Analysis of land use and land cover change and its impact on soil erosion in Nzhelele Valley, Limpopo Province, South Africa

By

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Submitted in partial fulfilment of the requirements for the degree in Ph.D. in Environmental Sciences, Department of Geography & Geo-Information Sciences in School of Environmental Science, University of Venda

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ABSTRACT

Globally, the rate of land use and land cover changes has affeceted the magnitude of soil eroion. Strategies to combat soil erosion can give assistance as solutions to provide food security in many agricultural areas. Although some changes are caused by natural factors, anthropogenic factors and an increase in population are major drivers of soil erosion. This study analyses land use and land cover change and its impact on soil erosion in Nzhelele Valley. To attain this goal, the objectives of this study are to classify land use and land cover change using GIS from 2005 to 2019 in Nzhelele Valley; assess the human influence of soil management strategies on soil erosion; determine the impact of soil fertility of different land use on soil erosion, and model soil erosion on different land-use areas of Nzhelele Valley. To select farmers, study used a stratified random sampling technique by dividing groups based on their villages. A systematic sampling technique was used to select 392 farmers. To collect 78 soil samples from Nzhelele Valley, the study used the Sampling Design Tool of ArcGIS 10.The study used supervised classification in Geographic Information System (GIS) to classify land use and land cover types. Semi-structured questionnaires were used to solicit data on human influence on soil management strategies on soil erosion. The study draws a systematic sample using Slovin's formula to determine the size of the sample from the Nzhelele Valley, and with a target population size of 657 farmers from the village, 398 farmers were selected for the study. The study also measured soil organic matter, soil pH, phosphorus, and nitrogen from collected soil samples to determine the impact of soil fertility on soil erosion. To collect soil samples from Nzhelele Valley, the study used the Sampling Design Tool of ArcGIS 10. The tool assisted in selecting the soil sample points within the study area and a total of 78 soil samples were collected for the study. The Soil and Water Assessment Tool (ARCSWAT) with an interface of ArcView Geographic Information System software modelled soil erosion within Nzhelele Valley. In terms of LULCC, results show that from 2005 up to 2019, forest increased significantly by 5%, agricultural land cover significant decrease by 11% from 36% to 25% land use/cover, bare land built-up land increase by 3% from 14% to 17%, as well as grassland increase by 3% from 19% to 22%. The results also show a significant correlation ($p < 0.05$) between land use management strategies and economic support systems. The physical characteristics (slope and terrace) significantly correlate ($p < 0.05$) with soil management strategies that limit soil erosion. The results illustrate significant variation ($p \leq 0.0002$) in nitrogen among different land-use classes. Significant variation was observed ($p \leq 0.0001$) in soil pH, phosphorus, and organic matter among the different land-use areas. Changes in LULC are more likely to have an effect on soil erosion in the grassland and bare land/built-up areas where infiltration is very limited. The recorded decrease in agricultural land use and an increase in forest cover are likely to reduce the impact of soil erosion. Using SWAT to model soil erosion, 26-sub basin and 301 hydrological response units were delineated. The statistical elevation of the watershed obtained a minimum elevation of 384 m, maximum elevation of 1680 m with a minimum elevation of 808.81 m. Sub basins 13, 23, and 25 demonstrated high erosion-prone classes with average sediment yield of 15.3%, 11.26%, and 11.5% respectively. The lowest sediment yield (2.1 t/ha-^{1}yr-^{1}) in the study area was observed in sub-basin 3. Overall synthesis of the findings illustrates that research into land-use changes and type of land use activities factors were key aspects in addressing soil erosion challenges. These findings vibrate strongly on the need to develop a systematic land management system that can solve unplanned land cover and land-use change. Based on the results, fostering better management investments through collaborative land management in Nzhelele Valley might improve the dissemination of information. Farmer to farmer training can improve the skills of the individual, which might allow smooth dissemination of information vital for land management. The problem of soil nutrient deficiency can be a central issue put forward to the local government, which needs to be addressed with specific sectors of the government to create a better environment for agriculture and food security especially in the marginalized community of South Africa. Sediment output based on the land use classes is potentially influenced by cropland with the study. This allows for further solutions on the type of land use activities to be narrowed to understand the levels of soil erosion based on the activities. The study findings from this area can be used for comparison to other areas with the same characteristics to gain insight into possible solutions to the challenges of soil erosion.

Keywords: *Land use; Land cover; SWAT; Latin Hypercube, and One Factor At-a-time*

DECLARATION

I Blessing Mavhuru, Student No: 11605726 declare that this Ph.D. thesis titled "*Analysis of land use and land cover change and its impact on soil erosion in Nzhelele Valley, Limpopo Province, South Africa"* submitted in partial fulfilment of Ph.D. in Environmental Sciences, Department of Geography & Geo-Information Sciences in School of Environmental Science, University of Venda, has never been submitted before to any institution. This is my work in design, and all reference materials within this thesis have been duly acknowledged.

Blessing Mavhuru 11605726

DEDICATION

To my mother

ACKNOWLEDGMENTS

I would like to take this opportunity to appreciate my Promoters Dr. N.S. Nethengwe, Professor B.D.O. Odhiambo and Dr. H. Chikoore who assisted me to finish my work. Many thanks goes to the University of Venda Higher Degrees Committee, for the financial support. I would also like to thank the National Research Foundation (NRF), for their financial support. Without them, it was not going to be an easy road, as they made sure I had all the necessary means to achieve my goal.

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$$\frac{Initial\ wt - new\ wt}{Initiak\ wt} \times 100.$$

$$n = \frac{N}{1 + N \times e^{2}}$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - P_i)*100}{\sum_{i=1}^{n}(O_i)}\right]$$

$$NSE = \frac{\sum_{i=1}^{n}(O_i - \overline{O})^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \left[\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sqrt{\sum_{i=1}^{n}(O_i - \overline{O})^2}}\right]$$

$$CC = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n}(O_i)}$$

List of Abbreviation and Acronyms

ANOVA	Analysis of Variance
ABM	Agent-Based Model ABM
ARC	Agricultural Research Council of South Africa
ARCSWAT	Soil and Water Assessment Tool with an interface of ArcView
C.A	Cellular Automata Model C.A
CAP	Common Agricultural Policy
CN	Curve Number
CFRG	Coarse Fragment Factor
CC	Correlation Coefficient
DEM	Digital Elevation Model
FRS	Forest
GIS	Geographic Information System
GD	Grassland
GPS	Global Positioning System
HRU	Hydrological Response Units
IGBP	Geosphere-Biosphere Program
ISSS	International Soil Science Society
K	Kappa
LOI	Loss on Ignition
LU/LC	Land Use and Land Cover
LH-OAT	Latin Hypercube and One factory At a Time
NSE	Nush-Sutcliffe Efficiency
N	Nitrogen

NM	New Maize Field
OM	Old Fields
SL	Shrub Land
SW	Sub-Watershed
ORD	Orchard
OM	Organic Matter
RSR	Observations Standard Deviation Ratio
P	Phosphorus
PBIAS	Percent Bias
PET	Potential Evapotranspiration
SSR	Sum of Squared Residuals
SCS	Soil Conservation Service

CHAPTER 1

1.1 Introduction

Land cover illustrates the type of physical landform which includes open bare area, water body, and forest. Land use indicates the type of activities people are using the land for. In a way, it illustrates the anthropogenic activities within a given landscape world (Poesen *et al*., 2003). Due to anthropogenic activities, soil loss accelerates due to soil erosion at a greater scale than the mechanisms meant to replace the lost soil (Amundson *et al*., 2015). Areas with high soil erosion intensities occupy large parts of areas with populations that are predominantly dependant on agriculture such as Nzhelele Valley. Soil erosion in these areas is causing problems for future agricultural and infrastructure development (Zang *et al.,* 2016).

Soil eroion is mainly dominant within small catchment areas of Nzhelele Valley. Soil erosion destroys both the physical and the chemical structure of the soil (Chen *et al*., 2016). Furthermore, it is a sign of severe land degradation, which seriously influences the surrounding agricultural areas, resulting in sediment-inducing siltation and catastrophic flooding (Vandekerckhove *et al*., 2000). To understand and predict the behavior of soil erosion, it is important to understand land-use change patterns and erosional processes over time (Li *et al.*, 2000). The rate of land-use change is determined by population pressure, environmental-economic structures of society, and the structure of soil within the land-use area. The different technological and economic advancement of different countries has become the determining factor for the susceptibility of areas to land-use change and soil erosion (McCloskey *et al*., 2016).

Soil erosion has a high occurrence in land use areas, resulting in high vulnerability to gully development. The population increase in South Africa between 1990 and 2000 brought about an increase in land use, especially in marginal rural areas (Kakembo and Rowntree 2003). With communal areas such as Nzhelele Valley population increase, in turn, resulted in land-use change and intensification of agro-pastoral land-use activities in marginal areas. Access to productive land reduces susceptibility to poverty, hence, an increase in agricultural practices and vulnerability to soil erosion (IFAD, 2008; Timmer, 2010; Dijk, 2011).

The dynamics of land use and the causes of change can be understood using land-use change models (Veldkamp and Verburg 2004). Modeling land use and environmental change to acquire a better understanding of the environmental system is very important especially in rural areas, where erosion is high and widespread (Sanchez-Lozano and

Bernal-Conesa, 2017). Land-use change models are developed to simulate the behavior of different activities and the upscaling of this behavior to relate it to changes in the land pattern (Berger, 2001; Parker *et al*., 2003). The intensive spatial increase of land use intensifies the rate of erosion and environmental degradation (Dymon, 1993; Du Plessis, 2000; Mileti, 1999 and Mamun and Amin 2000). Several approaches and tools, including Geo-Information Sciences (GIS), are employed to appraise land-use change, to develop solutions against soil erosion (Mararakanye and Sumner 2017; Bergonse and Reis 2016).

In conceptualising the impacts of land use on soil erosivity, the study intends to align an understanding of land use and land-use change with soil erosion through the ARCSWAT model. The approach will analyse the dynamics of land use and soil erosion, as well as land-use activities and the factors that determine the relationship between the community and land use. All these factors require a critical assessment to come up with a new paradigm to address the comprehensive problems of land use and soil erosion. Therefore, this study will add to the body of knowledge by understanding land dynamics and how they affect soil erosion in Nzhelele village in Limpopo Province of South Africa.

1.2 Background to the Study

Soil erosion in Nzhelele Valley has led to negative and detrimental effects on infrastructure especially in areas closer to the drainage system where there is loose soil compaction. Nzhelele Valley is located within the semi-arid zone where land is highly susceptible to soil erosion. Across the globe, soil erosion is mainly caused by land-use change, which ranges from rangeland to cropland, overgrazing especially in drought periods, and the destruction of ecosystems due to road construction and forest clearance (Slade, 1994). Increase in soil erosion in Nzhelele Valley has had detrimental effects to the agricultural sector. In most instance, this has increased the levels of vulnerability of the food security in Nzhelele Valley. Studies have illustrated that compaction caused by agricultural machinery increases soil erosion, reducing the food production (Alaoui *et al*., 2018; Schaffer *et al*., 2008; Stoessel *et al*., 2018). Similarly, this has also been the case in Nzhelele Valley whereby intensive use of machinery and all-year-round agricultural practices resulting in soil erosion.

To add on, heavy rainfall causes a negative effect on soil erion (Barrows 2014 and Mullan *et al*., 2012). Nzhelele Valley is mainly dominant in different land use areas such as on farmlands, settlement areas, grassland and forestry areas, which have contributed to soil erosion. The agricultural development and transformation through farmland reclamation in Nzhelele Valley have drastically changed the types of land use, soil fertility and this has resulted in extensive soil erosion problems. The heavy reliance of the communal people on agriculture in Nzhelele for their basic livelihoods has resulted in a negative impact on soil fertility, transforming different land use into agricultural practices, and increase rates of soil erosion. Transformation of land use influences soil infiltration, generating high runoff rates and in turn soil erosivity (Mao *et al*., 2008).

1.3 Problem Statement

Within Nzhelele Valley, soil eroision have resulted in siltation, causing a threat especially on aquatic life forms and disturbance of ecosystem. As a result of siltation, the tributaries within Nzhelele Valley have gradually decreased at the same time threatening the existence of aquatic habitat. The water quality of the inhabitant aquatic environments is affected by soil erosion (Vilayvong *et al*., 2016).

In some parts of the Nzhelele Valley, soil erosion threatened the sustainability of communal cattle and the cultural use of water bodies. Livestock has experienced leg injuries due to the development of gullies; they accidentally fall into the gullies. Land degradation in Nzhelele Valley has also increased susceptibility to gully development and results in negative socio-economic impacts, such as low yield and less dependence on agriculture. Sand mining activities have also caused severe negative impacts on agricultural land and forest on flood plains (Dacosta and Mathada 2017).

Within Nzhelele Valley, challenges of soil erosion have excluded some major anthropogenic factors especially on land use and soil erosion and yet they are part of the most influencial factors. There is need to evaluate the impact of human factors especially carrying capacity within land use and land cover.

An examination of existing literature on land use indicates that research on modelling land use change and soil erosion on livelihoods is limited, especially in the Vhembe District Municipality, and in South Africa. Only few studies have modelled land use change in relation to soil erosion such as out loop River Catchment, Northern Cape, South Africa (Mengistu *et al*., 2019, and Dacosta and Mathada 2017).

1.4 Research Aim and Specific Objectives

1.4.1 Research Aim

The main aim of this study was to analyse land use and cover change impacts on soil erosion in Nzhelele Valley, Limpopo Province, South Africa.

1.4.2. Specific Objectives

The specific objectives of the study are to:

- Classify land use and land cover change using GIS from 2005 to 2019 in Nzhelele Valley;
- Assess the influence of soil management strategies on soil erosion
- Determine the impact of soil fertility of different land use on soil erosion
- Model soil erosion on land use areas of Nzhelele Valley.

1.4.3 Research Question

- Has the land use and land cover change using GIS from 2005 to 2019 in Nzhelele Valley?
- How has the soil management strategies influence soil erosion?
- What is the impact of soil fertility of different land use on soil erosion?
- How has soil erosion on land use areas of Nzhelele Valley?

1.5 Hypothesis

The study sought to test a hypothesis that assumes that

- Soil erosion is impactected by soil fertility on different land uses
- Soil management strategies influences soil erosion
- Soil erosion is impacted by land use within Nzhelele Valley.

1.6 Justification of the Study

Soil erosion is one of the major problems responsible for environmental degradation, in areas with high agricultural practices and settlement, and grasslands such as Nzhelele Valley.By looking at the different land use classes, this research will assist in finding changes to land use caused by land use and land cover change. Most rural communities in South Africa are vulnerable to soil erosion, which has a major impact on land use.

The research will inform decision-makers about the rate of soil erosion. By looking at the soil types and land-use practices in Nzhelele Valley, this research will provide knowledge on how vulnerable the environment is to soil erosivity, based on land use and land cover over time. Population pressure has given rise to deforestation and clearing of forest to accommodate more people, which have resulted in an increase in the vulnerability of land to soil erosivity, which leads to the high susceptibility of the environment to gully development.

The proposed study will assist in visualizing the impact of soil erosion on soil fertility across the Nzhelele Valley. By looking at activities such as sand mining, agriculture, construction of informal settlements, and the cattle industry, this study will assist in understanding the changes in land use and land cover in Nzhelele Valley. Agriculture is one of the key factors that sustain the livelihoods of people in Nzhelele Valley. The ever-increasing pressure of population on the Nzhelele Valley has increased land use and land cover change.

1.7 Description of the Study Area and Delimitation of the Study

1.7.1 Description of the study area

Nzhelele Valley is situated in Vhembe District Municipality, Limpopo Province, North of South Africa (22° 50' 15.8 S and 22° 54' 5 S and 30° 03' 10.2 E and 30° 29' 23.5 E). The area is composed of flat topography in the North and South, separated by the east-west trending Soutpansberg Mountains, with steeper slopes and cliffs in places. The altitude varies from 1400-1500 m in the highest parts of the Soutpansberg Mountain. It is composed of different land use and land cover types such as plantation, grazing area, forest and thicket, an agricultural area, and settlement areas (Figure 1.1). Settlement patterns within this area consist of clustered and linear settlement patterns. The Nzhelele River is a major watercourse within this area and the river collects much of the drainage on the north slope of the extensive rock formation of the Soutpansberg Mountains.

The Nzhelele River valley consists of a number of villages namely Fondwe, Siloam, Dzanani, Phadzima, Ha-Mandiwana, and Ha-Maphada. In most of these villages, people are living within the sloppy areas of the valley, along the Nzhelele River valley. Settlement patterns in this area consist of clustered and linear settlement patterns. Furthermore, there is a linear settlement pattern along Nzhelele River and along the main roads, for easy access to the transport system. In built up areas, planned settlement mostly linear pattern is dominant especially along roads and business area.

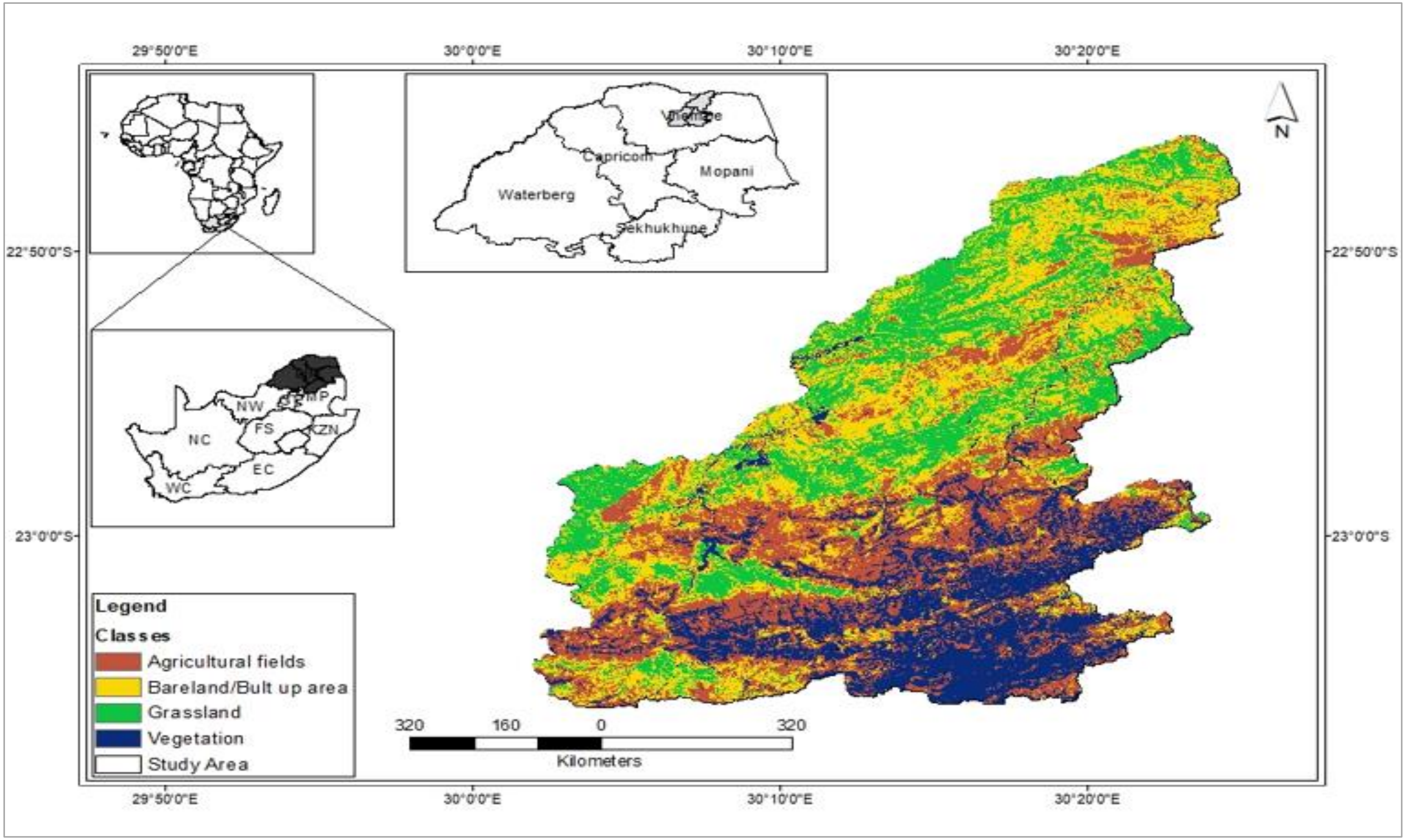

Figure 1.1: Study area Nzhelele Valley

- **Land use**

Agricultural land use is the most dominant land cover within Nzhelele Valley (Figure 1.2). However, grassland and forest areas are other land use areas dominant within the study areas. These land use and land cover areas are more visible in locations where there is limited human activities (Figure 1.2). Cultivation is the main and dominant land use activity in the study area because much of the area is highly covered by agricultural activities. Bare land/built-up areas are also another land use feature that is found within the Nzhelele Valley. This includes aspects such as residential areas, business areas, and other formal and informal human development sites. These developments have increased surface water runoff and resulted in a low infiltration rate (Department of Economic Development, Environment and Tourism 2009).

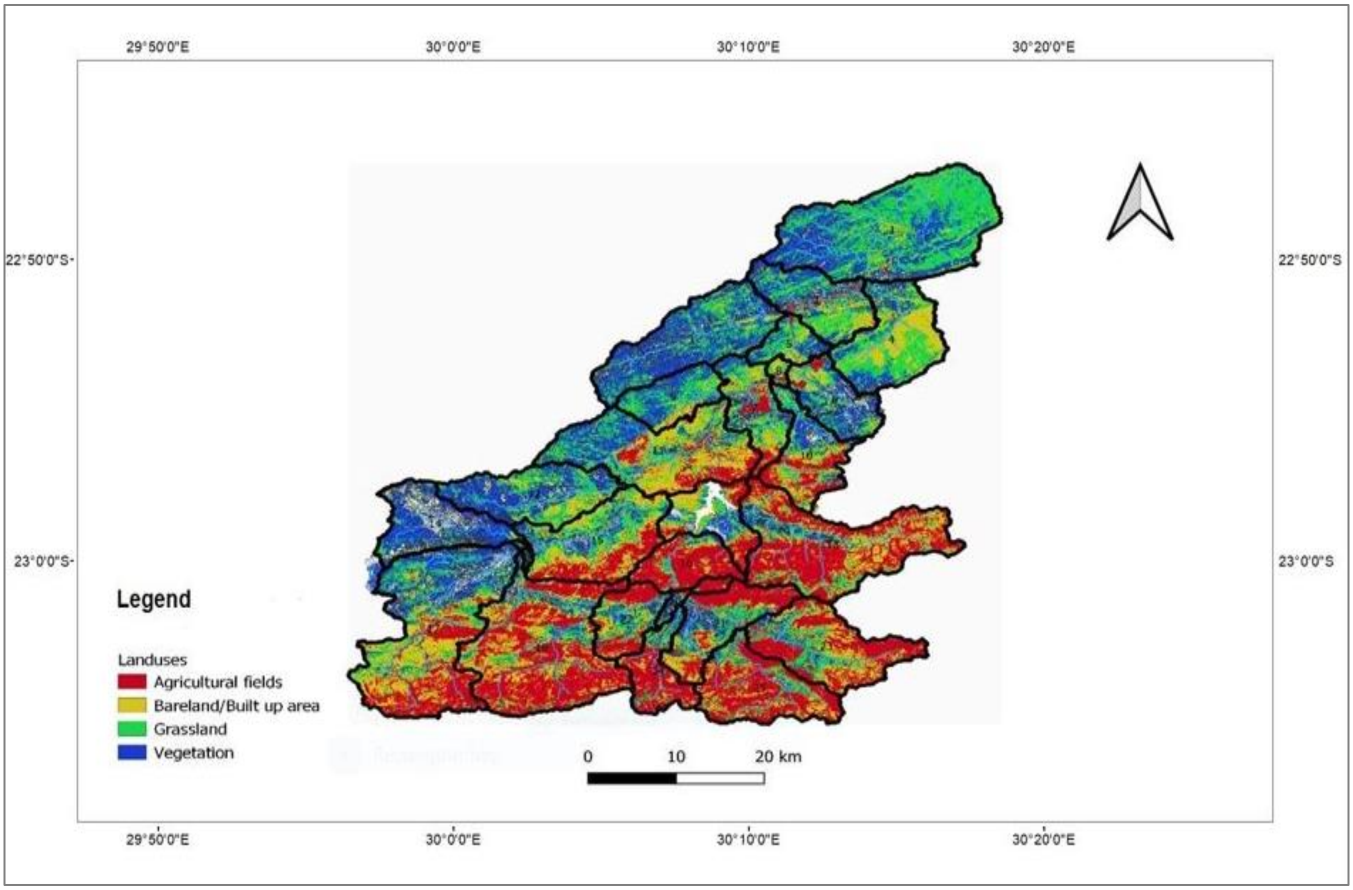

Figure 1.2: Nzhelele Valley Land Use.

1.7.2 Conceptual and Theoretical Basis of the Study

Various concepts such as land use, land-use change, soil erosion, biophysical forces, and socio-economic factors are significant to a study of this nature. The concepts of land use and land-use change and soil erosion provide dependable findings.

Land use is defined and understood in different ways, and is accessible from a different pool of connotations. Land use is a frequently used idea in urban planning, agriculture, industrial settlement, and geography. Land use by definition is the utilization of the natural environment to satisfy current needs. However, there is no typical definition of land use in literature reviews. Turner *et al*., (1995), define land use as biophysical attributes of the land changed from their original state and the intent of underlying the change.

Erosion and land-use changes are very complex, multi-dimensional, and multi-level concepts. The process of soil erosion, which is the outcome of land use from different actions, has a multi-spatial relevance (Figure 1.3). As land-use is the initial capacity and opportunity to utilize land, problems of erosion may take place naturally. However, the two concepts seem to have similar challenges because the problems of soil erosion are neglected land use issues that manifest over time. The most attention-grabbing point is that land use and soil erosion are two completely different aspects that are measurable using different inputs, yet they are closely related.

Land use demonstration involves the nature of activities (settlement, transport system) and is mostly associated with the spatial socio-economic description of the environment (Rodriguez. 2011). Theories of land use conceptualise land as an area used to accommodate settlement, farming, and leisure that serve them. Areas that need to accommodate human beings satisfying their needs is one of the basic needs that has created various changes in different areas of land use. Human needs are dynamic, structured in a sense where if the needs are not fully met change within space is likely to occur. Needs such as settlement area which brings a sense of belonging, farming that gives one food security and economic empowerment, as well as leisure which is part of family togetherness, provides different spatial construction that shapes land-use areas in many different forms

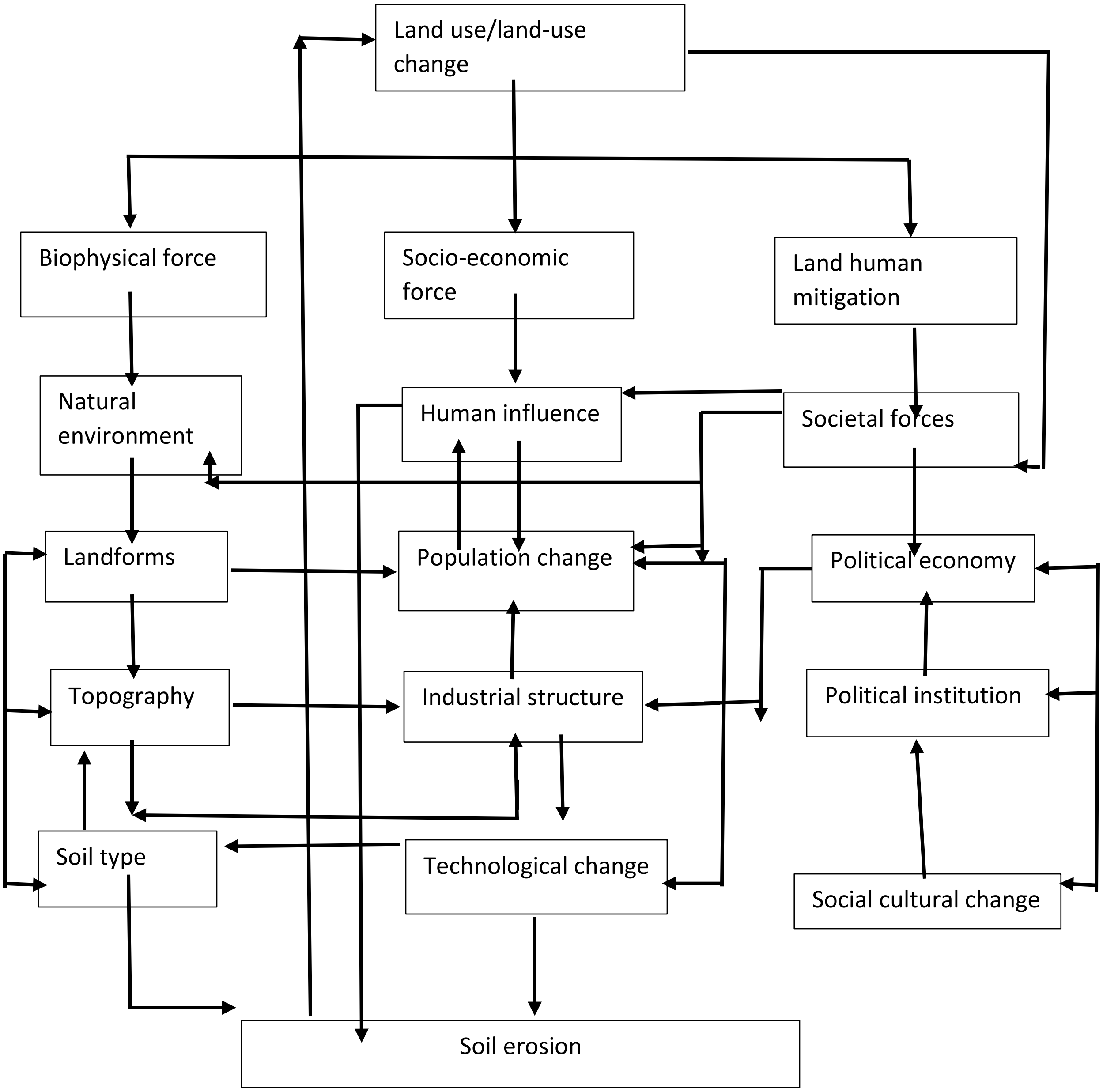

Figure 1.3: Conceptual Framework of the Study

The structuralist theories conceptualise space, spatial relations, locus and nature of the conflict, and mechanism's choice. The economy, state, and ideology are three main levels of the organization, which the structuralist theory distinguishes (Althusser and Balibar 1970). There is a high dominance of mode of production by capitalists with relations of production elements, machines, structures. There is a dependence between the three levels and their interrelationships, which affects the development of urban spatial structure: land use for production (production area and offices), land use for consumption (housing, welfare services), exchange land (transportation roads and communication).

However, within the structuralist theories, their concepts of space mainly focus on activities that highlight the land cover/use of various activities. It brings about the reasons why different structures a put together in a certain (space, spatial relation and locus, and mechanism's choice). A connection in various land use structures gives shape and structure to certain communities given that certain considerations concerning the ideas behind the spatial structure. With a subject to the setting of certain development and stages of development land use for production, consumption, and exchange land vary. This is evident in different areas, for example, developing countries where high levels of exchange land for transport vary depending on the level of development.

