Trends in soil erosion and land use in the upper Tugela River catchment

by

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for the degree Master of Science (Geography)

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DECLARATION

I,____________________, declare that this dissertation entitled **Trends in soil erosion and land use in the upper Tugela River catchment,** which is hereby submitted for the degree **Master of Science (Geography)** at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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Signature

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Date

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Abstract

Each year, approximately 75 billion tons of soil are eroded from the Earth's terrestrial ecosystems and the majority of agricultural land in the world is losing soil at rates of between 13 tons/ha/year and 40 tons/ha/year. South Africa is prone to soil erosion, because of poor farming methods, together with soils which are erodible. In order to understand more about the nature of soil erosion in South Africa, the geology and lithology needs to be well understood too. This study adds to the understanding of the relationship between soil erosion and land use. In South Africa soil erosion research has been undertaken, however, each and every region requires its own research on a different scale and using different technique to fit the unique characteristics of the area.

This research begins by investigating the studies which have been undertaken concerning soil erosion and land use, and how these processes are defined and expressed in different contexts. An historical analysis of the former Homeland areas, recreational resorts and Royal Natal National Park in the upper Tugela catchment was conducted over a 50-year period (1964 to 2014). Field trips were conducted in six study sites, in the Bergville district, Drakensberg, to carry out ground-truthing, obtain onsite imagery and validate/verify findings from the research. Desktop research entailed the use of ArcGIS, Google Earth, statistics and an analysis of aerial images which date from 1964 to 2014.

The results show a greater number of erosion features and more extensive erosion in the former Homeland areas, which form part of the rural area of the study site, compared to the Park (Royal Natal National Park) and recreational resorts. Erosion in the study sites was defined according to the SARCCUS framework, and this involves the development from primarily sheet erosion in 1964, to intricate gully patterns and river bank erosion in 2014. The study also shows that there is a relationship between population and the vegetated area: as the number of households increased from 1964 to 2014, the grass cover, trees and grazing land in the area declined.

Overgrazing plays a role in determining the extent of the erosion. However, it is the relationship between increasing population numbers and the nature of livestock keeping among village dwellers which influenced overgrazing levels, and subsequently the extent of erosion. Mitigating soil erosion impacts is an issue which has to be addressed not only on the local scale, but national government also needs to make it a point that the general landscape of the country is well managed with regards to soil erosion.

The outcomes from this study support the notion that soil erosion processes are very complex and that delineation of soil erosion features entails a certain level of subjectivity. Human influences and land use dynamics also influence the rates of soil erosion and this study shows how different land uses, but similar environmental factors, can lead to different rates and intensities of soil erosion. In conjunction with GIS and remote sensing, satellite imagery and aerial photos play an important role in the analysis and understanding of the study area and the different geological, biological and anthropological features present. The presence and the availability of high quality imagery helps then in ensuring that resolute and reliable information is established.

Indlela zokukhukuleka nokusetyenziswa komhlaba kwisithili esiphezu ngomlambo iThukela

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Isishwankathiselo

Ngonyaka nganye, umhlaba oqikelelwa kwi 75 billion yeetoni uyakhukhuleka endalweni, kwaye nomhlaba omninzi wezolimo uyalahleka kwizinga eliphakathi kwe 13 yeetoni/hectare/ngonyaka kwaye ne 40 yeetoni/hectare/ngonyaka. Umzants' Afrika usebungciphekweni wokulahlekelwa ngumhlaba, ngenxa yeendlela zokulima ezigwenxa. Ukuze kwande ukuqonda banzi ngendalo yokukhukuleka yomhlaba wase Mzants' Afrika, ulwazi oluthe vetshe mayelana ne geology ne lithology luyadingeka. Uphando oluninzi mayelana nokukhukuleka komhlaba lwenziwe, kodwa yonke ingingqi idinga uphando lwayo kwisikali esahlukiliyo kwaye nobuchule obuhlukileyo.

Esisifundo siqala ngokuphanda izifundo ezenziweyo ngokuphatheleleyo nokukhukuleko komhlaba kwaye nokusetyenziswa komhlaba, kwaye nendlela ezinqubo ezichazwe ngayo, nendlela ezibonakaliswa ngayo kwiimeko ezahlukeneyo. Ulwazi oluthe vetshe kwaye nezifundo ezibanzi zinikiwe, nemvelaphi mayelane nezizifunde yasekwa. Uhambo lwendawo luyelwenziwa kwizixeko ezisithandathu, ezifumaneka kwinqila yase Bergville, yalandelwa luphando lwase desikeni eye yabandakanya usetyenziswa kweArcGIS, Google Earth, izibalo zamanani nohlalutyo kwemifanekiso yasemoyeni esuka ku 1964 ukuya ku 2014.

Imiphumela iveza ukuba kukho imbonakalo yokhukuliseko kwizinga eliphezulu kwaye nokhukuliseko olubanzi kwindawo ezisundula ukuba zizwe zasemakhaya,

ezifumaneka kwindawo zophando zasezilalini, xa kuthelikiswa nepaka nerizothi. Ukhukuleko kwiindawo zophando kuchazwe mayelana nengcankciso ye SARCCUS, kwaye ibandakanya inkqubela esukela kukhukuleko lomhlabo elingekho nzulu ngomnyaka ka 1964, ukuya kwiindonga nokhukuleko komhlaba ofumaneka kummandla wemilambo. Esisifundo sibonisa ukuthi kukhona ukulamana phakathi kwenani labemi nezityalo: layelanda inani lezindlu ukusukela kunyaka ka 1964 ukuya ku 2014, izityalo zalendawo zancipha.

Amabanga aphezulu okutyiwa kwengca kumadlelo adlala indima ekumiseleni amzinga okhukuleko komhlaba. Kodwa ke, ukwalamane phakathi kwenani elandayo labemi kwaye nokufuywa koluhlu oluthile lwemfuyo kubahlali baselalini lichaphazele amazinga okutyiwa kwengca kumadlelo, nezinga lokukhukuliseka komhlaba. Ukucintshiswa kwemiphumela yokhukuliseko ngumba ongafanelwanga ukuqatshelwa kwisikali sasekuhlaleni qha, kodwa urhulumente wesizwe ufanele ukugxininisa ukuthi umhlaba mbaxa wesizwe uphathwe kakuhle mayelana nokhukuliseko komhlaba.

Iziphumo zoluphando zixhasa ingcinga ethi iinkqubo zokhukuleko komhlaba zintsokothile kwaye ukuhlela iinkcukacha zokhukuleko komhlaba luhambisana nezinga elithile lokujongwa kwezinto ngomntu nganye. Indima ezidlalwa ngabantu kwaye notshintso-tshintshwano kwenkqubo zomhlaba ziyawachaphazela amazinga okhukuleko kwemhlaba, kwaye oluphando liyaveza ukuthi ukwahlukana kweentsebenzo zomhlaba, kodwa ukufana kwemiba engqongileyo, ingakhokela kumazinga nobunzulu obuhlukileyo okhukuleko kwemhlaba. Ukudityaniswa kwe GIS ne remote sensing, imifakeniso ye satellite nemifanekiso yasemoyeni, idlala indima ebalulekileyo ekuhlinzeni nokuqondwa kwendawo zophando nokwahlukana kwemiba yegeology, biology ne anthropology ekhoyo. Ukubakho kwaye nokufumaneka kwemifanekiso ekwizinga elitshatsheleyo kunceda ekuqinisekeni ukuthi ulwazi oluthembekileyo nolugqibeleleyo liyasekwa.

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Chapter 1: Introduction

Water induced soil erosion is globally acknowledged amongst the chief reasons for land degradation (Luffman *et al.,* 2015). Approximately 100,000 km^2 of cropland are lost as a consequence of soil erosion each year, a rate that is 10 to 40 times higher than the development of soil by natural processes (Pimentel, 2006). Gully erosion is a crucial indicator of the degradation of land, leading to slopes being unsuitable for agricultural purposes and creating a vital source of sediment in various environments (Poesen *et al.*, 2003). Monitoring of land degradation and its environmental and socio-economic consequences can be achieved by mapping existing gullies and their activity over a number of years (Shruti *et al.*, 2015). The outcome of erosion is a decrease in soil water absorption capacity; approximately 300mm less water per annum is absorbed in soils that are moderately eroded compared to soils which are not eroded (Pimentel, 2006). The eroded soils and sediments are usually deposited in streams or lakes increasing turbidity, unsettling aquatic ecosystems and contaminating drinking water supplies Robertson *et al.*, 2004; O'Geen and Schwankl, 2006). The consequences of erosion on the environment and human health thus make soil erosion an important theme to investigate.

1.1 Erosion and land use change

Soil erosion research is an important theme in the broader earth sciences, but over time it has also been encapsulated in other academic disciplines, since soil erosion consequences cover a wide range of issues ranging from soil, economic and social settings. Land use change and land degradation are constantly being studied concurrently, due to the growing relationship between the alteration of land use and consequent loss of soil. In the past ten years, numerous models of land use change have been established to simulate urbanisation, deforestation and intensification of agriculture (e.g. Briassoulis, 2000; Verburg *et al.*, 2004; Lesschen *et al.*, 2007). An important factor not usually or typically addressed in land use modelling studies is land abandonment, even though it is one of the most extensive changes in land use in areas such as southern Europe and has potentially immense impacts on various environmental and socio-economic processes (Kakembo, 2001; Lesschen *et al.,* 2007).

Land use change can arise for a variety of reasons, usually in a bid to develop and improve human lives. However, the consequence of the alteration of land dynamics and natural land systems usually leads to the degradation of land and loss of soil. The extent of erosion can be determined by the degree of soil or land disturbance. Gully erosion is considered as a major threat to both landscape and country development, and weak management of gully systems is one of the chief reasons in the extension of gullies that lead to further environmental damage to an area (Salleh and Mousazadeh, 2011).

Over the years soil erosion processes have been extensively studied worldwide, because of the great environmental and socio-economic consequences associated with erosion. Understanding the continuum (from sheet erosion to gullies and riverbank erosion) is an important feature in erosion research, due to the different volumes of soil loss associated with each type of erosion (Xia *et al.,* 2014). Gully erosion has been recorded in many studies; gullies are found in numerous settings, but they can predominate in dry lands, and are usually considered as an indicator of disturbance and increased erosion brought about by land-use change and climate (Salleh and Mousazadeh, 2011). Although anthropogenic factors play a role in accelerating gully erosion, there are other natural factors which affect the development of soil erosion. It is the continuous development of high resolution images, field-based research techniques and more robust statistical methods that can assist in understanding and analysing soil erosion and land use change.

Quantification of soil-erosion dynamics may help in understanding the different erosion features and spatio-temporal evolution. Methods that are field-based were used until aerial photos and later satellite imagery became readily obtainable for visual interpretation and image processing techniques (Shruti *et al.*, 2015). Availability of repeatedly accessed satellite imagery can assist in analysing changes in the active area of soil erosion processes for long-term change studies (Taruvinga, 2008). The analysis of satellite imagery and aerial photos, combined with predefined field-based methods assist in the mapping of soil erosion features and quantifying erosion impacts. It is important that land managers are enabled to develop sustainable planning strategies for appropriate utilization of land.

The increased knowledge of soil erosion and impacts of land use change by a wide range of land use stakeholders (farmers, land use managers and villagers) could assist in hindering further degradation of land and soil loss. Stakeholders need to be aware of different expressions of soil erosion; for example, rills are different from ephemeral gullies, but ephemeral gullies recur in the same location each season and are highly influenced by the configuration of the landscape (Conoscenti *et al*., 2014). If these stakeholders are aware of the different type of erosion processes, it assists in controlling and mitigating soil erosion. However, the study of the development of soil erosion and soil loss still needs further progress, as a certain level of subjectivity and uncertainty still exists when classifying certain soil erosion processes. The transition of size from rills to ephemeral gullies and then to classical gullies does not have distinct limits and even the border between a river channel and a permanent gully is largely vague (Poesen *et al*., 2003).

1.2 Research question, aim and objectives

The study will assess the relationship between soil erosion and land use in the upper Tugela River catchment from 1964 to 2014. The aim of the study will be supported by the objectives given below.

Research question

How have changes in human activities over the last 50 years influenced soil erosion in the upper Tugela River catchment?

Aim

To investigate the observed erosion and land use changes in the Upper Tugela River catchment over a 50-year period.

Objectives

- To map changes in land use at different study sites in the Upper Tugela River catchment for the dates 1964, 1986 and 2014, as captured by aerial photographs.
- To map the extent and nature of observed soil erosion phenomena at different study sites in the Upper Tugela river catchment over the above period.

- To contrast erosion phenomena with change in land use over the 1964 to 2014 period.

1.3 Project Outline

The above aim and objectives will be fulfilled over seven chapters. Chapter 1 provides an overview of the relationship between soil erosion and land use, and how they play a role in soil loss. Chapter 2 explores soil erosion and land use research by covering various themes, such as, other academic insights and research findings associated with soil erosion and land use. Chapter 3 provides a detailed description of the study area utilised in this research in detail. Chapter 4 outlines the methodology developed and utilised in this research to achieve the objectives and support the aim of the study. Chapter 5 discusses the results and outcomes of the study while chapter 6 details how the results obtained in this study correlate with existing other soil erosion and land use research. Chapter 7 covers concluding remarks and recommendations pertaining to future research.

Chapter 2: Literature Review

This chapter is divided into different sections in order to support the aim of the study and fulfil the objectives mentioned in the previous chapter. An overview of soil erosion and land use change will be provided to express the soil erosion impacts in both the South African and international context. Italy will be used as international example of an area that have been impacted by soil erosion. Italy is an example of how different drivers and erosion processes can affect soil erosion dynamics.

This chapter will be divided into the following sections: erosion processes, the nature and causes of soil erosion, population and gullies, and GIS, remote sensing, aerial photos in geomorphology. The aim of this section is to explain the importance of this research in soil erosion studies.

2.1 Overview

Every year, approximately 75 billion tons of soil from the Earth's terrestrial ecosystems are affected by erosion. A majority of agricultural land in the world is losing soil at rates from 13 tons/ha/year to 40 tons/ha/year. As a consequence of soil being formed very slowly, soil is being lost 13-40 times faster than the regeneration and sustainability rate (Pimentel and Kounang, 1998). The two main causes of erosion from tilled or bare land are rain and wind energy. Erosion occurs when the soil lacks protective vegetative cover and under arid conditions with relatively strong winds, approximately 5600 t/ha/yr of soil has been reported lost (Gupta and Raina, 1996). Figure is an example of sheet erosion, where the protective cover has been removed.

Vegetation degradation in the form of decrease of cover and alteration in species composition is one of the leading environmental problems troubling many parts of South Africa. This occurs mainly in the former Homelands, and the marginal lands reserved for black people (Kakembo, 2001). Alterations in vegetation are responses to different variables, which range from adaptive ones, such as those imposed by the cyclicity of rainfall, to negative conditions which result from sustained anthropogenic activity (Ringrose *et al.,*1995).

Figure 2- 1: An example of a site with sheet erosion and rills (Photograph by Carel Greyling in KwaMiya Drakensburg, South Africa).

Soil erosion is a key obstacle confronting water and land resources in many areas of the world, and the problem may get worse in the future as a result of population growth and potential climatic and land use changes (Tibebe and Bewket, 2010). Gobin and Govers (2003) suggest that it is vital to provide information that can help to target policy to focus on the areas of greatest need, given the accumulative threat to land resources, particularly due to population growth and potential climatic changes. Soil erosion is a complex issue, as it touches upon a wide range of issues, including at the spatial and temporal scale. Erosion can be further exacerbated by other external issues, which then can lead to further enhancement of the system.

Unfavourable climate and soil conditions combined with weak environmental management, bad agricultural practices, and improper land planning are the most important driving forces of soil degradation in Italy. Soil erosion and mass movements are still the predominant forms of soil degradation (Costantini and Lorenzetti, 2013). Floods and landslides, the decline in soil organic matter, and biodiversity loss are all associated with water erosion (Costantini and Lorenzetti, 2013). Soil degradation is, however, not just limited to physical factors, but climatic and human factors also can be driving forces. Apart from the various drivers, the most important cause of soil degradation is careless soil and land management of fragile environments, which is the responsibility of both public administrators and farmers (Terribile *et al.,* 2013). Soil erosion in certain parts of southern

Italy has been shown to be linked with specific types of changes in land use as well as being stimulated by agricultural policy. The driving forces of degradation act on various levels: national, regional, municipal council and farms. Therefore, the sole response to fight land degradation is represented by integrated policy measures carried out on different spatial levels (Salvati *et al.*, 2011). Combating soil degradation is thus problematic in Italy as a result of the high variability in the environment meaning that application of soil and water conservation systems has to be fine-tuned (Corti *et al.*, 2013).

On hillslopes, gullies are effective as sources and pathways of sediment and runoff. Kakembo *et al.* (2009) explain that gullies are consequently significant elements of landscape connectivity, functionality and conversion to dysfunctionality. The term connectivity is utilised to describe the degree to which sediment produced on hillslopes is connected to a channel by overland and subsurface flow, as well as the linkage of streamflow and sediment within a channel network (Medeiros *et al.*, 2010). Soil erosion is a serious threat to worldwide soil sustainability because soil resources are finite on a human time scale (Vanwalleghem *et al.*, 2017). Land degradation as a result of soil erosion is not only limited to the loss of fertile topsoil and reduction of soil productivity, but also results in sedimentation of reservoirs and amplifies suspended sediment concentrations in streams with consequent repercussions on ecosystem health (Flügel *et al.*, 2003).

South Africa and other water scarce countries are gradually being threatened by pollution and sedimentation of water bodies because of suspended sediment concentrations in streams which affects water use and ecosystem health (Le Roux, 2012). Erosion occurs through the detachment and transportation of soil materials by wind or water (Morgan, 2005). Water is the principal agent causing erosion in South Africa, triggering erosion to occur in these different forms; in un-concentrated flow, water results in sheet erosion, or in concentrated flow it results in rill and/or gully erosion (SARCCUS, 1981).

Watson (1991) distinguishes between ‘geological’ and ‘accelerated’ erosion. Geological erosion refers to normal removal of soil without the influence of human activities. This erosion occurs at ‘normal’ rates which contribute to the establishment of a ‘normal’ soil profile. Different land use practises quicken the normal rate of soil removal. This anthropologically accelerated erosion is perceived as the ‘soil erosion’ problem and the ‘soil erosion’ term is mostly used in exclusive reference to it. The aim of soil conservation management in human altered systems is the decrease in soil erosion rates to the geological norm (Watson, 1991).

2.2 Erosion processes

This section provides an overview of erosion processes and the importance of understanding the landscape where erosion may occur. Understanding the landscape is a vital aspect in studying soil erosion and the development of erosive features. The occurrence of erosion features is usually underlain by certain soil and geological qualities, which provide conducive environments for such erosive phenomena. Approaching the history and future of a place through its landscape offers unique perspectives and opportunities (Showers, 2005; Salomon *et al.,* 2012). It is not sufficient to study erosive features at the present stage they are found in and draw conclusions, but it is of utmost importance to study the conditions preceding the soil erosion and the overall environment where they occur.

Understanding the topographic context occurring prior to the development of erosive landforms is of critical importance in the area of geomorphological research. Topography is an important aspect for both water and mass movement-related erosion and understanding of the original surface is a condition for quantifying the volume of eroded material (Hancock and Evans, 2010). Although contextual knowledge of the topography is essential, it must not end there, topography must be understood both as a cause as well as the result of erosive processes.

As mentioned above, it is important to understand the state of an area preceding the development of erosive features, as well as the roles that sheet erosion, rills, gullies and riverbank erosion play in soil erosion. In numerous catchments, gully incision and development are significant factors in soil erosion and catchment development (Hancock and Evans, 2010). The commencement of gullies, as well as the headward and lateral advancement, releases enormous amounts of sediment and this can heighten rates of overall landscape lowering and landscape evolution (Hancock and Evans, 2010). The commencement of gullies, as well as the headward and lateral progression, releases large amounts of sediment and can augment rates of overall landscape lowering and evolution (Alonso and Bennet, 2002). This can lead to an increased sedimentation and water quality problems in many catchments (Hyde *et al*.,2007). Therefore, the position and stability of gullies and gully processes are important determinants of the drainage network and landscape processes (Knighton, 1998). Yet, the initiation and development of soil erosion is a complex relationship, without set and defined causes, but various factors ranging from anthropogenic to natural. This complicated relationship of natural processes and anthropogenic factors leading to soil erosion and land use change has been explored by various international and South African authors, for example Kakembo and Rowntree (2003), Le Roux *et al*. (2008), Mararakanye (2015) and Mararakanye and Sumner (2017).

It has to be understood that soil erosion is a natural process, often accelerated by anthropological activities such as clearing of vegetation or by overgrazing (Snyman, 1999). Loss of fertile topsoil and lessening of soil productivity is coupled with serious offsite impacts related to amplified deployment of sediment and distribution to rivers (Le Roux *et al*., 2008). The role that humans play in soil erosion is a critical one, yet often overlooked. Human interaction with the soil influences water resources, which in turn negatively affects human health and livelihoods. An analysis and projection of areas that are primarily susceptible to soil erosion, while also being prone to potential human endeavours is a critical area that requires further investigation (Kakembo and Rowntree, 2003). Even further, the relationship between the impacts of water on soil erosion also needs to be assessed, because this relationship is a key factor in soil erosion (Le Roux *et al*., 2008). Seutloali and Beckhedahl (2015a) explain that the main contributing aspects to the formation of gullies, which are frequently overlooked, are subsurface movements of water and soil piping, as well as overland flow. A precise understanding of all the contributing factors which could lead to the development of sheet to gully and riverbank erosion can only be accomplished by investigating all the factors involved in soil erosion. These factors range from subsurface to external offsite aspects.

2.3 The nature and causes of soil erosion

The most widely recognised and accepted stages of soil erosion are sheet erosion, rill erosion, gully erosion and riverbank erosion (SARCCUS, 1981). Before one can properly fathom the causes which relate to the development of soil erosion, it is important to understand that erosion of the soil occurs in stages and activities. Continuous studying of soil erosion is necessary, and both soil and water erosion processes have to be encompassed in the studies.

A comprehensive summary of gully studies will be given in the following section, as gullies tend to be the most prevalent erosion type in this study. A gully is a complicated system because its progression is controlled by water erosion at the gully head and bed, which activates gravitational mass-movement on gully sidewalls (Sidorchuk, 2006). In addition to the factors influencing soil erosion at different stages, it is important to recognise that a continuum existing between sheet erosion and more intense forms of erosion (such as gullies and river bank erosion). There are different factors which influence the progression of soil erosion along this continuum and they will be discussed.

2.3.1 Sheet erosion

Sheet erosion is the process involving the gradual removal of the top layers of the soil. During sheet erosion a thin layer of soil is removed, as opposed to the discrete centimetres-deep channel that is a consequence of water concentration and rill erosion (Whiting *et al.*, 2001). Sheet erosion affects the surface, as opposed to gullies or dongas, which tend to affect even the soil well below the surface layer (Schnabel, 1997). Soil erosion, which is a main indicator of land degradation, is often expressed as sheet erosion on hillslides and as gullies on the bottom of small upland valleys (Whiting *et al.*, 2001). There is, however, a degree of subjectivity when it comes to defining and delineating sheet erosion from other forms of erosion. Another issue arises when it comes to deducing whether sheet erosion is human influenced or occurred as a result of natural causes, and this can influence environmental reporting indices and management strategies.

