that dominate this area are well drained, have a high base status and are classed as being Hutton or Clovelly, with inter-dune depressions being well drained, yellow Clovelly or grey Fernwood soils (Matthews *et al*., 2001; Fourie *et al*., 2002; Gaugris *et al*., 2004).

Soils in sand forest are more water repellent and have a lower permeability than other vegetation types at the surface but as depth increases, permeability increases rapidly. Soil water retention capacity increases with depth but only to 70cm deep when saturation point is reached and thus the infiltration rate remains constant. Fourie *et al.* (2002) showed that the impermeability of soil was as a result of high organic matter present in the A-horizon and that soils on TEP are coarse to medium grained sandy soil.

2.7 ECOLOGY

The northern extent of Maputaland consists of level planes of sandy soil, covered by open and closed woodlands with a patchy distribution of tall sand forests and grasslands. The vegetation of TEP and Tshanini was classified by Moll and White in the 1970's as an area with pallaeo sand bushveld, sand forest, swamplands, palmveld, Muzi swamp and grasslands, and categorised and displayed in a chart to interconnect soils and vegetation (Figure 2.4) (Matthews *et al.*, 2001; Gaugris *et al.*, 2004). Cowling and Hilton-Taylor (1994) described Maputaland as a biodiversity 'hot spot' as there is high species diversity and a high number of near endemic species inhabiting the area.

Matthews *et al*. (2001) identified eight major plant communities and their interconnectivity with soil (sand forest, closed woodland on clay soils, woodland on deep sandy areas, grassland associated with sand forest, grassland on clay rich soils, grassland associated with swamp/marsh/pan areas, aquatic vegetation of marshes/pans and reed-bed of the Muzi Swamps, in TEP) (Matthews, 2005; Morley, 2005). In this research the focus is on sand forest. Venturi *et al.* (2004) calculated the total land cover type in Maputaland, vegetation patches and dominant plant species and found that the sand forest covered 301Km^2 and was distributed in 55 patches with the average forest 0.6-33.1km^2 on the dune crests and high lying sandy soils (Matthews, 2005; Morley, 2005).

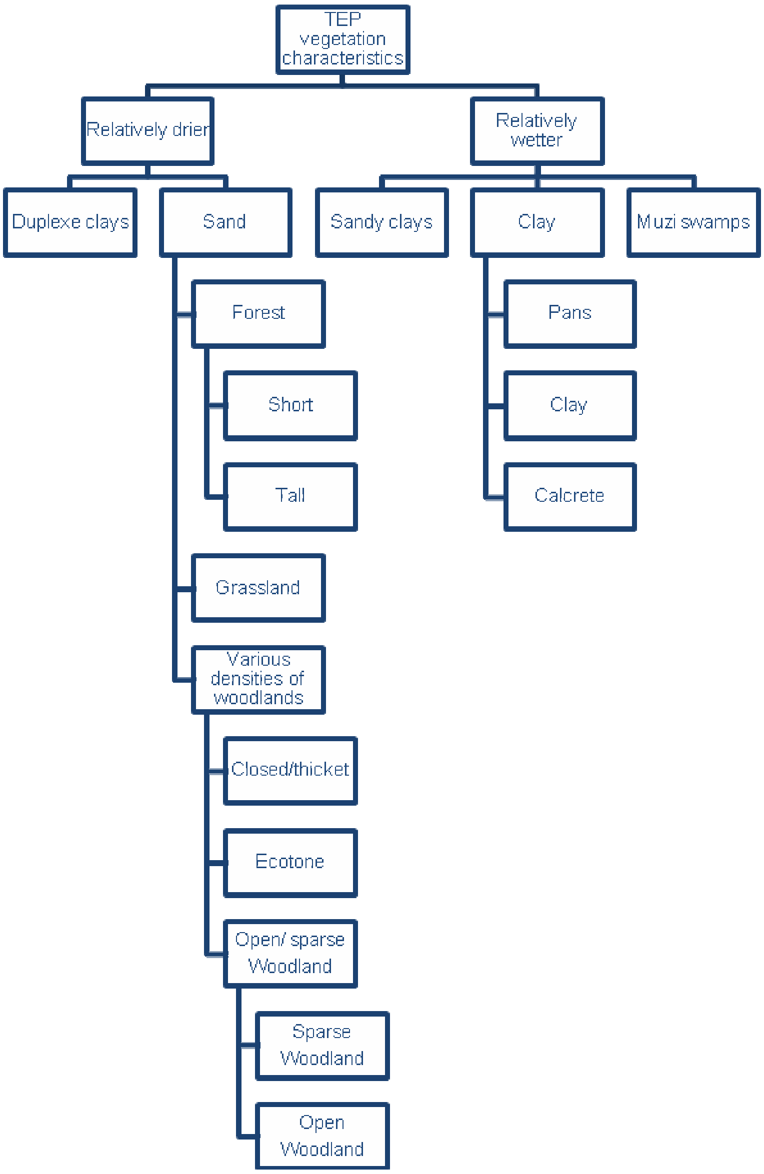

Figure 2.4 **Illustrating the habitat relationships of different plant communities with relative soils**
(Adapted from Matthews *et al.,* 2001:581)

2.8 SAND FOREST

Sand forest structure consists of dense vegetation at different strata with a distinct boundary. The majority of the vegetation is 5-12m tall with a closed canopy, a few large trees and little undergrowth with a low abundance of herbs. The general characteristics of sand forest were identified by Matthews *et al*. (2001) who found that regeneration of sand forest is slow as it relies on high rainfall and humidity. The root systems of sand forest plants are also shallow adventitious root systems, not exceeding 1.5m, the fruit on the plants are abundant and seed dispersal is largely reliant on animal ingestion. The environment that sand forest species are best adapted to consist of dry sandy soils as the vegetation effectively absorbs high quantities of moisture from soil in the first metre. Sand forest species are adapted dynamic systems that have a low environmental threshold and are dominated by *Afzelia quanzensis, Albizia adianthifolia, Bechemia caffra, Carissa tetramera, Cleisanthus schlechteri, Cladostemon kirkii, Coffea gratissimus, Croton steenkampianus, Cussonia arenicola, Dalbergia nitidula, Dialium schlechteri, Drypeters arquta, Erythrophleum lasianthum, Ficus tremula* and *Hyperacanthus microphyllus* plant species (Matthews, 2005). If moisture, predication and soil type are adjusted in this precious sand forest, it could degenerate and potentially be lost (Matthews, 2005).

2.9 CLIMATE

Maputaland (230 000ha) is situated south of the Tropic of Capricorn extending from Maputo in Mozambique to the North and the White Umfolozi river in Northern KwaZulu-Natal in South Africa to the south (Harris, 1852; Baldwin, 1895, Bulpin, 1966; Matthews, 2005) Summers are hot, humid and wet, and winters are cool to warm and dry. Temperatures range between 4°C and 45°C with mean annual temperature in the TEP area varying between 20°C and 22°C. Maximum daily temperatures in the summer months range between 28°C and 45°C (December to February) while daily temperatures in winter months (June-August) are never less than 10°C with no frost (Figure 2.5). Relative humidity and evaporation are generally high throughout the year where levels exceed 80% and range between 50% and 60%. Evaporation exceeds precipitation from March through to November (Schulze & Stott, 1997). Throughout the year mist is a common phenomenon in the swamp areas (Matthews *et al.,* 2001; Gaugris *et al.*, 2004; Matthews, 2005; Morley, 2005). TEP Elephant Park and Tshanini Game Reserve are both located within the Maputaland zone, their precipitation is approximately 700mm annually and evaporation, temperature and humidity are similar (Gaugris *et al.,* 2004).

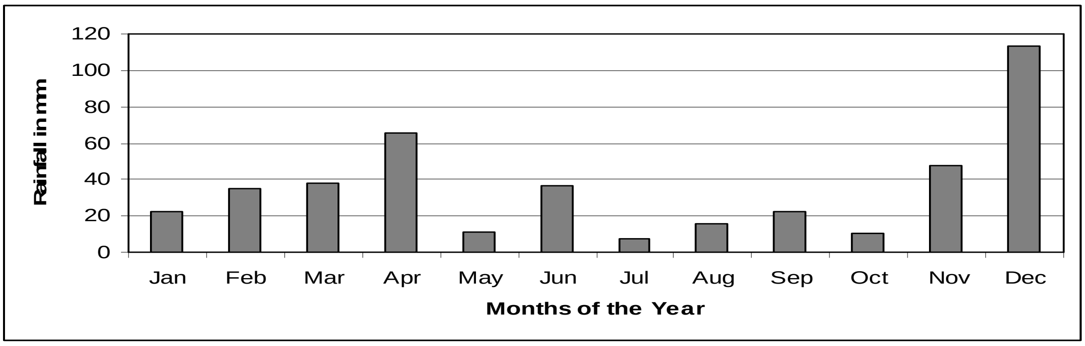

Figure 2.5 **Average rainfall from 2008** (records from TEP weather station)

2.10 SITE DESCRIPTIONS

The section to follow describes the individual sites, which were studied in this project.

2.10.1 Site where elephants wallow on TEP

Situated in the south-eastern part of TEP Elephant Park is Matlhasela water hole (Figures 2.6 and Figure 2.7). Historically, this area was once used as a cattle Kraal site for the Tembe family. Past cattle activity had geomorphic implication and when the area became proclaimed as TEP, the cattle were removed and the water hole was used for animals inhabiting TEP. This area is severely degraded and the piosphere effect is evident. The geomorphic change of the area has become dramatic as a result of consistent high frequency of animal activity in the area (water hole is fed artificially).

Ungulates on TEP have continued to congregate in large numbers at Matlhasela, which has additionally contributed to the area being sparsely vegetated and barren. The elephant interaction at Matlhasela is high, as they use Matlhasela to drink and wallow throughout the year due to a constant water supply (Figure 2.6). The presence of elephants at Matlhasela is evident as there are many elephant wallows, uprooted trees, elephant paths and mud packed trees present in the area (Figure 2.7). This overgrazed region has higher clay content than the surrounding sand forested area with the dominant vegetation type being closed woodland (5% trees, 20% shrubs, 30% grass, 45% bare ground) (Matthews *et al*., 2001).

Figure 2.6 **Elephant wallows at Matlhasela water hole (TEP)**

Figure 2.7 Area surrounding Matlhasela water hole and the elephant wallow on TEP (photographs taken by Taryn Bigwood, 2008)

2.10.2 Elephants present in high numbers in the sand forest on TEP

On TEP samples were collected in the sand forest where elephants are high in density. This site is situated in the Southern area of TEP Elephant Park within the sand forest classed vegetation group (Figure 2.8). The area consists of well-drained sandy soils but the vegetation cover is sparser than the sites where elephants have been excluded. There are high numbers of elephant paths that run through the area with large patches of bare ground. This area should be re-classified as open to closed woodland as the area has displayed such dramatic changes that the basic characteristics of sand forest are not clearly evident.


Figure 2.8 **Images of disturbed sand forest where elephants live in high numbers on TEP** (photographs taken by Taryn Bigwood, 2008)

2.10.3 Sample site where elephants have been excluded for five years (TEP)

This sample site was excluded from elephants by the park management in 2003 and is situated within the boundaries of TEP close to the main gate (Figure 2.9). The exclusion of elephants enabled all animals to frequent the area except for elephants and to enable long term ecological monitoring (to assess the rate of sand forest recovery after elephant damage has occurred) (Matthews, 2005). The five-year exclusion from elephant sites is typically sand forest with well-drained sandy soils and a small A-horizon, which is characteristic of sand forested soils (Matthews, 2005). The vegetation is dominated with 50% shrubs, 30% trees and approximately 15% grass cover, illustrating that the area had been degraded in the past, as sand forest should consist of a large percentage of trees and no grass with few shrubs. This site is not representative of those characteristics. It can be said that this area is going through a recovery process (Mathews, 2005).


Figure 2.9 **Images of disturbed sand forest where elephants lived in high numbers but have been excluded for approximately five years on TEP** (photographs taken by Taryn Bigwood, 2008)

2.10.4 Twenty-five years since elephants roamed on this site on Tshanini Game Reserve

The sample site where elephants have been excluded from the area is situated on Tshanini Game Reserve to the south of TEP Elephant Park in sand forest.

Figure 2.10 **Image of Thsanini sample site where elephants have been excluded for twenty-five years** (photographs taken by Taryn Bigwood, 2008)

The Reserve has no permanent water point and has never had elephants permanently as the elephants moved through the area in the wet season travelling along the Muputaland plains (Matthews, 2005). Tshanini has had elephants excluded for approximately twenty-five years (since the proclamation of TEP) for prolonged time periods. Soils and vegetation are typical of sand forest with well-drained soils and has over 80% tree cover (Matthews, 2001). The area has high species diversity with climatic conditions identical to TEP. The gradient of the site is gentle with undulating sand ridges across the landscape (Figure 2.10) covered with endemic rich sand forest.

2.11 RATIONALE

In order for the study to show its maximum potential a controlling factor is essential, namely study sites with and without elephants present. However, environmental variables such as climate, topography and vegetation must also be considered in establishing the geomorphic impact of elephants on TEP. As a result, one site was chosen to assess macro (wallowing) geomorphic and environmental impacts and three sites were chosen to measure the micro geomorphic alterations as a result of elephant activity with the sand forest. One of the three sand forested sites is disturbed by elephants and two without elephants (a five- and a twenty-five-year exclusion site all in sand forested areas). This study will illustrate the extent of geomorphic alteration, which may reveal a way to predict geomorphic degradation caused by elephants.

Chapter 3
METHODS

For this study to be relevant, it is essential to have defined previously tested methods adapted to this research and similar study sites regarding climate, topography, vegetation and animals. It is also vital to have a variant factor, namely sites with and without elephants so that the geomorphic impact of elephants on the sites can be quantified at a macro and micro level. Four sites were thus chosen encompassing two disturbed by elephants (one in sand forest and one at the artificial water hole) and two without elephants (a five-year exclusion and a twenty-five-year exclusion, both in sand forested areas). This is intended to illustrate the degree of geomorphic alteration on a macro and micro level, which will assist in devising ways to measure the levels of geomorphic changes caused by elephants.

3.1 COLLECTION OF CLIMATIC DATA

Air temperature, relative humidity and rainfall data were collected from February 2008 to January 2009 at each site. Two single channelled data loggers were placed at each study site in a tree at 1.5 meters off the ground in a radiation shield to record shaded air temperature and relative humidity at 30-minute intervals. One automated tipping bucket rain gauge was placed one meter off the ground at two sites (one on Tshanini and one on TEP) in the open to compare rainfall in the study areas.

Automated weather stations and data loggers have been used numerous times to record highly accurate microclimatic data through many disciplines. Examples, where such studies have been undertaken, were used in the decision making process to establish which methods would be adopted in this study. Sipe and Dale (2003) used automated weather stations to collect rainfall, temperature and relative humidity data where constraints in using GIS (Geographical Information Systems) to understand and control Malaria in Indonesia were identified. The constraints of the Malaria study were identified as being an insufficient number of automated weather stations present in the study area to accurately predict climatic gradient and linkages to the prediction of Malaria outbreaks. Sipe and Dale (2003) identified three possible solutions: firstly, to extrapolate from the data they had; secondly, to increase the number of automated weather stations; and/or thirdly, to train a GIS model and predict climatic change from the model. A GIS modelling approach was used and proved to be unsuccessful. Sipe and Dale (2003) therefore recommended using more automated weather stations to increase the accuracy of collecting climatic data.

Boelhouwers *et al*. (2003) studied the Maritime sub-antarctic periglacial environment with the use of single channel data loggers to record air temperatures, relative humidity, ground temperature, precipitation and soil temperature at different depths. In this study, loggers were placed on Marion Island to obtain the most accurate climatic change data in order to determine the rate of geomorphic change as a result of climate change (Boelhouwers *et al.,* 2003). Yates *et al.* (2000) conducted a study on the effects of grazing on plant cover, the soil and microclimate in fragmented woodlands in South West Australia. To gather data for the grazing project accurately, microclimate data needed to be collected and this was achieved by using automated sensors (multi channel data loggers) to measure relative humidity, air temperature, wind strength, soil temperature and soil relative humidity (Yates *et al.*, 2000).

Boelhouwers *et al.* (2003), Sipe and Dale (2003) and Yates *et al.* (2000), using single and multi channel data loggers were used to measure microclimatic conditions, found that the data loggers all record highly accurate data and the intervals of measurements may be altered according to the researchers needs. The loggers had also proved to be highly resistant to climatic conditions making the apparatus resilient and easy to use. These studies were selected as examples to illustrate the versatility and accuracy of data loggers as they can be used in GIS, ecology, zoology, geomorphology and other disciplines. Besides the microclimate data, vegetation data were collected to show differences and similarities in vegetation at each site.

3.2 COLLECTION OF VEGETATION DATA

Vegetation was considered in the overall assessment of the area and biotic and abiotic elements at all the study sites were integrated to view the intensity of the geomorphic change. This was achieved by estimating basal cover and classifying the areas according to Edwards' classification chart (Edwards, 1983). This classification system was used as it has universal application in assessing canopy cover in all vegetation types, including sand forest (Lal, 1998; Matthews *et al*., 2001; Castellano & Valone, 2007). Basal cover was additionally assessed at each site to analyse vegetation cover trends (Figure 3.1).

3.3 COLLECTION OF SOIL DATA

Soil samples were collected at three different times of the year, namely after the wet season (summer), the dry season (winter) and before a wet season (spring) to obtain the most representative results. Transect lines were plotted out at each site with the sample points being three meters apart. Every three meters a surface sample was loosely collected and a compacted subsurface sample was gathered at 20cm depth without disturbing the soil so that a compacted sample was drawn representing the compaction and density of the subsurface. Along the transect line 40 soil samples were taken at each site (20 surface and 20 subsurface) totalling 160 samples taken in total from the study area per season (Figure 3.1). Perpendicular to the soil collection transect line another transect line was established to test for compaction and infiltration. Along the perpendicular transect line at each study site five compaction tests (the decrease in volume of unconsolidated material owing to compression causing moisture and pore spaces in the material to be reduced) (Whittow, 2000:98) and five infiltration rate tests (the maximum rate at which water can enter the soil under specific conditions) (Whittow, 2000:266) were conducted every three meters for fifteen meters in each season (Schoeneberger *et al*., 2002; Burt, 2004).

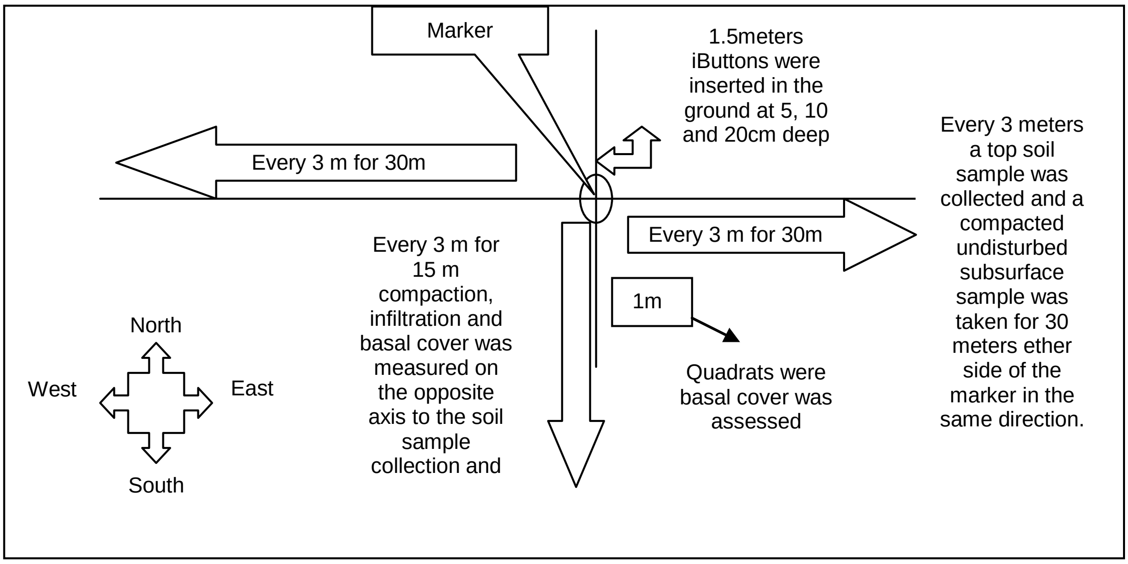

Figure 3.1 **Diagram of how the soil data were collected**

(In each season the sampling method was rotated to ensure disturbed areas from the previous sample collections would not influence the new samples collected.)

