

**Assessing the impacts of riparian land use on gully
development and sediment load: A Case study of Nzhelele
River valley, Limpopo Province, South Africa**

**By
Mavhuru Blessing**

University of Venda

November 2015

Assessing the impacts of riparian land use on gully development and sediment load:
A Case study of Nzhelele River valley, Limpopo Province, South Africa

By

Mavhuru, Blessing

Student Number: 11605726

Sign: Date.....

A Masters Research submitted to the School of Environmental Sciences,
Department of Geography & Geo-Information Sciences, University of Venda

Supervisor: Dr. N.S. Nethengwe

Sign:Date.....

Co-supervisor: Mr. F. Dondofema

Sign:Date.....

November 2015

DECLARATION

I, Mavhuru Blessing, hereby declare that the dissertation for Masters degree in the Department of Geography and Geo-Information Sciences, School of Environmental Sciences at the University of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any other University, that is my own work and that reference materials contained herein have been duly acknowledged.

Student: Mavhuru Blessing

Signature.....

Date.....

Supervisor: Dr. N. S. Nethengwe

Signature.....

Date.....

Co-Supervisor: Mr. F. Dondofema.

Signature.....

Date.....

DEDICATION

This research is dedicated to Francis Mberikwazvo Mavhuru and Margaret Chipangura who helped me to have this opportunity and which has elevated me to where I am. It has never slumbered throughout my academic journey and has miraculously positioned me for greatness. Not forgetting also my close friend S. N, Chisora.

ACKNOWLEDGEMENTS

First and most importantly my sincere honour and gratitude goes Doctor N.S. Nethengwe and Mr F. Dondofema who has supported and motivated me through ups and downs. Secondly I am indebted to my erudite supervisors again whose au fait propelled the research in the most sensible direction. They were meticulous with the finest details and imposed meaning in the research as they were true avatar of the idea. To my work supervisor and mentors I owe the success of this research to you

I also wish to thank Mr Mokgeobo, Mr Kori, Mr Chokoore and the many people who made provisions for this research to be a success. Also my sincere gratitude goes to my friends, Osidele. J, Khori. E, Sally Ibeh, Tunde Durowoju and Mukgoebo not forgetting and King Solomon Eghosa

To my sisters and brothers Charles, Beladine, Tanaka, Chris, Miranda, Christopher, Tinevimbo, Prince, Ngoni, Fleance, Wadzanai Chabikwa, Chabata, and many others who have stuck with me through the difficult times, your encouragement was nothing but uplifting and your true friendship refined my vision and goals. To Mr Francis Mavhuru, you have forever believed in my dreams and have supported me like a true confidant.

To my mothers, Mrs Margaret Chipangura you are the first in my heart and forever will be. My brother Luck, may you be blessed for all that you continue doing. To my sisters Mrs Sithole, and Mrs Madziwa you have stood by me and you continue to do so with no reservations. Thanks heaven, Shamiso, Ollen, Batsirai, Adonis, and Brenda Mavhuru, you are so dear to me and may your lives be greater than what you dream of.

ABSTRACT

Human activities on land degradation have triggered several environmental problems especially in rural areas that are under developed. The main aim of this study is to analyse the contribution of different land uses to gully development and sediment load on the Nzhelele River Valley in the Limpopo Province. Data was collected using different methods such as observation, field data techniques and experiments. Satellite digital images, topographic maps, aerial photographs and the sediment load static model also assisted in determining how land use affects gully development and sediment load. For data analysis, the researcher used the following methods: Analysis of Variance (ANOVA), descriptive statistics, Pearson correlation coefficient and statistical correlation methods. The results of the research illustrates that high land use activities create negative changes especially in areas that are highly fragile and vulnerable. Distinct impact on land use change was observed within settlement area (9.6 %) within a period of 5 years. High correlation between soil organic matter and soil moisture ($R=0.96$) was observed. Furthermore a significant variation ($p \leq 0.6$) between the soil organic matter and soil moisture was also observed. A very significant variation ($p \leq 0.003$) was observed in bulk density and extreme significant variations ($p \leq 0.0001$) were observed in organic matter and soil particle size. The sand mining and agricultural activities has contributed significantly to the amount of sediment load in the Nzhelele River. A high significant amount of total suspended sediment (55.3 %) and bed load (53.8 %) was observed within the agricultural area. The connection which associates the development of gullies to various land use activities determines the amount of sediment load. These results are consistent with other previous research and suggest that land use activities is likely to exacerbate the development of gullies and sediment load in the Nzhelele River Valley

Key words: land degradation, riparian land use, gully development, sediment load, geomorphological processes, and drainage basin.

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CHAPTER 1: INTRODUCTION

There is a wide ranging debate among scholars on gully development and land use because gully development is viewed as a problem that is mainly caused by rainfall and slope (Essen *et al.*, 2012; Godone *et al.*, 2012 and; Akenson *et al.*, 1984). Many studies have already indicated that the cause of gully development is rainfall intensity (Katsurada, 2007; Horel *et al.*, 1989 and; Rasool *et al.*, 2011). Large gully developments are not associated with land use, whereas in most parts of Europe they can be easily identified together with land use activities (Vanwalleghem *et al.*, 2005). Casali *et al.*, (2000) and; Moeyersons, (2000) underline that gully erosion represents an important sediment source in drainage areas, increasing also off site water erosion

Land use, within the context of this study, will refer to the interaction of people with the environment. This includes the exploiting and alteration of the natural surroundings into artificially built areas such as settlements, plantations, road construction sites, clearance of land for cultivation, as well as any arrangement of activities within a particular environment to sustain livelihood (Nolon, 1992). During the early 1990s and 2000, the rise in population growth in South Africa resulted in a marked increase in land use, especially in marginal areas of rural areas (Kakembo and Rowntree 2003). The resultant population increase in turn resulted in the intensification of Agro-pastoral land use activities in marginal areas. It is argued that when rural households have access to productive land, this decreases their susceptibility to poverty and hunger; thus increasing their capacity to devote time and energy to their dynamic activities (Timmer, 2010:4; Dijk, 2011:106; IFAD, 2008:4).

Worldwide soil erosion is one of the problems associated with land degradation and gully development (Valentine *et al.*, 2003). More emphasis has been put on the sustainable utilisation of resources as land use increases in response to population pressure. An increase in land use activities in the higher parts of the catchment, leads to an increase of sediment and high organic loads in surface runoff. This further decreases the quality of water and endangers the population downstream.

In conceptualising the development of gullies and sediment load, the study intends to align understanding with established works of livelihood impact assessment models such as the Revised Universal Soil Loss Equation (RUSLE), and the Turbidity index model (Borrelli *et al.*, 2013). Combined, the two models give useful input to enable one to better distinguish between the effects of short term human induced accelerated soil erosion and long term geomorphological processes. This approach has been used in many studies to analyse the dynamics of land use, sediment yield and gully development, socioeconomic activities

engaged in and the factors that determine the nature of power relations between the community and land use. All these factors need to be critically assessed in order to come up with paradigm with respect to activities which address comprehensive problems of gully development and sediment load. Therefore this study was pursued through exploring the relationships between land use activities and gully development characteristics of sediment yield as an output product in Nzhelele village in the Limpopo Province of South Africa.

1.1 Background to the study

The development of gullies in most cases causes significant damage to infrastructure, especially in areas near the drainage system and areas with loose soil compaction. Most semi-arid and semi-humid areas of the world are especially western USA, central USSR, and the Mediterranean lands highly susceptible to erosion (Morgan, 1990). Gullies are part of the source of sediments that end up in rivers and fill reservoirs. In most instances, a decrease in soil quality leads to soil erosion (Pathak, *et al.*, 2005). Gully development has been associated with early and they probably, the first farmers about 10,000 years ago in the northern mountains of ancient Mesopotamia (Wild, 1996). Globally, there are about 1.1 million hectares of land which have been affected by erosion. In India, there is an estimation of about 150 million hectares of land out of a total geographical area of 328 million hectares which is vulnerable to water erosion (Pathak, *et al.*, 2005). Gully erosion has affected more than a few catchments in the Souss Basin, Morocco (Klaus *et al.*, 2014).

The use of land for various purposes has become a crucial part in recent strategies of monitoring the natural environment and managing changes within the environment. Human activities on land degradation have been reported by many studies since the beginning of colonialism by referring to historical evidence, indicating that gully erosion was triggered in Africa after the migration of Europeans to this continent (Nyssen *et al.*, 2014). The causes of gully initiation and development worldwide include land use change from range land to crop land, higher occurrences of severe floods, overgrazing especially in drought periods, and the destruction of ecosystems due to road construction and vegetation clearance, as well as the over exploitation of land together with severe rainfall, (Slade, 1994). Changing native rangelands to low yield rain fed farms and later on abandoning them after a few years, and regional developments in watersheds, have had detrimental impacts on the instigation and development of gullies in various countries (Moeyersons, 2000).

Soil erosion and sediment load in South Africa are wide spread environmental problems (Kakembo *et al.*, 2003). Limpopo is singled out by Le Roux *et al.*, (2008) as a province in South Africa with the highest erosion potential. The actual causes of gully erosion and

sediment loads involving land use have not been fully addressed in erosion modeling (Sirdorchuck *et al.*, 2003). Most studies that focus on soil erosion have centered their attention on gully contribution without taking into account the assessment of soil losses in land use (Pusan *et al.*, 2003). The development of gullies is an efficient source and pathway of runoff and sediment from the hill slope to sediment sinks located within the drainage channels which affect the fluvial process and the environmental function.

According to the worldwide research, there is a compact bond between abandoned land and badlands gulling (Kakembo, 1997). However, similar trends have been identified within KwaZulu-Natal and Cape Town, South Africa and Gutierrez, south east of Spain (Desta and Adugna, 2012).

Rainfall and slope are two key components which are highly involved in the development of gullies and sediment load in rivers (Pravat *et al.*, 2013). There is a relationship which is built up between land use activities, rainfall intensity, rate of runoff and gradient of slope that initiate the formation of gullies (Brady and Weil, 2002). The fluctuation in rainfall availability that is often observed posed a great potential threat to land which obviously implicate on the development of gullies. If the amount of rainfall is more than the holding capacity of the soil, an increase in surface runoff is observed (Wild, 1996). Rainfall intensity and rate of runoff is accelerated by the angle of the slope which course a sharp head cut into the soil. Following the head cut a curving at the bottom of gully development starts to take place (Finked, 2000).

Mararakanye *et al.*, (2012) observed that in South Africa, gullies are highly widespread, especially in the drainage systems and sloppy areas, which were former homelands of the migrated population. Gullies are highly wide spread across the country in areas such as the Eastern Cape Province, Free State, Mpumalanga, Limpopo, as well as many other places in South Africa. In Limpopo Province, the soil characteristic is highly vulnerable to soil erosion and development of gullies because of various land use activities and grazing caused by a high cattle population within this province (Bonfire, *et al.*, 2009).

In some parts of South Africa, the major factor governing the development of gullies is the presence of erodible material in highly populated areas. These areas are most likely to be associated with concentrated surface or subsurface runoff that occurs in unconsolidated sediments and deeply weathered rocks and sediments (Haggard, *et al.*, 2005). In Nzhelele Valley, the highest development of gullies is mainly on cleared uplands which support erodible soil highly in lixisols and clay enriched at the lower horizon, especially in areas with a mean annual rainfall of around 500mm. The cleared uplands of most parts of South Africa receive above 1000mm of annual rainfall, which does not lead to gully erosion. However, the

factor responsible for the development involves various landscapes such as steep slopes (Fey, 2010).

1.2 Statement of the problem

The current approaches to sediment load and gully development have constrained the social, economic developments in most rural areas within South Africa (Dijk, 2011; Powers *et al.*, 2011; Restrepo *et al.*, 2013, and Norman *et al.*, 2012). Gullies have developed within the arable land of the Nzhelele valley. This has made it difficult for agricultural activities to be practiced within this area. Fertile soil has also been lost due to the development of gullies in this area, causing land degradation. Moreover due to various land use activities there is a problem of siltation in the Nzhelele River and Dam (Makungo *et al.*,). This has made the area highly vulnerable to flooding, especially during high rainfall periods.

Since the attainment of independence in 1994 many areas in the Eastern Cape Province have experienced some outstanding developments. These developments include expansion, growth and development of activities such as buildings, the construction of roads, increased cultivation, brick making, and many other anthropogenic activities (Kakembo and Rowntree, 2010). Seemingly, Nzhelele valley has also experienced the same developments, ranging from cultivation to intensive brick making. This has resulted in large land utilisation, and alteration as well as a modification in the condition of land use over time. The development of gullies apparently increased as land use activities increased. Many areas within the Nzhelele valley have been affected by the development of gullies, which is now a permanent endemic disaster in this area (Geng *et al.*, 2014). A high percentage of sediment loads has filled the sub catchment of the Nzhelele drainage basin, and is threatening the survival of the Nzhelele River, which is a source of water for most people within this area. It is, therefore, necessary for a study such as this to analyse the land use dynamics and how this has contributed to gully development and sediment load.

Many studies on gully development and sediment load, over the past centuries, do not fully address the problem of land use with the exception of Poesen's (2013) and Kakembo's (2009) which have made a great contribution in this area. The central aim of this study is to assess the impact of riparian land use on gully development and sediment load, in order to show the need for new approaches that would incorporate a new understanding of the realities of the prevailing physical problems and the sustainability of rural land use. This study attempts to provide a new paradigm and strategies that link land use to sediment load and gully development in Nzhelele valley. The developed strategies will serve as

mechanisms to unlock the potential for a dynamic, growing, and sustainable land use for poor rural people in South Africa.

A further cross examination of the existing land use literature points to the fact that research on the impact of land use and sustainable development on livelihoods is limited, especially in the Vhembe District. According to Pope (2013) a number of existing studies that have study land use and gully development mostly focused on large scale environment not specific confined areas. However, a few studies have made some efforts to show the link between land use and gully development in relation to climate change in China and Latin America (Peter *et al.*, 2014).

1.3 Research aim and objectives

1.3.1 Research Aim

The main aim of this study is to assess the impact of riparian land use on gully development and sediment load in the Nzhelele River valley, Limpopo Province, South Africa.

1.3.2. Research Objectives

The specific objectives of this study are to:

- Identify land use types and quantify land use changes in the Nzhelele River valley from 2007 to 2012;
- Assess the impacts of human activities on land degradation;
- Establish the relationship between land use and gully size; and
- Examine the relationship between land use and sediment load in the Nzhelele river valley.

To address the above objectives, the following research questions are proposed

1.4 Research Questions

- What are the significant indications of land use change over the period of 2007 to 2012?
- What is the role of human activities on land degradation?
- To what extent is gully development in Nzhelele valley related to land use?

- Is land use linked to sediment load in the Nzhelele valley?

1.5. Justification of the study

Environmental degradation has been identified as one of the biggest problems for people living in rural areas of South Africa (Kakembo *et al.*, 2010). However, the challenges of environmental degradation, which need to be looked at, are the key factors for sustainable land use. South African rural communities are characterised by high poverty which impacts on land use (Elsenburg, 2005). Most literature points to an increase in gully development and sediment load in previously disadvantaged rural areas in South Africa.

After the attainment of independence, the new South African government introduced and implemented various rural development activity programs to address livelihood insecurities of rural communities. These programs include the Rural Development Plan, which was accompanied by the construction of roads, building of houses, and other community development projects. However, these developments in the Nzhelele valley resulted in the manifestation of other environmental issues such as high surface runoff, soil erosion, development of gullies, increased sediment load in river basins, and water pollution.

Traditionally Rural poverty has always been viewed, understood and measured in terms of land use and development within a specific area (Joshi and Tambe, 2010). Due to lack of proper resources, many rural people rely on the land to sustain their lives, though activities such as brick making, cultivation, constructing informal roads, and cattle grazing. Agriculture is the key factor that sustains the livelihoods of people in Nzhelele valley. The ever increasing pressure of population on the Nzhelele valley can be attributed to an increase in land degradation and soil erosion.

Nzhelele valley rural disparate activities have had a great impact on the land; this has caused many problems such as gully development and siltation in river basins. This is, therefore a groundbreaking study that would reveal the nature of land use in relation to its triggers to gully development, which promotes high sediment load in river basins. This study will attempt to fill in the gaps by investigating the direct influence of land use to gully development. This will enhance one's understanding of the nature of land use and gully development in South Africa. Thus, the study attempts to address impacts of land use, arguments of sediment load in contribution to gully development, and it incorporates the views of the local people on land use. There is an important need for an alternative way of thinking about sediment load that will provide solutions on how best land can be used to limit

the loss of soil. It should be reviewed as a collective effort that focuses on the abilities and capabilities of land use and gully development rather than the geographical structure, soil type and rainfall variability.

1.6 Delimitation of the study and description of the study area

1.6.1 Delimitation of the study

The research study will focus on how riparian land uses contribute to gully development and sediment load. It will explain how land use has influenced and produced gully development and sediment load in Nzhelele River Valley. It will describe the relationship between the sediment load and gully development, and how their interaction has been caused by various land use activities. Although there are other factors such as slope, rainfall intensity and soil structure that play a pivotal role in the formation of gullies and sediment load, this study seeks to identify the roles of land use on the development of gullies and sediment load. The study also aims to examine how land use change has affected the development of gullies and sediment load.

1.6.2 Description of the study area

This study will be conducted in Nzhelele River valley, which is located in the Musina and Makhado Municipality in Vhembe District of Limpopo Province, South Africa. The area is located within an altitude of 813 meters above sea level. Milaboni, Dzarani and Chiefs Kraal are places that surround the Nzhelele valley as shown in Figure 1.1. Nzhelele is located about 157 kilometers north-east of Polokwane. It has an approximate population of approximately 39 273 within a radius of 7 kilometers. The area is located between 22 53' 15.8" S and 22 54' 5" S latitudes and 30 11' 10.2" E and 30 11' 23.5" longitudes (Makungo *et al.*, 2010).

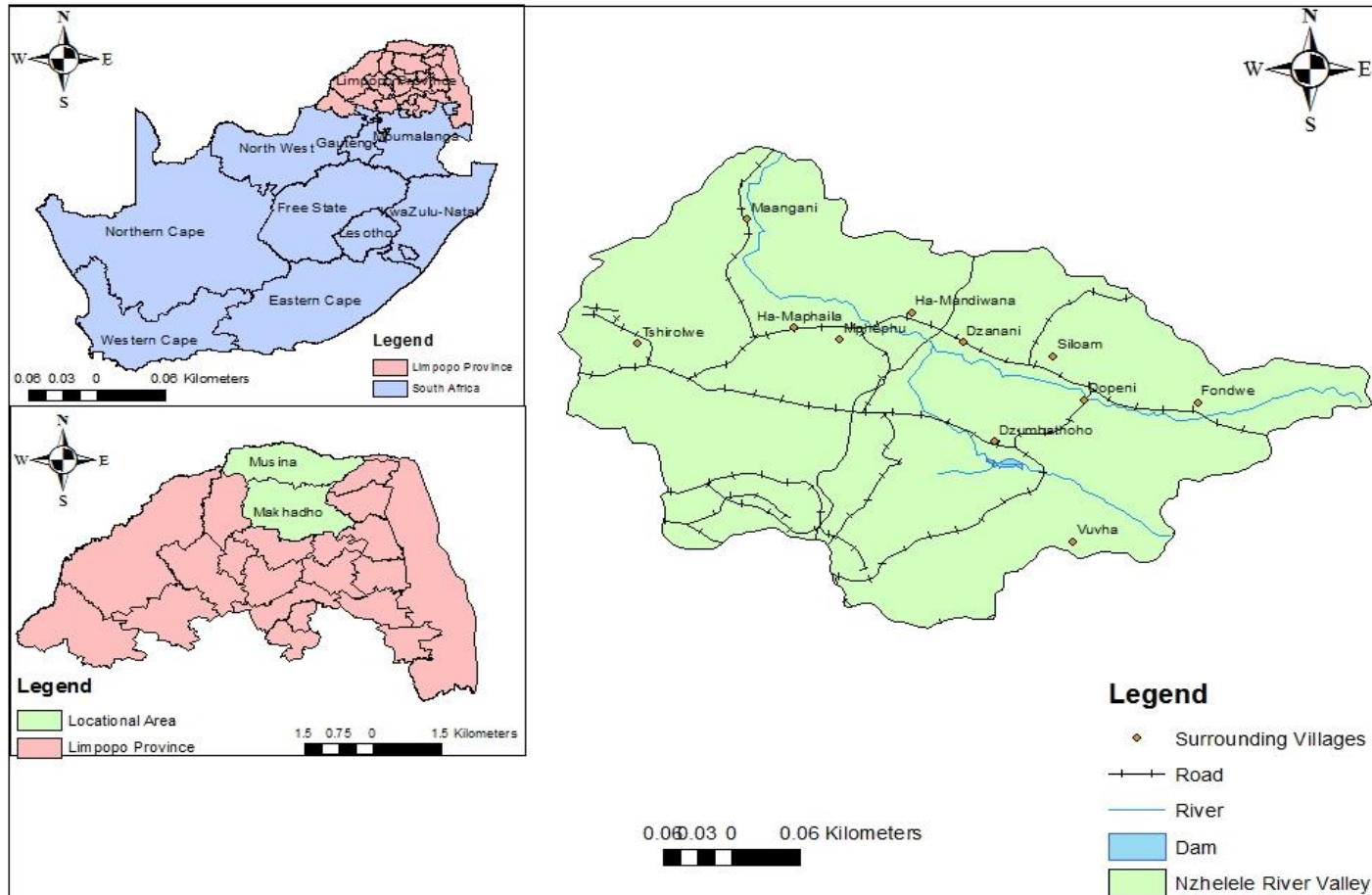


Figure 1.1 Study area showing Nzhelele River valley

- Drainage system

The Nzhelele River is a major watercourse in the Limpopo Province. The river catchment area comprises of 2,436 square kilometers. The river collects much of the drainage on the north slope of the extensive rock formation of the Soutpansberg Mountains. It meanders in a north-eastward direction across the Lowveld, with a wide plain that contains considerable biodiversity (Makungo *et al.*, 2010). The river joins the riverbank of the Limpopo River 33 kilometers east of Musina. Its tributaries are Mutamba, which is to the left and Mufungudi, which is to the right of Tshishiru. The source of the river is within Thathe Vondo which is within an elevation of 1.673 meters, and its mouth is the Limpopo River, with an elevation of 404 meters (Figure 1.1). Rainfall season within this area mainly occur between October and March (Ndivhaleni *et al.*, 2015).