One such cause of erosion is overgrazing. Grazing decreases biomass, which functions as protection against soil erosion, and trampling decreases the porosity of soil, thereby developing patches of bare soil and increasing run off (Ibáñez *et al.*, 2016). However, the relationship between overgrazing and sheet erosion is a complex one. One cannot deduce automatically that the presence of livestock will lead to sheet erosion. Economic and managerial factors are seen as drivers of the intensity of grazing, at least in commercial rangelands, and they are acknowledged as human induced soil erosion factors (Xia *et al.*, 2014).

Other factors which affect sheet erosion are topsoil erodibility and a combined factor associated with soil water storage capacity and the pasture production function (Whiting *et al.*, 2001). The principal vice associated with sheet erosion is that of removal of fertile top soils. Depending on the effectiveness of management strategies, sheet erosion can be exacerbated and become rill erosion because of a mixture of anthropological and natural factors, and concentration of run-off.

2.3.2 Rill erosion

Rill erosion is the intermediate point between sheet and gully erosion. Rills are a significant constituent of soil erosion on cultivated slopes and are important sources of slope erosion and principal channels for transportation of sediments (Vergari *et al.,* 2013). Rills tend to play an important role in agricultural contexts and are significant in farming. Productivity of agriculture and the quality of the environment have decreased as a result of the increase of rills on hillslopes (Comino *et al.*, 2015). However, rills are not only limited to agricultural and cultivated lands. They can exist because of natural factors.

Rill erosion is predominantly found in agriculturally disturbed dry areas and it has been demonstrated to be the main source of soil loss at many sites. Rill erosion is considered one of the principal processes affecting soil because of both the large amount of soil loss due to this phenomenon and the generation of a rill network which can produce stable and persisting landforms such as gullies. (Di Stefano *et al.,* 2017). Further studies on the complex nature of rill erosion need to be carried out, because ignored and abandoned rills can further deteriorate to a point where they can become gullies. Understanding the causes of rill erosion can assist in developing and implementing management strategies.

The two important factors which influence rill erosion are rainfall intensity and slope gradient. It is widely accepted that rill development is caused by concentrated flow (Romero *et al.*, 2007), whereas raindrop impact has more principal roles in interrill erosion (Shen *et al.*, 2016). Rill erosion increases the total sediment transport efficiency because rill flow is able to transport both interrill eroded particles and sediments which are eventually detached from the rill wetted perimeter. On natural hillslopes rill and gullies can show positive and negative changes of ground level, as a result of a combination of strong channel incision and sediment accumulation due to bank collapsing (Vergari *et al.,* 2013).

2.3.3 Gully erosion

Large and deep incised channels that cannot be easily destroyed by normal farm tillage equipment are defined as permanent or classical gullies (SARCCUS, 1981; Bergsma *et al.*, 1996; Poesen *et al.*, 2003; Mararakanye, 2015). Gullies are divided into six categories based on plan form as follows; linear, bulbous, dendritic, trellis, parallel and compound. Gully heads can be further classified according to their vertical profiles into four groups; inclined, vertical, cave and vegetated (Bergsma *et al*., 1996; Poesen *et al*., 2003).

The major processes involved during gully initiation include overland flow, development as a result of deepening and slumping of side walls of the subsurface flow or piping and gully head retreat at the knick. Overland flow processes are the primary causes of gully erosion (Mararakanye, 2015). Two acknowledged mechanisms of overland flow generation are Hortonian and saturation through the soil. Hortonian overland flow happens when rainfall surpasses the rate of infiltration and is mostly common on bare rock surfaces and deserts. Saturated overland flow will happen during events of rainfall on a saturated surface (Poesen *et al*., 2003; Rowntree, 2014).

Another cause of gully formation is rill expansion: deepening and slumping of a rill side walls through the shearing effect of concentrated overland flow can lead to the establishment of gullies (Mararakanye, 2015). Gully head retreat and deepening and subsurface erosion or piping depressions caused livestock tracks, furrows and ruts left by farm machineries or knick points or small surface natural depressions initiate gully erosion, specifically a bank erosion. When soils are removed under the surface this is called subsurface erosion (Beckedahl, 1996), as a result of water channels underground. The formation of gullies happens when water reaches and super saturates the relatively slowly permeable subsoil, and moves soil particles sideways as seepage, thereby forming subsurface channels which can collapse (Mararakanye, 2015). Climatic characteristics, topography, geology, soil properties, vegetation, and land management or land use activities control all forms of water erosion processes. Gully erosion is a threshold phenomenon which is influenced by a myriad of factors rather than a sole factor, according to studies (Grellier *et al*., 2012).

There are a number of factors which cause gullies, such as soil type, bedrock type, topography, soil surface features, and vegetation cover related to climatic conditions, especially rainfall intensity and interchange of wet and dry seasons. Human factors normally include land-use change (Ward *et al.,* 1998) and activities linked with road and construction sites including pathways for animals (Grellier *et al.,* 2012). The above-mentioned causes are very diverse, ranging from natural phenomenon to anthropological induced factors. These causes highlight an important aspect about gully formation; causes of gullies occur in separate trajectories and yet also possess a degree of interconnectedness. For farmers, the development of gullies results loss of crop yields and available land as well as an increase of workload (i.e. labour necessary to cultivate the land). Gullies can also change the mosaic patterns between fallow and cultivated fields, enhancing hillslope erosion in a feedback loop (Poesen *et al.,* 2003). In addition, gullies tend to enhance drainage and accelerate aridification processes in the semi-arid zones. If the vegetation cover is dense, runoff susceptibility will be decreased by rainfall interception and soil crusting being limited (Grellier *et al.,* 2012). As important and severe gully as gully erosion is, there is another critical state of soil erosion which occurs if gully erosion is not remediated and controlled. Riverbank erosion is a significant stage in erosion and possesses significant impacts on humans and the natural world (SARCCUS, 1981).

2.3.4 Riverbank erosion

The drivers of riverbank degradation are complicated, and mostly result from the interplay between natural processes and anthropological processes. Outcomes of riverbank erosion are intricate; this process consists of the obvious geomorphological and environment consequences, but it even has a far-reaching effect on society. The close proximity of riverbank erosion and fluvial systems means that sedimentation will be a consequence and other disruptions to aquatic systems will be prevalent. Riverbank erosion poses a grave problem to a fluvial system as it can produce up to 90% of the total sediment yield from a catchment (Bandyopadhyay *et al*., 2014). River engineers, environmental managers and farmers are usually faced with serious problems through loss of agricultural land, riparian and floodplain structures being endangered, and increased downstream sedimentation (Xia *et al*., 2014). This comes as result of riverbank erosion processes which are principal components in the evolution of channels of alluvial rivers. The increased bank erosion has consequences not only for sediment yields downstream but also results to alterations in the stability of the channel and associated channel patterns (Xia *et al*., 2014). Understanding the erosion continuum and causes of riverbank erosion is an important step in riverbank studies.

Over-cultivation, cultivated fields which are poorly managed, and indiscriminate cutting down of trees leads to riverbank erosion along with sedimentation of river, pollution of water and the changing of fish habitat (Das *et al*., 2014). The process which combines the erosive power of water and the effect of gravity results in bank degradation. Numerous geomorphic responses quicken the process of bank erosion include channel enlargement, bank instability and degradation of physical habitat (Bandyopadhyay *et al*., 2014).

2.4 Population and erosion

The relationship between soil erosion and population change is multifaceted. Understanding how the changes in population affect erosion rates and land use requires robust technical analysis and population statistics recorded over years where available. The literature provided will assist in building up the understanding of how population and soil erosion affect each other, and how they subsequently affect land use.

Land is one of the primary resources that humankind depends on. It gives humanity space to live in, nutrition and resources for energy. It serves human needs by providing land, ecosystem services and fresh water (Fritz-Vietta *et al.*, 2017). The issue with land is that it is a finite resource and is characterised by certain thresholds and limits, and with the continued population growth and exertion of pressure on resources, this will lead to the modification of land cover and land-use. A definition of land cover can be expressed as changes in land resources associated to biophysical factors such biodiversity, soil and ecological processes, whereas land use refers to the alteration of land for human needs such as transportation, recreation and housing (Pillay *et al.,* 2014).

The role of anthropological activities on soil erosion is a very important one which must be accounted for. As much as soil erosion is a natural process, which occurs as a result of geological, topographical and meteorological causes, it is human activities which can exacerbate soil erosion. Rowntree (2014) re-assessed soil erosion in the Karoo of South Africa as portrayed in century-old sources. The study showed that the Agricultural Journal of the Cape of Good Hope at the turn of the Twentieth Century carried a number of articles by farmers and agricultural officers concerning the 'evil of sluits'. The authors gave accounts of widespread incision of valley bottoms by deep, wide gullies. Articles presented by the Agricultural Journal of the Cape of Good Hope clearly express that by the turn of the nineteenth century the erosion of valley floors by gullies of great depth was an extensive problem of serious magnitude (Bradfield, 1903; cited in Rowntree, 2014). Gullies were a fairly recent process, but by 1903 gully development had accelerated in a rapid manner (Rowntree, 2014). Continued rapid expansion resulted in the formation and deepening of gullies. The ongoing rapid population growth is still prevalent in certain areas around the world and is one of the leading causes of extensive soil erosion (Rowntree, 2014).

The Bantu Land Act of 1913 and the Development and Trust Land Act of 1936 led to the allocation of 13% of the available land in South Africa to black people, who made up 80% of the population. This led to overcrowding of areas which had marginal potential for agriculture (Kerry, 1993). The areas or reserves where black people were forced to reside in were named “Homelands” or “Bantustans”. There are two influences which were responsible for intense population of the “Homeland” areas. The first reason was that the whole agricultural sector in South Africa was decreasing during this time as a consequence of severe droughts and stringent economic conditions Second was the policy of the government of forcing evicted workers to move to the specified “Homeland” (Cooper, 1988; Marcus, 1989).

The Native Land Act No. 27 of 1913 established the foundation for structural marginalization of black people which had commenced in the 1800s (South African History Online [n.d.]; Salomon *et al.*, 2012). The policies surrounding settlement of people and labour relations subsequently resulted in the development of environmental pressure and particular land use patterns. The era from 1976 beckoned the commencement of the end of Apartheid as domestic resistance and foreign protests grew stronger. The Apartheid scheme of utilizing cheap African labour for industry had reached its limits (Salomon *et al.*, 2012). During this time, an increase in growth in the study sites and development continued in the Homelands, and “by the late 1990s, the uKhahlamba Drakensberg area was defined as being among the most impoverished, degraded and underdeveloped areas in KwaZulu-Natal Province, and was so different when compared to the well-managed protected areas” (Sandwith, 1997: 124-125).

By the nineteenth century the landscape had changed from enormous tracts of chiefly uninhabited land with abundant wildlife into a patchy landscape: subsistence farms and large-scale commercial farms, towns mostly inhabited by white people and reserves inhabited by black people, expanding transport infrastructure and rapidly disappearing wildlife (Salomon *et al.*, 2012). Zulu people were more successful at cattle keeping than crop farming, which had been subdued by the lack of land available to African peasants. Families were more reliant on the breeding and selling of cattle as well as income from migrant labour, and this came as a result of a decline in homestead food production (Mackinnon, 2009). In 1921, the Livestock Improvement Proclamation No. 31, introduced by the Department of Native Affairs, was aimed at combating what they perceived to be ‘deleterious methods’ of cultivation and ‘overgrazing’ by Zulu ‘scrub’ animals. Reduction of herds and replacing these with commercial breeds was the aim of this betterment initiative, and this not only undermined “the base of Zulu survival” but also their cultural identity

(Mackinnon, 2009:250; Salomon *et al.*, 2012).

Modifications in land use mirror history and probably the future of humanity (Houghton, 1994). Land use change rates usually correspond to population growth rates but will often decrease local economically development. However, as simple as this may sound, the relationship population growth, economic development and land use change is more complicated than suggested by these statements (Houghton, 1994). The extent of the land use and the intensity of the modification can lead to the varying degrees of soil erosion and soil erosion forms. Therefore, the relationships between anthropological activities, land use and soil are an important (Pillay *et al.*, 2014). Another phenomenon associated with human activities and land use change and has led to increased soil erosion is road construction.

Road construction has increased globally in the past decades to meet the demands of the rising human population and this has resulted in severe soil erosion problems, the bulk of which is unaccounted for, especially in the developing world (Seutloali and Beckedahl, 2015a). This development in mobility and transport networks has led to a permanent change of the geomorphic and hydrological settings (Ramos-Scharron and Macdonald, 2007). Environmental problems caused by accelerated soil erosion due to roads have economic consequences related to soil rehabilitation and water treatment (Seutloali and Beckedahl, 2015a). Roads change the processes that control the storage and distribution of water on the landscape. Unpaved roads have an equally larger or greater effect on the rate which sediment is generated, routed and eventually exported from a catchment (Jungerius *et al.*, 2002). Rill and gully erosion can lead to dramatic soil loss, as the concentrated flow cuts through surface layers and carries away vast quantities of soil. Rill erosion is a particular pressing issue for highway and other sites for construction that contain impervious surfaces at the top of slopes, as these surfaces can create high flows and point discharges of water than can initiate rills and gullies that enlarge as water travels downslope (Persyn *et al.,* 2005). The resulting erosion results in serious loss of materials off-site, high maintenance costs, substantial generation of runoff and sediment from roadcut embankments and fill slopes (Arnaez *et al.*, 2004).

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The degree to which population changes can influence erosion may be observed by remote sensing, which provides accurate means of analysing the areal extent of the modifications (Kabanda and Palamuleni, 2013). Remote sensing offers assistance in understanding erosion spatially (Houghton, 1994). Technological advances assist us in a visual manner in understanding how population changes and erosion correlate. The documentation of historical policies also gives us an understanding of how the people came about to live in a place and what processes influenced their decision to locate in a certain area.

Policies like the South African Land Act of 1936 (Houghton, 1994) and other policies related to the Apartheid system concerning population placement have influenced the exertion of pressure on land resources. In the past, the orientation of the population based on the land quality and agricultural potential has affected the land use and land cover. Houghton (1994) elaborates that the chief cause of change in land use historically has been the global upsurge in agricultural land. The drought of the early 1980's had decreased the stocking rate to a more suitable to the carrying capacity. Approximately 70% of the land in KwaZulu-Natal was utilized for grazing purposes (Erskine, 1982). The 1913 Bantu Land Act and Land Act of 1936 resulted in the over-use of the reserves, because people exerted pressure on the natural base. The apartheid government effected the 'Betterment Scheme,' which included peasant farmers to be resettled, and this was motivated by the need to restrict excessive soil loss and improve rural livelihoods (Pile, 1996). By 1994 South Africa's government had inherited a system marked by gross inequalities in the distribution of resources according to race. The continuous loss of land during the country's colonial and apartheid past ingrained poverty and insecurity in its majority African population (Watson, 2001).

Wessels *et al*. (2007) express that land degradation poses a threat to the local resource base, which the local community depends on. In the South African Homelands, the stocking rates grew between 2 to 4 times the rates which were recommended, between 1913 and 1936 (Wessels *et al*., 2007). As a result of the policies which confined people to these various reserves, the increasing population led to an augmented pressure on the land and its resources, which in turn led to the land being eroded and resulting in gully initiation. Griscom *et al*. (2010) explain that rural livelihoods are linked to natural resources and this in turn is followed by activities which compact the soil. Therefore, any negative activities relating to the land will harbour unforeseen circumstances on the population dependant on the land.

The documentation of the extent and the intensity of soil erosion in South Africa dates back to the first decade of the 20th century (Sonneveld, 2004). At one point in South Africa, 87% of land was controlled the white minority, constituting only 14% of the population. The spur for change in South Africa has been the government, because at one-time, black people were legally hindered by the government to hold a land title after 1913 (McCusker, 2004). Even so, one has to understand that there are more complicated interactions between land use, climate and soil properties than just historical processes which have resulted in land erosion and gully development (Sonneveld, 2004). Botha (1996) further elaborates that there are also other important intrinsic aspects which similarly are imperative in soil erosion process, like specific rock types, which effect the profiles of a slope and colluvial layers. Understanding the underlying physical factors before inferring conclusions between population dynamics and soil erosion is thus necessary, because human-land interaction in geography and connected disciplines is a long-held tradition (McCusker, 2004). The anthropological and land dynamics influence not only land-centred disciplines, but also economic, social and scientific fields.

Smit (1965), Schultze (1969) and Hattingh (1973) developed similar techniques to estimate population numbers in rural areas. However, more recent work on population estimation techniques includes that of Henry (1990), Brown *et al.* (2001) and Wu *et al.* (2005). Smit (1965), Schultze (1969) and Hattingh (1973) based their studies upon rural areas, which were the former Homelands; hence they are useful as a framework for population estimation techniques, because of the similarity between their studies and this Tugela catchment research study. The technique included the estimation of the number of people in a settlement based on the types of dwelling; (a) traditional round hut houses had 4 people, (b) rectangular hut houses had 5 people, and (c) corrugated-iron-roofed hut houses had 5 people. However, useful the studies are, there were certain limitations which accompanied them. Henry (1990)'s work focussed on the importance of estimating population numbers for policy and social research, using various sampling techniques. Brown *et al.* (2001)'s work was based in Africa and Asia and was used to estimate population numbers in emergency or disaster situations. Wu *et al*. (2005)'s work focussed on areal interpolation methods and statistical modelling methods to estimate population numbers.

2.5 GIS, remote sensing and aerial photographs in geomorphology

Mapping processes of soil erosion over a landscape over years is beneficial in understanding how soil erosion is occurring in an area. The coupling of soil erosion mapping and ground-truthing can provide information of how the soil erosion is expressed over the landscape and the nature of the soil erosion (ranging from sheet erosion to severe gully networks, and riverbank erosion). This section provides insights and details of the different methods used in mapping soil erosion. Some of the methods provided in the section were used in the research. This section is aligned with the second objective of the study, which deals with mapping and evaluating the extent and nature of the gully erosion.

Remote sensing is usually coupled with GIS in order to provide a more efficient way of detecting changes in land cover. Remote sensing and GIS have been extensively used mutually in land cover change detection as they are together accessible at reduced cost and enables efficient and quantitative resource mapping (Kabanda and Palamuleni, 2013). The added advantage of utilizing remote sensing and GIS techniques is the degree of accuracy and precision it offers and compatibility with mathematical equations. GIS techniques and remote sensing are good for increased accuracy (Mhangara *et al.*, 2012).

In KwaZulu-Natal, amongst the wide array of different soils, fine-grained soils exist and these are the most vulnerable to water erosion and usually in South Africa. Gullies occur predominantly on soils which are underlain by shale or dolerite (Taruvinga, 2008). The coupled relationship of geology, soil and GIS and remote sensing further assists geomorphologists to draw up erosion risk prone areas.

There is a considerable amount of soil erosion research that has been undertaken in South Africa, however, each region requires its own research done on a different scale. This is a result of each region possessing unique and different soil and geological features, so therefore the research methodologies cannot be compared and hence the need for varied erosion research methodologies (Le Roux and Sumner, 2013). Mapping erosion and quantifying changes over time is essential for implementing soil conservation and understanding land use change (Shruti *et al.*, 2015). Understanding the unique qualities of each area and its geomorphic characteristics can assist in inferring the risk profile and assess the gully susceptibility of an area. The different techniques and methods involved in GIS and remote sensing in analysing an area, gives earth scientists valuable spatial information and an historical overview in addition to the physical outputs resulting from field studies and other site observations.

In conjunction with GIS and remote sensing, satellite imagery and aerial photos play an important role in the analysis and understanding of the study area and the different geological, biological and anthropological features present. There are various means of mapping soil erosion from an image including the extraction of information such as size, shape, shadow, tone and colour, texture, pattern and associated features (Taruvinga, 2008). The presence and the availability of high quality imagery assists in ensuring that resolute and reliable information is available for analysis.

2.6 Summary

This research is relevant in soil erosion studies because it assists in understanding that the nature of soil erosion can change over time and over different locations. The methods used in this study will be expressed in detail in chapter 4. The effects of increasing population numbers and limited land resource is another aspect highlighted in this research. The relationship between land use, population changes and erosion is a key aspect addressed, however, this requires more research. Understanding soil erosion development and erosion types is essential in erosion studies, Geography and in other related studies, because gully erosion is the chief process which results in the erosion of soil (Castillo *et al*., 2014). Physical assessment and verification is required in order to validate what is or was perceived on the aerial photos and satellite images.

Chapter 3: Study Site

3.1 Background and history of land use

At the foothills of the Drakensberg in KwaZulu-Natal lies the Okhahlamba Local Municipality (Mthembu, 2011). It is within the district of Bergville that Zwelisha, Clifford Chambers, KwaMiya, Mont Aux Sources and surrounding areas, Busingatha and Upper Thendele are situated. These villages, recreational areas and the National Park form part of the study site (Figure 3-1). Mont Aux Sources hotel and surrounding areas shall be referred to as Mont Aux from henceforth. This is because the study site delineation includes the Mont Aux hotel and the adjacent areas. The length of the uKhahlamba Drakensberg Park is approximately 180 km and ranges from the Royal Natal National Park in the north to Bushmen's Nek in the South (Chellan and Bob, 2008).

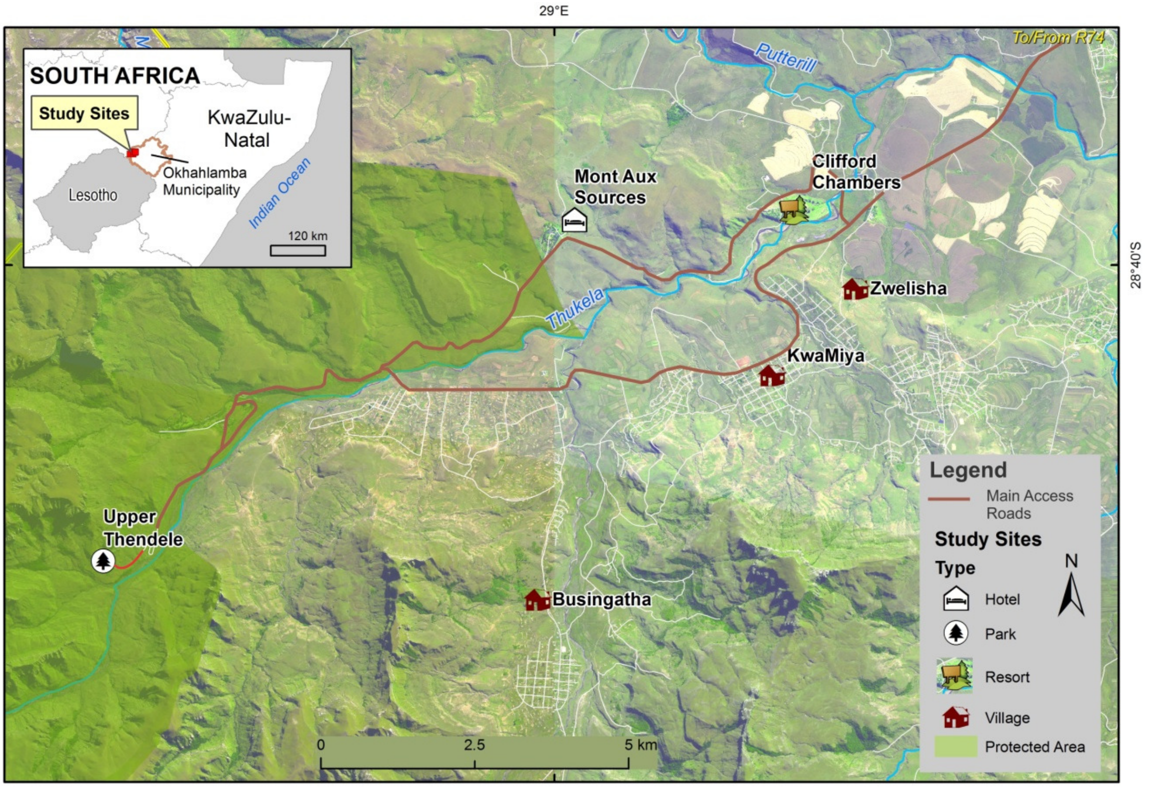

Figure 3- 1: Location of the study sites in the KwaZulu-Natal province. (Note access road from R74 ending at Upper Thendele).