Once the soil samples were collected, they were taken to the laboratory for analysis. Laboratory tests conducted on the samples consisted of moisture retention capacity, organic matter percentage, soil pH, soil conductivity, particle size analysis and bulk density tests.

In Matthews (2005), laboratory tests were conducted on the soils from TEP (pH, electrical conductivity, nitrogen, phosphorous, calcium, potassium, magnesium and sodium), according to the FAU soil classification system derived from the FAO-UNESCO (1974) and the South African soil classification (Soil Classification Working Group, 1991). In order to understand the complexity of the environmental systems on TEP, the soil and plant relationship must be considered (Matthew, 2005). Laboratory tests conducted on the samples in this study consisted of moisture retention capacity, organic matter percentage (loss on ignition method), soil pH, soil electrical conductivity, particle size analysis, and bulk density tests (Whittow, 2000; Flenniken *et al*., 2001; Erskine *et al.*, 2002; Schoeneberger *et al.,* 2002; Burt, 2004; Harden, 2006; Sumner *et al.*, 2008).

To establish accurate microclimatic data of the soil iButtons miniature temperature-loggers (17mm diameter, 6mm thick) called Thermochron were used, as they are inexpensive and self-contained. They operate within a broad temperature range, which makes them suitable for any soil conditions (Lewkowicz, 2008). Many ecological studies have used the sensors to monitor nests, microclimate, animal body temperatures (implants), water or liquid temperatures and snow, rock and soil temperatures (Boelhouwers *et al.*, 2003; Davidson *et al.*, 2003; Robert & Thompson, 2003; Van Marken Lichtenbelt *et al.*, 2006; Lewkowicz, 2008; Nel, 2009). This study assessed the macro and micro geomorphic changes where the macro refers to measuring elephant wallows and the micro, soil physical and chemical properties and micro climate in Sand forest.

3.4 METHODS: MACRO GEOMORPHIC CHANGES AS A RESULT OF ELEPHANT ACTIVITY

Since the African elephant can change the landscape so dramatically, Butler (1995) termed elephants as being geophagy (eat soil, literally and figuratively through removal of soil). At Matlhasela, water hole wallows were mapped and measured using a ranging rod and a tape measure. Each set of wallows (one wallow set is ¼ of the total area covered by wallows at one water hole) was measured twice in 2008 (February and November) so that changes in the wallows could be quantified over time.

The length and the breadth of the wallows were measured to determine the central point of each wallow set. The tape measure was then placed lengthways on the central point. Once the centre of the transect was placed, cross transects were conducted (every meter at wallow set two and every four metres at wallow set one, as the latter set of wallows was much greater in size than wallow set two) off the central line, and depth was measured with a ranging rod (Figure 3.2 and Figure 3.3).

Klaus *et al.* (1998) mapped salt licks with a Garmin GPS 49, which presented itself to be successful, but in this study the 3D exact extent of the wallows was assessed (Klaus *et al.*, 1998). With these results from 2008, the area and extent of each wallow, the average and maximum depth of the wallows, the estimated area the wallow covers and the amount of sediment removed from the site was calculated. These calculations could then be used to calculate the change in wallow extent, depth and sediment removal over an eight-month period. Additionally, when the total volume of soil removed at Matlhasela was calculated, it was divided by 0.31m^3, which is the amount of sediment removed by one elephant by one wallow (Flint & Bond, 1968), to determine how many wallows (pits *created* from animals rolling in muddy areas) had taken place at Matlahsela since the establishment of TEP.

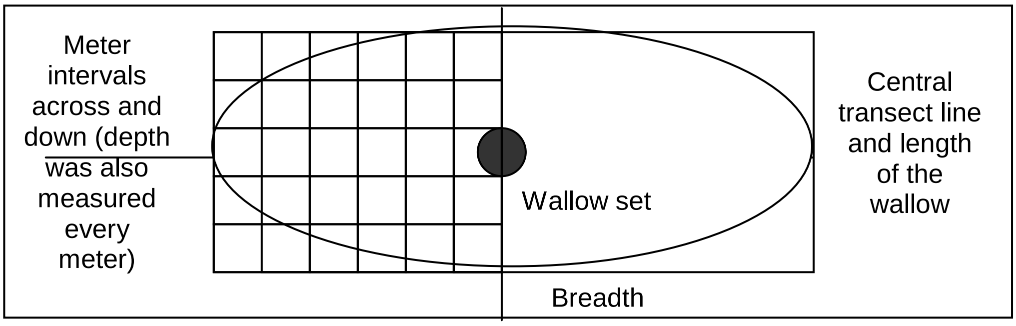

Figure 3.2 **Method used to map the wallows**

Figure 3.3 **Physically using the methods illustrated in 3.2 to collect wallow data** (photograph by Bigwood, 2008)

3.5 METHODS: SITE VARIATIONS

The physical environment is influenced and can be altered by the natural environment. To determine the geomorphic impact of elephants on TEP, it is important to evaluate the similarities of the sites chosen for the study to determine if the controlling changes to the landscape on a micro scale, within sand forest, are as a result of elephant activity. In this section of this study, microclimate, vegetation and soils are compared to determine the differences between the sand forest study sites. According to Matthews (2005) these study sites are all sand forest therefore the vegetation abundance, species, microclimate and soils should all be similar.

3.5.1 Microclimate and rainfall

Collection of microclimatic data to compare the sites was conducted with the use of single channel data loggers and tip bucket rain gauges. At each sand forest site two single channel data loggers were placed in radiation shields to record air temperature and relative humidity at 1.5 meters above the surface at 30-minute intervals (Yates *et al.*, 2000; Sipe & Dale, 2003). The data loggers were set at 30-minute intervals and downloaded every 1.5 months from February 2008 to the end of January 2009. One tip bucket rain gauge was placed on TEP in the centre of the sample site and one on Tshanini to confirm that the two study areas recorded the same rainfall. Rainfall is measured in 0.2mm-intervals per rainfall event. Once all the data were collected, it was analysed using Microsoft Excel to display trends, similarities and differences in the microclimate at all the study sites and areas.

3.5.2 Vegetation

Vegetation is not the primary focus of this study but to display site similarities and differences, the classification of Edwards (1983) was used to classify the vegetation structure of the study sites (determining cover class or basal cover, height class and crown cover or canopy cover) and two Quick Bird images were used to determine canopy cover changes. To determine basal cover, one-meter quadrates were placed on the compaction and infiltration transects lines every three meters. Once a quadrate was in place, the percentage of vegetation cover was measured.

Height class was determined through observation and canopy cover was estimated as a percentage three times (February 2008, July 2008 and November 2008 [summer, winter and spring]) at each study site. Once the data were collected, the results were assessed using the ranking matrix of Edwards (1983) and the vegetation structure was classified.

3.5.3 Soil

All soil samples obtained at each site were mixed (all surface together and all subsurface samples together). From the mixture, four top and four bottom samples were extracted from the grouped samples to form sub samples. These eight samples at each site were dried in the oven at 60^0C for 24 hours then sieved for 15 minutes using sieve sizes of 8000, 4000, 2000, 1000, 500, 125 and 63 micro-mm and then the samples were weighed. The results were statistically analysed by calculating the skewness value of the soil to determine the coarseness of the materials and the phi mean. These results were analysed according to the Wentwood's soil scale to classify the soils (a scale used to classify the particle size of sediment, outlined by C.K. Wentworth in 1922) (Whittow, 2000; Sumner *et al.*, 2008). These methods have been recommended and used by many to analyse soil type (Hall *et al.*, 1999; Driessen, 2001; Matthews *et al.*, 2001; Hall & Lamont, 2003; Burt, 2004). The results and classifications at each site were averaged and graphed according to particle size in an accumulative manner.

3.6 METHODS: IDENTIFYING PHYSICAL AND CHEMICAL PROPERTY CHANGES OF SOIL IN THE SAND FOREST

To identifying the physical and chemical property changes of soil in the sand forest, compaction and infiltration, bulk density, soil humidity and temperature, pH and electrical conductivity and organic matter content was determined and compared.

3.6.1 Compaction and infiltration

Compaction and infiltration were measured on three different occasions in the field to measure geomorphic change in the dry and wet seasons of the year. A hand shear vane was used to measure shear strength which represents soil compaction and a single ring cone infiltrometer was used to determine infiltration terminal rates along the transect lines (Murray *et al.*, 2002). Castellano and Valone (2007), Burt (2004) and Thrush (1997) used this method in different soil types to determine compaction and infiltration rates. At each sampling point (every 3m), compaction and infiltration was measured simultaneously along a transect line of 15m. To analyse the data collected in the field, correlation coefficients were calculated to identify the relationship between compaction and infiltration and the relationship between study sites.

3.6.2 Bulk density and soil moisture

Bulk density and soil moisture content were calculated from surface and subsurface soil samples. The samples were collected by pressing a fixed volume container (25.14cm^3), the surface sample was collected by pushing the cup into the ground and the subsurface samples were collected using the same copper cup forced into the soil horizontally at 20cm deep to collect an undisturbed compacted soil sample. Once the samples had been collected they were weighed and placed in an oven at 63^{o}C for 24 hours to dry. The samples were then weighed and the difference between the dry mass and wet mass was calculated and converted to a percentage to determine the water content of each sample. The weight (grams) of the subsurface samples was used to display bulk density as grams per centimetre (25.14cm^3) (Evans, 1998; Erskine *et al.*, 2002; Burt, 2004; Evens, 2005b).

3.6.3 Soil relative humidity and temperature

In collecting data on the microclimate of the soil, three sensors were placed in the soil (5, 10 and 20cm depths and 1.5 meters from the marker) at each study site to measure soil temperature and soil relative humidity.

Many disciplines have used iButtons including ecological studies to monitor nests, microclimate, animal body temperatures (implants), water or liquid temperatures, as well as snow, rock and soil temperatures. Lewkowicz (2008) tested iButtons to monitor snow pack and Permafrost microclimate in north-western Canada and obtained highly accurate data on the microclimatic conditions. Boelhouwers *et al*. (2003) used sensors in the soil at 5-, 10-, 20- and 40cm deep to determine temperature gradient in the subsurface soils on Marion Island. The loggers' data revealed a high level of accuracy as slight temperature differences in the soil were recorded (Boelhouwers *et al.*, 2003). Nel (2009) used iButtons to determine soil temperature and relative humidity gradients on Marion Island. Davidson *et al.* (2003), Robert and Thompson (2003) and Van Marken Lichtenbelt *et al.* (2006) used iButtons to measure living the body temperature of vertebrates (implants).

The soil sensors were important to this study as they aided in measuring the extent, depth and differences in compaction between the three study sites (data collected at 10cm and 20cm). Soils that have a greater soil temperature have lower moisture content. The reason for this is that drier soils, which are compacted, have a low water retention capacity as they are water repellent, causing the soils to be drier therefore warmer.

3.6.4 pH and electrical conductivity

Soil samples were taken to the laboratory and an electron soil probe was used to measure pH and electrical conductivity of the soil. The soils were first dried in the oven at 60^{o}C for 24 hours. A portion of the soil was then placed in a beaker with equal quantities of distilled water to soil. The soils were then tested for pH and electrical conductivity. The methods used in this study were derived from the soil survey laboratory methods manual of Murt (2004). To analyse the data, correlation coefficients were calculated to identify the relationship between ph and electrical conductivity between study sites.

3.6.5 Organic matter content in the soil

All soil samples obtained at each site were mixed (all top samples together and all bottom samples together). From the mixture four top and four bottom samples were extracted from the grouped sample to form sub samples. These eight samples at each site were dried in the oven at 60^{o}C for 24 hours; they were then weighed and placed in the oven at 550^{o}C for four hours. The samples were then weighed and the difference in weight indicates the organic matter content in the soil (Erskine *et al.*, 2002). The methods described above outline how the objectives of this study (to study the general topography of the area, climate, vegetation, soil and animal interaction), which involves the site description of the general area; to determine the rate of geomorphic alteration [macro geomorphic change] at the water points by mapping and measuring elephant wallows; to analyse the micro environments [microclimate, air temperature and humidity and rainfall], vegetation and soil [soil type and soil micro climate] in the sand forest study areas with elephants being one variation between the sites; and to identify soil property changes in sand forest [physical and chemical] caused by elephants) were achieved to obtain the geomorphic impact of elephants on Tembe Elephant Park. Once all the methodology and methods were identified and used to collect and analyse the data, the results displayed a number of trends and patterns, which is evident in Chapter 4.

Chapter 4
RESULTS

In this chapter, the data collected in the field will be presented and will display the macro (visible changes in the landscape) and micro (chemical and physical changes to the soil which makes up the landscape) geomorphic changes across the study area. The macro geomorphic changes were seen as elephant wallows, as they represent visible changes to the landscape. The micro geomorphic changes were measured in sand forest specifically, as the vegetation diversity in Mputaland is great and it was important to keep as many similarities as possible. The micro changes were categorised into two categories, namely assessing the site variable, which included the micro climate, vegetation and the soils, basic composition and analysing the physical and chemical changes in the soil.

4.1 MACRO GEOMORPHIC ALTERATIONS: ELEPHANT WALLOWS

The macro geomorphic alteration is here considered as a change to the landscape, which is visible to the human eye. This can be seen in the area where the elephants wallow. In this study, the elephant wallows are analysed quantitatively and qualitatively.

4.1.1 Qualitative analysis

On observation, it was noted that each set of wallows had circular uniform craters within the greater wallow area (Figure 4.5). The shrubs had been browsed and uprooted, and the trees displayed mud patches (Figure 4.6) as a result of elephants using the trees as rubbing posts. Whilst observing the site it was noted that the elephants moved into the area on well used paths they had created and walked directly to the water. The species tended to have a system where they waited under a large tree before consuming water from the waterhole. As the elephants waited their turn to drink water, soil was gathered with their trunk and showered over their bodies. After the elephants had drunk water, they migrated to the wallowing area. In the wallows, elephants used their feet to dig against the walls of the craters and proceeded to cover themselves in the mud by wallowing. In the dryer times of the year the elephants just showered themselves with soil after they had drunk water. Upon mapping these wallows the exact shape and parameters of the wallows were accurately drawn.

Figure 4.1 **Portion of the elephant wallows in February and June 2008**

Figure 4.2 **Tree where elephants dust bath and use the tree as a rubbing post**

4.1.2 Quantitative analysis

The elephant wallows were assessed as two sets of wallows and in this study they will be referred to wallow 1 and wallow 2. In February 2008, wallow 1 was 18m less in length, 9m less in width, its maximum depth was 0.03m less, the average area the wallow covered was 765m^2 less and the estimated soil removed from the wallow was 158.97m^3 less than wallow 2. Table 4.1 presents exact parameters.

Table 4.1 **Wallow parameters at wallows 1 and 2 in February 2008**

Parameters	**Wallow 1**	**Wallow 2**
Length of the area covered by the wallow (m)	23.00	41.00
Breadth of the area covered by the wallow (m)	22.00	31.00
Maximum depth reached (m)	1.09	1.06
Average depth (m)	0.15	0.18
Estimated area wallow covers (m^2)	506	1271
Estimated volume of soil removed from elephant activity (m^3)	79.87	238.84

In November 2008, the differences between the two sets of wallows was similar, as wallow 1 was 26m less in length, 12m less in width, 0.02m less in depth, the total area was 1642m^2 less and the estimated soil removed from the wallow was 502.8m^3 less than wallow 2 (Table 4.2). In mapping the two wallows, the wallows are circular in shape, never deeper than 1.9m and cover a large surface area (Figure 4.1. and Figure 4.2).

Table 4.2 **Wallow parameters at wallows 1 and 2 in November 2008**

Parameters	**Wallow 1**	**Wallow 2**
Length of the area covered by the wallow (m)	48.00	74.00
Breadth of the area covered by the wallow (m)	29.00	41.00
Maximum depth reached (m)	1.09	1.11
Average depth (m)	0.23	0.27
Estimated area wallow covers (m^2)	1392	3034
Estimated volume of soil removed from elephant activity (m^3)	328.51	831.31

After the same wallows were measured and mapped in February and November 2008, the parameter change over the eight-month period could be calculated to predict a rate of wallow change. In Table 4.3, these changes (from February to November in 2008) are evident in both wallows. In the case of wallow 1, the total percentage of length increase was 52%, breadth 24% and volume of soil removed from the wallow 75%. At wallow 2 (from February to November 2008), the length had increased by 44%, the breadth by 23% and the volume of soil removed at the wallow was 71% greater (Table 4.3).

Table 4.3 **Difference parameters at wallows 1 and 2 between February and November 2008**

Parameters	**Wallow 1 Increase in size**	**Wallow 2 Increase in size**
Length of the area covered by the wallow (m)	25.00	33.00
Breadth of the area covered by the wallow (m)	7.00	10.00
Maximum depth reached (m)	0	0.05
Average depth (m)	0.07	0.08
Estimated area wallow covers (m^2)	886	1763
Estimated volume of soil removed from elephant activity (m^3)	248.64	592.46

The average increase of surface area at the wallows at Matlhasela was calculated to an approximate 165.5m^2 per month and the average soil removed from the wallows was 52.5m^3 per month. When the total volume of soil removed at Matlhasela was calculated, it was divided by 0.31m^3 (the amount of sediment removed by one elephant by one wallow) (Flint & Bond, 1968) to determine how many wallows had taken place at Matlhasela since the establishment of TEP.

The results showed that approximately 6500 wallows by elephants had taken place at Matlhasela in the two sets of wallows since the establishment of the park, and approximately 170 wallowing events have accrued per month between January and November 2008. The dramatic increase of surface area and volume of soil removed from the site is attributed to elephant activity in the area (Muller, 2009). The constraints to these figures are that the rainfall may play a role in the rate of change but, largely, these changes are accelerated through elephant activity. Using the measurements, the wallows were mapped in 3D.