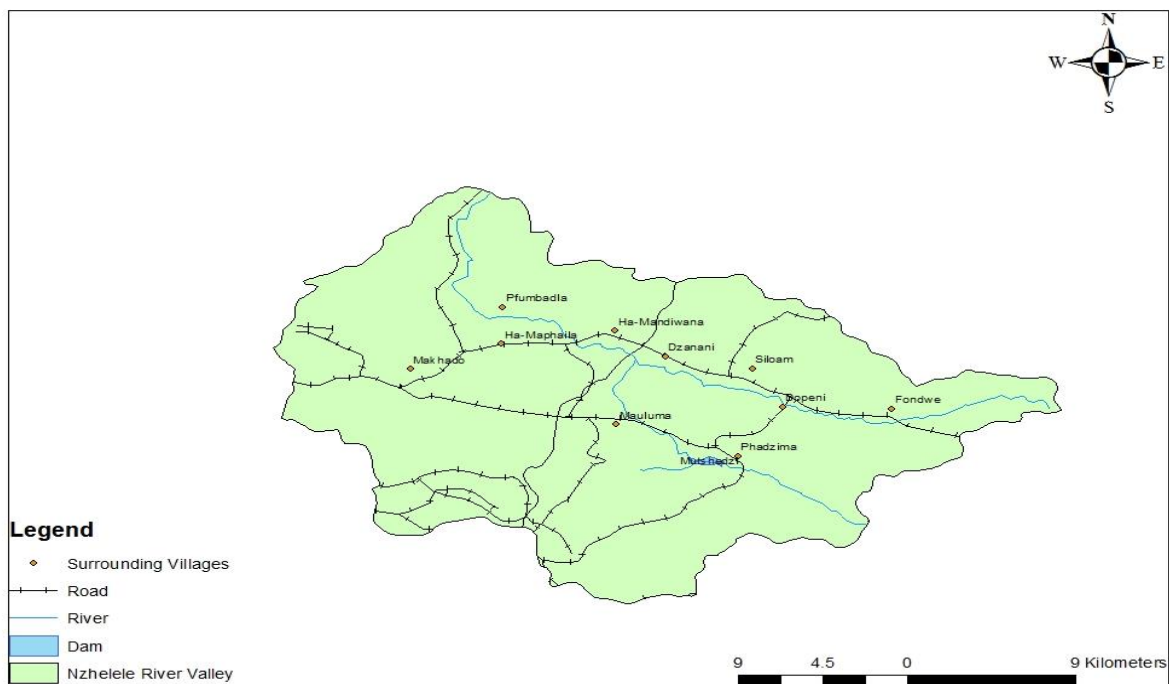


Figure 1.2 Drainage pattern

- Settlement pattern

The Nzhelele River valley consist of a number of villages such as Fondwe, Siloam, Dzanani, Phadzima, HA-Mandiwana and Ha-Maphada. In most of these villages, people leave within the sloppy areas of the valley along the Nzhelele River valley. Settlement patterns within this area is mixed consisting of clustered and linear settlement patterns. Within the villages, clustered unplanned settlement patterns are found as most of the people are given land by

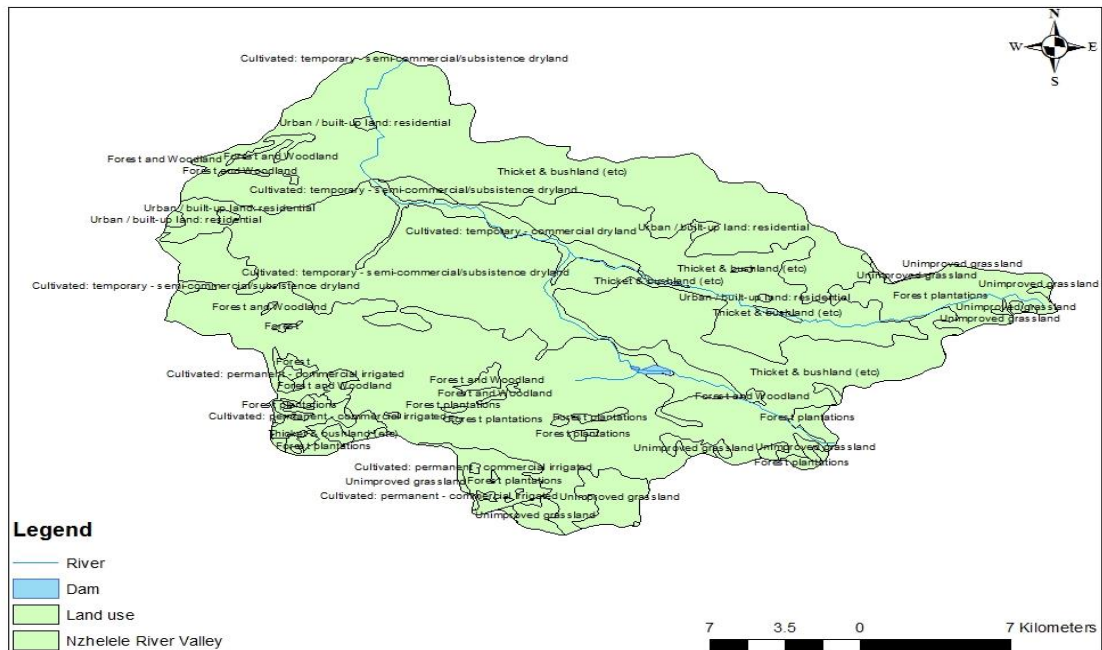


Figure 1.4 Land use

1.7 Definition of key terms

Land degradation:

- The temporal or and permanent lowering of the productive capacity of natural environment, such as land, water, air, and biodiversity deteriorating at a faster rate, leaving no time for the environment to recover. This is caused by various factors such as land use, climatic variability and soil characteristics, leading to a serious threat to the lives of people, animals and plants (Valentin *et al.*, 2005).

Sediment load:

- This is the solid matter that is carried from the drainage area and is as a result of deposition and erosion processes in a basin. It is managed by the aspects that control erosion and sediment delivery, which include load landscape, soil characteristics, climate, vegetation cover, catchment morphology, drainage network characteristics, and land use (Restrepo *et al.*, 2006)

Riparian land use:

- The exploitation and alteration of the interface between land and river or stream into artificially built area such as settlement, road construction sites and clearance of land for cultivation (Gyawali *et al.*, 2013)

Gully development:

- Gully development involves a narrow steep sided channels formed in loose earth by running water with a certain velocity which erodes sharply into the soil continuously from one stage to another in a changing situation, especially on steep slopes or hillsides Chleq, *et al.* (1988).

Land use:

- Land use is the management of the environment which involves exploitation and alteration of the natural environment into artificial landscapes (settlement and semi-environment) and habitats (plantations and urban ecosystem). It is given as the actions of management and inputs people undertake in a certain land cover type, in order to produce change (Nolon, 1992).

Geomorphological processes:

- Geomorphological processes refer to physical and chemical interaction of the earth's surface and the natural services, acting upon it to create landforms from which the process is strong-minded by such environmental variables such as geology, climate, vegetation, and base level, to say nothing of human interference, where the nature of these processes and the speed at which it operates is influenced by a transformation of these variables (Billi and Dramis, 2003).

Drainage Basin:

- Drainage basin refer to the earth's structure where water from various sources such as rain, ice or snow is collected down a hill into a surface stream or water bodies in association with some tributary streams, subsurface and surface water flows such as rivers, lake, reservoirs, estuaries, wetlands, seas or oceans (Waiker and Nilarwar., 2014)

1.8 Structure of the Dissertation

The logical structure of this text is given below in order to provide the reader with the review of the contents as well as the substance for each chapter.

Chapter 1 establishes the background to the study, research problem, research aim, objectives and questions, and the conceptual framework.

Chapter 2 sets to review materials on land use activities, impact on development of gullies and sediment load. Focus was based on farming, settlement, road construction, grazing and how it interact with the development of gully and sediment load.

Chapter 3 presents the materials and methods that were used to collect and analyse data on different land use activities, how they influence the development of gullies and sediment load in the study area.

Chapter 4 focuses on the presentation and analysis of data obtained from the field work for the research within the communities on land use activities and gully development as well as sediment load in the Nzhelele River Valley.

Chapter 5 presents the discussion of output data analysed. The discussions of the findings articulate the findings that are alluded in data presentation and analysis in chapter four.

Chapter 6 gives conclusions and recommendations on sustainable utilisation of land. The recommendations are based on the major findings of this study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature review of this study focuses on issues related to the different land uses and land use change, past land use and climate change, present land use change, sediment production. It also include human impacts on soil erosion such as farming, road construction, over grazing and footpaths created by domestic animals, hydrological function, piping and the impacts of farming activities. It will attempt to identify gaps in the literature and show how this study will attempt to fill these gaps. It will explain the main concepts and processes that result in gully development and sediment load as a result of various land uses and land use change.

2.2 Land use and land use change

2.2.1 Impact of land use on river ecosystem

Land is one of the most important resources in supporting rural development especially in the face of an increasing population and environmental pressure (Stankoviansky 2003). Increase in population pressure often results in a high carrying capacity disturbing the balance of the few resources that are available. The over-exploitation of land resources inevitably leads to more serious environmental problems (Longgao *et al.*, 2014). Different land use patterns have serious effects on river, water quality and aquatic ecosystems within a watershed. However, numerous problems related to river sedimentation are caused by inappropriate land use and practices in a river basin, for example population increase, urbanisation, and industrial and agricultural activities because these activities are directly reflected in land use (Hongmei *et al.*, 2014)

Soil erosion problems in Southern African countries are the main issues affecting inhabitants and agriculture in rural and urban areas (Sidorchuck *et al.*, 2003). At the beginning of July, after the crop has been harvested, large surfaces are left bare during the most receptive phase (between July and October), and this paves the way for erosional processes, leading to the development of gullies and loss of soil (Kertesz, 2009) Due to land use, a large number of farms in Southwest Spain, approximately 23%, have suffered a high risk of soil degradation and rill erosion, which has occurred mainly in cultivated areas (Ibanez *et al.*, 2014).

Historical evidence, according to Gabris *et al.*, (2003) and Kertesz (2009), suggests that during the nineteenth century, very severe gully erosion activity took place when big areas enclosed by loose sediments were cleared and designed for arable farming. The

deforestation activity, together with farming activities and a wooded environment, accelerated the probability of gully development. When the vegetation cover is removed from the land surface, the rate of sediment load, increase rapidly (Leopold *et al.*, 2014).

2.2.2 Functional aspects of land use

Various scholars have distinct and interpreted land use and land cover as an area of more importance within the area of geography. Land use and land use change is mostly applied in remote sensing and geographic information systems relating the subject to human activity or economic function associated with a specific piece of land area (Lillesand *et.al.*, 2007). Land use involves the way in which, and the purpose for which, human beings explore the land and its resources (Meyer 2005). However, it is valued as the common purpose of land and is distinguished by its utility and not by its physical qualities (Longley *et.al.*, 2005). Land use can also be described, as the functional aspects of an area with respect to man's participation on the land in terms of his occupations and cultural activities. The function of land is frequently inferred from the appearance of the land, that is, what physical or natural structure covers a specific parcel of land. According to Coppock (2003) land use is often described as land cover, particularly the vegetative cover of land in rural areas.

Land is considered to be among the most important natural resources available to man, and there is no doubt that human activities have profoundly changed land cover during the last decades. Most, if not all agricultural, animal and forestry productions depend on the productivity of the land. The majority of land-use and land cover patterns of a region as an outcome of natural and socio-economic factors and their utilisation by man in time and space (Bhagawat, 2011). Viewing the earth from space is now crucial to the understanding of the influence of man's activities on the natural resource base over time. Likewise, in situations of fast development and often undocumented and unrecorded land use changes, observations of the earth from space provide objective information of human activities and utilisation of the landscape.

According to Zubair (2006) land use affects land cover, and changes in land cover affect land use. A change in either, however, is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply degradation of the land. However, many shifting land use patterns driven by a variety of social causes, result in land cover changes. These changes affect biodiversity, physical structure of the land, water and other processes that come together to influence the development of gullies and sedimentation in river beds (Riebsame *et al.*, 2004).

Land cover relates to the type of feature present on the surface of the earth by (Lillesand *et al.*, 2007). Residential areas, grazing areas, and concrete highways are all examples of land cover types. Forces other than anthropogenic activities such as natural events of weather, flooding, fire, climate fluctuations, and ecosystem dynamics can alter land cover and may also initiate modifications of land usage (Zubair, 2006).

Globally land cover today is altered principally by direct human use, for example by agriculture and livestock raising, forest harvesting and management, urban and sub-urban construction, and other developmental activities (Meyer, 2005). Land cover resulting from other human activities such as forest, lakes, dams also play a significant role in reducing the rate of sediment load and gully development. As the human population is increasing at an alarming rate the rate of human settlement is also increasing resulting in high land use cover and land use change.

Land use and land cover change has become a significant aspect of global environmental change. Since land use/land cover change is a major factor for global environmental change because of its interactions with climate, ecosystem processes, biogeochemical cycles, biodiversity, and, even more important, human activities much attention needs to be paid on land use (Jieying *et al.*, 2006). Increase in land use/land cover has triggered a number of problems especially climate change. This has resulted in high flooding and heavy rainfall creating more problems such as gully development and heavy siltation in rivers.

2.2.3 Past land use and climate changes

Within most parts of Africa, the development of gullies can be qualified under mature forests, especially with quite a substantial magnitude (Grellier *et al.*, 2012). Within given high infiltration rates under the current environment, most of the gullies are formed under different climate situations and land uses (Torri and Poesen, 2013). In some current, comprehensive analysis of soil profiles with the use of high resolution stratigraphy, together with some archaeological dating of pottery and ¹⁴C dating of wood and charcoal, this makes the reformation of the chronological causes of development of gully erosion in different areas.

Three main gully development periods have been acknowledged in Europe (Dotterweich *et al.*, 2002; Schmitt *et al.*, 2003), in Germany (Stankoviansky, 2003); and in Slovakia; (Vanwalleghem *et al.*, 2005). A large number of gullies were created through the time of wide forest clearance and development of agricultural area with the influence of heavy rain fall during the 14th century, between the last period of the 16th century period, as well as at the turn of the 18th and 19th centuries at some point within the Little Ice Age. In Kinsasha

(DR Congo), gully development is closely associated with high urban growth which have taken place over the past years (Imwangana *et al.*, 2014).

However, Sidorchuk and Golosov (2003) calculate approximately that since the end period of the 17th century, 2106 gullies longer than 300 m have developed, and creating almost 4109 m³ of sediment. Approximately 97% have been re-deposited and accumulated, filling up diminutive valleys with sediments 5 to 6 meters thick. Tremendous gully development has disturbed a number of catchments in Ngqushawa district, Eastern Cape with studies providing links between land use change in the form of land abandonment and badland gulling (Kakembo *et al.*, 2009).

The collapsing of the vegetative valley bottoms in the upper Murrumbidgee River, and Australia, because of the introduction of stock in the 1840s and 1850s, triggered a huge segment of gully erosion, escalating the sediment flux out of the catchment by a factor of about 200 (Lovino *et al.*, 2009). A huge variation in rainfall has caused less than a two fold increase in the sediment transport capacity of the river in comparison (Olley and Wasson, 2003). Moreover, overgrazing has also contributed as it has caused severe gully development at the turn of the 19th and 20th centuries in Easter Island (Mieth and Bork, 2005) and in Northern Namibia (Eitel *et al.*, 2002).

In some parts of South Africa, the population density and the number of cattle grew considerably within the third decade of the 20th century, due to the result of the apartheid system. Owing to the cleared vegetation cover and an increased number of activities along paths, intensive rainfall concentrated and infiltrated the deeper swelling and shrinking clay soil layers. After the intensive sub-surface erosion, gully development rates in Iran reached 60 Mg ha⁻¹ yr⁻¹ (Bork, 2004).

Within Germany, an analysis of about 2300 areas shows that, on average, rill and gully erosion rates have increased from 2 to 6 Mg ha⁻¹ yr⁻¹ between the 1950s and 1975 (Bork, 2004). With no considerable increase in the rainfall intensity or frequency, high levels of rainfall were experienced over this time. Such a drastic increase should be attributed to current land use change. Because of lower prices within the world market, crops were cultivated with a low cover density during the erosive summer months. The portion of land was expanded due to land redistribution. Conservation activities of the soil, which include terracing and hedging, and which were frequently practiced from the beginning of the last phase of intensive soil erosion (18th century), were deserted. The introduction of new

technologically advanced equipment in agriculture has caused soil to become compact, which has, in turn, reduced infiltration capacities.

2.2.4 Present land use changes

Natural gully development processes are often increased by the escalation of agricultural activities. Over exploitation of the soil biomass reduces the stability of soil structure and encourages crusting, high surface runoff and soil erosion (Valentin, 2004). In many mountainous areas, the yearly cropping has resulted in an increase in rill and gully development processes, as well as in vineyards in the Eastern Cape Province. If irrigation channels are not well managed, this can lead to gully development.

Overgrazing has frequently been reported as one of the major causes of gully development, especially in rangelands. Mieth and Bork (2005) argue that current gulling development is greater than $190 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ because of overgrazing by sheep on Easter Island in Rapa Nui. Extensive fallow periods are seen as a means of rehabilitating soil structural strength an action which will subsequently decrease gulling hazards.

Recently, it was discovered that in sandy Sahelian soils that soil crusts develop during fallow periods because of dust deposition and colonization by blue, green algae (Valentine *et al.*, 2004), thus attracting gully development. In these conditions, tillage restricts soil erosion, but increases wind erosion (Rajot *et al.*, 2003). Some related crusting processes may give an explanation as to why the extensive desertion of communal subsistence fields in South Africa has been related to gully instigation and development (Kakembo and Rowntree, 2003). An unmanaged Irrigation, system over bare deserted farms usually prompts serious gully erosion, as revealed in the oasis of San Pedro de Atacama in northern Chile (Bork, 2004).

2.3 Dictating land use and land cover change using GIS

2.3.1 Land use and land cover dictation

Land use types such as urban expansion, agricultural land loss and forest cover change has been historically addressed in different studies. The effect of past land use on present and future land use are becoming so widespread that they cannot be ignored in descriptions of production techniques (Bhagawat, 2011). Land use change provides more insight, as well as identifying problems for the ever expanding industrial, residential and commercial purpose, and to ensure sustainable development in the environment. However, different spatial units make the examination of changes over space and time difficult in analysing the impacts of

such changes on the environment. The most fundamental data constraints are the changes in the nature of land use activity (Oellermann, 2005).

Timely and accurate change detection of the earth's surface features provides the foundation for a better understanding of relationships and interactions between human and natural phenomena to solve the environmental problems (Lu *et al.*, 2007). Changes in land cover and the way people use the land have become recognised since the mid-1980s as important global environment changes in their own right (Turner, 2002).

Empirical studies from various disciplines initiate that land use/land cover and its change have become key to many diverse application such as gully development, soil erosion, agriculture, hydrology, (Li and Yeh, 2008 and Weng, 2007). This attempt has stimulated many studies to apply various techniques to detect and further model environmental dynamics at different levels, including on local, regional and global scales. Change brings new conflicts between the uses of the land, the interests of individual land users and the common good (Turner *et al.*, 2007).

The major aspects of change detection which are important to consider when monitoring and studying changes in the environment include, detecting the changes that have occurred, identifying the nature of the change, measuring the extent of the change and assessing the spatial pattern of the change (Zubair, 2006). Surveying methods were originally used to map land changes before the development of satellite remote sensing techniques. Satellite remote sensing techniques have been developed, and these have proved to be of immense value for preparing accurate land use/land cover maps and monitoring changes at regular intervals of time (Lillesand *et al.*, 2007).

According to the study carried out by Mehta (2011) land use/land cover change in the eastern district of Delhi. However, the study failed to address the issue over the entire study area. Moreover, the study focused on the quality of urban environment. The study assessed the urban environment quality within built-up areas, open spaces, household density, occupancy ratio, population density, accessibility to roads, noise and smell affected areas. It revealed that the urban environment has been largely degraded compared to the period between 1982 and 2003.

A study done in Bogosu-Prestea area, south west Ghana by Edward *et.al.*(2009) on open pit gold mining and land use changes, describes land use change due to mining in the area over a twenty year period (1986 – 2006) the impact of mining activities was analysed within the Golden Star Resources Bogosu Prestea Limited concession. The study revealed that mining in the area increased by 12.1% in land coverage from 1986 to 2006 and that there

was a decrease in agricultural land use from 97.8% in 1986 to 82.7% in 2006. Settlements increased from 0.45% in 1986 to 4.95% in 2006 due to rural- urban migration giving birth to the development of gullies in the area.

2.4 Soil structure and Sediment load

2.4.1 Soil composition and geomorphology

Soil geomorphology comprises of a specific subfield of earth surface processes, which are equally important in the development system and in creating the surface landscape (Sherwood *et al.*, 2010). Weathering and soils are of interest to a broad range of sciences, and their role in geomorphology is specific and important. Weathering is the pioneer in both chemical and mechanical erosion. Therefore, it is important for the generation of sediments carried by other surface processes. Weathering is also important in the creation of soils, and in most cases, is relevant to erosional and depositional landforms.

Ephemeral gully erosion is a central process in the black soil region in Northeast China, and it can be responsible for severe damage to agricultural lands (Vandekerckhove *et al.*, 2000). Gully development is severe in Swaziland and has huge impacts to sustainable agricultural production. The problem has increased over the past two decades in the Middle veld between 1972 and 1990 with severe gully erosion from 6.7% to 13.6% (Morgan and Mongomezulu 2003). However, after a century of intense cultivation, the productivity of these soils has been severely damaged by water erosion (Pande *et al.*, 2013). About 37.9% of the total cultivated land in this area is subject to water erosion, and the depth of the black soil layer varied between 0.50 and 0.80 m before reclamation of the land for agriculture (Morgan and Mongomezulu 2003).

The progressive loss of soil material, a reduction in organic matter content and effective soil depth, Calcium Carbonate (CaCO_3) enrichment of arable layers and degradation of soil structure found in vineyards in North East Spain have paved the way for extensive gully development (Peter *et al.*, 2014). Heavy rainfall and relatively sparse vegetation has resulted in the development of gully systems and land degradation. Long spells of drought interrupted by intensive precipitation intervals, often causes land degradation where rapid channeling processes at different scales may cause gully erosion and the formation of badlands. Gully erosion significantly contributes to soil loss in the Mediterranean region, for instance, in South East. Ephemeral gully erosion generates sediments from 3.4 to 9.7- $\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$, representing 44% to 83% of total sediment production from agricultural lands (Kheir *et al.*, 2008).