1.8 Ethical Considerations

To gain entry to the study area, permission to conduct the research was obtained from the tribal authorities and the municipality in Nzhelele valley governing this area. This followed obtaining UHDC Ethical clearance from the University of Venda (Appendix 1). This was done to avoid the violation of privacy and as a way of observing good ethical practices. The permission enabled the researcher to research all relevant areas. There was also careful management during data collection exercise in sensitive environments within this study area, such as gullies, wetlands as well as rivers.

1.9 Definition of Key Concepts

Land-use change:

A process in which an area or natural environment becomes different from its original form. In most cases, this process involves alteration by different action (human activities, time), which causes some differences from the initial state of observation (such as from cold to hot or small to big) within a certain period (Kakembo *et al.,* 2010)

Erosivity:

The potential of raindrop impact, runoff from snowmelt, or water applied with an irrigated system rainstorm to detach and erode soil (McCool and Williams, 2008).

Soil erosion:

The wearing out of topsoil at a much faster rate than the rate at which the soil-forming process can replace it. This wearing out is mainly caused by natural factors (wind and water) or anthropogenic factors (agriculture, mining, urbanisation, land abandonment, and overpopulation (Mahommad and Mahommad, 2010).

Modeling:

It is a process of projecting an item or real object within a definite scale to examine and understand the processes and dynamics of a certain real object or process. It is mainly designed to give an overview of a phenomenon that seeks to simplify an object or phenomena to give solutions to a given scenario or activity that seeks to help in decision-making (Veldkamp and Verburg, 2004).

Land cover:

The term land cover relates to the type of feature present on the surface of the earth. Agricultural fields, forest, and tarred roads are various examples of land cover types. (Lillesand *et.al*, 2007)

1.10 Structure of the Thesis

The structure of the thesis presents readers with the contents and organization of each chapter as well as their presentations.

Chapter 1 forms the base of the study, which involves the research problems together with the objectives guiding the study. It gives an outline of the study, together with how the research has come about and the reason prompting the study. It provides direction in which the research is shaping into and the area where the study is being carried out.

Chapter 2 entails literature on land use activities, the impact of land use on soil erosion. The focus is on land use activities (farming, settlement, road construction, grazing), and how it interacts with a soil erosion problem. This chapter provides an overview of different literature on how they encapsulate issues of land use and soil erosion.

Chapter 3 presents the materials and methods that were to collect and analyse data on different land-use activities. It links the research objectives given in chapter one to the research methodology articulated in Chapter Three. Chapter 3 provides research methodologies that are used in analyzing land use and land cover change and its impact on soil erosion. The chapter constitutes research sampling methods that were used to select data from the study area,. It gives a detailed description of the research methods that were used to address the research objectives in the study. Lastly the research analytical methods are also given in Chapter Three which shows how data was analysed.

Chapter 4 -Objective One- focuses on the presentation and analysis of data on land use/cover change within Nzhelele Valley. It provides a detailed analysis of the change of different land-use activities over 15 years. It also provides a sound discussion of changes in land use/cover and gives direction on different land use and land cover changes. It gives a constructive, detailed and alignment of the results obtained from analysed data and analysis based on the given methods from the objectives.

Chapter 5 Objective Two- presents the discussion of output data analysed on land use, management strategies. The discussions of the findings articulate various factors that promote different behaviors based on several factors such as income, age, perceptions, and level of education. A clear path on how results are obtained. The study presents the discussions on management strategies, as well as some views from different scholars are also included.

Chapter 6 Objective Three- provides presentation and analysis of data regarding the impact of land use on soil fertility. The study provides a detailed arrangement of various soil characteristics affected by different land use. This chapter presents a sound analysis of soil chemical and physical aspects that address the research objective. Furthermore, this chapter provides a thorough discussion of soil characteristics that have been analyzed to find common ground as well as gaps within the study. This chapter gives a constructive and detailed discussion based on the analysis made guided by the methods of the research through the research objective.

Chapter 7 Objective Four- Dwells much on modeling land use within the Nzhelele watershed. It gives detailed results and discussion of sediment output and annual precipitation output from 1980 up to 2010. The chapter provides a sound discussion of sediment output from different Nzhelele sub-basins simulated by the model.

Chapter 8- focuses on the summary, of the research. The chapter provides recommendations based on the findings from the study, which can address the research problems. It also provides a conclusion from the empirical evidence obtained from the research findings.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The previous chapter looked at the research problem and the specific reasons why the study is important; this section will focus on views of different literature on soil erosion in various land use and land cover areas. The human process forms an important base of the study, as it is the key driver to the transformation in the spatial arrangement of the society. The themes within this section of literature review give direction to the empirical research of land use and change in the study. This chapter aims to provide more information on previous studies providing an understanding of ways of representing knowledge on land-use and land cover change and its impact on soil erosion. Various literature from was presented in this chapter, providing an overview of research ideas from different scholars.

2.2 Environmental Determinism Theory in Land Use and land Cover

The philosophy of geographical determinism regards that human life, similar to that of other organisms is molded by the physical environmental conditions. . This is a paradigm which argues that, man is dependent on nature. For one to be successful in life, human beings have to adapt to the rules of nature (Tunc, 1997). The determinist theory argues that, human nature and the nature of human activities are shaped based on the set invariable rules of nature (Sahin and Belge, 2016). The Environmental determinist view assets the superiority of the environment over man. Based on the environmental determinism theory, a man is a product of nature. The shaping or forming is not absolute; human beings can isolate the limitations based on their needs, traditions and technical means they poses, because they can shape and benefit from the environment with accumulation of knowledge (Sahin and Belge, 2016).

This approach points out the relationship between science and technology, at the time and the extent of their use by human beings (Kaygalak, 2011). The concept of environmental determinism holds the environmental features directly determining the aspects of human behavior and the society. Variations among people are mainly through the influence of climate, landscape and other environmental aspects. The aspects of change in land use and land cover is highly connected to the determinist theory with changes in landscape relating to climate and the human behavior

2.3 Perspectives on Land Use and Land Cover

Various studies have described, evaluated, and deduced land use and land cover as a field of interest in the discipline of geography. The term land use in GIS, geographic and remote sensing applications is very important. The use of land involves the management and modification of the natural environment into built environments such as settlement and semi-natural habitats (pastures and arable fields) (Lillesand *et.al,* 2007). Meyer (2005) described land use as a means of exploiting resources through anthropogenic activities. Land use includes uses for social purposes and is not resolute by physical qualities but rather by its function (Longley *et.al,* 2005). Furthermore, land use is a practical aspect of an area concerning man's contribution to the land in terms of his livelihoods and traditional activities.

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).

Land cover relates to the type of features present on the surface of the earth (Lillesand *et.al*, 2007), Agricultural fields, forest, and tarred roads are various examples of land cover types (Zubair, 2006). Other issues not including human activities such as natural events (floods, veld fires, dynamics of ecosystems) can change land cover initiating modification of land use (Zubair, 2006). Changes within various human interactions increases the vulnerability of soil erosion in both disturbed and undestubed land cover (Meyer, 2005). Furthermore, related effects on land cover brought about from anthropogenic activities affect the extent of land usage and land cover of an area (Meyer, 2005). The definition to explain land use has been adapted from the land use classification for British Columbia in which Land use defines a specific combination of land activity and land cover (Oellermann, 2005). The activity involves the anthropogenic action man makes on the environment. This should not be confused with other variables (tenure, ownership, and economic activity or land value). Land-cover describes the cover (natural or artificial) covering the environment under study (Harper, 2007). This provides spatial details within a certain environment that has to do with human behaviour or natural condition that are influencing the environmental structure within a specific period (Harper, 2007).

Land use and land cover change have become a critical aspect worldwide of natural change, and/or global warming research (Jieying *et.al*. 2006). This is because environmental change is a major factor for global environmental change caused by interaction with climate, biological system forms, biogeochemical cycles, biodiversity, and, indeed more imperative, human exercises (Jieying *et.al*. 2006). It isfor this reason that, land use and land cover change are subsequently, treated as one core joint extend of the Universal Geosphere-Biosphere Program (IGBP) and the Worldwide Human Dimensions Program on Worldwide Natural Alter (IHDP) (Stow and Chen, 2002). Within the last decade, much more consideration was on urban areas affected by anthropogenic activities and close relations with the world’s population (Stow and Chen, 2002).

Verburg *et.al,* (2004) established that scenario analysis together with models of land-use, supporting the planning and policy. There have been various land-use models within diverse disciplinary backgrounds (Yesserie, 2009). These models are tools to support the analysis of the causes and consequences of land use/ land cover changes, in order to understand the functioning of land-use systems, and to support land use planning and policy (Yesserie, 2009). Models are very important as they simplify the complex system that has an impact on the rate and spatial patterns of the environment, as they estimate and predict the impacts of land-use changes (Yesserie, 2009).

The land use and land cover change involves a wide range of factors, this was evaluated by (Sylla *et. al.,* 2012) in studies done in Conakry, Coyah, and Dubreka regions. These factors include natural and human causal factors, including meteorological factors (climate, rainfall, temperature and humidity, population growth) (Sylla *et. al.,* 2012). Furthermore, other factors include land tenure desire for each occupant in the region, the income of the population, feeding of the population, the region's extensive agriculture and breeding systems, industrialization pressure, fishing, transport, and artisan activities, and the frailty influences of cultural and institutional forces (Sylla *et. al.,* 2012). All these factors combined have resulted in the deterioration of the current state of the environment (Sylla *et. al.,* 2012).

Under various conditions, models can support the exploration of future land use (Costanza and Ruth, 2008).They provide meaningful ideas on the spatial construction of land depending on different variables. There is a wide range of ideas given, with a different assumption on how certain spatial construction came about, which enables certain views to come out (Costanza and Ruth, 2008).The simulation of various models of land use provides critical thinking on various views of land use which with time increases the thinking capacity on certain views of land-use problems (Costanza and Ruth, 2008). The simulation creates innovative models that provide solutions to land use problems bridging the gap between land use and soil erosion problems (Costanza and Ruth, 2008).To sum up, land-use models are useful and reproducible tools complementing our existing mental capabilities to analyse land-use change and to make educated decisions (Costanza and Ruth, 2008).

2.4 Land Use Land Cover Change (LULCC)

Land use (LU) and land cover (LC) change is a function of population, affluence and technology (Nguyen, 2008).The intensity of land-use change in response to the world's population and its consequences for the environment warrants in-depth studies of this transformation (Nguyen, 2008). Due to rapid population growth, transformation of forest resources has increased in many parts of the world into other forms of agriculture (Nguyen, 2008). In many cases, these transformations result from socio-economic degradation and natural systems problems from global warming (Nguyen, 2008). In most cases, population density is associated to agricultural expansion and intensification (Nguyen, 2008). Lower Mekong delta in Vietnam has the second largest (80%) rice produce for export. The drastic growth of rice production for export and intensification of the activities covers a large land use, increasing land cover and soil erosion problems (Nguyen, 2008). The larger the area for land-use change, the bigger the extent of vulnerability of the area to soil erosion (Nguyen, 2008). Due to production and constant use of an area for agricultural production, many environmental problems manifest as the human use is involved without proper management systems (Nguyen, 2008).

Accompanying LU/LC change is a question of population density and population needs (IPCC, 2001) These problems emanate from socioeconomic degradation and natural systems from global warming (IPCC, 2001) Changing in climate conditions have produced negative effects including loss of biodiversity, droughts and floods which in turn results in land use and land cover change (IPCC, 2001). One case study predicts that due to climate change, 10.8% of the population and 28% of the wetlands in Mekong and Red deltas is due to the 1m sea-level rise (Dasgupta, 2007). This will have a recurrent effect of land use and land cover change, causing a change in land cover pattern and shift in land use (Dasgupta, 2007). The dominant land cover and land use is settlement and agriculture occupied by human activities. The farming areas tend to change over some time due to changes in climate and population demand. Institutions that govern land cover tend to fragment land use and more often changes occur with a short space of time (Dasgupta, 2007).

Terrestrial ecosystems between 39% and 50% have experienced modification through human activities (Lambin *et al*., 2003). The main drivers of LULC change are socio-economic development, population expansion, and pressure for land for agriculture (Lambin *et al*., 2003). In East Africa, there has been a high demand for land because it has been a critical resource for livelihood (Maitima *et al*., 2009). This demand has caused immense LULCC resulting in the loss of natural forests to human settlement, urban centers, farmlands and grazing lands (Maitima *et al*., 2009). East African forest cover has decreased annually between 1990 and 2015 by 1%; while the human population increased at an average rate of 2%. LULCC has resulted in a trade-off between meeting the human needs and influencing the natural land cover over a short period (Maitima *et al*., 2009).

2.5 Supervised and unsupervised classification

Remote sensing data is mostly used for land cover identification and classification of various features of the land surface from satellite or airborne sensor. Application of remotely sensed data for land cover and land use mapping and its changes is a key to many diverse applications such as environment, forestry, hydrology, agriculture, and geology, (Meyer, 1995). Acquired information from images remotely can be a valuable tool for a variety of resource-based applications. For example in forestry the images were used to assist in inventory assessment of their allotted forest stands. Ecologists may use image classification to categorize plant zones, wetland classification, etc. Data obtained from classification of images can then be utilized to assess changes in various ecosystems through time due to anthropogenic interference or global climate changes and natural disasters (Nerd, 2004).

Classification in remote sensing involves clustering the pixels of an image to a (relatively small) set of classes, such that pixels in the same class are having similar properties. The majority of image classification is based on the detection of the spectral response patterns of land cover classes. Classification depends on distinctive signatures for the land cover classes in the band set being used, and the ability to reliably distinguish these signatures from other spectral response patterns that may be present (Eastman, 2003). There are many different approaches to classifying remotely sensed data. However, in common they all fall under two main topics: unsupervised and supervised classification technique.

In unsupervised classification, an algorithm is chosen that will take a remotely sensed data stand find a pre-specified number of statistical clusters in multispectral or hyperspectral space. Although these clusters are not always equivalent to actual classes of land cover, this method can be used without having prior knowledge of the ground cover in the study site (Nie et al., 2001).Supervised classification, however, does require prior knowledge of the ground cover in the study site. The multispectral or hyperspectral data from the pixels in the sample area or spectral signatures from spectral library are used to train a classification algorithm (Kamaruzaman et al., 2009). Once trained, the algorithm can then be applied to the entire image and a final classification image is obtained.

In remote sensing-land cover mapping study, accuracy assessment is important to evaluate remote sensing final product. The purpose of assessment is important to gain a warranty of classification quality and user confidence on the product (Foody, 2001). Normally, accuracy result are derived from supervised or unsupervised or both techniques. However supervised and unsupervised technique relatively shows different level of accuracy after accuracy assessment was performed.

2.6 Causes of Land Use Change

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.

Ecologists concentrate mainly on the ecological and ephadic pressure of human activity (decision of placing nature reserves and agricultural activities) (Walker *et al.,* 2000). Further, ecological processes related to disturbance and species range expansion could result in land-use changes, independently or with the interaction of human activity (Walker *et al.,* 2000). Land use varies depending on the activities within a particular environment (Geist and Lambin 2001). Within a bigger environment or heterogeneous region, various agents can be active, which adds spatial complexity to any attempt at causal explanation (Walker *et al.,* 2000). Moreover, the dynamic interaction among agents, between agents and their environment complicates land-use change (Geist and Lambin 2001).

Geist and Lambin (2002) describe the interaction of agents as constituting the proximate causes of land use. Research on ultimate causes has to dwell much on economic factors such as (Kaimowitz and Angelsen 1998; Irwin and Geoghegan 2001), but these are built up by the underlying environmental heterogeneity and variability, demographic change, technological evolution and institutional intervention (Walker *et al.,* 2002).

The micro-scale involves the quest of an individual to achieve his or her objective and the macro scale shows the context of these decisions. Comprehended in these decisions are processes such as population growth and movement, climate and soil processes that hinder production on the land. Furthermore are t introductions of commodity and labor markets, constant evolution of technological changes, and the behavior of the government bureaucrat's reaction to political forces. Micro-scale shifts are usually unpredictable, as they often react from versatile cohesion of economic, political, and transnational institutions and social processes. The macro-scale processes and changes are often at the end understood as the causes of land use and land-use change.

Numerous causal paths are running through macro-scale forces to micro responses of individuals. However, individuals and society illuminate notable resilience and ingenuity in adapting to a changing context to focus on their own goals. Macro-scale factors ultimately shape the environment of choices available to agents; hence, they by no means predetermine any particular land use.

2.7 Trends in Land-use Change and Soil Erosion

The results of land-use change models whether targeted human influence, topographic landscape or climatic conditions over the past decades differ from one area to another and from time to time (Piguet *et al*., 2011). Nevertheless, common changes manifest over time. These changes illustrate the spatial-temporal dynamics of land use (Piguet *et al*., 2011).

Table 2.1 Erosion rate status for each land-use changes from 2000 to 2011 in ha (Zare *et al*., 2017)

Land use	**Mean soil erosion** (ha)
Forest	70.3
Rangeland	349.19
Settlement	452.83
Agriculture	104.98

We can deduce that within a decade, human interaction with the environment such as agriculture and settlement are the most dominant aspects in land-use change and soil erosion occurrence (Table 2.1). Each land use regardless of the magnitude generates erosion. Land use erosion tends to differ within different land uses. However, with the influence of climate change, technological advancement and the continuous increase of population, drastically influence future land-use change.

The pace, magnitude and the spatial reach of human alteration of the environment is unprecedented (Eric *et al*., 2001). Studies by (Zhou *et al*., 2008; li *et al*., 2014) have found that, changes in forest cover greatly affects the intensity of soil erosion. In Iran, conversion of forestlands into agricultural areas, rangelands and residential areas have increased the generation of runoff and hazards with high levels of serious soil erosion problems (Gholami *et al*., 2010). One estimate, for example, holds that the global expansion of croplands since 1850 has converted some 6 million km^2 of forest/woodlands and 4.7 million km^2 of Savannas/Grassland/Steppes (Eric *et al*., 2001). Human-induced land use change/ cover have a significant impact on soil degradation, including soil erosion, soil acidification, nutrient leaching and organic depletion (Zare *et al*., 2017). Widespread of modification of land cover, changes the magnitude of soil erosion within a short period (Zare *et al*., 2017).

Agricultural intensification permitted the doubling of the world's food production from 1961 to 1996, with a 10% increase in arable land; globally increasing the rates of land use/cover change and soil erosion (Tilman 1999). Soil erosion accelerated by human activities has become a serious environmental problem and the influence of anthropogenic activities such as agriculture, settlement and grazing intensifies runoff, generating high sediment transportation over time (Tilman 1999). Soil erosion differs from one case study to another, depending on the changes of topography of the watershed and soil characteristics (Tilman 1999). However, the combination of population pressure, land use management strategies and climatic condition of the area increases its rate (Tilman 1999).

2.8 Impact of Soil Management on Soil Erosion

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)

Farming for example, is the alteration of the natural environment to create an artificial landscape that brings food production with the intent to provide food security to the growing population (Poesen *et al*., 2003). This process alters the structure and chemical composition of the soil, reducing the levels of organic matter, making the soil highly susceptible to erosion (Poesen *et al*., 2003). Most small agricultural areas erode due to confined overland flow, only to rejuvenate again in the same location by additional runoff events (Poesen *et al*., 2003). Erosion mostly occurs in areas where there is high flow concentration within natural drainage (hallways of zero-order basins or hallows) and linear landscapes (drill lines, dead farrows headlands, parcel borders, and access roads) (Poesen *et al*., 2003). Land use especially in agricultural practices (tillage), results in channel incisions (Poesen *et al*., 2003).

In Ethiopia, soil loss in highlands increased from 33% to 55% because of increased surface runoff concentration from agricultural practice (Poesen *et al.,* 2003). Soil is limited and irreplaceable resource, very important for the biosphere (International Soil Science Society (ISSS); Duran *et al*., 2010). Soil erosion by water involves a process where there is detachment of soil particles due to water drops and runoff, transporting practices from one point to the other through shallow and small catchment (Duran *et al*., 2010). This is an environmental concern around the globe with long lasting effects affecting the physical and chemical structure of the soil (Poesen *et al*., 2003).

Terracing in mountainous areas of Spain over the last few decades is one of the important elements of agricultural development since its enrolment in the European Union in 1986 (Dijk, 2002). Construction of terraces has resulted in the detachment of soil from taluses causing the accumulation of soil below the terraces Dijk (2002). Problem of soil erosion due to soil loss within agricultural development areas resulting from various land use activities creates issues of environmental degradation Dijk (2002). In a study by Purwanto (1999) and Dijk (2002), terracing does in some cases cause soil erosion. In steep highlands with exposure to agricultural activities, gradual land degradation occurs resulting in soil erosion. This results in the some terraces collapsing increasing the rate of soil erosion.

In instances where natural forest is replaced by agricultural practices, soil and nutrients are likely to be transported from one point to the other (Kuhn and Armstrong, 2012). Carbon mobilization takes place in the inter-rill erosion because of cultivation over time (Kuhn and Armstrong, 2012). Globally 14 million km² of land under agriculture is lost because of surface runoff (Kuhn and Armstrong, 2012). In Semi-arid Mediterranean environments, forest cover is very important as it plays a fundamental role in protecting the environment from soil erosion (Pardini *et al*., 2003). Resources are growing closely to their extinction because of growing environmental degradation (Pardini *et al*., 2003).

For the past 40 years, one third of arable land globally has been degrading because of soil erosion (Bhatt and Khera, 2006). Anthropogenic activities have resulted in land degradation, which has led to desertification especially in arid and semi-arid areas (Duran *et al*., 2007). Agricultural practices in some cases uproot aromatic plants during harvesting resulting in some parts bare vulnerable to splash and raindrop impact during torrential rains (Duran *et al*., 2007). This has resulted in soil erosion and unexpected rill and gully erosion (Duran *et al*., 2007).

2.9 Environmental Degradation and Soil Erosion

Environmental degradation influences forest variability especially forest cover and species community (Schunn and Rogers 1991). Soil erosion associated with environmental degradation is due to anthropogenic activities, and continuous disturbance of land over time (Ibanez *et al*., 2002). High vulnerability of erosional problems manifesting from excessive livestock emanates from the decline of physical, chemical and biological structure of the soil; that leads to environmental degradation (Ibanez *et al*., 2002).

Soil erosion, especially within communal areas, develops within livestock and footpath trails which run along hillsides (Thiemann *et al.,* 2005). Paths created by livestock movement and overgrazing creates environmental degradation and it leaves soil uncovered reducing soil saturation levels (Thiemann *et al.,* 2005). The bare footpaths made up and down the slopes during rainfall (raindrop impact and splash drop) results in concentrated flow of high runoff and less infiltration (Thiemann *et al.,* 2005). Over time with constant runoff, soil particles move from one point to the other resulting in soil erosion. In some instant, the concentrated soil erosion will further aggravate into gully erosion within grazing areas (Thiemann *et al.,* 2005).

In addition, understanding and explaining the soil erosion process through relying on the characteristics and behavior of the agents as they offer the possible means of accelerating the rate of soil erosion. In regards to different causes of soil erosion, the occurrence and rate of soil erosion, increases through the extent, amount of climatic events and causation of the activity. Repeated activities increase the volume of erosion necessary to allow the erosional process to occur within a short space of time, allowing the problem to be huge within unmanaged environments.

Unfortunately, areas speedy erosional process has minimum or non-management plan, becoming very difficult to make decisions to prevent the erosion from taking place. The concept of soil erosion does not apply to people living under poor economic conditions, as they continue to exploit the environment which then increases the chances of soil erosion. However, the growth of population, cities and a rise in economic growth may also result in high levels of soil erosion vulnerability, as it creates a huge gap between economic emancipation and environmental management. The process of erosion occurs when there is to exploitation of the natural environment, improving humans' livelihood, in turn increasing land use and erosional vulnerability.

2.10 Land Use and Soil Erosion

To get an in-depth understanding of soil erosion, the study requires further description of the concept of land-use change, as it is associated with the concept of soil erosion (Torri and Poesen, 2004). Torri and Poesen (2004) define land-use change as a process by which human activities transform the landscape from its original state into another state that suits their needs. This definition describes the manipulation of the natural environment by people without any consideration, to improve their livelihoods at the expense of the environment (Carely 2006). A study by Nolon, (1992) suggests that, land use involves environmental management, which is the utilisation, and changing of the environment into man made landscapes and habitats. The exploitation of the environment derives a certain number of consequences that in most cases have negative implications if not executed sustainably (Nolon, 1992).

Land-use change goes far back as far as the Neolithic cultural revolution around 7500 years ago (Dotterweich *et al*., 2013). The long history of land-use change has significant implications on environmental change at different levels, from local social-economic patterns to global environmental patterns (Fraser 2010). The different use of land often controls the linear dense road networks that control gully formation in artificial landscape elements (Stankoviansky, 2009). The use of land has different formations that increase erosion levels when it has not properly managed (Stankoviansky, 2009). Climate, topographic location, human behaviour, and attitude, as well as other factors, negatively implicate land use, which leads to soil erosion (Stankoviansky, 2009).

The concept of land-use change gives rise to the problem of erosion (Marden *et al*., 2012). The effect on anthropogenic activities within different land use practices such as agriculture, industrialisation, and urbanisation leaves the soil vulnerable to abrasive actions, exposing it to soil erosion (Marden *et al*., 2012). Land-use change is as a key process that results from a shift in the social, political, climatic and economic structure of a society (Marden *et al*., 2012). The process of gully reclamation often identifies land use activities and human environmental benefits that concentrate on the profiling of the area (Marden *et al*., 2012).

Views by Sajikumar and Remya (2015) allude to the fact that change in land use results from human activities rather than natural events. Shi *et al*., (2007) have supported this notion, by arguing that agriculture expansion, fuel wood consumption, deforestation, expansion of grazing land, construction work and urbanisation are some of the human activities that result in land use and erosion. Lotcha *et al*., (2016) state that an increase in human impact on the environment has been found in many parts of the world following a change in land cover and development of gullies.

Human intensification or de-intensification and abandonment of land manifest into changes of magnitude of different morphological processes, especially soil erosion. Studies by Mayo *et al*., (2008) which have mainly concentrated on the mechanism of soil structure, suggests that changes in land use structures and spatial patterns have a substantial effect on the development of gullies and soil erosion. Raya et al., (2006), have supported their findings in their study, emphasis that the structure of land use and type of land has an effect on soil water saturation point, mostly when there is change in land use. In agricultural areas, intensive soil erosion is likely to occur in catchments used for agriculture, regardless of how small the area or the inclination is (Torri and Poesen, 2014). Negative environmental problems are likely to occur in areas where intensive land use or areas where land use change is detected (Zglobicki *et al*., 2014).

Dotterweich (2008); Poesen *et al*., (2003) submit that the occurrence of soil erosion creates problems and its magnitude differs over time based on the land use type and soil structure of the area. Kaplan *et al*., (2010) argue that the history of human activities and important impact on the local hydrology to world climatic patterns. Anthropogenic history on the environment provides crucial information that will make people to understand how best they can sustain the environment (Dearing *et al*., 2010).

2.11 Adoption of the soil Conservation Measures

Soil conservation measures have relied largely on food-for-work programs as an incentive; and have been oriented toward labour-intensive activities such as terracing, bund construction and tree planting (Pender, 2004). With this, Ethiopia became the largest food–for-work program beneficiary in Africa and the second largest country in the world following India (Woldeamlak, 2007). A total of 50 million workdays were devoted to the conservation work between 1982 and 1985 through food-for-work (Woldeamlak 2007). Between 1976 and 1988, in Ethiopia, some 800,000 km of soil and stone bunds were constructed on 350,000 ha of cultivated land for terrace formation, and 600,000 ha of steep slopes were closed for regeneration (Woldeamlak 2007).

Soil erosion poses a serious threat to national and household food security (Bekele and Holden, 1998) and therefore its management is essential for improving food security in seriously affected areas. Initially, most of the soil conservation works included construction of the stone and earth embankments, which the farmers believed took extra Land from their small land holdings and sheltered rodents (Awdenegest and Bolden, 2006).

The adoption of soil and water conservation measures in Africa has been very limited (Girma, 2001). A study by Belay (1992) shows that, the problem of soil erosion is compounded by the fact that some farmers dismantled the conservation structures built in the past through few incentives. In fact, until the early 1990s farmers were not allowed to remove the conservation structures once built on their land (Ludi. 2004). This shows that the conservation efforts have also neglected the pronounced regional disparities and have frequently been implemented in a top-down manner, excluding the participation of the local community (Ludi. 2004).

It is further clarified that some techniques such as terracing and other land management practices can increase productivity and thus be profitable in some areas like in low rainfall area (Ludi. 2004). However, the same techniques are much less profitable in other areas, like in high rainfall areas because they can actually reduce farmers' yields as they reduce the effective area of the plot, causing water-logging, or harbor pests (Ludi. 2004). .

However, the introduction of economic reform program in 1990s and subsequent liberalization of the economy brought more freedom and hence conservation structures could be removed if the land users so wished (Ludi. 2004). . Conservation practices have mainly been undertaken in a form of a campaign and quite often, farmers have not been involved in the planning process (Ludi. 2004). This exclusion shows that soil conservation projects implemented failed to consider local people's economic, demographic, institutional and technical factors from their very inception (Ludi. 2004). Obviously, the adoption of soil conservation technologies considerably is influenced by different factors (Ludi. 2004). Among other influences, the characteristics of farmers such as age, education, household size, farm size and experience are some major influences in decisions concerning the application of soil conservation (Ludi. 2004).

2.12 Land Use and Soil Fertility

Soil erosion is a widespread human-induced land degradation, which has affected soil fertility (Brevik *et al*., 2015). Land use has a strong effect on soil organic carbon loss across different landscapes (Mol and Keesstra 2012). A different variation of soil organic carbon determines the fertility of the soil affecting crop yields and threatening the soil system (Mol and Keesstra 2012). Soil erosion leads to nutrients loss, loss of soil water holding capacity, decrease in soil thickness mostly useful for plant growth and reduction of biodiversity (den Biggelaar *et al.,* 2003). In Australia, wheat yield loss ranged from 0.04%yr-1 to 0.67%yr-1 due to the effects of soil erosion affecting soil productivity (den Biggelaar *et al.,* 2003). The loss of soil affects food production, implicating different sectors of the developmental spheres such as economic and social livelihoods (den Biggelaar *et al.,* 2003). The structure of the soil can be easily be affected by the rate and duration of soil erosion (den Biggelaar *et al.,* 2003). In some instances, the extent of soil erosion breaks down the soil nutrients, negatively affecting the yield of a particular production (den Biggelaar *et al.,* 2003).

In a normal situation, soil erosion by water is a natural process, which in general balances with natural soil formation through weathering (Zhang *et al*., 2017). However, human activities increase the magnitude of soil erosion over equilibrium levels with several impacts on the environment (Zhang *et al*., 2017). Vineyards in Mediterranean hilly places have exceeded such equilibrium with erosion rates up to 100 Mg ha-1 y-1 (Rodrigo-Comino *et al*., 2016). Similar erosional rates are observed in vineyards under temperate climate conditions and improper management such as soil tillage, low organic matter content and biomass removal (Rodrigo-Comino *et al*., 2016). (Prosdocimi *et al*., 2016) has exacerbated the soil erosion risk. Sediment loss due to erosion has been widely elucidated, but the influence of the soil erosion process on soil organic carbon cycling needs more attention (Jacinthe and Lal, 2001). Soil erosion can have a negative impact on carbon sequestration being a source for atmospheric carbon dioxide, as the net primary production on eroded soil and high soil organic carbon decomposition in buried sediments decreases (Jacinthe and Lal, 2001).