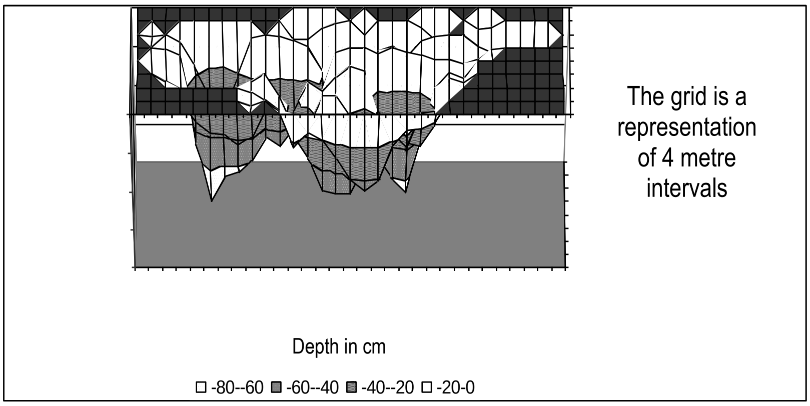

Figure 4.3 **3D view of wallow 1 displaying depth and shape of the wallow**

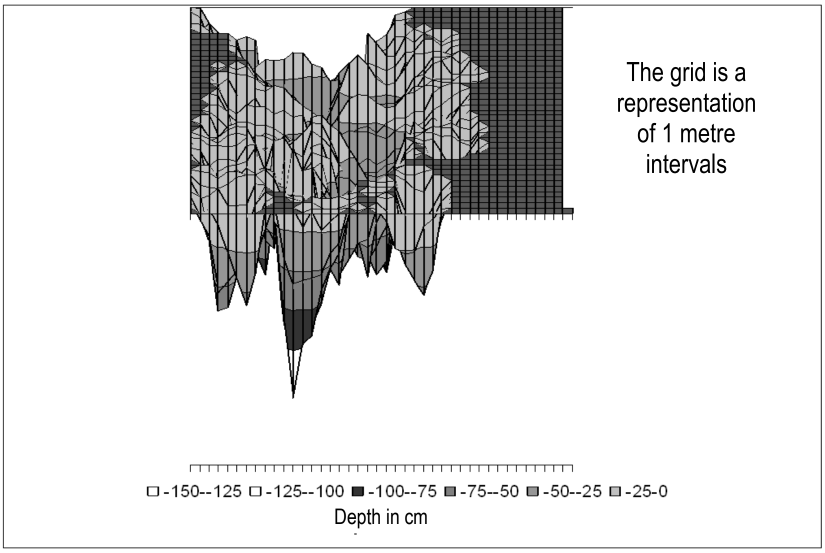

Figure 4.4 **3D view of wallow 2 displaying depth and shape of the wallow**

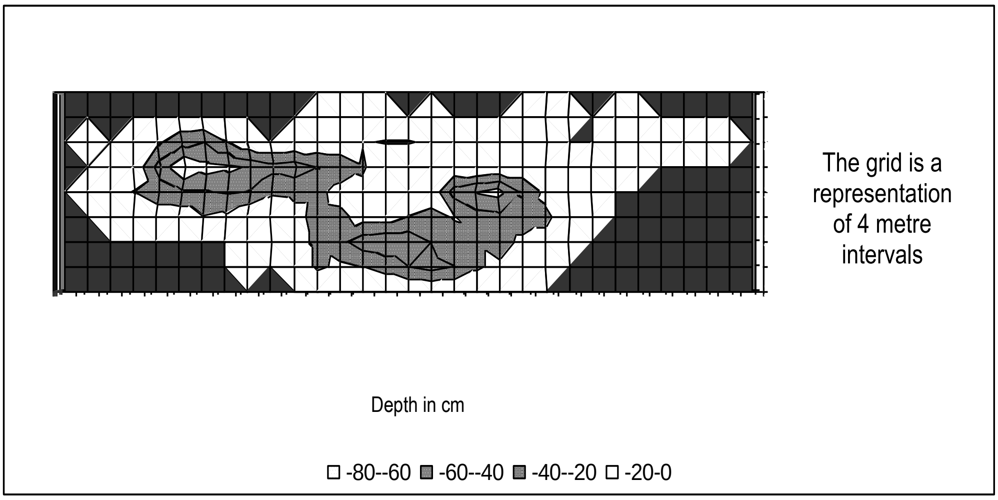

Figure 4.5 **Surface view to show the extent and shape of wallow 1**

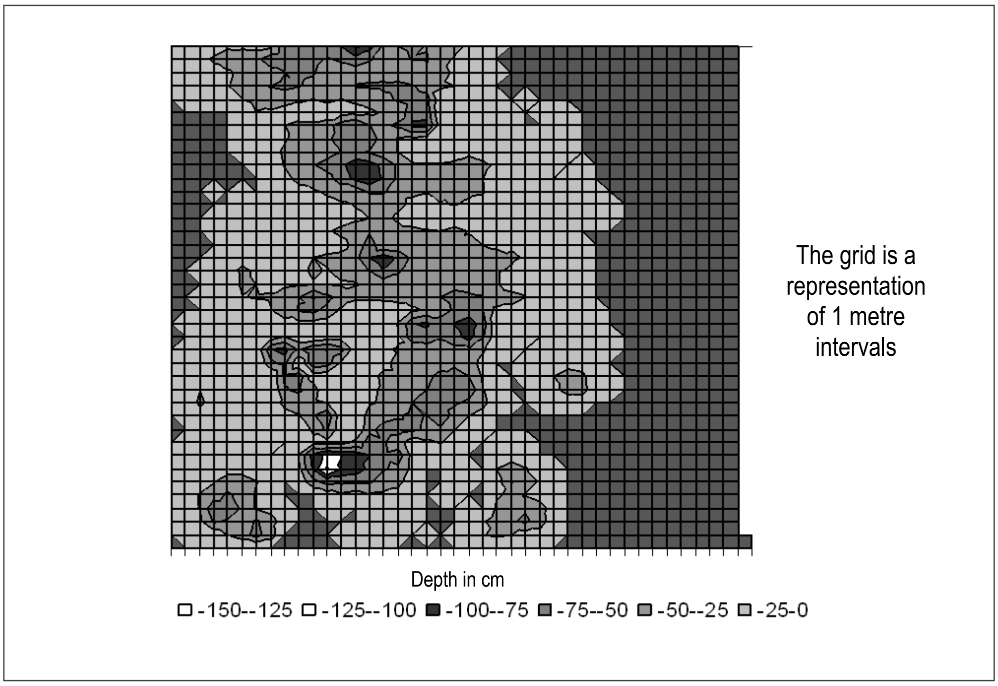

Figure 4.6 **Surface view to show the extent and shape of wallow 2**

Once the macro geomorphic alterations were analysed and assessed through recording the size and extent of elephant wallows, the sand forest sites were assessed to see if the abiotic and biotic variables were and are consistent between the sites with elephants being the controlling factor.

4.2 ASSESSING THE VARIATION OF STUDY SITES

Assessing the variation of sand forest study sites comprised of analysing essential variables within the system, microclimate, vegetation and soil. These results were essential to determine if the presence of elephants in an area contribute to micro geomorphic changes in the sand forest. To assess the variations, the first data that were collected was the microclimatic data, which consisted of air temperature, relative humidity and rainfall.

4.2.1 Micro-climate and rainfall

Air temperature, relative humidity and rainfall are all facets of the microclimate. In this study, October 2008 was excluded due to an error in the data for air temperature and relative humidity, but was included in the rainfall data.

4.2.1.1 Air temperature

Upon analysing the single channel data logger results, it was noted that air temperature at all study sites was marginally different (less than 0.5^{o}C difference between sites). Temperatures are relatively similar between study sites throughout the year where the coolest month averaged 17^{o}C and the hottest 27^{o}C. November to March are the hottest months of the year with May to September being the coolest months (November 2008 was the hottest and June 2008 was the coldest month in this study) (Figure 4.7 and Table 4.4).

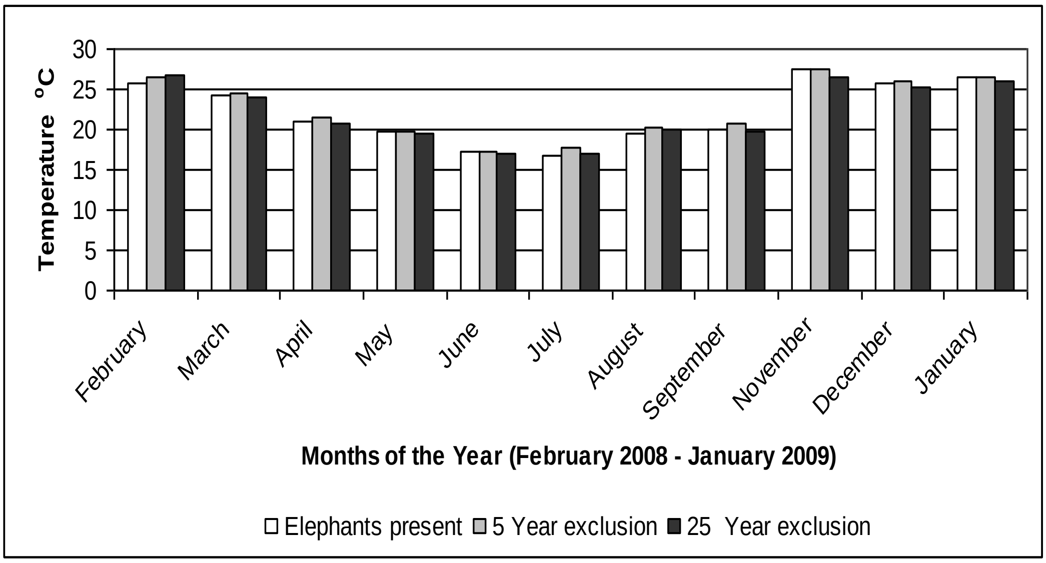

Figure 4.7 **Average air temperatures from February 2008 to January 2009**
(October was not included as a result of a data error)

Table 4.4 **Average temperatures (^{o}C) and relative humidity (%) from February 2008 to January 2009**

Parameters	**Wallow/ elephants present**	**5-Year-exclusion**	**25-Year-exclusion**
Average air temperature ^{o}C	22.18	22.55	22.06
Average relative humidity %	83.02	79.85	78.59

4.2.1.2 Relative humidity

The results of the relative humidity readings from the single channel data loggers showed that relative humidity varied between study sites. The average relative humidity at the twenty-five-year and five-year exclusion study sites was almost the same but, where elephants are present, the humidity is approximately 4% higher. On average, the relative humidity exceeded 78.59% at all study sites. The most humid sites were where elephants are present and at the wallows (except for January 2009, the twenty-five-year exclusion was more humid). The lowest relative humidity at the twenty-five-year exclusion and the five-year exclusion displayed intermediate results. The most humid month overall was January 2009 and the least humid month was September 2008 (Figure 4.8 and Table 4.4).

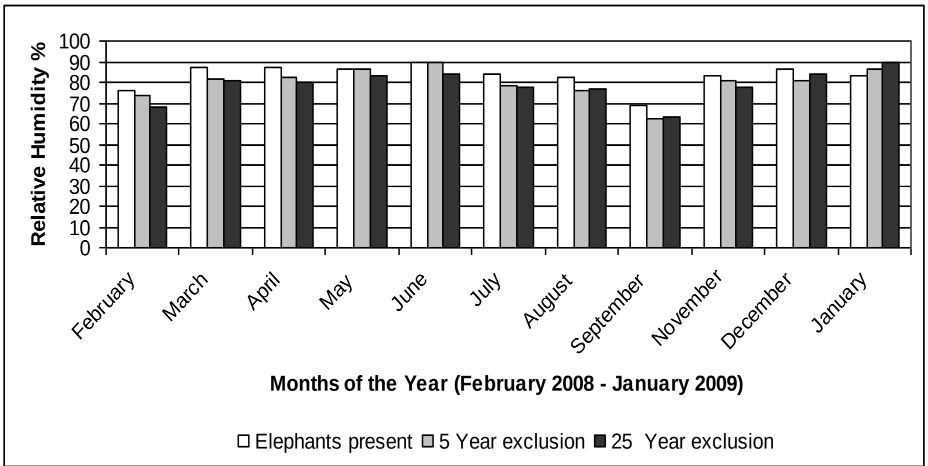

Figure 4.8 **Average relative humidity for air from February 2008 - January 2009** (October was not included due to a data error)

4.2.1.3 Comparison between air temperature (^{o}C) and relative humidity (%)

Results of correlating air temperature and relative humidity have displayed differences between study sites. Comparing study sites, air temperature and relative humidity data function together (as air temperature increases, relative humidity increases) as displayed in Figure 4.9. Overall, the correlation coefficient results (R) when N=36 (number of values used to calculate correlation coefficients) show that although there are slight variations between study sites, they are insignificant (Figure 4.9).

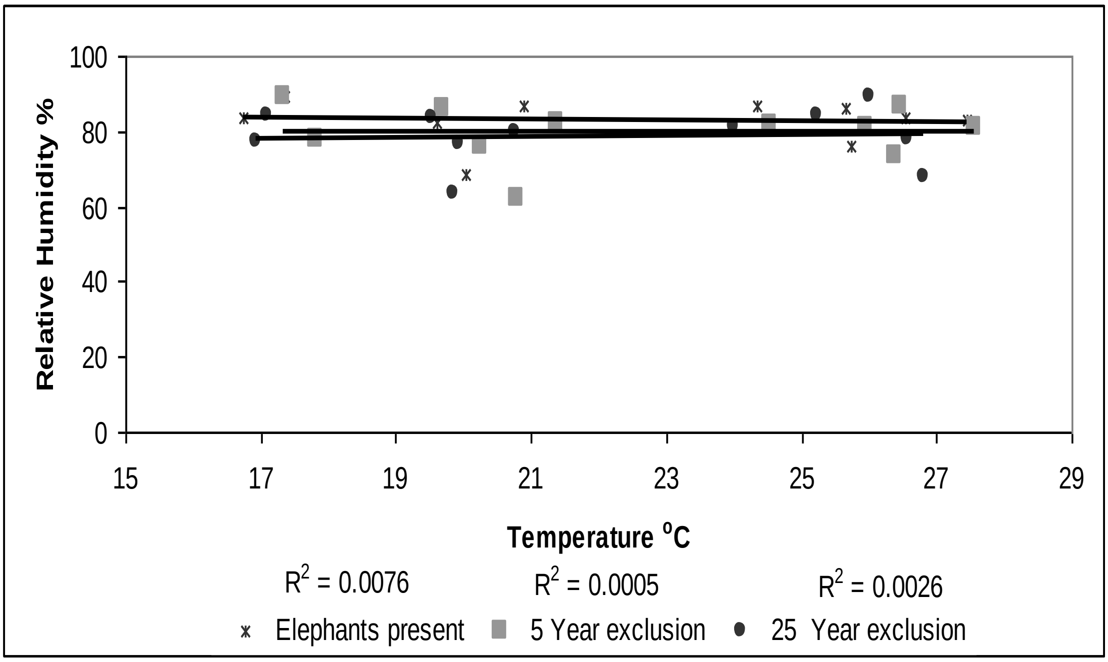

Figure 4.9 **Correlation coefficient calculated to display correlation between air temperature (°C) and relative humidity (%) at each study site (February 2008 to January 2009)**
(The average four values from each season were used to calculate each correlation coefficient. October was not included as a result of a data error.)

4.2.1.4 Rainfall

Measuring rainfall on TEP and Tshanini showed that the two study areas receive very similar precipitation throughout the year, which totalled as 494mm (TEP) and 517mm (Tshanini Game Reserve). Figure 4.10 shows that the highest rainfall received throughout the study period was in January 2009 (when air relative humidity was the highest) and the lowest was between August and October 2008. After the microclimate had been assessed, the next variable in the sand forest, which was assessed, was vegetation.

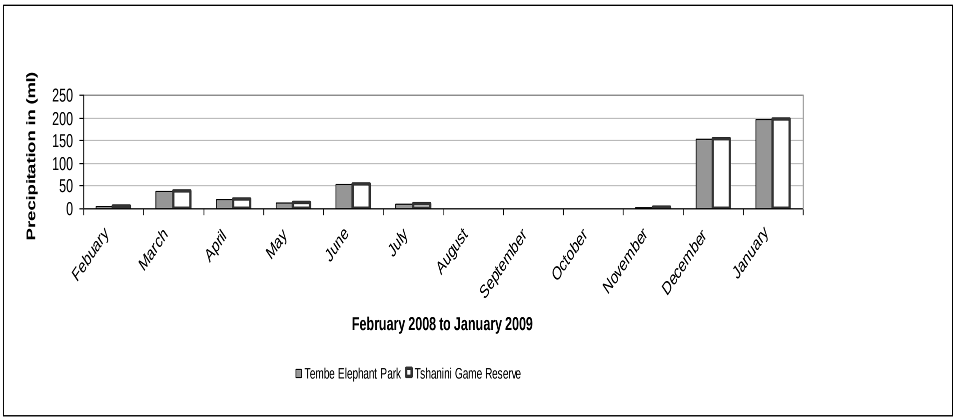

Figure 4.10 **Average rainfall for February 2008 to January 2009**

4.2.2 Vegetation

Vegetation differed at each site, as elephant and ungulate activity have altered the vegetation. To determine basal and canopy cover, vegetation height and structure was classed and measured.

4.2.2.1 Basal cover

In Figure 4.11 where basal cover is represented as measured at the three different sand forest sites along a transect line from the centre of the site marker, it is evident that the five-year exclusion site and the site where elephants are present, have similar basal cover vegetation. However, the five-year exclusion site has more vegetation and the twenty-five-year exclusion site has a very different basal cover to the other sites as it has a constant cover of 0% (sand forest has a high dense canopy with no understory). Figures 2.8 and 2.10, in Chapter 2, display the vegetation cover in each study site.

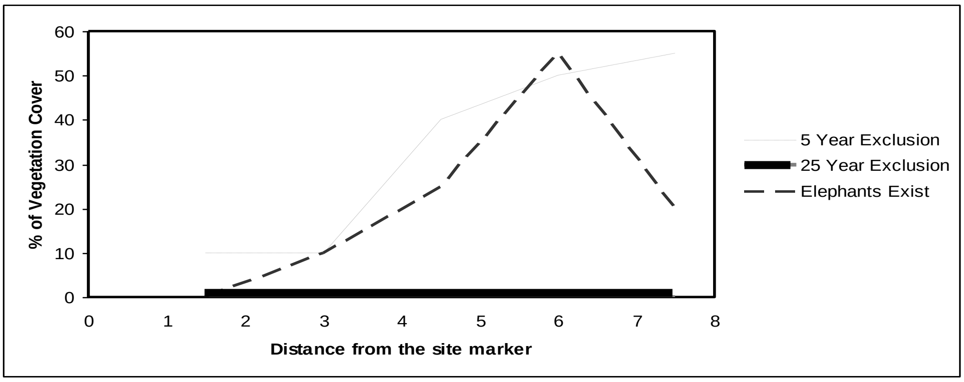

Figure 4.11 **Basal cover at each site, distance from the marker**

4.2.2.2 Canopy cover

In Figure 4.12 the average canopy cover of all the study sites is displayed. The results of the canopy assessment showed that at the twenty-five-year exclusion site, the canopy was the densest by more than 20%. The canopy cover assessment also showed that the study site, where elephants are present and where they wallow, had the least canopy cover. The five-year exclusion site had the intermediate cover but was still closer in magnitude to where the elephants are present. These results indicate that the five-year exclusion vegetation cover was damaged before the exclusion took place and that the recovery rate of sand forest vegetation is slow.