2.4.2 Sediment production

Sediment load is very variable and may be as high as $34 \text{ ha}^{-1} \text{ yr}^{-1}$, and $32 \text{ tons ha}^{-1} \text{ yr}^{-1}$ to $64.9 \text{ tons ha}^{-1} \text{ yr}^{-1}$ in various regions (Poesen *et al.*, 2003). Historical and present day gully erosion are important in addressing the consequences of future land use and climate change, as land managers need to forecast the effects of land use change, infrastructure construction and urbanisation on gully development. The loss of soil due to gully development and soil erosion strongly jeopardise in-situ and downstream agricultural production (Valentine *et al.*, 2005). Compilation of data by various researchers indicates that there is variation with respect to gully development and sediment yield. However, data from different parts of the world indicates that the soil loss rates of gully erosion ranges from 10% to 94% of the total sediment yield. (Poesen *et al.* 2003). There are also other factors such as spatial scale and temporal scale that are very important with respect to sediment yield and soil loss within gully development.

Development of infrastructure, such as irrigation canals or roads in catchment areas induces an increase in the gully erosion rate due to inappropriate drainage of surface water. Recent studies indicate that gully erosion represents an important sediment source in Mediterranean environments, aggravating off-site effects of water erosion (Zucca and Canu., 2006). As the soil is transported from one place to another, the continuous removal of soil from one point for a long period of time will eventually create a deep incision, which develops into a gully. As the soil is being removed, it is transported and deposited in a different location. Gully erosion represents an important sediment source in a range of environments and gullies, which are effective links to the transference of runoff and sediment from uplands to the valley bottom and permanent channels where they offset the effects of water erosion (Kertesz, 2009).

The historical anthropogenic activities have had some significant implications for environmental changes in different scales from regional gully development to sediment influx (Hoffmann *et al.*, 2007). Potential erosional landforms soil sediment structures for the reconstruction of past soil erosion, colluviation and floodplain development have been recognised during the last decade by an increasing number of studies, which assess human impact and land use development. Dotterweich (2013) has reviewed the global context of the perception of soil erosion in historical times, and many case studies in Europe are also extensively reviewed in Lang and Bork (2006) and Dreibrodt *et al.*, (2010).

2.5 Human impacts on soil erosion

2.5.1 Overgrazing trails and footpaths by domestic animals

Vegetation cover and production variability are the major parameters, which indicate land use degradation in terms of vegetation cover and species community (Schunn and Rogers 1991). Soil degradation, which is highly associated with overgrazing, is highly favored by the abandonment of transhumance and the predominance of fencing, as well as permanent grazing over restricted areas. Excessive livestock causes soil degradation, which is usually a deterioration of the physical, chemical and biological properties of the soil that result in a higher vulnerability to erosion problems (Ibanez *et al.*, 2002).

In rural areas and farmlands, gullies are formed on livestock and vehicle trails that run along hill sides. This is because the livestock and traffic on them compact the soil as they move up and down, and this reduces the water holding capacity. The sunken footpaths made up and down the slope eventually become the focus of a concentrated flow which finally turns into gullies. This, then, results in the development of new footpaths that turn into gullies as time passes. The improper handling of footpaths, cattle trafficking lines and poorly designed and constructed roads further aggravate gully erosion. Unplanned land use can disturb the natural drainage ways (Thiemann *et al.*, 2005).

2.5.2 Different farming activities

Most small channels are eroded by concentrating the overland flow that can be easily filled by normal tillage, only to reform again in the same location by additional runoff events. Gullies form in concentrated flow zones located, not only in natural drainage lines (hallways of zero order basins or hallows) but also along linear landscape elements such as drill lines, dead farrows headlands, parcel borders and access roads. Land use often causes channel incisions in linear landscape elements normally generated by tillage or land-forming operations (Poesen *et al.*, 2003).

Soil loss in the Ethiopian highlands increased from 33% to 55% after the construction of a road which had been caused by an increase in runoff concentration (Poesen *et al.*, 2003). Soil, according to the International Soil Science Society (ISSS), is a limited and irreplaceable resource. Without the soil, the biosphere would collapse with devastating effects on humanity (Duran *et al.*, 2010). With respect to this, soil erosion by water is the detachment of soil particles by the direct action of raindrops and runoff water and the transport of these particles by splash and very shallow flow to small channels or rills (Duran *et al.*, 2010). This

environmental problem is one of the most serious problems worldwide, and its effects are long-lasting, exerting both physical and chemical effects.

Mountainous areas in Spain were terraced during the last few decades, as one of the driving forces of agricultural development and, especially, since the admission to the European Union in 1986. The construction of these terraces has caused the detachment of soil from taluses of orchard, resulting in terraces accumulating on the platform below the terraces. A lot of soil has been lost due to the development of agricultural activities and land use development, creating a huge problem in the environment in the long run. Purwanto (1999) and Dijk (2002) argue that terracing is not always effective in reducing soil. Soils on the high sloping lands cultivated for thousands of years, have been gradually degraded by soil erosion as the presence of taluses without vegetal protection has led to the destructive erosion. This has caused the terraces to slump and collapse.

When agricultural crops replace native vegetation, the natural cycle is altered; soil and nutrients can be readily transported by erosion and runoff destroying the level of organic matter gradually. Within cultivated areas due to interrill erosion, a significant process of carbon mobilization has been observed. Worldwide, on approximately 14 million km² of cultivated land 0.6 to 1.3 gigatonnes of carbon have been affected annually by raindrop impact, splash and non-concentrated runoff (Kuhn and Armstrong, 2012). In agricultural practices under semi-arid Mediterranean conditions, the vegetation cover plays a fundamental role by scattering the runoff and buffering its erosive power (Pardini *et al.*, 2003). The growing degradation and loss of soil means that the expanding population in many parts of the world is pushing resources to its limit.

In the last 40 years, about one-third of the total arable land of the world has been progressively at a high rate affected by soil erosion (Bhatt and Khera, 2006). Impacts of human activities have brought about degradation and eventual desertification, mainly in arid and semiarid areas. Farmers, sometimes, indiscriminately uproot aromatic plants in the harvesting period, leaving the soil bare, thus increasing the risk of soil loss during torrential rains. This means that certain human practices are causing high soil erosion (Duran *et al.*, 2007).

The anthropogenic modification of landscapes dates back to the Neolithic cultural revolution when the woodland was cleared, in order to provide new agricultural land for crop production around 7500 years ago (Dotterweich *et al.*, 2012). From that period, many phases of agricultural expansion and contraction have occurred, resulting in the high influence of biodiversity, energy and matter by human impact.

Although wildfires are essential agents responsible for shaping vegetation dynamics, they are also major agents of soil erosion and land degradation. Some major concerns about wildfires and their effects in most regions were raised between the 1960s and 1980s when there was an exponential rise in fire activities (Shakesby, 2007). Human influence, including land use change, brought about by widespread socio-economic change, and urban expansion has been viewed as the main driver of the dramatic increase of wildfire activities (Pausas *et al.*, 2008).

The loss of vegetation cover may lead to the formation of soil seals, which can increase the runoff and erosion during the early stages of seal development. According to Vacca *et al.*, (2000), runoff and soil erosion in three areas under different land use (abandoned grazing land, burned *Machia* and *Eucalyptus sp*) have different amounts of runoff, and soil erosion results from different land uses where the highest surface occurs from bare inter-canopy patches. Decrease in canopy cover density due to overgrazing leads to rapid water erosion in rangelands and the loss of vegetative cover as a result of human activities such as overgrazing and deforestation, leads to the formation of soil seals (Oztas *et al.*, 2003), which increases the risk of runoff and soil erosion.

Snyman and duPreez (2005) assert that range land degradation leads to increased surface water runoff and composition of soil due to the decreased plant cover, reduced aggregate stability, reduced soil fertility, and decreases in the soil water content in all soil layers. According to Merzer (2007), bare plots produce significantly more runoff than in vegetative plots. Due to the lack of natural resources management, most forests that have undergone deforestation, especially over the past two decades; have led to the development of gullies and high surface runoff (Mohammad and Mohammad, 2010).

From the first sowing and planting, agriculture has been synonymous with land degradation and soil erosion. This is because agriculture and animal grazing encourages the removal of native forests, prairies and scrublands, which reduce seed completion. Ploughing, together with other tillage, also results in soil degradation and often increases soil erosion. Agriculture, soil erosion and natural resource degradation have been linked together since agriculture was innovated (Lah, 1999). Some agricultural strategies have been developed to avoid and/or reduce soil erosion (terracing on steep slopes, use of cover crops, mulching and no tillage). Even after the green revolution and technological improvements, agriculture is still the source of most sediment in surface runoff (Cerdeira *et al.*, 2007). With regards to agriculture, soil erosion by water detaches and removes soil particles which, in turn, reduces soil fertility and induces land degradation. This eventually causes soil erosion and sediment deposition in rivers.

In disturbed deforested areas, the occurrence of high erosion rates may result in on-site and off-site environmental impacts. On-site impacts include the removal of the forest litter layer, changes to surface to surface characteristics, breakdown or alteration of the soil structure, decline in nutrients and organic matter in the soil and soil compaction. This will result in the further reduction of infiltration and water storage capacities, as well as the formation of crusts with the consequent compaction of the soil with a significant increase of runoff (Lovino *et al.*, 2009). Off-site effects that are due to increased soil erosion can result in increased bed load transport and ecological disturbance in the river network. Beyond that, the sediments transported downstream into the drainage network can cause river siltation and high flood risks. This accumulation of sediment material can reduce drinking water quality, storage capacity, and problems of channel stability (Fanelli *et al.*, 2000)

2.5.3 Road construction

The construction of roads through steep lands, without adequate provision for drainage systems, is one of the major causes of gully erosion. Inadequate drainage systems for roads, such as a small number of culverts and insufficient capacity of road ditches, are a major cause of gulling (Zhang *et al.*, 2015). When road cuts and fill slopes are not re-vegetated during or immediately following road construction, gullies form on both sides of the road due to compactness of pore spaces (Ozgan *et al.*, 2015). In line with different procedures that are undertaken in road constructions, the area experience high soil compaction increasing soil bulk density. Bulk density involves the ratio of dry soil mass per unit volume and it's a measurement of soil compactness (Zeng *et al.*, 2014). The soils within road constructing area comprise of solid materials that include minerals and organic matter together with some pore spaces that hold air in the soil are highly compacted which influence the bulk density of the soil (Nyssen *et al.*, 2002). The structure of the soil influences the amount of pore spaces, size and orientation of the pores. Its measurements range between 1.0g/cm^3 to 2.0g/cm^3 , whereas $1,6\text{g/cm}^3$ or more severely impacts root penetration. Bulk density is a crucial characteristic that affect major soil functions that includes water holding capacity, infiltrability, aeration, plant germination and root growth (Mora and Lazaro, 2014).

The widening operations along roadsides do not often follow road construction, but where widening is practised, the operation usually causes landslide erosion and, then, gulling within the first rainy season. Although road-caused erosion may occur anywhere in the world, the problem is mostly severe in developing countries because of neglecting maintenance and the lack of provision of safe outlets for excess runoff. Some of the problems related to roads are poorly managed and abandoned quarry sites, which are also potential sites for runoff

generation and concentration flow to low lying drainage ditches and farmlands (Heping *et al.*, 2008).

2.6 Gully erosion process

2.6.1 Development of gullies

Gully erosion is acknowledged as a key erosion process whereby land degradation in dry land occurs and contributes 50% to 80% of the overall sediment production (Frankly *et al.*, 2013). Torri and Poesen (2004) define a gully as an intermittent water course, where processes of channel erosion can be very intense. These intermittent water courses are important sediment sources, lines of preferential connection between upland areas and the channel network with a capacity to modify water and sediment connectivity during intense rainstorms, especially in cropland. Gullies grow initially to large dimensions, becoming the main source of sediments. The incisions erode alluvial sediments and are less deposited along valleys. According to Valentine *et al.*, (2005), in the Ethiopian highlands, gully development has led to an enlarged drainage of the inter-gully area, resulting in soil moisture decrease. The development of gullies varies in shape and size depending on the predominance of their development, such as relief field patterns or dirt road patterns (Superson and Jan Reder 2014).

Gully development is mainly caused by mankind and or geological erosion (Desta and Adgan, 2012). The influence of human intervention that is through various human activities such as road construction, clearance of forest for farming or residential purposes exposes the soil directly to abrasive actions creating vulnerability of the area to erosion. These actions cause runoff concentration and flows at high velocity that is sufficient to detach and transport soil particles from one point to another (Carey, 2006). Depending with the runoff rate of the water flow, soil particles are carried in different sizes some plunging over the gully head increasing the gully size. Gullies develop where watercourses or other places where runoff is highly concentrated, such as paved roads or built in canals and contour ridges. Advanced rill erosion usually develops into gullies when there is high pressure of water flow greater than that of soil particles over a certain period of time. Carely (2006) argues that soils with dispersible sub soils are highly vulnerable to erosion especially when there is high concentration of water flow

2.6.2 Gully classification

The classification of gullies depends on various characteristics exhibited by the gullies themselves (Thomas 1997). There are a number of classification methods, of which one of

them is based on size-depth and drainage. This classification identifies small gullies as one which are within a depth of less than 1.5 meters and a drainage area of less than 10 hectares (Herwey, 1999). In the same classification, medium gullies are between a depth of 1.5 and 3 meters are surrounded by 10 to 30 hectares of drainage area. Lastly, large gullies have a depth of more than 3 meters with a drainage area of more than 30 hectares (Belayneh, 2010).

Gullies are formed channels mostly on valley channel slopes that previously existed within channels that are always ephemeral (Brookes, *et al.* 2003). They develop when surface runoff concentrates in an area where an abrupt change of elevation and or gradient is accompanied by high intensity of rainfall. The development of gullies initially takes place when the force of water increases, exceeding the resistance of the soil (Hudec, *et al.*, (2005). Once initiated, gullies offer avenues for easy down slope movement of water from later storms. The flowing water in gullies, during its early stages of development erodes soil from the sides and floor of the gully creating wider and deeper channels.

The soil particles are forcefully removed from their compaction position and transported downstream. With 0.3 to 0.6 meters per second of velocity that occurs on sheet erosion, soil within the thin layers on slope land can be removed, leading to the formation and development of gullies (Pathak, *et al.* 2005). However the formation of gullies is normally where rills join and gain up to more than 30cm of depth. In addition, gully development usually depends on run-off, which, in some cases, produces characteristics of water shade. Gullies develop in three main stages, namely waterfall erosion, channel erosion and landslide erosion.

2.6.3 Contribution of rainfall on gully erosion

According to Haggard *et al.*, (2005) rainfall intensity involves the total amount of rainfall falling over a given period of time/duration. Characteristics of high intensity and short duration rainfall are independent of locations within an area, and are more or less the same in some parts of the world. In most cases, this type of rainfall occurs within a short period of time, leading to surface runoff with little or no infiltration especially in areas influenced by human activities (Godone 2012). These activities weaken and loosen soil. This causes it to slump under high intensive rainfall and renders the soil easily detachable. However, some of the soils tend to slake and form a seal under intense rainstorms. This results in runoff and erosion.

Gully erosion, increases with an increase in rainfall intensity (Mbaya, *et al.*, 2012). This produces rapid saturation, leading to the down cutting of gullies. In the equatorial zone, high

rainfall intensity is experienced over a long period of time (Plaster 2003). This causes high surface runoff and increases the water force of erosion within sloppy environments. In most cases the intensity of rainfall and duration are the main determining factors that influence the strength of water erosion which create gullies.

The ability of rainfall to cause erosion is highly complex, but it usually it depends on several characteristics of rainfall. The mean annual rainfall is one of the factors that have the highest influence on soil erosion. With this type of rainfall, there is mostly surface runoff, which erodes soil, forming part of the process of gully formation (Matthew 1984). Erosion is very insignificant in little rain and most of it is taken up by vegetation leaving very little as runoff (Bork, 2004). If the rainfall patterns are evenly distributed throughout the year, there is less erosion because rainfall is usually gentle (Haggard *et al.*, 2005). More so, because rainfall is spread over a large period of time in the year, vegetation is usually dense most of the time and it acts as a shield protecting the soil. When rain falls in winter, it is mostly gentle in nature.

In most parts of Africa, rill and gully erosion are the most dominant forms of water erosion (Hudec, *et al.*, 2005). A portion of rainfall, which does not infiltrate into the soil, flows downhill under gravity, which is known as runoff or overland flow. Runoff, in most cases, may occur because of two good reasons: if rainfall arrives too fast for it to infiltrate or when the soil is already saturated (Brooks 2003). If the rainfall arrives with high intensity, runoff might result in what is known as infiltration excess.

Furthermore, if runoff occurs when the soil is already saturated, the soil can no longer hold more incoming water, resulting in saturation excess runoff. As one of these two actions occur runoff moves downhill. At first, this is a thin diffuse film of water that has lost all the kinetic energy which it previously possess as falling rain. The water moves slowly with a low flow power incapable of detaching or transporting soil particles. Millar (2007) argues that the small scale patterns of irregularities of the soil surface cause overland flow to concentrate within closed depression. This protects the soil from high kinetic rain drop impact which decreases with time within a storm, as depth of surface water increases.

If the rainfall continues, it overtops the micro-topographic depression, creating an overland flow which flows downhill faster and in greater quantities of water body. This overland flow possesses more power due to the kinetic energy which will make the water to transport sediments and even detach soil particles from their original matrix position. As this process takes place, the surface level will begin to go down as particles are eroded, thus forming preferential flow paths for subsequent flow. As rainfall continues over a long period, the flow

paths are, in turn, eroded, further resulting in small, well defined linear concentration of overland flow.

An individual linear concentration becomes ineffective over a period of time because of sedimentation. However, a subset grows further and become rills. Smaller subsets develop into gullies. Completion between rills and gullies eventually leads to self-organised networks of erosional channels (dentric on natural soil surfaces) which form pathways for the removal of water from slopes (Le Roux, 2007).

2.6.4 Impact of rainfall intensity on gully development

Erosion is caused by rainfall through splash erosion, which detaches soil particles with kinetic energy (Essen, 2011). The kinetic energy impacts and encases soil in a film of water. Runoff carries the detached particles away into flow concentrating channels. The raindrop size in the Guinea savannah ecological zone of West Africa ranges from 0.6 to 3.4 mm, moreover from the research done the average drop size of 28 rainfall events ranged between 1.1 mm to 2.9 mm. This suggests that the intensity and energy of rainfall are closely associated with erosivity (Godone, 2011).

With the recent investigation in temperate latitudes, the relationship between drop size and drop size distribution differs from the rain of the same intensity, but with different origins (Morgan, 1990). This is because the drop size characteristics of convectional and frontal rainfall are different, as rain formed at the warm and cold fronts of a temperate depression (Pulwarty, *et al.*, 1992). Despite difficulties posed by variation it is possible to have a general relationship between kinetic energy and the intensity of rainfall.

Energy exerted by the rain drops can, in a way, be called the pioneer for gully development as it paves the way for gully development (Horel *et al.*, 1989). The impact of the soil is very explosive, and its force on the soil particles is very unbearable. When the raindrop impacts the soil, it exerts three detrimental effects, which include ditching the soil, destroying granulation, and splashing under certain conditions. This causes the transportation of soil particles. The great force of raindrops does not only loosen and detach soil particles, but it beats the granules into pieces. This opens up a way for runoff to take place if the rainfall reaches saturation point. There is a relationship between rainfall and runoff (Pathak, *et al.*, 2005). Big storms can cause severe gulling. Intense rainfall coupled with soil prone to sealing and crusting, generates high runoff volumes and concentrated flow. The force brought about by the runoff causes gully erosion, especially in semi-arid regions with scanty vegetation cover. If rainfall exceeds the soil infiltration capacity, the water will settle on the soil surface and, in no time run down slope.

The large spatial and temporal variability of rainfall contributes to gully development. Aggressive rainfall and the ratio of the highest monthly rainfall of total, annual and concentration of rainfall are good indicators of gully texture. Rainfall moves the soil indirectly by means of gullies which are too big to be removed by tillage (Rasool, *et al.*, 2011).

2.7 Slope and critical drainage area

The total stream length per unit area which represents the degree of fluvial dissection is called drainage density (Lin and Oguchi 2004). The slope angle or relative relief which is correlated with drainage density is positively correlated within some regions, but negatively in other regions. Thus the negative correlation has been attributed to the decline of channel sidewalls on steep slopes related to slope failure. Howard (1997) indicated that drainage density and slope angle correlate negatively in quickly eroding areas, but positively in slowly eroding areas. Within headwater systems, in dry climate mountain landscapes that are considered to react sensitively to climate change and human impact, the role of hill slopes, functioning as the key elements for sediment production, storage and transfers, is particularly important, (Beylich and Laute 2014). The development of gully systems is an indication of severe accelerated soil erosion, and gullies are an important sediment source in both dry lands and humid regions.

Gully initiation occurs above a threshold value of the shear stress indicator within uniform geomorphic and hydrologic conditions, and various threshold values are anticipated where geology, soils, climate and vegetation are different. The idea is based on a contrary relationship between drainage area and valley slope, describing the threshold for gully initiation. In an urban area with a high population growth and high rainfall intensity, soil erosion could be accelerated and become very severe. This phenomenon has assumed destructive dimensions in many parts of the world, especially in the high land use zones of the rural urban environment.

The relationship between the spatial distribution of gully erosion and topographic thresholds, as well as land use change in the form of abandoned lands, has affected several catchments of the Eastern Cape Province, South Africa (Adediji *et al.*, 2013). The development of the gully is formed when the hydraulic threshold exceeds the resistant soil surface, whereby the flow intensity at the soil surface of any landscape position is controlled by topographical parameters such as local slope and drainage-basin area. In the Mediterranean catchments, gully erosion is responsible for significant amounts of soil loss and, normally, this can be considered as an indicator of desertification (Vandekerckhove *et al.*, 1998).

2.8 Conceptual framework

The key themes and associated debates have set the ground work for the conceptual framework whose parameters are shown in Figure 2.1. Due to the enhancement of the various land use developments, the development of gullies has led to unsustainable rural development. Thus, the study uses the intertwined conceptual framework as stated by many authors. This will allow credibility to the alignment between land use, gully development and sediment load in the context of sustainable land use towards gully development in rural areas.