The uKhahlamba Drakensberg Park has been declared a World Heritage Site for both its natural as well as its cultural importance. The Drakensburg encompasses a range of mountains that reach more than 3000 metres in height (Chellan and Bob, 2008). The San or Bushmen have lived in the southern Drakensberg for the past 10 000 years, according to archaeological research. They were hunter-gatherers who lived off wild animals and wild berries and plants, and their rock paintings are found all around the Ukhahlamba-Drakensburg Park (Ezemvelo KZN Wildlife, 2016). Farmers settled in the area in the 19th century and this made it difficult for hunter-gatherers with their traditional lifestyle, leading to tension between the two groups. The new settlers hunted and killed a large number of the wildlife on which the hunter-gatherers were dependent on and they retaliated by hunting the livestock belonging to the farmers (UNEP, 2008). By the late 1600s African cattle-herding people started to live in permanent settlements in areas next to the northern and central Drakensberg region. The people who lived in the north were known as the Zizi and the people of the South were known as the Tsolo (UNEP, 2008).

The study sites are found in the area characterised by the Northern KwaZulu-Natal Moist Grassland and the Northern Drakensberg Highland Grassland, with the Low Escarpment Moist Grassland vegetation also covering a portion of the study site (Okhahlamba Local Municipality, 2013). Bergville and other nearby towns such as Winterton are inclined towards supporting agriculture (Mthembu, 2011). There are five rivers which rise in the region; the Tugela flows into the Indian Ocean; the Khubedu, a tributary of the Orange River and its own tributary the Khubela; and the Elands, a tributary of the Wilge and hence also of the Vaal and the Orange. The Royal Natal National Park forms part of the splendid Drakensberg Mountain range and became part of the 630 World Heritage Sites on the 29 November 2000 (Ezemvelo KZN Wildlife, 2016).

Irrigation is an important part of the land use, from a water resources perspective. Commercial timber also plays a significant role in the land use of the Tugela river catchment and has an impact on the water resources. Other land uses include subsistence dryland agriculture (mostly maize), and cultivation of sugar on the flat alluvial land or rolling hills which surround the estuary (Department of Water Affairs and Forestry, 2004).

The local municipality of Bergville is made up of privately owned commercial farmland and two tribal authorities: Amazizi and Amangwane, and privately-owned smallholder settlements (Mthembu, 2011). The tribal areas are situated on the western portion of Bergville located on the edge of the interior basin and the foothills of the Drakensberg and ranges up to the Drakensberg Mountains and to the Lesotho borders in places. The commercial farms were not included in the study sites because they were distant the Upper Thendele study site (control site), village study sites and the recreational study sites. The study area had to be contained so as not to introduce numerous variables. A range of natural, cultural and socio-political landscapes constitute the physical characteristics of Bergville, making this area a unique study site (Mthembu, 2011).

KwaMiya, Busingatha and Zwelisha (rural study sites) are similar in land use, because of subsistence farming, keeping of livestock and growth in settlement. Mont Aux and Clifford chambers are similar, as both sites are resorts/recreational centres and have low population numbers. Upper Thendele Camp is found in the Royal Natal Park; it is in an enclosed area, open for tourists and visitors. Commercial These study sites contain similar vegetation cover, land types, geology and climatic conditions, but have different population numbers and erosion agents. The rural study sites and commercial zones are separated by a road, which intersects with the R74 (Figure 3-1).

3.2 Climate

There is approximately double as much total runoff in KwaZulu-Natal per unit of rainfall than for the average of South Africa as a whole, and the province is a contributor of a quarter of the streamflow of South Africa (Whitmore, 1970; Nel and Sumner, 2006). This area can be described as South Africa's most important source and the Tugela-Vaal transfer tunnel (TUVA) and the Lesotho Highlands Water Project (Nel and Illigner, 2001), rely on these upper catchments (Nel and Sumner, 2006). The study sites are situated in this region and are affected by the climatic conditions in this region. South African Weather Services stations are situated in the conservation areas, at resort offices, farms and in towns (Nel and Sumner, 2006).

Bergville receives an average of 767mm of rain per annum, with the majority of the rainfall occurring during mid-summer (Nel and Sumner, 2008). Royal Natal National Park has an average rainfall of 1314 mm (Nel and Sumner, 2006) and the average midday temperatures for Bergville vary from 19.3°C in June to 27.9°C in January. The lowest rainfall occurs in Bergville in July and the highest occurs in January (SAexplorer, 2014). Rainfall events in winter show a decline in the rainfall total, production of kinetic energy, and the rainfall intensity on the escarpment. Generally, for the same summer rainfall event, rainfall is of a longer duration on the escarpment, but the depth of the rainfall is less than in the foothills (Nel *et al.*, 2010). Characteristics of the discrete erosive rainfall events which generate rainfall in the foothills and the escarpment show that when the rainfall event meets the criteria for erosivity (intensity and depth) in the foothills, it does not necessarily generate erosive rainfall on the escarpment (Nel *et al.*, 2010).

3.3 Geomorphology, topography, soils and geology

The landscape of southern Africa is characterized by numerous spectacular scarps developed by a diversity of other resistant lithologies – particularly quartzites and dolorites – within the horizontal or mildly deformed platform sequences, ranging from Archean to Proterozoic in age, covering a large part of the sub-continent (Moore and Blenkinskop, 2006). There is a possibility that the evolution of the Drakensburg may have included the interplay of the extreme models which are scarp retreat, and the influence of an inland drainage divide (Moore and Blenkinskop, 2006). This means that rivers which rise off an inland divide could have led to the degradation of an initial escarpment close to the coast if lava flows extended to the coast.

An escarpment developed when thick lava flows were exhumed, after rapid erosion, possibly in area of the eastern edge of the dense dyke (Moore and Blenkinskop, 2006). The study sites form part of the Drakensburg section of the Great Escarpment, which developed as a consequence of scarp retreat (Moore and Blenkinskop, 2006), and are part of the of the 34 geomorphic provinces and 12 sub-provinces which were delineated for South Africa, Lesotho and Swaziland by Partridge *et al.* (2010). The Great Escarpment is underlain by a diversity of rocks which have different ages; granite-gneisses and sedimentary strata of the Transvaal Supergroup are found in the in the northeast; Karoo Supergroup sediments and lavas make up the escarpment in the KwaZulu-Natal region (Figure 3-2), while erosion of the Cape Supergroup sediments and Namaqualand granite-gneisses create its topography in the west coast. The fragmentation of the Gondwanaland in the late Jurassic and early Cretaceous is credited for the formation of the Great Escarpment (McCarthy and Rubidge, 2005; Partridge *et al.*, 2010).

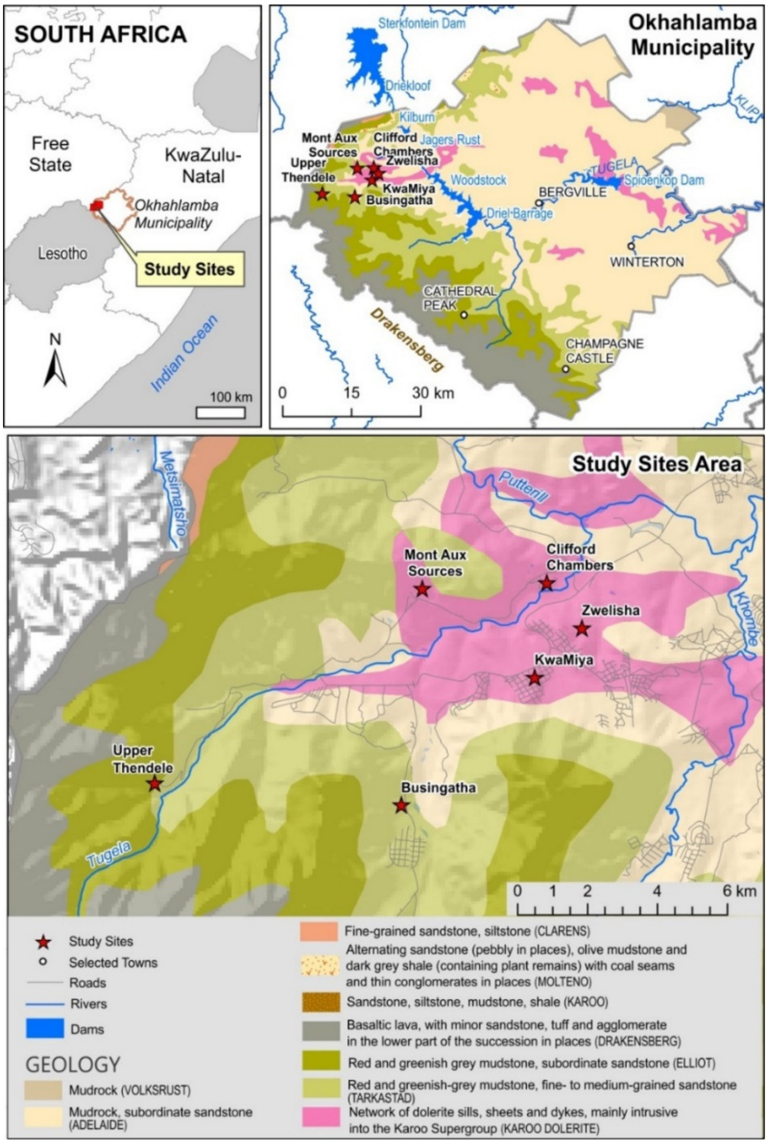

Figure 3- 2: Geology of the study area and of the Okhahlamba municipality (Agricultural Research Council, 2015).

Bergville is found in the area east of the Drakensburg situated towards the eastern boundary of the municipality and possesses immense soil potential. The north-east and south-west surroundings of the area have soils of high quality (Okhahlamba Local Municipality, 2013). The soils (Figure 3-3) situated around the Drakensburg region have a low potential for agriculture, but good to high agricultural potential exists in the majority of the area beyond the municipality of the Drakensburg (Okhahlamba Local Municipality, 2013).

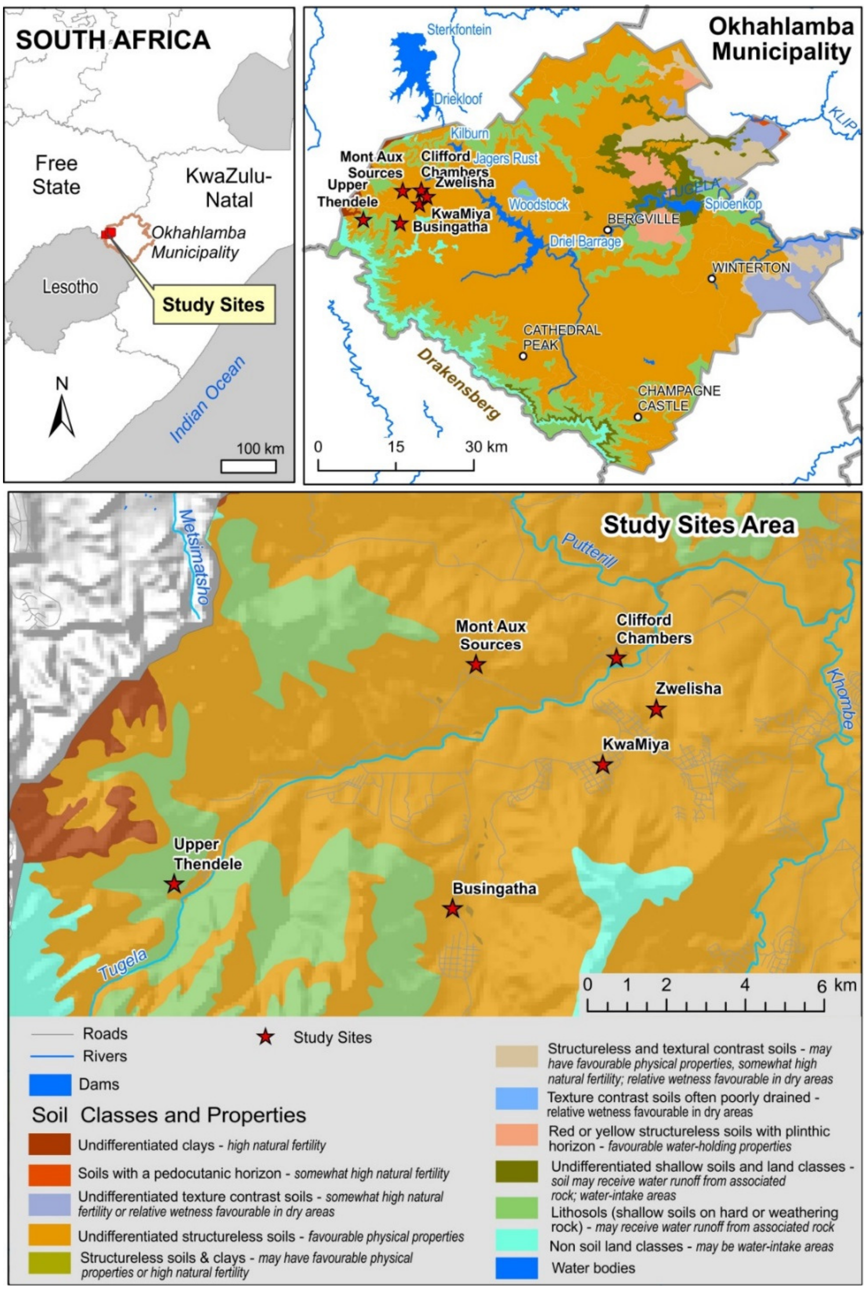

Figure 3-3: Soil classes types found in the study sites and in the Okhahlamba municipality (Agricultural Research Council, 2015).

The study area is situated on a mixture of soils, namely Mispah and Glenrosa forms (with little or no lime) and dystrophic/mesotrophic, apedal soils and have different characteristics (Agricultural Research Council, 2015). The geology of the study area ranges from medium grained sandstone towards the west end and central part of study area, and green and blue mudstone of the Tarkastad Formation towards the west end of the study area.

Erosion by water usually occurs as sheet and gully erosion (Stronkhorst *et al.*, 2010). Figure 3-4 depicts the rainfall totals over the study sites. For land which is used for grazing purposes, the prominent erosion type is gully erosion, in croplands all three erosion types are active, and in home gardens rill erosion is more prevalent (Stronkhorst *et al.*, 2010).

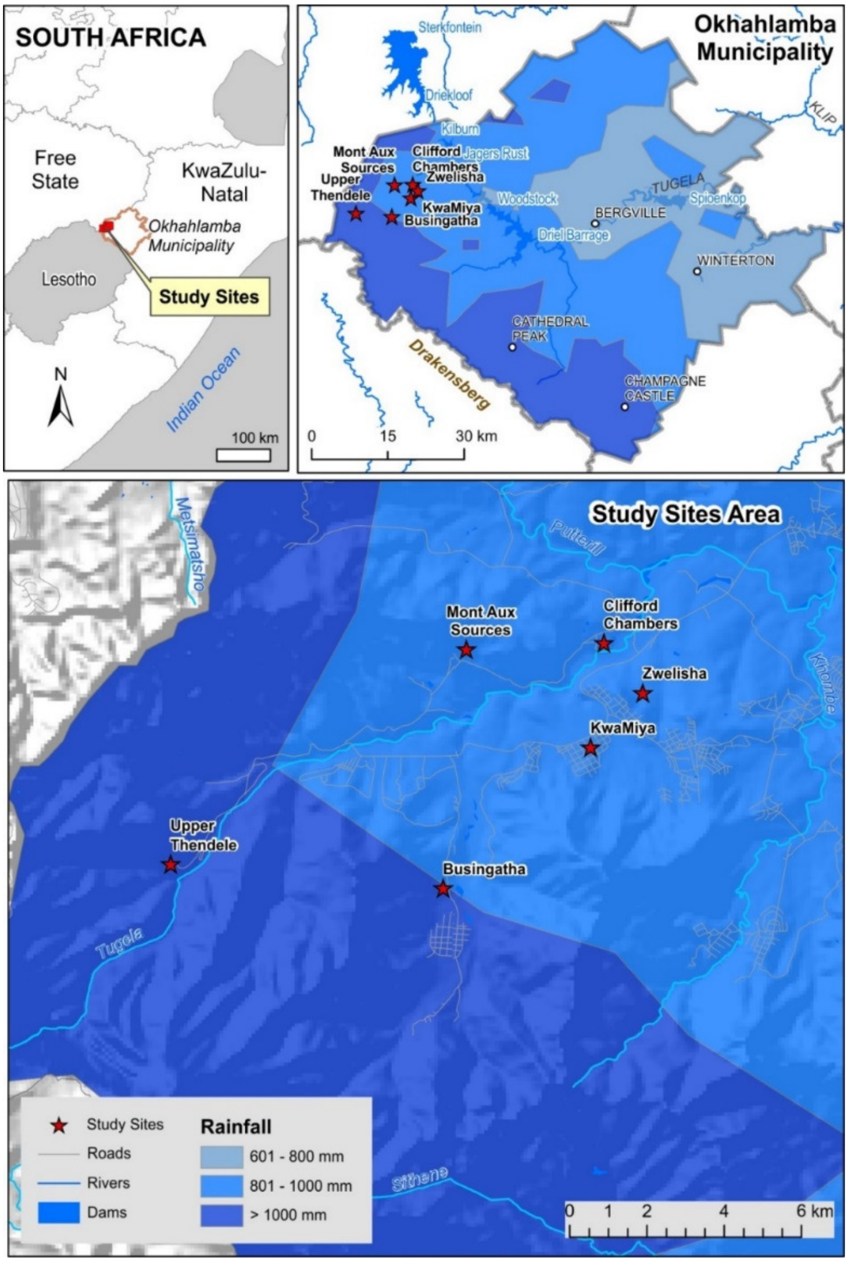

Figure 3- 4: Rainfall totals in the study sites and in the Okhahlamba municipality (South African Weather Services, 2015).

Topography, alignment of river channels, soil types and agricultural potential of an area is influenced by its geological nature. The geological composition of Bergville area is as follows: the mountainous area is covered by a basaltic layer which is about 1400 meters thick, the lower peak peaks possess sandstone which leads to a combination of steep sided blocks and pinnacles (Okhahlamba Local Municipality, 2013).

3.4 Vegetation

The Bergville area is rich in terms of plant life, as it contains a great quantity of species which are threatened, endangered and near endemic. There are various plants species found in the Bergville area, namely creeping plants, tussock grass and shrubs such as Ericas, and unique and rare plant species such as the Spiral Aloe (Mthembu, 2011). The Bergville and Drakensburg study area is also rich in numerous endemic plants with grasses such as *Monocymbium ceresiiforne*, *Diheteropogan filifolius*, *Sporobolus centrifuges*, Caterpillar Grass, *Cymbopogon dieterlenii* and *Eulalia villosa* (Mthembu, 2011).

The study area is predominantly covered by Northern KwaZulu-Natal Moist Grassland and Northern Drakensberg Highland Grassland, with Drakensburg foothill moist grassland covering certain areas of the study site (Okhahlamba Local Municipality, 2013). The study area and Okhahlamba area is characterised by grassland vegetation (Figure 3-5), and huge diversity in plant communities, therefore a certain level of balance need to be attained in terms of conservation and tourism attraction so that this sensitive environment is preserved. There are also pockets of forests which are indigenous all throughout the municipality, but commercial forestry is also found in the area. The Grassland Biome covers the study area predominantly and there are scattered bushland present (Okhahlamba Local Municipality, 2013; South African National Biodiversity Institute, 2017).

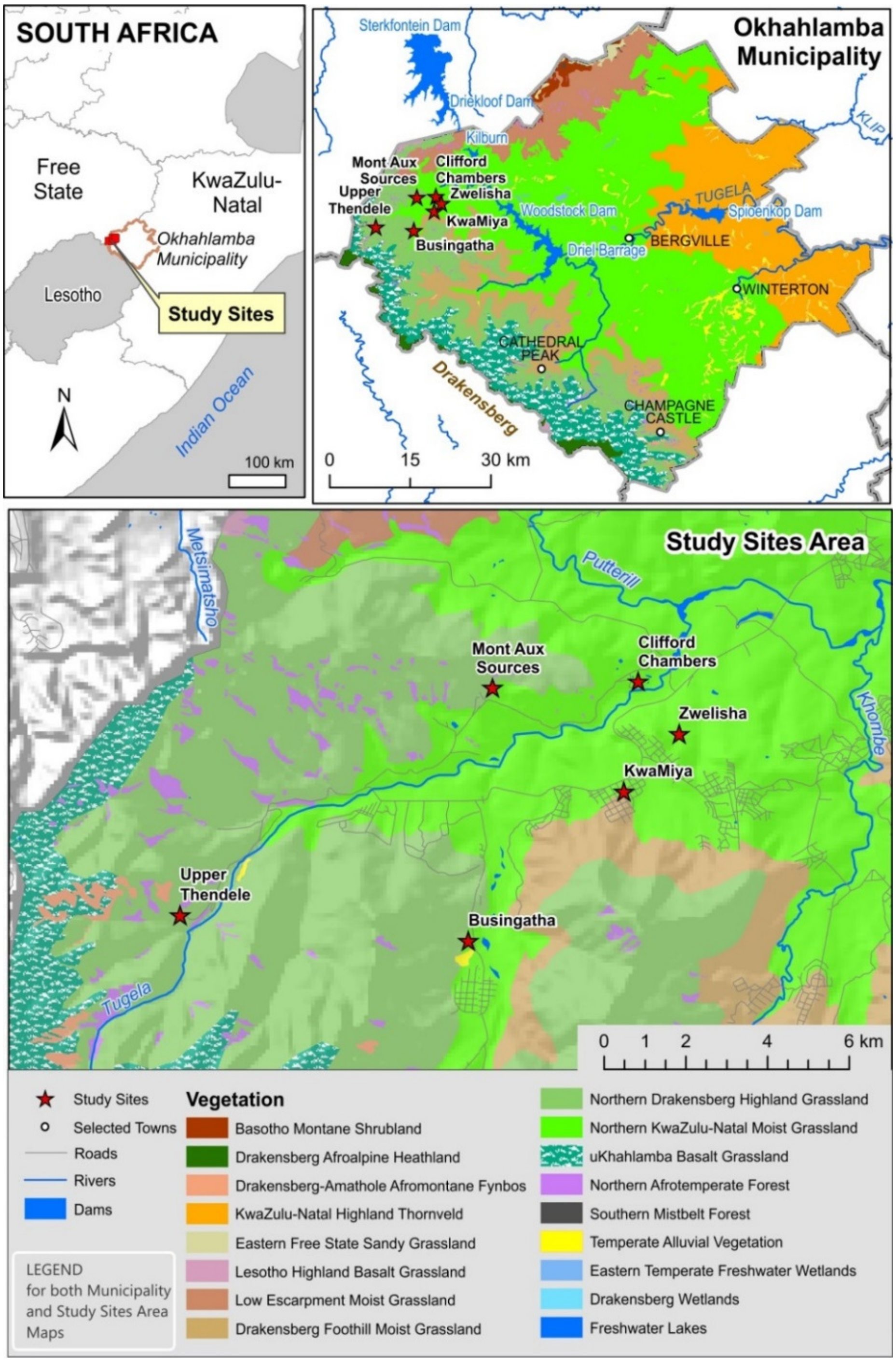

Figure 3-5: Vegetation types found in the study sites and in the Okhahlamba municipality (South African National Biodiversity Institute, 2017).