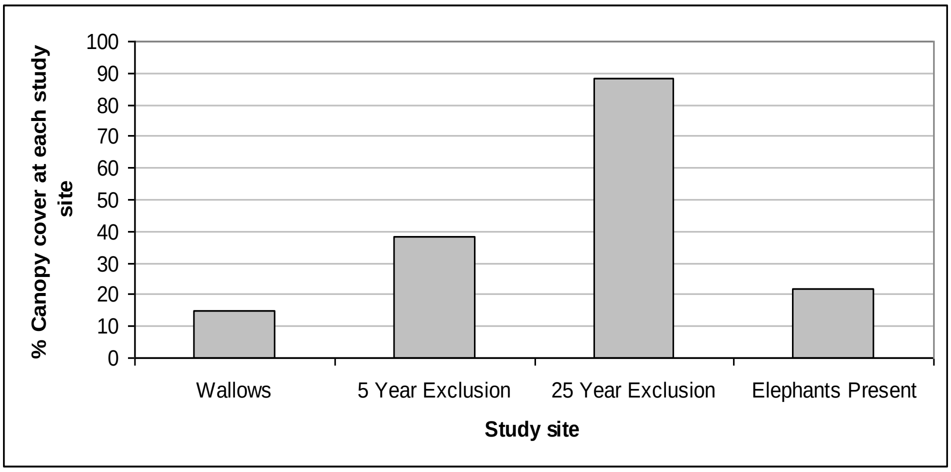

Figure 4.12 **Average canopy cover for 2008 at each study site**

4.2.2.3 Height class

Height class was determined by observation and evaluating the height classes according to the height class table of Edwards (1983) (Table 4.5) as a percentage. At the twenty-five-year exclusion study site it was evident that the vegetation height was broken into 90% tall trees, 10% high shrubs and no grass was present. Concerning the five-year exclusion study site, there were 5% tall trees, 30% short trees, 30% low trees and high shrubs and 35% short grass and herbs. Where elephants are present the sand forest has lost many characteristics, as it consists of 2% tall trees, 5% short trees, 40% low trees and high shrubs, 20% low shrubs and 25% short grass. The wallows study site has extremely low tree abundance, as it consists of 5% tall trees, 40% tall shrubs and 30% short grass and herbs.

Table 4.5 **Height classes** (Edwards, 1983:708)

Parameters	Trees	Shrubs	Grasses & Herbs
High	<20m	2 - 5m	>2m
Tall	10 – 20m	1 – 2m	1 – 2m
Short	5 – 10m	0.5 – 1m	0.5 – 1m
Low	2 – 5m	<0.5m	<0.5m

4.2.2.4 Structural classification

Structural classification is derived from a combination of the basal cover, canopy cover and vegetation type and height. Edwards (1983) combined the three fundamental factors of vegetation structure and derived a matrix to classify vegetation. Using Edwards' matrix, all the sites fall under the forest and woodland classification. The twenty-five-year exclusion is sub-classed as high forest, the five-year exclusion as short closed woodland, and where elephants are present, excluding the wallow study site can be sub-classed as short open woodland (Edwards, 1983:710). After the vegetation was analysed and the results obtained, the soils were assessed for their similarities, differences and characteristics.

4.2.3 Soils

To assess the variation of the sites, soils were analysed by conducting a particle size analysis and categorising them according to the soil scale of Wentwood and then classifying them according to colour using the soil classification chart of Metre.

In the study, surface samples were analysed separately to the subsurface samples. After sieving the surface and subsurface samples and comparing them (Figures 4.13 to 4.15), it was clear that particle size structure was closely related and the majority of the samples consisted of soil particles that were between 250 and 500 micro millimetres. When these figures were assessed according to the Wentworth soil scale (using the mean phi value), the surface and subsurface soils were classed as medium sandy soil. However, when calculating the phi mean, the surface average soil grain size was 333.3 and the subsurface was 583.3 microns millimetres indicating that the subsurface particles were coarser sandy soil than the surface soils (Figure 4.15).

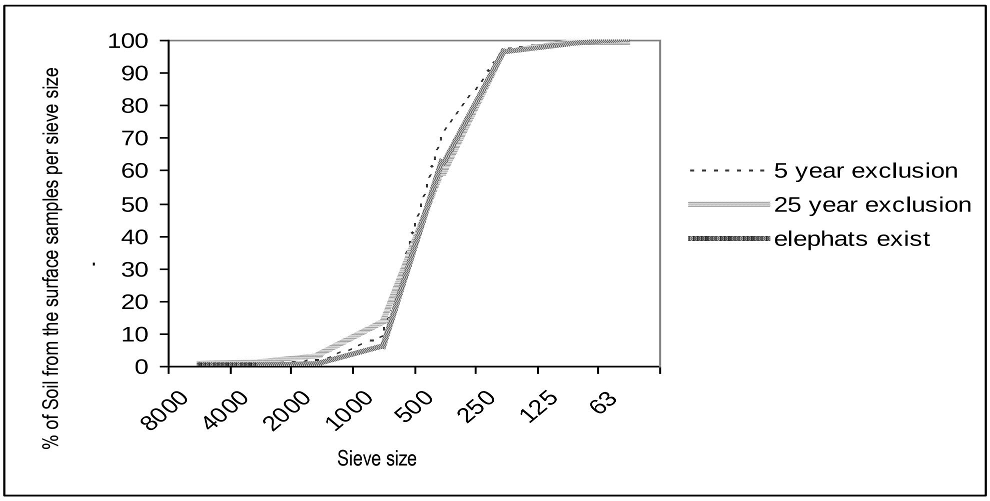

Figure 4.13 **Cumulative percentage of surface sample in each sieve size**

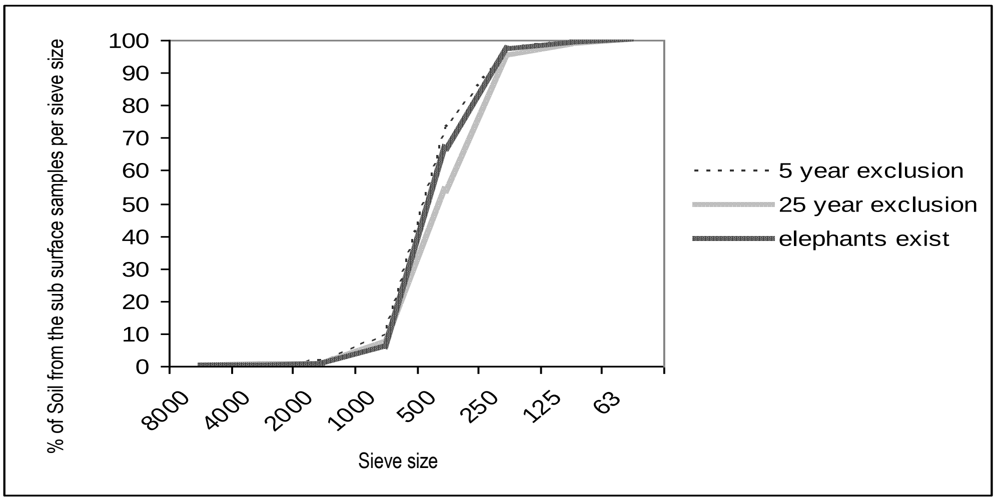

Figure 4.14 **Cumulative percentage of subsurface soil in each sieve size**

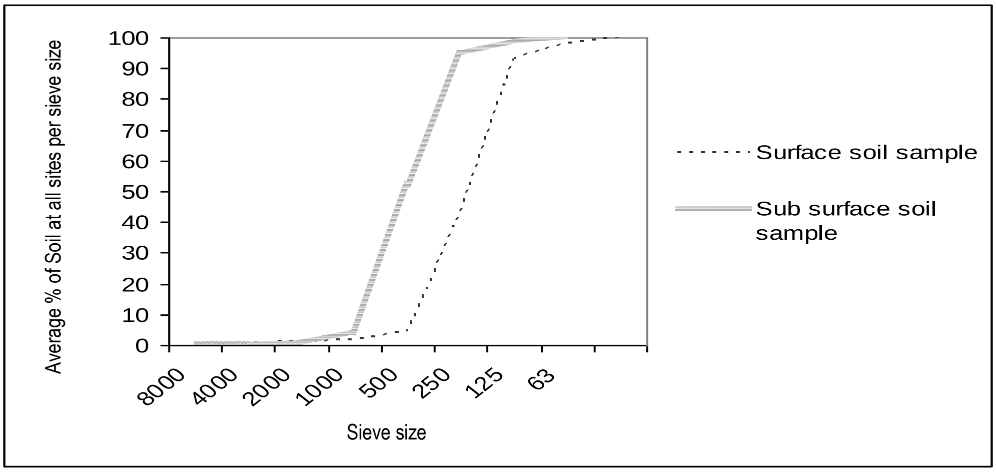

Figure 4.15 **Mean cumulative percentage of subsurface and surface soil samples in each sieve size**

When using phi values, once again the skewness of the samples was calculated to determine the greatest percentage of coarse or fine material. The skewness was calculated and the results showed that the samples collected on the surface (-4.9) and subsurface (-3.67) consisted of a high percentage of coarse materials. When using the Munsell Chart to classify the soils in the sand forest at all three study sites, the chart showed that the surface and subsurface soils at all three study sites were classed as Hutton soils. Once the abiotic and biotic variables of all the study sites were assessed, this study focused on the micro geomorphic differences between sand forest sites.

4.3 PHYSICAL AND CHEMICAL SOIL CHARACTERISTICS OF THE SAND FOREST

In assessing the physical and chemical characteristics of the sand forest soils, a number of tests needed to be conducted. In this research, compaction, infiltration, bulk density, soil temperature, soil relative humidity, pH, electrical conductivity and organic matter content was collected and analysed.

4.3.1 Compaction and infiltration

The results of measuring sheer strength and infiltration revealed trends regarding the greater the elephant occupancy, the greater the compaction and the lower the infiltration rate. Figure 4.16 indicates that where elephants are present, the terminal rate of infiltration was the lowest, at the twenty-five-year exclusion the highest and at the five-year exclusion terminal infiltration was marginally higher than where elephants are present yet much lower than where elephants have been excluded for twenty-five years.

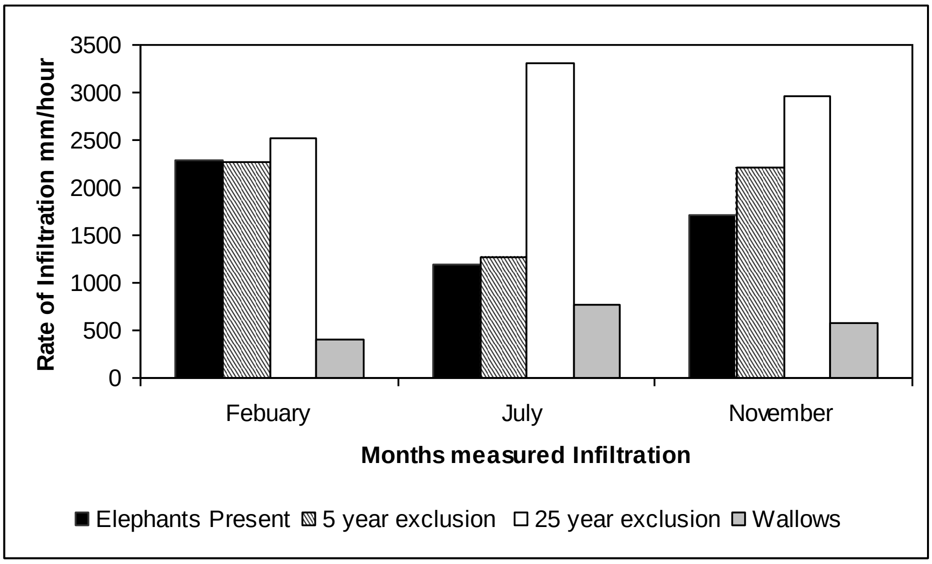

Figure 4.16 **Terminal rates of infiltration at all sand forest study sites (mm/hour)**

Figure 4.16 displays the opposite trend to Figure 4.15. In figure 4.17, where elephants are present the most compaction (where sheer strength was the highest) was present, the five-year exclusion was the next most compact (marginally less than where elephants are present, intermediate sheer strength) and the twenty–five-year exclusion study site was the least compacted (lowest sheer strength). This indicated that there is a relationship between compaction and infiltration thus the strength of the relationship was calculated.

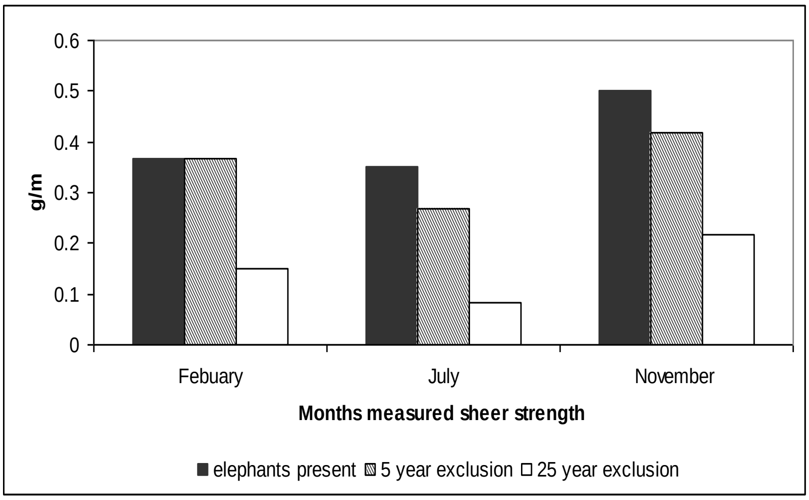

Figure 4.17 **Sheer strength at all sand forest sites**

In determining the relationship between compaction (sheer strength figure 4.17) and infiltration (figure 4.16) the data were graphed and the correlation coefficients were calculated. Figure 4.18 displays a trend that as compaction increased, infiltration decreased. When calculating the relationship between the total compaction and infiltration (n=16) at all three sites, there was a significant negative relationship between infiltration and sheer strength (r^2= -0.76), which proved implies that as compaction increased, infiltration decreased. When calculating the correlation coefficients between infiltrations at all the sites, there was a strong positive correlation between the five-year exclusion and where elephants are present. There was a strong negative correlation between where elephants are present and the twenty-five-year exclusion site. This shows that the infiltration rates, at the five-year exclusion site and where elephants are present, were insignificantly different, whereas the relationship between the other study sites was significantly different in rate of infiltration (Table 4.6). In calculating the correlation coefficient for compaction (sheer strength) between study sites, all the sites had a positive correlation where the r^2 value was greater than 0.5, revealing that there was a significant relationship between all the study sites (Table 4.6).

Table 4.6 **Correlation between infiltration & sheer strength between study sites**

Parameters (n=16)	Infiltration correlation coefficients (r^2)	Compaction correlation coefficients (r^2)
25 Year exclusion and 5 year exclusion	0.87	0.98
Elephants present and 5 year exclusion	-0.99	0.81
Elephants present and 25 year exclusion	-0.85	0.91

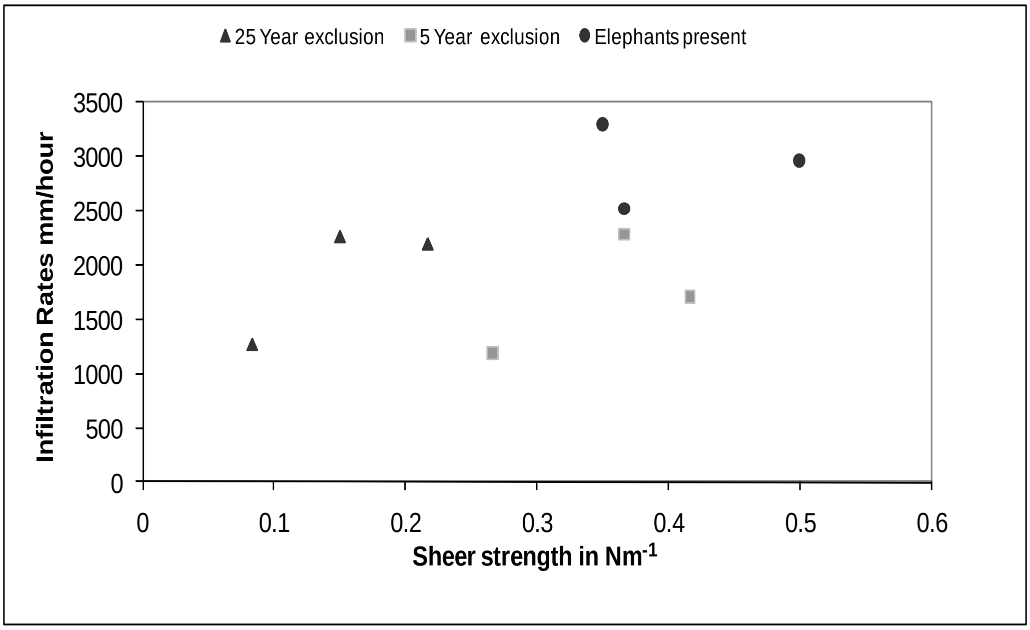

Figure 4.18 **Relationship between sheer strength and infiltration where n=16**

4.3.2 Bulk density and soil moisture

Density (the subsurface [20cm deep] undisturbed soil density) of the soil was marginally influenced by elephant frequency. In Figure 4.19 the bulk density displayed a trend related to elephant frequency. In areas where elephants are present, the samples weighed an average of 118g per 78.55cm^3, which resulted in 1.50 g/cm^3. In sites where elephants have been excluded, the longer the site has been without elephants, the less dense the soils were, but as Figure 4.18 shows, the density difference of each sample is marginal.

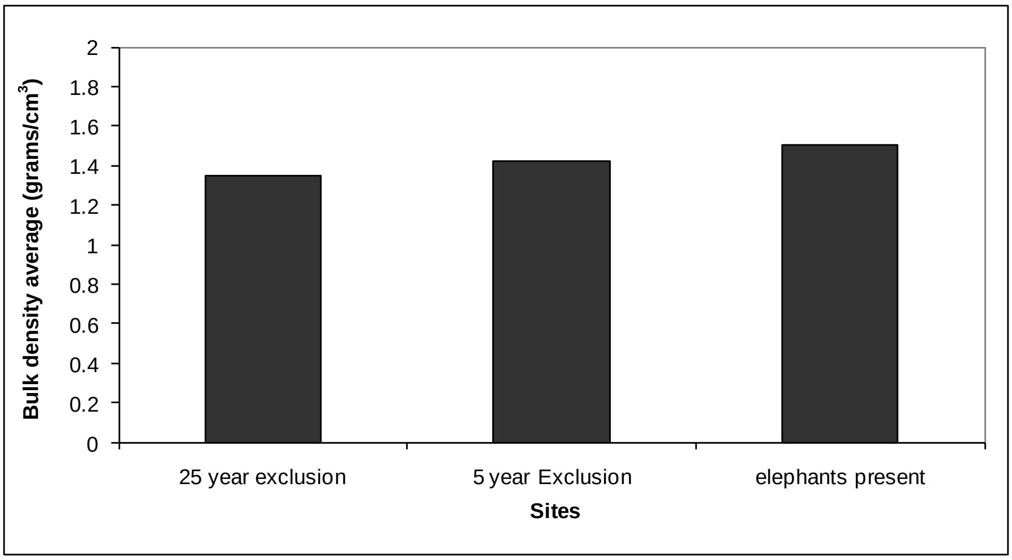

Figure 4.19 **Bulk density averages (gram/cm^3) at the sand forest sites**

Once the soil moisture was calculated from the wet and dry mass of the soil samples, a distinct difference in soil moisture was evident in the surface samples, but there was almost no difference in the subsurface samples. According to Figure 4.19, the average moisture percentage in the surface soil samples at the twenty-five-year exclusion was ±3% higher than the five-year exclusion and where elephants are present. The average moisture percentage of the surface soil samples where elephants are present and the five-year exclusion were almost identical, which shows there is little soil moisture content difference over five years of excluding elephants from a site. In the subsurface sample (20cm deep), all three study sites showed an insignificant difference in soil moisture (Figure 4.20), which suggests that frequency of elephants only affects the soil moisture content of the surface and not the subsurface.