The earth's ecosystem dwells much on the soil as it regulates the earth's cycle and influences the hydrological and erosional processes (Rodrigo-Comino *et al*., 2018). However, soil erosion is a major threat to sustainable agro ecosystems and a high rate of erosion disturbs the natural cycles and crop production. This makes soil erosion an important subject in order for one to achieve soil sustainability (Panagos *et al*., 2010). Soil erosion rate is high in vineyards as compared to other orchards such as olives, almonds, apricots, citrus and avocados (Kairis *et al*., 2013). Due to the nature of their production, harvesting methods and the area of production, vineyards have caused several erosional problems within the Mediterranean region (Kairis *et al*., 2013). Land management helps in increasing the chances for changes in soil structure and the chemical composition of the soil (Kairis *et al*., 2013).

Soil fertility negatively affects productivity, if soil erosion occurs at a much faster rate than normal and therefore; influencing the physical and chemical characteristics of the soil (Rhoton *et al*., 2002; Lal, 2003). Raindrop impact and surface runoff of soil Trans-locates the upper layers containing organic matter and nutrients (Evans and Brazier, 2005). This then results in not only the removal but also a deposit of materials within the agricultural land use area (Evans and Brazier, 2005). The removal and deposition process then affects the proportional distribution of mineral content and nutrients in soil (Evans and Brazier, 2005). Soil erosion can change the physical, chemical characteristics of the soil (Xu *et al*., 2010), and biological characteristics of the soil such as microbial composition, abundance, and activity. Soil erosion reduces the microbial biomass and enzyme activity in soil; this was further illustrated in a study Huang *et al*. (2013), whereby, water erosion significantly reduced the abundance of microbial organisms in soil. This reduction affects the mineralization of organic matter, which is ensured in the soil by different organisms with a wide range of metabolic processes enabled by enzyme activity (Nannipieri *et al*., 2002).

Soil erosion by water causes soil organic carbon loss, degrading soil quality and in turn may increase carbon emission from the soil to the atmosphere (Doetterl *et al*., 2016). Organic carbon in soil is disturbed when erosion takes place through detachment, transport, redistribution and deposition (Lal, 2005). The protected organic matter is likely to be lost through breaking down of soil aggregates caused by raindrop splash and runoff shear stress (Nie *et al.,* 2015). However, this process can as well increase the decomposition of organic carbon as it is exposed to oxidizing conditions, losing protection from macro aggregates (von Lutzow *et* a*l*., 2006). Transported and deposited organic matter belongs to light and labile fraction and the accumulation burial of this material improve soil aggregation, hence protecting organic matter from decomposition (*Wang et al.*, 2013).

Understanding the connection between soil physical, chemical and biological processes is vital as these processes govern a wide range of ecosystem services such as feed and fiber, carbon sequestration, hydrological regulation and contamination attenuation (Costanza *et al*., 1997). The soil ecosystem functioning has greater influence from land use and land use management (Costanza *et al*., 1997); which then influences the stability and structure of the soil performance in ecosystem services. Furthermore, the soil nutrient/ chemical/ physical structure are given a particular signature that reflects the richness of the soil. Soil microorganisms constitute 95% of soil biomass and play a pivotal role in soil formation and cycling of nutrients (Pulleman *et al* 2005). However, the biochemical processes mediated by soil microbes are sensitive to land use such as rooting depth and turnover rates (Pulleman *et al* 2005: Wright and Anderson 2000: Stenberg 1999). The land-use activities determine the foundation and structure of soil microorganisms, which intend to structure the soil fertility, affecting the soil chemical structure (Stenberg 1999).

Land-use effects have been identified on soil microbial biomass and community structure in rooted topsoil with evidence of differences in litter composition and root turnover rates. Studies have identified that microbial biomass decreases with an increase in soil depth (Ekelund *et al*. 2001; Taylor *et al*., 2002) which is likely to decrease soil organic matter. Potentially, with the intensity of land use, the structure and composition of the soil are likely to change with time. Phospholipid Fatty Acids (PLFA) may also vary and decrease within different soil horizons, putting across questions such as: how differences in microbial community structure of the soil may be affected by land-use type. This has some altercation on the soil nutrients in different land use and soil horizons that give different soil structure across the land (Fierer 2003).

Soil nutrient status, quality, composition of organic detritus entering the soil and the turnover of soil organic matter are influenced by land use and management practices (Chen *et al*., 2018). Native conversion in New Zealand of the forest into grassland increased soil carbon content caused by soil fertility and root system of pasture species (Sparling and Schipper 2004). In contrast to this, the conversion of land from pasture to cropping leads to loss of soil carbon through the disruption of aggregates (Six *et al*., 2000). Disruption of aggregates results in the exposure of organic matter (Six *et al*., 2000) and little input of organic matter into the soil (Six *et al*., 2000) and fluctuation of temperature and moisture (De Troyer *et al*., 2014).

2.13 Empirically Fitted Models

Empirically fitted models are statistically matching temporal trends, spatial patterns, and variable predictors (Muller and Middleton 1994). Land use and land cover change, represents variables that predicts and measures pixels resulting from remotely sensed data, parcels (such as irregularly shaped spatial units defining legal ownership) or aggregated over jurisdictional units (Muller and Middleton 1994). Predictor variables often affect land use, including proximity to roads, cities, and towns, mixed economic activity, demography, income, wealth and biophysical factors such as slope and soil (Muller and Middleton 1994).

Markov's random (empirically fitted model) processes characterize land use, where the state of land will be a utility of its current state, illustrated by a transition probability (Muller and Middleton 1994). However, they have a diminutive utility for analyzing policy despite minimum data requirements and analytical properties. Markov's framework speaks to some of the diminutives, adding a dependency on a neighboring state (Tuner 1987), introducing temporal non-stationary and spatial transitional probabilities (Brown *et al*., 2000).

Land-use models use statistical estimation methods and are the unattached association to theory, whereas some fabricates in an economic and theoretical context (Wear and Bolstad 1998). With the distinct manner of land use and changes, the relevant method is to estimate a logical regression function, which alludes to the probability of a particular land classification or land transitioning from one class to another (Wear and Bolstad 1998). This model has also been implemented with the rural-urban gradients and tropical forest (Wear and Bolstad 1998; Chomitz and Gray 1996).

In a study by Seto and Kaufmann (2003) in Pearl River Delta South China; a panel econometric technique was used, to model land-use change. Remote sensing on the other was used to data determine the type of land use model used. The data was useful in extracting land-use trajectories and had nine consecutive images from 1988 to 1996. These had insufficient degrees of freedom, to estimate a statistically reliable model. The socioeconomic factors correlated with land-use change within the Pearl River Delta. Causation among dependent and independent variables was determined using Granger causality (Granger 1969; Granger and Huang 1997), and exploring chains of causation.

2.14 Dynamic Process Models

The dynamic process models of land-use change illustrate the interaction between agents, organisms and their environment (Fitz *et al*., 1996). Simulation is very important within this process model but places very little emphasis on the fitting of data (Fitz *et al*., 1996). However, much emphasis is on elements and processes of models on the process (Fitz *et al*., 1996). The model monitors material and energy flows within a given environment, while the transitioning of landscape, illustrates a well natural process representing a stagnant stylized socioeconomic system (Fitz *et al*., 1996). These are useful in different environments such as the Everglades (Wu *et al*., 1996) and Patuxent Watershed (Voinov *et al*., 1999) and common strands. The modeling process often includes stochasticity, which simulates platforms to assess empirical models (Voinov *et al*., 1999).

Cellular Automata Model (C.A): In literature, several studies utilized cellular automata (C.A) model (Botty and Xie 1994; Clarke and Gaydos 1998). The C.A model illustrates the condition and dynamics of an area (Botty and Xie 1994; Clarke and Gaydos 1998). Cells within the model show a representation of a portion of land with different characteristics, each altering due to fixed rules based on each cell's condition and the state of its neighbor (Botty and Xie 1994; Clarke and Gaydos 1998). The C.A model together with data about the heterogeneity of the area unveils the dynamics of land-use changes, such as road drove and spatial random changes (Clarke and Gaydos 1998). The C.A model represents an endogenous interaction and feedback, as they are dynamic and iterative (Clarke and Gaydos 1998).

Agent-Based Model (ABM): The agent-based model (ABM) constitutes one or more types of agents and the environment where the agent operates (Parker *et al*., 2003). They are entities and dynamics on a smaller scale, such as the level of interaction among actors and the environment (Parker *et al*., 2003). The agents represent individuals such as miners, settlers and institutions such as government (Janssen 2003). The environment of ABM represents the physical environment, such as roads, land, water or infrastructure (Lynom 2003). The environment is associated with different elements, such as soil type, land cover type, and aesthetic quality (Lynom 2003). Entities of the environment within the model describe the change in type for independent and the result of agent behavior, such as soil erosion process, as well as aspects of environmental change and forest growth (Lynom 2003).

The behavior of an agent affects other agents and the environment (Parker *et al*., 2003). A change in the environment is the resultant response to the behavior of the agent and its dynamics. ABM involves complex feedback relationships resulting in nonlinear, path-dependent dynamics visualized in a complex system (Lynom 2003). It is essential to note that the outcomes are behaviors of micro agents, the environment and the emergent macro levels structures, relationships from micro-level activity (Parker *et al*., 2003). Change in behavior of the agent implicates several behaviors on both other agents and the environment (Parker *et al*., 2003). In a way, the relationship between and among every element is influenced by the other.

Behavior change on land use has an impact on the neighbor hence influencing the decision of the next agent (Lynom 2003). The changes in behavior from the ABM influence the overall behavior of the system (Lynom 2003). This influences the pattern of land use as other agents' takes shape due to the action of the surrounding agents (Lynom 2003). In a way, various land uses spatial arrangements are due to a reaction from different agents influenced by one another creating certain spatial patterns (Lynom 2003).

2.15 Summary

This chapter has presented and explained land use and land cover change. The chapter further explained theories, models, concepts and strategies. Land use/land cover provides the key concepts, which formulate the foundation for analyzing soil erosion in this research. Land use/land cover also identifies the socio-economic conditions that are likely to push people into activities that contribute to environmental degradation (Bryant and Bailey, 1997). The conceptual framework has been used to understand and identify the processes of land use/cover on soil erosion. Trends in land use/land cover change have been presented with a wider concentration on soil erosion within land-use activities in farming and developing areas. This presentation of land use/land cover then links the discussion to the main aim of the research. To prevent and reverse the impact of soil erosion on land use/land cover change, human activities, policies, socioeconomic factors, and political issues should be keenly addressed and widely explored. Even with the understanding that land-use activities affect soil erosion, land use activities alone will not fully address the issues of soil erosion independently. Several factors need to be explored that will enable and facilitate the connection, inclusiveness, and contribution of soil erosion based on various factors. Local community members should engage in socio-economic and land use activities that affect their environment such as: soil erosion. In short, soil erosion lessons from the chapter include:

- ***The need to manage land use activities***: All land use activities from the settlement, deforestation, development for human enrichment and agricultural activities have a certain implication on soil erosion. The alteration of the natural environment on its own creates a disturbance on the environmental ecosystem. The need to please other certain necessities has some gross impact on the environment. Environmental implications in both developed and developing countries have illustrated that natural environment alteration has detrimental implications on the environment and in most instance causes soil erosion and the development of gullies.
- ***Common land-use change can be defined over time***: From the observed land-use change case studies, central to the story is that soil erosion is a natural process. However, it is accelerated by human factors. Climatic conditions and topographic landscape have a normal role to play in soil erosion yet the interference of human activities, accelerate the rate of soil erosion in both developing and developed countries. Conversion of forestland into agricultural areas has increased surface runoff and soil erosion; perpetuating the problem of soil erosion in many countries. An increase in population has resulted in the growth of cities t which has caused an increase in surface runoff and soil erosion.
- ***Soil structure and chemical composition***: Variation in soil structure and chemical composition affects soil erosion. Deterioration of the soil structure as observed by many studies, increased the risk of poor plant growth and soil erosion. Studies have also indicated a poor water holding capacity due to the structural and chemical disturbance of the soil, which in most instances leads to soil erosion. While the availability of forest improves the chemical and physical structure of the soil, interference of human activities decreases the soil structure of the soil.

A combination of various dynamic factors can cause changes, however a change in one aspect can also lead to changes in other neighboring factors within the same environment. Different dimensions of spatial changes lead to negative and positive changes in land use. However, certain changes increase the rate of soil erosion. Land use activities intertwined by socio-economic factors, climatic conditions, physical and chemical structure of the soil has a lot to contribute to the process of soil erosion.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents techniques and procedures used. It explains the application of various methods for data collection and analysis. It also explains the different techniques that were applied to gather data that address the objectives of the study.

3.2 Research Design

The research used a mixed-method, which involved both quantitative and qualitative research design such as application of GIS, laboratory analysis, and questionnaires. This mixed approach was employed in a complementary way to yield an in-depth analysis of a complex land use land and cover change and soil erosion interaction (Figure 3.1). To classifying land use and land cover, changes were observed in agriculture, built-up areas, and change in the forest area of the study. This was done to analyse the degree of soil erosion in land use land cover change (Figure 3.1).

In determining theimpact of soil fertility of different land use on soil erosion, soil samples were collected from various land use activities. In assessing the influence of soil management strategies on soil erosion, questionnaire was used within the study area (Figure 3.1).

The ARCSWART model was used within the study. This involved the use of parameters such as climatic variables (precipitation, humidity), soil type, and surface runoff, baseflow, and sediment yield obtained from the study. This was done to model soil erosion within the Nzhelele Valley and to assess the erosion risk (Figure 3.1).

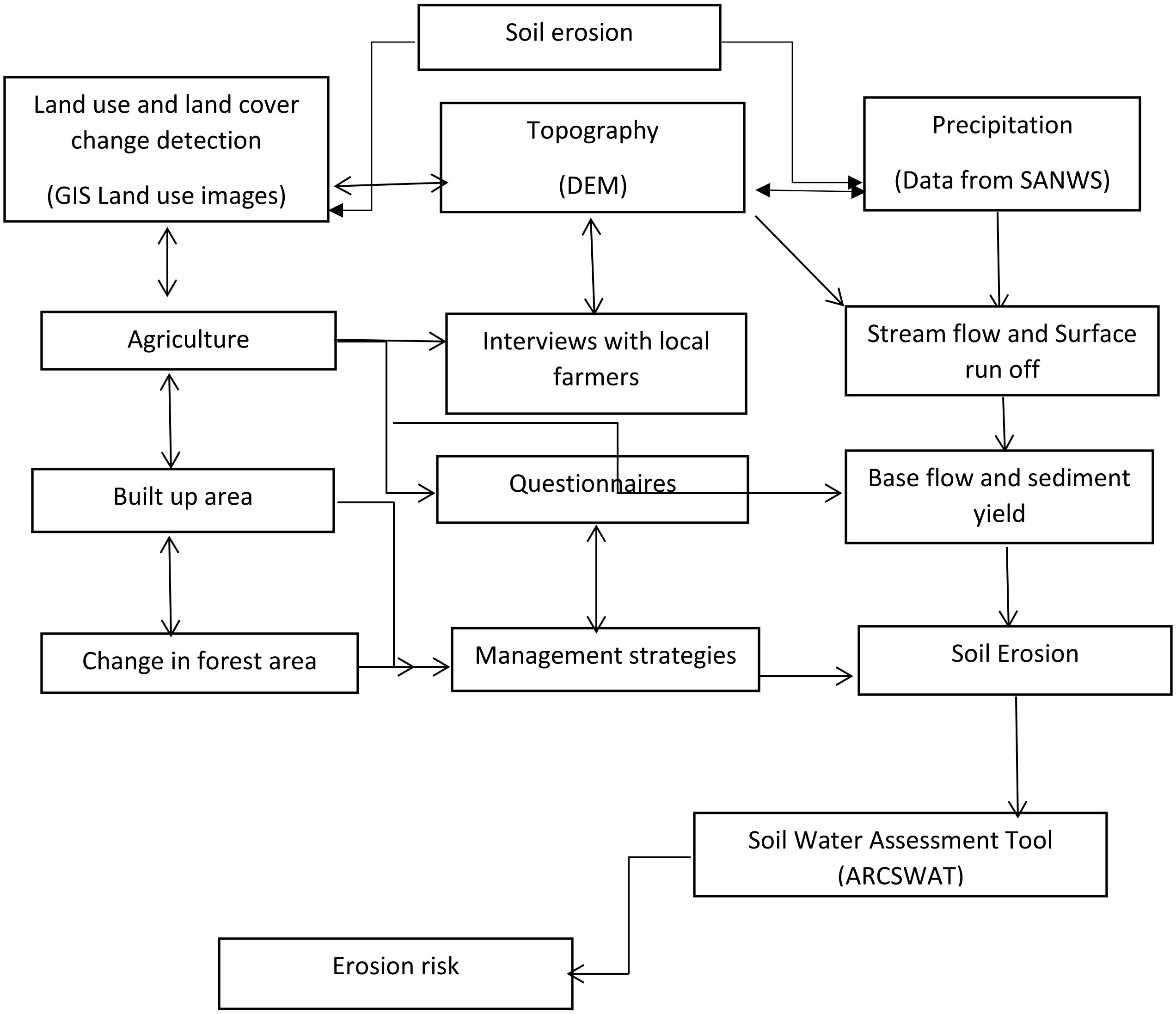

Figure 3.1 Research design

3.3 Sampling Method and Size

The sample size involves entities within a subset of the entire population, which is a crucial figure of the study in which the aim is to acquire a reference about the population; a bigger sample would produce more significant results. The study draws a systematic sample from the Nzhelele Valley. The farms were numbered, selected every 3rd farm for the distribution of research questionnaires. These farmers were identified through referrals from the previous recruit of the study samples. With a target population size of 657 farmers registered under their local farmers union. The study used Slovin's formula (Sunarsi, 2020), below to determine the size of the sample from the target population of the farmers n = sample size of the population.

N= population size

e = accepted level of error set at 0.05.

$$n = \frac{N}{1 + N \times e^{2}}$$

$$n = \frac{1314}{1 + (1314 \times (0.05)^{2}}$$

$$= 1314/\,(1 + 2.62)$$

$$1314/3.62$$

$$= 362.98 + 29 \text{ therefore sample size } (n) = 392$$

A 10% (29) was of the calculated sample size was added to create room for non-responses. The study used a stratified random sampling technique by dividing groups based on their villages. A systematic sampling technique was used to select farm numbers. Furthermore, to find K, the total number of the farms in the study area was divided by the sample size giving the interval value: *K value = 1314 /398 = 3.*

3.4 Data Collection

The study links sections of specified themes below to the data collection methods.

3.4.1 Objective 1: Assessment of Land Use and Land Cover Change

Landsat 7 and 8 images obtained from the Department of Lands and Rural Development of South Africa were used to assess land use and land cover changes. The land use and land cover change analysis was based on a set of four images for the years 2005, 2010, 2015, and 2019. The associated results from this data collection method are found in chapter four.

The Landsat Collection 1 Data with a spatial extent of 180 x 180 km for each Path/Row were re-projected into the same spatial extent and data dimension to make them comparable. The presents of cloud and cloud shadow can result in sudden changes in reflectance and have severe effects on the consistency of LTS. Screening of clouds and cloud shadows in Landsat was done using Fmask 4.0 to improve cloud shadow detection accuracy and separating water and land.

The characteristics of the collected images and sources were geographic coordinates referenced in Hartebeesthoek 1994, processed, and analysed using ArcGIS software 10.2. Due to the different contrast levels, the 2005 and 2019 images were cross-referenced with topographic representations. The supervised classification analysis was conducted using fieldwork as a control to integrate images from different sources as recommended by Rezenstein and Karneili (2011).

A total of 33 specified various pixel values or spectral signatures that were associated with each class were chosen. This was done by selecting representative samples of a known cover type (Training sites). The computer algorithm then used the spectral signatures from these training areas to classify the whole image. The maximum likelihood classification was used. The use of maximum likelihood classification gave a greater efficiency and better numerical stability taking advantage of the properties of the specific estimation problem. It also returned explicit confidence interval. This classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Each pixel is then assigned to the class that has the highest probability. The classes that were selected included forest, bare land/built-up area, grassland, and agricultural field.

Software 10.2 was used to process images that were later visually interpreted. Using the supervised approach digital image classification was done with the true colour composite of the RGB band on the satellite images. Different image enhancements were used to ensure a good visual interpretation of the satellite images.

- **Accuracy Assessment**

Accuracy assessment is an important validation technique (ground-truthing), where there is a comparison between the accuracy of the satellite image and the ground-truthing of an area (Congalton and Green, 2009). This study undertakes the accuracy assessment of the classified image to identify the level of agreement of classified images with a set of reference data. This was carried out using 33 ground-truthing regions of interest for 2005, 2010, 2015, and 2019 respectively. The validation of the region of interest used for 2005, 2010, 2015, and 2019 was acquired through visual interpretation based on the local knowledge of the study area referring to historical Google Earth Images, and those for 2019 were acquired from ground-truthing undertaken in the same year. Statistical comparison between reference data and the classified images was performed using error matrices. The Kappa (K) coefficient and overall accuracy (Producer and User accuracy) were computed for all supervised classification using an error matrix.

- **Analysis**

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

3.4.2. Objective 2: Influence of Soil Management Practices on Soil Erosion

A semi-structured questionnaire and observations were used to determine the influence of soil management practices on soil erosion. Data was collected from small-scale farm holds in Nzhelele Valley with the help of research assistances. Nzhelele Valley was divided into two sections for data collection, Makhado, and Musina section. A total of 392 questionnaires were distributed within the Makhado and Musina sections of Nzhelele Valley. The associated results from this data collection method are found in chapter five.

An inventory within the farmers showed the following main land use management strategies such as terraces (length of the terraces), cut-off drains, and manure (organic and inorganic fertilizers). The quantity of organic fertilizers was obtained by asking farmers how much manure they applied within each farmland. Other strategies that were also considered include slope, type of soil, soil fertility, the technology used, type and availability of labor, and accessibility of programs and training. These values were converted into standard units to grade and give value to the management strategies within each farmland (Adimassu *et al*., 2012).

Calculations were based on the observation when converting the farmer's strategies into standard units: (i) 2 m terraces= 1 unit and 6 m terrace = 3 units, 20 kg manure or compost = 1 unit and 60 kg manure = 3 units. (For every 2 m terrace constructed by the farmer, one unit of land management strategy was given to the farmland, and for 6-meter terrace three units were given to the farmland). The land use-management strategies were obtained by summing up the soil conservation for each farmland.

Using the Factor analysis and Spearman Correlation Coefficient farm holds were categorized into three categories (low, medium, and high) as shown in Table 3.1. Characteristics from the farm holds were considered through observation and information from the farm owners. A total of 14 characteristics were considered for statistical analysis purposes and were grouped into 4 classes.

Table 3.1 Description of farm household characteristics considered.

Farm characteristics considered
1. Topographic structure of the field (flat; medium or steep slope)
2. Size of the farm- the total area of the farm in hectares (>1; 1 to 2 or <2)
3. total number of farms within the study area (>1; 2to 5 or <5)
4. Type of soil type (Soil depth if it's shallow; medium or Deep)
5. Soil fertility (soil fertility quality i.e. low, medium, or high)
6. Type of soil erosion (vulnerability to soil erosion i.e. low; medium or high)
7. Availability of manure (the type of manure and its accessibility low; medium and high)
8. Accessibility to credit facilities (low; medium or high)
9. Availability of income (Low; Medium or high)
10.Programs for land use management (Low; Medium or high)
11.Available training on land use management strategies (low, medium, or high)
12. Availability of labour (low, medium, or high)
13. Training and management accessibility (low; medium or high)
14. Age of the farm owner (between 20 to 30; 30 to 45 or <45)
15. Equipment used for land management (Low; medium or high)

- **Analysis**

Exploratory factor analysis was used to identify environmental-economic factors on land use management strategies. Exploratory factor analysis makes interpretation of salience very straightforward, eliminates cross-loading acceptability debates, and often makes the characterization of a factor somewhat easier.Variables were grouped based on their inter-correlation among farm households. The Varimax orthogonal rotation was utilized to obtain a rotated component matrix, which assists in interpreting environmental-economic factors. Variables were retained due to a factor loading of 0.4 or more (Field, 2005 and Kessler, 2006) using the screen plot test. To identify determining factors at householdlevel, Pearson correlation was used between household investmentin land and these household scores for each production domains. Spearman correlation was used between land use management strategies investment and scores for each environmental-economic factor to identify determining factors. The level of significance was set at 0.05.

3.4.3. Objective 3: Different Land Use Practice Impact on Soil Fertility

Soil organic matter, soil pH, nitrogen, and phosphorus content were measured to assess the impact of different land-use practices on soil erosion. All the analyses were done in triplicate and the average value was taken (Appendix 7). The associated results from this data collection method are found in chapter six.

To collect soil samples from Nzhelele Valley, the study used the Sampling Design Tool of ArcGIS 10. The tool-assisted in selecting the soil sample points within the study area. Firstly there was the installation and setup of the samplingTool.10.esriAddIn to commence the ESRI Add-In Installation Utility and later installed in ArcMap toolbar. The procedure generated stratified random placed points within the defined polygon data set. The procedure was optimal due to little information on spatial patterns of the study area. A total of 78 soil samples were collected from the selected study area using the Sampling Design Tool of ArcGIS 10. (Appendix 4). For non-regular areas without delineated plots, houses were digitized by referring to the roof and their geographic coordinates were integrated into the GIS for the sampling. Soil samples of 100g each at 10cm depth were collected from different land uses identified within the study area using auger holes. A 10cm depth provides valuable information of soil resource condition and constrains. Collected data was send to the Agricultural Research Council (ARC) laboratory in Pretoria for analysis.

- **Soil organic matter content**

To determine the organic matter contains a total of 26 soil samples were collected at 100g each. Samples were pre-weighed (Initial weight) at 20g per sample before heating it in an oven. The samples were then placed in an oven at a temperature of 110 ºC degrees for 16 hours to dry up, remove all the moisture within the soil, and were left to cool to room temperature. The soil samples were again placed in an oven at 450 ºC for 4 hours to incinerate all the organic carbon (net weight) and were left to cool for 5 hours. After cooling off the soil samples were weighed again to find the new weight. The following equation was used to determine:

$$\frac{Initial\ wt - new\ wt}{Initiak\ wt} \times 100. = \text{Organic matter}$$

Initial wt = initial weight

New wt = New weight

- **Soil pH**

The collected 26 soil samples of 100g were sieved to remove twigs and leaves. From each 100g soil sample, 20g of soil samples were measured, and placed into beakers, followed by heating in an oven for 24 hours at 110 degrees Celsius. This was done to burn all the organic matter that might influence the soil pH.

The soil samples were scooped into three different paper cups where 10ml of distilled water was added to each sample. A pH meter (Crison MM40+) calibrated over the appropriate range using standard buffer was then used to determine the soil pH.

- **Nitrogen (N) and phosphorous (P)**

To measure phosphorus and nitrogen, 26 soil samples of 100g were collected, one gram of soil was scooped from the 100g collected soil sample and air-dried. The sample was then mixed with 10ml of extractant solution (solution consisting of 0.025 normal HCI and 0.03 normal NH4F) and shaken for 5 minutes. The extracted phosphorus was then treated by adding moiybadate ascorbic acid reagent. To measure the available Phosphorus, a Brinkman PC 900 colorimeter was used.

For nitrogen content, soil samples were dried at 55^0C and ground to pass a 12-mesh screen. From each 26-soil sample of 100g, 0.5g was weighed into a clean dry digestion tube. Within each tube, one (metal catalyst) digestion tablet and 3.5 ml of H_2SO_4 were added. The tubes were then placed in a block digester at 380^oC for 4 hours and were allowed to cool for 15 minutes. De-ionized water was filled to 50,0ml and 7ml of the digested solution to FIA tube. A flow injection analyzer was then used to measure nitrogen concentration.

- **Analysis**

Analysis of variance (ANOVA) was used to analyse the differences in soil fertility in various land use areas. Data were first checked for normality and homogeneity before variance analysis. The analysis of variance was used to examine the difference in soil fertility among land use/land cover types at P< 0.05 significance level.

3.4.4 Objective 4: Modelling Land Use and its Impact on Soil Erosion

ARCSWAT (Soil and Water Assessment Tool with an interface of ArcView Geographic Information System (GIS)) was used to model soil erosion on land use and land cover. Input data such as land use, soil type, and weather components are required to run the model. Missing data from the observed records of weather data were simulated using weather simulation components of ARCSWAT. Based on the Digital Elevation Model (DEM), Swat subdivided the total watershed into sub-watersheds, in order to simulate surface runoff through channel networks in the sub-watershed. The sub watersheds were divided into multiple homogeneous Hydrological Response Units (HRU) (Welde, *et al.,* 2017). Climate parameters consisted of rainfall, temperature and wind speed. Surface runoff and sediment yield were computed at each HRU level using the SWAT tool and rooted to the watershed outlet through stream network. The Soil Conservation Service (SCS) Curve Number (CN technique was used to calculate the daily surface runoff (Williams *et al*., 2012). The SCS CN based on William (2012) computes daily rainfall access using the antecedent rainfall dependent CN values and links with the soil moisture (M) as $M = S_{abs} - S$. Where S_{abs} is absolute potential maximum retention equal to 20 inches.