Different physical attributes and characteristics cover the six chosen sites (Table 3-1). The study site is composed of different land uses and land class features which overlay the area. The land use features overlap on the Park, resorts and rural areas; meaning that it encapsulates the villages, park and resort sites. Some study sites are protected and have been designated for recreational purposes which has led to limited human influence and has allowed certain vegetation to flourish and some land sites to be preserved. Zoning of the area has still remained the same and the study sites have still been under the same land use, even after Apartheid.

Table 3-1: Attributes of the six selected study sites (South African National Biodiversity Institute (2017) and Agricultural Research Council (2015)).

Site	Altitude (masl)	Designation	Vegetation	Soil type (geological composition)
Upper Thendele	1605	National Park	Northern Drakensburg Grassland	Coarse grained sandstone and medium grained sandstone (Fa828 & Ab189)
Busingatha	1397	Village	Drakensburg Foothill Moist Grassland	Dolerite and dark-grey shale and medium grained sandstone (Ab209 & Ab189)
Mont Aux	1430	Hotel	Northern Drakensburg Grassland	Medium grained sandstone (Ab189)
KwaMiya	1357	Village	Drakensburg Foothill Moist Grassland	Fine-to medium-grained sandstone and dolerite and dark-grey shale (Ab210 & Ab 209)
Clifford Chambers	1242	Resort	Northern KwaZulu-Natal Moist Grassland	Fine-to medium-grained sandstone and dark grey shale (Ab210 & Ab208)
Zwelisha	1288	Village	Northern KwaZulu-Natal Moist Grassland	Dark grey shale (Ab208)

The types of rock and some physical characteristics of this area can also be seen Figure 3-6 and Figure 3-7. Figure 3-6 is a view towards the rural study sites of the overall study area and Figure 3-7 is a view towards recreational study sites. The village study sites possess the similar physical characteristics as the more commercial areas, but differ in population numbers, vegetation cover and settlement patterns.

Figure 3-6: Busingatha village with the huts, houses, vegetation and topography

Figure 3-7: Clifford chambers, showing sheet erosion in the field.

The two above figures show that even though areas can have similar topographic and geological characteristics, they can have different erosion patterns based on anthropogenic influences and other factors. Salomon *et al*. (2012) state that the uKhahlamba Drakensberg history shows that a landscape is more than just a set of geographical features of an area; it is the result of socio political processes and interactions between people imprinted onto the natural environment (Sithole, 2003), and people give meaning to the landscape (Bender and Winer, 2001). The characteristics (topography, geology, climate and soils) between the former white areas and communal lands is similar; the difference in erosion status was attributed to the land-tenure and farming systems. The history of land used was parallel to the history of erosion within the communal lands (Kakembo and Rowntree, 2003).

Chapter 4: Methodology

4.1 Introduction

Study methods were selected according to two main criteria; the objectives laid out in the Introduction (Chapter 1) and their suitability in terms of achieving the aim of this study. Some of the methods used in this research are already established and others were adapted for this research. The methods incorporated both desktop research and ground-truthing techniques.

Six study sites were chosen: Upper Thendele (Park), Mont Aux, Clifford Chambers, Busingatha, KwaMiya and Zwelisha. Upper Thendele is a national park. Mont Aux and Clifford Chambers are recreational resorts. Busingatha, KwaMiya and Zwelisha are all villages. Upper Thendele was chosen as a control site because it had the least human interference over the study period. Mont Aux and Clifford Chambers were chosen because they are close to the control site (Upper Thendele) but have lesser people and a lower number of animals grazing on each site respectively. Busingatha, KwaMiya and Zwelisha were chosen because they have a higher population number and more animals which were grazing, on each site respectively.

Shapefiles were produced to create a distinction between the different erosion types in 1964, 1986 and 2014. Different erosion types were classified by inspection and were digitized from the three sets of images. Erosion types were given different markers and colours in order to distinguish between the different years. The digitized erosion types were overlain over each other, so that they could graphically express the extent of the erosion and land use change over the three different sets of years.

4.2 Mapping trends in land use over time in the study area

Aerial-photographs are valuable in conjunction with sample surveys, as they assist in expressing feasible current and past population figures (Hattingh, 1973). Taruvinga (2008) states that the extraction of information from an image such as size, shape, shadow, tone and colour, texture, pattern and feature association, can be utilized to map gullies. There are also various techniques and approaches in terms of assessing and analysing data from aerial photographs (Van Zuidam, 1985). Aerial photographs and georeferenced images, in conjunction with other relevant data made it possible to document trends and changes over the study sites.

4.2.1 Digitizing process

The process of digitizing is when coordinates from a map, image or any other sources undergo conversion into a format which is digital in Geographical Information Systems (GIS) (Fonji and Taff, 2014). Aerial photos and satellite images were first georefenced and the process of digitizing was then applied. ArcGIS 10.2.2 was used to digitize erosion, land use classes and other appropriate features required for the research purpose. Shapefiles were produced and these were important in terms of analyzing geology, soil, vegetation and rainfall data for the study area.

4.2.2 Relationship between land use, erosion classes and study sites.

The Bergville district is composed of different land uses and land class features which overlay the area. Common land uses were identified for the park, resort and rural study sites and land cover maps were drawn up for all of them. The vegetation classification relates to the land use, rather than the botanical classification. Therefore, all the chosen classes represent a distinct land use. Land use was divided into four categories; Settlement, Vegetation, Cultivated land and Grazing land. The Settlement class refers to the population and dwelling area in a study site. The Vegetation class refers to the trees, bushes and normal vegetation in a study site. The Cultivated land class refers to exposed soil and farmed lands. The Grazing land class refers to the areas which are open fields and veld (this includes open fields which are found in the villages, recreational sites and the Park). The methodological framework to divide these land use classes is similar to that used by Kakembo and Rowntree (2003) and Salomon *et al.* (2012).

The nature of the erosion types was assessed using the adapted SARCCUS (1981) method (Table 4-1). The method was modified because not all the rills could be properly distinguished on the aerial photographs, due to poor photo resolution. Erosion classes 2 and 3 were therefore merged to form one class, which was renamed sheet and rill erosion class. The qualitative segment of the methodology, which is the description of the erosion, was used to classify the different types of erosion. Erosion classes are adapted from SARCCUS (1981) and consist of the erosion classes (1 to 5).

Table 4 -1: Erosion classes in the study sites (adapted from SARCCUS (1981))

Erosion Class	Description
1.	No apparent erosion
2.	Slight sheet and severe sheet erosion with rills
3.	Severe rill and gully erosion
4.	Intricate gully patterns and degraded gully remnants
5.	Riverbank and footpath erosion

4.2.3 Erosion and land use demarcations

The spatial statistics feature calculated the area of the different land uses with respect to the study site it was part of. Results from the spatial statistics tool for the different land uses were then converted into a percentage. The percentage of each land use class was then recorded in an Excel spreadsheet, which consisted of the years 1964, 1986 and 2014. From the data in the Excel spreadsheet, a graph was created to express the land use classes, and how they changed between 1964, 1986 and 2014.

The method to calculate the erosion cover for the study site is similar to that of the land use area method. Different erosion types (sheet and rill, and gully) were identified on each of the different study sites. Erosion dynamics were digitized according to the erosion type/classification it fell under. The spatial statistics tool calculated the size of the different erosion types which were found in a study site. Total erosion cover of a study site was the sum total of the different erosion types which were found in the study site. Digitized erosion types were then superimposed on the different land uses in the study sites. For each land use in the study site the type of erosion is identified and the sum total of the size of the erosion types is calculated. For each land use, the percentage of the different erosion types is calculated by dividing the size of each different erosion type (e.g. sheet and rill) to the land use. The totals of the different erosion types are then expressed as a percentage on the different land use types in the study sites. This expresses which type of erosion occurs predominantly in a study site and which land use in a study site is affected mostly by erosion, and by which type of erosion.

4.3 Evaluating the extent and nature of soil erosion

This section deals with mapping erosion types, settlements and vegetation found in the study sites. These study sites were chosen strategically, in a bid to show that erosion rates can differ in places based on land use systems, political influences and socio-economic factors.

4.3.1 Mapping erosion types, settlements and vegetation over study sites at three-time periods; 1964, 1986 and 2014

The different study sites have different land uses and population dynamics. Aerial photographs and ArcGIS were used to analyse erosion and land use change in the study sites, at three points in time. Aerial photographs from a discrete number of years were selected from the 50-year period: from 1964, 1986 and 2014. The 50-year period is considered long enough to show any changes and developments which could have occurred in the area, as in the case of the Mfolozi catchment study in KwaZulu-Natal (Watson, 1997) and the Peddie study in the Eastern Cape (Kakembo and Rowntree, 2003).

The erosion types and intensities were sorted by using an adapted classification system that has been designed specifically for erosion mapping in Southern Africa- the Southern African Regional Commission for the Conservation and Utilization of Soil (SARCCUS, 1981). This system shows the different types of erosion which can occur in an area, ranging from sheet erosion to complex interconnected gully networks, and river bank erosion. Arc GIS version 10.2.2 was used to determine the size and area of the soil erosion types, vegetation and soil profiles in the Upper Tugela catchment basin.

4.4 Erosion phenomena and change in land use over the 1964 to 2014 period

The position and properties of interesting features can be identified primarily by the utilization of aerial images (Fonji and Taff, 2014). Monitoring and detection of change can be done by the use of satellite images, and also for the creation and updating of land cover layers of data (Fonji and Taff, 2014). Aerial photographs assist in providing the longest-available, temporally continuous, and spatially complete record of changes in the landscape, ranging from the early 1930s in some instances (Morgan *et al*., 2010). As a result, many important management decisions are usually made on the basis of maps derived from aerial photographs (Morgan *et al*., 2010). Satellite imagery and aerial photographs were used to detect changes in erosion processes which occurred over the study sites from 1964 to 2014. Differences in land use over the study sites were visible from the images, and the changes which occurred in the land uses over the years were digitized and classified accordingly. Georeferenced images in conjunction with the aerial photos and topographic maps were important in identifying and confirming the features which were present in the study sites. Ground-truthing was done by means of a field trip to the study sites and this was done to supplement the recent aerial photographs and satellite imageries.

4.4.1 Population changes over time in the study sites

Recent work on population estimation techniques includes that of Henry (1990), Brown *et al*. (2001) and Wu *et al.* (2005). Henry (1990)'s work focussed on the importance of estimating population numbers for policy and social research, using various sampling techniques. Henry (1990)'s work was geared towards formulating an approach to sample design provides a basis for decision making about design alternatives throughout the research process. This body of work was for researchers who would require sampling as a research tool. Brown et al. (2001)'s work was based in Africa and Asia and was used to estimate population numbers in emergency or disaster situations. The technique is valuable as a public health tool in situations of emergency, but it has various limitations. Brown et al. (2001)'s stated that statistically valid methods should be developed in the future to assist in situations of public emergencies and disasters. Wu *et al.* (2005)'s work focussed on areal interpolation methods and statistical modelling methods to estimate population numbers. The methodology which was used included separating population estimation methods into areal interpolation and statistical modelling. Wu *et al.* (2005)

concluded that remote sensing provides valuable resources for useful ancillary information, when compared to past studies of population estimation mainly relied on images of relatively coarse spatial resolution.

Population density information underwent clipping in ArcGIS, and this was helpful in terms of assessing the number of dwelling units and an estimate of the number of people who were present in the study sites. The population estimation methods used by Schultze (1969) was employed as a means to estimate the number of people who resided in the study sites for the 1964 and 1986 years. The population estimation methods by Schultze (1969) was more suited to this study than the recent above-mentioned methods because it was not necessary to precisely estimate the population increase, but rather that merely getting an idea of population increase by way of settlement size increase and number of dwellings was enough to show a relationship between human population increases and soil erosion increases. In addition, the method of the chosen author was relevant and valid at the time of the earlier aerial photographs and also included village settings. Information from the shapefiles, the digitized information from the land use map, census from StatsSA and the population estimation data was important to create a more substantial population outlook.

<u>4.4.2 Population estimation technique</u>

Population estimation techniques play a critical role in understanding population densities in certain areas which are not necessarily covered by census counts. Areas which are not covered by census counts are usually villages and other rural areas which are difficult to get to by using motor vehicles. The study by Schultze (1969) was based on rural areas, which were classified previously as Homelands; hence they are useful as a framework for population estimation techniques, because of the similarity between their studies and this Tugela catchment study.

A field trip was conducted, so that the information which was perceived from the aerial photographs and other sources could be validated. The technique which was expressed by Schultze (1969) requires site validation, which includes visiting the study sites and actually taking photos of the study areas. The technique for population estimation is a method which was derived from the studies by the authors mentioned above. It is as follows:

(a) A traditional round hut houses 4 People.

(b) A rectangular hut houses 5 People.

(c) A corrugated-iron-roofed hut houses 5 People.

From the study by Schultze (1969), clusters of modern buildings which evidently constituted schools, churches, or trading stores were absent in the counts, but the huts surrounding them were assessed according to the above criteria. Grain huts could straightforwardly be differentiated from huts which for settlement purposes on the aerial photographs by their shape and size and they were also not included for the population estimation (Schultze, 1969).

To estimate the population growth, the land use change maps which were constructed for the 1964, 1986 and 2014 years were used. The settlement class was used as an indication of a growing population. The settlement class did not exactly give the population numbers, but it expressed that the number of dwellings were increasing. The topography map was also used to analyse how the study sites grew from huts to fully fledged settlements. Information from Statistics South Africa (2011) was helpful in providing recent information to estimate the population growth.

ArcGIS was used to digitize the settlement patterns and assess how many traditional round huts and rectangular-shaped houses were present in a village. The number of rectangular-shaped houses and huts which existed in a certain “block” were counted and then the number of rectangular-shaped houses and huts were averaged for the blocks. Excel was then used to tabulate the number of rectangular-shaped houses and huts, by multiplying the number of rectangular-shaped houses and huts with the number of grids (square blocks visible on the maps dividing the settlements) in a village. The next step was then to multiply this number with 4 (number of people in a traditional round hut) and 5 (number of people in rectangular-shaped house) in the area. This gave an estimation of the total number of people in a village. This method may not yield the precise number of people which made up the population number, but it was beneficial in showing the population trends over the years.

4.5 Summary

The methodology was designed to meet the objectives which were laid out for the study. Aerial photographs, georeferenced photographs and the google images were digitized so that the land use could be analysed in the study sites. Land use change was then mapped, to express how changes in the land use occurred in 1964, 1986 and 2014 at the six different study sites.

Aerial photographs and georeferenced images were digitised to analyse the erosion. The digitization was based on the SARCCUS classification, which separates erosion in classes. Erosion on the different study sites was then mapped, to express how erosion progressed from 1964, 1986 and 2014 at the six different study sites.

Erosion maps which were digitized for the years 1964, 1986 and 2014, were superimposed on the maps which were digitized for land use. The population estimation technique was also used to see how the number of people had progressed over the years. This was done to contrast erosion phenomena with change in land use over the 1964 to 2014 period. The number of people influenced the settlement size respectively and also the land use. Higher numbers of people result in an increase in the settlement size and a higher number of animals. The stocking levels also play a role in influencing the erosion rates in a study site.

Chapter 5: Results and Observations

5.1 Introduction

The Results and Observation chapter is divided into three main sections and subsections. Section 5.2 deals with mapping and investigation of trends in land use over time in the upper Tugela River catchment, by means of expressing the digitised study sites with erosion features and associated graphs. This section will also include the location of the soil erosion features in the landscape and topography. Section 5.3 will be an analysis of potential relationships between land use, population changes and erosion. Section 5.4 is the concluding section; it will deal with the changes which were observed in the study sites from 1964 to 2014.

5.2 Mapping and investigating trends in land use over time in the upper catchment

Changes in land classes from 1964 to 2014, for the six study sites are presented in this section. Vegetation class is represented by trees, bush and normal vegetation, the settlement class by dwelling area and population, cultivated class represented by exposed soil and farmed lands, and the grazing land includes the veld and open fields.

The six chosen study sites were analyzed and discussed in this section. The changes in the individual sites which occurred over the years 1964 to 1986, and 1986 to 2014 were expressed and presented in the form of graphs and tables. The extent and nature of observed soil erosion phenomena in six different study sites was also discussed. Erosion cover totals over all the study sites, in three-time periods; 1964, 1986 and 2014 were also presented. A graph was produced to show the changes in erosion cover totals for the individual sites. Erosion cover of recreational, park and village study sites, in three-time periods, 1964, 1986 and 2014 was shown. This was to show erosion coverage in the different sets of study sites. Upper Thendele (Park) is demarcated as the control site. Mont Aux and Clifford Chambers are the recreational sites. Busingatha, KwaMiya and Zwelisha are the village sites.

I. Upper Thendele (control Site) (1964-2014)

Upper Thendele is a recreational study site and is utilised for tourist purposes. Wildlife grazing land covered the majority of the study site in 1964 and the vegetation cover was also dense in 1964. The settlement was restricted to the small buildings which were used for tourist purposes. In 1986 the settlement size did not experience notable changes. Vegetation cover decreased minimally. Open fields and veld (grazing land class) were still the same size and the vegetation cover in this area was a mixture of trees and grasslands. In 2014 the settlement area increased because of the growth in building size. Vegetation cover continued to dwindle where access to people was given in the reserve.

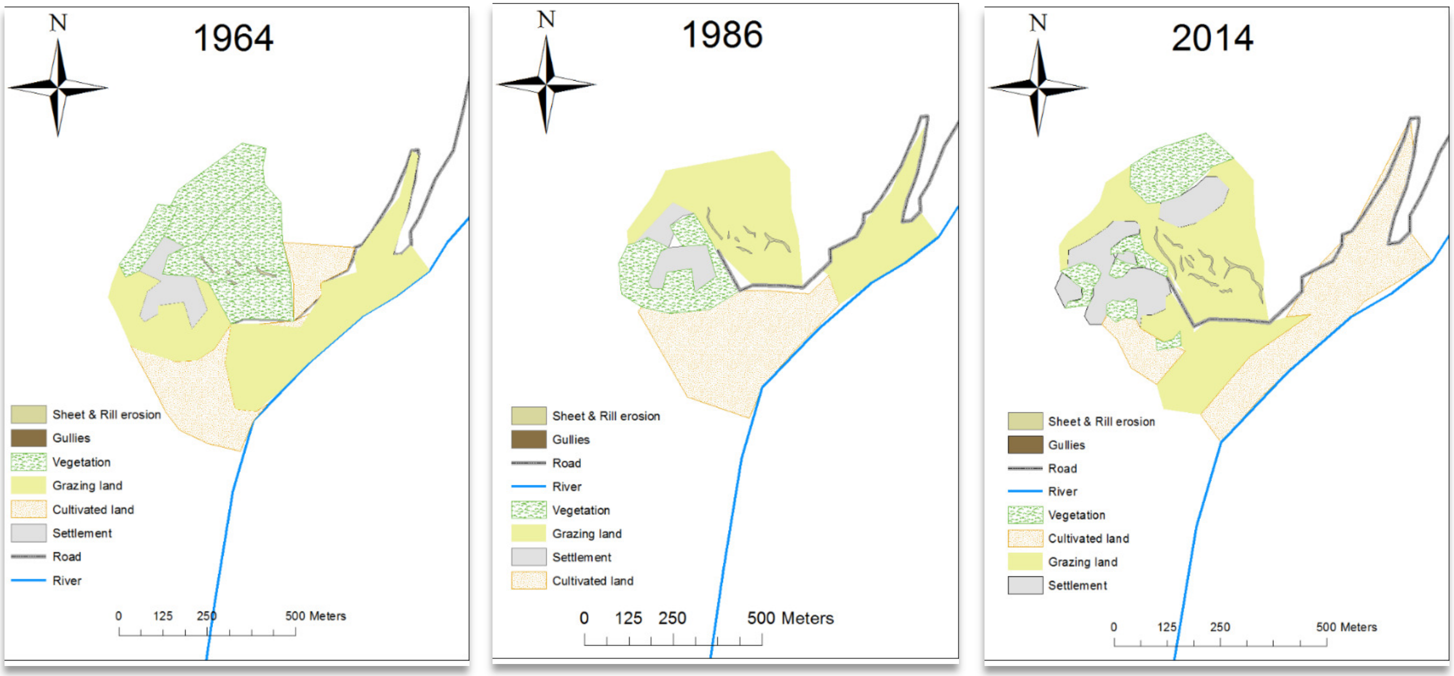

Figure 5-1: Trends and changes in land use over time in Upper Thendele, in three-time periods: 1964, 1986 and 2014.

In 1964, the sheet and rill erosion in Upper Thendele only covered approximately 6% percent of the vegetated area. No other erosion was seen on the other land use classes at the resolution of the aerial photograph. Upper Thendele has the least erosion than all the sites. Erosion in this occurs naturally, rather than being human induced. It is a secluded area with considerable vegetation cover and a minimum number of people.

Upper Thendele had sheet and rill erosion in 1986 and had less erosion (approximately 20% erosion cover) than all the other sites. Sheet and rill erosion covered the wildlife grazing land area only. No other erosion was seen on the other land use classes at the resolution of the aerial photograph. By 1986 the Upper Thendele site had extended. It still remained a controlled area and access restricted in 1986. Erosion occurred here mostly because of natural factors rather than anthropogenic influences.

In 2014, erosion in Upper Thendele was still less when compared to the other sites. Sheet and rill erosion covered approximately 35% in Upper Thendele. Erosion covered the open fields and veld (wildlife grazing land class). No other erosion was seen on the other land use classes at the resolution of the aerial photograph. Soil piping, which developed into a gully system, was present at one location in the study site and was confirmed on the field trip in 2014. The gully was not visible on the aerial map. Erosion intensified because of natural factors. Sheet and rill erosion forms developed over time and indicate that there is an increase in erosion in the study site.