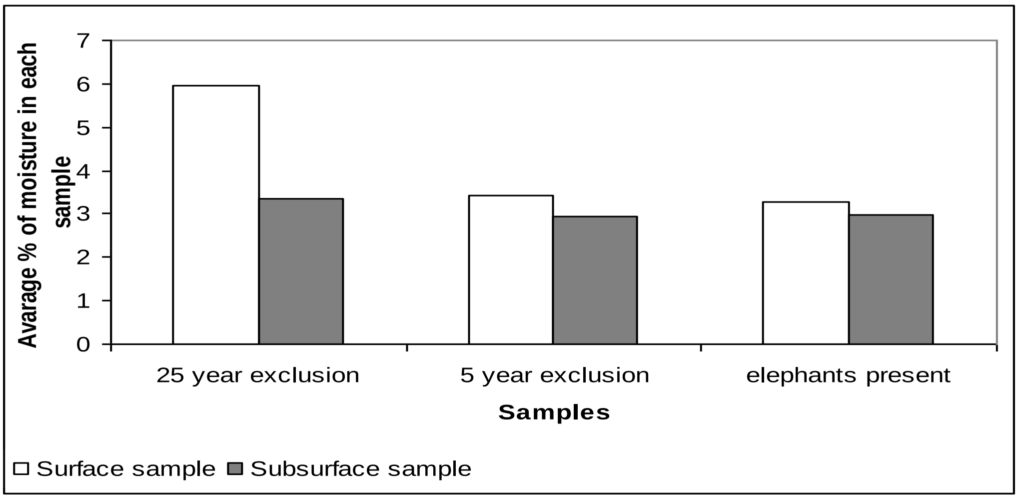

Figure 4.20 **Soil average moisture content of surface and subsurface soil of all three season sampling sessions at all three sand forest study sites**

4.3.3 Soil relative humidity and temperature

Soil humidity and temperature was measured at intervals of 5cm and 10cm in the soil as the results from the iButtons showed that measurements differed between study sites. Using these depths, showed a highly accurate measurement of moisture and temperature changes in the soils at 5cm and 10cm deep where elephants are present, five-years excluded and twenty-five years excluded from elephants.

In Figures 4.21 to 4.24, average soil relative humidity is displayed showing data from February 2008 to January 2009 (the duration of the sampling time), March 2008 (randomly selected month) and for 3rd March 2008 (one week in the selected month) to show the soil humidity at each site in detail) at 5cm deep in the soil. It is evident from these results that at the twenty-five-year exclusion the soil's relative humidity was constantly close to 100% and much greater than the five-year exclusion and where elephants are present.

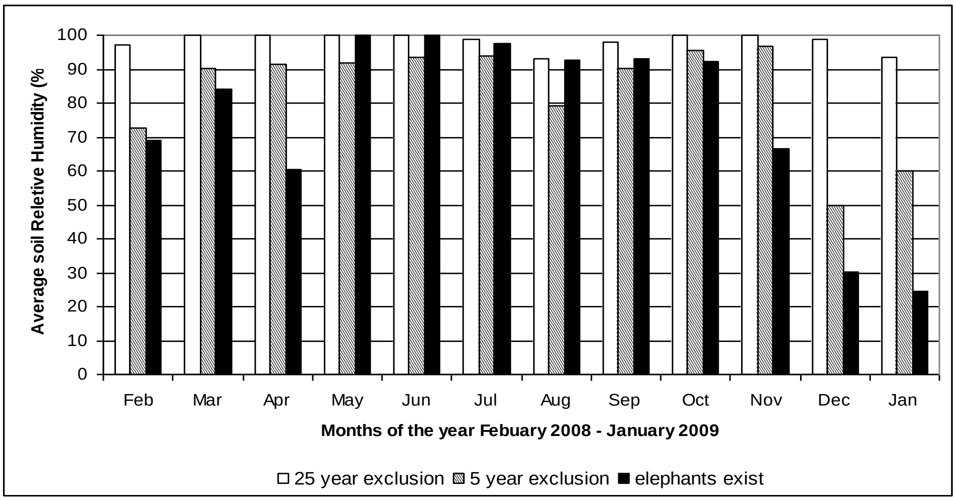

Figure 4.21 **Soil average relative humidity in the sand forest study sites using an iButton at 5cm deep from February 2008 to January 2009**

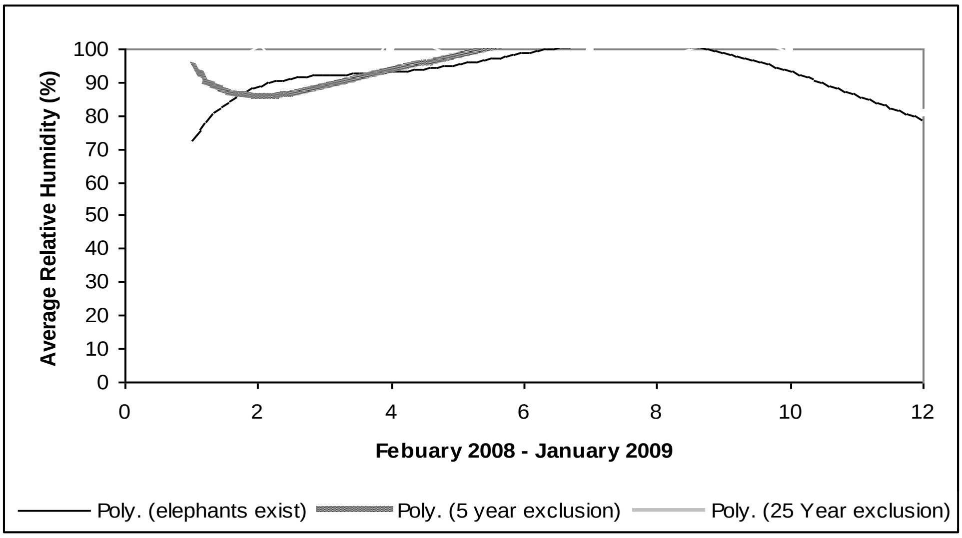

Figure 4.22 **Soil average relative humidity in the sand forest study sites using an iButton at 5cm deep from February 2008 to January 2009**
(site where elephants were excluded for twenty-five years displayed 100% soil humidity at all times)

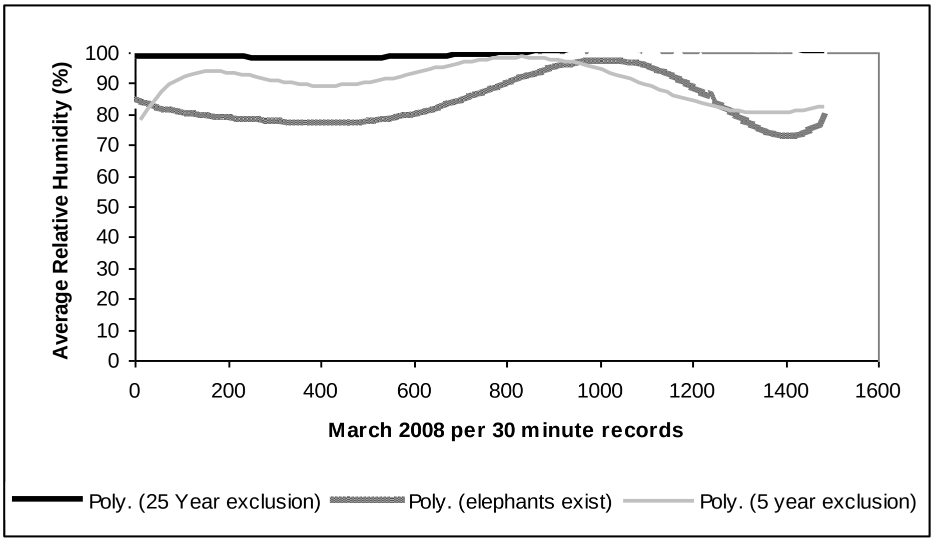

Figure 4.23 **Soil average relative humidity in sand forest study sites using an iButton at 5cm deep for March 2008**
(site where elephants were excluded for twenty-five years displayed 100% soil humidity at all times).

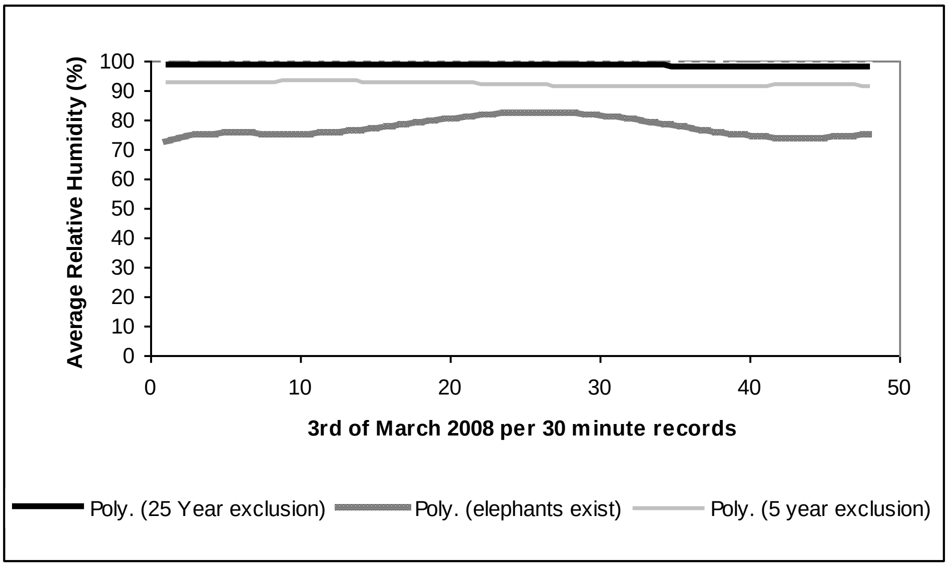

Figure 4.24 **Soil average relative humidity in sand forest study sites using an iButton at 5cm deep for 3rd March 2008**
(site where elephants were excluded for twenty-five years displayed 100% soil humidity at all times).

In Figures 4.25 to 4.28, the average soil temperatures are displayed showing data from February 2008 to January 2009, March 2008 alone and for the 3rd of March 2008 at 5cm deep. On average at the twenty-five-year exclusion, the soil temperature was the lowest and the five-year exclusion and where elephants are present, experienced hotter soil temperatures. The differences in temperature as a whole between study sites were only marginal.

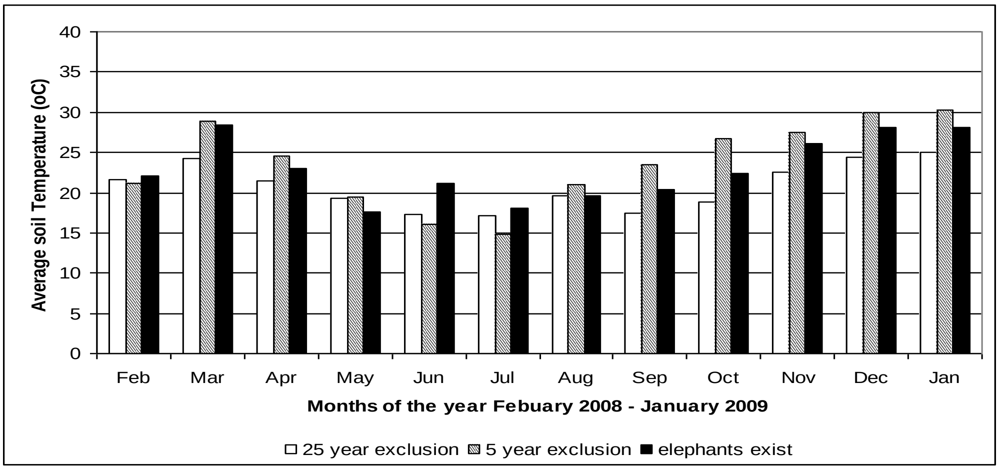

Figure 4.25 **Soil average temperatures (^{o}C) in sand forest at three study sites using an iButton at 5cm deep from February 2008 to January 2009**

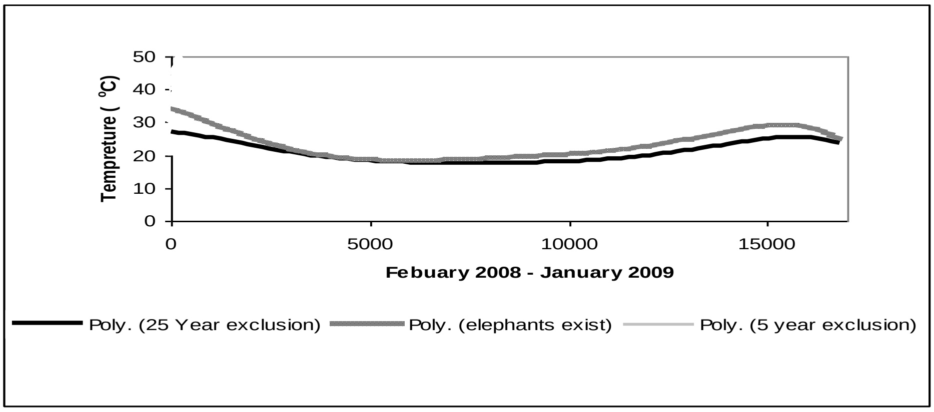

Figure 4.26 **Soil temperatures (^{o}C) in the sand forest at three study sites using an iButton at 5cm deep from February 2008 to January 2009**

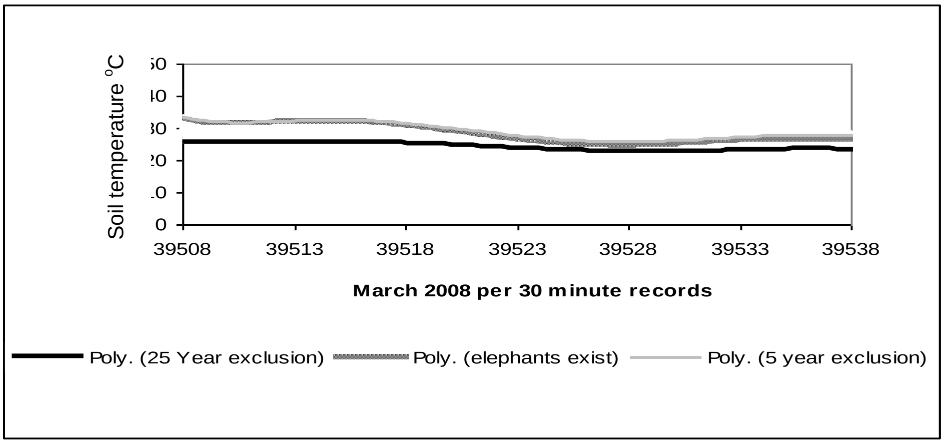

Figure 4.27 **Soil temperatures (^{o}C) in sand forest at three study sites using an iButton at 5cm deep for March 2009**

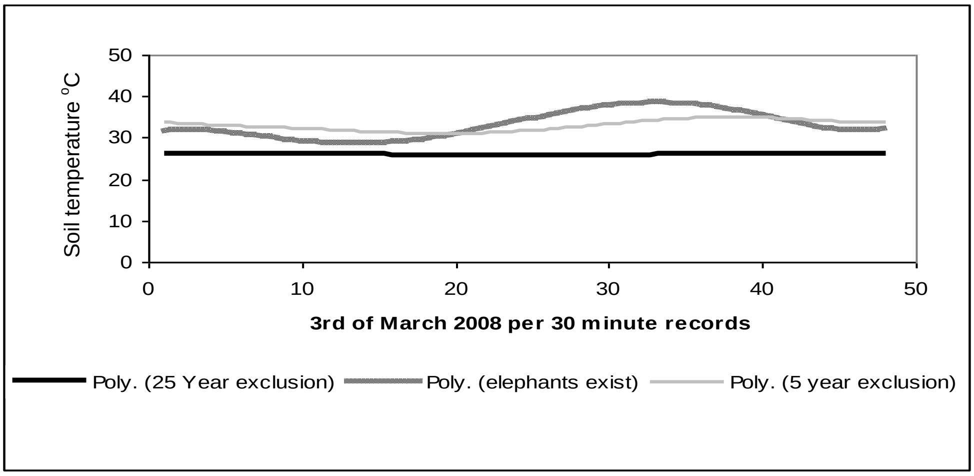

Figure 4.28 **Soil temperatures (°C) in sand forest at three study sites using an iButton at 5cm deep for 3rd March 2009**

In Figures 4.29 to 4.32, average soil relative humidity is displayed showing data from February 2008 to January 2009, March 2008 alone and for the 3rd of March 2008 at 10cm deep in the soil. It is evident that at the twenty-five-year exclusion the soil relative humidity was constantly in the high nineties and much greater than the five-year exclusion and where elephants are present.

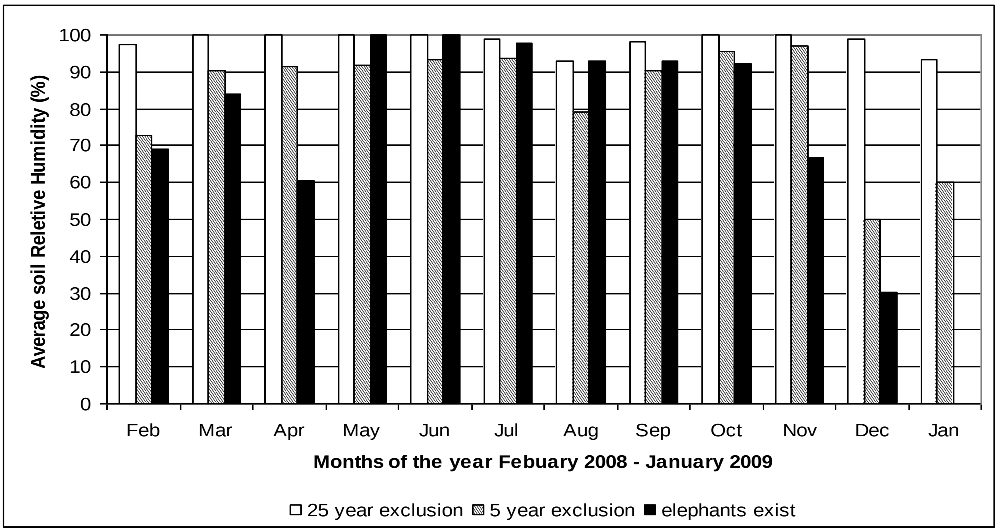

Figure 4.29 **Average relative humidity (%) in sand forest at three study sites using an iButton at 10cm deep from February 2008 to January 2009**

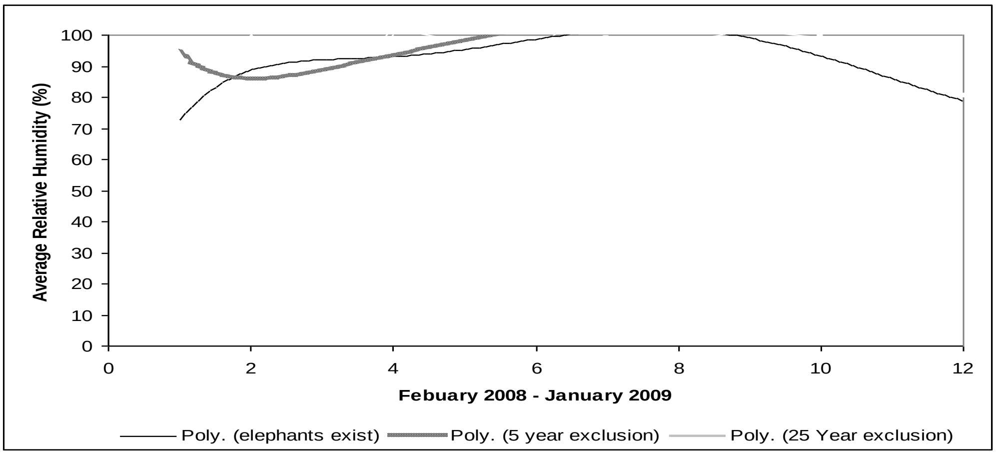

Figure 4.30 **Average relative humidity (%) in sand forest at three study sites using an iButton at 10cm deep from February 2008 to January 2009**