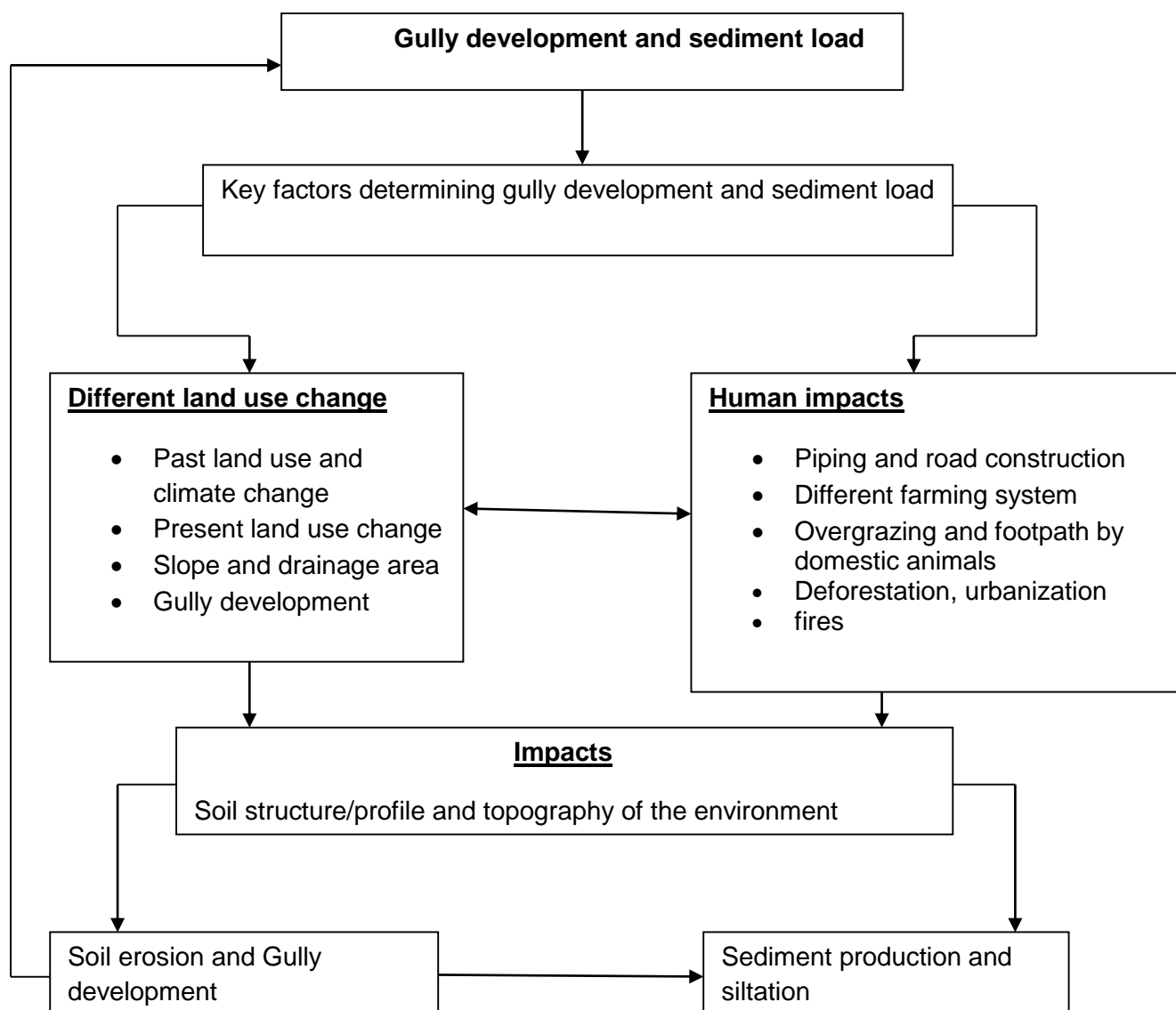


Figure 2.1 Conceptual framework

The conceptual framework is used as a mechanism to improve the researcher's understanding of the gully development in relation to land use. Sediment load brings the concept of the need to quantify the contribution of land use in the development of gullies. There should be equilibrium on the environment's capability to present the amount of sediment load in respect to gully depth. The study conceptual model draws on the main factors that affect gully development and the relationship among these factors. With regards to this study, some of the factors are listed below:

- Land use development;
- Road construction;
- Farming activities;
- Gully development; and
- Sediment load.

A number of rural people depend mainly on land, cattle, farming and marketing, to enhance their family's well-being and sustain their lives. This accelerates the exploitation of the available resources, creating a high probability of gully development and sediment accumulation in the river basin. Land use sustainability can be effective if it positively stimulates people's livelihoods and diverse strategies, leading to a reduction of poor farming activities and the over exploitation of resources.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

A fine research plan involves a very detailed design that has precise methods and specific processes to be followed when collecting data and analysing the needed information. The purpose of this chapter is to present the methods to be used to carry out the research, as well as the empirical techniques applied. It describes how different parameters will be applied, in order to analyse how land use has affected gully development and sediment load. Other subsequent sections within this section explain how data will be collected to investigate sediment load on land use.

3.2 Research design

3.2.1 Type of research design

Experimental research design was used in this study on different elements such as sediment load, soil samples, and gully size. This involved collection of data in different land use activities in order to assess their impacts on gully development. In order to get the actual effect of land use on the study area, some treatment samples and control samples were provided. The treatment samples received the intervention and the control samples will have the definite conditions. This will determine whether the treatment samples and control samples have had some effect or not.

A survey was also conducted within the study that includes the use of some satellite image data of the Nzhelele River valley. The data helped in identifying the specific areas under survey. The satellite image data assisted in assessing areas of land use and gully development and how they interplay in the development of gullies in the area of study.

The diagram in Figure 3.1 below illustrates different data collection methods and design implemented within the study.

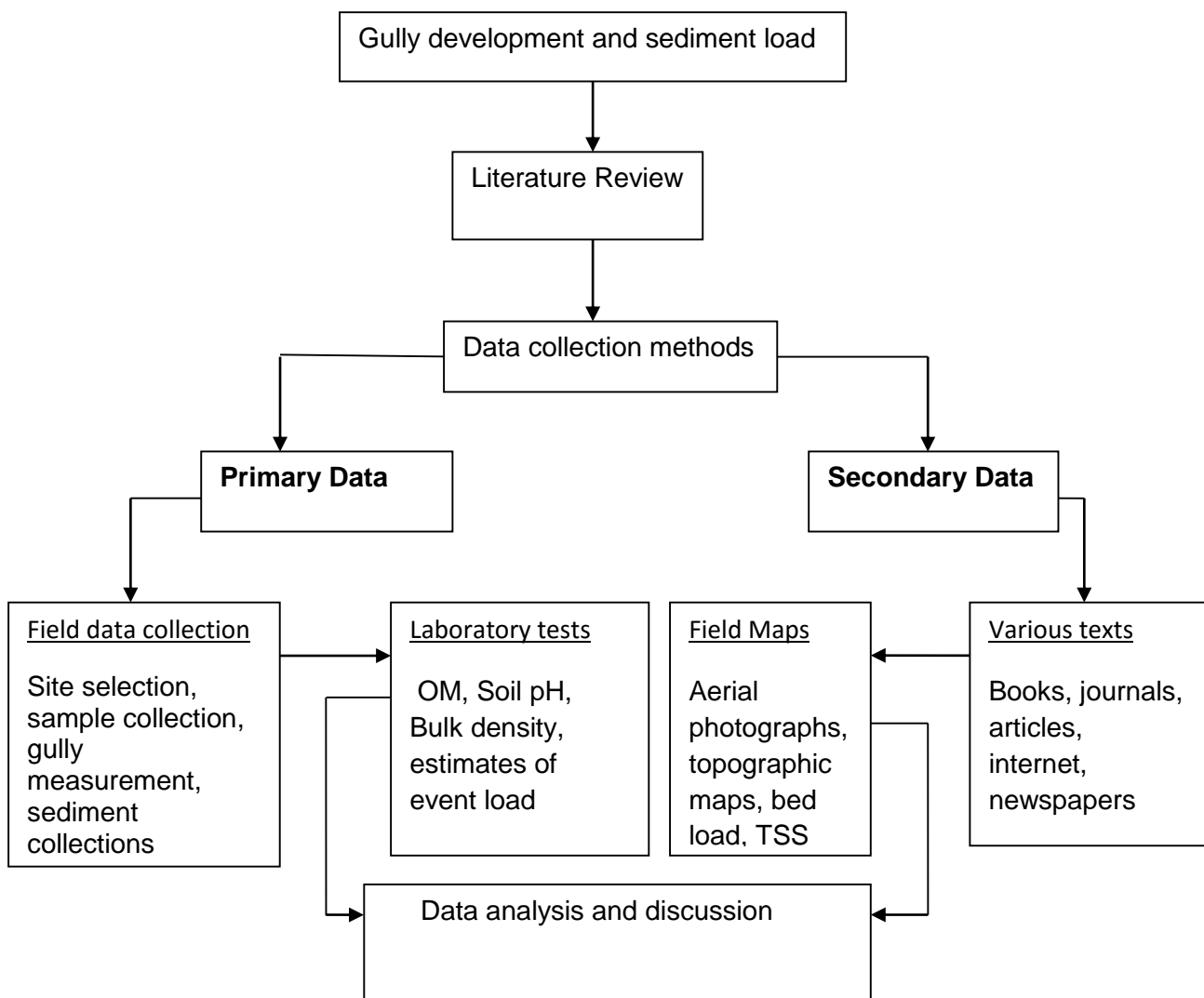


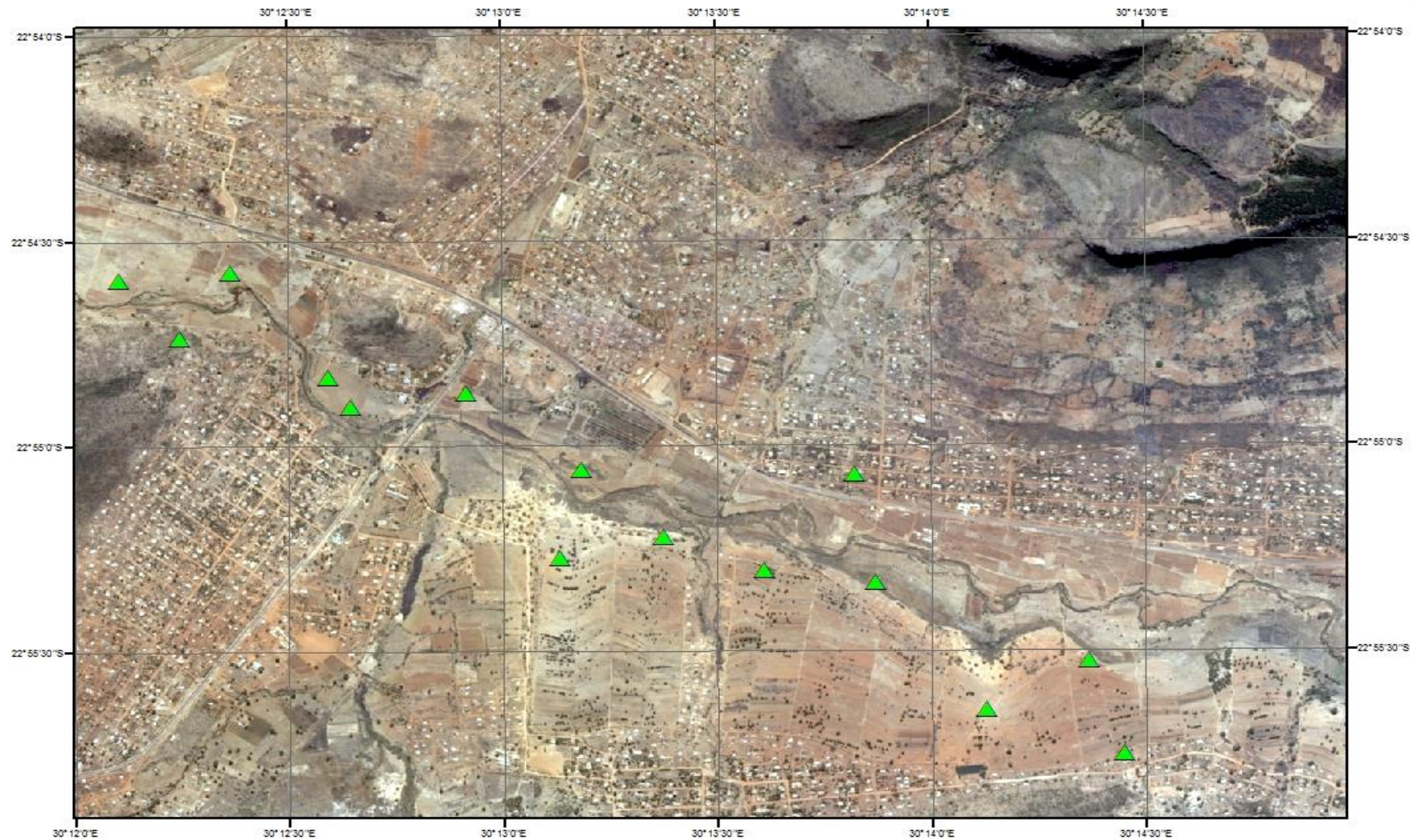
Figure 3.1 Research design

3.2.2 Sampling method and unit of analysis

Within the study area where data was collected, the area was divided into geographic coordinate system, which was used to construct transects to select the sites for data collection (Rudnicki and Meyer 2007). The coordinates (longitudes and latitudes) were separated by 30 minute interval creating transects within the study area as show in Figure 3.2. More-so, within the created transects a systematic sampling method was used to select some data collection points after every 4th interval. Random selection was used in selecting points for total suspended sediments and bed load in the Nzhelele River.

Within the selected transects 100g soil samples were collected using an auger. The samples were collected to test bulk density, soil pH, soil particle size, and organic matter. Total suspended sediment (TSS) and bed load were collected from the Nzhelele River. After

collecting the samples, they were put into plastics and wrapped in aluminum foil paper. All the samples were put in insulated boxes in order to prevent environmental conditions influencing the results.



Legend

▲ Sampling Points



Figure 3.2 Data sampling points

3.2.3 Ethical considerations

In order for the researcher to gain entry to the study area, permission to conduct this research was obtained from the Tribal authorities in Nzhelele valley governing this area, in order to avoid the violation of privacy and as a way of observing good ethical procedures. Permission sought allowed the researcher to conduct the research in all relevant areas. Sensitive environments found within this study area, such as gully sites that can collapse any time, as well as rivers, which can endanger the researcher and his assistance's lives were carefully managed during data collection exercise.

3.3 Data collection

This section has linked the data collection methods to the following specified themes

3.3.1 Familiarising with the environment

In order to start data collection and identifying areas that are significant for the study, as well as familiarising with the area, field observations was carried out. The researcher assessed the environmental condition of the area, particularly areas associated with high gully development and land use with the help of research assistance that comes from Nzhelele village and who has better knowledge of the spatial distribution of the place. The major purpose of field observation was to identify critical areas where land use has highly influenced gully development and also to identify relevant areas to consider as sampling points. Observations were also done to identify various land use activities that are still occurring within this study area, as well as some related land use change and land development that might have an impact on gully development and sediment load in Nzhelele valley. In addition to field observation, some special attention was given to areas with gully development within the drainage catchment area and various land uses.

3.3.2 Land use change of the Nzhelele valley

To assess the land use change, topographic maps from the Land Affairs with a scale of 1: 50 000 and 1: 250 000 were used to identify various land uses within Nzhelele valley. Satellite images data from SPOT 4 and 5 was collected from South African National Space Agency (SANSA), in order to assess land use change. The land-use change analysis was based on a set of two images displaying the 2007 and 2012 time frames. The images were divided into two time frames within a period of 5 years as follows; 2007 to 2012.

The characteristics of the collected images and sources were digitized, Geo-referenced, processed and analysed using ArcGIS software 10.2. Due to differing contrast levels the

2001 and 2012 images were cross-referenced with other topographic representations. A systematic supervised analysis was carried out using fieldwork as a control, in order to consistently integrate images from different sources (Rezenstein and Karneili 2011). All the interpretive work will be carried out by the same operator to minimise possible interpretation errors.

The second step involved analysing the land cover classification of Nzhelele valley. Visual image interpretation of the satellite images was carried out using the digital image processing software, ArcMap 10.2. This was used for processing, analysing and integrating spatial data available to attain the research objectives. Digital image classification using the supervised approach with the true colour composite of RGB band was carried out on the satellite images. Ground control points of five points per area were cross-checked using Trimble GPS to get their coordinates and determine the present category of land usage. Different image enhancements were used to ensure a good visual interpretation of the satellite images.

3.3.3 Role of human activities on land degradation

In order to analyse the role of human activities on land degradation, soil samples of 100g each was collected from selected sites in order to analyse the soil structure. The physical properties (grain size composition and bulk density) and the chemical properties (organic matter (OM) and soil pH) were analysed. All the analyses were done in triplicates and the average value was taken. The underlying principle for the selection of soil quality indicators were the detection of long-term cultivation impact on soil properties (Panwar *et al.*, 2011).

- **Bulk density**

In order to find the compactness of the soil, a steel ring, with a 4.4cm diameter and a depth of 10cm, was used to determine the bulk density. The steel ring was hammered into the ground in 5 different locations of the selected sites of the study area. It was later removed, leaving holes left in the ground. The depth of the soil core was measured by measuring the length of the ring. The radius of the soil corer was also measured, in order to find the volume of the corer. The following equation was used to calculate the volume:

$$volume = \pi r^2 h$$

Where r = radius (cm)

h = depth (cm)

$$\pi = 3.14$$

After obtaining the volume of the collected samples, the researcher weighed the samples using the electronic scale, in order to find soil mass, which was used to find the bulk density. The following formula was used:

$$\text{Bulk density} = \frac{\text{weight (g)}}{\text{volume cm}^3}$$

Weight is the mass of the corer removed from the ground and volume is the calculated volume of the steel ring.

- **Soil particle size**

The soil particles in Nzhelele village was also analysed to determine the degradation of the soil. Five soil samples of 200g each were collected from the study sites and the soil samples were aired for two days, in order to dry it up. Soil samples were taken to the laboratory to analyse the soil particle size. Each soil sample was put in a sieve shaker where it was shaken for 15 minutes in order to separate different soil particle sizes. This allowed all the soil particles to be collected within their sieve sizes. Soil from each of the sieve that was used was weighed, in order to determine the mass from each sieve. The following formula was used to determine the soil particles:

$$\text{Soil particle size} = \frac{\text{weight of soil particles in sieve}}{\text{total weight of soil}} \times 100$$

After obtaining the soil particle percentage, the results were used to determine the soil particle size, thus allowing the soil type to be determined from the soil samples.

- **Soil organic content**

In order to determine the effects of human activities on land degradation, 5 dry soil samples of 150g each were collected from the selected sites. The samples were pre-weighed before heating them in the oven, in order to get the initial weight of the soil sample before heating. The 5 dishes, with 150g soil samples, were placed in an oven at a temperature of 110 °C and left for 16 hours overnight. This was done in order to remove soil moisture content in the soil. After heating the soil samples, they were left to cool to room temperature for an hour and weighed again to get the soil dry weight.

$$\text{Soil moisture} = \frac{\text{Wet wt} - \text{Dry wt}}{\text{Wet}} \times 100$$

The samples were later placed into an oven at a temperature of 450°C for 4 hours. This was done to ensure that all organic matter is incinerated, and it will then be left to cool for two hours after heating the soil samples. The burned soil was weighed to get the total weight of the soil. The figures will be substituted into the following equation:

Mass of organic matter = $\frac{\text{weight loss on burning}}{\text{weight of dry soil before burning}} \times 100 = (\% \text{ of organic matter by weight of dry soil})$

- **Soil pH**

Soil sample of 100g from 5 different sites were collected. The samples were later taken to the laboratory where they were sieved in order to remove some twigs and leaves. Soil sample of 10g was collected from the 100g sample from each sample where it was weighed and placed into a beaker. The 5 samples were put into an oven for 24 hours at a temperature of 110 degrees Celsius. This was done to in order to burn up all the organic matter which could influence the soil pH. The pH meter by Jenway was calibrated over the appropriate range using the standard buffers. The 5 soil samples were scooped into 5 different paper cups where 10ml of distilled water was added to each sample. The samples were mixed and stirred vigorously for 15 seconds. They were left to stand for 30 minutes. The soil pH was later placed in the slurry, swirled carefully to read the soil pH.

3.3.4 Relationship between gully development and land use

To determine the relationship between land uses and gully development, three basic approaches proposed by Morgan (1993) were used. The three approaches are, namely survey of informed opinion, survey of loss of original soil profile, and mapping of erosion features using aerial photographs or satellite imagery. These surveys specifically targeted changes and the extent of gully erosion in the Nzhelele area.

A survey on the history gully development in the area was carried out with the help from the local people in order to find informed opinions. Information about the type of land use activities that were practiced before gullies developed and during the development within that area was collected using short semi structured interviews from the local people in the Nzhelele Valley. In addition, with the help of people living around the area, some input on the location of these gullies was collected.

For the survey of loss of original soil profile, a pit exposing a vertical face across and appropriate depth of the biggest gully depth, was dug to determine loss of original soil profile. After digging the pit, the sides of the pit was cleaned to remove all the loose material

that were disturbed during the digging process and this allowed visibility of different soil layers. The exposed vertical face was examined, starting from the down layer going upwards, to identify significant changes in properties. The boundaries between layers were marked on the faces of the pit, and the layers were identified and described.

A detailed survey of soil erosion was carried in the field, at the pre-selected areas or points, to give the extent and severity of erosion. Semi-detailed surveys were carried out from aerial photographs imagery. Aerial photographs showing different areas of different types of soil erosion at different levels of severity were taken for use in the survey. Satellite images at 1: 10 000 scales was used to identify homogeneous landscape areas. Each area was visited in the field to determine its constituent erosion types and severity grading.

3.3.5 Relationship between land use and sediment load

To determine the relationship between land use and sediment load, measurements from the Nzhelele River were taken three times before rainfall to get the actual water flow. Three different sites along the Nzhelele River were selected, in order to collect data. The two sites were selected based on land use activities near or adjacent to the river and one was adjacent to the forest where no land use activities are prevailing. The latter acted as a control. Measurements of the amount of total suspended sediment (TSS), discharge and bed load were taken. Monitoring of the river levels was done on a regular basis, in order to check on the water level of the river flow before and during the rainfall period. On the sites where samples were collected, a staff plate was installed to monitor and measure the river water level before and during rainfall. Samples were collected within a period of two minute interval, but these depended on the stream flow and the bed load movement.

The total suspended sediment was measured using a DH-48 sampling device, and where applicable, otherwise grab samples were taken. The DH-48 samples were collected in the center of the channel in a vertical integrated manner. The discharge measurement was taken using an impeller type flow meter along an extended transect type. Collection of TSS at different levels of discharge helped to obtain the discharge curve.

The bed load samples were collected using a Helly-Smith bed load sampling device. If the stream bottom and bed load movement is visible, the estimates for the representative widths were assigned for each sample. Samples were collected within a period of two minutes, but these depended on the stream flow and the bed load movement.