II. Mont Aux (recreational site) (1964-2014)

Mont Aux was densely covered with vegetation around the settlement area in 1964. Open fields and veld (grazing land class) covered the surroundings of the site and the vegetation area of Mont Aux. The settlement only constituted of the hotel and a small number of people. In 1986, the vegetation cover decreased as the sheet erosion spread over the vegetation in the site. Grazing land did not change in area over time since this is a resort. The hotel size did not extend immensely from 1964 to 1986. In 2014, the hotel grew and extended in size and this influenced the vegetation layer size. Grazing land in Mont Aux was disturbed by anthropogenic factors which included the construction of roads and clearing of vegetation around the study site.

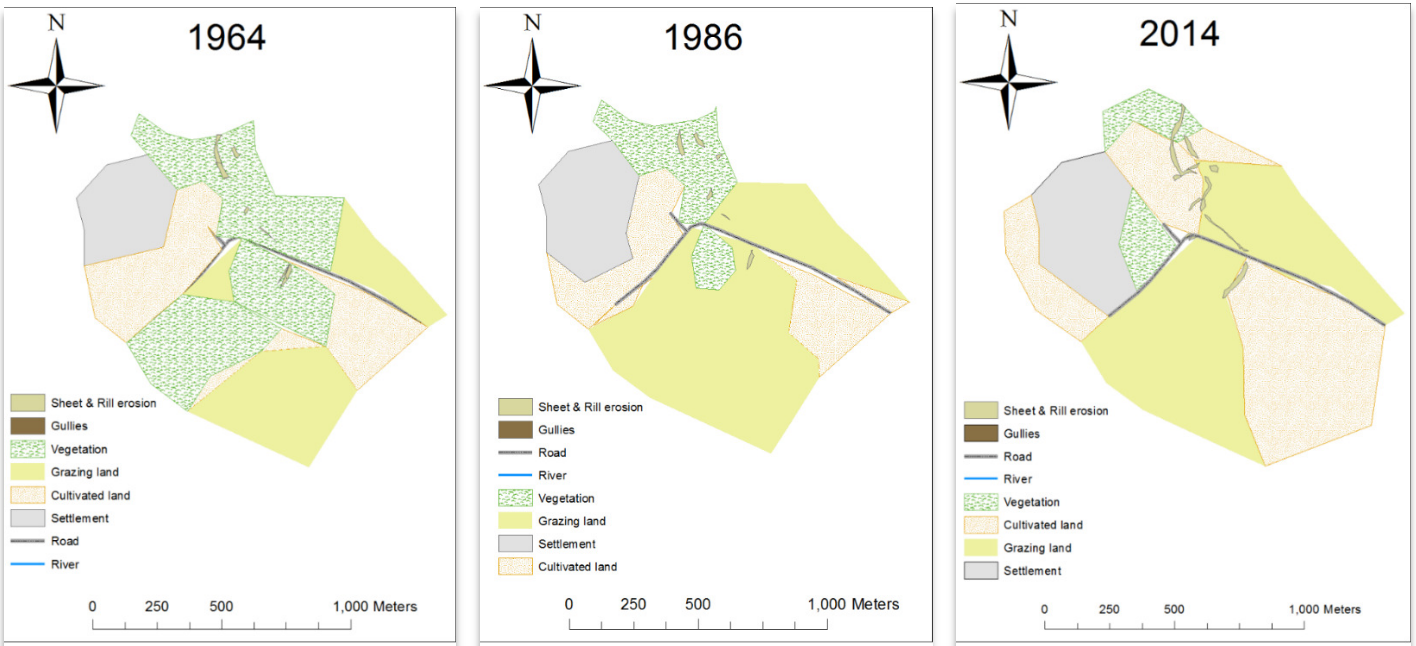

Figure 5-2: Trends and changes in land use over time in Mont Aux in three-time periods: 1964, 1986 and 2014.

In 1964, the sheet and rill erosion covered most of the vegetated area of Mont Aux. Sheet and rill erosion covered around 9% of the vegetated area. Erosion on the other land classes was not visible at the resolution of the aerial photographs. Erosion occurred in the area which was outside the hotel. Removal of vegetation from Mont Aux was because of grazing by animals and erosion occurring naturally. Sheet and rill erosion was present in Mont Aux. Mont Aux does not have gullies.

In 1986, Mont Aux experienced approximately 19% erosion cover in total. Only sheet and rill erosion were present. No livestock is kept permanently in Mont Aux for farming purposes. Sheet and rill erosion covered around 15% of the vegetated area and approximately 4% of the grazing land, this is because this site is entrance restricted and humans do not influence erosion rates. Erosion in Mont Aux is influenced mostly by natural factors and vegetation covers most of the area, hence the erosion is mostly on the vegetation class.

In 2014, Mont Aux still had less erosion cover, approximately 35%. Sheet and rill had approximately 14% cover on the grazing land. The vegetated area in Mont Aux was transformed into land used for human purposes. Sheet and rill erosion only covered approximately 21% of cultivated land (Figure 5-3). Erosion cover increased from approximately 9% in 1964 to 35% in 1964.

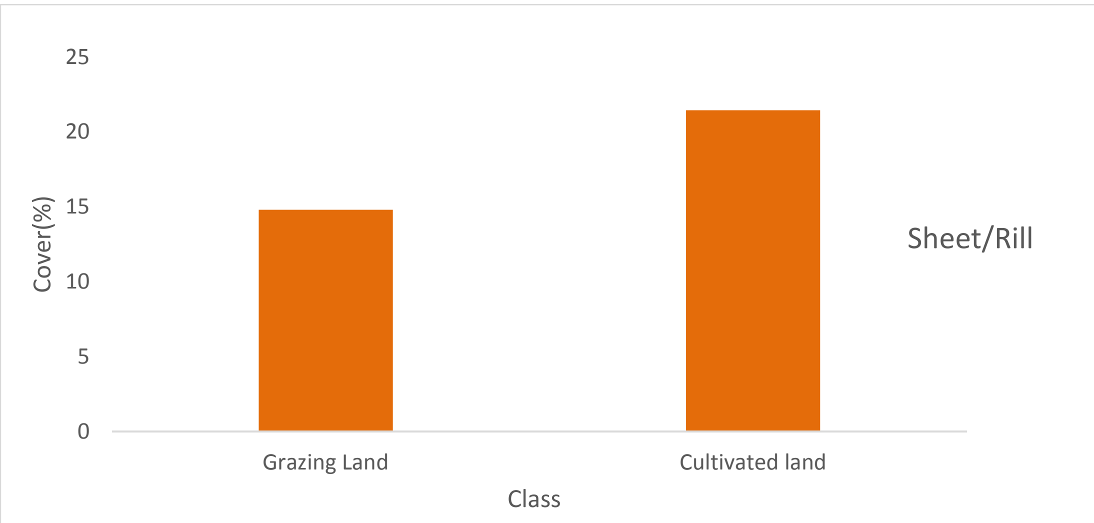

Figure 5-3: Sheet/rill erosion present in the grazing and cultivated land use in Mont Aux in 2014, with no gullies.

III. Clifford Chamber (recreational site) (1964-2014)

Zwelisha and Clifford Chamber (Figure 5-4) are adjacent to each other and are separated by a road. In 1964 the grazing land in Clifford Chamber covered a large part of the study site. Clifford Chamber is a resort and is used for commercial purposes. Vegetation cover in the study site had decreased in the period 1964 to1986. Settlement size of Clifford Chamber remained unchanged. In 2014, the was an increase in the vegetation around Clifford Chamber. There was grazing towards the periphery of the Clifford chamber by livestock. There was no change in settlement size.

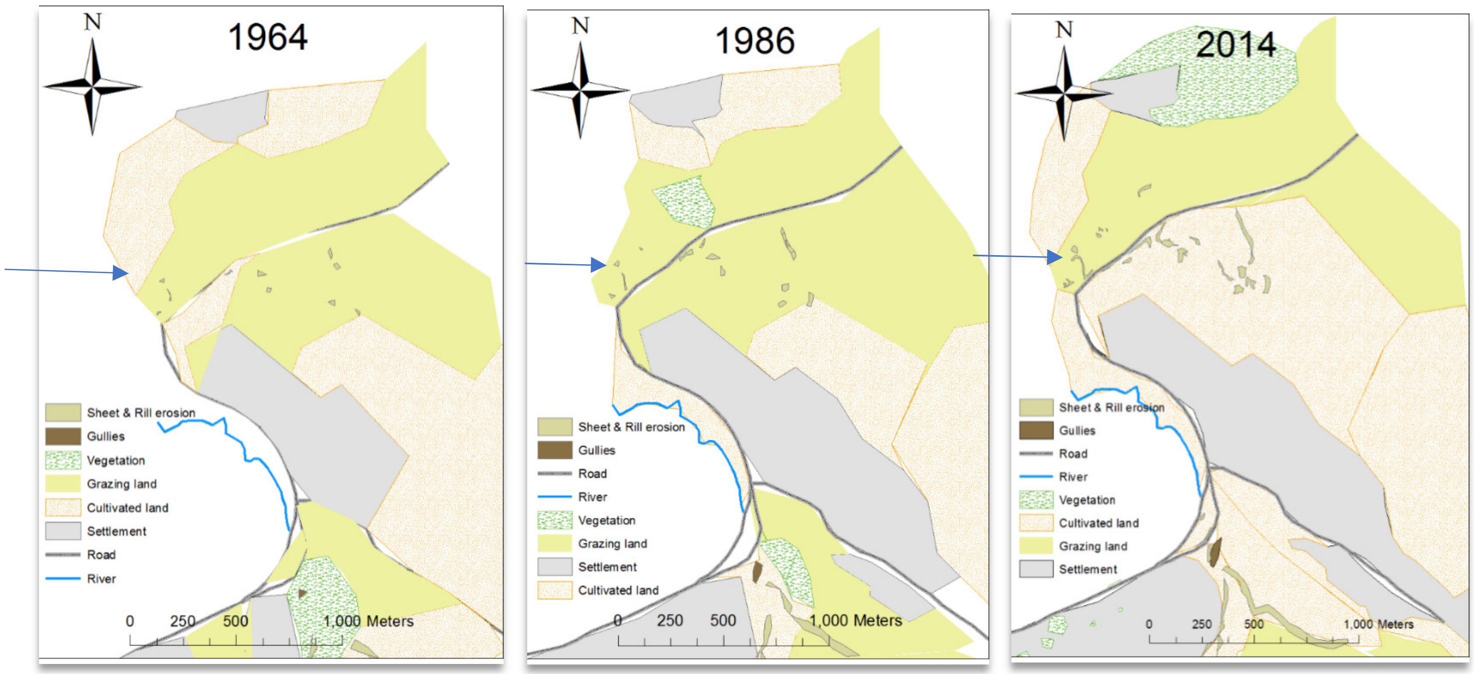

Figure 5-4: Trends and changes in land use over time in Clifford Chamber, in three-time periods: 1964, 1986 and 2014

Erosion in Clifford Chamber was low in 1964, approximately 3.5% (Figure 5-5). The study site did not have any gullies present. Sheet and rill erosion only covered the grazing area (2.5%) and a small part of the cultivated land area (approximately 1%) in the study site. Clifford Chamber is an excluded area and entrance restricted and erosion is influenced mostly by natural factors.

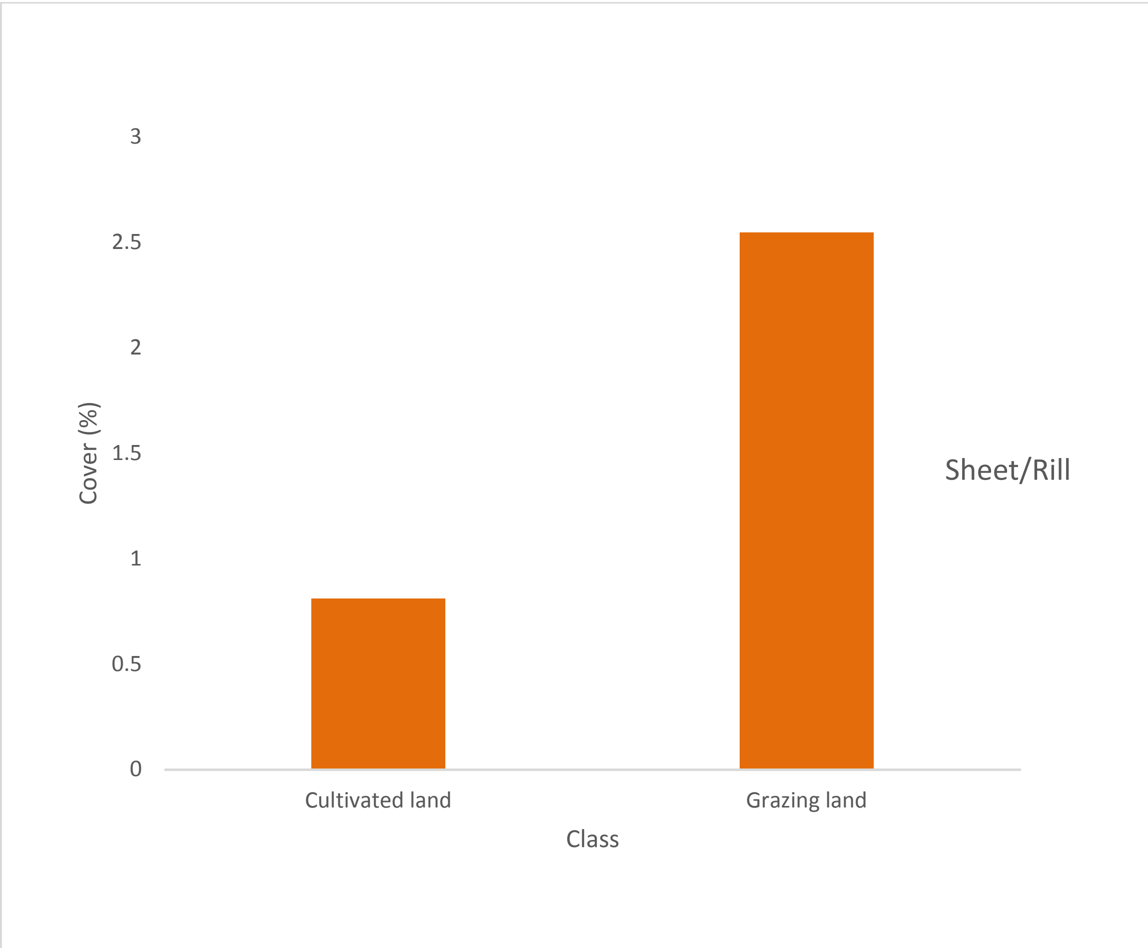

Figure 5-5: Sheet/rill erosion present in the grazing and cultivated land use Clifford Chamber in 1964,

In 1986, Clifford Chambers had sheet erosion covering approximately 10% of the open fields and veld (grazing land class) and 2% of the cultivated land. Erosion in this study site was low in 1986 (approximately 12%) because the resort is small and it is used for tourist purposes. Erosion in Clifford Chamber is influenced primarily by natural factors.

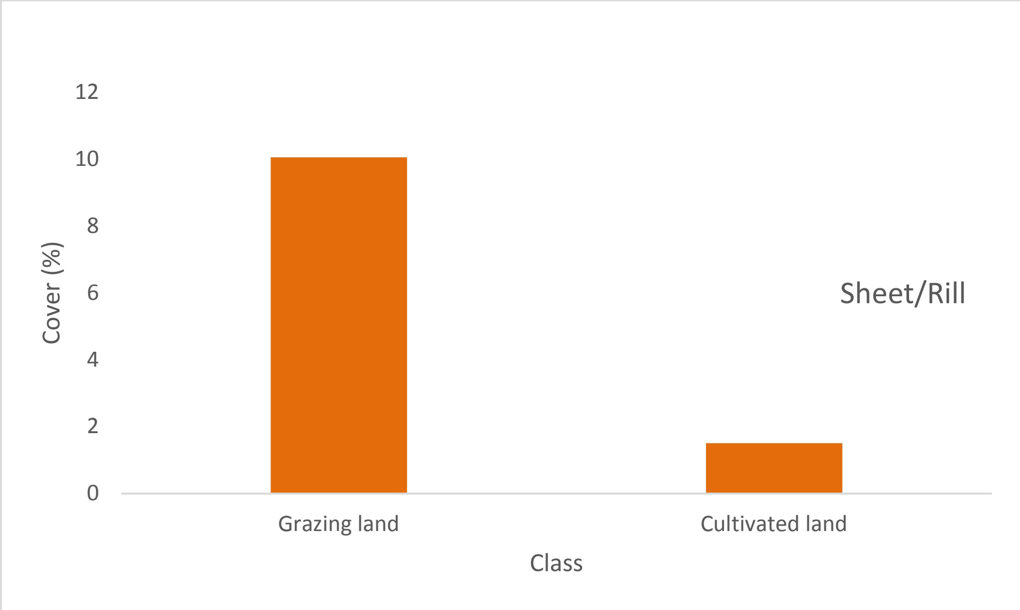

Figure 5-6: Sheet/rill erosion present in the grazing and cultivated land use Clifford Chamber in 1986, with no gullies.

In 2014, Clifford Chamber had no gully erosion. Sheet and rill erosion increased in cover over the grazing land in the study site to approximately 20% (Figure 5-7). Sheet and rill erosion covered approximately 4% of the cultivated area. Clifford Chamber had approximately 24% in erosion cover. Clifford Chamber is a resort which has not undergone major changes since 1964.

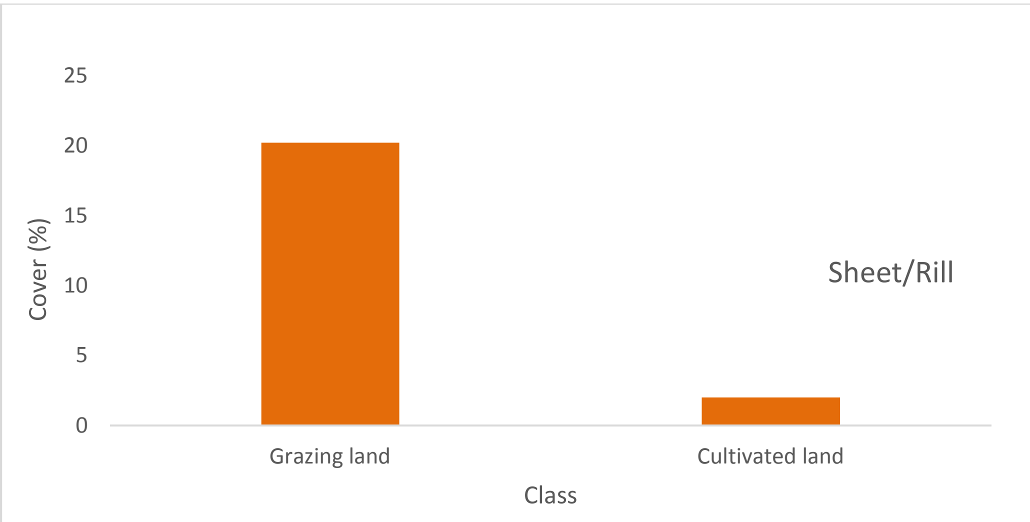

Figure 5-7: Sheet/rill erosion present in the grazing and cultivated land use Clifford Chamber in 2014.

IV. Busingatha (village site) (1964-2014)

In 1964 vegetation cover was mostly bush and dense grass. The settlement was just limited to a few huts which were dispersed. Grazing land covered a substantial portion of the study site. In 1986 the cultivated land area increased in size as the settlement increased and more land was required to farm and produce food for more people. In 2014 the vegetation area had dwindled extensively, because the settlement had increased and more land was required to build houses. Cultivated area land use also increased as people transformed the land use for anthropogenic purposes. Grazing land become more eroded over time and had lesser dense vegetation cover.

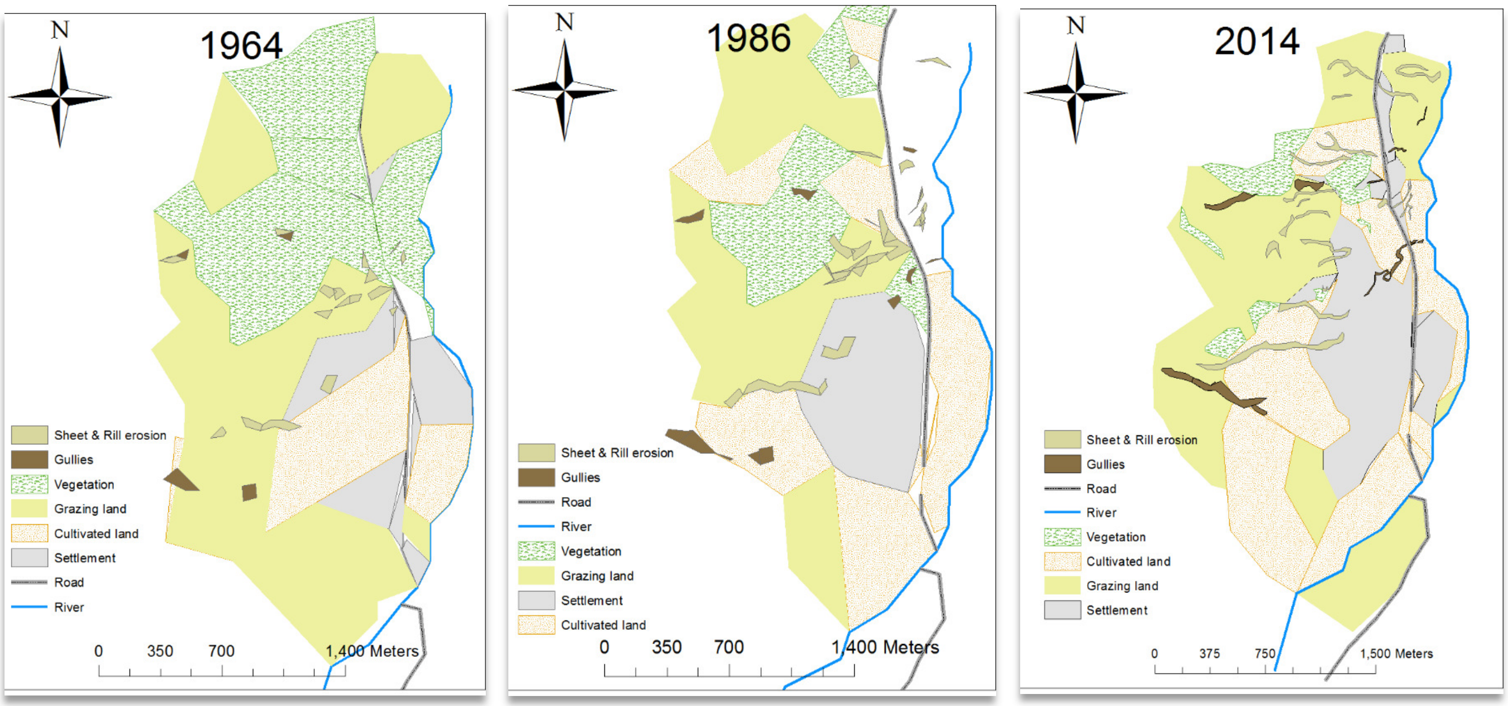

Figure 5-8: Trends and changes in land use over time in Busingatha, in three-time periods: 1964, 1986 and 2014.