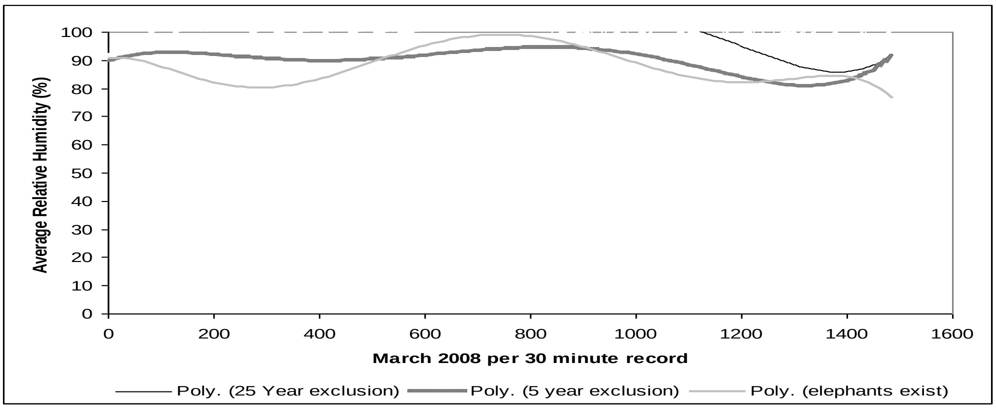

Figure 4.31 **Average relative humidity (%) in the sand forest at three study sites using an iButton at 10cm deep for March 2008**

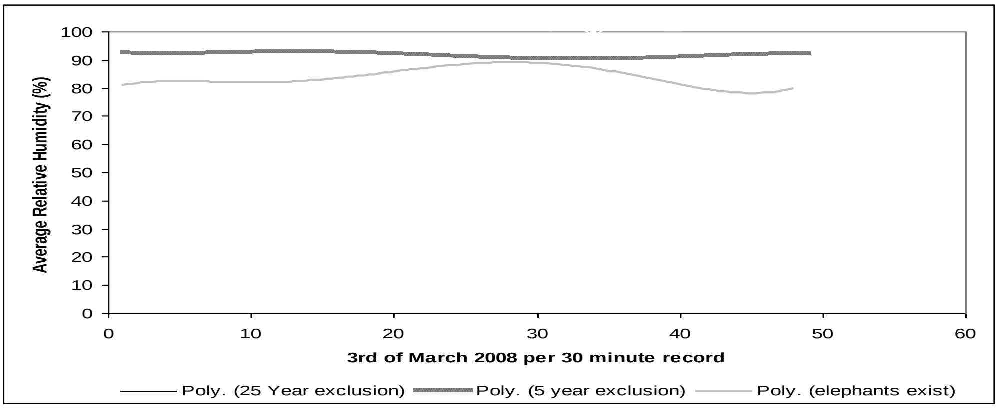

Figure 4.32 **Average relative humidity (%) in the sand forest at three study sites using an iButton at 10cm deep for 3rd March 2008**

In Figures 4.33 to 4.36 the average soil temperature is displayed showing data from February 2008 to January 2009, March 2008 alone and for the 3rd of March 2008 at 10cm deep in the soil. On average at the twenty-five-year exclusion, the soil temperature was the lowest and the five-year exclusion and where elephants are present experienced hotter soil temperatures. Upon analysing the differences in temperature as a whole between study sites, the temperature differences between study sites were only marginally different.

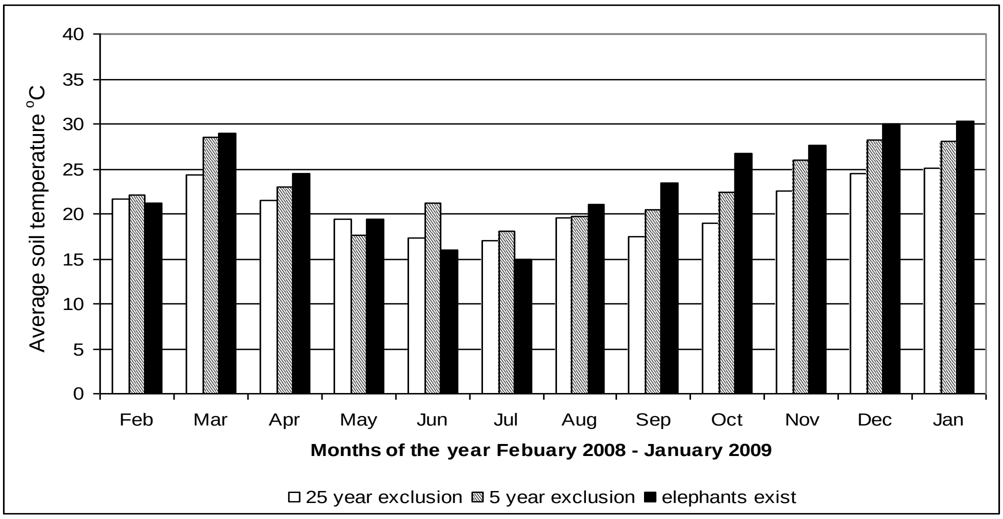

Figure 4.33 **Soil average temperatures (°C) in sand forest at three study sites using an iButton at 10cm deep from February 2008 to January 2009**

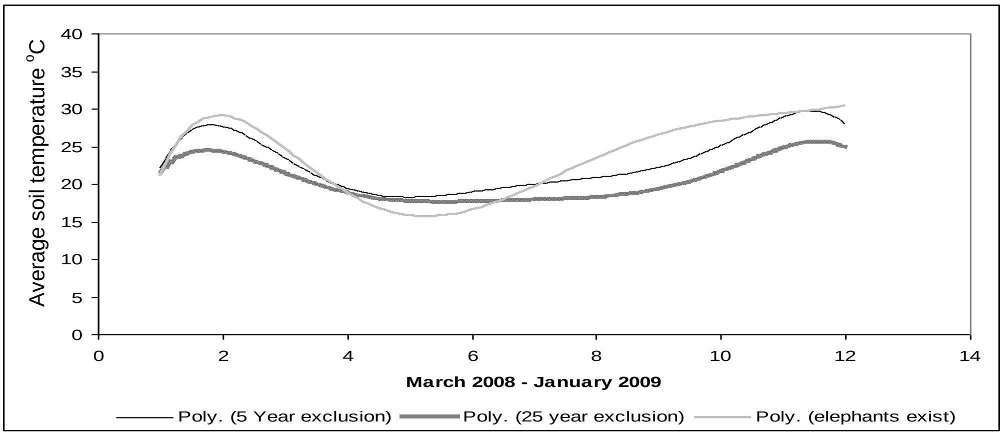

Figure 4.34 **Soil average temperatures (°C) in sand forest at three study sites using an iButton at 10cm deep from February 2008 to January 2009**

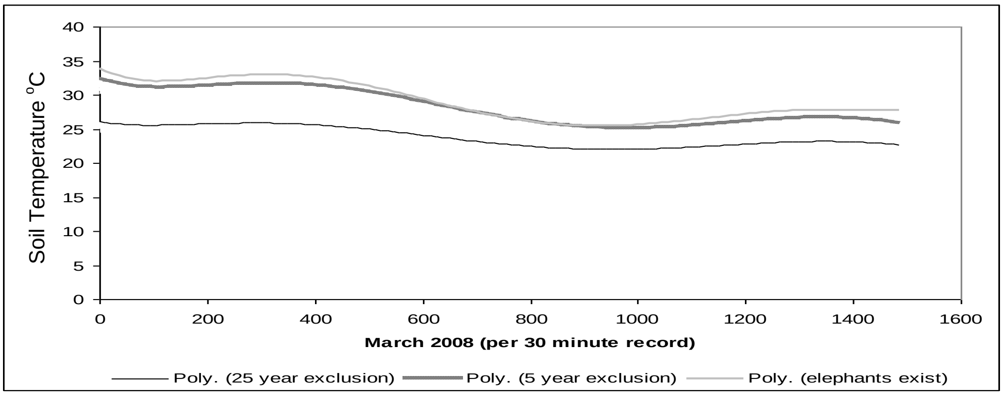

Figure 4.35 **Soil temperatures (°C) in sand forest at three study sites using an iButton at 10cm deep for March 2008**

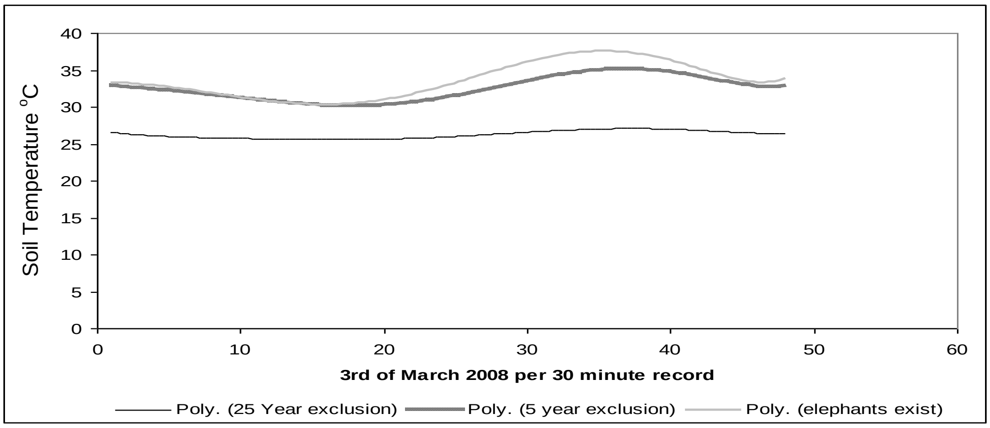

Figure 4.36 **Soil temperatures (°C) in sand forest at three study sites using an iButton at 10cm deep for 3rd March 2008**

The trends displayed in the soil temperature and relative humidity illustrate a gradient change related to the presence of elephants (where elephants are present, the soils have the highest temperature and the lowest relative humidity of all the sand forest study sites; where elephants have been excluded for twenty-five years the soil's relative humidity was the highest and the temperature was the lowest of all the sand forest study sites; where elephants have been excluded for five years illustrated intermediate results of all the sand forest study sites). The next microclimatic factors, which were analysed to aid in achieving the objectives (the soil physical and chemical properties in the sand forest) of this study, were the pH and the electrical conductivity.

4.3.4 pH and electrical conductivity

pH and electrical conductivity was measured in each soil sample to identify the chemical (acidity and salinity) differences in the soil between all three sand forest sites.

4.3.4.1 pH

It is evident that after testing (360 samples) the pH in the sand forest, the soil was acidic throughout all the study sites but elephant frequency and activities had affected levels of pH. In Figure 4.37 it is clear that there was a dramatic pH variation between study sites. Where elephants are present the pH was the least acidic and at the twenty-five year exclusion the pH was the most acidic while the five-year exclusion had an intermediate acidity. There was a difference between surface soil samples and subsurface soil samples. pH at the surface samples was less acidic than the subsurface soil samples.

When calculating the relationship between the surface and subsurface soil samples, the average pH per season (n=18 (9x surface and 9y subsurface) at all three study sites had an average strong positive correlation (0.95). There was a strong positive correlation in the pH between study sites, namely a correlation coefficient of 0.77 for the relationship between the twenty-five-year exclusion and the five-year exclusion, between the five-year exclusion and where elephants are present the correlation coefficient is 0.99, and a correlation coefficient of 0.80 between the twenty-five-year exclusion and the five-year exclusion. All these results indicate that there was a strong relationship between the sites and the acidity of the sites, and that elephant frequency alters the pH. The relationship calculated between sites affected the electrical conductivity of the soil in addition to pH.

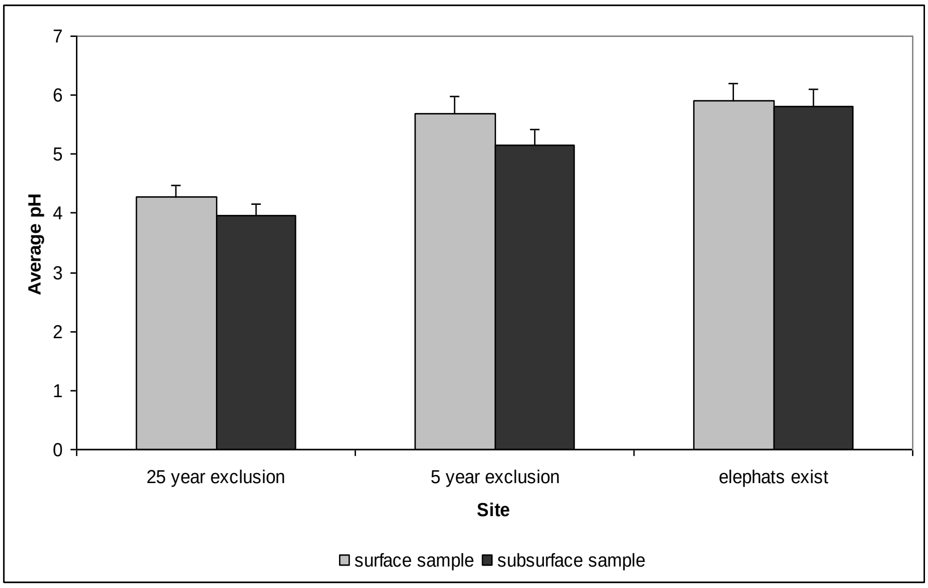

Figure 4.37 **Average pH for all the soil samples taken (n=360) throughout the year (2008) at all study sites in the sand forest**
(error bars were set at 5%)

4.3.4.2 Electrical conductivity

It is evident that after testing the electrical conductivity in the sand forest, elephant frequency and activities have affected the salt levels in the soil. According to Figure 4.38, there is a variation between study sites. Where elephants are present the electrical conductivity of the soils is lower than at the twenty-five-year exclusion, while the five-year exclusion displayed intermediate results. There was a difference between surface samples and subsurface soil samples as far as electrical conductivity was concerned. The surface samples had a higher electrical conductivity than the subsurface soil samples.

The relationship between the electrical conductivity in surface and subsurface soil samples (n=16, 9x surface and 9y subsurface values were used 3x and 3y at each site) at all three study sites displays a strong positive correlation (average of all correlations calculated from the three sites, 0.99). With regard to comparing the average correlations, at each study site, the electrical conductivity between sites, the relationship was 0.95 between twenty-five-year exclusion and five-year exclusion, 0.99 between the five-year exclusion and where elephants are present, and 0.97 between the twenty-five-year exclusion and the five-year exclusion. These results indicate that there is a strong relationship between the sites and the electrical conductivity of the sites and that elephant frequency alters the electrical conductivity and pH.

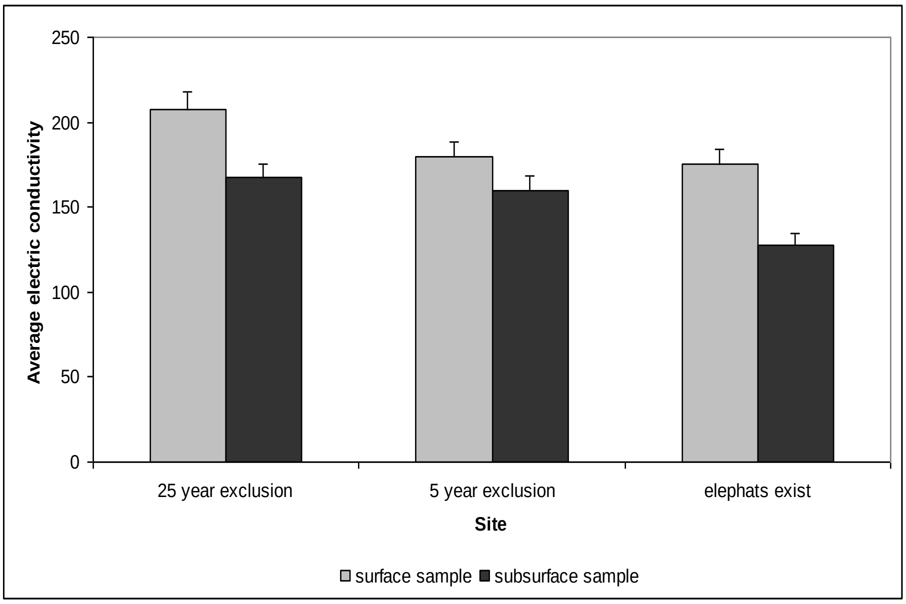

Figure 4.38 **Average electrical conductivity for all soil samples taken (n=360) throughout the year (2008) at all study sites in the sand forest**

4.3.4.3 Relationship between pH and electrical conductivity

The relationship between pH and electrical conductivity is evident in the surface and subsurface soil samples at each study site. When acidity increases in the samples, electrical conductivity increases (Figure 4.39). In calculating the relationship between the ph and electrical conductivity in the average surface samples (n=18, 9x surface and 9y subsurface values in total were used), it was established that there is a significant average correlation (-0.59). The average subsurface soil samples (n=18 (3x and 3y values were used) at each study site showed the same trends and the relationship between them was similar (0.57) to the surface samples. The only difference between the surface and the subsurface was that the subsurface samples were slightly more acidic and had a higher electrical conductivity than the surface samples (Figure 4.40).

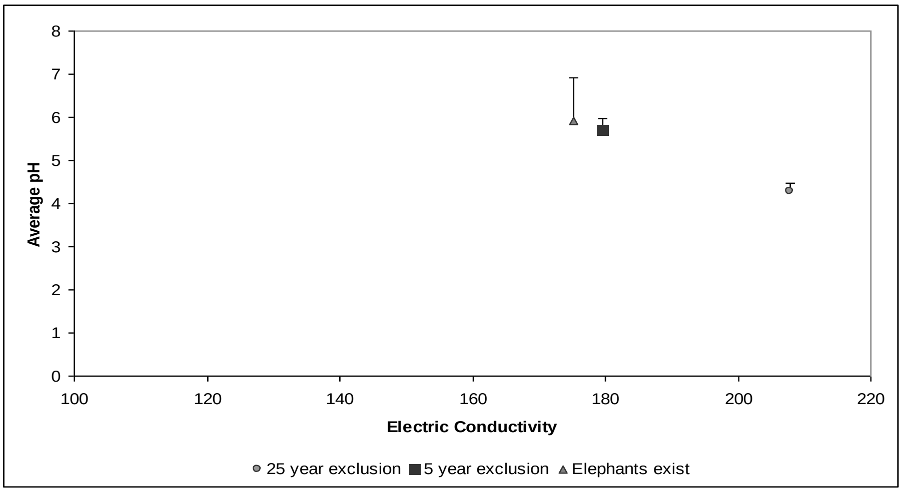

Figure 4.39 **Relationship between average pH and electrical conductivity of the surface soil samples at all three sand forest sites**

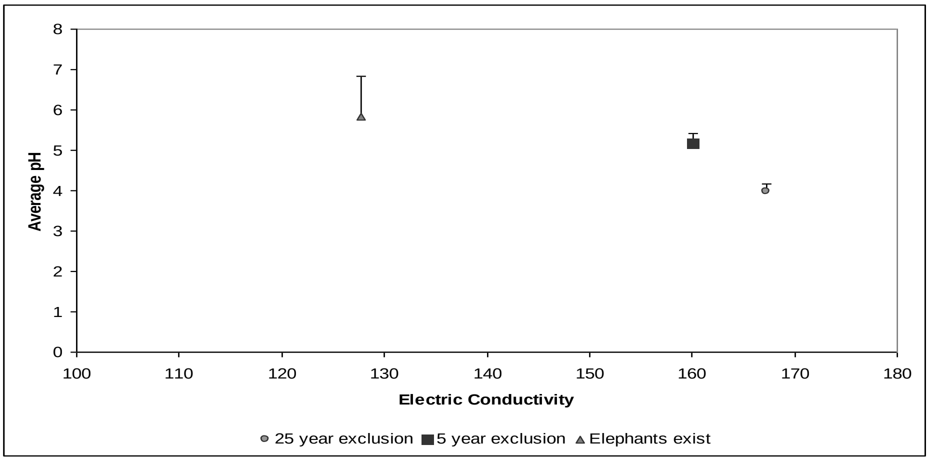

Figure 4.40 **Relationship between average pH and electrical conductivity of the subsurface soil samples at all three sand forest sites**

4.3.4.4 Organic matter content in the soil

Organic matter plays a crucial role in the cycling of nutrients in the soil. In analysing the organic matter content in the soil at all sand forest sites (Figure 4.41), it was found that the organic matter in the samples was highest in the twenty-five-year exclusion and the lowest where elephants are present and at the five-year exclusion. The five-year exclusion had slightly higher organic matter content than where elephants are present (2%).