- **Model Input**

ARCSWAT was used to simulate soil erosion at a sub-watershed level. The study area was delineated using ARCSWAT in Digital Elevation Model (DEM). A 30 m resolution DEM was downloaded from the STRM digital elevation data (strm.csi.cgiar.org/strmdata/). Land use and land cover was obtained from the Global land cover soil types. The soil map of the study area was sourced from the Department of Land and Rural Development and was digitized for further reclassification

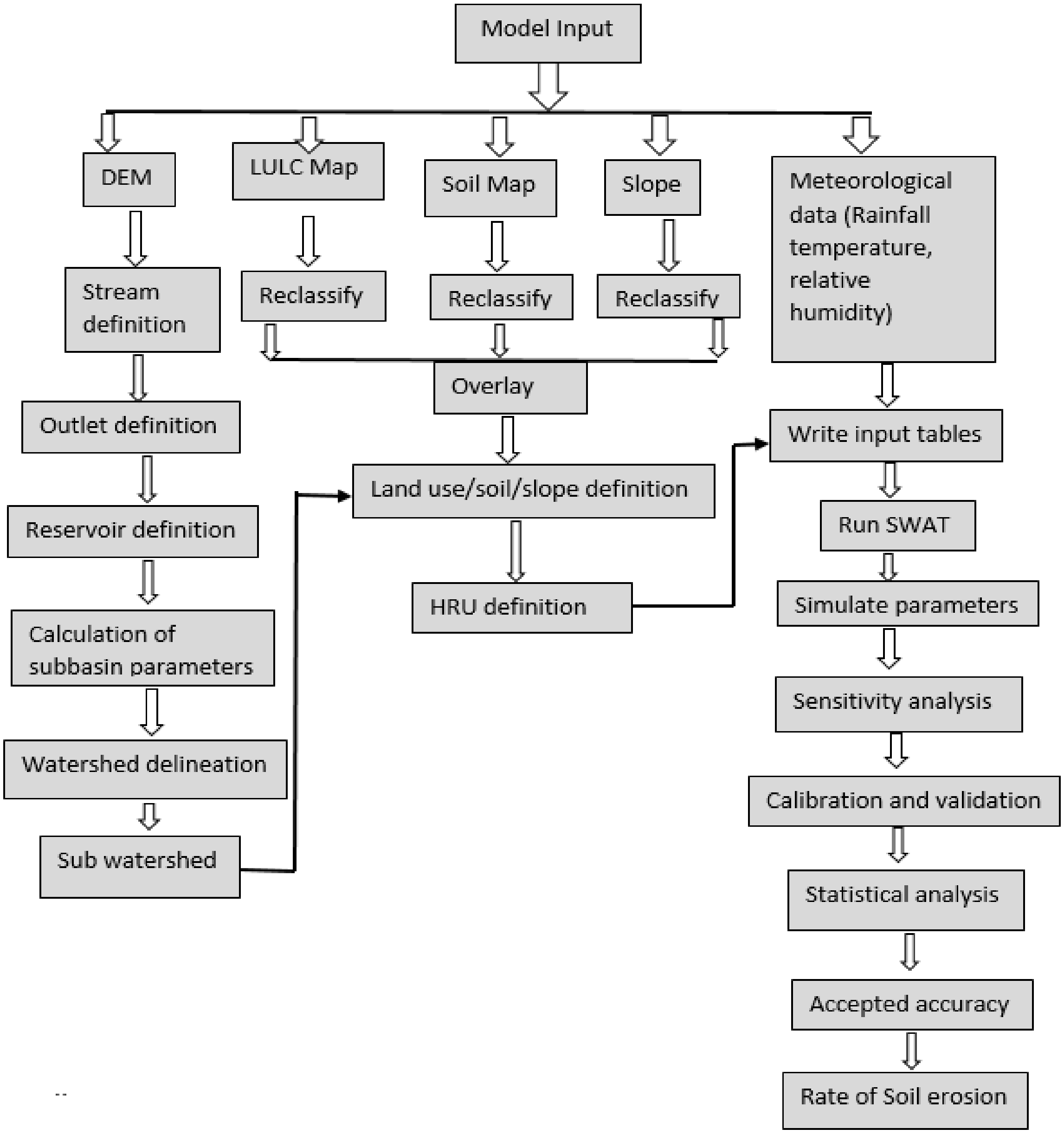

Figure 3.2: Algorithm showing how ACRSWAT was used.

- **Sensitivity Analysis, Calibration and Validation**

Sensitivity analysis for data that was replicated involved calibration and validation, which was carried out using Latin Hypercube and One factory At a Time (LH-OAT) as per the Griensven and Meixner (2006) sampling method. The Sum of Squared Residuals (SSR) was used as an objective function for sensitivity analysis.

Calibration, which in this case refers to the process of modifying sensitive input parameters, was carried out for the simulation of discharge and sediment load of the model. The hydrological component was calibrated manually, to optimize simulated discharge based on daily observed data.

Validation was performed without changing the values of calibrated parameters, to verify the model's ability to simulate the discharge at the same sub-watershed. Same time calibration and validation were selected for sediment load simulation based on the available data at a year time step by SWAT model on the study area. The model was run several times to get optimum calibrated values of the input parameters

The statistical indices, Percent Bias (PBIAS), Correlation coefficient (CC), Nush-Sutcliffe Efficiency (NSE), and Observations standard deviation ratio (RSR) were used to evaluate the performance of SWAT for accuracy and consistency of the prediction of discharge and sediment load.

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (O_i - P_i) * 100}{\sum_{i=1}^{n} (O_i)} \right] \quad \text{EQ (1)}$$

$$NSE = \frac{\sum_{i=1}^{n} (O_i - \bar{O})^2 - \sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \quad \text{EQ (2)}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \left[\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2}} \right] \quad \text{EQ (3)}$$

$$CC = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} (O_i)} \quad \text{EQ (4)}$$

Where *O* observation for the constituent being evaluated, *P* is the simulated value for the constituent being evaluated, Ō is the mean of observed and simulated data for the constituent being evaluated, and n is the total number of observations during the simulated period. The rational method was used to simulate the Peak rate of runoff and the Penman-Monteith (Allen *et* *al*., 1989) method was used to calculate the potential evapotranspiration (PET). The Hydrological cycle was simulated based on the following water balance equation:

$SW_t = SW_0 + (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$

Where SW_t is the final soil water content (mm) at a time *t* in days

SW_o is the initial soil water content (mm)

R_{day} is the amount of rainfall per day *i* (mm)

Q_{surf} is the amount of surface runoff *i* (mm)

E_a is the amount of evapotranspiration per day *i* (mm)

W_{seep} is the amount of water entering the vadose zone from the soil profile on the day *i* (mm)

Q_{gw} is the amount of groundwater per day *I* (mm)

To predict soil erosion, Universal Soil Loss Equation (USLE) was used in SWAT at HRU level as ero= 1292 * EI_{USLE} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG

Where: ero is the quantity of eroded soil

EI_{USLE} is the rainfall erosion index (0.017 m-metric ton cm/(m2h))

K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m2h/(m3-metric ton cm))

C_{USLE} is the USLE cover and management factor

P_{USLE} is USLE support practice factor

LS_{USLE} is USLE topographic factor

CFRG is the coarse fragment factor

3.5 Summary

This chapter has illustrated the methodology used in the research, as well as, the sample frame and size used to administer the survey. The main aim and objectives of the study were also articulated in this chapter. The study's objectives included classifying land use and land cover change using GIS from 2005 to 2019 in Nzhelele Valley; assessing the influence of soil management strategies on soil erosion, determining the impact of soil fertility of different land use on soil erosion, and modeling soil erosivity on land use areas of Nzhelele Valley (Table 3.2).

The central notion of modeling soil erosion on land use/land cover has been discussed. Methods of data collection that were used include the use of semi-structured questionnaire and observations, measurements of soil organic matter, soil pH, soil nitrogen, and phosphorus content; and the use of ARCSWAT (Soil and Water Assessment Tool with an interface of ArcView Geographic Information System (GIS)). The key articles and journals that have informed this study were duly reviewed. The methods used in this research complement each other through the different objectives, which are connected to the main aim of the research. All the structure and organization of the methodology had the total effect of increasing the quality of data and information collected for it to be analysed and presented as research outcomes (Table 3.2).

Table 3.2 Description of data collection methodology

Objective	Method of data collection	Method of analysis
Assessment of Land Use and Land Cover Change	GIS and Remote Sensing	A supervised analysis in ArcGIS
Influence of Soil Management Practices on Soil Erosion	Semi-structured questionnaire and observations	Exploratory factor analysis
Different Land Use Practice Impact on Soil Fertility	Soil measurements for organic matter, soil pH, nitrogen, and phosphorus content.	Analysis of variance (ANOVA)
Modeling Land Use and its Impact on Soil Erosion	ARCSWAT (Soil and Water Assessment Tool with an interface of ArcView Geographic Information System (GIS)) was used to model soil erosion on land use and land cover.	Calibration and validation using Latin Hypercube and One factory At a Time (LH-OAT)

CHAPTER 4: LAND USE AND COVER CHANGE IN NZHELELE VALLEY

4.1 Introduction

This chapter focuses on presenting and discussing the data collected on land use classification and change detection using ArcGIS software. GIS was used to identify the spatial extent of land use and land use change. The results of land use mapping of Nzhelele Valley would provide information on aerial distribution of land use categories, identification and estimation of land use changes.

The chapter also shows the analyzed data on land use and land cover change in Nzhelele Valley from 2005 up to 2019. The intention of the discussion in this section is to identify the existing land use/cover change and to highlight the major trends in changes of land use in the area of study. Discussions in this chapter mainly focus on the land use and land cover classification in Nzhelele Valley. The discussions of the findings were arranged into different themes in relation to the findings. Discussions presented in this chapter are mainly summaries of a large quantity of data that has been presented in data analysis of this study.

- **Overview of Land Use and Land Cover Change**

In order to understand the trends and changes in land use /land cover, it is necessary to conduct an evaluation assessment of change over a period of years. This shows the extent to which changes have occurred in order to identify the rate at which the identified land use and land cover is influencing change in this area. The intention is to identify the trends of land use/land cover change and the existing trends of land use/land cover. In turn, highlighting their major implications towards environmental change.

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 level was greater than 5% (0.05). For the purpose of the study, an image from 2005 (Figure 4.1) was therefore the master image with which the subsequent changes are compared. The images 2010 (Figure 4.2), 2015 (Figure 4.3), and 2019 (Figure 4.4) were regarded as the images showing changes that took place.

4.2 Land use and Land Cover Classification for Nzhelele Valley 2005 to 2015

The satellite image was corrected for atmospheric, sensor, and illumination variance sources through radiometric calibration procedures. Satellite images tend to have relatively accurate location information, but might need slight adjustments to line up all GIS data point (Pardini et.al. 2003). The land use and land cover classification 2005 (Figure 4.1) shows different land use classifications. The image shows four-land use and land cover classifications, which include agricultural fields, bare land/built up area, grassland, and forest. The land use and land cover for the Nzhelele Valley was classified into different colors, which demarcates the area covered by each of the classes (Figure 4.1). Each of the land use and land cover classes as illustrated in Figure 4.1 demonstrated the extent and coverage of the entire area of Nzhelele Valley with each land use and land cover occupying the study area in different patterns and direction.

More-so, Figure 4.2 shows land use and land cover classification in 2010 for Nzhelele Valley. The land use and land cover for the Nzhelele Valley was given different colors (agricultural fields, bare land/built up area, grassland, and forest), which demarcates the area covered by each of the classes (Figure 4.2). Each of the land use and land cover classes as illustrated in Figure 4.2 demonstrated the extent and coverage of the entire area of study. With each land use and land cover occupying the study area in different patterns and direction.

Figure 4.3 illustrates land use and land cover classification of Nzhelele Valley in 2015. The image shows four-land use and land cover classifications. Each of the land use and land cover classes as illustrated in Figure 4.3 demonstrated the extent and coverage of the entire area of the study with each land use and land cover occupying the study area in different patterns and directions.

Lastly, results shown in Figure 4.4 illustrate land use and land cover classification in 2019 for Nzhelele Valley (Figure 4.4). The results given in Figure 4.4 illustrate the observed land use and land cover change for 2019, which is different from other observed years. The classes used within the study period shows various land use classes, ranging from agricultural fields, bare land/built up area, grassland, and forest. The classification was prepared to observe the changes that have occurred over the period of the study.

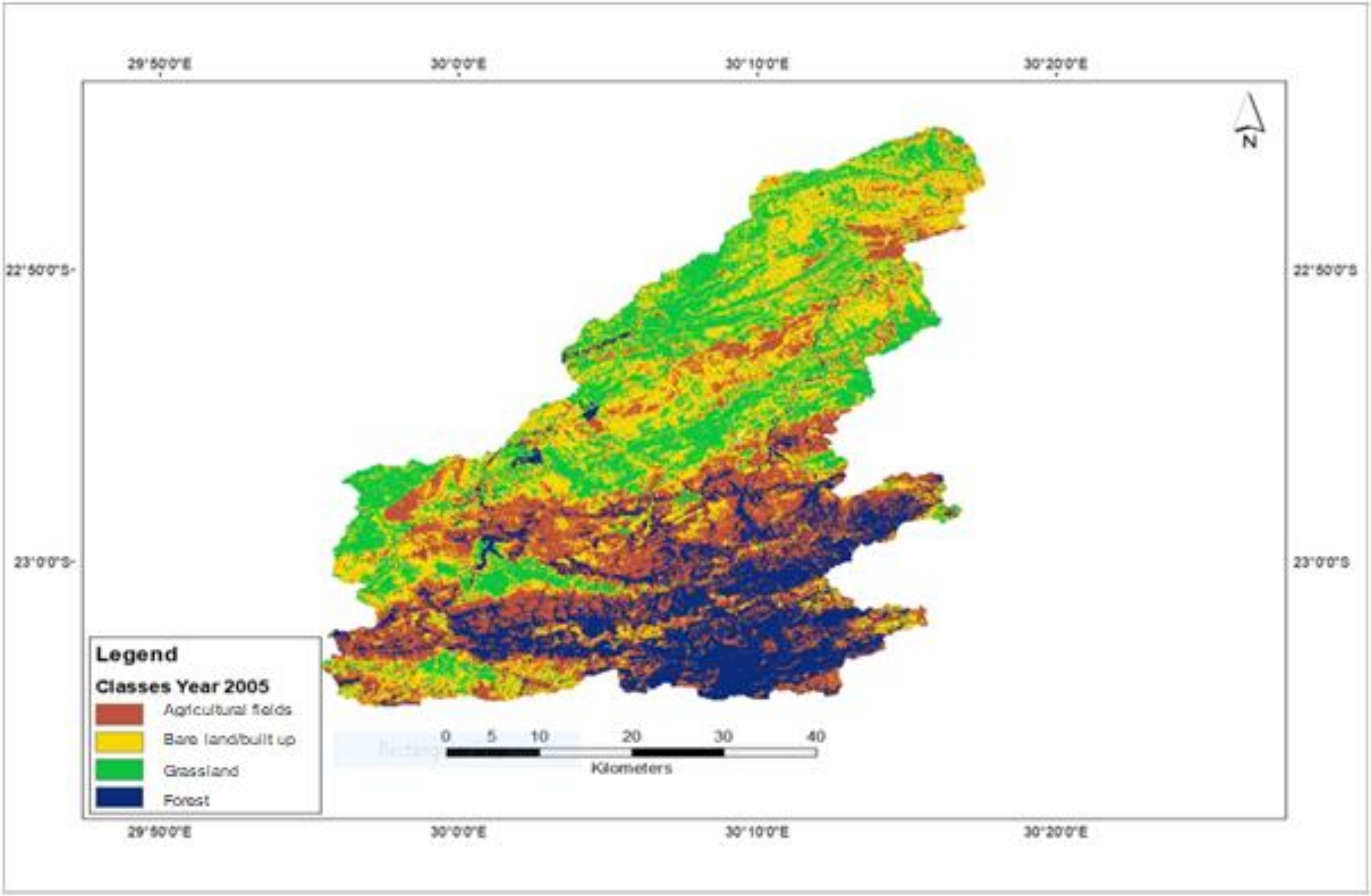

Figure 4.1: Nzhelele Valley land use and land cover classification 2005

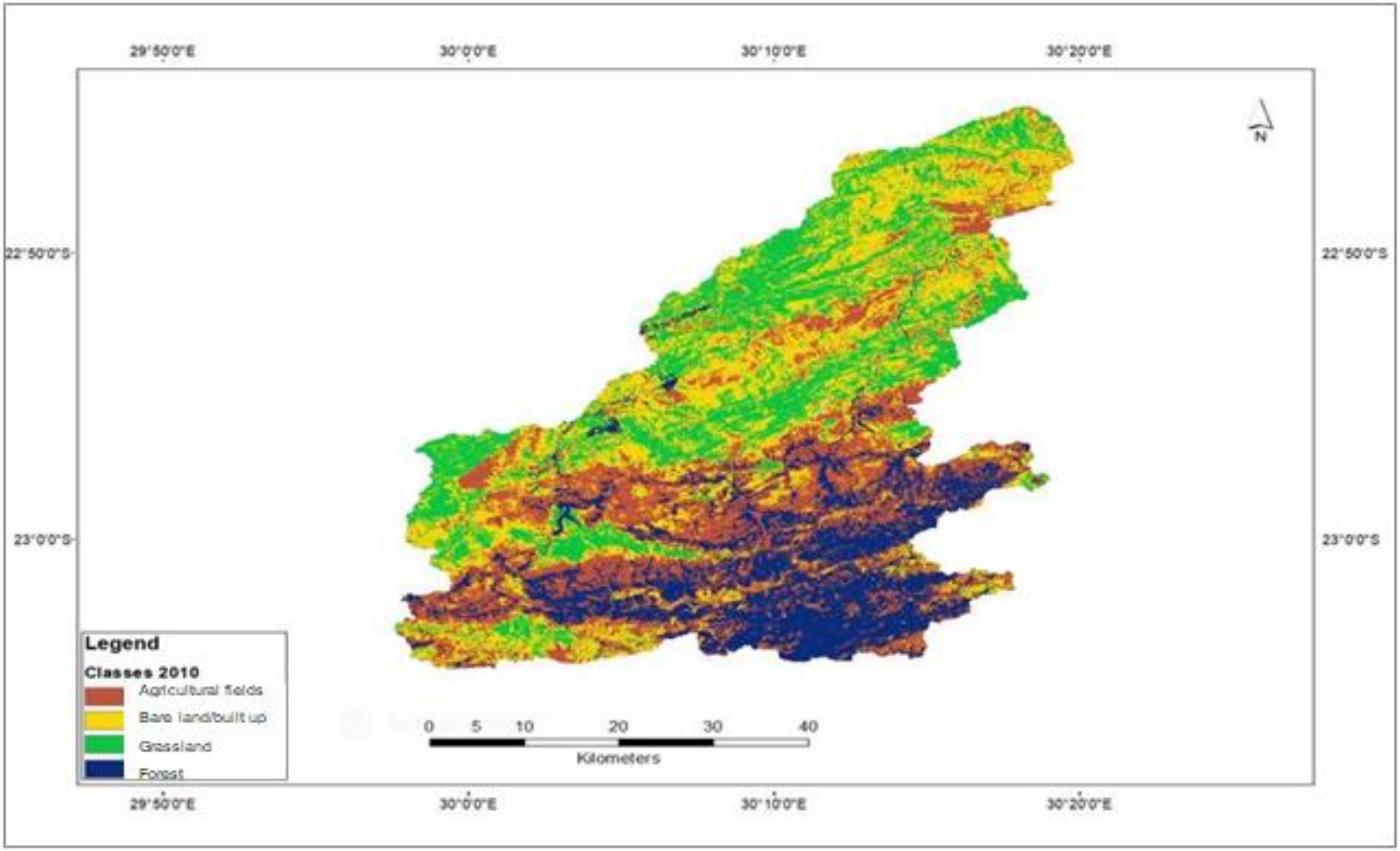

Figure 4.2: Nzhelele Valley land use and land cover classification 2010

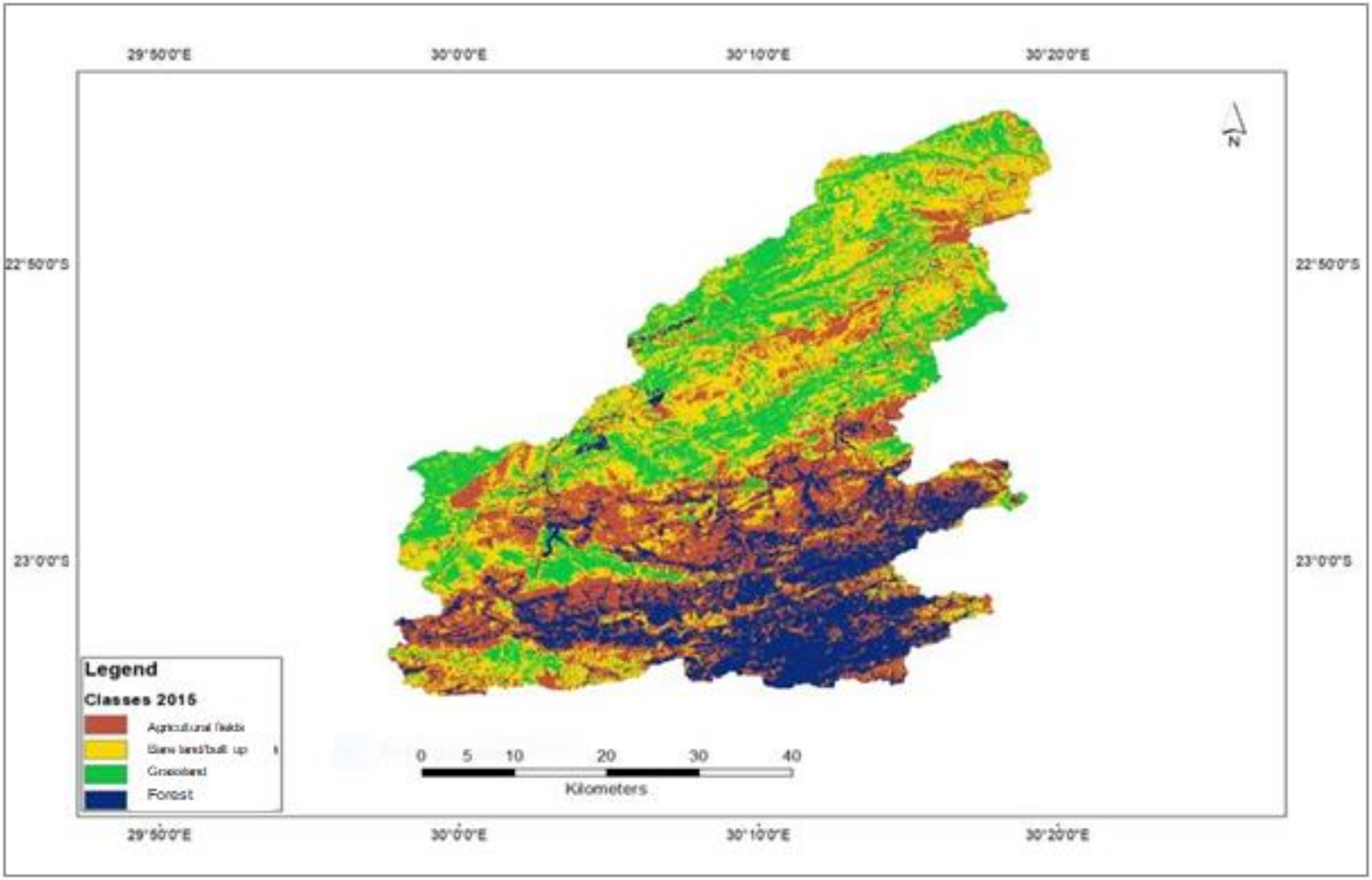

Figure 4.3: Nzhelele Valley land use and land cover classification 2015

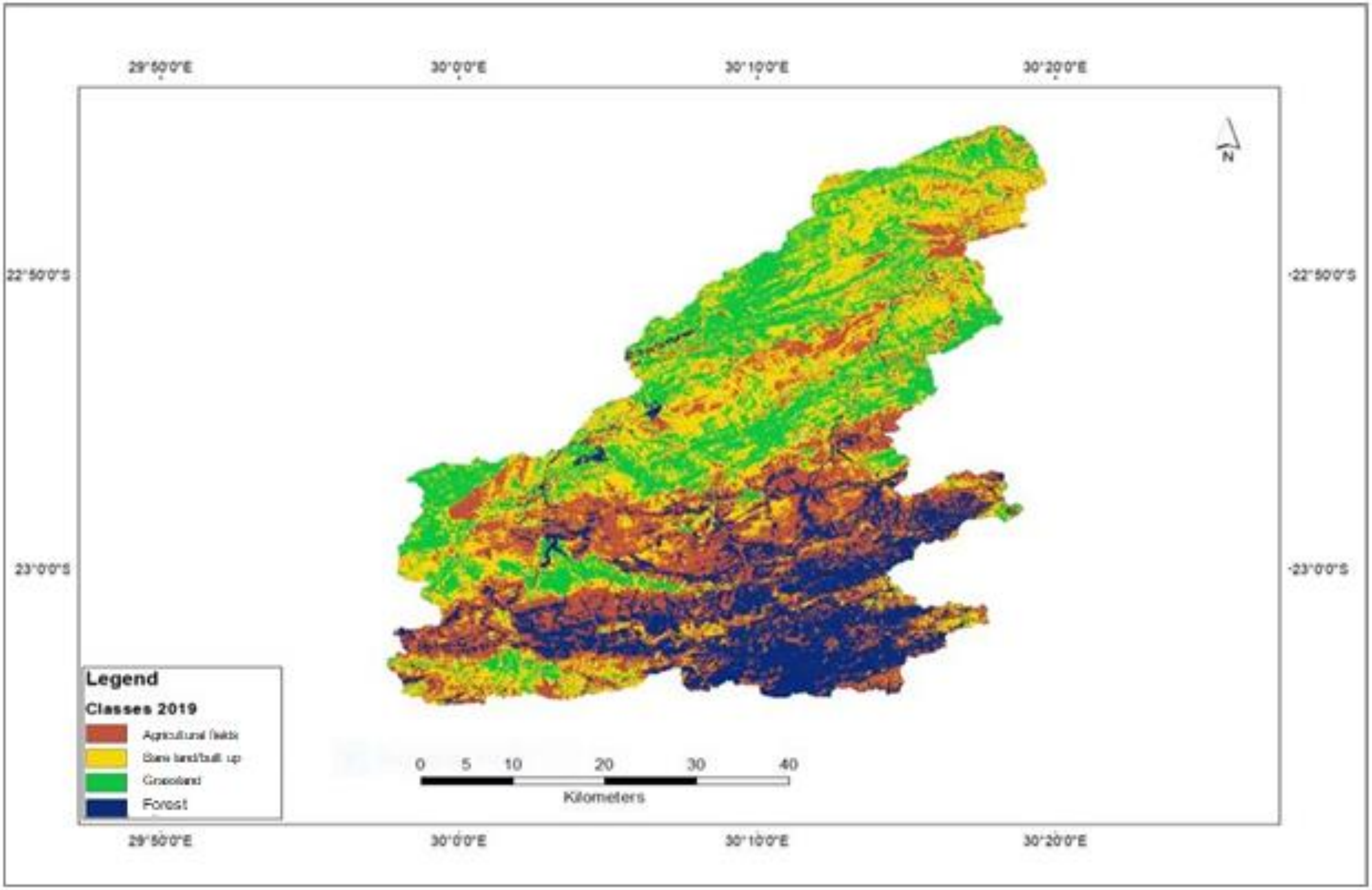

Figure 4.4: Nzhelele Valley land use and land cover classification 2019

4.3 Land Use and Land Cover Patterns over a Period of 14 Years in Nzhelele Valley

The result of land use mapping reveal an estimation of land use and land cover in the years 2005, 2010, 2015 and 2019. A total of four land use and cover categories were identified from the study area (Table 4.1). Results illustrate that, forest was the dominant (46%) land use/land cover in Nzhelele Valley among other categories in 2005. The second highest land use/cover was agriculture (36%). The Bare land/built-up area reveal the third in the dominance of land use/cover within the study area (14%), while grassland was the fourth land use/ land cover (4%) in 2005 (Table 4.1).

The results reveal that in 2010 land use and land cover classification, the highest land use category was forest land cover with 48%, having a 2% increase of from 2005 to 2010. Forest and tree plantation contributed much of land cover for forest classification category. The grassland had the least land cover within the study area (5%), observing a significant increase (1 %) from 2005 to 2010 (Table 4.1). The bare land/built-up area had observed no change, retaining similar land use/cover (14%) in 2010 same as that observed in 2005. Agricultural land use/cover observed a significant (3%) decrease from 36% in 2005 to 33% in 2010 (Table 4.1).

The results also illustrates that, there was significant change observed in 2015. With an increase in forest from 48% in 2010 to 58% (Table 4.1). Furthermore, an increase in grassland cover classification of (7%) was observed in the study (Table 4.1). However, the agricultural land use and land cover classification shows, a decrease (20%) during this period.

The result in 2019 reveals an increase in land use and land cover area for bare land/built up area (17%) (Table 4.1). Furthermore, an increase in agricultural field (25%) was observed during this period. The results reveal decrease in land use and land cover classification for forest from 58% in 2015 to 52% in 2019. This was also similar to grassland classification, which observed a decrease form 7% in 2015 to 6% in 2019 (Table 4.1).

Table 4.1 Land use/land cover classification for Nzhelele Valley.

Classification	**2005**	**2010**	**2015**	**2019**	**Total change**
forest	31%	33%	40%	36%	5%
Agricultural field	36%	33%	20%	25%	11%
Bare land/Built up area	14%	14%	15%	17%	3%
Grassland	19%	20%	25%	22%	3%

4.4 Change Detection in Land Use and Land Cover

The following discussions is based on the results presented above (section 4.3) on land use and land cover change in Nzhelele Valley that have occurred after a period of 14 years.

4.4.1 Impact of Forest-land Use and Land Cover Change on Soil Erosion.

Based on the study, the results reveals that there have been a significant land use and land cover change from the period of 2005 up to 2019 in Nzhelele Valley. The results indicate that forest significantly (5%) increased from 2005 up to 2019 (Table 4.1). Similarly, a study in Guadua forest in Colombia observed an increase in forest cover in the area between 1954 and 2009 with a 1.42% annual change rate (Quintero-Gallege *et al*., 2018). Increase in forest cover (from 46% in 2005 to 52% in 2019) reduces soil from erosion (Figure 7.4).

The results indicate that, over the period 2005-2019, a decrease in agricultural area (-11%) was observed simultaneously with increase in forest cover (+6%). This observation mirrors that of Rawat and Kumar (2015), who observed an increase in forest cover with a decrease in the agricultural area between 1980 and 1989 in Almora India, that have regenerated into forest area. Absorption of land use by forest cover, increases the soil organic matter (Forest land, 7.36%) of the soil and reduces soil erosion (Figure 7.4).

Change in agricultural land cover (-3%) from 2005 to 2010 resulted in increased land cover for forest (2%). Encroachment of forest in agricultural land use reduces soil erosion with more cover of forest; protecting vulnerable agricultural land use cover (Figure 4.2). Similarly, studies by Giest *et al*., (2006) and Lambin and Mayfroidt, (2010) suggest that, changes in forest cover; demonstrating nonlinear changes in land use is associated with a decrease in agricultural land use and land cover changes through a series of transitions that occur over time. Increases in forest cover (31% in 2005 to 36% in 2019) decreases the rate of soil erosion (Figure 7.4). A study by Wu *et al.*, (2005) and Adam, (2010) suggested that, increase in forest cover reduces surface runoff and soil loss. Forest area observes interception and absorbing rainfall kinetic energy protecting the soil from erosion (Bochet *et al*., 2006).

The increase in forest cover (5%) has been observed in Nzhelele Valley over the 14-year period (Figure 4.5). Similarly, these results can also be related to numerous studies, which indicated an increase in forest cover (Falcucci *et al*., 2007; Muchova and Tarnikova, 2018). Increase in forest cover (Figure 4.5) reduces the rate of surface runoff and soil erosion as demonstrated in Figure 7.4. Change in forest cover illustrates that, land use change in Nzhelele Valley, has influence on the decrease in agricultural land use (Figure 4.4). Areas with low-density forest cover have a high risk of soil erosion (Zare *et al*., 2017). Change in forest cover as observed in Nzhelele Valley provides a mirror indication of other parts of the many areas; since it is a common phenomenon in different areas (Loffe *et al*., 2012; Meyfroidt *et al*., 2016).