In 1964, gullies were not extensive and widespread in Busingatha, sheet and rill erosion were more apparent. Gullies covered approximately 13% of the cultivated land area in Busingatha and covered a small portion of the grazing land (2.5%), vegetation (2%) and the settlement (0.5%) (Figure 5-9). Overall gully coverage in Busingatha was minimal in 1964, approximately 18%. Sheet and rill erosion in Busingatha were mostly present in the cultivated land area and only covered a small portion of the settlement area, approximately 6%. Sheet and rill erosion was also present in the grazing land area (22%), which is where the livestock graze.

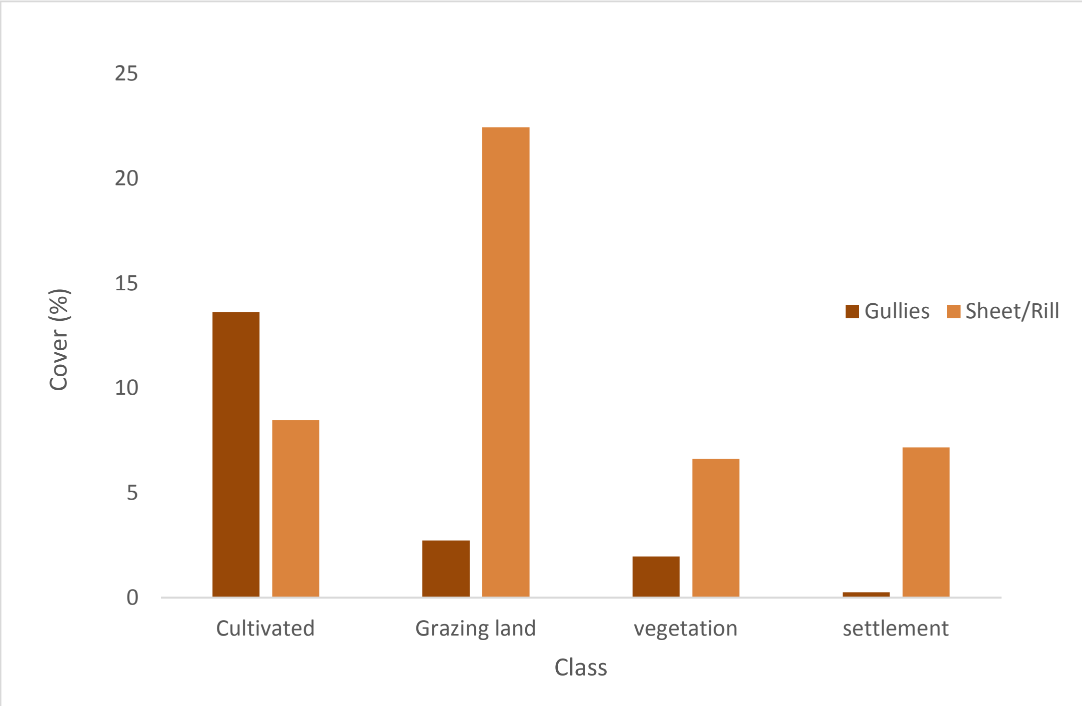

Figure 5-9: Sheet/rill and gully erosion present in the cultivated, vegetation, grazing and settlement land use in Busingatha 1964.

Sheet erosion leads to overland and surface loss of soil. Erosion was not extensive in the settlement area (approximately 6%) in Busingatha. Busingatha was primarily agricultural and pastoral inclined, so footpaths and animal tracts were more prevalent than conventional roads.

Busingatha experienced changes in erosion cover in 1986, from. A noticeable change was the increase in the gully erosion over the area. Gullies had covered approximately 15% of the cultivated land, 4% of grazing land, 9% of the vegetation area and 6% of the settlement area (Figure 5-10). Cultivated land use also changed, because people needed to convert natural land to farm land for growing food. The road adjacent to the village has created channels which allow for erosion to occur. Sheet and rill erosion covered approximately 34% of the settlement area. Busingatha was still growing in 1986 and the settlement expanded from 1964.

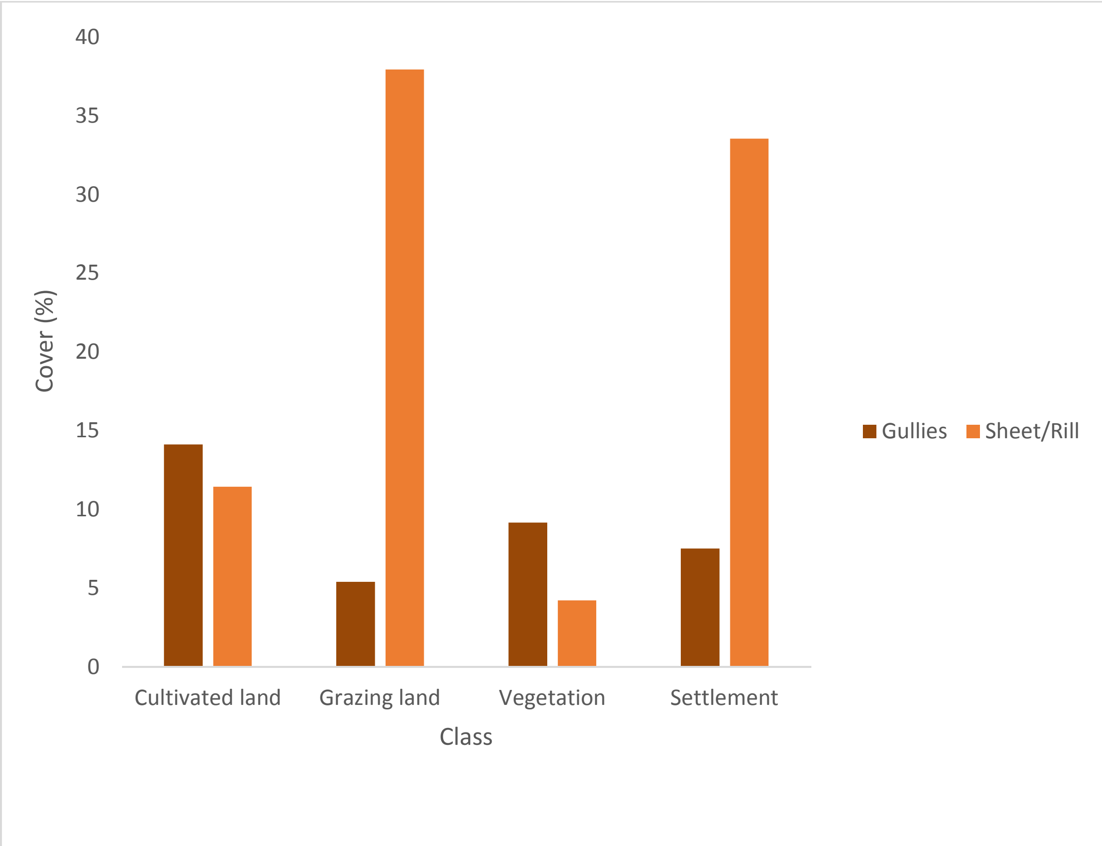

Figure 5-10: Sheet/rill and gully erosion present in the cultivated, vegetation, grazing and settlement land use in Busingatha 1986.

In 2014, sheet and rill erosion, and gully erosion were present in Busingatha. Erosion was expressed over the cultivated lands, grazing land and settlement land use zones mostly. Sheet and rill erosion was mostly expressed over the cultivated land and grazing land zones (Figure 5-11). Sheet and rill erosion covered approximately 27% of the cultivated area and nearly 36% of the grazing land by 2014, because of the further intensification of the erosion.

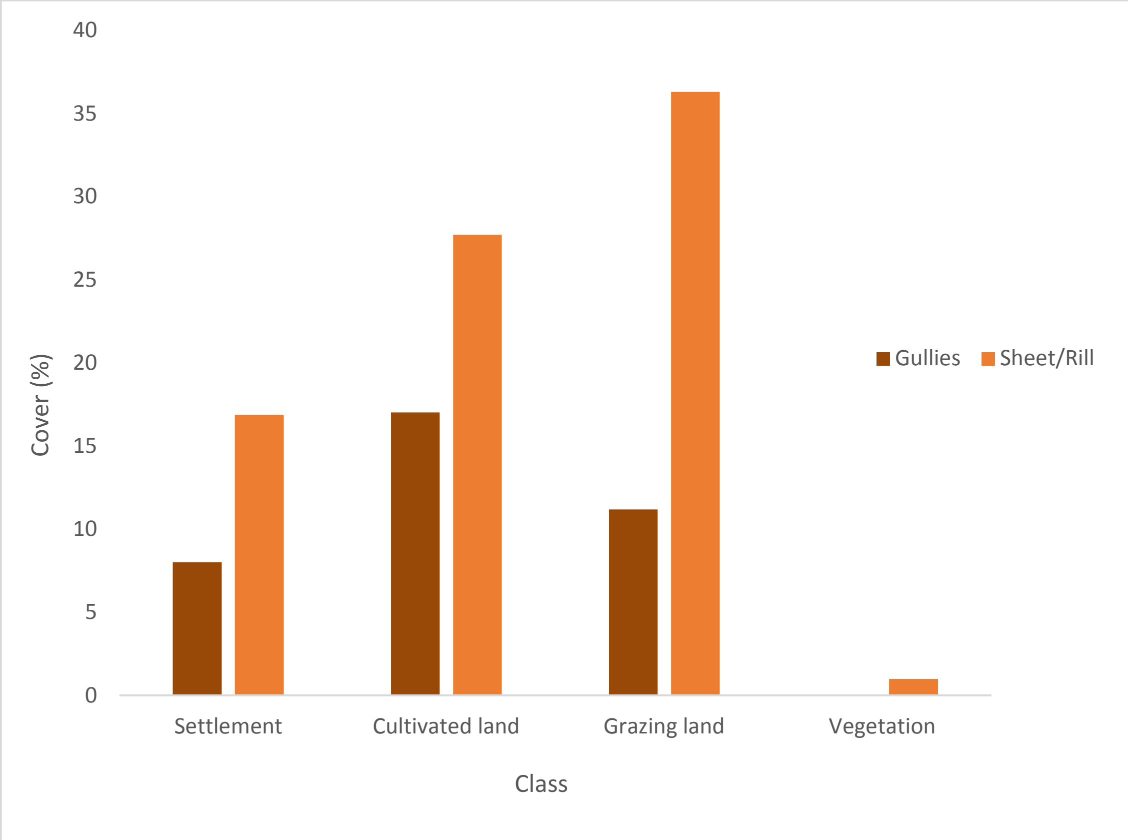

Figure 5-11: Sheet/rill and gully erosion present in the cultivated, vegetation, grazing and settlement land use in Busingatha 2014.

Gullies have grown to intense levels in the settlement land use (approximately 8%) that they even pose a threat to the dwellings of the villagers and to the livestock. Gullies in Busingatha play a role in the washing away of soil in this village.

Road-cuts have also played a role in the erosion along the road because road construction creates channels for sediment flow. Cultivated lands have also increased in sheet and rill erosion from 1986 to 2014 (by approximately 20%), because more people require the land for farming purposes. As the settlement increased in size, sheet and rill erosion also increased in time because of the increasing population pressure and the building of infrastructure. Gullies in Busingatha covered approximately 8% of the settlement area, 15% of the cultivated area and 11% of the grazing area. Gullies are severe forms of erosion in the study site and have led to soil loss in Busingatha. An increasing population number has led to increased erosion because of usage of land to build more dwellings. Continuous ploughing of the land to produce food and for agricultural purposed has led to gullies forming over time in Busingatha.

V. KwaMiya (village site) (1964-2014)

KwaMiya in 1964 did not have a dense and widely dispersed vegetation cover when compared to the other study sites. Grazing land and cultivated land use took up most of the study site. In 1986 the settlement increased in size and grazing land was converted to dwelling areas for people. The cultivated area increased in size as the number of people increased in KwaMiya. Vegetation in the study site decreased too as more land was converted to agricultural land for farming purposes. In 2014 the settlement had also increased more in size and even extended towards the main road and grew along the road. Growth in the settlement led to construction of new roads within the village. Grazing land was also transformed into cultivated land and was situated more towards the periphery of the settlement.

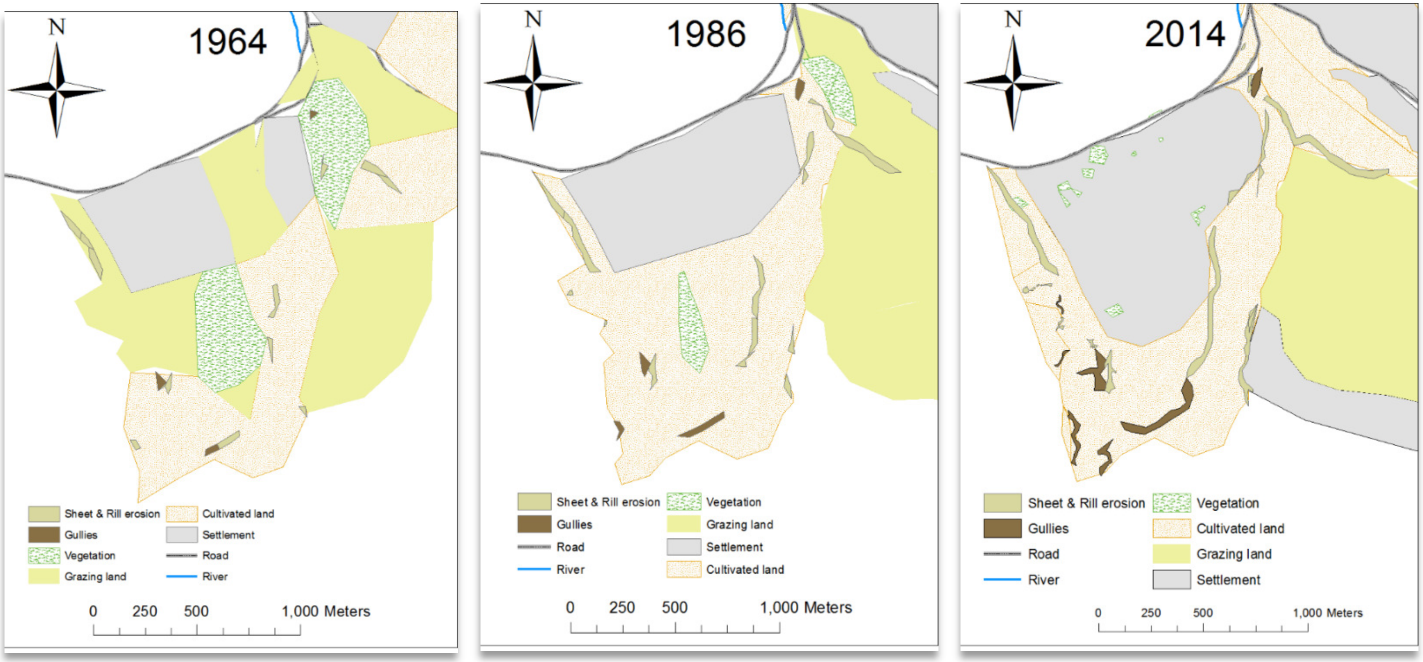

Figure 5-12: Trends and changes in land use over time in KwaMiya, in three-time periods: 1964, 1986 and 2014.

KwaMiya had gullies present in the cultivated land and vegetated area in 1964. Gullies cover is approximately 10% of the KwaMiya site in total (Figure 5-13). Sheet and rill erosion in KwaMiya is mostly found in the cultivated, vegetation and in the grazing land area. Sheet and rill erosion could not be identified in the settlement area because of the photo resolution. Sheet and rill erosion in the cultivated area will increase and develop into gully erosion if not managed properly, because the cultivated land is the area where alteration of land use occurs.

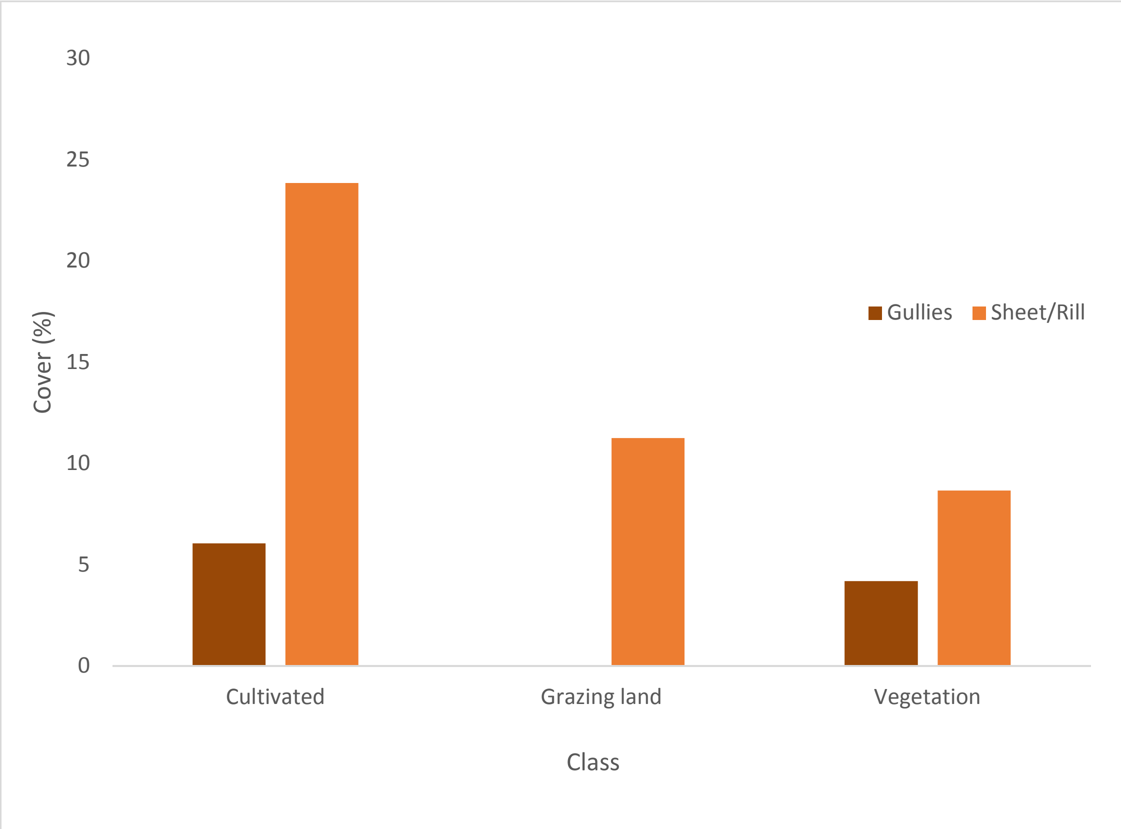

Figure 5-13: Sheet/rill and gully erosion present in the cultivated, vegetation and settlement land use in KwaMiya in 1964.

KwaMiya experienced sheet and rill erosion, and gully erosion in the cultivated land area in 1986. Sheet and rill erosion covered approximately 45% of the cultivated land. Gullies increased in size and coverage in the cultivated area because more people altered the ground for cultivation purposes. There were roads inside and adjacent to KwaMiya, meaning more human-induced erosion (Figure 5-14). Gullies developed from human-induced erosion.

Figure 5-14: Sheet/rill and gully erosion present in the cultivated and settlement land use in KwaMiya in 1986.

In KwaMiya, the cultivated land use category had sheet and rill erosion, and gully erosion in 2014. There was an increase in gullying (approximately 16% in cultivated land and 2% in grazing land) as more people dwelt in the area. Gully erosion increased in the cultivated area as more people required the ground for food cultivation. Sheet and rill erosion developed into gully erosion as time progressed. Gully erosion covered 27% of the cultivated area (Figure 5-15). KwaMiya over time grew in settlement size. Increasing gully erosion percent shows that land is being lost at high levels and that the gullies could develop into more serious erosion systems.

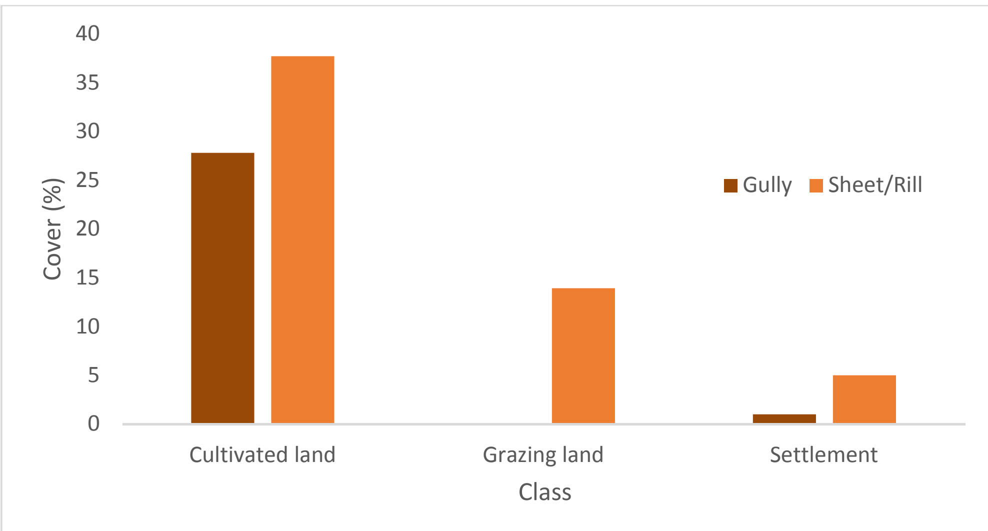

Figure 5-15: Sheet/rill and gully erosion present in the cultivated and grazing land use in KwaMiya in 2014.

VI. Zwelisha (village site) (1964-2014)

Zwelisha and Clifford Chamber (Figure 5-16) are adjacent to each other and are separated by a road. In 1964 the grazing land in Zwelisha a large part of the study site. Zwelisha is a village and the settlement developed over the years. Vegetation cover had decreased in the period 1964 to1986. In 2014, the cultivated land area increased substantially in Zwelisha and moved into the grazing land zone. Grazing shifted towards the periphery of the settlement and the cultivated land was situated near the growing settlement.