The data collected was taken to the laboratory, and each sample had sodium hexametaphosphate applied to it to keep sediment particles from flocculating. Samples were

filtered using a vacuum pump, a 63 µm sand break filter, Millipore AP40 coarse filter (2.4-6 µm). All the filters, except the sand break, were dried for 2 hours at 100°C in an oven. They were cooled for 15 minutes after drying and reweighed for post filter weights. Bed load samples were dried in oven bags at 120°C for 24 hours and later cooled for 2 hours. They were weighed to attain their total mass in grams

- **Land use Analysis**

To conduct the land use-sediment load for Nzhelele village, the sub-catchment areas for sampling was calculated. Google Earth was used to calculate the total watershed drainage area and percentage of land use practice per sub-catchment. The Google Earth images (2.5m spatial resolution) were used to extract catchment characteristics such as catchment area, drainage lengths. Digital land use/cover type maps dated 2012 were also used. Using the catchment areas and seasonal loads, a sediment load static model was formed to identify which land use practices was producing higher sediment load in Nzhelele village. The following equation illustrates the basics of this model;

- **Predicted load**

$$L_i = \sum (K_j, A_{j,i} - \Delta S + L_{i-1})$$

- L_i is predicted load on the site (i) or catchment ($i=1..3$)
- K_j is sediment load coefficient for the (j) land use practice ($j= 1-3$)
- $A_{j,i}$ is the area of the (j) land use practice permitting to the river
- ΔS Is the change in storage for the (i) river ($+\Delta S$ net deposition and $-\Delta S$ net scoar for the read above the (i) river).
- L_{i-1} is the load at the previous catchment

3.4 Data analysis

A supervised method was used to analyse satellite images for land use type and land use change. Satellite correction for radiometric and geometric errors was done. Corrections were done using visual image interpretation. Supervised classification was done due to familiarisation of the study area with training sites of land use types. The training sites were adopted for maximum likelihood classification to produce land use map of the area.

Analysis of variance (ANOVA) was used to analyse the different soil characteristics. It was used to analyse variation in characteristic of soil (bulk density, soil particle size, organic matter, soil pH) in different location of the study area and to compare and identify significance difference in these areas. The Pearson correlation coefficient was also used to

analyse the correlation between soil moisture and soil organic content. Data analysis was done through the use of the SPSS and Microsoft Excel.

Descriptive statistics was also used to analyse different measurements of gully depth. This involved quantitative description of the main features of collected data and summarizing the basic outcome from data processing. Statistical correlation method was used to analyse the relationship between land use type and gully depth. The land use type and the size of gully acted as variables. The two variables helped to indicate whether the relationship is positive correlated or negative correlated. This also helped to determine how strong the relationship between land use type and gully size is.

CHAPTER 4: DATA PRESENTATION AND ANALYSIS OF RESULTS

4.1 Introduction

This chapter focuses on the presentation and discussion of data obtained from the field work. Field work techniques were used to elicit data of land use such as survey, observations, soil sample collection and gully measurements which were done to achieve the study objectives. Experimental processes such as soil incineration, soil pH test and soil particle measurements were also done to provide data necessary to establish the aim of the study. GIS techniques were used to identify the spatial extent and severity of gully development in riparian land use. This chapter is organised into major themes which include; influence of human activities on land degradation, gully development in different land use and relationship between land use and sediment load. Therefore the discussions will particularly focus on these major themes.

4.1 Different land use and Spatial pattern changes

4.1.1 Different land use categories description in Nzhelele Valley

Aerial photograph shown in Figure 4.1 indicating different land use types in the Nzhelele River Valley. The area constitutes mainly of residential areas, roads, agricultural area and forest area. Nzhelele area is located within a valley with a high population which relays on agriculture practice for their basic day to day lives.



0.45 0.225 0 0.45 Kilometers

Figure 4.1 Aerial photograph with different land uses

The following are the major land use types that are found within the Nzhelele Valley characterising the spatial distribution pattern

- **Settlement area**

Settlement pattern in the periphery areas are dispersed with no uniformity creating bigger open spaces in-between settlements. They are separated by small informal dust roads which have been created by people and or domestic animals. Mostly houses that are located within the study area are far away from the Nzhelele River. Residential houses located within the CBD area are well organised into linear patterns. Roads that are built in between residential area are well tarred with some clear organisation.

- **Forest area**

Denser vegetation is visible especially within the mountainous area and along the river line. Vegetation becomes less dense near residential settlement suggesting a sign of high land use activity in the area. High population settlement areas have little vegetation cover. Forest area is very limited and prominently dominant far away from human dominant areas such as mountains and inaccessible parts of the Valley.

- **Roads**

There are a number of different roads that are found within this area. Tarred road found along the area is located in between the settlement area linking the whole area. Other tarred roads that are within residential areas are mainly found within the CBD area within developed smaller communities. Most of these roads are informal and are created by local people. They link each other from one house to the other and are not planned. They only exist within the dominant unplanned settlement.

- **Crop land**

Farming is a highly dominant land use practise in the Nzhelele riparian zone. The agricultural practise is extremely dominant along the river. A vast amount of land has been occupied by agricultural fields that run all the way from the top part of the river going down as illustrated in Figure 4.1. Most of the fields are owned by subsistence farmers who rely heavily on rainfall for water supply. Land for agricultural purposes is very vital to the community as a result it is the second highest land use practise after residential area.

- **Bare open area**

Open areas are not dominant within the study area. These open bare areas are usually located close to the settlement area and they bare land uncovered with vegetation. They are mostly located in very few places but are highly visible and more vulnerable to gully development. These open spaces are as a result of abandoned fields and or houses due to migration. However some of the open areas are used mainly as open play ground by local people and church gathering in some cases.

- **Business Centre**

The business centre with the study area are very small but highly organised. The centre provides a number of services such as banking, shopping and transport. The centre has a high sphere of influence which stretches to a number of kilometres attracting most villages that surrounds it. The settlement patterns that are around the business centres are organised and well planned. Most of the areas are paved within the business centre which results in high runoff resulting soil erosion.

4.1.2 Change detection for the study period (2007-2012)

The map algebra raster calculator was used for change detection analysis to produce raster change classification. Furthermore, the percentage of the difference was calculated from the output raster layer attribute table. The difference in results was considered statistically significant when the confidence interval was greater than 5% (0.05). For the purpose of the study, image for 2007 was regarded as land use pattern before change and image 2012 was regarded as image showing changes that took place after a 5 year interval as shown in Figure 4.2 and Figure 4.3.

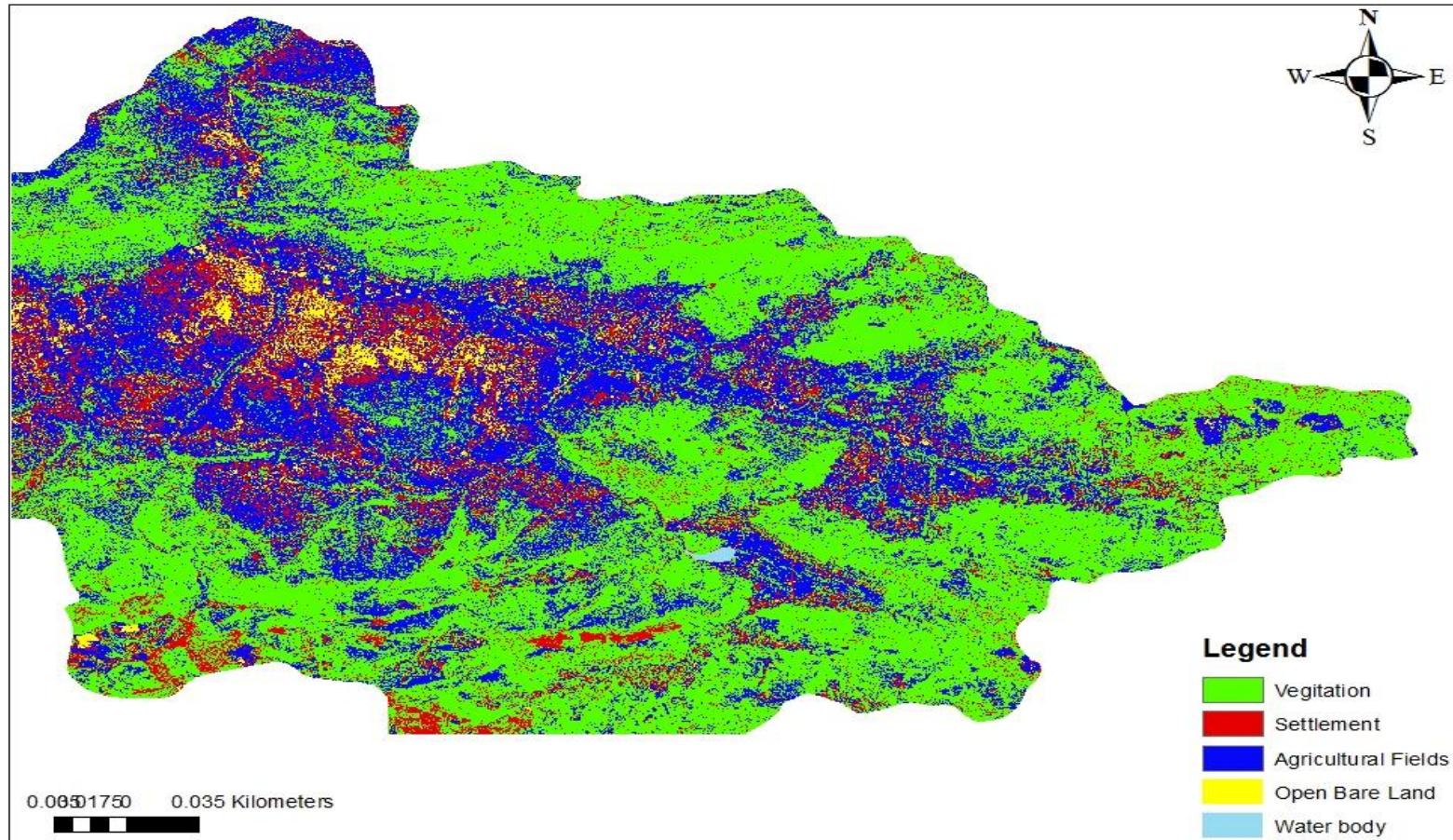


Figure 4.2 Land use classification pattern of the study area in 2007

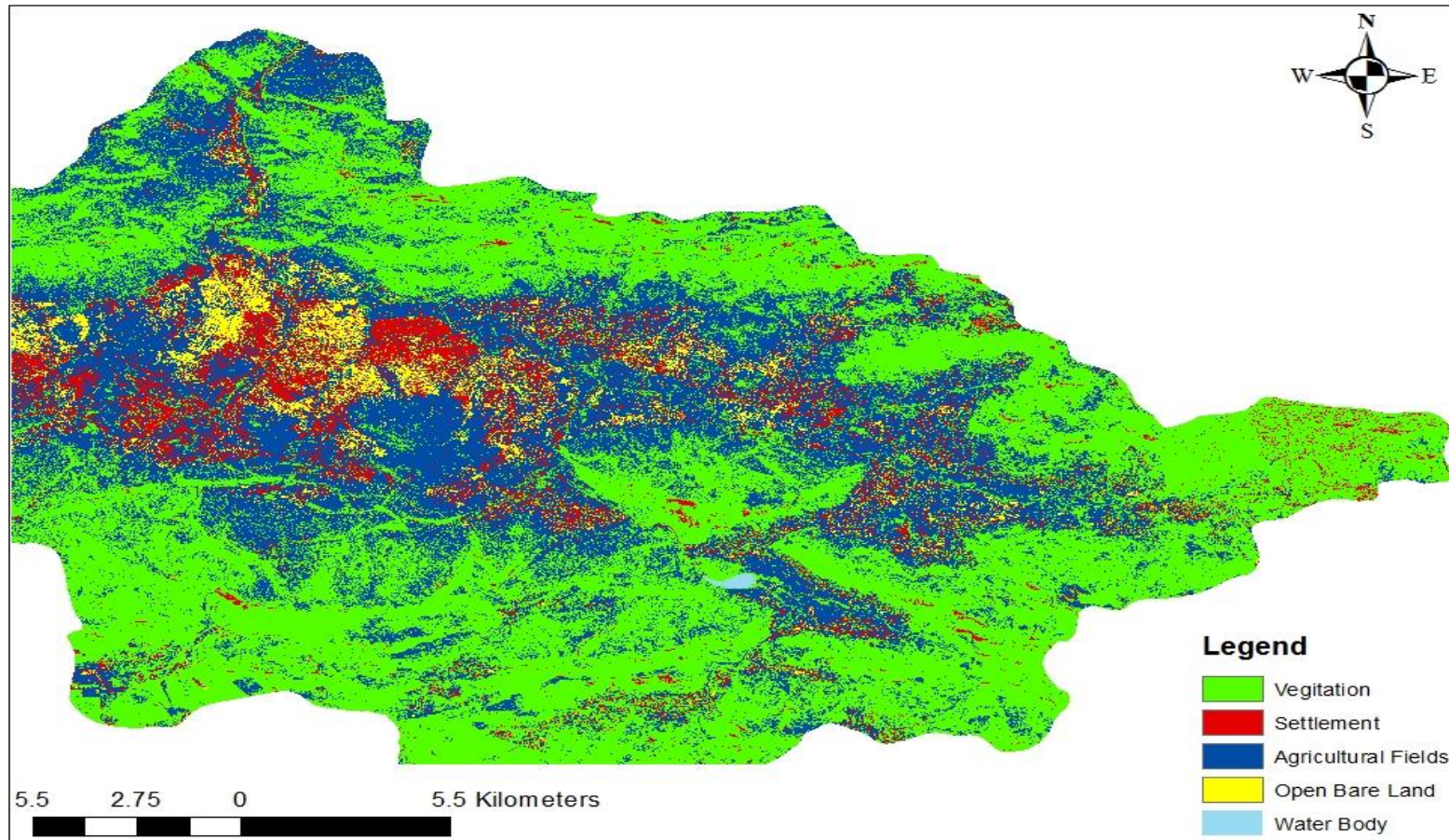


Figure 4.3 Land use classification pattern of the study area in 2012

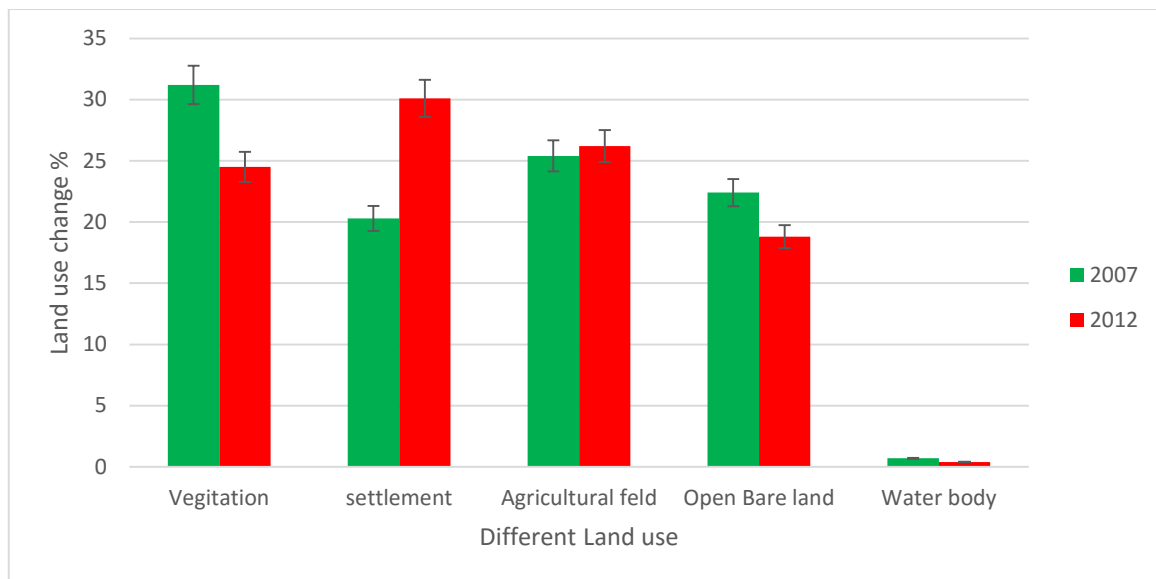


Figure 4.4 Land use/land cover for 2007 and 2012

The Kappa coefficient of supervised classified images which is 0.87 indicates that the classification method substantially captured the dynamics of land use and land cover of the area of interest in the Nzhelele River Valley. Slight changes in open bare land cover (3.9 %) are observed from 2007 to 2012 as illustrated in Figure 4.4. However, Water body had the lowest value change (0.3 %) with settlement showing the largest land use change from 10.3 to 39.8. The highest increase in land use change was observed in settlement (9.8%). This illustrate an increase in land use within the Nzhelele River Valley. Slight increase (0.8%) was observed within the agricultural area from 2007 to 2012. However, there was a decrease in vegetation cover from 31.2 % in 2007 to 24.5 % in 2012 as illustrated in Figure 4.4. This illustrates an increase in land use activities increasing the vulnerability of gully development.

4.2 Influence of human activities on land degradation

4.2.1 Bulk density

Spatial variation of bulk density analysis was made using the One-way Analysis of Variance (ANOVA). The analysis showed a very significant variation ($p \leq 0.0031$) of bulk density among all sites. The Site 1 and site 2 had more or less measurements of average bulk density of 1.3g/cm^3 and 1.4 g/cm^3 respectively with a mean difference of $\pm 0.1\text{ g/cm}^3$. Bulk density showed a spatial homogeneity in site 4 and 5 of the Nzhelele Valley which is related to the growth of grass and trees as shown in Figure 4.4. It has its highest values in site 3 (Figure 4.4) which was influenced by roads and construction of building. In addition, bulk density showed a significant variation between the site 2 and site 3 (Figure 4.4) with a mean difference of $\pm 0.2\text{ g/cm}^3$ showing significant variation ($p \leq 0.05$). The significant variation ($p \leq 0.01$) was observed between site 3 and site 4 with a mean difference of $\pm 0.4\text{g/cm}^3$.

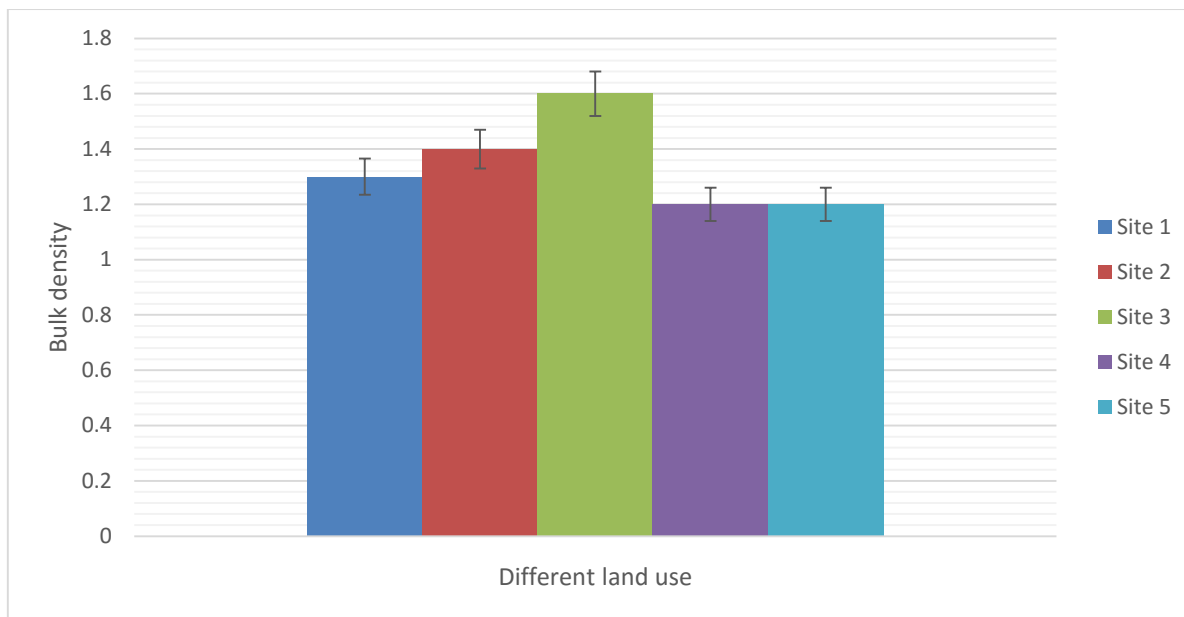


Figure 4.5 Mean bulk density for different land use

Based on the analysis made the mean soil bulk density of the study area is 1.3g/cm^3 . Within site 4 and 5 as shown in Figure 4.5 results indicates low bulk density of 1.2g/cm^3 and 1.2g/cm^3 respectively which is highly desirable for plant growth. However within site 3 there is high bulk density of 1.6g/cm^3 giving an indication of human influence in the area as most activities such as house and road construction increases bulk density, reducing pore space in soil. As the density increases, pore spaces decrease as well as the amount of water and air.

4.2.2 Soil particle size

Figure 4.6 illustrates soil particles sizes from five different locations which are classified into different soil types. Analysis made using the one way ANOVA indicated extreme significant variation ($p \leq 0.0001$) on soil types from different sites. From the selected sites, site 1 and 3 has more or less similar characteristics of soil particle sizes. They exhibit a high percentage of clay and silt soil particles that are above 6% and have a mean difference of ± 5.275 resulting in a significant variation ($p \leq 0.05$). These two locations have soil particle size that contain a higher proportion of medium to sand soil particles that is above 40% as shown in Figure 4.6. Clay-sized particles are highly related to aggregation by rearrangement and flocculation (Bronic and Lal, 2005).

Figure 4.6 shows general soil particle sizes patterns for all the selected locations in the Nzhelele River Valley. It illustrates the pattern of different soil particles sizes and how the structures differ from each other.