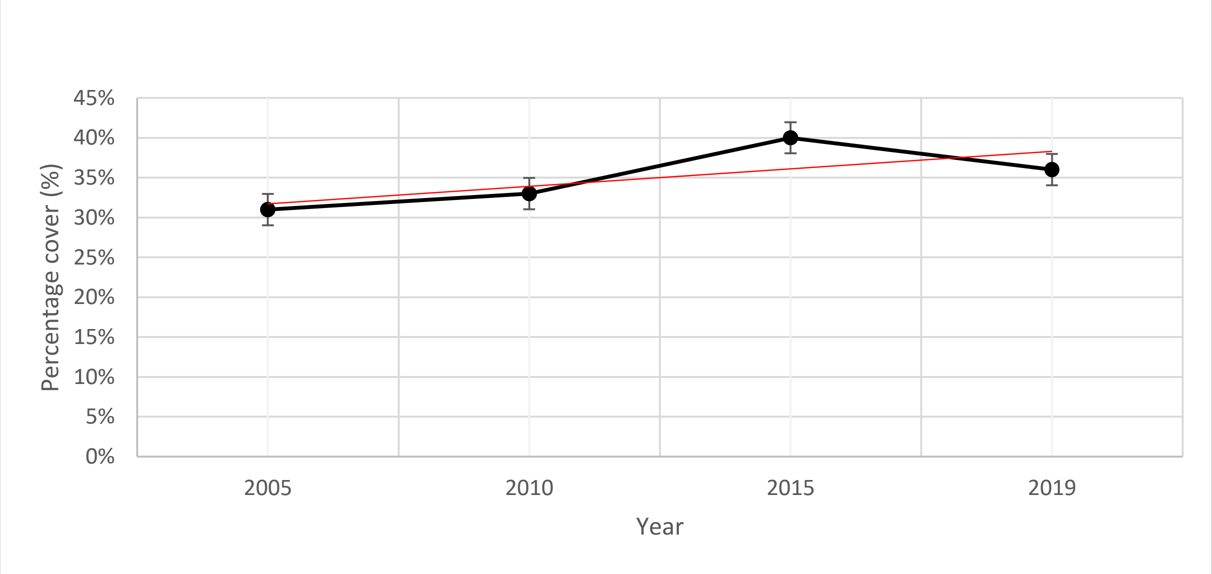

Figure. 4.5: Change in Forest area land use/cover from 2005 to 2019.

4.4.2 Effect of agricultural land use and land cover change on soil erosion.

Changes in agricultural fields were observed between 2005 and 2010 providing a negative trend (-3%) in land use and land cover change (Figure 7.4). A further negative change of -5% (Figure 4.6) which, is the highest change observed within the study within a period of 9 years (2010 to

2019). A significant change in agricultural land use and land cover from 36% in 2005 to 25% in 2019 shows an increase in soil erosion (Figure7.4) with a decrease in forest (Figure 4.6). A change in land use and land cover affects the soil organic matter (OM-1.32%) as shown in Table 6.1. Similarly, Ranzi *et al*., (2012) observed a decrease in agricultural land cover by 35% in the past decade.

The gradual decrease in agricultural land cover in Nzhelele Valley has been observed with a gradual increase in forest cover and soil erosion. Land use change is commonly experienced in Nzhelele (Agricultural field from 36%-2005 to 33%-2010 and Forest from 46%-2005 to 48%-2010 (Figure4 4.2)); increasing the vulnerability of the area to soil erosion. Land use and land cover changes and degradation is mainly characterized by low organic matter (Table 6.1). The results illustrate part of agricultural land use being converted into forest cover over time. Due to inappropriate agricultural land use in Nzhelele Valley.

Decrease in agricultural land (Figure 4.6) was caused by increase in built up, which observed an increase in land use land cover from 2005 (14%) to 2019 (17%). Decrease in agricultural land due to less productivity, changes the physicochemical soil properties (organic matter content (OM-1.32%) which strongly impacts the rate of soil erosion (Table 6.1). Furthermore, a decrease in agricultural land use and land cover may result in an increase in intensive agriculture, causing land degradation over time. This will cause a reduction of nutrients weakening the physicochemical and soil microorganisms, resulting in soil erosion (Huang *et al*., 2013).

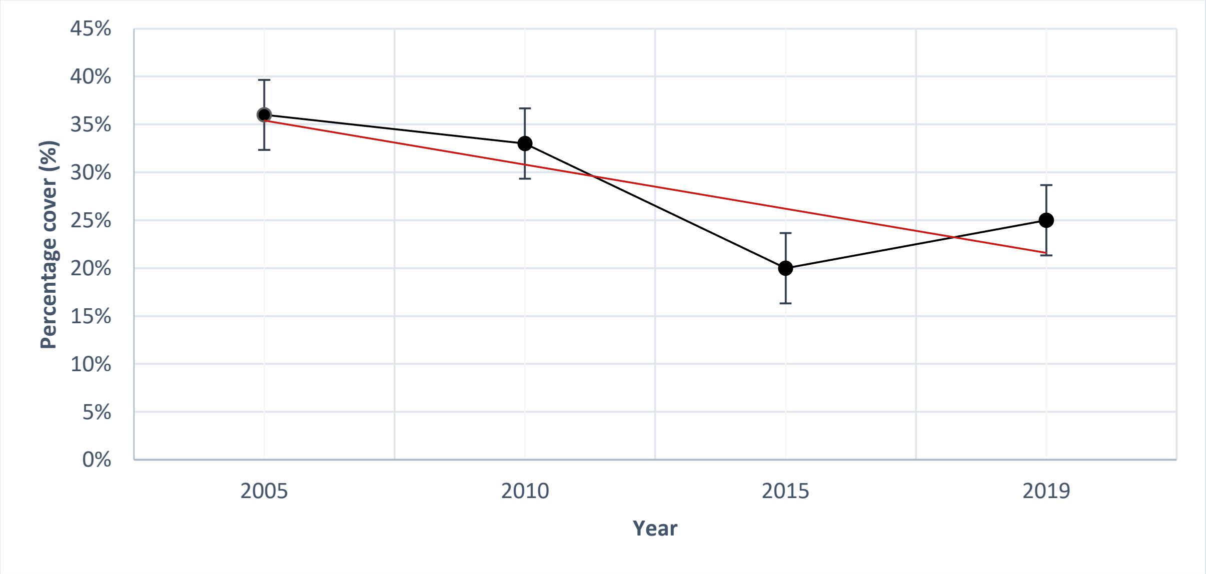

Figure 4.6 Changes in agricultural area land use/cover from 2005 to 2019.

4.4.3. Influence of Bare/built-up land use and land cover change on soil erosion

Results show that the built-up area within the study site remains stable within the first period of the study (2005 up to 2010) with a 14% land use and land cover area (Figure 4.7). The extent of change in human settlement especially in communal areas is invisible as development is influenced by economic developments, which are very rigid and slow in most instances. Economic and population growth provides for infrastructural development that leads to an increase in settlement area indicating to land use and land cover change.

The build-up area shows an increase in trend from 14% to 17% during the 2010-2019 period (Figure 4.2 and Figure 4.4). During this period, agricultural area is converted into built up (3% increase between 2005 and 2019) resulting in change of soil fertility structure and soil erosion. Due to low soil fertility, land use management strategies such as fallow, terraceing and application of manure were put in place (Table 5.1) A study by (Kaliraj *et al*., 2017) exhibits similar results in Kanyakumari, Kovalam, and South Thamaraikulam Indian where the marginal area of cultivable land use was converted into settlements resulting in increased pressure on coastal aquifer leading into groundwater contamination and seawater intrusion into inland aquifers as well as soil erosion. In addition, an increase in settlement (tarred roads, houses, and recreational areas) due to hard surfaces increases runoff generation that triggers soil erosion (Gholami *et al*., 2009).

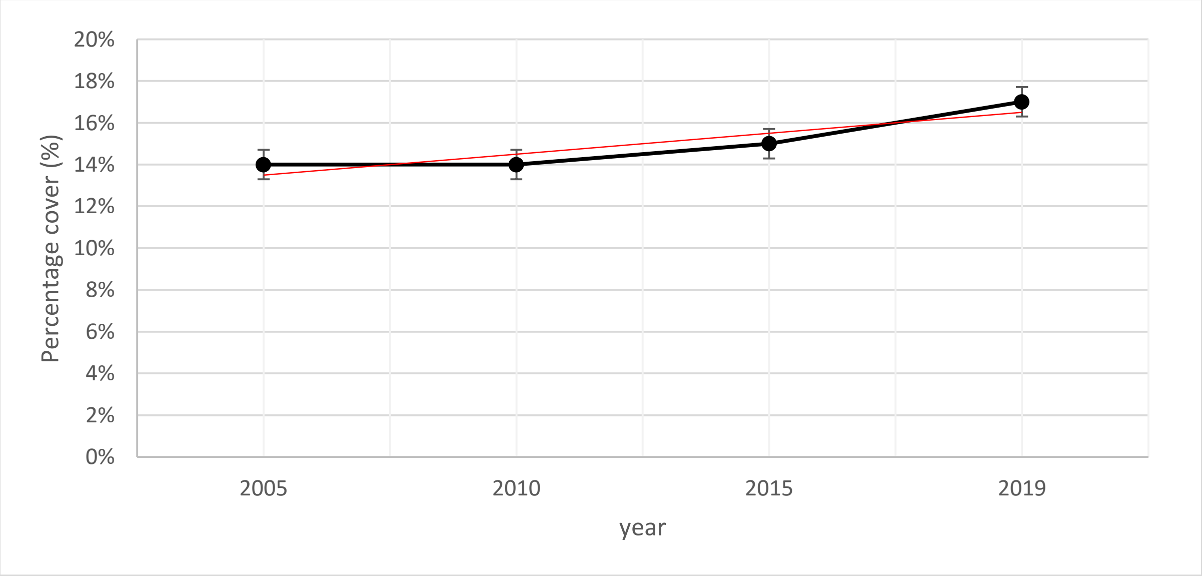

Figure 4.7: Change in bareland/built-up area land use/cover from 2005 to 2019

4.4.4. Influence of grassland on land use and land cover change on soil erosion

Results reveal that the grassland area within the study site remains stable within the first period of the study (2005 up to 2010), with a 14% land use and land cover area (Figure 4.7). The extent of change in human settlement especially in communal areas is invisible, as development is influenced by economic developments. These economic developments are very rigid and slow in most instances. Economic and population growth provides for infrastructural development that leads to an increase in settlement area, leading to land use and land cover change.

The grassland shows an increase in trend from 14% to 17% during the 2010-2019 period (Figure 4.2 and Figure 4.4). During this period, agricultural area is converted into built up (3% increase between 2005 and 2019) resulting in change of soil fertility structure and soil erosion. Due to low soil fertility, land use management strategies such as fallow, terracing and application of manure were put in place (Table 5.1). A study by (Kaliraj *et al*., 2017) exhibits similar results in Kanyakumari, Kovalam, and South Thamaraikulam India. In these three aeas, the marginal area of cultivable land use was converted into settlements, resulting in increased pressure on coastal aquifer, leading into groundwater contamination and seawater intrusion into in land aquifers and soil erosion. In addition, an increase in settlement (tarred roads, houses, and recreational areas) caused by hard surfaces, increases runoff generation that triggers soil erosion (Gholami *et al*., 2009).

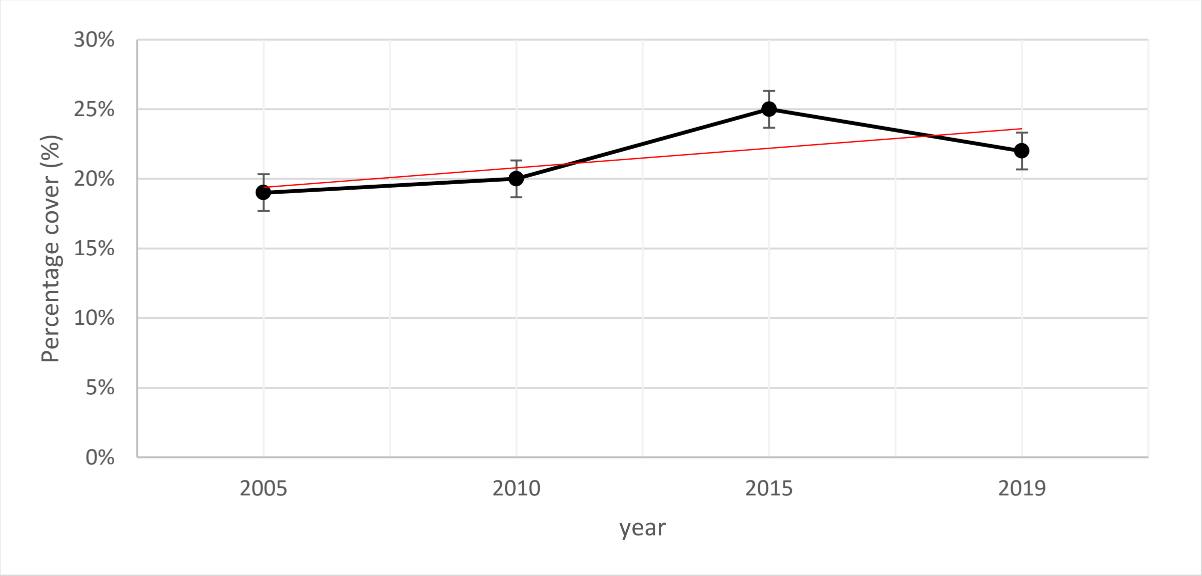

Figure 4.7: Change in grassland area land use/cover from 2005 to 2019

4.5 Kappa Statistics and Accuracy Assessment

4.5.1 Accuracy assessment for land use and land cover classification for 2005

Table 4.2 shows the actual land use and land cover averages generated from classification of land use classes. It revealsthe count of different land use classes generated from supervised land use classification. Table 4.2a illustrates the summary of supervised classification accuracy for 2005. The Confusion matrix illustrates the overall accuracy and Kappa (K) statistics for 2005 supervised classification. Results demonstrates the highest user's accuracy (100%) in forest and lowest producer's accuracy (63%) in forest cover (Table 4.2b). Highest producer's accuracy (100%) was observed in built-up areas and lowest (67%) in forest cover. The overall accuracy (81.1%) observed in 2005 demonstrates significant classification of land use/cover. Overall Kappa statistics (0.75) observed from the study demonstrates a perfect match between the classified and referenced data in the classification system for 2005.

Table 4.2: Averages of land use and land cover classification 2005

Value	Count	Km^2	Classes
1	975882	1302.93	Forest
2	1124216	1513.08	Agricultural fields
3	437195	588.42	Bare land/Built up area
4	585529	798.57	Grassland

Table 4.2a Confusion matrix for supervised land use classification 2005

			Reference data			Total
	Class	Forest	Agricultural field	Built up area	Grassland	
Classified data	Forest	**8**	0	0	0	8
	Agricultural field	3	**5**	0	0	8
	Bare land/Built up area	0	0	**6**	2	8
	Grassland	1	0	0	**8**	9
	Total	12	5	6	10	**33**

(Bold numbers are used for computation of the overall accuracy measure).

Table 4.2b Accuracy measures for supervised land use classification 2005

Class	Producer's Accuracy	User's Accuracy

Forest	67%	100%
Agricultural field	70%	63%
Bare land/Built up area	100%	75%
Grassland	83%	89%

Overall class accuracy = 81.1%

Overall Kappa statistics = 0.75

4.5.2 Accuracy assessment for land use/land cover classification 2010

Table 4.3 shows the actual land use and land cover averages generated from classification of land use classes. It further shows the count of different land use classes generated from supervised land use classification. Table 4.3a illustrates the summary of supervised classification accuracy for 2010. The Confusion matrix shows the overall accuracy and Kappa (K) statistics for 2010 supervised classification. Results demonstrated the lowest producer's accuracy (69%) in forest. Lowest user's accuracy was observed in agricultural field (75%) built-up area (75%). Forest (100%) and grassland (100 %) observed the highest user's accuracy (Table 4.3b). Furthermore, forest (100%) and built-up area (100%) observed the highest producer's accuracy. The confusion matrix illustrates the overall accuracy of 87% and Kappa (K) statistics for 2010, supervised classification of 0.83.

Table 4.3: Actual averages of land use and land cover classification 2010

Value	Count	Km^2	Classes
1	1034434	1386.99	Forest
2	1030531	1386.00	Agricultural fields
3	437194	588.42	Bare land/Built up area
4	620660	840.6	Grassland

Table 4.3a Confusion matrix measures for supervised land use classification 2010

		Reference data				Total
	Class	Forest	Agricultural field	Built up area	Grassland	
Classified data	Forest	**9**	0	0	0	9
	Agricultural field	2	**6**	0	0	8
	Bare land/Built up area	2	0	**6**	0	8
	Grassland	0	0	0	**8**	8
	Total	13	6	6	8	**33**

(Bold numbers are used for computation of the overall accuracy measure)

Table 4.3b Accuracy measures for supervised classification 2010

Class	Producer's Accuracy	User's Accuracy
Forest	69%	100%
Agricultural field	100%	75%
Bare land/Built up area	100%	75%
Grassland	100%	100%

Overall class accuracy = 87%

Overall Kappa statistics = 0.83

4.5.3 Accuracy assessment for land use/land cover classification 2015

Table 4.4 shows the actual land use and land cover averages generated from classification of land use classes. It further shows the count of different land use classes generated from supervised land use classification. Table 4.4a illustrates the summary of supervised classification accuracy for 2015. The Confusion matrix illustrates the overall accuracy and Kappa (K) statistics for 2015 supervised classification. The results demonstrated the lowest producer’s accuracy in forest (67%) producer’s and the highest accuracy in built-up area (100%). Lowest user’s accuracy was observed in built-up area (56%) (Table 4.4b). Forest (100%) exhibits the highest user’s accuracy. Results of the supervised land use classification

2015 indicated a significant (75%) overall accuracy classification. Results observed Kappa (K) statistics of supervised classification of (0.68).

Table 4.4: Actual averages of land use and land cover classification 2015

Value	Count	Km^2	Classes	
1	1229611	1681.2	Forest	
2	1030531	840.6	Agricultural fields	
3	437194	630.45	Bare land/Built up area	
4	727766	1050.75	Grassland	

Table 4.4a Confusion matrix measures for supervised classification 2015

	Class	Referenced data				Total
		Forest	Agricultural field	Built up area	Grassland	
Classified data	Forest	**8**	0	0	0	8
	Agricultural field	1	**7**	0	0	8
	Bare land/Built up area	3	0	**5**	1	9
	Grassland	0	3	0	**5**	8
	Total	12	10	5	6	**33**

(Bold numbers are used for computation of the overall accuracy measure).

Table 4.4b Accuracy measures for supervised classification 2015

Class	Producer's Accuracy	User's Accuracy
Forest	67%	100%
Agricultural field	70%	88%
Bare land/Built-up area	100%	56%
Grassland	86%	63%

Overall class accuracy 75%

Overall Kappa statistics 0.68

4.5.4 Accuracy assessment for land use/land cover classification 2019

Table 4.5 reveals the actual land use and land cover averages generated from classification of land use classes. It further shows the count of different land use classes, generated from supervised land use classification. Table 4.5a illustrates the summary of supervised classification accuracy for 2019. The Confusion matrix illustrates the overall accuracy and Kappa (K) statistics for 2019 supervised classification. Results demonstrate the highest user's accuracy (100%) in forest and lowest producer's accuracy (70%) in forest cover (Table 4.5b). Highest producer's accuracy (100%) was observed in built-up areas, agricultural field (100%) and grassland (100%). The overall class accuracy (81%) observed in 2019 demonstrates significant classification of land use/cover. Overall Kappa statistics (0.82) observed from the study demonstrates a perfect match between classified and referenced data in the classification system for 2019.

Table 4.5: Actual averages of land use and land cover classification 2019

Value	Count	Km^2	Classes
1	1132023	1513.08	Forest
2	780705	1050.75	Agricultural fields
3	530880	714.51	Bare land/Built up area
4	679214	924.66	Grassland

Table 4.5a Confusion matrix measures for supervised land use classification 2019

		Reference data				Total
	Class	Forest	Agricultural field	Bare land/Built up area	Grassland	
Classified data	Forest	**7**	0	0	0	7
	Agricultural field	1	**8**	0	0	9
	Bare land/Built up area	2	0	**6**	0	8
	Grassland	0	0	0	**8**	8
	Total	10	6	6	8	**33**

(Bold numbers are used for computation of the overall accuracy measure).

Table 4.5b Accuracy measures for supervised classification 2019

Class	Producer's Accuracy	User's Accuracy
Forest	70%	100%
Agricultural field	100%	88%
Bare land/Built up area	100%	75%
Grassland	100%	100%

Overall class accuracy = 81%

Overall Kappa statistics = 0.82

4.5.6 Accuracy assessment and Kappa (K) efficiency.

The study used confusion matrix to extract features from the classified images (Table 4.2a, 4.3a, 4.4a, and 4.5a). Confusion matrix or error matrix is the standard method used to assess the accuracy of classified images (Story and Congalton, 1986, Biging *et al*., 1998, Zhang *et al*., 2000 and Foody, 2002). A comparison from the study was made on products accuracy, conducted among all the four land use images and its statistical significance. The supervised training of all the images produced good results.

From the error matrix, the accuracy assessment was implemented using different scales namely: producer's accuracy, user's accuracy and overall accuracy; as done in previous studies of Coppin and Bauer, (1996), Boschetti *et al*., (2004), Carlotto (2009). The best overall accuracy obtained in this study is 87% (Table 4.2b) which is higher than 85% level set as satisfactory for planning and management purpose by Anderson *et al.*, (1976). As indicated in this study as I with a study by Mekonnen *et al.,* (2018), classification accuracy of more than 85% reveals an effective analysis of land use/cover change. Furthermore, of the classification from many studies, there is a general accuracy, which is below the common recommended target (Foody, 2002; Wilkinson, 2005). Classification is different; it is also difficult to understand how the accuracy assessment was conducted from their better accuracy assessment from a publication (Koutsias and Karteris, 2003). The accuracy obtained in this study (75%) in 2005, (87%), in 2010 and 81.1% in 2015) is quite satisfactory. This study obtained results that also resembles that of the validated studies of Lea and Curtis, (2010) and Bradley (2009).

This study has observed a significant (81%) overall accuracy land use/land cover change from 2005 up to 2015 in Nzhelele Valley. Several land use/land cover studies present accuracies such as 65-82% (Homer *et al*., 2002), 70% to 98 %, with an overall accuracy of 83.9% (Homer *et al.*, 2007 and Homer *et al*., 2004). Several changes have been observed from the study. The observation is from different land use and land cover change with high significance changes and sound data output.

4.6 Summary

The results obtained from this study illustrate that, indeed land use and land cover changes occurred within Nzhelele valley. The methodology used in this study could generalize quite well Nzhelele Valley; accurately identifying areas such as agriculture, built up land, forest, and grassland. The bare land/build-up area reveals an increase in trend from 14% to 17% during the 2010-2019 period. During this period, agricultural area is absorbed into built up (3% increase between 2005 and 2019), resulting in change of soil fertility structure (Table 6.1) and soil erosion. The overall accuracy in the study is 82%, which is quite satisfactory. The accuracy assessment indicated Kappa coefficient nearer to one.

Consequent to detailed review and analysis of the study, one important finding from the research was that land use and land cover change occurs within Nzhelele Valley (Table 4.1). Changes in land use and land cover occurs within all land use areas namely: agriculture (11%), built-up (3%), forest (5%) and grassland (3%). The fact that change is observed in all land use and land cover areas demonstrates that, land use change is complex and can be influenced. Interesting enough, change in land use/cover is a phenomenon that is driven by both natural and human factors. This is well documented in various studies (Quintero-Gallege *et al*., 2018; Rawat and Kumar 2015; Chen *et al*., 2018), where spatial changes increase over time around the world.

Land use and land cover changes increase soil erosion, which is entrenched in many land use activity studies. The change in land cover increases the rate of surface runoff, resulting in soil erosion. The transitional change from agricultural cover into settlement increases the levels of surface runoff and soil erosion. The anthropogenic activities play a pivotal role in changing the land use/cover of the Nzhelele Valley. These activities increase the encroachment, the spatial land use cover of one land use area while reducing the other. Our analysis of change and spatial arrangement demonstrated that, there is change in land cover within the grassland (3%) which has an influence on soil erosion. The increase in land cover increases the vulnerability of areas to soil erosion, in turn providing an impact on the soil structure. Vulnerability of an area to soil erosion due to land use/cover change demonstrates visibility of change in land use.

Built up area demonstrated sufficient increase in land use/cover within the study area. Increase in built-up land cover reduces the spatial area for agricultural area. An increase in built-up improves the soil compaction and promotes surface runoff. Increased spatial area in forest is mostly associated with decrease in agricultural cover. The decrease in agriculture area (-11%) reveals an increase in forest areas fostering different outcomes pertaining soil erosion. Encroachment of forest areas is resultant to land abandonment in Nzhelele Valley. Consequently, increased land cover of forest (5%) increases abandoned land previously agricultural area, which in some instances accelerates surface runoff and soil erosion. Changes in land use/cover has a contributing factor in the rates of soil erosion and surface runoff. Findings are therefore corroborated by earlier studies (Richards, 1990; Amin and Fazal, 2012; Lambin *et al*., 2003; Leh *et al*., 2013).

CHAPTER 5: LAND USE MANAGEMENT STRATEGIES ON SOIL EROSION

5.1 Introduction

This chapter presents data on land use management strategies on soil erosion. Expected outcomes on strategies of land use management, provide information on land use and the implemented strategies. The study area is agrarian with a rural population that mostly practices subsistence farming. The most dominant agricultural practice is maize farming, livestock and emerging cash crop/tree harvesting. Performance in land use and crop production depends on different characteristics of a farmland.

Furthermore, this chapter discusses the analyzed data on strategies of land use management in Nzhelele Valley. The intention of the discussion is to identify the existing strategies on land use, the strengths and weakness of the strategies that were implemented by the community of Nzhelele Valley. It addresses various factors that were investigated in the study, which include: programs used in land use strategies, management strategies on soil erosion, income investment on land from land use output and types of equipment used on land use management as a strategy. Discussions in this chapter mainly focus on the data that has been given and how it influences soil erosion. The discussions of the findings were arranged into different themes related to the findings.

To understand the strategies of land use and land cover management on soil erosion within rural subsistence farmers, there is need to identify management strategies and the conservation methods that are practiced towards land use. Challenges of farming such as: soil erosion and land degradation, influence the type of land use management strategies. Management strategies on land use, that address issues of soil erosion are dynamic depending on the problem, intensity and depth of the problem (Slegers, 2008). The success of famers in solving soil erosion dwells much on land use management strategies. Land use management strategies can improve crop yield while at the same time, decrease soil erosion problems (Mazoyer and Roudart, 1997; Tilman, 1998). Irresponsible land use management has an impact on soil quality, influencing soil erosion (Junior *et al.,* 2014). Management strategies are dynamic in nature and apply in different situations. These situations need more conservation strategies, understanding the nature of the problem and the environment at large (Kaplan *et al*., 2010).

5.2 Correlation analysis on environmental-economic factors and land use management strategies

Four land use management strategies were generated using the Factor Analysis (Table 5.1). These factors all together explained 70% of the total variance. The results show environmental and economic factors which include: the physical characteristics of farmland, soil fertility, economic support system and accessibility to resources (Table 5.1). From the results, each generated factor illustrates a statistical relationship (correlation) between land use variables and the generated factors

Only 14 characteristics with a value loading greater than 0.4 were established from the Factor Analysis (Table 5.1). From the 14 characteristics, four factors (physical characteristics, soil fertility, economic support system, and accessibility of resources) were identified after the Factor Analysis was completed which explained 70% total variance.

The first factor, physical characteristics, amounts to 18% of the total variance. It constitutes characteristics such as topographic features of farmland, size of farmland and total number of fields within the farmland. The size of farmland constituted characteristics such as how many hectares of land a farmer owns, whether it is small or big. In addition, the number of farmlands a farmer hold was considered.

The second factor, which is the soil fertility, is comprised of characteristics such as soil type, soil fertility, and vulnerability of the soil to erosion and availability of manure. The availability of manure constituted whether there is organic manure, from compost or inorganic manure, which the farmers were using at that time. This factor observed 22% of the total variance. This factor draws up the vulnerability factors which farmland experienced from land use activities during the period of farming. Soil type within a farmland was also a characteristic used within the study.

The third factor is the economic support system, which constituted to 16% of the variance. This factor is comprised with characteristics such as accessibility of credit facilities, availability of money and accessibility to information. Credit facilities involves aspects such as loan from private or government, which can help the farmers to be fully equipped for them to invest in management strategies. Information availability is regarded in terms of the greater availability of skills and information through research and new innovative technological science, which can assist farmers to invest in land as strategies.

Table 5.1 Rotated component matrix for subsistence farm characteristics

Farmland characteristics	Environmental & economic factors produced from Factor analysis			
	Physical characteristic	Soil fertility	Economic support system	Accessibility of resources
Topographic location of farmland	**.732**	.221	.207	.101
Size of farmland	**.852**	.335	.367	.304
Total number of farmlands	**.721**	.239	.209	.101
Soil type	.301	**0.764**	.211	.322
Soil fertility	.214	**.661**	.109	.299
Vulnerability to soil erosion	.321	**.671**	.228	.129
Availability of manure	.211	**.721**	.223	.233
Accessibility of credit facility	.367	.318	**.839**	.221
Availability of income	.341	.332	**.769**	.219
Availability of information	.221	341	**.821**	.315
Availability of labour	.321	.311	.288	**.751**
Training and management	.123	.201	.209	**.753**
Age	.224	.226	.210	**.736**
Equipment	.211	.103	.382	**.814**
Explained variance (70 %)	18%	22%	16%	14%

The fourth factor is accessibility of resources includes variables such as availability of labour, training and management, age of farmers and equipment available at the farm. This factor accounts for 14% of the variance. The labour availability variable indicates labour for example available for its skills, hired or family labour that the farm uses. Furthermore, equipment available at the farm involves the type of machinery farmer's use. Lastly, the age factor demonstrates the age of farm owner, illustrating management and decision-making based on experience and level of investment into land use-management strategies.

5.3 Economic support system on land use management strategies on soil erosion

Economic support system concerning land use management strategies involves the accessibility of assistance financially and knowledge that can assist farmers to deal with soil erosion problems. Results demonstrate a significant correlation between economic support system and land use management strategies at (0.05 and 0.01) significant level in both Musina and Makhado areas of Nzhelele Valley. This illustrates that there is a positive correlation between economic support system and land use management strategies in Nzhelele Valley. High accessibility to economic support has improved the ability to invest in land use management strategies through purchasing of new technology, which can assist in dealing with soil erosion. Availability of income positively contributes to land use investment by farmers (Wambugu *et al*., 2011). Economic support for the small-scale farmers in Nzhelele reduces the risk of soil degradation, as they can afford to purchase better equipment and advanced techniques, which assists in solving soil degradation problems.