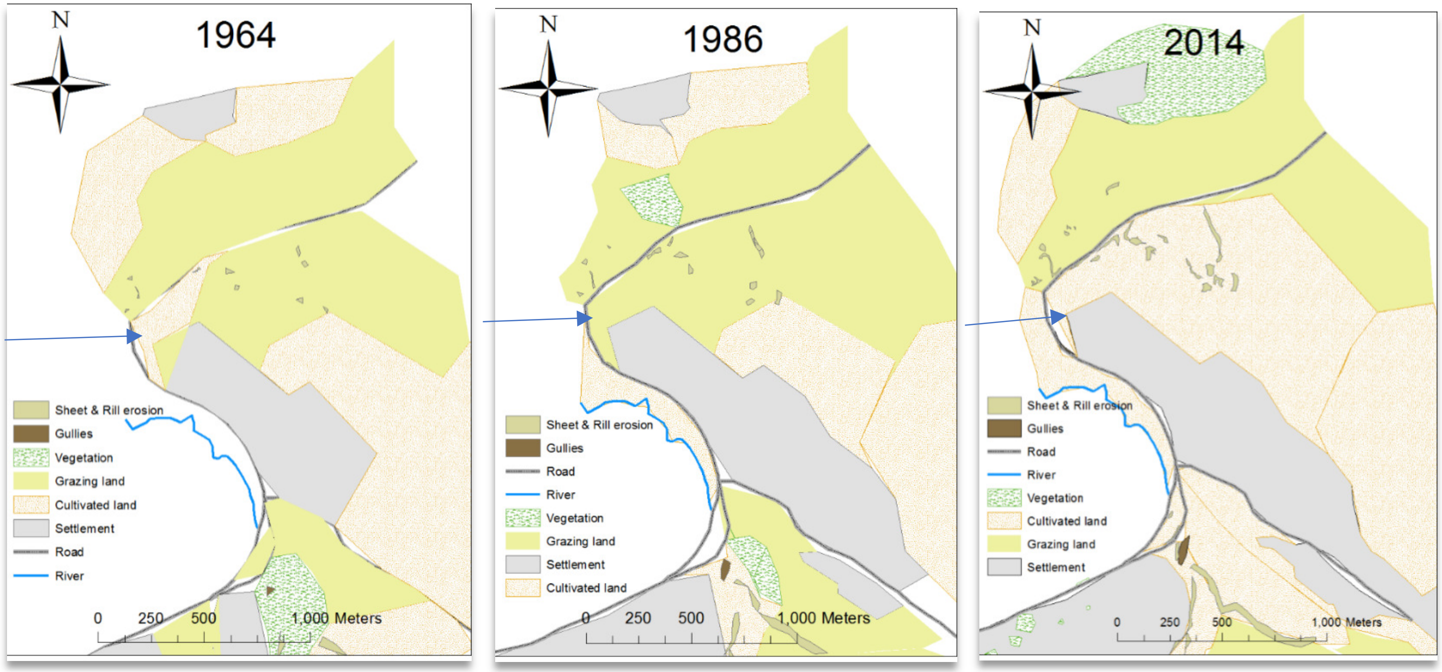

Figure 5-16: Trends and changes in land use over time in Clifford Chamber and Zwelisha, in three-time periods: 1964, 1986 and 2014

In 1964, sheet and rill erosion in Zwelisha only covered approximately 1% of the cultivated land in Zwelisha. The sheet and rill erosion covered approximately 10% of grazing land. Sheet and rill erosion on the grazing land shows that livestock is a factor in influencing erosion. In addition to livestock and farming, the road which was constructed near Zwelisha led to the initiation and intensification of sheet and rill erosion.

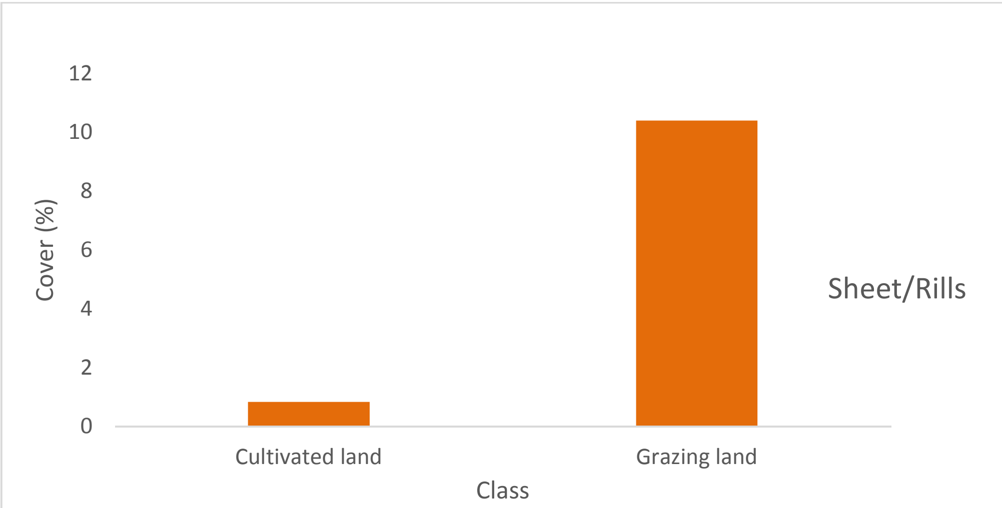

Figure 5-17: Sheet/rill erosion present in the grazing and cultivated land use in Zwelisha in 1964.

In 1986, Zwelisha had erosion on the grazing land predominantly. Sheet erosion and rill covered 24% of the grazing land and approximately 2.5% of the grazing land (Figure 5-18). The erosion in Zwelisha increased from 1964 to 1986 by approximately 16%.

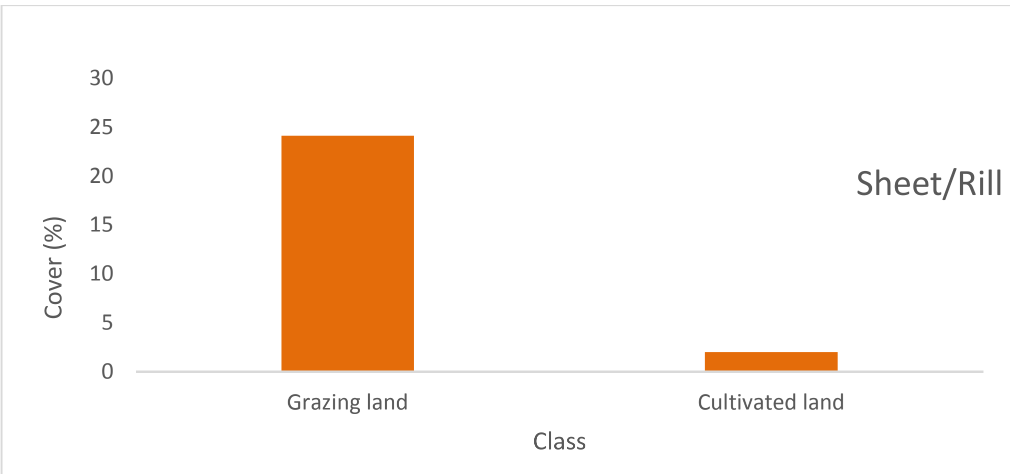

Figure 5-18: Sheet/rill erosion present in the grazing and cultivated land use in Zwelisha in 1986.

From 1986 to 2014 the settlement area in Zwelisha increased and the grazing land was transformed to cultivated land to assist with food production for the growing population. Zwelisha experienced erosion in the cultivated area mostly. Sheet and rill erosion was approximately 21% in the cultivated area and gully erosion was 2% (Figure 5-19). Prevalence of sheet and rill erosion expresses that mostly surface erosion is occurring.

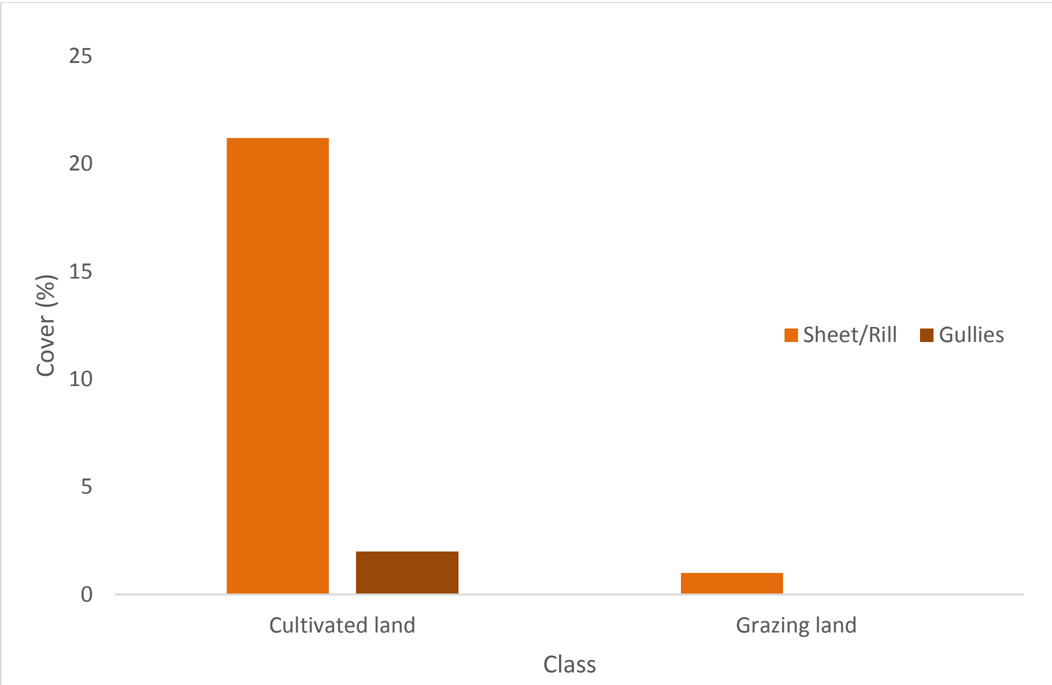

Figure 5-19: Sheet/rill and gully erosion present in the cultivated and grazing land use Zwelisha in 2014.

5.2.2 The extent and nature of observed soil erosion phenomena in six different study sites

Figure 5-20 shows that there is more erosion in the village study sites (approximately 11% in 1964, 24% in 1986 and 52% in 2014) when compared to the park and recreational study sites. In 1964, erosion levels in all study sites were relatively low (approximately 2% in the park, 6% in recreational sites and 12% in the villages), meaning less erosion in the study sites. It was in 1986 that gully erosion increased in the different study areas (approximately 3% in the park, 8% in recreational sites and 24% in the villages), with village study sites surpassing the park and recreational sites.

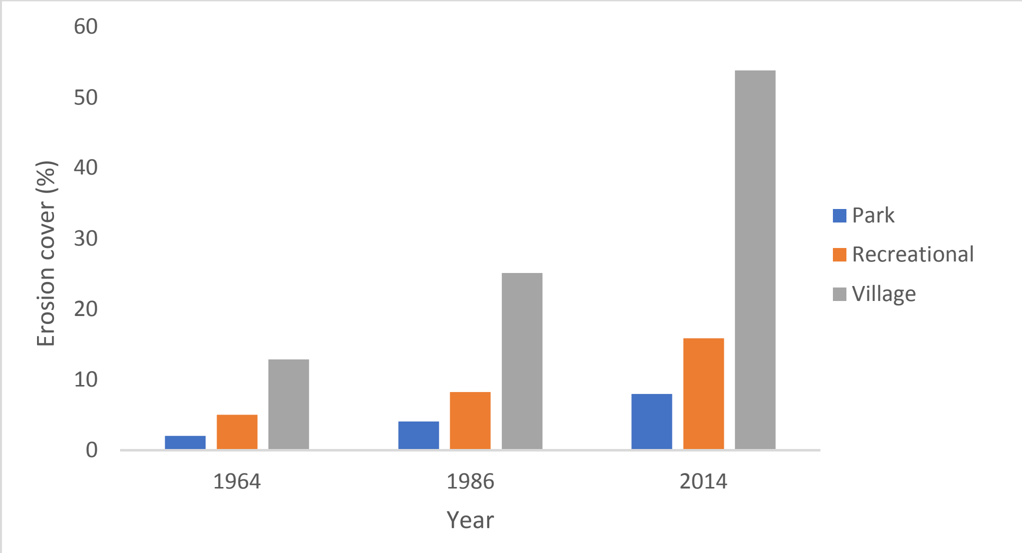

Figure 5-20: Erosion cover of recreational, park and village study sites, in three-time periods; 1964, 1986 and 2014.

Figure 5-21 shows that the erosion coverage increased from 1964 to 2014; with the village study sites experiencing higher erosion (Zwelisha 21% erosion cover in 2014, KwaMiya 32% erosion cover in 2014 and Busingatha 41% erosion cover in 2014) when compared to the park and recreational study sites. In 1964 and 1986, erosion coverage was less in most study sites with gully cover being less than 40%, with Busingatha being the exception. Upper Thendele experienced the least erosion, with erosion increasing from 4% to 8% between 1964 and 2014.

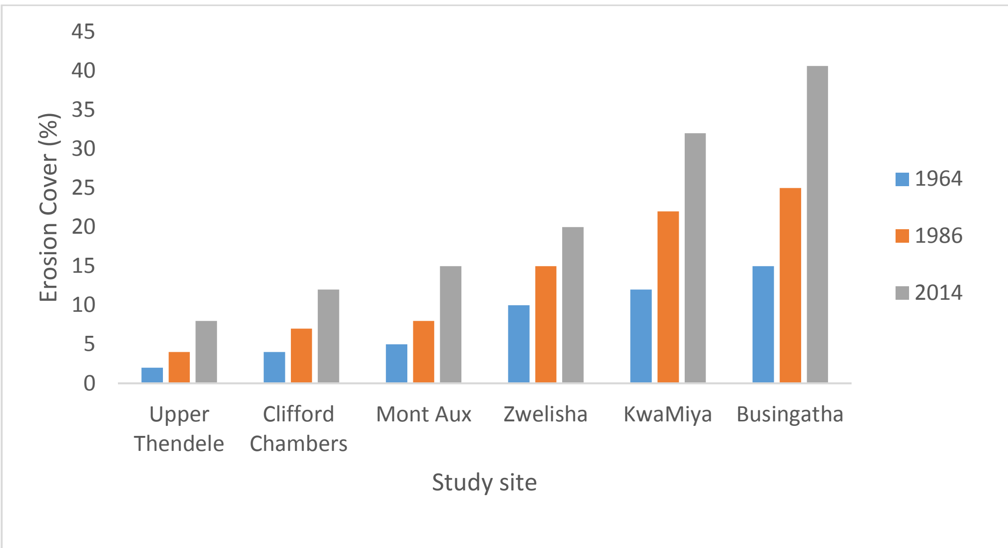

Figure 5-21: Erosion cover totals over all the study sites, in three-time periods; 1964, 1986 and 2014.

The population estimation method (see section 5.3 below) showed the population growth which occurred in the study sites and that Busingatha experienced the highest settlement growth (approximately 400 dwellings between 1964 and 2014). Population growth is linked with erosion, and an extensive gully system was present in Busingatha during the ground-truthing field trip.

5.3 Erosion phenomena and change in land use over the 1964 to 2014 period

This section deals with understanding the link which exists between erosion, changes in the population and usage of the land in the study sites, over the past 50-year study period. Different classes adapted from past studies will be used to show the different relationships.

5.3.1 Relationship between population dynamics, human settlements and vegetation

The method by Schultze (1969) was adopted to this study, to try and identify the population dynamics which occurred in the rural study sites. Figure 5-22 shows that there was a growth in the number of dwelling units in the village study sites; these numbers are not absolute values but estimates. This method could not be applied to the recreational and park sites; because the method relies on permanent dwellings. Over the 50-years the number of European-styled houses (5 people) increased and the huts (4 people) decreased. European-styled houses are linked to the increasing population which was experienced in this area and also show how the people in the villages started to become more modern over time.

Apartheid and other historical land use policies also influenced the population dynamics, because black people were forced to resettle in the Bantustans. However, there could have been some population growth in the study sites naturally in spite of governmental policies. In 2014, Busingatha had the highest number of people (approximately 2560), followed by KwaMiya (2050) and Zwelisha (1850). The influence of public transport allows the people in the settlements to work in the urban centres, but still reside in the villages.

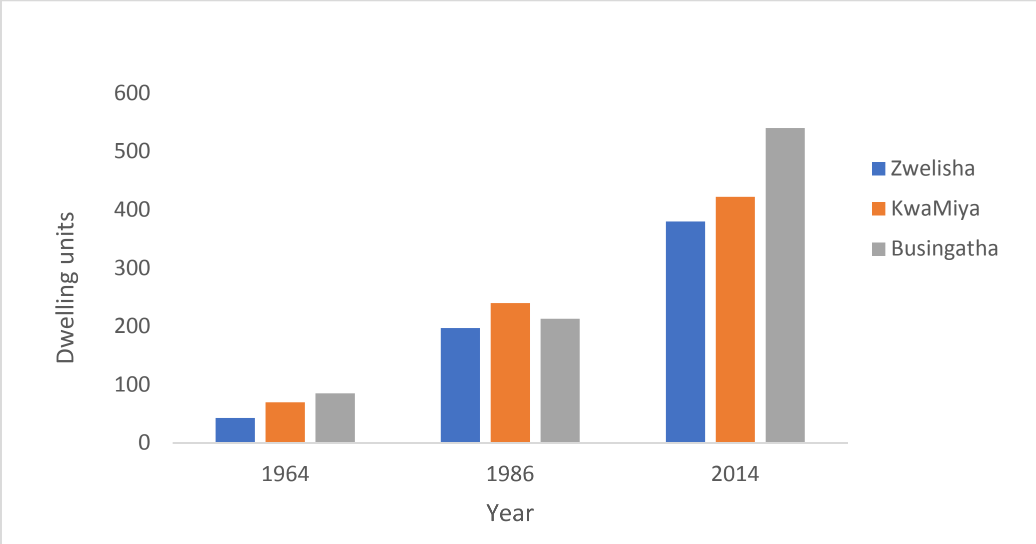

Figure 5-22: Dwelling unit estimates of village sites (Busingatha, KwaMiya and Zwelisha) from 1964 to 2014.

The relationship between settlement and vegetation classes from 1964 to 2014 is depicted in Figure 5-23. Vegetation class (vegetation cover) decreased from 1964 to 2014 (by approximately 10%) and the settlement area class (population numbers) increased from 1964 to 2014 (by approximately 37%). Figure 5-18 shows an inverse relationship between the two classes, which was an anticipated outcome. This is a result of an increasing population which will require more land for buildings and therefore clearing of vegetation in order to construct dwelling places.

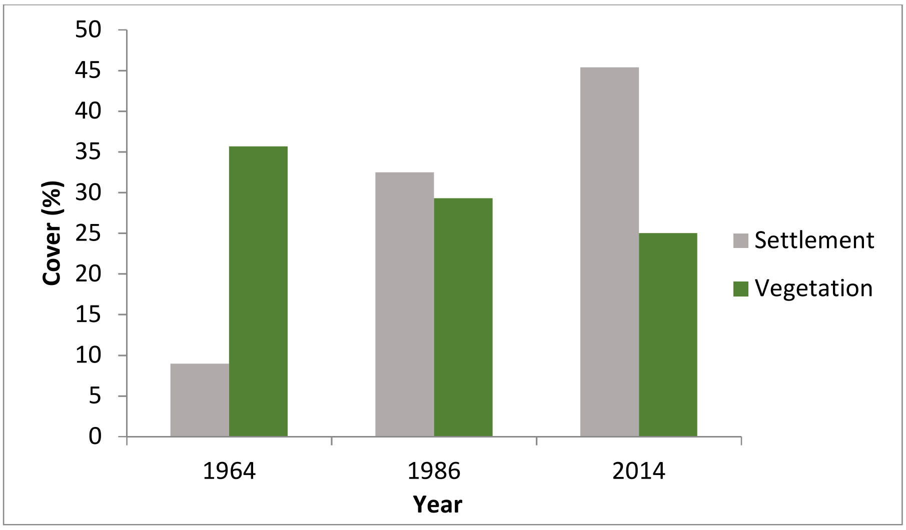

Figure 5-23: Settlement and vegetation classes (according to above mentioned classification system) of the study sites from 1964 to 2014.

Population numbers grew from 1964 to 2014, as mentioned above, and this was expressed by the enlargement of the settlements. By 2014, dwelling units had increase by about 50%. According to the maps and images from past years, the area which is now occupied by the settlement was open fields (grazing land)/vacant land and in some areas covered by vegetation. Movement of people into this area led to the development of dwellings over the open lands, and as time went by, the population numbers increased and this led to the development of more dwellings.

5.3.2 Relationship between population, erosion classes and study sites

Busingatha had sheet, rill erosion and gully erosion. In 1964, when the population number was lower (400 people), sheet, rill erosion and gully erosion was already covering a part of the study sites (Table 5-1). As time progressed, the number of people increased (from 400 people in 1964 to 2560 people in 2014) and gully erosion also developed and covered more of the study site. No riverbank erosion (severe form of erosion) was noted in the study site, but continuous erosion was apparent during the field trip to the study sites.

Table 5-1: The population and erosion relationship in Busingatha three-time periods; 1964, 1986 and 2014.

	Population estimation number	Coverage (%)	
		Sheet/Rill erosion	Gully erosion
1964	400	30.9	10.7
1986	1010	35.7	20.6
2014	2560	40.6	25.9

KwaMiya had mostly sheet and rill erosion in 1964, while the population numbers were low (approximately 330 people in 1964) (Table 5-2). Sheet and rill erosion increased in 1986. There was a general increase of all erosion classes in 2014, as the number of people also increased (from approximately 330 to 2050 people in 2014) in the study sites. Busingatha and KwaMiya were devoid of class riverbank erosion, which is classified as intricate gully patterns according to the SARCCUS (1981) classification system. KwaMiya was developed later than Busingatha, so the extent of erosion is not as advanced as the erosion in Busingatha. Sheet and rill erosion remained constant over the years between these two study sites. Gully erosion increased over time as the number of people increased in the area.

Table 5-2: The population and erosion relationship KwaMiya for three-time periods; 1964, 1986 and 2014.

	Population estimation number	Coverage (%)	
		Sheet/Rill erosion	Gully erosion
1964	330	21.3	3.9
1986	1200	27.0	5.0
2014	2050	35.2	7.1

Zwelisha had a lesser erosion coverage in 1964 than the other village sites (approximately 10% lesser than KwaMiya and 20% lesser than Busingatha overall) (Table 5-3). This trend also persisted in 1986. It is only in 2014, when the population numbers increased (approximately 1850), that the erosion class cover also increased. Sheet and rill erosion was the most dominant erosion type to cover the study sites. In 1964, the overall erosion was low in this area. In 1964 there was no gully erosion in this area. In 1986 sheet and rill erosion increased this study site, as the Zwelisha village increased. Gully erosion was not apparent in 1986. In 2014 the erosion increased drastically when compared to the other years (see above in section 5.2). Population numbers also had increased in the same way with approximately double the population numbers between 1986 and 2014 (approximately 950 people in 1986 to 1850 people in 2014).

Table 5-3: The population and erosion relationship in Zwelisha for three-time periods; 1964, 1986 and 2014.

	Population estimation number	Coverage (%)	
		Sheet/Rill erosion	Gully erosion
1964	200	15.8	0.0
1986	950	20.31	0.0
2014	1850	23.08	2.2

5.4 Summary

General observations from the six study sites were that the village study sites had similar changes over time. Vegetation class decreased over the years and the settlement class increased in size over the years. An increase in the settlement class, occurred mostly on the village study sites. Grazing land class (open fields and veld) also experienced a decrease over the years, as the settlement sizes increased. The Park and recreational study sites did not experience similar trends to that of the village study sites. No drastic change occurred in the grazing land and vegetation class over the years, when compared to the village study sites. Settlement class increase is low, because these are access controlled sites. Differences between the village study sites, park and recreational study sites show that erosion is affected by land use and that increase in population numbers will influence the settlement dynamics. Road construction and road-cuts played a role in influencing erosion rates in the study sites. Road construction mostly influenced sheet and rill erosion, which is a precursor to gully erosion.

Chapter 6: Discussion

6.1 Introduction

The discussion chapter is divided into three main sections. Section 6.2 examines the trends which were found in the Upper Tugela River catchment and discusses what caused the changes in the study sites and potential reasons for these changes. Section 6.3 discusses the relationship between land use, population changes and erosion. Studies concerning the influence of society and anthropological forces on erosion will be presented and compared to the findings of this study. Section 6.4 summarises what occurred in terms of the relationship between soil erosion and the study sites.