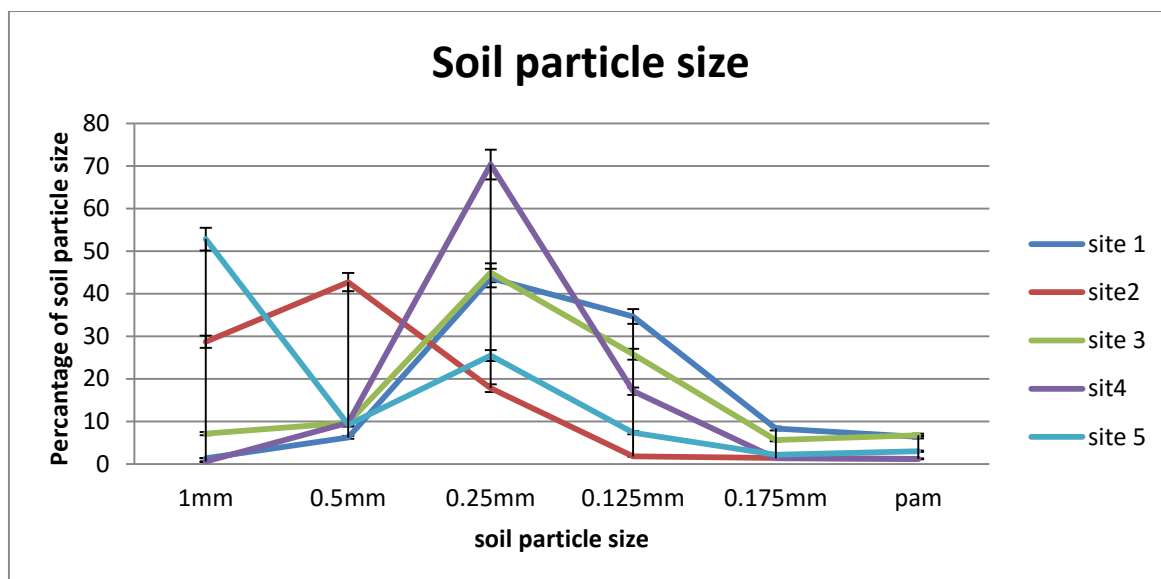


Figure 4.6 Mean soil particle size for different land use

From the analysis made using the one way ANOVA analysis a comparison between site 1 and site 2 indicate high difference between the two groups as shown in Figure 4.6, with a mean difference of ± 36.465 . Furthermore a significant variation ($p \leq 0.001$) is shown of soil particles between the two sites. From the analysis, site 5 shows soil with high amount of coarse sand particles (52.8 %) as shown in Figure 4.6. The soil shows some low percentage of clay silt soil particles (2 %) with more coarse-medium sand (25 %), making the soil more coarse sandy soil. In comparison of site 2 and site 4, both locations exhibit soil characteristics that have different particle size distribution as shown in Figure 4.6 with a mean difference of ± 50.274 giving a significant variation ($p \leq 0.001$). Site 2 has a high amount of coarse sand particles (29 %) whereas site 4 has the least coarse sand particles of 0.5%. Site 4 contains medium sand soil particles (70 %) with fine sand particles (17 %) as illustrated in Figure 4.6.

4.2.3 Soil organic content

Organic matter contributes to productivity through its effect on physical, chemical and biological properties of the soil. Different land use activities increase or decrease the levels of organic matter in soil over time. Properties such as soil structure and moisture holding capacity are highly influenced by organic matter affecting the susceptibility of soil erosion (Wenming *et al.*, 2014).

Table 4.1 below shows the amount of soil organic content extracted from the soil samples after the soil moisture content was removed from the soil samples.

Table 4.1 Soil organic matter content

	No. of Samples	Minimum (g)	Maximum (g)	Mean (g)	%
site1	3	1.50	1.56	1.5300	1
site2	3	3.49	3.55	3.5200	2.4
site3	3	1.61	1.69	1.6500	1.1
site4	3	5.84	5.86	5.8500	4.2
site5	3	4.02	4.08	4.0533	2.8
Valid N (listwise)	3				

From the analysis made using the One-way ANOVA the results indicate extreme significant variation ($p \leq 0.0001$) among all sites. From the analysis made within the Nzhelele riparian land use zone an average of 2.3% of the organic matter is indicated, signifying a relatively low amount of organic matter in the soil. Site 1 (1%) and site 3 (1.1 %) has more or less similar amount of organic matter as shown in Table 4.1. There is a mean difference of $\pm 0.1g$ between the two sites with a significant variation ($p \leq 0.01$). The two sites have also the least amount of organic matter showing some high significant susceptibility of the areas to erosion and development of gullies. Site 4 has the highest average organic matter (4 %) as shown in the Table 4.1. Site 2 and site 5 has a mean difference of ± 0.533 indicating a significant variation ($p \leq 0.001$). This shows a lower percentage of organic matter owing to different land use type within the area. Generally the whole area has low percentage of organic matter that might have been attributed by different land use types over time which has resulted in higher rate of soil erosion and development of gullies.

4.2.4 Soil pH

The analysis made using the One-way ANOVA among all sites indicates extreme significant variation ($p \leq 0.000184$) in soil pH. A comparison of soil pH from different locations, site 1 and site 3 indicates variance of ± 0.13 . Site 3 indicated a strong acid pH of the soil whereas site 1 shows a moderate soil pH. However, both site 1 and 3 range within the acidic soil pH in which many plants thrive to adapt. Site 4 and 5 has a variance of ± 1.1 and ± 1.3 respectively with a pH that is within the neutral range. On the other hand, site 4 has an ultimate neutral soil pH (7.34) which is ranging within the standard scale of 6.6 to 7.3. Site 5 has a soil pH (7.64) which is slightly alkaline soil, falling within the range of 7.4 and 7.8. Site

2 indicates a different soil pH that is very high (9.84) above all the sampled soils. The soil pH of site 2 indicate very strong alkaline. Figure 4.7 illustrates different soil pH from the five different sites:

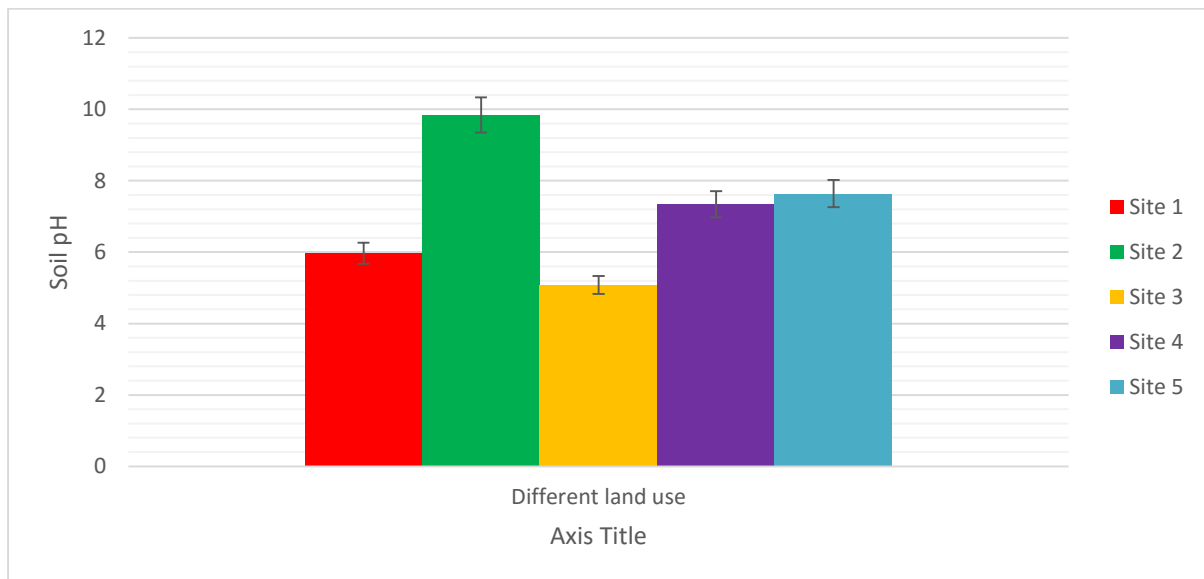


Figure 4.7 Soil pH for different land use

At Site 3, the soil has high resemblance of being acidic soil (5.08) which is normally low pH. Both Site 1 (5.97) and Site 3 (5.08) has a low soil pH that damages the roots of plants causes plants to have smaller, less durable roots, damaging tips of the roots resulting in further restriction of growth. However the acidic soil within Site 1 and Site 3 on another note reduces the number of most micro fauna as well as affecting the survival of rhizobium and persistence. In strongly acidic soils, the associated toxicity may lead to the decrease of plant cover leaving the soil more vulnerable to erosion by water and wind (Jien and Wang 2013). The low pH (5.08) in soil may also result in structural decline as a result of reduced microorganisms and organic matter, bringing susceptibility to erosion under high rainfall events and agricultural disturbances.

4.2.5 Land use activities and land degradation

Clearly, soil characteristics are very important in controlling and determining the resistance of soil by the force exerted by overland flow (Gyssels *et al.*, 2005). Nogueras *et al.*, (2000) showed the importance of above ground biomass and plant roots in concentrated flow zones for reducing gully development risk. Correlation analysis was done to find the relation between different variables. From the analysis results illustrates low a negative correlation (-0.3) between bulk density and soil pH. However, a positive correlation analysis (0.5) between organic matter and soil pH of was observed. This illustrates a relationship between

organic matter and soil pH towards land degradation. Furthermore a strong negative correlation (-0.6) was observed between soil organic matter and bulk density.

Figure 4.8 illustrates the relationship between soil moisture content and organic matter. It demonstrates the interaction between the two variables and how they relate in different land uses.

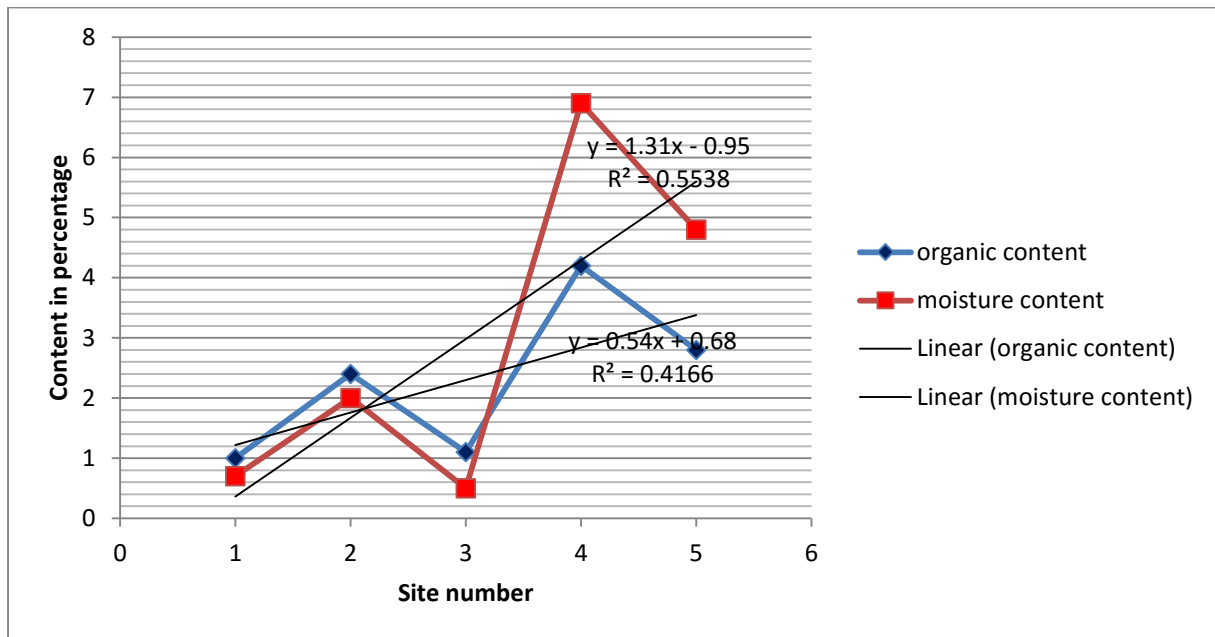


Figure 4.8 Relationship between soil moisture content and organic matter content

Statistical analysis was done using the Pearson correlation coefficient between organic matter and soil moisture content was calculated. Figure 4.8 illustrate a positive significant relationship of soil moisture with a correlation coefficient $R^2 = 0.4$. The results indicated that there is a high correlation ($r = 0.96$) between organic matter soil moisture content. This also indicates a linear relationship between the 2 variables. Based on the analysis made using ANOVA a significant variation ($p \leq 0.6$) was observed. However there is a difference in pattern on the relationship between organic content and moisture content among site 1, 2, 3 with site 4 and 5 as illustrated in Figure 4.8. Site 1, 2 and 3 has more organic matter than soil moisture content whereas site 4 and 5 has more soil moisture than organic content. This illustrates a change in soil type in site 4 and 5 resulting in change in soil moisture content within the selected sites. A change in the relationship between soil moisture and organic content within different sites indicates instability of some soils which is likely to cause vulnerability of soil erosion.

4.3 Gully development in different land use

4.3.1 Surveying of gully development in the Nzhelele riparian zone

A survey was conducted on the areas with gully development within the Nzhelele riparian zone. The purpose of the survey was to obtain specific location and causes of gully development within the riparian land use. Of the 60 locals, 47 responded to the survey. The device of a relatively short face to face questions to solicit scientific opinion on the topic as complex as gully development may appear of limited utility. However, there is an authority inherent in the massed, yet independent responses of a sizable number of active and renowned community members that perhaps cannot be obtained in any other way. However, a GPS monitor was also used to detect the geographical coordinates of the specific locations where the gullies were located from the aerial photographs that were used.

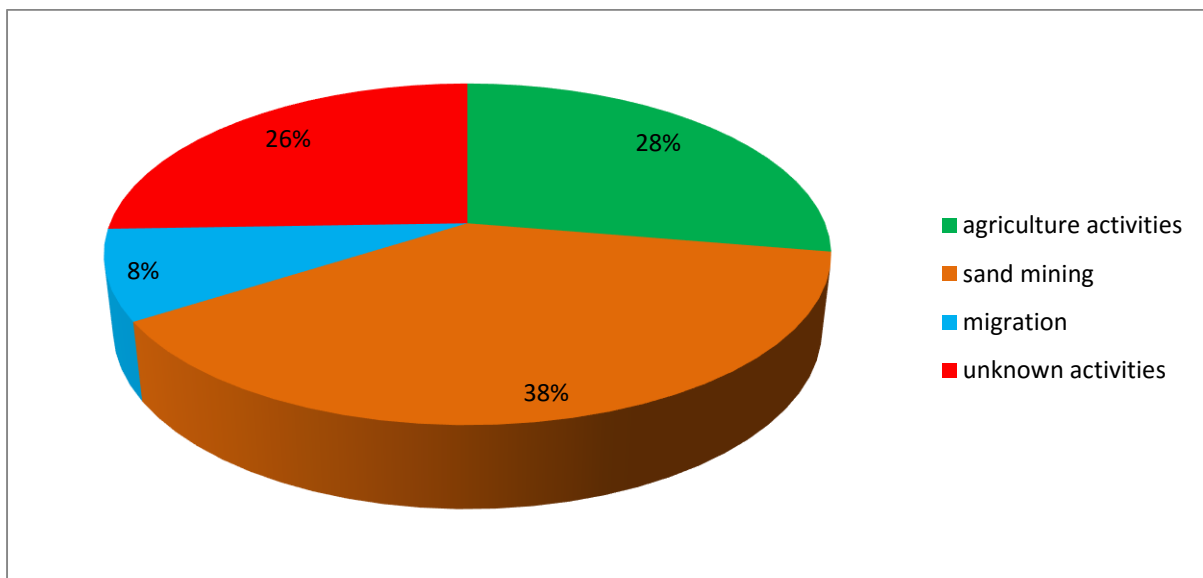


Figure 4.9 Factors influencing the development of gullies

Sand mining has damaged the original steady state of river and has scoured the upper edge of the sand pit causing transversal erosion (Zhuo-fu *et al.*, 2012). Based on the statistical analysis made, sand mine activities is the highest human activity (38.3 %) causing gully formation (Figure 4.9). This was also supported through some observation made as most of the gully developing areas indicated evidence of sand mining. Conferring to the analysis made from the interviews, 27.7% of the gullies have developed due to different agricultural activities within the Nzhelele River Valley. However, 8.5% of the gullies have developed due to migration of people from one area to another. The movement of people from one place to another has left the abandoned land bared and highly vulnerable to erosion which has caused the development of gullies. On the other hand 25.5% of the gullies that have

developed have likely been caused by unknown factors. These were different factors that most people would not have understood the reason behind the development since there could not provide some explanation.

4.3.2 Internal structure of gully

Figure 4.1.0 illustrates the vertical face of a gully with the highest gully depth from the survey that was carried out. The gully is situated within the agricultural area in the riparian zone of the Nzhelele river valley.

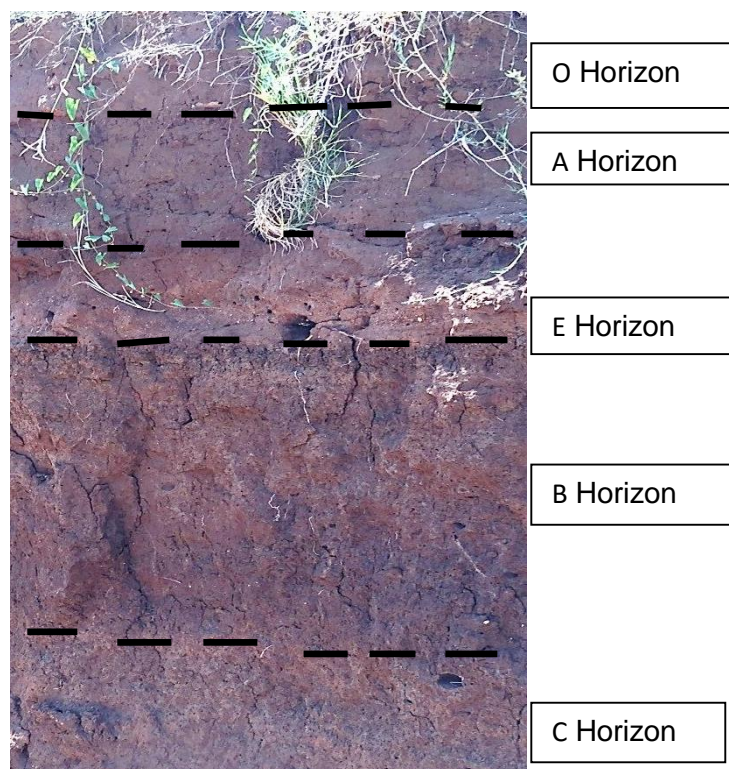


Figure 4.1.0 Vertical face of gully

The vertical surface of the gully shown in Figure 4.1.0 is 4.7 meters deep and has been stratigraphically grouped into 5 horizons with reference to the soil profile. From the bottom lower horizon “C”, the soil is categorised as dark brown homogenous silty clay loam. Horizon “B” demonstrates an alternation of fine laminated bands, intermixed layers of silty clay in dull greyish brown colour. A brownish colour in horizon “B” looks more or less similar to horizon “C” as illustrated in Figure 4.1.0. Within this horizon, each thin small sediment layer begins with greyish to brownish silty material at the top, grading downwards into a reddish brownish clayey material at the bottom. In “E” horizon, reddish-light brownish sediment is observed which was homogenized by heavy ploughing. Some of the slightly wavy layers are very silty

and less than 1mm thick while others contains more sand. Such alternating and continuous deposits of course to fine sediments often occurs during recurrent sheet flow with flow deposition rates of fine material in sink or on gentle slope position (Dotterweich *et al.*, 2012). The horizon “A” is about 45 cm thick and it has dark brown colour with some homogenous characteristics. It has humic material mixed which is likely to have been caused by ploughing. In the upper part in horizon “O”, which is the current top soil, platy aggregates are occurring. This is most likely caused by compressed soil during ploughing.

4.3.3 Spatial distribution of gully development

SPOT 5 satellite image of the study area was divided into 3 segments as Figure 4.1.1, 4.1.2, and 4.1.3 in order to show the spatial distribution of gullies around the Nzhelele Valley. Data obtained in Figures 4.1.1, 4.1.2 and 4.1.3 illustrate aerial photographs 2012; showing gullies that were identified and indicated within the study area. Gully erosion distributions are reconstructed by analysing aerial photographs of the Nzhelele River Valley taken in 2012. The distributions of the phenomena are mapped and quantified using Arc GIS 10.2. Gullies identified by aerial photographs shown in Figures 4.1.1, 4.1.2 and 4.1.3 have been acknowledged when carrying out ground truthing exercise.