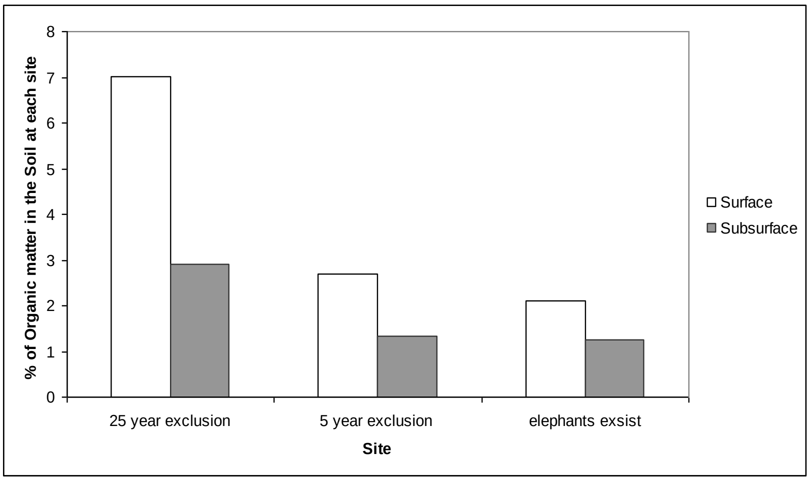

Figure 4.41 **Organic matter content in the soils**

4.4 CONCLUDING COMMENTS

In summary, the data, trends and results quantified the macro geomorphic impact of elephants, identified differences (air micro climate, vegetation, soil microclimate, soil physical and chemical properties) in the sand forest sites and outlined the geomorphic alterations caused by elephants on TEP. The results from this entire study thus displayed trends of elephant presence and the influence elephants have on the landscape change. This influence can be quantified.

Chapter 5
DISCUSSION

The geomorphic impact of elephants on Tembe Elephant Park (TEP) was assessed with the environmental variables. To achieve the aim of this research first, the macro geomorphic (visible landscape features changes caused by elephants) features were assessed and measured (elephant wallows) in order to quantify sedimentary changes from January to November 2008. Second, abiotic and biotic elements of the sand forest sites were analysed to identify differences in the environmental variables (micro climate, rainfall, vegetation and soil) to investigate whether the changes occur within the sand forest area related to elephant activity. Last, the micro geomorphic (non visible landscape changes in sediment properties) changes in the sand forest were determined, through analysing physical and chemical characteristics of the soils.

The assessments and experiments in this study were used to determine the validity of the aim and objectives. The aim was achieved by through applying and understanding the objectives of this study (to study the general topography of the area, climate, vegetation, soil and animal interaction, which involves the site description of the general area; to determine the rate of geomorphic alteration [macro geomorphic change] at the water points by mapping and measuring elephant wallows; to analyse the micro environments [micro climate, air temperature and humidity and rainfall, vegetation and soil [soil type and soil micro climate] in the sand forest study areas with elephants being one of the variations between the sites; and to identify soil property changes in sand forest [physical and chemical] caused by elephants.). The results of this study have therefore facilitated an understanding of the landscape changing abilities of elephants on TEP.

The fundamental impetus for this research was based on an interest in the contribution of animals to changing the landscape and being geomorphic agents. Animal activity actions that cause landscape alteration initiated zoo-geomorphology (the study of how animals change or alter the landscape). Prior to discovering the interaction between animals and the landscape, the progression to researching zoo-geomorphology was slow under geomorphology but was established in other disciplines (Renschler *et al*., 2006). There are many different disciplines that have researched the geomorphic impact of animals, causing other factors to be the focus of the study and not only geomorphology. The lack of understanding the geomorphic impact of animals, results in not completely identifying the relationship between abiotic and biotic elements on the earth and how they function as a system. Consequently, in order to understand the importance of the geomorphic role of animals, it is imperative to identify and quantify the geomorphic role of animals. This study recognises the need to identify and analyse the geomorphic changes caused by elephants on Tembe Elephant Park (TEP), but at the outset, the ability of the elephants to change the landscape, needed to be identified and described.

The impact elephants have on the environment has been observed and recorded with the primary focus being on vegetation and not geomorphology. Kerley *et al*. (1999) studied the effects browsing on succulent plants by elephants and goats have on the soils in Addo Elephant Park. This study showed that when elephant populations increased, runoff increased (a consequence of soil compaction and water repellent soils) (Kerley *et al.*, 1999). Laws (1970) recorded how elephants alter the landscape; Butler, (2006) described the geomorphic impact of elephants' wallows; Cumming and Cumming (2003) quantified the theoretical trampling impacts of elephants; and Chamaillé-Jammes *et al*. (2007) evaluated the 'piosphere' effect of elephants on surrounding waterholes (in Hwange National Park, Zimbabwe) using vegetation cover as the indicator. All these studies have not addressed the geomorphic impact of elephants adequately so that a quantification of their impacts to the landscape may be known, however, the alterations may not have been quantified but have been described qualitatively (Butler, 1995). Elephants are responsible for geomorphic alterations through macro (visible changes to the landscape) and micro (no visible changes such as physical and chemical property changes of soils in the landscape) geomorphic change, which have been described by Flint and Bond (1968), Weir (1969), Laws (1970), Pullan (1979), Skinner and Smithers (1990) and Butler (1995). The geomorphic alteration described in the literature were as a result of elephants uprooting vegetation, pushing over trees, using trees and rocks as rubbing posts, creating paths, geophagy, dust bathing and wallowing.

5.1 MACRO GEOMORPHIC ALTERATIONS: ELEPHANT WALLOWS

Elephants dust bathe and wallow to keep them cool, protected from the sun and to reduce parasites (Flint & Bond 1968; Skinner & Smithers, 1990). The geomorphic impact described of when elephants wallow, is that the animals cause clay to be compacted through trampling and deflation (Butler, 1995). In this study on TEP, wallows were mapped and measured to determine the rate of change through 'hollow deflation', which also causes clays to be compacted. The compaction seals the earth's surface, which causes impervious zones of depressions that form ponds. Flint and Bond (1968) estimated that an individual elephant eroded $0.31m^3$ of sediment every time they wallowed in Ayeni, Zimbabwe. In Kenya, Thomas (1988) [in Butler (1995)] reported that elephant wallows range in size between $0.45Km^2$ and $0.49\ Km^2$ and were on average 200m in size. Neither of these studies quantified change over time. As deflation contributes to the size and extent of wallows, other factors, in addition to the deflation, contribute largely to the formation of pans, namely, trampling, drinking and geophagy (Flint & Bond 1968; Skinner & Smithers, 1990; Butler, 1995).

Laws (1970) and Skinner and Smithers (1990) explained that elephants trample areas, through wallowing and path creation. Compacted surfaces on TEP begin with the paths, which lead to Matlhasela. The elephants' action on the surfaces causes the soils, on paths and at the wallows, to be highly compacted and susceptible to erosion (soils become impervious, causing water to pool, thus increasing runoff along paths and into wallows) (Laws, 1970; Skinner & Smithers 1990). Geophagy in addition to wallowing, dust bathing and trampling influences the geomorphology of an area (Flint & Bond, 1968).

Flint and Bond (1968) described how elephants ingest soils and have a preference for saline rich soils to increase the mineral intake, which influences the removal of soil. In 1971 the Tsavo National Park, Kenya, experienced a decrease in termite mounds as the elephant population increased since elephants were eating the soils of termite mounds in addition to using mounds as rubbing posts (Pullan, 1979; Butler, 1995). This ingestation of soil by elephants was seen while elephants were wallowing at Matlhasela on TEP, which may influence the rate of wallow creation, but the focus of determining the macro geomorphic impact of elephants in this study was to map and qualitatively analyse the wallows and the elephant action at the wallows.

Although research into the mapping and measuring of the wallows has not been conducted in South Africa in the past, the description of the elephant wallows and the behaviour of the elephants at the wallows have been reported. By conducting this research on the measurements and calculations, which were undertaken at the wallows and the observations concerning the behaviour of elephants at wallows, it was possible to reach a greater understanding of the exact extent of landscape change as a result of elephant activity at the Matlhasela water hole (Flint & Bond, 1968; Skinner & Smithers 1990; Butler, 1995). When mapping the elephant wallows at Matlhasela, it was calculated that the average area covered by the wallows exceeded that of Thomas

(1985) [in Butler (1995)] in Kenya. The total set of elephant wallows measured at one site on TEP was 2.69km^2 in extent.

Using Flint and Bond's (1968) figures to calculate how many times elephants had wallowed at Matlahsela, aproximately 6500 wallowing events had taken place since the establishment of the park and 170 monthly since January to November 2008. Using these figures indicates that there is a high population of elephants in the area and that different environmental factors (elephant frequency, elephant numbers, water supply, rainfall, soil type, humidity, temperature and topography) could cause or influence the extent (sizes and depth), the rate at which these features could form and the time taken for them to expand as the figures differ extensively from Thomas (1985) [in Butler (1995)] in Kenya. After mapping, measuring and quantifying how many wallowing events had taken place, the size, extent and area covered by wallows at Matlhasela, the elephants' actions at the wallows were qualitatively analysed.

The elephants at Matlhasela were seen to create paths (the impact of paths is similar to the effect of the compaction in elephant wallows and has been described above) uprooting and displacing vegetation, digging in the wallows to increase mud abundance for the wallow to take place and using trees as rubbing posts. Elephants have been described as mixed bulk grazers (eat grass, trees and shrubs in large quantities and are not selective in what they eat), which remove vegetation from the soil or off the host plant or pushing trees over causing them to be uprooted. When vegetation is removed from the ground or trees are pushed over, the soil is disturbed, exposed and vulnerable to weathering and erosion (exposed soils are dried out by the sun and become water repellent, therefore runoff increases and infiltration is reduced and the roughness of the surface is, in addition, reduced which accelerates runoff, and the soils are exposed to wind erosion) (Skinner & Smithers, 1990; Butler, 1995*).*

When elephants wallow at Matlhasela, they rubbed themselves on trees to reduce parasites. As a result, the mud and dust, which collected on the animal's body is attached to the rubbing post or deposited in the area of the rubbing post. This causes a build up of sediment in the general area and on the object that the animal has rubbed itself on (Skinner & Smithers, 1990). The qualitative results showed how elephant activity has an influence on landscape alteration on TEP.

After mapping, measuring, calculating and qualitatively analysing the wallows at Matlhasela on TEP, it is evident that the macro geomorphic impact of elephants can be quantified and described as it was done in this study.

5.2 ASSESSING THE VARIATION OF STUDY SITES

The microclimate, vegetation and soil function together in a system thereby influencing one another. In this study soil type has been shown to be the same, the microclimate is marginally different (humidity variations) and the vegetation structure (basil cover and canopy cover) is significantly different throughout all the study sites. The microclimate consists of the air temperature, relative humidity and rainfall. Relative humidity between the different study sites showed a marginal difference between sites. It has been displayed in the results of this study that relative humidity is greatest where elephants are present and least at the twenty-five-year exclusion site. Vegetation coverage (surface and canopy) between sites was found to be the lowest where elephants are present and the highest at the five-year exclusion site, but the twenty-five-year exclusion had the most canopy cover of all the sites. Microclimatic differences in this study can be attributed to destruction of vegetation and grazing pressure.

There are two reasons for the change in relative humidity between study sites - grazing pressure and canopy cover (Chazdon and Fetcher, 1984; Kauffman, 1990; Yates *et al.*, 2000). According to Yates *et al*. (2000), the effect of grazing on plant cover, soil and microclimate in fragmented woodlands in south-western Australia was determined and they found that in areas that had been grazed, the daily relative humidity ranges were marginally higher, soil temperature was greater, soil moisture was lower and air temperature remained constant.

Kauffman (1990) reported in a study on vegetation variation (deforestation, fire response and tree response) conducted in Brazil that areas that were forested had a higher relative humidity than open grassland sites. Aussenac (2000) determined that regardless of vegetation cover, relative humidity remains constant. Both these studies show that the grazing pressure where elephants are present has marginally adjusted the relative humidity and not the change in vegetation cover.

To investigate vegetation, basil cover was calculated, and canopy cover height and structure was analysed. The results were compared using the ranking system explained by Edwards (1983). It was found that the twenty-five-year exclusion zone was classed as a tall forest, the five-year exclusion as short closed woodland, and where elephants exist and where they wallow, it was classed as short open woodland. The canopy cover showed different trends. Where elephants were excluded for twenty-five years the canopy was the most dense, the five-year exclusion zone was the next dense and where elephants exist, the wallow site had the least dense canopy cover. Canopy height revealed similar trends to the canopy cover, as the twenty-five-year exclusion had the highest canopy, the five-year had a varying intermediate canopy height and where elephants exist and at the wallow site the canopy was low. The structural classification of the sites was the last vegetation variation testing conducted and this is made up of the basil cover, canopy cover and canopy height and the structure and shape of the vegetation.

The vegetation variation displayed trends of animal frequency and where elephants are present, the vegetation cover was the highest, vegetation height and canopy cover was the lowest. At the twenty-five-year exclusion site, the vegetation cover was the lowest but canopy height and canopy cover was the highest while the five-year exclusion displayed intermediate results. The change in vegetation cover can be attributed to animal and elephant activities. The results of this study show that the vegetation cover at the sites influences the physical and chemical properties of the soil with differences at each site.

Vegetation growing in the soil has the ability to change the physical and chemical structure of the soil, which alters the landscape (Viles *et al*., 2008). Physically, vegetation growing in the soil causes the surface of the soil to become rougher (the roughness of the soil increases the infiltration potential of the soil as runoff is slower) (Carey, 2006). Vegetation needs water to survive and as a result large amounts of vegetation growing in one area can have an effect on the water table, causing a change in the physical properties of the soil. Vegetations intricate root system binds soil together causing the potential for erosion to be reduced, the water retention capacity to increase, increasing percolation (increased pore spaces in the soil) and reducing runoff (Jacobsen, 1987; Liu *et al.*, 2003; Castellano & Valone, 2007). Vegetation abundance increases organic matter, decreases bulk density and increases infiltration in mosaics of Mediterranean vegetation in southeast Spain (Bochet *et al.,* 1999). The carbon and nitrogen relationship in the soil between ungulates and the landscape alters soil moisture and temperature, which is influenced by vegetation (mulch, surface and subsurface vegetation), and the rate of mineralisation in the soil is influenced by vegetation (Frank & Groffman, 1998; Freifelder *et al*., 1998). In duplex soils, a high vegetation cover increases infiltration and causes subsurface erosion (soil pipes) (Bryan & Jones, 1997).

Chemical changes and pH in the soil are influenced by vegetation growing and organic matter (reduction of vegetation into the soil) decomposing in the soil and a low frequency of grazing in areas with sandy soil cause the acidity to increase. The acidity increase displaces minerals in the soil causing the salination of the soil to increase, which also increases the electric conductivity (Hiernaux *et al*., 1999; Li & Rengel, 2007). Heirnaux *et al.* (1999) analysed the rate of vegetation cycling in the soil (from vegetation to organic matter to minerals) and found that soil texture influenced the rate of vegetation breakdown into the soil (the courser the soil, the faster the organic matter cycles through the soil). Upon analysing soil texture in this study, Wentworth's scale described the soils at all study sites on TEP and Tshanini as being medium to coarse-grained sandy soil.

As elephants are the controlling factor of this study, the vegetation destruction and alterations can be largely as a result of elephant activities since they destroy vegetation cover through grazing, browsing and pushing down trees (Flint & Bond, 1968; Weir, 1969; Laws 1970; Pullan, 1979; Skinner & Smithers, 1990; Butler, 1995) and the soil type and texture is using the vegetation changes to accelerate the physical and chemical changes in the soil.

5.3 PHYSICAL AND CHEMICAL SOIL CHARACTERISTICS OF THE SAND FOREST

An analysis of the physical and chemical characteristics in the sand forest was conducted to achieve the final objective of this study, namely to determine the geomorphic impact of elephants on TEP.

5.3.1 Compaction, infiltration, bulk density, soil temperature and moisture functioning together as a system

The results of this study display a relationship between compaction, infiltration, bulk density, soil temperature and soil moisture. This study showed that as compaction decreases infiltration and soil moisture increase, bulk density in the subsurface remains constant and soil temperature decreases with a decrease in soil moisture. The surface and subsurface showed the same patterns (as compaction and infiltration) in the data except that the percentage of soil moisture and bulk density in the subsurface showed that all sites were the same regardless of elephant activity. Some of the patterns in the data can be related back to elephant frequency. Where elephants are present, the study site is the most compacted and at the twenty-five-year exclusion study site the compaction is the lowest; the-five year exclusion study site shows trends similar to where elephants are present but with intermediate results. These relationships have been identified in many studies of soil physical properties and changes.

Phillips (2003) calculated that when compaction increased, the infiltration rate decreased as the water absorption potential decreased, and runoff increased. Lal (1998) looked at the influence of compaction and bulk density on plant growth. The results of his study showed that as compaction and bulk density increased, infiltration decreased and root growth was reduced (Lal, 1998; Phillips, 2003). Castellano and Valone (2007) conducted infiltration, compaction and bulk density tests in an arid area to quantify the geomorphic change caused by livestock. This study showed that animals cause soils to become compacted, which cause the bulk density to increase and infiltration rates to decrease as a result of animal interaction with the landscape. The study concluded by stating that the frequency of domestic animals contribute considerably to land degradation (Castellano & Valone, 2007). Thrush (1997) observed and measured the piosphere effect in the Kruger National Park. It was found that when bulk density and infiltration was measured at a distance from water, infiltration increased and the density of the soils decreased the further they sampled from the water's edge (Thrush, 1997). All these studies identify the relationship between infiltration, compaction and bulk density.

Thrush (1997) and Castellano and Valone (2007) encountered the same trends as the present study did, whereby the presence of animals caused the infiltration, compaction and bulk density of the soil to be altered. Martin and Bolstad (2005) conducted a study on the annual soil respiration in broadleaf forests of northern Wisconsin and focused on how moisture influenced the biological, chemical and physical characteristics of the soil at the sites. They concluded that soil temperature and moisture is related to compaction and infiltration rates of the soils. Their study showed the same trends as this study, namely when compaction increases, infiltration and soil moisture decreases which cause an increase in soil temperature.