From the findings of this study, farmers in Nzhelele Valley have better access to information and credit facilities. Reliance on information from programs, training and agricultural extension officers improved the understanding of environmental problems such as soil erosion and land degradation. Results from this study are similar to the findings by Adimassu *et al*., (2012) who suggested, that availability of information influence farmers' decision on investment in land use management. This foster better and improved techniques that can be applied to solve issues of soil fertility and soil erosion, especially in areas where erosion is highly dominant. Similarly, findings by (Wambugu *et al.*, 2011) suggest that dissemination of information through facilitators in Central Kenya improved the investment management strategies of farmers in erosional control measures. Accessibility to the economic support system for small-scale farmers in Nzhelele, improves the accessibility of information, which is used in land use management strategies such as contour lines and terracing in upland fields to reduce soil erosion problems. Moreover, smooth dissemination of information from agricultural extension officers to the local subsistence farmers improves the level of implementation of technologies of agriculture (Sulo *et al*., 2012). Accessibility to capital promotes cooperative behavior and facilitates the flow of information that can be relevant to land management investment (Adesina *et al*., 2000)

Availability of economic support system such as credit services, plays an essential part of land use-management strategies. Credit services in Nzhelele Valley assist farm owners to purchase needed inputs that can address soil erosion problems such as: labour and advanced technology (drip irrigation). This result correlates with that from other studies, which generally observes a positive correlation between income and investments in agricultural technologies (Sulo *et al*., 2012, Kessler, 2006, Iheke *et al*., 2012 Illukpitiya and Gopalakrishnan, 2004). Economic support improves the investment capacity of farmers in soil production, hence investing in land use-management strategies such as: organic fertilizer. Similarly, in Ethiopia by Adimassu *et al*., (2012), farmers invest in land management from their financial agricultural gains. Availability of money has provided farmers with better access to information that allows them to identify soil degradation problems such as: soil fertility, soil structure and improved ways of management.

5.4 Influence of physical characteristics of farmland on soil erosion

As depicted in the results, Spearman correlation was computed to investigate the significant correlation of environmental and economic factors on land use management strategies (Table 5.2). Results illustrates the correlation analysis between land use strategies as well as environmental and economic factors. More so, a significant correlation was observed between land use management strategies and physical characteristics of farmland in Nzhelele-Musina areas at 0.05 level of significance (Table 5.2).

Results demonstrate a significant correlation between the physical characteristics of farmland and land use management strategies (Table 5.2). Intensive land use activities farmlands (Figure 4.4) in Nzhelele Valley contribute immensely to the high levels of soil erosion (Figure 7.4). Results from the study illustrate that low land use management strategies such as the application of manure, terracing and contour ridges are implemented in large farm areas due to the high cost of investment, resulting in the high vulnerability of farmlands to soil erosion and land degradation.

The physical structure of the farmland strongly affects the investment of land use-management strategies. Most small-scale farms are found within flatlands in Nzhelele Valley where there is a low vulnerability of soil erosion, which explains the correlation between environmental, economic factors and physical characteristics (0.2) (Table 5.2). Within bottom farm areas, manure is more applied unlike in the upland fields (Tenge, 2005). In steep slopes of the Nzhelele Valley, less investment is observed because of high rates of soil erosion (Figure 7.4). In vulnerable plots, farmers hardly invest in erosional control (Adimassu and Kessler 2012). A study by Clay *et al*., (1998) indicated, that steep slopes are much costly in maintenance and require much less erosive forms of land use. Small-scale farmers in Nzhelele Valley practice much of their farming within flatland where there is low surface runoff and soil erosion.

Land use management strategies in Nzhelele Valley are mainly influenced by the size of the farm, where more implementation and investment are highly favorable to small farms with fewer expenses and better management. Similarly, Clay *et al*., (1998) alluded that small-scale farmers have high labour accessibility enough to build and maintain land conservation. The size of farmland in Nzhelele Valley have a big labour pool, which provide enough needed labour that allows farm holders to invest in management strategies such as: terracing, contour ridges, cover plants and supply of organic manure that supports land conservation.

5.5 Impact of soil fertility on soil erosion

The correlation between land use management strategies and soil fertility was analyzed. The results illustrated that there is no significant correlation between land use strategies and soil fertility for both Musina and Makhado areas within Nzhelele Valley at 0.05 level of significance. However, significant correlation was observed between land use strategies and economic support system for Nzhelele-Makhado area at 0.05 level of significance.

Results from the study show an insignificant correlation between soil fertility and land use management strategies for both sections of Nzhelele Valley (Table 5.2). This is because small-scale farmers with infertile land tend to invest much into land in order to improve the soil composition. Farmers' investment in land use management strategies (organic fertilizer and construction of waterways) in Nzhelele Valley demonstrates the vulnerability of the study area to soil erosion (Figure 7.4). Land use management strategies used in Nzhelele Valley (Table 5.1) shows the risk of soil erosion with the study area. Similarly, Amsalu and de Graaff (2007) illustrated that farmers invest in plots where there is high risk of soil erosion to occur.

Land use management strategies in Nzhelele Valley has an impact on soil fertility. This explains the insignificant correlation of the result (Table 5.2). Similarly, findings by Amsalu and De Graaff (2007) suggest, that farmers invest in farms where they expect to benefit from. Small Scale farmers undertake management strategies such as: terracing, manure and contour ridges in infertile and water-prone erosion areas. Investment in land use-management strategies within fertile soil is influenced by the size of farms. Due to their level of available labour and capital, most small-scale farmers with small farmlands in Nzhelele are able to provide manure and fertilizers to their farms. The study results agree with the findings by (Adimassu *et al*., 2012) which established, that farmers can provide manure and labor to small-scale farms in order to control land degradation and soil erosion. Large areas vulnerable to erosion have limited water control measures.

Land management strategies to current soil erosion and soil fertility problems in Nzhelele Valley such as: infiltration ditches and cut off drain is limited within infertile farmland. The land use management strategies invested in fertile soil are mainly used to protect crops and high yield from the farm. There is an increased level of soil erosion vulnerability within infertile farmland due to low investment in land use-management strategies.

5.6 Accessibility of resources and stages of development on land use management strategies

Moreover, the Spearman correlation was also computed to analyze the relationship between the stages of development and accessibility of resources. The results showed a significant correlation between land use management and accessibility of resources in Nzhelele-Makhado area at 0.05 level of significance. In addition, a significant correlation was also observed between land use management strategies and accessibility of resources at 0.01 level of significance in Nzhelele-Musina area.

Accessibility of resources in land use management mainly involves the availability of training and management support; availability of skilled labor and the importance of age in management strategies. Results illustrate a significant correlation between accessibility of resources and land use management strategies. This is mainly because older farmers' have experience in farming, and they provide better strategies to land use problems. Research offer mixed results concerning age in affecting land management strategies (Baidu-Forson 1999 and Bekele and Drake, 2003). Old age farmers in Nzhelele Valley invest in land use-management strategies that continuously allow land to provide for their basic needs such as: terracing in sloppy farmlands, which prevents soil erosion and application of manure, which then reduces soil degradation. These findings are supported by a study done by Amsalu and Graff, (2007) who observed, that age influences investment in land use. Other studies indicated that older farmers invest more in land use-management practices as they are regarded wealthier and have the means to supply knowledge and labour on soil erosion control (Udayakumara *et al*., 2010).

Furthermore, farmers in Nzhelele Valley invest in labor, programs and training. This is mainly influenced by the topographic location of farmland and soil type. Programs provides channels where they share info through groups, which in turn influence investment into land use (Wambugu *et al*., 2011). Most of the farmers within Nzhelele Valley through programs and training obtain better management strategies to deal with erosion such as contour lines and waterways. Further analysis observed that investment in skilled labor is central to farmer's decision on land use-management strategies. Similarly, Wambugu and Booth (2010) suggest, that in Kenya farmers consider inexpensive labour before investing in land for agricultural practices. Farming in fertile soils allows small-scale farmers to invest in information and labor that assist in solving soil erosion problems through educating programs and hiring skilled labour that understand soil degradation. In Kenya, availability of skilled labour in assisted 150 farmer groups, which constituted 2600 farmers in land use and plant cover management (Wambugu *et al*., 2001).

The correlation of accessibility of resources and land use management strategies is better explained by the fact that older farmers are better equipped with knowledge and experience that enable them to manage soil erosion problem. Montgomery (2007), reported similar findings that agricultural practices knowledge can limit the magnitude of soil erosion. The consistency of old aged farmers into farming allows them to invest more in land use management strategies such as shifting cultivation and monoculture which improves soil structure. However, in a study by Illukpitiya and Gopalakrishnan, (2004), young farmers are more aware of soil erosion problems as they are educated and have knowledge about land use-management practices.

Accessibility to training and management programs influence farmers to invest in land use-management strategies as they gain much better knowledge of soil and land degradation. This result correlates the findings Wambugu *et al*., (2011) who suggested in their study that the existence of programs and farm groups is crucial for investment, as they are key entry points for dissemination and training for farmers. However, (Pimental *et al*., 1995 and Crosson 2007) argues that application of agricultural inputs, no-tillage systems and fertilizers are costly and are highly unaffordable to local subsistence farmers, which might result in them accruing losses in farming in their bid to prevent soil erosion.

5.7 Summary

The environmental and economic factors provide ways of investing in land use-management strategies in Nzhelele Valley. The results demonstrate a significant correlation of land use-management strategies with physical characteristic of farmland, economic support system and accessibility of resources in Nzhelele-Musina and Nzhelele-Makhado. However, no significant correlation was observed between land use management strategies and soil fertility.

The significance of physical characteristics of farmlands reveals that investment in land use-management strategies in both sections of Nzhelele Valley must take the topological characteristics of farmland into consideration. The sizes of farmlands have an impact in influencing land use investments. Investments into farmland characteristics reduces the chances of soil erosion and soil degradation within sloppy farmlands.

The most important fact is that human activities have perpetuated soil erosion and surface runoff unconsciously under environmental and economic challenges in order to address their own problems in Nzhelele Valley. This is evident with the land use activities and perceptions, which are given by many of the villagers. While the intent was to acquire strategies on land use management and ways to combat soil erosion however, the actual reality was that the results from the study illustrates slight significant effort to manage problems of soil erosion (Table 5.2). Significant correlation between land use management strategies and physical characteristics of farmland was observed within the study. This has resulted in more issues satisfactory yield and low levels of soil erosion. This further accentuate the environmental characteristic of the farm areas that influence the investment decisions of farms within sloppy and infertile farmlands.

Significant correlation ($p < 0.05$) between economic support system, environmental and economic factors demonstrate sound land use management. Implementation of programs in farms, which can assist farm owners on skills, knowledge and understanding of the environmental problems, have been fully exploited in Nzhelele Valley. The effectiveness of programs and how they best address issues of soil erosion and management assist in reducing the vulnerability of soil erosion. Implementation significantly influence the degree of soil erosion problem and assist in addressing the smooth dissemination of knowledge from one farmland to another.

Farmers' investment in activities such as programs and training is of paramount importance when implementing ideas to solve soil erosion. Land management strategies on soil erosion and land degradation have been through different spectral ideas through education and skills on how they can fully understand the nature of the problems at hand. Structures from different sectors of society and programs has been of greater value in dealing with issues such as soil erosion. Findings were contextual relevant and have similar findings to other studies (Adimassu *et al*., 2012; Nyanga *et al*., 2016; TNSGRP, 2005) which suggested that better management strategies in Ethiopia promoted sound solutions that solved problems such as soil erosion.

However, from the results no significance correlation was obtained between land management strategies and soil fertility. Soil fertility do not provide better ways to invest in land use, but rather exploit the available resources. Challenges from this study include how to ensure that investments in land use strategies are provided in fertile areas with no soil erosion vulnerability

In conclusion, investment in land use-management strategies involves various factors such as economic support system, accessibility to resources and favorable topographic structure of a farmland. Identified environmental-economic factors can assist in the investment of land use management strategies such as manure, terracing, construction of waterways, which can improve soil structure and crop yield. On the other hand, land use activities increase the vulnerability of soil erosion without any investment. From the factor analysis, findings reveal that three factors significantly correlate to land use management strategies, while one factor insignificantly correlate to land use management strategies. Therefore, the study concluded that the environmental-economic factors are very important in influencing land use management strategies.

Table 5.2 Spearman correlation on land use-management strategies

Factor	**Area-Nzhelele Valley**	
	Nzhelele-Makhado	Nzhelele-Mussina
Physical characteristics of farmland	*0.213*	0.209**
Soil fertility	*-0.042*	0.002
Economic support system	*0.230***	0.115
Accessibility of resources	*0.251***	0.220
**** Spearman correlation is significant at 0.05 level**		

CHAPTER 6: THE INFLUENCE OF SOIL FERTILITY ON DIFFERENT LANDUSES ON SOIL EROSION.

6.1 Introduction

This chapter focuses on the presentation and discussion of data obtained from the analyzed field samples. Fieldwork techniques were used to collect data on land use, such as surveys, observation, and soil samples to achieve the study objective. Experimental processes (soil incineration, soil pH test, and measurements of nitrogen and phosphorus) were carried out to establish the influence of soil fertility on different land uses on soil erosion. This chapter is organized into major themes that address the key fundamental elements that give a guideline towards presenting the results of the study.

The purpose of the chapter was to provide a detailed discussion and identify the extent of land use activities on soil erosion based on the different strategies implemented in land use areas in Nzhelele Valley. The discussion shows various ways in which soil fertility has been influenced by land-use activities and how different studies view this area of study. The discussions of this chapter were arranged into different themes related to the findings. As a result, the chapter addressed various areas on soil fertility and soil erosion, which include the impact of land-use on soil erosion and nutrient losses, soil pH levels on different land use, the impact of land use on soil organic matter content, influence of land use on soil nitrogen and effect of land use on soil phosphorus. These discussions are mainly summaries of a large quantity of data that has been presented in the data analysis of this chapter.

Soil characteristics and fertility are mainly formed through various processes ranging from climate, parent rock, forest (Glendell *et al*., 2018; Schroter *et al*., 2005). Despite all these factors influencing the chemical characterization of the area, soil structure changes over time, and depending on the land use activities, some chemical characteristics also change over time (Amundson *et al*., 2015). The interference of human activities on land use results in different soil composition; positive as well as negative effects that impact soil fertility (Van Oost *et al.,* 2006). The need for food security plays an important aspect in land use activities and soil erosion.

Different land-use activities do not only affect soil structure and chemical composition but also, have an impact on soil fertility (Berhe and Torn, 2017). Changes in soil fertility in most instances are a natural process however, the inclusion of human activities accelerates the loss of soil productiveness. Poor soil fertility does not only affect the yield production but increases the vulnerability of soil erosion depending on the topography of the area, land use management as well as rainfall intensity (Quinton *et al.,* 2010).

6.2 Variation of nutrient contents in different land use

Variation in soil fertility is caused by different land-use activities. Results show soil properties of old fields (OM), forest (FRS), new maize field (NM), grassland (GL), shrubland (SL), and orchard (ORD) in Nzhelele Valley. Different soil parameters from various land use (Table 6.1) shows the concentration of soil nutrient content within a 0–10 cm depth in Nzhelele Valley.

The results show the highest soil pH (7.62) within the orchard land-use area. However, the lowest soil pH was observed in the new maize field (6.98). The forest area recorded the highest soil organic matter (7.36), whereas the shrubland recorded the lowest amount of organic matter. High soil fertility increases forest capacity reducing the level of soil erosion (Table 4.1). However, the new maize field (2.97) and the grassland (2.49) provided closely similar results to soil organic matter. The shrubland exhibited the lowest nitrogen content (0.059) whereas the forest land use showed the lowest phosphorus content of 3.95 mg/kg (Table 6.1).

Table 6.1 Mean values of soil nutrient content for different land use classes

Site	Depth	Soil pH	Organic Matter %	Nitrogen %	Phosphorus mg/kg
OM	0–10 cm	5.98	1.32	0.046	18.81
FRS	0–10 cm	5.15	7.36	0.165	3.95
NM	0–10 cm	6.98	2.97	0.069	22.52
GL	0–10 cm	7.4	2.49	0.099	42.19
SL	0–10 cm	7.49	1.43	0.059	21.04
ORD	0–10 cm	7.62	3	0.1	11.41

6.3 Soil pH content of different land uses on soil erosion

The lowest soil pH is observed in the forest area (5.15) within the 0-10 cm depth (Figure 6.1). However, the highest soil pH was observed in orchards (7.62) indicating slight alkaline of the soil. Results also indicated similar results of soil pH for grassland areas and shrubland with a soil pH of 7.4. New maize fields observed a neutral pH (6.98) (Figure 6.1). A significant difference between forest area and orchard is observed with the two different land-use showing strongly acidic (5.2) and slightly alkaline (7.2) respectively.

The results illustrate significant variation ($p \leq 0.0001$) among different land-use types (Table 6.2). The soil pH based on the results ranges from strongly acidic (5.15) to slightly alkaline (7.62). However, a comparison of soil pH between different land-use types shows no significant variation ($p< 0.05$) between the old maize field (pH 5.98) and the new maize field (pH 6.98). Significant variation was observed between the old maize field and grassland area with $p<0.001$ (Table 6.2). Similarly, the same results were established between the old maize field and shrubland and between the old maize field and orchard. However, there was no significant variation observed between the old maize field and forest area (Table 6.2). Significant variation ($p < 0.001$) was also observed between the forest area and the new maize field. Significant variation ($p < 0.001$) between forest and grassland, forest area, and orchard were observed from the results. However, there was no significant variation observed between the new maize field and grassland area.

Soil pH Standard Scale		Nzhelele Site	Nzhelele Mean Soil pH
Extremely acid	3.5 – 4.4	OM	5.98
Very strongly acid	4.5 – 5.0	FRS	5.15
Strongly acid	5.1 – 5.5	NM	6.98
Moderately acid	5.6 – 6.0	GL	7.4
Slightly acid	6.1 – 6.5	SL	7.49
Neutral 6.6	– 7.3	ORD	7.62
Slightly alkaline	7.4 – 7.8		
Moderately alkaline	7.9 – 8.4		
Strongly alkaline	8.5 – 9.0		

Figure 6.1: Variation of soil pH within different land use.

Table 6.2: Analysis of variance for soil pH in different land-use areas of Nzhelele Valley

Comparison	n=?	q	P-value
OM vs FRS	0.8300	3.813	ns P>0.05
OM vs NM	-1.000	4.594	ns P<0.05
OM vs GL	-1.420	6.524	*** P<0.001
OM vs SL	-1.510	6.938	*** P<0.001
OM vs ORD	-1.640	7.535	*** P<0.001
FRS vs NM	-1.830	8.408	*** P<0.001
FRS vs GL	-2.250	10.338	*** P<0.001

FRS vs SL	-2.340	10.751	*** P<0.001
FRS vs ORD	-2.470	11.348	*** P<0.001
NM vs GL	-0.4200	1.930	ns P>0.05
NM vs SL	-0.5100	2.343	ns P>0.05
NM vs ORD	-0.6400	2.940	ns P>0.05
GL vs SL	-0.09000	0.4135	ns P>0.05
GL vs ORD	-0.2200	1.011	ns P>0.05
SL vs ORD	-0.1300	0.5973	ns P>0.05
The P value is < 0.0001, considered significant.			

The agricultural practices in Nzhelele land-use practices made the soil acidic (Old Maize field 5.9 pH) through the use of fertilizers, growing of legume crops and pastures. Acidic soils caused nutrient deficiencies which can reduce forest cover (Figure 4.4). A decline in forest cover contributed to soil erosion (Figure 7.4).

The results illustrate significant variation ($p < 0.001$) in soil pH between the old maize field and grassland use area. Variation in soil pH demonstrates differences in land use activities as well as the difference in crop production. Acidic soils within old agricultural land use demonstrate the use of fertilizers that influence soils to become acidic over time. This is also caused by the removal of plants after harvesting which in most instances result in soils becoming acidic in nature. This is supported by Bezdicek *et al*., (2003) who observed that acidic soil is caused by the removal of agricultural product from the fields, leaching of nitrogen as nitrate below the root zone, and inappropriate use of nitrogenous fertilizers. Furthermore, acidic soil mainly occurs due to anthropogenic activities such as draining water from waterlogged areas that change the chemical structure of the soil. Acidic soil, however, does not promote plant growth but decreases plant availability. This harms the old maize field in Nzhelele Valley as plant availability is reduced increasing the vulnerability of surface runoff and soil erosion.

A decline in soil pH (Table 6.1) can lead to soils being acidic attributed to continuous farming practices of the same land use over time reducing forest cover (Figure 4.4) increasing soil erosion (Figure 7.4). Continuous and intensive farming within the old maize field has resulted in acidic acidic. Similar views are shared by Scott *et al*., (2000) who suggested in their study that a decrease of soil pH could be due to intensive farming practices such as continuous cropping, long periods of cultivation, and long-term annual pastures. Mingxiang *et al*., (2015) support this notion as they reported that several factors such as high variability of soil disturbances by human activities are highly responsible for low soil pH level which attributes to soil degradation and rill or inter-rill erosion. Long-term agricultural practices have an enormous impact on the soil degradation process, which in turn causes soil erosion. This is evident within old maize fields where soil pH is significantly low due to long periods of intensive land use.

The study observes acidity to alkaline soils than acidic soil from the different land-use activities sampled. However, significant variation ($p < 0.0001$) of soil pH from the different land use in Nzhelele Valley. Differences in soil pH within Nzhelele Valley suggest a difference in land use activities caused by agricultural land-use practices. Comparison analysis between grassland land use area and orchard results demonstrated no significant variation ($p > 0.05$). Soil pH in grassland and orchard land use demonstrates slightly alkaline levels. Slight alkaline soils promote plant growth increasing the availability of crop yield (Cregan and Scott, 1998). The results suggest that similar land use practice has been practiced within these land use areas. The availability of alkaline pH exhibits better land-use practices, which promotes high plant availability. Availability of plant growth due to alkaline pH improves soil compaction reducing the level of soil vulnerability to soil erosion. Similarly, Munns, (1986) found that plant availability reduces soil erosion, increasing soil infiltration.

The formation of acidic soil due to land use activities (Farming), has some negative implications such as low productivity, loss of soil ability to grow crops, and reduced farm productivity. Results indicate slight acidic soil within the old maize field (5.9) which affects the plant productivity. Disturbance in plant production has implicated plant growth resulting in low yield that affects farmer's crop production. A decrease in production because of soil chemical composition affects soil structure as well as the soil fertility exposing the land-use area to soil erosion. Similarly, a study by Crigan and Scott, (1998) indicates that Australia lost productivity on soil, leading to a decline in soil fertility and the development of toxic levels of aluminum affecting 90 million hectares of agriculturally productive land.

Clearing land for agricultural practices as well as the application of fertilizers reduces the soil pH of land resulting in land degradation. Despite other drivers that may influence the availability of plant richness, there is a correlation between soil pH and plant availability (Crespo-Mendes *et al*., 2019). Condition of soil pH within Nzhelele will gradually decrease due to the land use activities such as continuous land use and forest clearance of land for new agriculture practices. Availability of nutrients for plant uptake is low within acidic soil, which is often hindered by decreased solubility in highly basic soils and increased susceptibility to leaching or erosion (Havlin, *et al*., 1999). Continuous cultivation has been an ongoing process in Nzhelele Valley as agricultural practices are the primary economy in this area. However, this has had a negative implication on soil pH as it decreases the level of soil pH leaving the soil acidic. Acidic soil disrupts plants' ability to absorb nutrients creating a low plant coverage on soil, which affects soil erosion in the end.

6.4 Soil organic matter content (OM) and its effect on soil erosion

The results shows that soil organic matter in different land use areas of the Nzhelele Valley is very low with the highest of 7.36% within the forest which is very low (Figure 6.2). Soil organic matter under different land-use ranges from 1.32% in the old maize field to 7.36 % in the forest area. In new maize fields (2.97%) and grassland (2.49%), very low soil organic matter within the same range was observed. Furthermore, results indicate the lowest organic matter content within shrubland (1.43%) and (1.32%) old maize field.

Based on the results given, extreme significant variation ($p \leq 0.0001$) was observed in the study area (Table 6.2). Significant variation ($p < 0.001$) of organic matter content was observed between the old maize field and forest area. Furthermore, within Nzhelele land use areas, significant variation ($p < 0.05$) was detected between the old maize field and new maize field and between shrubland and orchard land use. A comparison between forest area and new maize field demonstrated extreme significant variation ($p < 0.001$) between the two land use areas. More-so, extreme significant variation ($p < 0.001$) was again observed between forest area and grassland use, between forest area and orchard, and between forest and shrub land-use area. However, there was no significant variation observed between new maize field and shrubland, old maize field and grassland use, new maize field and orchard, and between grassland use and shrubland.

OM		Nzhelele Site	Organic Matter %
Low	0-25	OM	1.32
Medium	25-50	FRS	7.36
High	50+	NM	2.97
		GL	2.49
		SL	1.43
		ORD	3

Figure 6.2: Difference in organic concentration with different land-use of Nzhelele Valley.

Table 6.3: Analysis of variance for organic matter in different land-use areas of Nzhelele Valley

Comparison	Mean difference	q	P-value
OM vs FRS	-5.782	12.255	*** P<0.001
OM vs NM	-2.433	5.158	* P<0.05
OM vs GL	-1.570	3.328	ns P>0.05
OM vs SL	-0.09333	0.1978	ns P>0.05
OM vs ORD	-2.197	4.656	* P<0.05
FRS vs NM	3.348	7.097	*** P<0.001
FRS vs GL	4.212	8.927	*** P<0.001
FRS vs SL	5.688	12.057	*** P<0.001
FRS vs ORD	3.585	7.599	*** P<0.001
NM vs GL	0.8633	1.830	ns P>0.05
NM vs SL	2.340	4.960	* P<0.05
NM vs ORD	0.2367	0.5016	ns P>0.05
GL vs SL	1.477	3.130	ns P>0.05
GL vs ORD	-0.6267	1.328	ns P>0.05
SL vs ORD	-2.103	4.458	* P<0.05
The P value is < 0.0001, considered significant.			

The amount of soil organic matter in the arable soil is affected by land use activities such as agriculture (Figure 4.4) in Nzhelele Valley. The use of land (agricultural field (Figure 4.4)) increases the level of soil erosion (Figure 7.4). More severely eroded areas lost more soil and soil organic matter hence less soil organic matter and nutrients were left available for plant nutrition on the newly exposed eroded topsoil (Table 6.1).

Levels of organic matter concentration vary depending on the degree of land use as well as the type of land use activities. Significant variation ($p < 0.001$) was observed in the organic matter within different land-use areas of Nzhelele Valley. This is explained by different land-use activities that are within the study area such as maize farming, forest area and orchard land use that experience different levels of land-use intensity (Table 6.1). The study illustrates significant low levels of soil organic matter are across different land use areas reducing agricultural practices (Figure 4.4) increasing soil erosion (Figure 7.4). Similarly, from the findings by Ondrasek and Rengel, (2012) they observed that soil organic matter is already depleting especially in agro-ecosystem. However, Jones, *et al*., 2012 alluded that within agricultural zones where there are warm to hot and humid temperatures (Mediterranean climate) 75% of the topsoil contains <3.4% of soil organic matter. Due to different exposure to different land-use activities, significant variation ($p < 0.001$) in soil organic matter was observed between forest area and grassland area. High availability of water in grassland increases the intensity of land use, which results in high utilization of organic matter and surface runoff. This has resulted in a decrease in soil organic content due to high utilization, which can cause soil erosion problems.

Despite the extremely significant variation, a comparison of variation between new maize field and orchard as well as grassland area with shrubland illustrates no significant variation ($p > 0.05$) in soil organic content. Results illustrate low levels of organic content (Orchard 3% and new maize field 2.97%; Grassland 2.49% and shrubland 1.43%) in these land use, which explains no variation. The outcome of low levels of organic content in different land-use areas is typical (Zhang *et al*., 2015). The observed results of low concentration of organic matter in Nzhelele Valley relate well to other studies, which observed low organic carbon in different land use in sub-Saharan Africa (Luther-Mosebach, 2017; Toure *et al*., 2013 and Demessie *et al*., 2013). Similarly, Van camp *et al*., 2014 suggest that in Europe 45% of agricultural land use areas have low organic matter content (2-4%) or very low (<2%). A lower concentration of organic matter in Nzhelele Valley demonstrates high land-use activities that reduce soil water holding capacity increasing surface runoff and soil erosion. Mingxiang *et al*., (2015) in their study demonstrated that soils with low organic establishes this carbon are highly vulnerable to soil erosion.

Old maize fields (1.32%) have the least concentration of organic matter comparing it to other land use areas. Due to continuous land-use practices in the old maize field (Nzhelele Valley), the amount of organic carbon concentration in the area has decreased over time. This corresponds to the study in Andic Paleustalfs South of Ethiopia, which observed a lower concentration of organic matter within old agricultural fields due to cultivation (Demessie *et al*., 2013). Extensive exploitation of land has decreased the concentration of organic matter in Nzhelele Valley increasing the vulnerability of the area to soil erosion and gully development. Similarly, Elliot, (1986) and Zhang *et al*., (2007) in their studies detected that excessive tillage has a serious negative impact on soil structure which causes problems of soil erosion in the end.

The results show no significant variation ($p > 0.05$) in soil organic content between old maize fields and shrubland with results showing low concentration in both land use areas. Lower concentration of organic matter in different land use (old maize field 1.32% and shrubland (1.43%) demonstrates long periods of land use activities within the study area. Excessive use of land destroys the soil structure in association with other environmental factors such as rainfall, slope structure, and soil type. Maiga-Yaleu *et al*., (2015), support this, in their study, organic carbon loss is observed to be correlated with land use activities causing problems of soil erosion in land use activities. The increased concentration of anthropogenic activities within the same areas increases the vulnerability of the area to soil erosion due to lack of organic matter concentration.

The decrease in levels of organic matter attributed to land use activities has serious consequences on land degradation. Significant variation ($p < 0.001$) observed in the organic matter between forest area and new maize field demonstrates the difference in land use activities. Lower levels of soil organic content within the new maize field are caused by surface runoff and, low availability of manure. Continuous cultivation without the feedback of organic matter into the soil reduces the carbon content of the area over time. This is supported by Dignac *et al*., (2017) and Pisani *et al*., (2016) who alluded that long-term cultivation has the potential to decrease soil organic matter storage and it can also change the chemistry of soil organic matter associated with minerals. Lower concentration of organic matter due to continuous tillage practices reduces water infiltration leading to high surface runoff and soil erosion. Poor supply of organic matter has resulted in disturbance of compactness, which has resulted in increased surface runoff and a decrease in soil infiltration. Ellerbroke *et al*., (2016) also demonstrate this in their study; low availability of organic matter destroys the soil structure that improves water infiltration increasing the susceptibility of soil to compaction and soil erosion. Poor soil structure caused by the change in soil chemical composition also causes the formation of soil crust that blocks the surface from infiltration causing high surface runoff resulting in rill erosion.

Significant variation ($p < 0.001$) was observed of organic matter between the old maize field and forest area. The difference in organic content observed between the old maize field and forest area indicating a difference in land use activities. Levels of farmer engagement inland production (old maize field 1.32%) illustrate a decrease in organic matter increasing the vulnerability of soil erosion. Negative feedback illustrated with low levels of organic matter in soil shows little or no land-use investment into the soil. Increased and continuous farming (tillage) with little investment into land explains significant variation ($p < 0.001$) with low organic content in an old maize field and high content in forest area, increasing the susceptibility of old maize land use to lower concentration of organic matter. The high concentration of organic matter content promotes the availability of plant growth reducing the vulnerability of soil degradation.