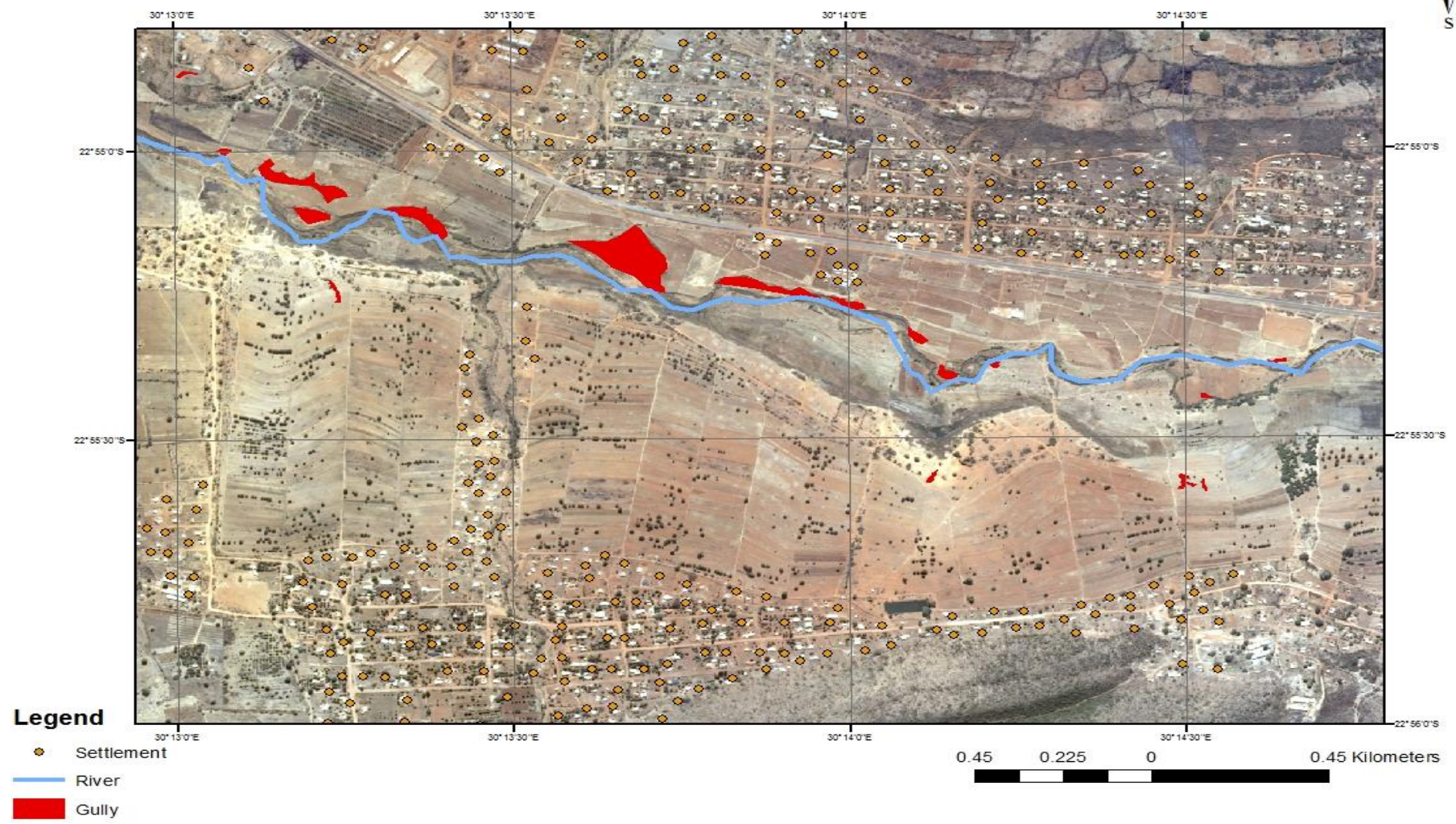


Figure 4.1.1 Areas with gully development



Legend

- ◆ Settlement
- River
- Gully

0.45 0.225 0 0.45 Kilometers

Figure 4.1.2 Areas with gully development

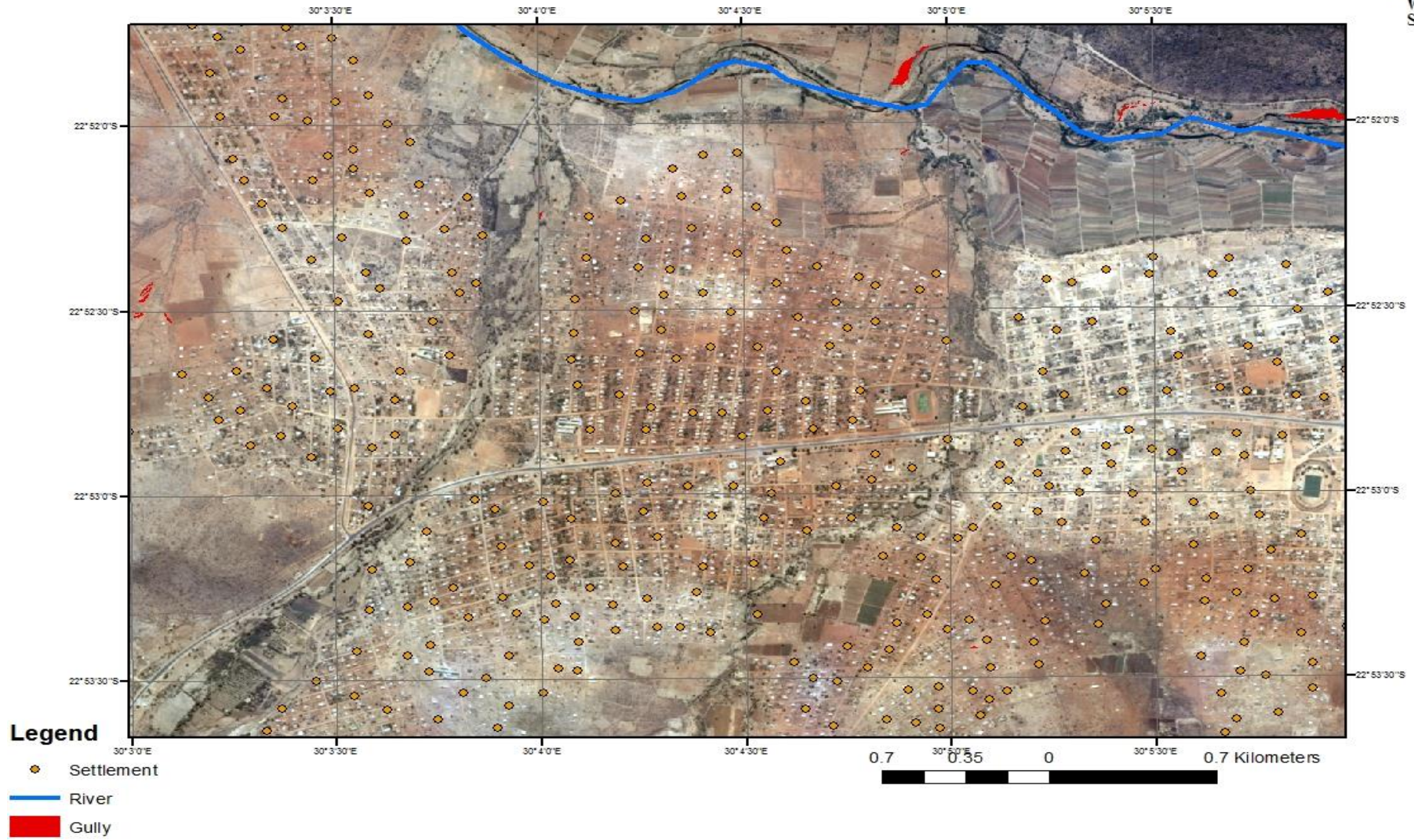


Figure 4.1.3 Areas with gully development

Spatial distribution of gullies within the study area differs from place to place due to difference in land use activities. Figure 4.1.1 shows SPOT image covering some local communities within the Nzhelele river valley which are Tshikombani, Dopeni, Mandala and Fondwe. The magnitude of gully development within this area is high and severe along the Nzhelele River as shown in Figure 4.1.1. Most of the gullies are encroaching towards the agricultural areas and to the main road as illustrated in Figure 4.1.1.

Additionally, Figure 4.1.2 shows local communities which include Matanda, Ha-Raliphaswa, Dzanani, Ha-Mandiwana and Ha-Mphaila. Gullies are sparsely distributed within the agricultural areas as indicated in Figure 4.1.2. However, there are generally small gullies and rill erosion occurring within this area. On the other hand, the gullies regardless of generally being small, they are highly dominant along the river and sloppy areas within residential settlement.

Figure 4.1.3 shows local communities which are Tshikikinini, Mabirimisa and Makhado. Data obtained in shows that more gullies are occurring along the river channel adjacent to agricultural fields as illustrated in Figure 4.1.3. However, despite these gullies found along the river lines, they are also located along within sloppy areas where runoff rate is relatively high within the settlement area as shown in the upper part of Figure 4.1.3. The resolution of the aerial photographs was observed to be very low however; most gullies were able to be identified.

4.3.4 Land use and gully development

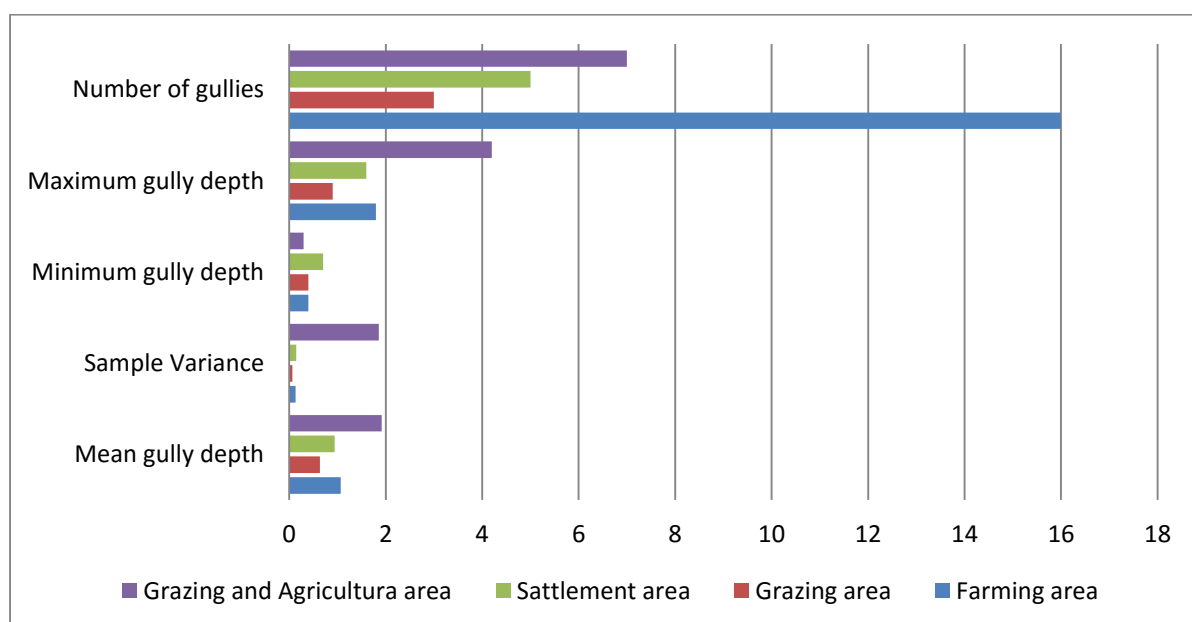


Figure 4.1.4 Statistical relationship between land use and gully development

A total of 31 gullies were identified within the riparian zone of the Nzhelele Valley. From the analysis made using descriptive statistics, farming area has the highest gully developing area which is higher than in any other land use activity with a mean gully depth of 1.06 meters. The area has a sample variance of ± 0.13 with the highest gully depth of 1.8 meters and the minimum depth of 0.4 meters. Grazing and agricultural area is the second highest gully developing area with a mean depth of 1.9 meters. Furthermore the area has the highest sample variance and gully depth of ± 1.8 . The lowest minimum gully depth of 0.3 meters was observed within settlement area as illustrated in Figure 4.1.4. The grazing area has the lowest number of gully development as compared to other areas. Its minimum gully depth is 0.4 meters and its maximum depth is 0.9 meters. The sample variance of the grazing area is ± 0.06 with a mean depth of 0.6 meters. The highest gully depth in the settlement area is 1.6 meters with a sample variance of ± 0.14 . A minimum gully depth (0.7 meters) was observed in the settlement area as illustrated (Figure 4.1.4).

4.4 Relationship between land use and sediment load

4.4.1 Total suspended sediment and bed load

The following results were collected during six rainy days from the different sites in the Nzhelele River. Data collected was measured with an accuracy of approximately plus or minus eight mg/l. The rainfall events were not covered in great detail due to number of research assistance that were available during data collection. It was very difficult to get samples from the study sites due to low of expertise from the research assistance and the environmental set up of other places where data was collected. From the 3 different sites, a total of 18 samples of total suspended sediments were collected. The data collected from these 3 different Sites shows the highest recording of total suspended sediment (TSS) of 6.3 g with the lowest recording of 0.1 g. Different measurements of the sediments was observed with some surrounding environment influencing the measurements. Figure 4.1.5 illustrate three different location where total suspended sediments and bed load data was collected with the Nzhelele River.



Bridge

Forest area

Agricultural area

Figure 4.1.5 Different land use areas

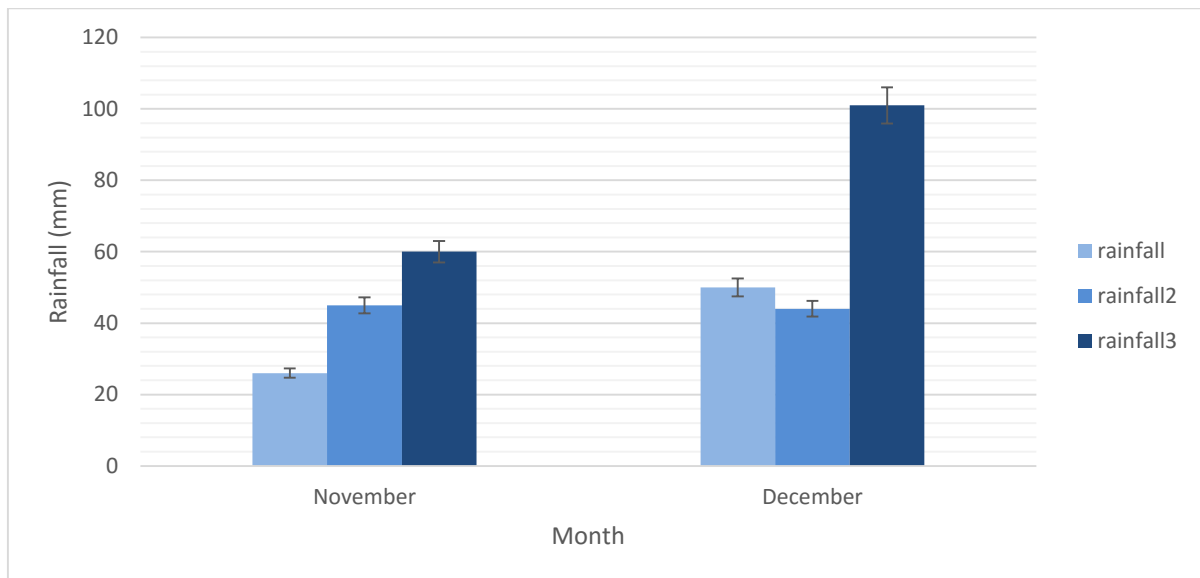


Figure 4.1.6 Total precipitations recorded for each day of data collection

Figure 4.1.6 illustrates the total rainfall for each month of the three days in Nzhelele River Valley when data was collected. The month of December 2014 received the highest rainfall of 101mm with a sum total of 195mm for the 3 collection days. The minimum rainfall was recorded in November 2014 of 26mm. The highest average rainfall was experienced in December 2014 of 65 mm. November had a sum total of 111mm of rainfall recorded in this 3 collection days with an average rainfall of 37mm.

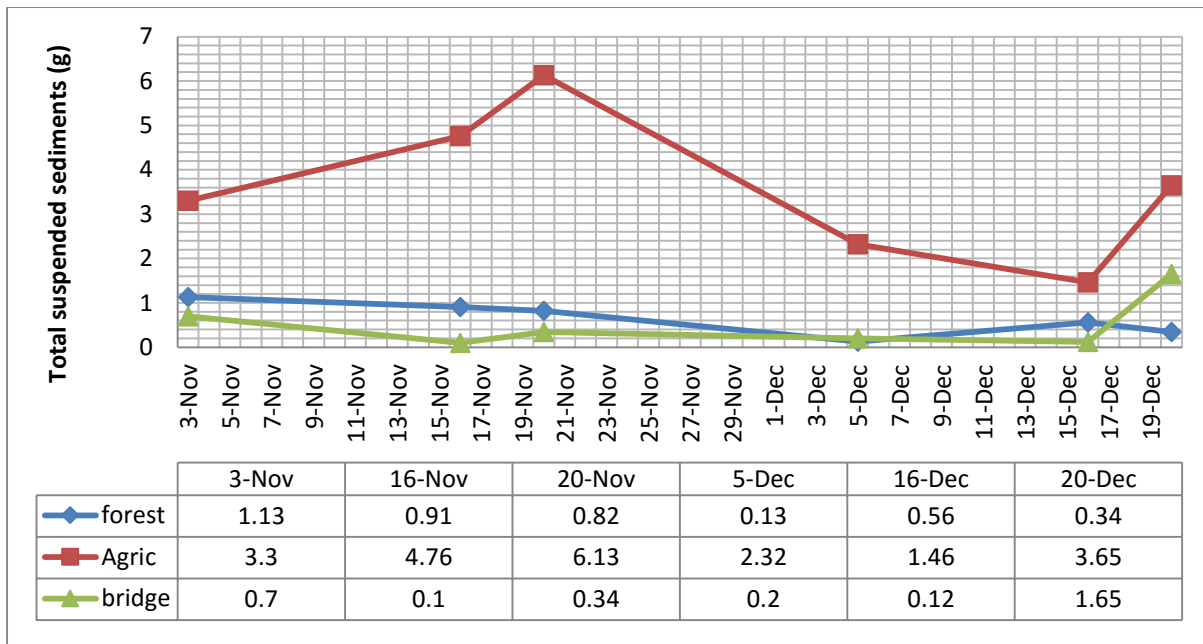


Figure 4.1.7 Trend in suspended sediments collection

The highest total suspended sediments (TSS) are recorded in November of 6.13 g in the agricultural area. The sediments are generally higher within the agricultural area than any other area with a total of 4.3 g total sediments collected. The forest area had a more constant trend of suspended sediment ranging from 0.1 g up to 1.1 g as illustrated in Figure 4.1.7. The area around the bridge had a down ward trend of sediments that were collected which range between 0.7 g going down wards to 0.12 g and then having a sudden pick of 1.65 g in the last day of data collection.

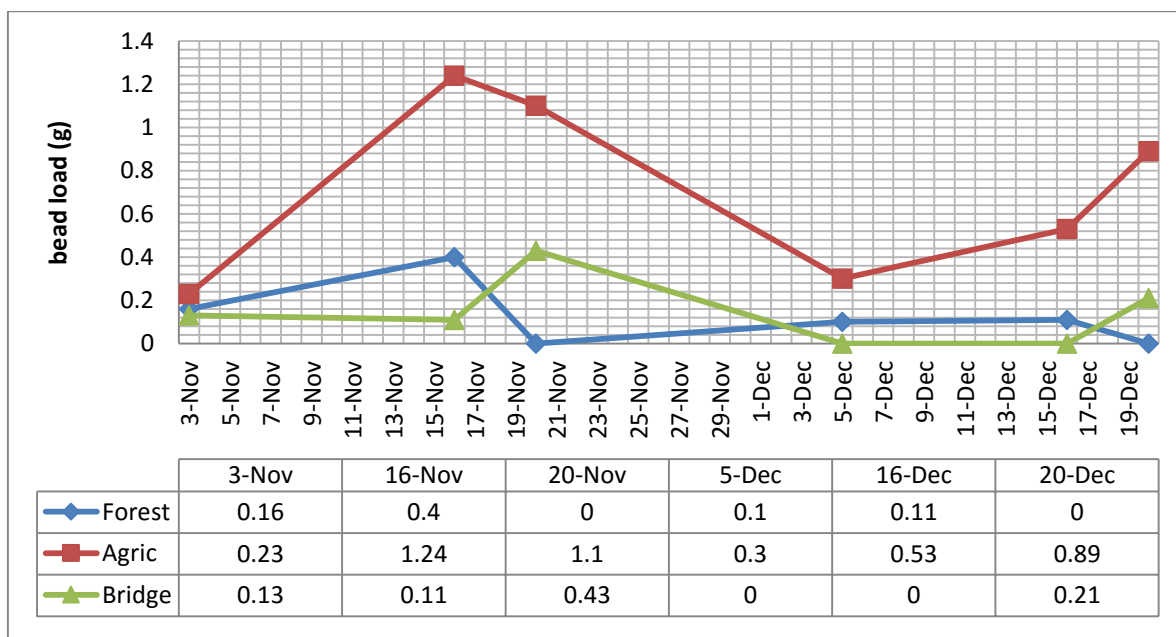


Figure 4.1.8 Trend in bed load collection

The agricultural area had the highest amount of bed load of 1.24 g than any other area. Its lowest recording is 0.3 g. The forest area had the lowest recording of 0.1 with some area having no record. The bridge had are high bed load record of 0.4 g and the lowest of 0.11 g.

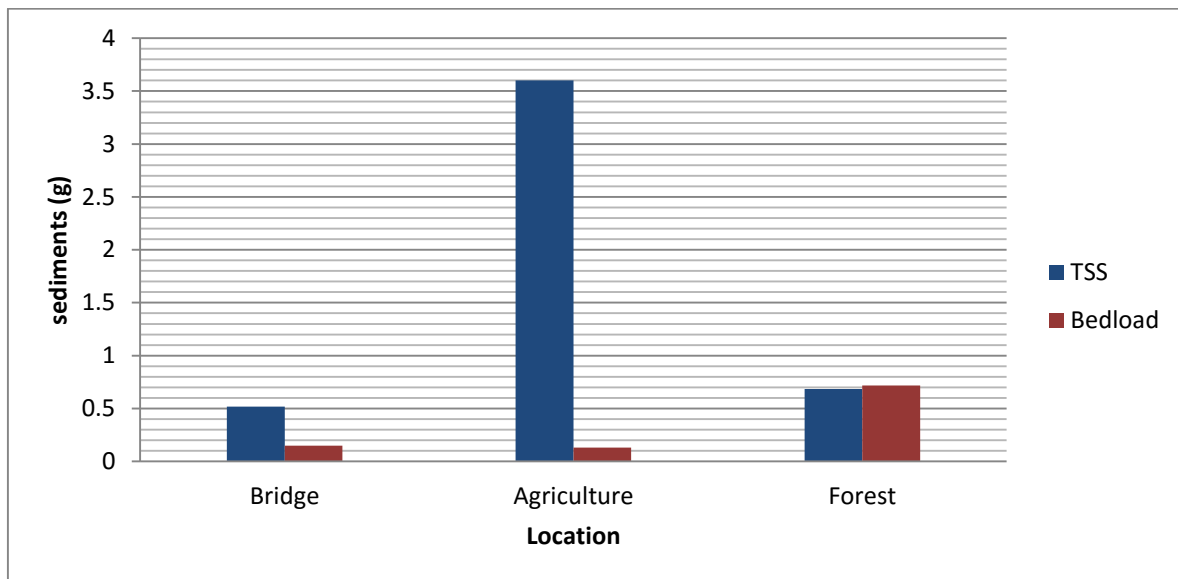


Figure 4.1.9 Total averages for Suspended sediments and bed load

From the results obtained, high total suspended sediments were measured along the agricultural area with an average of 3.60 g. The forest area had mean suspended sediment of 0.68 g slightly higher than that of the bridge which was 0.51 g as illustrated in Figure 4.2.0. Concentrations of suspended sediments were extremely high along the agricultural area. A decrease in total suspended sediments was measured at the forest area, which might have been caused by the gradient of the surrounding area in connection with the area. The load decrease gradually along the bridge with the least amount recorded among all sites. This might possibly be a response to the surrounding area with little disturbance. However, there is a mean slight difference between the bridge site and the forest site of 0.11 g.

Overall, bed load is generally higher along the agricultural area with a mean value of 0.71 g which correlates the suspended sediments due to presumably some surrounding activities and the gradient of the slope. The bed load of the forest area had a considerable decrease as compared to suspended sediments with a mean value of 0.12 g (Figure 4.1.9). There is a minor increase in bed load within the bridge as compared to the forest area with a mean value of 0.15 g.

4.4.2 Six event data totals

There is a significant increase at the agricultural area in both suspended sediments and bed load of 21.62 g and 4.29 respectively. The total discharge within the agricultural area (29905m³) is much lower than the other two sites. The total suspended sediment is higher within the forest site 0.78 g greater at the bridge site. At the forest area the total amount of total suspended sediments decreased due to low discharge caused by surrounding location with slow water movement into the stream. However, the concentrations of bed load is much higher within the agricultural areas as compared to bridge with a difference of 3.41 g. There is a remarkable decrease in bed load within the bridge when looking at the amount of discharge comparing it to other sites. This is totally the opposite when comparing with the forest area where the discharge is high with no amount of bed load recorded.

4.4.3 Land use analyses

Table 4.2 summarises the total area for each sub-catchment based on the monitoring site as well as the total drainage area for each site. Figure 4.2.0 illustrates a map of the sub-catchments indicating data collection points.