As all sand forest sites variables were and are similar (vegetation change differed because of elephant activity but the microclimate, rainfall and soils were only marginally different) and except for elephants, one can conclude that elephants are responsible for the amount of infiltration and compaction in the soil in the sand forest on TEP.

5.3.2 pH, electric conductivity and organic matter interact and impact each other

There is a clear gradient in soil chemical property (pH and electric conductivity) changes from the site where elephants are present to the site where they have been excluded for twenty-five years. From this study it is clear that pH, electric conductivity and organic matter in soil function together to determine the dynamics of the nutrient cycle (when organic matter increases in the sand forest on Tshanini and TEP, the acidity and the electric conductivity increase).

pH, electric conductivity and organic matter function together as a system in soil to determine the dynamics of the nutrient cycle. This is evident in many ecological cycle studies (Li & Rengel, 2007). In the rain forests of central Africa, Klaus *et al.* (1998) analysed soils chemical properties and found that the soils had high organic matter content, were highly acidic and had high electric conductivity.

Research on elephants in Uganda revealed that when woody cover increases, associated with the exclusion of elephants in the experimental plots, there was a dramatic increase in soil organic matter, calcium, potassium, magnesium, organic carbon and nitrogen (Hutton *et al.,* 1985). Frank and Groffman (1998) studies the carbon and nitrogen relationship in the soil in Yellow Stone National Park and found that soil moisture and temperature is influenced by vegetation (mulch, surface and subsurface vegetation), and the rate of mineralisation is influenced by organic matter and the nitrogen and carbon cycles in the soil are driven by vegetation. Bochet *et al*. (1999) showed how topsoil within island patches in the Mediterranean (southeast Spain) has been modified according to vegetation abundance and concluded that an increase of vegetation causes an increase in organic matter, a decrease in bulk density and an increase in infiltration.

Hiernaux *et al.* (1999) discovered that when grazing is low the sandy soils in Sahelian rangelands, the acidity in the soils increases. Lemmnitz *et al*., (2008:1977) stated that "*sands, partly containing small amounts of lignite and xylite fragments, are characterized by a highly acidic soil solution, higher organic carbon content, and higher electric conductivity"*, therefore, the pH of the soil is related to electric conductivity and organic matter content (vegetation). As the pH is changes, electric conductivity is altered. Heirnaux *et al.* (1999) analysed the rate of vegetation cycling in the soil (from vegetation to organic matter to minerals) and found that soil texture influenced the rate of vegetation breakdown in the soil (the courser the soil, the faster the organic matter cycles through the soil). Lal (1998) pointed out that the pH in soil can change the nutritional value of the soil as the pH alteration can change the behaviour of minerals in the soil (phosphorous and magnesium) causing plant re-growth to become limited (Klaus *et al.,* 1998; Lal, 1998).

Pimentel and Kounang (1998) conducted a study on the physical and chemical changes in soil as a result of erosion and found that, when wind and water removes the organic rich A-horizon in the subsurface, soils are exposed, resulting in a reduction of organic matter in the soil. When soils are eroded, basic plant nutrients such as nitrogen, phosphorus, potassium, and calcium are lost. The rich A-Horizon soils contain about three times more nutrients than the remaining soil. A ton of fertile topsoil (organic rich) typically contains 1–6kg of nitrogen, 1–3kg of phosphorus, and 2–30kg of potassium, while soil on eroded land frequently has nitrogen levels of only 0.1–0.5kg/t. Plant productivity is significantly reduced when soil nutrient levels are low (Pimentel & Kounang, 1998). The electric conductivity can increase in acid rich soils due to displaced minerals in the soils (Driessen, 2001).

The results of this study on Tembe Elephant Park (TEP) and Tshanini display a trend that as organic matter increases, the pH in soil becomes more acidic and electric conductivity increases. If this cycle experiences a reduction of vegetation, thus organic matter, the soil pH will become less acidic but not alkaline, and the minerals will not be displaced, which will reduce the electric conductivity. On TEP there is a breakdown of the nutrient cycle, as the presence of elephants increases. Vegetation cover is reduced, soils are more exposed and the feedback of organic matter is reduced as the canopy cover is altered.

In TEP and Tshanini a consistently high amount of organic material is crucial for the nutrient cycle to remain constant and in medium- to fine-grained soils the nutrient cycle is accelerated. On TEP it is evident that this is occurring based upon the results from this study. As organic matter was the lowest where elephants are present, the pH was the least acidic and the electric conductivity was the lowest therefore altering the nutrient cycle. These alterations are prominent due to the rapid nutrient cycling in the medium- to fine-grained soils. This states that due to elephants reducing vegetation cover on TEP the nutrient cycle is changed rapidly. This causes the requirements for the continued existence of biota in the sand forest to be threatened. Matthews (2005) describes how the sand forest is a nutrient poor system and any disturbance could cause the biotas existence to be threatened. Physical and chemical properties in the sand forest have been altered as a result of the abundance of elephants on TEP and elephant frequency effects all the biotic and abiotic elements of the nutrient cycle. This implies that the geomorphic consequences of elephants in sand forest has a dramatic rolling effect and must be taken into account when population dynamics are considered.

5.4 FINDINGS

In summary, this study shows that elephant interaction with the landscape has geomorphic (macro and micro) consequences and it can be quantified. An elephant's size, activities (wallowing and trampling) and feeding habits alter landscape shape, microclimate, vegetation and physical and chemical properties of soil.

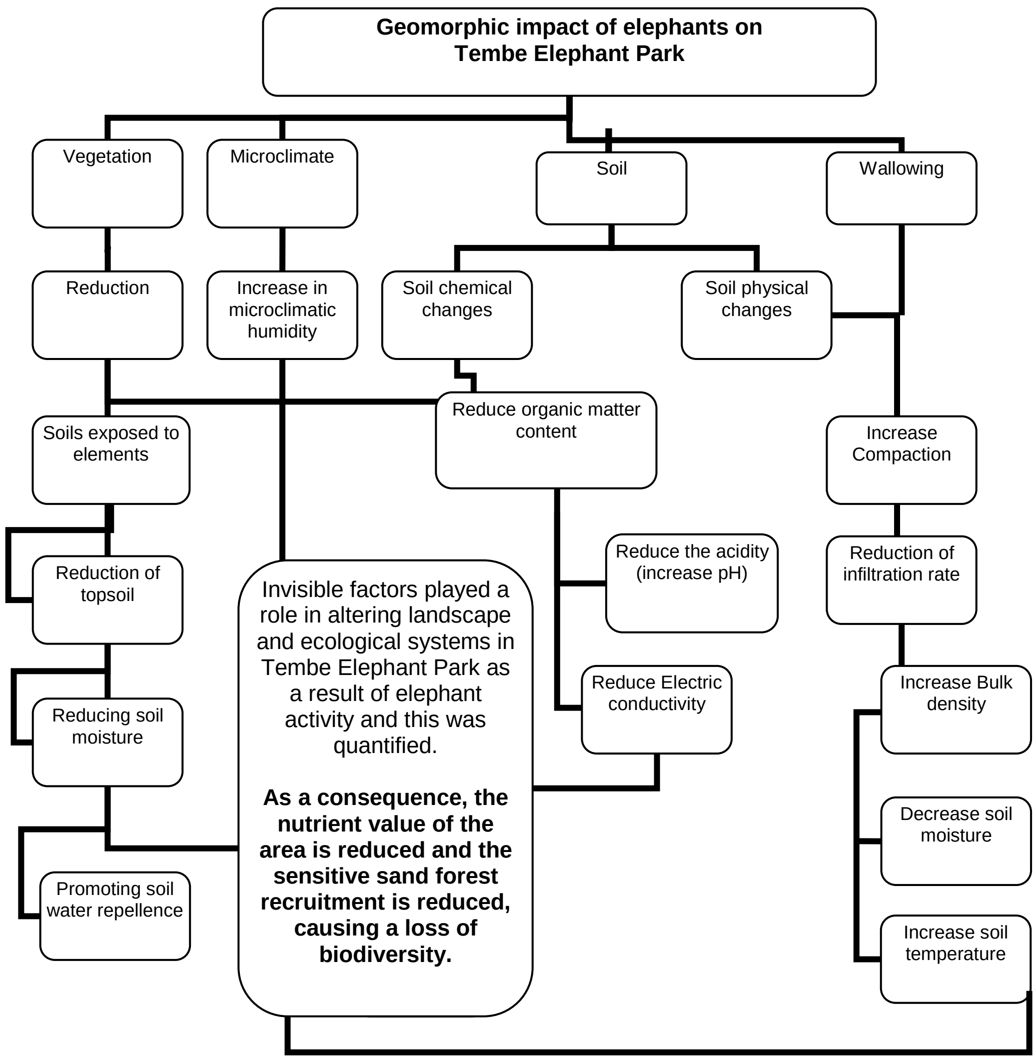

Figure 5.1 **Indirect geomorphic changes on TEP caused by elephants and the consequences**

In Figure 5.1 the results of this study are represented, and the relationship between the results shown. This display of variables interconnectivity reveals that TEP's ecological systems and landscape drive one another and an alteration in any of the systems changes the other. Based on the evidence from this study, Figure 5.1 shows that the systems functional relationship explains that abiotic and biotic systems work as one system and an alteration in either can have an influence on the other. This has implications for TEP and how elephants are managed.

On TEP there are 250 elephants present on 30013ha, which puts 0.008 elephants per hectare on the reserve. According to Matthews (2005), there should be a total of 70-80 elephants on TEP, which is approximately 170 elephants too many. This abundance of elephants is causing ecological damage. Matthews (2005) described how elephants are threatening the endemic flora through thinning the sand forest (it is a unique vegetation type of limited distribution and coverage). Elephants were never on TEP for prolonged time periods, therefore the vegetation is not ideal and adapted to have a high frequency of elephants using it as a resource, which causes the recovery of vegetation and specifically, sand forest, to be slow (Matthews, 2005). If the mega herbivores (elephants) change vegetation, it is detrimental for other herbivores (Fritz *et al*., 2002). Ecological damage on TEP is great as a result of elephant impact (Matthews, 2005) thus the soils and the landscape changes on the area must be accelerated as elephants were never intended to be there in such high numbers.

This study aimed to quantify and identify the geomorphic characteristics (macro and micro) of TEP to an area, which has had no elephants for twenty-five years (Tshanini). To achieve the aim of this study, macro geomorphic features were quantified and described (wallows) and the sand forest sites (where elephants are present, five years and twenty-five years where elephants have been excluded) were assessed for similarities and differences in microclimate, soil, vegetation and physical and chemical properties within the soil. All of these objectives have been addressed thus the aim of this project has been achieved.

The exclusion of elephants, regardless of the evidence present in this study, would not be the ideal geomorphic or ecological model of what Maputaland sand forest should be like, as elephants are meant to move through the area occasionally in low numbers. In essence, the influence of elephants on TEP, as displayed in this study, has a great geomorphic influence and extended quantification of the geomorphic impacts of elephants may enable geomorphologists to model the impacts and quantify them in a way to improve stocking rates of elephants on protected areas to enable preservation of biodiversity. According to the National Environmental Management: Biodiversity Act 10 (2004), the National Environmental Management: Protected Areas Act 57 (2003) and the Environmental Conservation Act 73 (1989), the mandate of Ezemvelo KZN Wildlife is to preserve biodiversity highlighting the importance of continuation of this research as an essential part of their task to enable them to manage the areas more effectively with geomorphic consideration.

Chapter 6
CONCLUSION

Quantifying the geomorphic impact of elephants on Tembe Elephant Park (TEP) is complex, as there are many facets to their direct and indirect impacts on the landscape. Objectives were identified as analysing the general topography of the area, climate, vegetation, soil and animal interaction, which involved the site description of the general area, and determining the rate of geomorphic alteration [macro geomorphic change] at the water points by mapping and measuring elephant wallows. The final objective in this study was to determine environmental and micro geomorphic changes in sand forest with varying levels of elephant presence over time by analysing the micro environments [microclimate, air temperature and humidity and rainfall, vegetation and soil type and soil microclimate] and physical property changes (soil physical and chemical). The objectives set out in this study were achieved to assist in quantifying the geomorphic impacts of African elephants in TEP.

This study on the geomorphic impact of elephants on TEP revealed that after assessing all the objectives, the sites displayed similarities and variations through differences in the chemical and physical properties of the soil and by measuring the elephant wallows, the sites displayed many similarities, but also many differences, which effect the nutrient cycle on TEP and how the landscape is physically changed directly. The research began by describing the importance of geomorphology, zoo-geomorphology, the geomorphic impact of vegetation, invertebrates and vertebrates then shifted its focus on the geomorphic impact of elephants and the importance of understanding it on TEP. Once an understanding was drawn of the importance of this study a method was designed to quantify the geomorphic impacts of elephants on TEP.

Finally, four sites were chosen, three sand forest sites (where elephants exist, five- and twenty-five-year (Tshanini) sites where elephants were excluded) and one elephant wallowing site so that a rate of change could be identified, as well as the extent of the geomorphic impacts of elephants. The first step was to quantify the changing ability of the landscape of elephants and to identify and measure macro geomorphic alterations and then show that the sites chosen for this study were similar in topography, geology, soil, climate, vegetation and animal species composition so that the micro geomorphic alterations could be quantified to a certain level.

The selected elephant wallows were measured and the parameters were calculated and quantified to determine the rate of geomorphic change as a result of elephants wallowing. To conduct this task, two elephant wallows were mapped and measured to calculate the area covered by the wallow, the volume of soil removed or deflated at the wallow, and the average depth and shape of the wallows.

The results showed that the elephants at Matlhasela water hole increase their wallows by 165.5m^2 per month, increase the wallows volume by 52.5m^3 per month and 167 wallow events take place each month by elephants. The average depth of the wallows remained constant throughout the eight months but the extent of the wallows increased in surface area and volume. The wallows seemed to have had a circular form and, as a wallow reaches just over one metre, the elephants create an additional wallow site off the wallowing area. The rainfall in the area aids in the formation of the wallows since if the wallows have water in them the elephants wallow more.

Throughout this study it is evident that elephants are responsible for direct and indirect geomorphic changes on TEP and that the sites had similarities. Site variation testing focused on the sand forest sites (had the same topography, geology, soil, climate and species richness), as these sites were chosen as all being sand forest with the variable being presence or time since presence of elephants. These tests were conducted not only to gather information on the general characteristics of the sites, but the micro-characteristics as well. To achieve this task the microclimate, the vegetation and the soil was analysed. During this section of the study, measuring the microclimate showed results that temperature and rainfall were the same at all the sites, but humidity varied according to animal abundance (the more abundant animals are the more humid it is) showed that the study sites had microclimate variation. The next focus on this section of the study was the vegetation similarities.

To analyse vegetation, basal cover was calculated, and for canopy cover, height and structure (using Edwards' [1983] classification) was analysed. These results showed that basal cover was the least where elephants were excluded for twenty-five years, the most where they had been excluded for five years, and the intermediate result (very similar to the five-year exclusion) was where elephants existed and at the wallow site. However, with all the vegetation differences, the soil type, particle structure and classifications remained the same. On the surface the soils all seemed similar, as they were medium- to course-grained sandy soils. When a closer study was undertaken of the physical and chemical differences of the soil between sand forest sites, many differences between sites were discovered.

The first step taken to identify physical and chemical changes in the soil was to measure compaction, infiltration, soil temperature (throughout the year), soil moisture (throughout the year), and take soil samples three times in the year (after the rainy season, in the winter and before the rainy season). Once the data were collected the physical and chemical characteristics of the soil were tested. The physical characteristics were broken up into compaction, infiltration, soil temperature, soil humidity, soil moisture and bulk density.

Physically the results from this study showed that the longer time an area is without elephants, the quicker the area recovers geomorphologically and ecologically. In the twenty-five-year exclusion, the soils were the least compacted, had the highest infiltration rates, the lowest soil temperature, the highest soil humidity, the highest soil moisture and the lowest bulk density of all the study sites. Where elephants exist, the soils showed the opposite trends. The compaction was the highest, the infiltration was the lowest, the soil temperature was the highest, the soil humidity was the lowest, the soil moisture was the lowest and the bulk density was the highest. The five-year exclusion zone showed intermediate results but with similar trends to where elephants exist. The only similarity found in studying the physical characteristics of the soil in the sand forest was that, when soil moisture was tested 20cm deep in the ground, all sites had the same soil moisture. The chemical characteristics in the soil also showed dramatic differences.

To measure the chemical characteristics of the soil, samples were taken and analysed for pH, electric conductivity and organic matter in the laboratory. The results showed that as organic matter content decreased in the soil, the pH increased (became less acidic) and the electric conductivity decreases. These results additionally showed that where elephants exist, the organic matter in the soil was the least and where elephants have been excluded for twenty-five years it was the most. These trends compared to the literature showed that a constant canopy creates more organic matter than an elephant pushing trees down, defecating and displacing vegetation.

The organic matter in the soil is acidic, making the soil acidic. Acidity displaces minerals in the soil causing salts to displace thus increasing the electric conductivity of the soil. But in an area with fine-grained soil this change in chemical composition of the soil is slow and thus the changes are not dramatic. On TEP, the changes are dramatic as a result of the soils being fine-grained to medium-grained. In medium-grained soils, the breakdown of organic matter and minerals in the soil area is fast, causing the nutrients in the soil to cycle rapidly (Lemmnitz *et al*., 2008) In order for the chemical composition of the soil to remain constant and the nutrient cycle to function as it should, a constant quantity and influx of organic matter is needed. On TEP there is a breakdown in this cycle as there was less organic matter in the soil and all the other results provided evidence that there is a breakdown in the nutrient cycle on TEP (Figure 5.1). The nutrient cycle breakdown effects species richness, species diversity and plant recruitment (slows it down) causing the one of five biodiversity hotspots in the world to be threatened. By analysing the soils, direct and indirect geomorphic impacts were identified, quantified and studied.

Studying the geomorphic changes on TEP as a result of elephant activity has shown that quantifying the changes is possible. The geomorphic impact of elephants is evident and the alterations to the landscape occur on a micro and macro geomorphic scale. This study aimed to show the geomorphic impacts of elephants on TEP and to quantify them. Thus the study demonstrated that it was possible to measure the alterations to the landscape caused by elephants but external variables (other species of animals abundance on the study sites was unknown) limit this study. The findings of this study contributed to understanding the geomorphic role of elephants on TEP through identifying the micro and macro geomorphic changes in the landscape but further research is needed to completely quantify the geomorphic impacts of elephants on TEP.

In further studies it would be beneficial to model the figures obtained from this study with the elephant population structure and elephant distribution patterns at TEP to establish a holistic understanding of the geomorphic changes caused by elephants. If these figures are then used in conjunction with the carrying capacity model (water availability and vegetation type and abundance) and all mammal present on the reserves dynamics, a more accurate figure of elephants per hectare will be established. This model is important for the survival of TEP, as the park is overpopulated with elephants, has a nutrient poor ecosystem and is one of five biodiversity hotspots in the world. Thus, if this model is not created and applied soon, the ecological value of the park will be lost and the reason for the existence of this natural will diminish (preserve biodiversity and to use biodiversity to sustain the local economy through eco-tourism).

As Frank Borman states in Clark (2004:IV): "*The only real recourse is for each of us to realize that the elements we have are not inexhaustible".* It is imperative that we as responsible people need to be proactive in managing our protected areas effectively with the knowledge obtained about abiotic (including geomorphologic knowledge) and biotic systems so that these resources will be here for years to come.

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