Availability of plant growth covers bare land protecting the area from erosion as well as binding the soil together. However, a continuous decrease in organic content prevent plant growth and increases the level of surface runoff. The risk of soil erosion can be controlled by restoring forest, which is positively related to soil organic matter accumulation (Zhang *et al*., 2019).

6.5 Impact of Soil phosphorus content (P) on land use and soil erosion

The results illustrated high levels of phosphorus (42.19 mg/kg) within the grassland use area (Table 6.4). However, the lowest concentration of phosphorus was observed within the forest area with a concentration level of 3.95 mg/kg. A remarkable difference of 38.24 mg/kg is observed between grassland and forest land use (Figure 6.4). Furthermore, the new maize field and shrubland area did not significantly differ on the concentration of phosphorus with results of 22.52mg/kg and 21.04mg/kg respectively. Old maize field observed 18.81 mg/kg concentration of phosphorus slightly higher than that observed at orchard land use of 11.41 mg/kg.

Phosphorus content in soil provides the soil measurements that are necessary for plant growth. Its fundamental role involves the storage and transference of energy necessary for the growth and reproduction process. Test for phosphorus indicates the P-cycling in soils and is an indicator for crop response to growth. Phosphorus (P) concentration differed significantly amongst different land uses. Based on the analysis made using ANOVA significant variation ($p \leq 0.0001$) was observed (Table 6.4). Significant variation ($p < 0.001$) of phosphorus content was observed between old maize fields and grassland. Furthermore, within Nzhelele land use areas, very significant variation ($p < 0.01$) was detected between forest area and old maize field (Table 6.4). A comparison between forest area and new maize field demonstrated significant variation ($p < 0.001$) between the two land-use areas whereas no significant variation was observed between forest area and orchard land-use area. Significant variation ($p < 0.001$) was again observed between forest and grassland use and between forest and shrubland use. However, no significant variation was detected between shrubland and orchard land use whereas e significant variation ($p < 0.001$) was observed between orchard and grassland use area.

Phosphorus Standard Scale		Nzhelele Site	Phosphorus mg/kg
Low	0-25	OM	18.81
Medium	25-50	FRS	3.95
High	50+	NM	22.52
		GL	42.19

		SL	21.04
		ORD	11.41

Figure 6.3: Difference in phosphorus concentration with different land use.

Table 6.4: Analysis of variance for phosphorus in different land use within Nzhelele Valley

Comparison	Difference	q	P-value
OM vs FRS	14.860	5.645	** P<0.01
OM vs NM	-3.710	1.409	ns P>0.05
OM vs GL	-23.380	8.881	*** P<0.001
OM vs SL	-2.230	0.8471	ns P>0.05
OM vs ORD	7.400	2.811	ns P>0.05
FRS vs NM	-18.570	7.054	*** P<0.001
FRS vs GL	-38.240	14.526	*** P<0.001
FRS vs SL	-17.090	6.492	*** P<0.001
FRS vs ORD	-7.460	2.834	ns P>0.05
NM vs GL	-19.670	7.472	*** P<0.001
NM vs SL	1.480	0.5622	ns P>0.05
NM vs ORD	11.110	4.220	ns P>0.05
GL vs SL	21.150	8.034	*** P<0.001
GL vs ORD	30.780	11.692	*** P<0.001
SL vs ORD	9.630	3.658	ns P>0.05
The P value is < 0.0001, considered significant.			

Based on the analyses made from the results, significant variation in phosphorus content ($p < 0.0001$) was observed within the study. Variation in phosphorus in land use areas of Nzhelele signifies differences in land use activities as well as the vulnerability of soil erosion of some areas. Low levels of phosphorus content in forest areas demonstrate low or no human activities within the area. Land use and the loss of phosphorus were mainly observed from the orchard (11.41 mg/kg) and shrubland areas (21.04 mg/kg) whereas forest areas have significantly the lowest concentration of phosphates (3.95 mg/kg). Deficiency in phosphorus within forest area demonstrates no application of fertilizers and land use activities within forest area which suggest ($p < 0.001$) significant variation between forest areas and other land use areas such as new maize field, grassland area, and shrubland. Similarly, a study by Ferreira *et al*., (2015) shares the same view that phosphorus availability in agricultural land use is mainly caused by the application of fertilizers. The productivity of crops is highly limited by phosphorus deficiency within arable land (Balemi and Negisho, 2012). A low concentration of phosphorus in forest areas results in low plant growth, which increases the vulnerability of the area to soil degradation and soil erosion. Wyngaard et al., (2016) suggested that the availability of phosphorus in soils sustains plant growth, as well as the development of crops, which supports this. However, the concentration of phosphorus from fertilizers is mostly absorbed by soil and is not available for plant growth Dey *et al*., (2017).

Results illustrate no significant variation in phosphorus content between forest area and orchard-land use area with a $p > 0.05$ (Figure 6.4). In Nzhelele Valley, the characteristic of orchards available have little or no land use management, which reduces the level of soil nutrients. Lack of investment in soil nutrients and mismanagement of land in Nzhelele orchards increases surface runoff and low infiltration reducing the levels of phosphorus, which resulted in a decrease in soil phosphorus level and erosion. Similarly, Di Stefano *et al.,* (2016) in their study observed that loss of phosphorus was mainly caused by soil erosion. However, the loss of phosphorus increases the levels of soil deterioration and change in the chemical composition (Heathwaite and Dils, 2000). A change in chemical composition has some negative effects on plant growth and resistance to soil-to-soil erosion. This is evident in the lower levels of phosphorus in the orchards area. Variation in land use activities and land-use change imply nutrient loss leading to soil erosion. Levels of phosphorus content (forest area 3.95mg/kg) indicate the levels of surface runoff influencing nutrients to wash off and soil erosion.

With the results illustrating the lowest values of phosphorus within the forest area (3.95mg/kg) which is an area with less land use management, it is worth noting that areas with less management have the highest levels of nutrient loss. This is explained by the lack or no fertilizer application within the forest area and surface runoff. The high capacity of phosphorus in the soil is due to surplus input from fertilizers that tends to accumulate in soils (Withers *et al.,* 2001). This explains the low levels of nutrient availability in the forest area. Low phosphorus content reduces plant growth and plant availability hence increasing surface runoff and vulnerability of the area to soil erosion.

Significant variation ($p < 0.001$) was observed between grassland and shrubland. The low concentration of phosphate content within shrubland suggests low availability of bacteria that enhance phosphorus availability caused by poor farming methods such as the burning of plant residue. Lack of bacteria such as Pseudomonas, Azotobacter, Burkholderia, Bacillus, and Rhizobium reduces the availability of Phosphorus (Jones and Oburger, 2011). The depletion of phosphorus is because of intensive biochemical transformation (Fang *et al*., 2012). Depletion of phosphorus has had a negative implication on plant growth within the arable land of Nzhelele resulting in low plant growth. This is supported by Sanyal and De Datta, (1991) who alluded that total phosphorus in topsoil depends on soil management and forest. A decrease in plant growth increases the chances of surface runoff and low infiltration of precipitation, which causes soil erosion and land degradation.

Low levels of phosphorus are observed within the orchard area as compared to the grassland area illustrating a significant variation ($p < 0.001$). Lower availability of phosphorus within Nzhelele orchard area mismanagement of land leaving some areas bare and uncover which promotes surface runoff. Precipitation removes soil phosphorus through surface runoff (Roberts and Johnston, 2015). The levels of phosphorus due to soil erosion illustrates the levels of soil erosion. The lower level of phosphorus content in some parts of Nzhelele areas demonstrates soil erosion through surface runoff, leaching, and flow via soil matrix. The more erosion takes place the more surface runoff occurs which has an influence on nutrient availability within the soil (Li *et al*., 2016).

6.6 Soil nitrogen content (N) and its impact on soil erosion.

Results show that forestland use recorded the highest concentration of nitrogen (0.16%) followed by orchard land use (0.1%). The difference between the two land uses is relatively insignificant. Furthermore, the old maize fields and shrubland has slightly similar results of 0.046% and 0.059% respectively (Figure 6.4). The grassland use observed a 0.099% concentration of nitrogen, which is slightly closer to that of the orchard. However, there is a slightly significant difference in nitrogen concentration between the new maize field (0.069%) and forest area (0. 165%).

The results show significant variation ($P < 0.0002$) in nitrogen concentration among all land use areas of the study. Significant variation ($p < 0.001$) of nitrogen content was observed between the old maize field and the forest area. Furthermore, significant variation ($p < 0.01$) was observed between the forest area and the new maize field. A comparison between forest area and shrubland demonstrated significant variation ($p < 0.001$) between the two land use areas. However, there was no significant variation observed between new maize field and shrubland, old maize field and grassland use, new maize field and orchard, and between grassland use and shrubland (Table 6.5).

Nitrogen		Nzhelele Site	Nitrogen %
Low	0-25	OM	0.046

Medium	25-50	FRS	0.165
High	50+	NM	0.069
		GL	0.099
		SL	0.059
		ORD	0.1

Figure 6.4: Difference in nitrogen concentration with different land use

Table 6.5: Analysis of variance for Nitrogen content in different land-use areas of Nzhelele Valley

Comparison	Mean Difference	q	P-value
OM vs FRS	-0.1190	7.425	*** P<0.001
OM vs NM	-0.02300	1.435	ns P>0.05
OM vs GL	-0.05300	3.307	ns P>0.05
OM vs SL	-0.01300	0.8112	ns P>0.05
OM vs ORD	-0.05400	3.369	ns P>0.05
FRS vs NM	0.09600	5.990	** P<0.01
FRS vs GL	0.06600	4.118	ns P>0.05
FRS vs SL	0.1060	6.614	*** P<0.001
FRS vs ORD	0.06500	4.056	ns P>0.05
NM vs GL	-0.03000	1.872	ns P>0.05
NM vs SL	0.01000	0.6240	ns P>0.05
NM vs ORD	-0.03100	1.934	ns P>0.05
GL vs SL	0.04000	2.496	ns P>0.05
GL vs ORD	-0.001000	0.06240	ns P>0.05
SL vs ORD	-0.04100	2.558	ns P>0.05
The P-value is 0.0002, considered significant			

Nitrogen content in soil varies in different areas depending on the rate of soil erosion and the type of land use activities. Results shows significant variation ($p < 0.0002$) nitrogen content within different land uses. Variation in nitrogen content signifies differences in land use activities demonstrating differences in the chemical composition of soil fertility. The low concentration of nitrogen within the old maize field demonstrates the availability of surface runoff and soil erosion that leads to the washing away of nutrients. The transportation of nutrients through erosion decreases the level of nitrogen concentration. Similarly study by Lal, (2003) demonstrated that nitrogen concentration in soil was significantly lower in sloppy cropland due to transportation and erosion. The presents of erosion in the old maize field within Nzhelele due to harvest practices and low plant availability decreased the availability of soil nutrients. This is also observed by Li *et al*., (2017), in their study suggested that large amounts of nitrogen content are transported from surface soil by erosion process.

Land use areas such as the new maize field and shrubland demonstrate no significant variation ($p > 0.05$) with both areas indicating low nitrogen content. The decrease in nitrogen content is caused by low forest cover and high land-use activities in Nzhelele Valley. An increase in land use activities such as continuous farming, tillage, and intensive farming significantly destroys the soil structure and contributes to the deterioration of nitrogen in land use areas. Similarly, a study by Wang *et al*., (2018) suggests that reduced forest cover significantly decreases soil structure and contributes to the reduction of soil nitrogen and organic matter. A significant decrease in nitrogen content shown in the study is mainly contributed by a decrease in plant cover due to harvest, which has a negative implication on the nitrogen levels.

Variation in land use activities as observed in Figure 6.4 has an influence on the nitrogen stock in the soil. Results indicate significant variation ($p < 0.001$) levels of nitrogen content between (old maize field 0.046% and forest are 0.165% a) demonstrating different land use management practices hence influencing the nitrogen stock in the soil. Despite low nitrogen content indicating soil erosion, the level of nitrogen stock within this study demonstrates the land use activities. Continuous cultivation and improper land use in Nzhelele Valley increased surface runoff and soil erosion causing a change in the chemical structure of the soil. Due to continuous land use and poor management practice in the old maize field, the nitrogen stock decreases with increased land-use practices. Similarly, other studies (Lal, 2003; Fu *et al*., 2010 and Han *et al*., 2010), indicate that low levels of nitrogen stock within the soil are influenced by management practices and forest types. The implication of low levels of nitrogen in soil mainly due to disturbance of soil structure because of tillage and land mismanagement, which might result in soil erosion. However, a study by Li *et al*., (2017) demonstrates that changes in land use alter the nitrogen content at different temporal and spatial scales.

6.7 Variations of soil fertility within different land use activities on soil erosion

Significant variation in soil characteristics illuminating different patterns of soil content in different land uses (Figure 6.5). Results indicate significant variation ($p \leq 0.0001$) among different land use on soil pH. Grassland use observed the highest soil phosphorus content (42.19 mg/kg) and high soil nitrogen content (0.99%) as compared to the other land use areas.

However, the grassland use exhibited high content of soil pH (7.4) with relatively low levels of organic content (2.97) (Figure 6.5).

Forest area observed the least concentration of soil phosphorus (3.95 mg/kg) however, no significant variation ($p < 0.05$) was observed with orchard land-use area. Furthermore, the forest land use also observes the lowest soil pH level with a significant variation ($p < 0.001$) demonstrated within new maize fields; grassland; shrubland, and orchard (Figure 6.5). However, the forest area has significantly the highest soil organic matter content (7.36 %) and nitrogen (0.165%) than any other land-use area.

Within the shrub, a land-use area, of significant note is high levels of soil pH (7.49) but no significant variation ($p < 0.05$) was observed between the shrubland and orchard land-use area. To add on the phosphorus content within the shrubland is high (21.04), detecting a significant variation ($p < 0.001$) with forest area. Results demonstrate no significant variation ($p > 0.05$) between shrubland and grassland area despite the shrubland observing the lowest organic matter content (0.143). The old maize field exhibit the lowest levels of nitrogen content (0.0046%) illustrating a significant variation ($p < 0.001$) with forest area which has a high nitrogen content. The lowest levels of organic matter content (1.32%) is observed in the old maize field producing a significant variation ($p < 0.001$) between old maize field and forest area demonstrating different soil nutrient pattern.

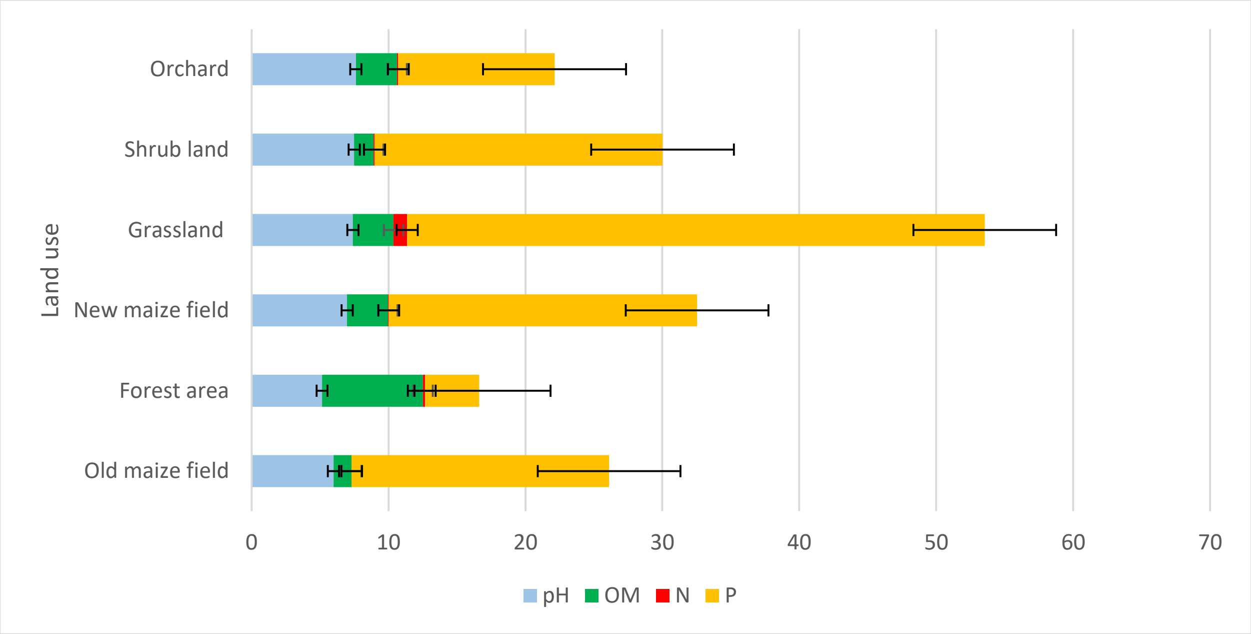

Figure 6.5: Pattern of soil fertility in different land uses

- **Impact land use on soil fertility deficiency and soil erosion**

Nzhelele Valley has an extensive variation in topography land use character. Variation in the topographic structure influences the type of land use activities, which in turn determines the nutrient content within soil. Significant ($p < 0.0001$) variation in organic matter is observed within different land-use areas of Nzhelele Valley. Low levels of soil organic content within the old maize field suggested long periods of farming which gradually decreases the soil fertility with time. Low levels of organic matter have a correlation with soil pH within old maize fields with an observed slight acidic soil pH (5.98). This has an impact on the soil characteristics, which can result in low plant growth and high surface runoff causing soil erosion. The reaction of different soil forms contributing to soil pH links to chemical processes such as rainfall root respiration and plant growth (Toure *et al*., 2013).

Significant variation ($p < 0.0001$) in phosphorus was observed within Nzhelele Valley. Different land use-management strategies play a very important role in the variation of soil nutrients such as mulching, tillage, and addition of manure into the soil. Fertilization and high surface runoff attribute to the loss of phosphorus (Qinghua *et al*., 2002). Observed results of significant variation ($p < 0.001$) in phosphorus between in grassland and orchard, which gives an indication of high supply of fertilizers into grassland area. Significant low phosphorus content in orchards illustrates low plant growth and high surface runoff indicating high levels of vulnerability of the area to soil erosion. This is also evident with low levels of nitrogen availability within the orchard area (Figure 6.5).

Fertilizers react with the soil, which in turn results in soil acidity causing the soils to be more acidic resulting in low plant productivity. Rainfall dissolves and or washes away fertilizers especially during the beginning of the rainy season when fields are bare causing soils to be acidic. Similarly, Qinghua *et al*., (2002) in their study alluded that the decrease in soil pH was due to surface runoff. Significant high loss of phosphorus within the Hilly loess plateau in China is due to fertilization of the plot (Meng *et al*., 2001). Fertilization assists temporally in increasing plant production but affects the soil chemical structure in the end after heavy rainfall. Acidic soils have low plant productivity decreasing the plant-soil compaction. This results in high soil vulnerability to surface runoff and erosion causing soil erosion.

Soil mostly acidic is caused by the drainage system, especially in riparian zones. Farmers create easy access to water drain riparian zones in Nzhelele Valley regarded as a source of water. This provides new areas of farming in which better access to water and easy production is viable. However, the riparian zones with waterlogged areas and wetlands when drained cause acid sulfate soils (Old maize Field (5.98). These areas when drained become acidic which results in low plant production (Havlin, *et al*., 1999). Low plant production increases the leaching of nutrients, which in most instances results in acidic soils (Crigan and Scott, 1998). However, the root cause of soil pH needs to be pointed out. The results indicate acidic soils in the old maize field (Figure 6.5).

6.8 Summary

Land use activities result in changes in soil fertility parameters (organic matter, nitrogen, soil pH, and phosphorus. Various activities on land respond differently and, in every case, increase or increase the soil nutrient availability. In studied soils of different land-use areas, soil nutrient decreases with increased intensity of land use and low management of the land within acidic soils and low soil phosphorus prevailing in high surface runoff areas. Significant variation ($p < 0.001$) between old maize field and forest area in organic matter illustrates a process of soil erosion and depth of soil profile provides the structure of the soil nutrient. This can be explained by the soil organic content and soil pH levels within a specific land use activity. Significant variation ($p \leq 0.001$) in different land-use activities explains different intensities in land use and variations in surface runoff causing different soil nutrient available. Different land uses have different levels of nutrient availability and stability (Old maize field >2% of organic matter, new maize field <6 soil pH, and grassland with < 40mh/kg of phosphorus). The concentration of available soil nutrients naturally decreases with time however, certain aspects such as tillage, water drainage, and mulching practices also influence the structure and concentration. Furthermore, concentration levels of soil phosphorus indicate the levels of soil erosion (orchard 11.41mg/kg) with different land use areas. Concentration levels of soil nutrients provide land-use intensity signature and vulnerability an area is to soil erosion as well as signifying management levels.

Nzhelele Valley has a substantial agricultural land cover, which is the biggest land use activity that affects soil erosion (Table 6.1). The implication of agricultural practice on soil includes a change in soil structure, a decrease of soil nutrient content such as soil organic matter, soil nitrogen levels, soil pH levels, and soil phosphorus content. Results from the study on land use and soil structure reveal low levels of soil organic matter (old maize field 1.32%) intensive agricultural land use. In this light, the land use activities have been shown to promote a decrease of soil nutrients increasing soil vulnerability to soil erosion.

A synthesis of our research findings suggests that a particular land management scheme is required to reduce the rate of soil erosion in Nzhelele Valley. This was confirmed by the results from the study of low levels of phosphorus (orchard 11.41 mg/kg) that demonstrates loss of phosphorus nutrient in the soil resulting from surface runoff and soil erosion. Results indicated that 80% of the organic matter has been depleted and the capacity of the land to sustain crop production is very low. Mass deletion of the organic matter content increases the vulnerability of land to soil erosion, especially within agricultural practices. The results mirror that of studies in Africa and Europe (Maiga-Yaleu *et al*., 2015; Dignac *et al*., 2017; Pisani *et al*., 2016).

A series of acidic soils in an old maize field (5.98) and forest (5.15) areas demonstrates a decrease in soil quality, which affects the soil nutrient structure, and, in many instances, results in soil erosion and high surface runoff. A combination of different nutrient losses in soil provides a bigger picture of the management strategies of land and the chances of soil erosion in the area (Table 6.1). A measure of soil parameters gives direction on how best certain types of soil have been used and how the best solution be made to improve the structure. Phosphorus levels of (forest area 3.95mg/kg) show the lowest levels of soil nutrient levels, articulated to high surface runoff and soil erosion that have eroded the phosphorus level within the land-use area. This, however, does not deter from the fact that improper land use management in Nzhelele Valley will go a long way in increasing the challenges of low yield and high vulnerability of soil erosion. The introduction of manure and fertilizers are some of the interventions that the farmers have introduced to improve yield production. However, this does not improve the soil quality as this is only a temporary solution to a long-time problem. The evidence of soil erosion has already been showing in most of the soil parameters such as acidic soil (old maize field 5.98), new maize field (organic content 2.97%) and nitrogen levels (0.046% old maize field).

CHAPTER 7: MODELING SOIL EROSION ON LAND USE AND LAND COVER OF NZHELELE VALLEY.

7.1 Introduction

This chapter presents results and discussion of data following a SWAT report obtained from the Arc SWAT Model Interface. Attaining land-use intensification from the valley at the same time limiting soil erosion requires a better understanding of the valley land use characteristics and soil types. This chapter aims to model land use and its impact on soil erosion, dwelling much on the dynamics of hydrological processes and soil loss in the Valley, which occurs in different land uses. This chapter is organized into major themes, which address the key fundamental elements that provide direction towards presenting the results of the study.

7.2 Watershed delineation

The land use, slope, and soil delineation were created from the Arc SWAT model. This generally describes the watershed based on land use, soil, and slope. The SWAT model defined the soil type, slope, and land cover for all the sub-basins found within the watershed. The map shows the HRUs (Hydrological Responds Units) to define HRU as one field, each field needed to have land use, soil type, and one slope. It should be noted that the study utilised slope, soil type, and land use type embedded in the software.

For accurate routing of water and sediment, the Nzhelele basin was divided into 26 natural sub-basins (Figure 7.1). This was meant to preserve the natural flow paths, boundaries, and channels of water flow. A total of 301 HRUs were further obtained from the sub-basins. The HRUs are normally defined by taking similar land use, soil type, and slope characteristics within a given sub-basin based on user-defined thresholds for each category. In this standard method, the user can control the number of HRUs by applying a threshold on land area permitted for given land use or soil type within a sub-basin. This study used a threshold of 10% land use, 10% soil, and 15% slope class.

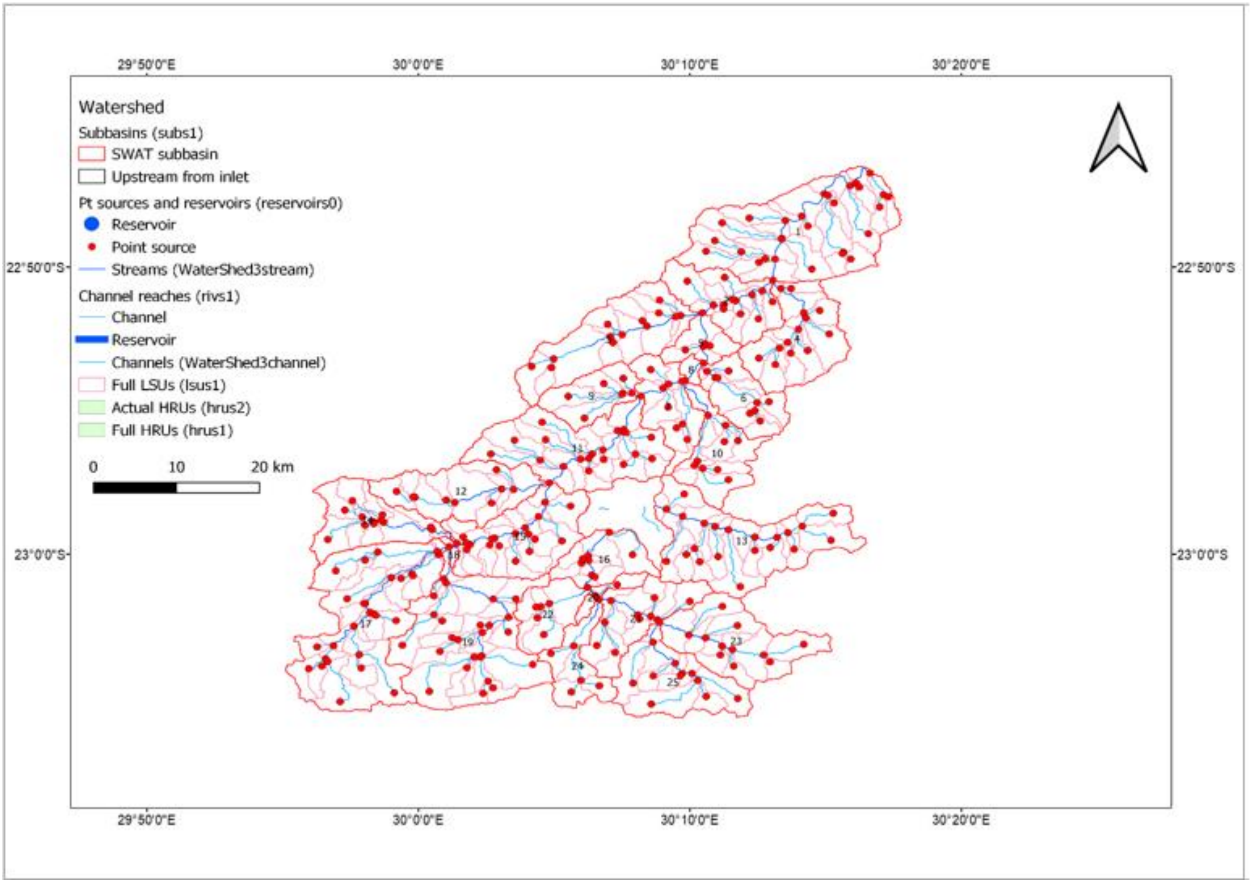

Figure 7.1: Hydrological Response Units of Nzhelele Valley

7.2.1 Topography

The terrain of the study area is based on the elevation from the given results. The SWAT works even when the elevation is less than 384m. The topography has been modified to speak to the elevation data used in the SWAT software. The results illustrate statistics of the elevation of the watershed with a minimum elevation of 384 m, maximum elevation of 1680 m, and mean elevation of 808.81 m, and a standard deviation of 277.84 m.

7.2.2 Land use

The study delineated land into different land use within the study area. A total of 4 land use classifications are produced from the SWAT model (Figure 7.2) which include: Agricultural fields, bare land/built-up area, grassland, and forest. The land-use dataset used in the study on other chapters has been modified and it is different from the land use data which was used on the chapter of SWAT model. This is because the SWAT model has an inbuilt land cover type that is geo-located for any location in the world. Thus this study utilised the software embedded land use dataset.

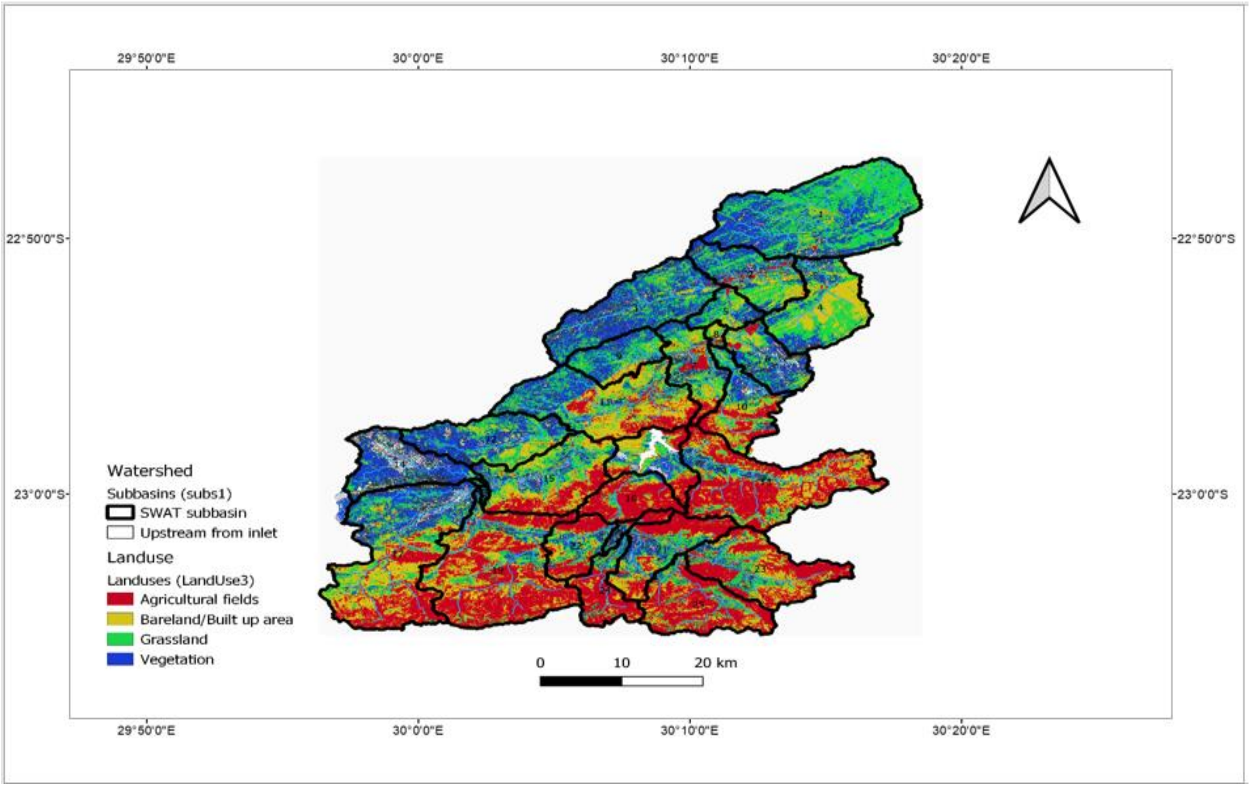

Figure 7.2: Land use delineation within Nzhelele using Soil and Water Assessment Tool (SWAT)

7.2.3 Soil type

The soil type categories were adopted from the SWAT model. These classes are embedded in the software and geo-located to be used all over the globe. The results illustrate the classification of different soil types including clay loam, sandy clay loam, sandy clay, loam, silt loam, clay, loam sandy, clay silt, and clay loam silt (Figure 7.3). The model establishes spatial variation of unique soil characteristics across the sub-basins. Specific soil types were captured from the study area that influences the various spatial distribution of different land use within the Nzhelele watershed.