Table 4.2 Sub-Catchment and total drainage area for each monitoring site.

Sampling Site	Sub-catchment Area (km ²)	Drainage area (km ²)
Bridge	6.75km ²	6.75km ²
Agriculture	3.49km ²	3.49km ²
forest	1.02km ²	1.02km ²

The values of ΔS are estimated grams per square km that were deposited in each of the three sites. However, not every site used this value. The mean absolute error for TSS for static model was 27% and 11% for bed load. For both TSS the estimated k for the crop area is significantly higher than both the bridge and forest site. The bed load k-value for the bridge site was set at 0 and k^0 was set to 3g/km. this was done to ensure that all bed load will be deposited in selected areas. A small value of 0.24g/cm was estimated for bridge and forest site.

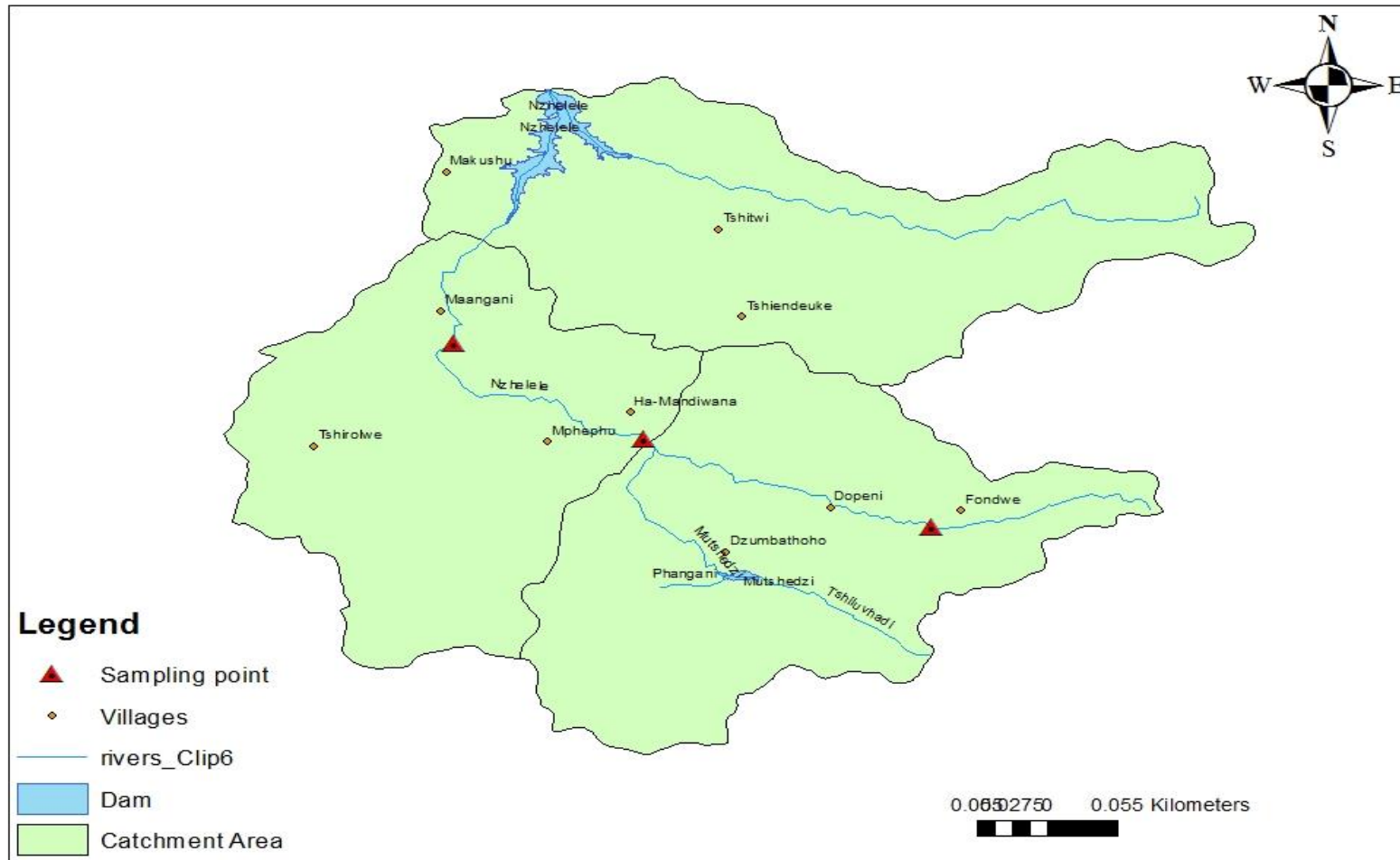


Figure 4.2.0 Sub-catchment areas

The sub-catchment area within which the bridge site is located had a bigger area covered with Agricultural fields of 80%. It also included a smaller portion of settlement of 20%. The agricultural area site consisted of 39.8% grazing area and 60.2% agricultural area. However within the forest site the area was mainly dominated with forest with no any other activity involved. Throughout the whole study area the agricultural area and the grazing area increased downstream as settlement pattern increased.

From the results the total suspended sediments are significantly higher with the agricultural area with a total of 55.3% of predicted TSS. However, there is lower amount of TSS within the Bridge area and forest area with a total of 15.8% and 28.9% respectively. Within the agricultural area the total percentage of bed load is 53.8% higher than any other area. It shows a high rate of land use activities within the area suggesting high probability levels of soil erosion. Nevertheless, along the bridge and forest the amount of bed load show very little significance of sediment load displaying a total of 15.3% and 30.9% respectively.

CHAPTER 5: DISCUSSION OF THE FINDINGS

5.1 Introduction

This chapter focuses on the discussion of output data analysed. The discussions of the findings were arranged into different themes that are related to the findings. The discussions relate to: variation in land use and land cover, control of human action on land use, gully development and factors affecting gully development, perpendicular expression of gully depth, and land use and sediment load. The discussions presented in this chapter are the summaries of large quantity of data presented in data analysis of this document.

5.2 Spatial variations in land use and land cover

Vegetation area makes up the one of the largest percentage of the study area with 31.2% in 2007 and 24.5 % in 2012. It can be said that significant changes took place in land usage patterns between 2007 and 2012. Based on the results, there are huge changes in the period 2007-2012 of vegetation cover which was reduced by 22%. Ranzi *et al.*, (2012) observed similar results in their study that forest area decreased up to 35% in the past decades, with a 20% of forested area converted into rice fields and agricultural crop area. It is significant to note that the biggest portion of land use change was highly visible within the vegetation cover area with a decrease of 6.7% from 2007 to 2012. A decrease in vegetation cover signifies an increase in another land use activities which is taking up more land for different land use. Boori *et al.*, 2015 had similar evidence where forest area decrease by 11% between 1991 and 2001 and pasture and agriculture increased by 4.44% and 5.17% respectively. Rawat and Kumar, (2015) also observed that 11.91% vegetation cover has been converted into agricultural area in their study.

Some significant changes were also indicated within the residential areas on land use land cover change. With reference to Figure 4.2, residential areas increased from 20.3 % to 30.1%. This illustrates the encroachment of residential expansion into the bare open area. Since there has been a decrease in the open bare area, residential area has expanded by 9.8% within a period of 5 years. Rawat and Kumar, (2015) observed similar results in Almora district in India that the built up area increased from 2.72km in 1990 to 12.20km in 2010 accounting to 3.55%.

Farming area had a slight increase in land use land cover. There is an increase of 0.8 % from 2007 to 2012 of farming area. The significant increase in farming area could also lead to increase in land degradation. The irrational way of land use such as conversion from woodland to farmland has led to land degradation (Boori *et al.*, 2015). However, on the other

note increase in farming area increases the economic livelihood of the local people in the Nzhelele valley. The slight expansion of farming area from 25.4 % in 2007 to 26.2 % in 2012 creates high vulnerability of land to environmental problems especially when land use activities are not practised in a more effective and efficient manner (Figure 4.4).

5.3 Control of human exploitation on land use

Site 3 indicates a high significant value of bulk density of 1.6 g/cm^3 higher than any other sites in the study area (Figure 4.5). High bulk density in site 3 highly influences the compaction level of the soil. These results correspond to the findings of (Gerke and Hierold, 2012) where maximum bulk density were observed with sand percentage of 70-75% decreased porosity with increased confining pressure due to compaction. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect the soil from soil erosion (Arshard *et al.*, 1996). However site 4 and site 5 has bulk density of 1.2 g/cm^3 and 1.2 g/cm^3 respectively. They indicate some spatial homogeneity of bulk density which is highly desirable for plant growth. Batey (1995) suggested that the mechanical load pressure from agricultural machineries could have affected the bulk density especially in the soil underneath the plough layer.

The effects of soil erosion on soil properties depend on soil types, soil fertility, soil and residue management, and degree of erosion among other factors (Lal 1999). The extent and severity of different soil particles size determine different consequences for soil erosion and infiltration rate. Data showed that the Nzhelele soil presented more resistance to the surface, especially in site 1 and 3 which led to a very high infiltration rate and a consequently low runoff rate (Figure 4.6). Site 1 has high silt soil particles that are highly vulnerable to soil erosion. This is supported by Gumiere *et al.*, (2009) in which he said that silt soil has a high erodability. Well structure clay and sandy loam soils, only fine particles are easily eroded in flow without rainfall (Asadi *et al.*, 2007). Site 4 is highly associated with fine soil particle which is highly vulnerable to surface runoff. Similar results were found by Heng *et al.* (2011), which suggest that in different soil texture high proportion of fine particles dominate runoff.

The organic matter content from the study indicates significant lower levels of organic matter with an average of 2.3%. This illustrates higher exploitation of the land by different land use and high vulnerability of the area to erosion processes. Some scholars have demonstrated that excessive tillage and fertilization can seriously degrade the soil structure (Elliot, 1986 and Zhang *et al.*, 2007). Site 1 and 3 had the least amount of organic matter which explains the intensity of land use within that area (Table 4.1). Further Mingxiang *et al.*, (2015) added that infertile soils are highly vulnerable to soil erosion which leads to the development of

gullies. However Maiga-Yaleu *et al.*, (2015) oppose this as he finds that nutrient losses signify correlation with slope length which in turn leads to erosion. Garcia Rodeja and Gil-Sotres (1997) suggest that rainfall characteristic could however correlate with nutrient losses such as rainfall intensity and storm duration. Furthermore, Ahearn *et al.*, (2004) indicates that precipitation was not a sufficient factor to efficiently flush nutrients from soil in longer fields.

Our results demonstrate that site 1 and 3 have acidic soils of 5.97 and 5.08 respectively that might induce serious degradation to soil (Figure 4.7). The formation of acidic soil is likely to have been caused by land use activities. This was supported by (Bezdicsek *et al.*, 2003) who suggested that Acidic soils is a result of removal of agricultural product from the fields, leaching of nitrogen as nitrate below the root zone, inappropriate use of nitrogenous fertilizers and build up organic matter. Further more Mingxiang *et al.*, (2015) reported that several factors, including high variability of soil disturbance by human activities is highly responsible for low soil pH level which attributes to soil degradation and rill or inter-rill erosion.

5.4 Gully development and aspects affecting their development

Data from the study elucidate that sand mining activities have significantly contributed to the development of gullies in the Nzhelele Valley based on the analysis made. Based on the statistical analysis, the sand mine activities has the highest contribution of 38% to the development of gullies which is 4 times bigger than migration factor that constitute 8% (Figure 4.9). According to Moreno *et al.*, (2014) traditional and minor mining activities such as caprock removal or sand extraction have triggered gully formation or at least favoured its development. Erosion scarp formation on beaches is known to be one of the negative consequences of beach sand mining (Mensah 1997 and Esteves *et al.*, 2002). The continuous sand mine activities has created significant number of gully development which has become dominant in some parts of the Nzhelele Valley.

Agricultural activities are also part of the contributor to the development of gullies with 25% of the gullies formed due to agricultural practise. It has some significant impact to the development of gullies within the study area with more people relying on subsistence farming in sustaining their livelihoods. This agrees to observations of Moreno *et al.*, (2014) that, intense human deforestation is likely the main cause of the Ribagorda gully development, assisted by grazing and farming. Since most of the farmers within Nzhelele Valley are subsistence farmers, agricultural practices are normally environmentally unsustainable which likely has caused the development of gully. As supported by Merten

and Minella (2013) an area of degraded agricultural activity contributes 50% of total water erosion caused by agricultural activity

However, some other unknown activities has also contributed significantly (26%) to the development of gullies in the Nzhelele Valley (Figure 4.9). These factors also have an impending contribution to the development of gullies. These causes are different and may vary based on the vulnerability of the area to erosion, time, and influencing capabilities of various activities.

5.4.1 Perpendicular expression of gully depth

Generally, cultivated soil profiles consist of multiple layers including natural soil horizons and those imposed tillage and erosion (Mingxiang *et al.*, 2015). The top layer “O” horizon (Figure 4.1.0) from the vertical analysis of the gully has dark brown colour soil mixed with organic matter. In this horizon, there is evidence of high agricultural activity of mixing and turning the soil which results in platy aggregates influencing the compaction of soil. The A horizon of the gully face is 45cm thick with some dark brown soil. This horizon also indicates some human influence of humic mixed which has been caused by ploughing. This has been supported by Dohler *et al.*, 2015 who alluded that a thin “A” horizon (<5cm) are developed in anthropogenic sediments in upslope position. Some sudden vertical underlying layers of loess, periglacial deposits are observed in “E” horizon indicates that runoff and very intensive gullyng took place at many sites in the Nzhelele catchment. The sediments located in “B” horizon have some blocky and disturbed structure which is more likely for mud-flow like deposit process (Figure 4.1.0). These features suggest that after clear cut and subsequent land use, intensive runoff took place resulting in washing away of soil.

5.5 Land use and sediment load

At this stage it is very challenging to precisely determine whether or not the suspended sediments that is measured came from adjacent land or from in stream storage. Woodward and Foster (1990) confirm this by stating that data collection at a gaging station downstream provides information on the material that is actually leaving that particular catchment but fails to detect the amount and spatial pattern of the primary erosion, deposition or storage.

Data from this study suggest that agricultural lands delivered significant sediments to the Nzhelele River, based on the three events. The TSS and bed load totals are significantly higher in areas where there are agricultural practices. The TTS load for agricultural area was 55.3% which is 2 times that of forest and 3 times that at the bridge (Table 4.12). Heathwaite *et al.*, (1990) find similar results and concluded that agricultural land use is one of the major

controls on the source of sediment transfer to streams. According to Yuan *et al.*, (2015) increasing the area covered by forest or shrubbery plantation will generally reduce sediment, while an increase in cropland would increase sediment load. The bed load was also significantly much higher within the farming area than in any other sites indicating a high supply of bed load from agricultural activities.

The natural site, forest area appeared to be a source of TSS loads in the Nzhelele River even though the supply (28.9%) is not as bigger as that at the agricultural area. However, forest land appeared to have very low significant effect on bed load (30.9%) presumably because of the nature of the environment. According to Yuan *et al.*, (2015) area covered by trees or shrubs generally reduces amount of sediment flow, whereas increasing the area of cropland increases stream flow and sediment flow.

Bridge area appeared not to deliver any significant bed load sized material (15.3%) during the event monitored. The TSS (15.8%) appeared to not be impacted and is 2 times smaller than that at the forest area. The physical crust reduces infiltration and also inhibits consequent vegetation growth which leaves soil unprotected against plash and soil erosion (Klaus *et al.*, 2014).

Heathwaite *et al.*, (1990) suggested that heavily grazed lands resulted in high suspended sediment production during the rainfall season. While the ratio of crop to grazing area for agricultural area is 3:2, grazing area makes up 39.8% of the total watershed area within the farming area. It is highly visible that the total sediment loads from grazing land use practice is significant on a larger watershed scale.

CHAPTER 6: CONCLUSION AND RECOMANDATIONS

6.1 Introduction

This chapter presents the conclusions and recommendations of the study which assesses the impacts of riparian land use on gully development and sediment load in Nzhelele River valley. The influence of land use change and gully development and its relative contribution to the predicted sediment load in the river are also evaluated and recommendations made. Conclusions are driven from the results yielded from the case study. This gives a clear picture of the problem. The recommendations in this chapter are drawn from the conclusions and this allows specific measures to be taken to solve the problem of gully development.

6.2 Conclusion

6.2.1 Change in land use and land cover

Within the riparian land use of Nzhelele River valley, it was noted that a significant land use change had occurred between 2007 and 2012. The findings of the research showed that more forest land was converted into farming area. A conversion of 14% of land within a period of 5 years indicate that there is high possibility in future that forest land will be used up to pave way for the expansion of farming land to accommodate the increase in population size.

A decrease in forest area is also shown in the study from 82% in 2007 to 60% in 2012 (Figure 4.4). The decrease of forest area illustrates the encroachment of different human activities into the forest area. Fragile ecosystem, biodiversity and vegetation are lost due to land use/cover changes in Nzhelele Valley. This however, creates a lot of environmental problems that leads to the area vulnerable to soil erosion and the development of gullies. Clearing the vegetation creates bare environment that is highly unlikely to withstand the pressure of surface runoff and soil erosion.

A decrease in forest area also resulted in an increase in residential areas by 8% within the period of 5 years. An increase in residential land use cover within the riparian zone of Nzhelele Valley also created vulnerability of the area to gully development. As some areas where residential expansion is occurring, some of the areas are fragile to erosion. Zoning and planning principles are not observed within this area. This results in highly improperly organised and distributed houses. Due to the haphazard planning associated with this area, the vulnerability of the residential area to gully development is high which will likely lead to high sediment load in the river.

6.2.2 Land degradation associated with human activities

Significant variation of bulk density was observed in different sites (Figure 4.5). The results show high bulk density in site 3 of 1.6 g/cm^3 indicating high level of human influence within the area. This is mainly influenced by different human activities such as building of house and road construction. High bulk density decrease soil porosity and lower vegetation growth increasing surface water runoff and lower infiltration rates. Site 4 and 5 shows lower levels of bulk density which indicates generally little or no human influence to the environment. Soil particle size from different sites illustrates extreme significant variation. The different soil particle sizes range from fine soils to sandy soils that are highly associated with different land use activities. Farming activities influences the type and characteristics of soil properties with time as they change size. However soil particle size alone might not show how human activities have influence their size.

Significant lower organic matter content of 1% and 1.1 % in site 1 and 3 was observed. Low amount of organic matter in farming areas is mainly influenced by continues farming without replacing the manure. This illustrates the role of human activities on land degradation. Lower levels of organic matter affects the water holding capacity of the soil which likely leads to surface runoff and soil erosion. The soil moisture content correlates to organic matter among different sites, with site 4 and 5 having the highest amount of soil moisture. High soil moisture content accelerates surface runoff and reduces the rate of infiltration. Soil pH of 5.08 and 5.97 from site 3 and site 1 respectively indicates acidic soil. Acidic soils are highly influenced by leaching of nitrogen as nitrate and the removal of agricultural products from the field. This illustrates the influence of human activity on land use which is likely to cause land degradation and rill and inter-rill erosion.

6.2.3 Sources of gully development

This study used interviews, observation and Satellite data to reconstruct the causal factors and spatial distribution of gullies in the Nzhelele River Valley. The spatial distribution and magnitude of gully development in the investigated Nzhelele riparian zone indicate that intensive gully development has taken places more in high land use zone. A few human activities (sand mining) probably caused intensive development of gullies. The development of the dense network of permanent gullies in the Nzhelele riparian zone can be associated with transformation of forest into farmland. Gully system and soil erosion in the Nzhelele valley also contribute to sediment load along the river.

This study has revealed key factors that support a better understanding of human environment interactions. It provides evidence on the interconnections between causes of

land use and soil erosion. It highlights the importance of observing and understanding the relative significance of slow processes, resulting in profile organisation. Extreme soil erosion events forced by human activities have affected the exploitability of farmland. However, it is unclear how much land has been degraded to such a degree that human activities became problematic. In Nzhelele Valley it is evident that today's human activities and possible future land use trajectories are strongly connected to the past land use challenges and soil erosion.

6.2.4 Land use and river sediment load

Data suggest that agriculture practise contribute significant proportions of total suspended sediments in Nzhelele River Valley. It is presumed that riparian corridors help to retain sediment loss from streamside agricultural areas. Agricultural reaches transported the most bed load during the rainy season that was monitored. Further work should be done to see if the load is currently coming from the adjacent areas where data is being collected. The forest and the bridge site provides very little significant load to the Nzhelele river.

Bridge site area also contributed a certain amount of suspended sediment. Its total suspended sediment is highly insignificant and adds very little to total load. The forest site area contributes a reasonable amount of TSS and bed load compared to that at the bridge site. However with the amount of rainfall observed within the period of data collection, the amount of data which was collected seems to be limited by the intensity of rainfall.

6.3 Recommendation

6.3.1 Responsiveness on best agricultural practices

All agricultural activities need to be examined and carefully executed. Scrutiny of practices should be prioritized. Community members need to be given better ways of practicing agricultural activities which do not lead to land degradation and development of gullies. The municipality should also educate the community on the best agricultural and creating a buffer zone within the Nzhelele River to avoid continuous transportation of sediments into the river. The municipality should also create some programme to educate and raise awareness on the effects of gully development as well as come up with ways to prevent gully development in the early stages of development.

6.3.2 Essential conservational consciousness

The responsibility of environmental protection lies in the hands of all those benefiting from its resources. The Municipality serving the Nzhelele Valley needs to embark on programs that address all its environmental aspects, including sand mining, improper farming and

unnecessary land degradation activities. In order for the community to address the problem of gully development, there is need to involve all local people in activities that would prevent and control of soil erosion. The awareness programmes should involve correct farming techniques, a strict adherence to soil erosion and sustainable land use formulated by the local municipality and the traditional leaders enforced by the local community members.

6.3.3 Management of riparian zones

Land owners and managers especially those adjacent to the Nzhelele River within unbuffered zones must be recommended to adopt a management plan that incorporates the use of riparian corridors and riparian grazing areas. Avoiding grazing access to local domestic animals especially in the late periods before rainfall would help to reduce the chance of bank fall during the rainy season reducing the TSS and bedload.

6.3.4 Vegetation of degraded environment

The community must also plant some water moist tolerant trees, shrubs and grasses such as *Accacia melanoxylon*, Phalans aquatic and *Pennisetum purpureum*, as well as green gold grass on gully bed. This will break the flow and velocity of water runoff, trap sediments and protect the gully beds from erosion that will avoid sediment transportation into the river. Stabilised gullies should be managed by planting of edible and exotic tree species, grass and legumes to forestall future gulling and riling. This creates a stable environment, which will grow to resist soil erosion.

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