6.2 Trends in land use over time in the upper Tugela River catchment

Settlement, vegetation, grazing land and cultivated land classes were utilised as a means to express the nature of change which occurred over the study sites. The four classes assisted in terms of quantification of the change, so that the data may be more easily understood. Results showed that there was a relationship between the settlement and vegetation classes. From the year 1964 to the year 2014, there was an inverse relationship between these two classes; as the number of dwelling units increased, the percentage of vegetation cover decreased accordingly. The reason for the decrease in vegetated cover is because the settlement grew into the vegetated areas over time, as the village size increased.

The system used to delineate the different land uses was adapted from Kakembo and Rowntree (2003). Results which were perceived from the study also align with the findings of Kakembo and Rowntree (2003). In Kakembo and Rowntree's (2003) study, when the population number increased, so did the settlement and cultivation land uses. This was the same phenomenon which occurred in this study. Increase in the numbers of people also means more livestock, and this leads to an increase in agricultural land and more cultivation necessary for food production. The outcome of rapid and intensive cultivation, and over-grazing leads to increased erosion.

Even though a relationship exists between population changes, settlement and cultivation classes, and erosion, there are other factors which lead to these occurrences and correlations. Lesschen *et al.* (2007) state that the temporal and spatial variation in erosion usually comes as a consequence of complicated interaction between human and physical variables. This is true with the upper Tugela Valley catchment too; temporal and spatial variations played a big role in erosion processes and land use trends. The former Department of Native Affairs policies were instrumental in influencing the cattle numbers found in the reserves, as mentioned in Chapter 3; even though there was agricultural potential in the reserves, overpopulation and overstocking became an issue and influenced the accelerated erosion levels. Erosion is a natural process (Figure 6-1) and occurs at different rates depending on the spatial conditions; so, this factor coupled with temporal variability and human influence can result in different erosion rates in areas which may occur in the same region.

Figure 6-1: Rills and gullies being naturally re-vegetated in the Upper Thendele study site

Although as erosion is a natural process, the influence of humans in accelerating the erosion rates has to be understood and factored into erosion studies. Rising population numbers also lead to an increase in the infrastructure of a certain area. One of those infrastructures comes in a form of road construction. Erosion which comes as a result of road-cuts is a concern because it has the potential of causing environmental degradation, which has major economic costs. Road-cuts affected the village study sites mostly and Mont Aux. Zwelisha is still a developing village and there is a tar road immediately adjacent to the village. Construction of the road led to soil in Zwelisha to be channelled and also exposed. Other study sites were not as highly influenced by road-cuts as Zwelisha. Understanding the relationship between road-cut characteristics (Figure 6-2) and soil erosion is imperative for designing road-cuts that are less susceptible to erosion and to assist road rehabilitation works (Seutloali and Beckedahl, 2015b).

Figure 6-2: Signs of erosion on a roadside slope (Seutloali and Beckedahl, 2015b).

Even though soil erosion is a natural process, it has been increased by the activities of people due to agriculture, grazing, mining and fire, but the construction of roads, railways and other infrastructures has also led to the degradation of the soil and alterations in the landforms. The re-vegetation of road-cuts as well as the construction of gentle gradients could lessen rill erosion and offset the negative on-site and off-site effects (Seutloali and Beckedahl, 2015b).

In West Pokot, Kenya, a study was done to understand the relationship between road-cuts and soil erosion. The effects of road-cuts on the degradation of the environment is not limited to South Africa, but it is a phenomenon which occurs in other countries experiencing population expansion as a consequence of development. In times past, the focus of erosion studies has been confined to agricultural and pastoral lands. Minimum attention has been given to the outcomes of roads on soil erosion, even though they lead to more inconvenience than any other form of soil erosion (Jungerius *et al*., 2002).

Results in Chapter 5 showed visually how the changes in the land use and erosion occurred visually over the 50-year period. This documented change is a result of a number of people which increased over the Busingatha, KwaMiya and Zwelisha villages. In addition to the increased population numbers, the village dwellers also increased the number of housing units in their homesteads, to further include bigger dwellings with corrugated iron roofs to the dominant huts unit. Increased population and dwelling units also meant an increase in livestock numbers; therefore, the livestock required pasture and more vegetation to feed on. A progression from scattered huts to large settlements came because of the population increase, which was expressed by the increase in European-styled houses (which could house 5 people), and the decreasing number of huts (which could house 4 people).

Another interesting outcome from the Results section and Kakembo and Rowntree's (2003) study was the similarity in the nature of the relationship between the settlement class and the grazing land class. Grazing land class represents predominantly the areas which are open fields and veld. People in the study site utilize this area as grazing area for the livestock. An increase in population is the reason for the decrease in open area because more people means more land is required to build dwelling units for the population. An increased population size meant that more cultivation land was also needed, and the grazing land (open fields) would also be converted for agricultural purposes. Notable change documented in the Results section was that of the grazing land class.

It was the grazing land class which also occupied the largest area in the study sites, which shows why there was a widespread problem of erosion on the study sites (because grazing land is susceptible to erosion). Severe erosion occurs mostly on grazing land, which is usually communal (Kakembo and Rowntree, 2003). Abundance of people, livestock and their grazing abilities have led to the expansion of the cultivated land class in the study area, and this has resulted in severe forms of erosion. Livestock trails play a role in the establishment of the erosion features on grazing lands (Figure 6-3).

Figure 6-3: Livestock trails found on eroded land, by the Zwelisha study site

The relationship between present-day land use and erosion is more multifaceted than it is perceived at face value, usually concealing the historical causes of land degradation. It is therefore important to investigate the problem in a spatial–temporal context to achieve pointers to the dynamic geomorphological and human factors responsible for the commencement and intensification of erosion (Xia *et al.*, 2014). This means that erosion causes are not just a result of physical conditions, but human factors influence erosion, and therefore must be considered when analysing erosion. The time factor is also significant, because erosion dynamics change over time and that has to be put into consideration. Prolonged erosion leads irreversible soil loss over time, reducing the ecological (e.g. biomass production) and hydrological functions (e.g. filtering, infiltration and water holding capacity) of soil (Department of Agriculture, 2005).

The presence of hunter-gatherer communities in the KwaZulu-Natal province from approximately 1.5 Myr and their regular use of fire from about 150000 BP did not have any serious long-term environmental consequences (Hall, 1981). The early Iron Age communities who settled in KwaZulu-Natal's valleys and coastal lowlands around 1700 BP are also unlikely to have severely increased the rate of erosion. Considerable human-induced accelerated erosion in KwaZulu-Natal evidently started with the introduction of sheep and goats around 1400 BP, and this was augmented by the introduction of cattle a century later (MacDonald, 1981). Watson (1991) state that numerous sources indicate that accelerated soil erosion peaked early in the 19th century. In KwaZulu-Natal the accelerated erosion was a result of human activities and gully processes were selectively favoured. The Zulu people used the major gully systems as concealment in ambush situations and as escape routes from the Early Dutch settlers (Watson, 1991). The European settlers had caused serious environmental despoliation and erosion by the early stages of the 20th century and this happened in two stages. The first stage commenced in the latter parts of the last century and involved the shifting from subsistence farming to small scale market farming. The second stage started in the early years of the 20th century and this involved the intensification and commercialization of agriculture that laid the basis for increased mechanization (Erskine, 1982). Ross (1967; cited in Watson, 1991) estimated that although sediment losses in South Africa over 20-year period after the 1946 Act continued to increase, the loss was equal to half of the period preceding the Act. The effect of European settlers on soil erosion in South Africa was similar to other identified countries in Africa, countries such as Kenya, Tanzania and Lesotho (Watson, 1991).

This study also demonstrated different results when compared to the findings presented by Salomon *et al.* (2012). In this study, animal trails played a role in erosion increase over time. However, in the study by Salomon *et al.* (2012), animal trails do not necessarily lead to an increase in erosion. The study presented by Salomon *et al.* (2012) did not conform to the dominant view held by numerous government officials and scientists, that in areas which are under communal land tenure, cattle numbers continue to increase and lead to an increase in soil erosion. Even though there might be different views with regards to cattle numbers and erosion levels between these two studies, the uniting theme between these two studies is the fact that a landscape is an outcome of different physical, anthropological, political and economic factors. A landscape is more than just a set of geographical features of an area; it is the result of socio political processes and interactions between people imprinted onto the natural environment (Hancock and Evans, 2010).

6.3 Evaluating the extent and nature of gully erosion

The observed changes over the 50-year period for the study are a result of various occurrences which happened over the study sites. Maps in the result section showed the changes which occurred over the rural, resort and park sites. Observable changes can be perceived; namely erosion, population and vegetation changes. These are general observations, but they are explained more in detail below.

Vegetation cover is also another factor which is linked to erosion and population pressure. Vegetation has decreased extensively in the study sites, especially in the rural study sites. Park and recreational sites do not have high population pressures, when compared to the rural study sites, and are well managed. The geology underlying the study sites is similar and the all the study sites are in close proximity, so some of the observed changes can be attributed to the mismanagement of the land and the clearing of the vegetation especially in the rural study sites. In Mont Aux and Clifford Chambers, the lodges grew in area and new buildings constructed, so that the lodges can accommodate more people. In the rural study areas, the settlements were initially just a few huts, but thrived to villages that consist of four roomed houses with huts outside and special huts designated for the dwelling of ancestors. Removal of vegetation results in the removal of roots, which play a role in anchoring the soil. Removal of vegetation results in the decrease of soil protection, inevitably resulting in the washing away of soil and erosion of the landscape.

Alteration of land and removal of vegetation for human activities is not a new phenomenon. Flanagan (2002) state that land use is one of the most significant factors influencing soil erosion because of its effects on variations in surface roughness, the organic content of soil, the soil structure and infiltration rate. A study by Zhang *et al.* (2015) indicated that farm land was the main element for contributing to soil erosion, even beyond fallow land. Land use came as a result of humans cultivating the soil to produce more food in order to sustain themselves. Results from this Chinese study highlight the similar phenomenon which occurred in this study, whereby land use change came as a result of anthropogenic activities and subsequently led to soil erosion. Soil erosion has been a worldwide environmental issue, significantly threatening the sustainable development of the economy and society (Bakker *et al*., 2008).

In their study, Vanwalleghem *et al*. (2017) showed that there are strong links between historical land use and soil management changes, soil erosion and agricultural sustainability. Driving forces behind this intensification of soil use is a complex mixture of population, economic and social variables, but recent research indicates that even more complex issues might underlie observed changes. Observations and analysis from Vanwalleghem *et al*. (2017) express similar sentiments with this study because soil erosion did not just arise because of one variable, but a myriad of social variables, government regimes and also other natural factors. In this study, Apartheid policies and removal of people led to the settlement of people in the different villages. The movement of people and the growth of the settlements led to the increase in livestock numbers and increased cultivation rates. In the villages, erosion is also occurred naturally, without any anthropologic influence. Since prehistoric times, farmers have experienced the challenge of balancing the demand for rising food production from existing soil resources with conservation of these resources. Land use alteration from natural vegetation to agricultural land and intensification of agricultural soil management are closely linked to amplified rates of soil erosion (Ewert *et al.*, 2005).

In their findings and results, Kakembo and Rowntree (2003) verified that temporal and spatial changes in their study area was an outcome of the complicated interaction between anthropogenic and physical variables. Soil and gully erosion cannot just be attributed to an isolated variable, but a transdisciplinary approach has to be undertaken in order to understand all the forces at play in an area which is under threat by soil erosion. Gully initiation and amplification is usually a response to changes in land use within a specific land-tenure system (Showers, 2005).

The differences which Kakembo and Rowntree (2003) highlighted between former white owned land and the black communal lands were also similar to the differences which were in the recreational areas and villages in this study; no extensive erosion was perceived from the aerial photographs in 1964. There was very minimal erosion in this study observed, with some former white areas not experiencing any noticeable erosion until the 1980s. Physical characteristics (topography, geology, soils and climate) between the former white areas and communal lands is similar; the difference in erosion status was attributed to the land-tenure and farming systems.

6.3.1 Nature of erosion over all the study sites

Results show that sheet and rill erosion was the most prevalent in all three chosen study years. The reason for such a great prevalence of sheet erosion and rill is because according to the SARCCUS (1981) framework, sheet erosion refers to the beginning stages of erosion, and this also indicates the nature of erosion which prevailed in the study area from the 1964 date. This is an indication that the erosion apparent in 1964 had already started in the study area even before 1964, because rill erosion is a result of the development from one lower level erosion to a higher-level erosion class. 1964 data shows that there are different natures and types of erosion which can occur in one area.

Data also show that erosion can develop from just slight erosion to gully erosion if it is not managed in due time. In 1986, the sheet and rill erosion increased in cover over the study area. Gully erosion also increased in cover over some of the study sites. From 1964 to 1986, the erosion process intensified to a point where gullies were apparent and covered a large part of some of the study sites. Associated with gully erosion type is soil piping because gully erosion is highly associated with soils being lost and washed away (Figure 6-4).

Figure 6-4: Soil piping found in the Upper Thendele camp

In 2014, gully erosion intensified in cover of over the study sites. Gully erosion is a severe form of erosion, with class river bank and footpath erosion being the most severe, according to the SARCCUS (1981) framework. If the study sites have severe gully forms, then this means that there is a higher percentage of soil which already has been lost in the area and is being lost each time it rains. This stage of gullying has occurred predominantly in the rural side of the study area, while the slight erosion is mostly found on the recreational and park sites of the study. An increased number of livestock and people has led to the trails and rills to fully develop and mature in highly incised gullies, and the rains have further led to continuous deterioration of the land system. The lower prevalence of gully erosion is because of the natural development of gullies from a lower level to a higher level of degradation. As the erosion agents persist, the gullies will mature and develop into deeply eroded system. Severe erosion types and intensive gully erosion rose mostly in the communal areas, and this was consistent in this study and also with Zhang *et al.* (2015), Salomon *et al.* (2012) and Kakembo and Rowntree (2003). The major difference was that there was no riverbank erosion which was noted in this study.

6.3.2 Erosion changes over all the study sites

Busingatha, KwaMiya and Zwelisha show how the erosion in 2014 was so extensive, in comparison to 1964 and 1986. In addition to this factor, severe erosion is extensive in the former Bantu Areas, i.e. villages, in comparison to the resort and park areas. Erosion progressed over the 50-year period, as perceived from the satellite imagery. Nonetheless, there could have been erosion features which could have developed between the year 1964 and 2014, but because of the analysis which could only be expressed 20 years later, these erosion features could have been overlooked.

Busingatha, KwaMiya and Zwelisha have experienced more erosion. While Mont Aux, Upper Thendele and Clifford Chambers on the other side of the main R74 road have experienced the least erosion. Busingatha has experienced the highest erosion and gully development in the study area, while Upper Thendele experienced the least erosion and gully development. The study sites are similar in geological make up, with mostly dark shale constituting a majority of the area, with some dolerite present in the geology of the area. Soils, topography and climate for the study area are also similar, between the commercial and rural side, so therefore there has to be other reasons other than geological and soil factors. Land tenure systems, different farming systems and land management systems are the probable causes for the differences in erosion levels in the study sites.

Upper Thendele did not experience considerable changes in terms of soil erosion between 1964 and 2014, and one reason is that this area is based in the area of the game reserve and has not experienced a population increase. Busingatha is situated opposite

Upper Thendele but possesses the highest erosion. Two main reasons for this marked difference are the high population numbers which exists in Busingatha firstly, but another critical factor is the livestock which create trails along the Busingatha landscape, which further develop from overland erosion to deep gullies. Zwelisha and Clifford Chambers are separated by a road, they are adjacent and possess similar environmental characteristics. It would be assumed that since they are so similar, the level of erosion would be similar, but there is a difference based on the results. Zwelisha lies on the village side of the study area, and from 1964 to 2014 this village developed from a few huts to a fully-fledged settlement. Clifford Chambers on the other hand is found on the other side which possesses few population numbers and lower impacts from erosion. Salomon *et al.* (2012) state that the uKhahlamba Drakensberg history shows that a landscape is more than just a set of geographical features of an area; it is the result of socio political processes and interactions between people imprinted onto the natural environment (Sithole, 2003), and people give meaning to the landscape (Bender and Winer, 2001).

6.4 Erosion phenomena and change in land use over the 1964 to 2014 period

Land use is characterised by the four mentioned classes in 6.2, but for the purpose of this section, two of those classes will be discussed, namely the settlement and vegetation class. The settlement class represents the population in a study site, therefore as the area of the settlement class increases, so does the population number increase. From the population and erosion relationship between village study sites, park and recreational areas in the results section, there is a relationship which is perceived; as the settlement class (land use) increases, the population number increases, leading to an increase in the erosion and therefore influencing the type and extent of the erosion. In 1964, the settlement class was particularly small, with an abundance of slight sheet erosion dominating the study area. However, in 2014, the settlement class had increased rapidly in comparison to 1964, which conversely relates to the population numbers which rapidly increased over the 50-year period. This occurrence shows that the more the land use is changed from natural to artificial (residential or any anthropogenic outcome), the higher the number of people in an area will be present, leading to higher erosion and soil loss rates, and more extensive erosion types. This is because of the difference in erosion classes, as stated in SARCCUS (1981) because sheet erosion will not result in that much soil being washed away in comparison to a very deep gully system.

Chapter 7: Conclusion

The conclusion chapter will endeavour to capture the significant elements which were brought forth in the preceding chapters and highlight their importance in terms of the wider context of erosion studies. The aims and the objectives which were stated in Chapter 1 will be considered. The final component of the conclusion will be geared towards providing recommendations and benefits of repairing erosion and provide some insight and suggestions on the direction that future research should take.

7.1.1 Accomplishment of aim and objectives

Investigating the trends in land use in the upper Tugela River catchment was accomplished by using methods and techniques ranging from analysing aerial photographs and academic publications. The method to identify the changes in land use was taken from Kakembo and Rowntree (2003) but was adapted to fit the context of this study. The study expressed that there were changes over the 50-year sample period with regards to the vegetation, grazing land, settlement and cultivated land classes. Vegetation and tree cover (vegetation class) decreased in extent because of the influence of the increasing population on the land and the consequential exacerbation of soil erosion. There has been an upward trend in terms of population growth and this growth is anticipated to continue. As the population and livestock numbers rise, more vegetation and tree cover should be expected to be cleared and more erosion should be expected. The settlement class (population numbers) and the vegetation class have a unique relationship, because over the years as the vegetation class decreased, the settlement class increased. Grazing land and cultivated land class also experienced changes, but not to such a great extent as the former Homeland areas.

Results from this study and other studies highlight the fact that agricultural activities need to be guided and done in a responsible way if soil erosion and gully growth should be mitigated. Some of the reasons to manage human interactions on the soil include: the field can be damaged by overgrazing by too many animals; animal hooves can damage the veld leading to soil erosion; runoff can be increased if slope is ploughed upwards; and dam outlets which are not properly constructed or designed can lead to erosion (Department of Agriculture, 2005).

The 50-year study showed that the intensity of the erosion increased. The danger of not managing the soil erosion in this area is that if the intensity is not mitigated, the average erosion will increase to unprecedented heights. Increased erosion should be avoided, because the following can occur; dams and rivers can silt up, runoff can be accelerated and lead to drying out of soil (leading to the detriment of grazing and crop production), and lands which could be used for agriculture could be rendered unproductive (Department of Agriculture, 2005).

7.1.2 Main findings, recommendations and further studies

Below are some of the main findings from the study:

- Overgrazing plays a role in determining erosion. However, it is the relationship between increasing population numbers and the particular nature of livestock keeping among village dwellers which influences overgrazing levels, and subsequently the erosion.

- This study shows that population numbers directly influence erosion processes. Population changes can cause sheet erosion to develop into interconnected and complicated gullies, and sometimes into riverbank erosion if not mitigated in time.

- Road construction influences the initiation and acceleration of erosion. Sheet and rills usually develop where there have been road-cuts, and they form channels for sediment transportation and environmental despoliation.

Below are some of the main recommendations from the study:

- Mitigating soil erosion impacts is an issue which has to be addressed not only on the local scale, but even national government needs to make it a point that the general landscape of the country is well managed with regards to soil erosion.

- Obtaining high quality imagery, robust mapping and statistical analyst programs, and specialists from different science fields to work along with the soil erosion data should also be top priority in further studies.

- Road engineers need to work with geomorphologists to understand the landscape before constructing roads or building new infrastructures. It is important for the geomorphological process to be understood and also merged with technical expertise.

- Studies that include mapping of soil processes should indeed not just be limited to geomorphologists but should encompass a more transdisciplinary approach.

Soil erosion and gullies have posed significant threats on the landscapes which threaten not only the livelihoods of people, but also alter geomorphic and hydrological processes which have existed on landscapes for a while. Managing soil erosion and repairing gullies is process which has to become assimilated by land managers and district overseers, because agriculture tends to be the first to be affected by the above processes. Soil erosion and gully processes can be managed, and also repaired, in order to mitigate the washing away of soil.

Kakembo *et al*. (2009) state that it is not adequate to assign soil erosion directly to over-grazing. Instead it should be noted that the grazing–erosion–climate interactions are characterized by the features of complexity thresholds, emergence, non-linearity and disequilibrium (Kakembo *et al*., 2009). The above-mentioned statement goes against many views presented in popular erosion studies, which put emphasis on overgrazing as being a direct cause in soil erosion. So therefore, in order to understand and even before remediating soil erosion, the spatial extent of the problem must be established (Le Roux *et al*., 2008). The history of human influence is also an important factor to consider in soil erosion and land use studies, so as to identify if soil erosion is occurring ‘normally’ or is being influenced by humans. In KwaZulu-Natal the progressive increase in soil erosion associated with settlers from Europe had resulted in some of the most serious veld deterioration before the turn of the 20th century (Watson, 1991). The European settlers had confined traditional farming to designated tribal areas, and coincidentally led to a rise in the Zulu population and in their livestock (Watson, 1991).

However, this study provided just a glimpse of soil erosion and land use change processes because it only concentrated on one particular region, and therefore could not provide a comparative analysis. Further studies of this kind should seek to build upon what has been established in this study, ranging from the methodological framework to choosing of a study site. Government policies and land use strategies are also very important factors to be considered when assessing erosion and land use systems, because they do affect physical and anthropological factors, and subsequent environmental pressures.

There appears to be a link between roads and erosion, and this is an opportunity for further research. Soil erosion studies, especially in South Africa, have been confined to agricultural and pastoral land, and research which investigates road-related soil erosion is scarce. Roads lead to lasting changes of the geomorphic and hydrological settings of the landscape which results in a rise in soil erosion. Erosion studies in the past have revealed that roads lead to the formation of road-cuts that add to runoff and high sediment production that lead to intense degradation of the land (Seutloali and Beckedahl, 2015b). Lessons from these studies can influence road engineers and geomorphologists to work hand in hand in constructing roads. Moreover, these case studies highlight that the processes of landforms need to be understood, before applying technical measures to construction of infrastructures and roads. It is through technological advances and understanding of the topography that we can gain a more precise analysis of soil erosion and various erosive processes.

Chapter 8: References

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