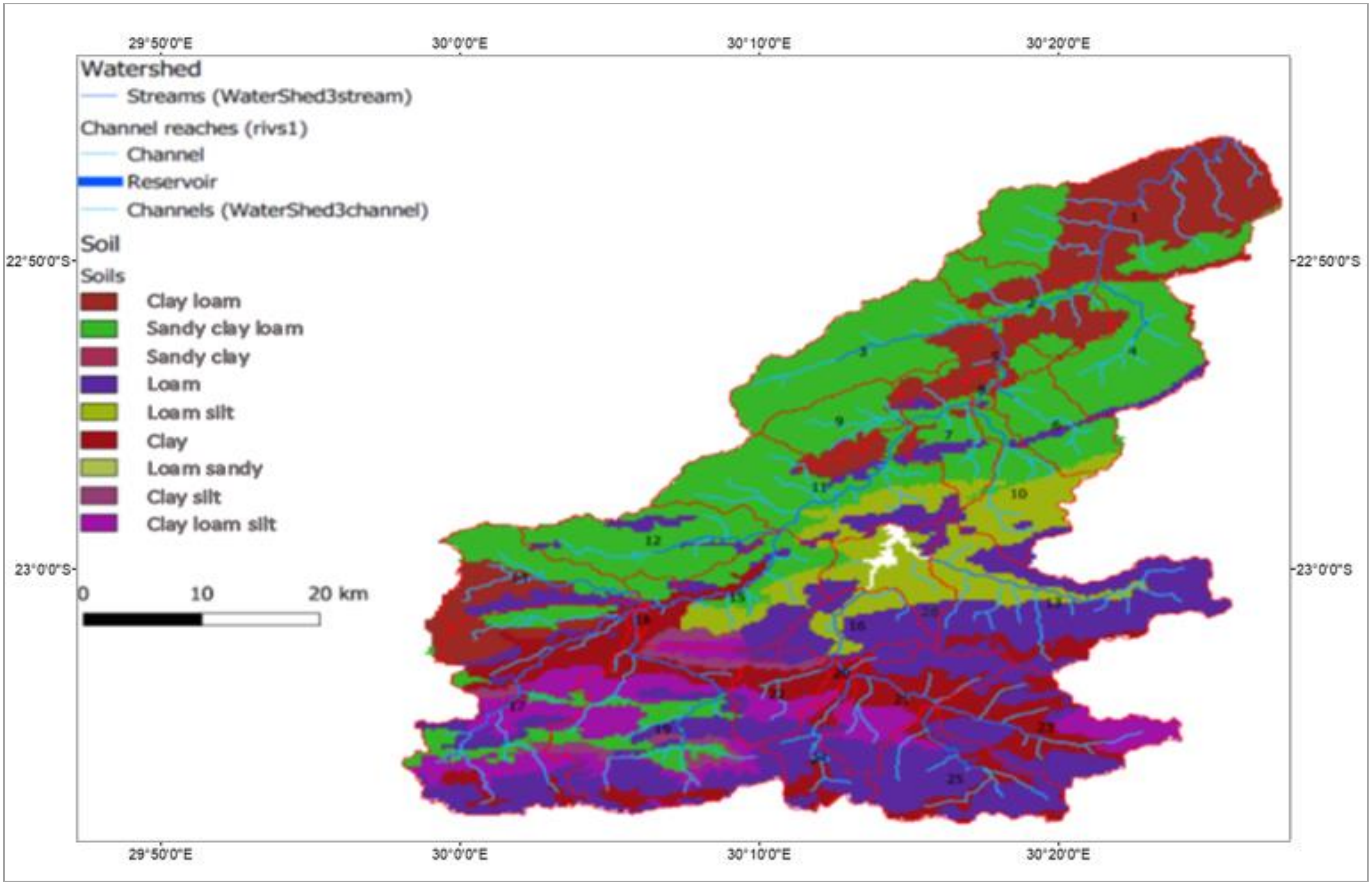

Figure 7.3: Soil type's delineation within Nzhelele using Soil and Water Assessment Tool (SWAT

- **Soil erosion in Nzhelele sub-watershed**

The results show variation in sediment yield within each of the observed sub-basins in the study area. The sub-basin annual average sediment yield (t/ha-1 yr-1) were grouped into different priority scales based on guild lines by Singh (1995): slight (<5), moderate (5-10), high (10-20), very high (20-40), severe (40-80) and very severe (>80). Based on the results, the majority of the sub-basins fall within the slight erosion category. The results shown in Table 7.1, recorded high erosion-prone areas within the sub-basins are 38.14% while moderate erosion-prone areas are 34.06%. No sub-basin within the entire watershed is falling within the very high to very severe erosion-prone categories. Sub basin 13, 23, and 25 demonstrate high erosion-prone classes with an average sediment yield of 15.3%, 11.26%, and 11.57% respectively (Table 7.1). The highest sediment yield (15.30%) is observed in sub-basin 13 showing a high soil erosion class category. Sub basin 3 observes the lowest sediment yield (2.1 t/ha-1 yr-1) within the entire watershed. The sediment output decreased over the years from 1980 going up to 2010 with an increase in years. A study done in the Krishna River basin Marol water shed India which experience average annual rainfall of 1624 mm by Himanshu *et al*., (2019) suggested that maximum sediment yield (69.8 t ha yr-^{1}) was caused by high land-use activities within a steep slope of up to 59.1% and undulating topography. Amongst the slight erosion class category observed in the study, the majority of the HRUs are located within the deciduous woodland, closed deciduous forest areas, and closed evergreen lowland forest areas (Figure 7.4). The high rates of soil erosion from the results are mainly caused by high land use activities within the sub watershed. Himanshu *et al*., (2019) suggested that maximum sediment yield (69.8 t ha yr-^{1}) was caused by high land-use activities within a steep slope of up to 59.1% and undulating topography.

Table 7.1. Different soil erosion classes in Nzhelele Watershed.

Sr. No.	Sediment Yield (t.ha^{-1}yr^{-1})	Sub-watershed	Percentage Area	Soil Erosion Class
1	0-5	1, 2,3, 4, 5, 6,8,9, 11, 12	50.4	Slight
2	5-10	7, 11, 14, 15, 17,20, 24	31.6	Moderate
3	10-20	10, 19, 22, 16, 18	12.5	High
4	20-40	13, 23, 21,25	5.5	Very high

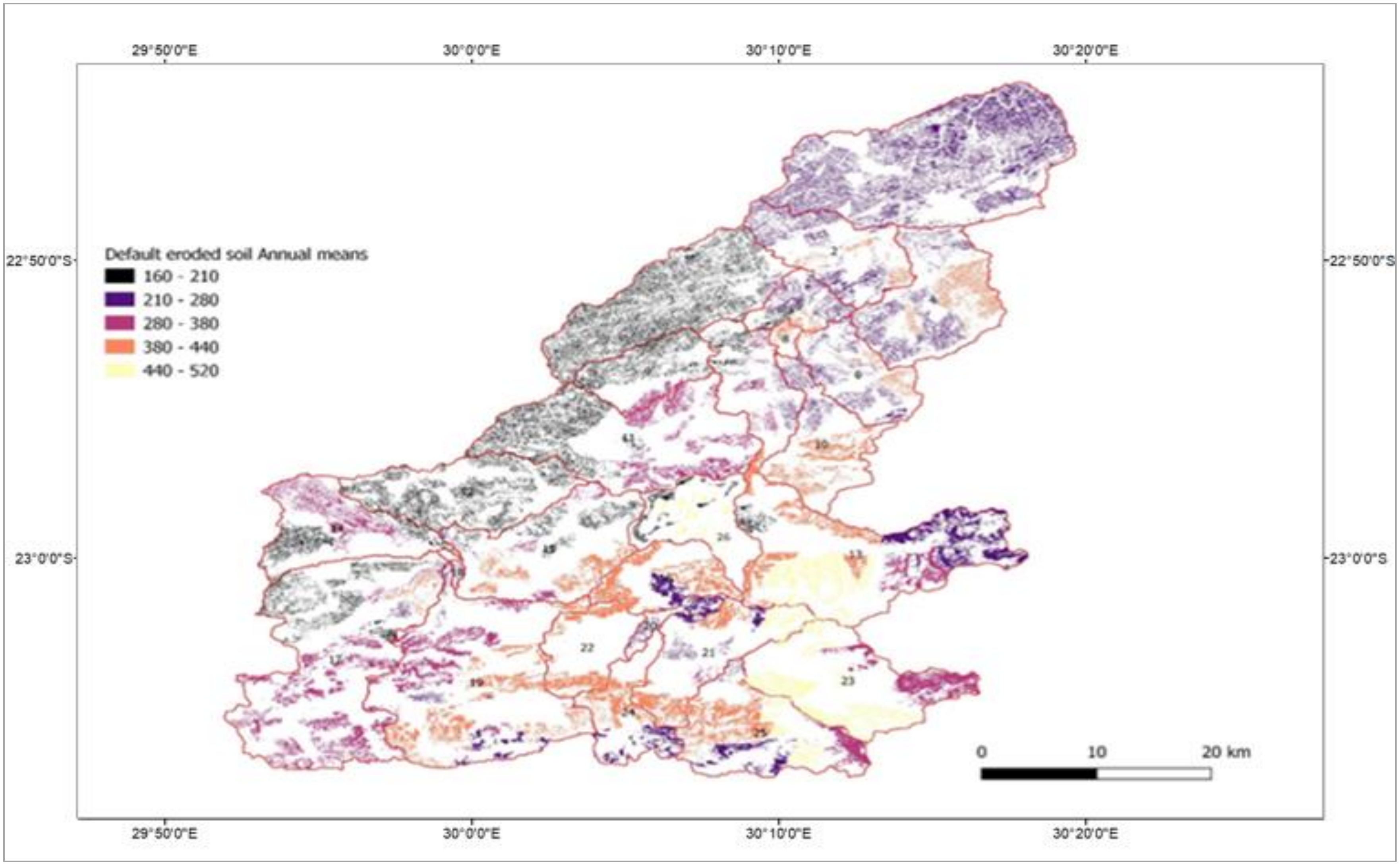

Figure 7.4 Sub-watershed annual average sediment yield (ton/ha/year) map.

Sediment load and land use change

Changes in agricultural fields illustrates a negative trend (-3%) in land use and land cover change, which suggest high sediment load observed within sub basin 13, 23 and 25 (Figure 7.4). A further negative change of -5% (Figure 4.6) which is the highest change observed within the study. This result relates to a 50.4% of slight erosion class within Nzhelele watershed. A significant change in agricultural land use and land cover from 36% in 2005 to 25% in 2019 shows an increase in soil erosion (Figure7.4) with a decrease in forest

The build-up area shows an increase in trend from 14% to 17% during the 2010-2019 periods (Figure 4.2 and Figure 4.4). These results suggest that Sub basin 13, 23, and 25 demonstrate high erosion-prone classes with an average sediment yield of 15.3%, 11.26%, and 11.57% respectively (Table 7.1). During this period, agricultural area is converted into built up (3% increase between 2005 and 2019) resulting in soil erosion (Figure 7.4).

Table 7.1 shows high soil erosion and sediment load (12.5%) within the Nzhelele watershed. The sediment load (Figure 7.4) suggests an increase in grassland from 14% to 17% during the 2010-2019 periods (Figure 4.2 and Figure 4.4). During this period, agricultural area is converted into built up (3% increase between 2005 and 2019) resulting in change of soil fertility structure and soil erosion.

7.2.4 Sub basin distribution within Nzhelele watershed

The results show the different parameters that generally describe the watershed in terms of these three factors used for the analysis: soil, slope, and land use. It describes the land use; soil type and slope cover within the watershed. The slope area between 0.7 degrees observes the highest area cover (51.72%) within the watershed. The slope area from the study area ranges from 7.0 degrees to 76 degrees within the watershed.

Table 7.2: Sub basin distribution of land use, soil type and slope

Land use/Soil/Slope Distribution
No short channel merge
Number of sub basins: 26
Number of channels: 301
Number of LSUs: 301

	Area [ha]
Watershed	271,343.60

Parameter	**Area [ha]**	**%Watershed**
Land use		
Closed evergreen lowland forest	53866.11	19.85
Closed deciduous forest	65569.34	24.16
Deciduous woodland	21617.02	7.97
Deciduous shrub land with sparse trees	56567.05	20.85
Open deciduous shrub land	25586.34	9.43
Cropland	48137.72	17.74
Soil		
Clay loam	36163.26	13.33
Sandy clay loam	48634.92	17.92
Sandy clay	45710.27	16.85
Loam	66364.96	24.46
Loam silt	20054.68	7.39
Clay	10893.38	4.01
Loam sandy	19119.19	7.05
Clay silt	4390.11	1.62
Clay loam silt	20012.79	7.38
Slope		
0-7.0	140329.33	51.72
7.0-19.0	64195.22	23.66
19.0-39.0	48667.20	17.93
39.0-76.0	16222.40	5.9
76.0-9999	1929.42	0.71

7.3 Evaluation of SWAT model for discharge and sediment yield

The SWAT model was evaluated on annual basis using the observed and simulated discharge and sediment load of the study area watershed. The total observed data series were divided into two segments, 1980 to 1993 for calibration and 1995 up to 2010 for validation. The performance evaluation of the SWAT model based on annual discharge and sediment load is shown in Table 7.3. The observed and simulated monthly and annual sediment load and discharge for calibration and validation periods are shown in Figure7.5. Scatter plots of observed versus simulated monthly discharge and sediment load are presented in Figure 7.6, 7.7, 7.8, and 7.9 respectively supporting the preceding outcomes.

Streamflow simulation, the obtained (NSE) values of 0.82 for annual calibration and 0.79 for annual validation respectively illustrating very good simulation. The (PBIAS) values of -12.45 for annual streamflow calibration and 7.78 for annual validation (Table 7.3) show an underestimated discharge by the SWAT model by 12.45% and overestimation by 7.78% during the annual calibration respectively. Other evaluation criteria demonstrated a very good agreement between observed and simulated hydrographs on the annual time scales showing the very good performance of the SWAT.

Similarly, sediment load simulation indicated the same trend as that of streamflow discharge. The NSE annual value of 0.74 demonstrated good performance. However, PBIAS values of -22.67 for annual calibration and 16.81 for annual validation show an underestimation of sediment load by 22.67% during the annual calibration. There was also an overestimation of annual validation of sediment load by 16.81%. The statistical performance illustrated a very good performance of the SWAT model for the sediment load simulation.

Table 7.3 Performance evaluation of SWAT model

	Total stream flow			Sediment load	
Sr.No.	Parameter	Annual		Annual	
		Cal	Val	Cal	Val
1	NSE	0.82	0.79	0.74	0.71
2	PBIAS	-12.45	7.78	-22.67	16.81
3	CC	0.94	0.92	0.93	0.89
4	RSR	0.41	0.47	0.43	0.47

Observed and simulated sediment load for annual calibration and validation (1980-2010). The results demonstrate the highest and the lowest points of observed and simulated validation discharge within the study area. It illustrates the annual discharge for the entire study period.

Note: *Cal = Calibration, Val = Validation*

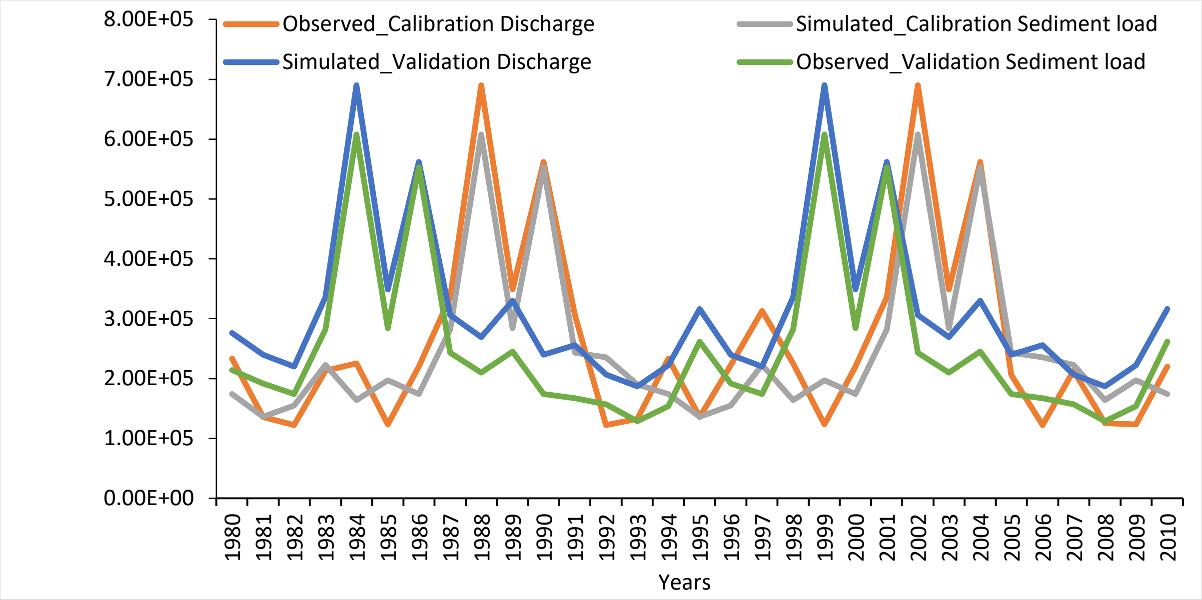

Figure 7.5: Simulated vs Observed discharge for annual calibration

The observed discharge about the annual calibration was regressed against the simulated discharge also related to the annual calibration using a simple linear regression technique (Figure 7.6). From the scatter plot 7.6, it can be observed that there is a positive correlation between the two variables. With $R^2 = 0.63$. In the scatter, plot points follow the line of best fit.

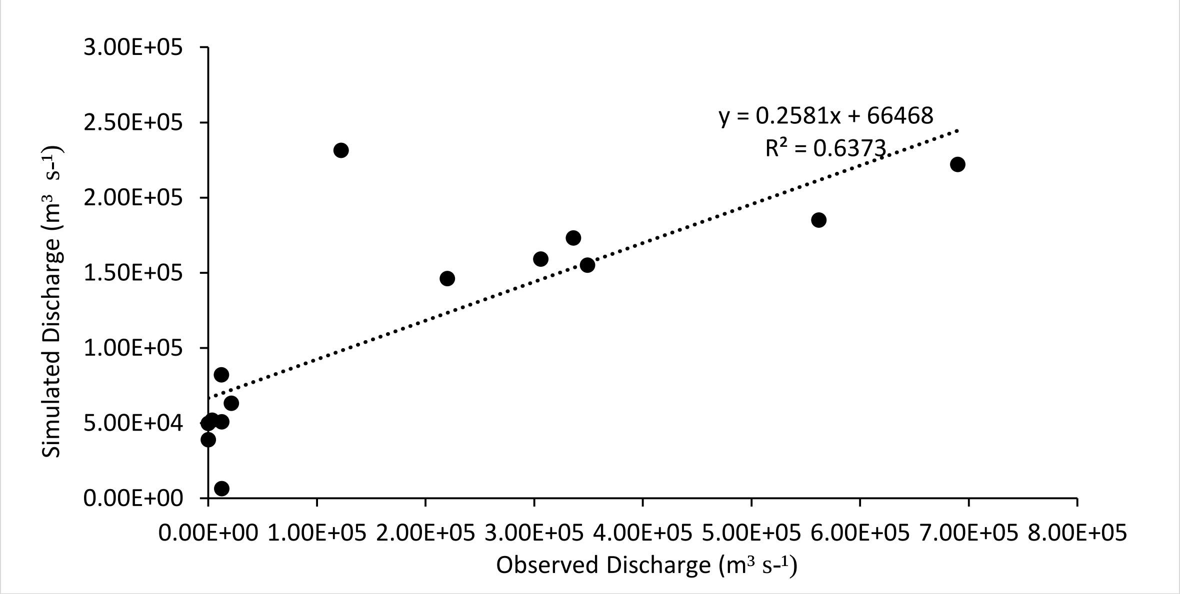

Figure 7.6: Simulated vs Observed discharge for annual calibration

The scatter plot below shows the association of the observed discharge and the simulated discharge of the validation. It can be observed that there was a weak relationship between the two variables (observed and simulated discharge) with the R^2 =0.3. (Figure 7.7).

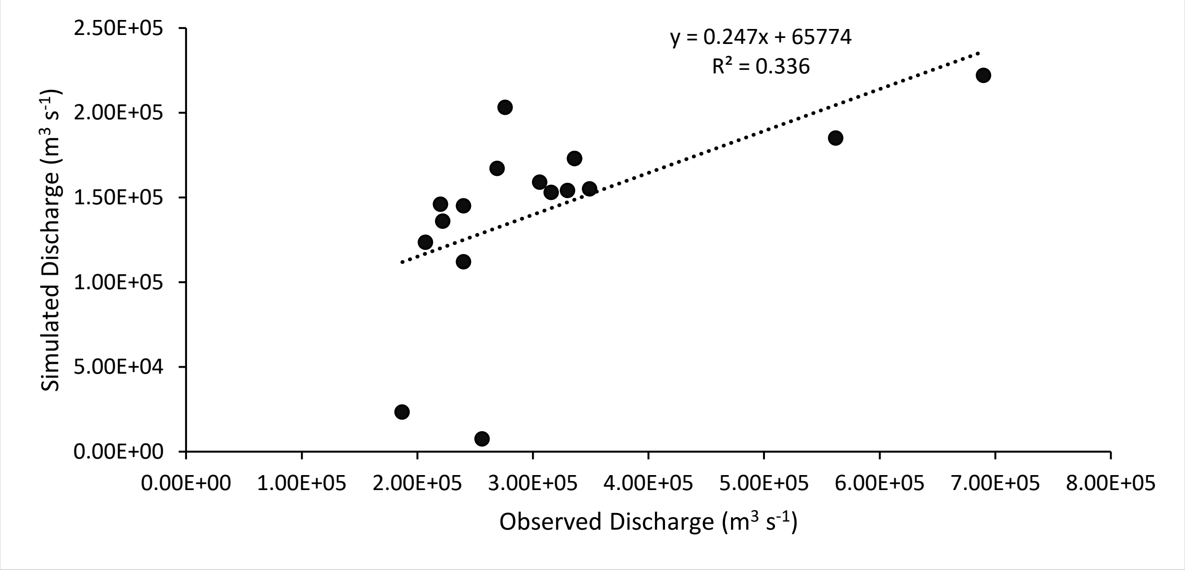

Figure 7.7: Simulated vs Observed discharge for annual validation

The relationship of the observed sediment load was regressed against the simulated sediment load. The scatter plot showed a high correlation between the sediment load and the simulated load. With the R^2 of 0.9 (Figure 7.8). The lowest observed sediment load was recorded with the value of 20000 which was also comparable with the simulated sediment load and the highest capping at 4500.

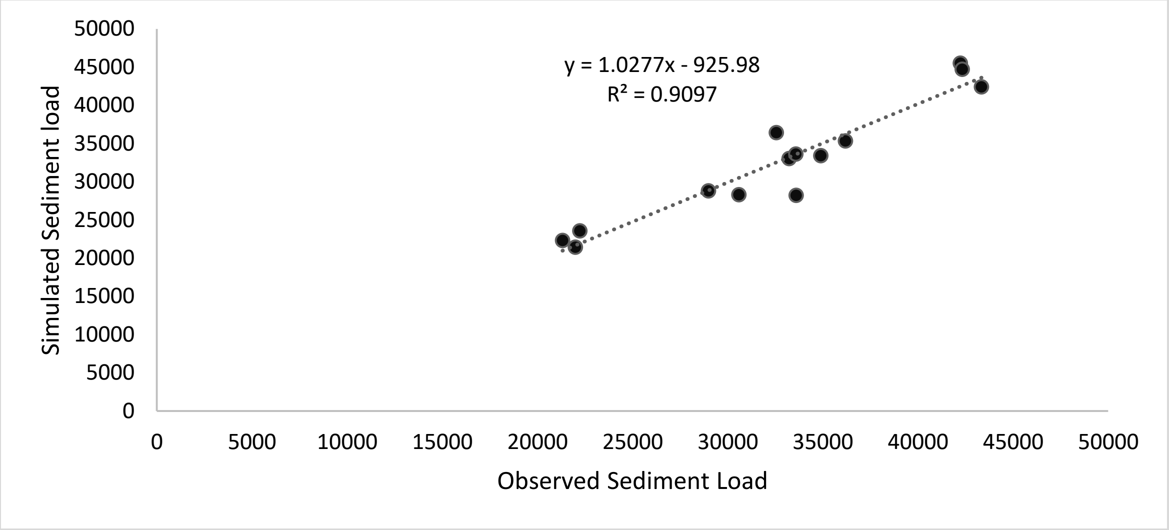

Figure 7.8: Simulated vs Observed sediment yield for monthly calibration

The relationship of the observed sediment load was regressed against the simulated sediment load. The scatter plot showed a high correlation between the sediment load and the simulated load. With the R^2 of 0.8. The lowest observed sediment load was recorded with the value of 19000 which was also comparable with the simulated sediment load and the highest capping at 45000 (Figure 7.9).

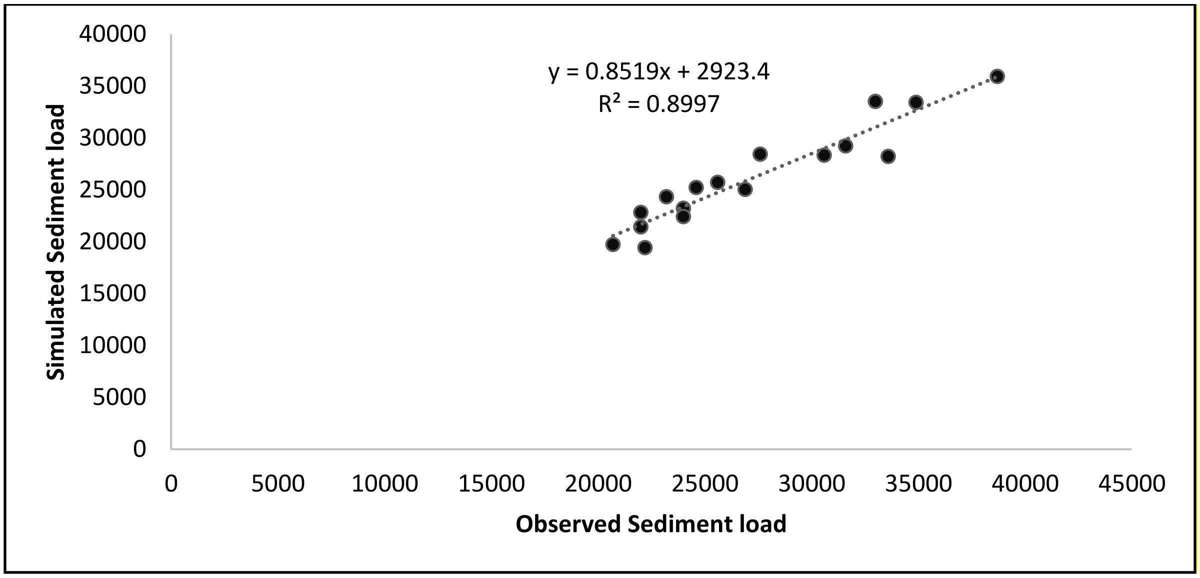

Figure 7.9: Simulated vs Observed sediment yield for monthly validation

7.4. Sub-watershed water balance

A water balance is based on mass conservation. It reflects that the rate of change in water stored in a hydrological unit (e.g. catchment) is balanced by the rate at which water flows in and out of the unit. In the medium term, the application of water balances will support integrated water resources management and decision-making at different scales; a critical review of current water allocation mechanisms between and within water use sectors; the definition of policy (water quantity) targets; and the drafting and adoption of measures that account for the (quantitative) sustainability of water resources.

Water balance $P = R+E + \Delta S$

ΔS = is the change in storage (in soil or the bedrock/groundwater)

P = Precipitation

R= streamflow

E= Evapotranspiration

This equation uses the principles of conservation of mass in a closed system, whereby any water entering a system (via precipitation), must be transferred into either evaporation, surface runoff (eventually reaching the channel and leaving in the form of river discharge), or stored in the ground. This equation requires the system to be closed, and where it isn't (for example when surface runoff contributes to a different basin), this must be taken into account.

The mean annual water balance over the simulation period (1980-2010) has been established for 26 sub-watersheds using the SWAT model (Table 7.3). Evapotranspiration is predominant accounting for 45.3% of the average annual precipitation and 43% of surface runoff has been observed to be leaving the watershed. However, the entire watershed converts 25% of the annual precipitation into surface runoff. This demonstrates the need for suitable soil management programs that would address problems of runoff, which will reduce soil erosion.

The results suggest that the monthly evapotranspiration in wet months is lower than precipitation during that month. This is caused by the low evapotranspiration throughout the day and night when precipitation is not occurring. Evapotranspiration rates are influenced by the root zone depth and surface moisture and availability of sunlight during the day. However, annual precipitation is greater than annual evapotranspiration. The results demonstrate the highest evapotranspiration in sub-watershed 23 and the lowest in sub-watershed 19 (Table 7.3). This shows that high surface runoff and soil erosion especially in areas of agricultural practices

Table 7.4: Sub-watershed annual mean water balance within the study area

Sub- watershed	Area (km^2)	Evapotranspiration (mm)	Surface run-off (mm)	Lateral Flow (mm)
SW-1	528.31	64.8	148	0.3
SW-2	104.01	44.9	141.3	0.3
SW-3	13.57	75.3	141	0.4
SW-4	497.67	63.6	149.8	0.2
SW-5	115.65	51.6	141	0.5
SW-6	119.27	19.4	149.8	0.2
SW-7	1997.5	75.4	143.9	0.3
SW-8	71.16	75.9	123.4	0.1
SW-9	593.38	58.7	177.6	0.4
SW-10	593.38	38.7	179.6	0.2
SW-11	730.26	44.4	127.2	0.7
SW-12	664.54	88.7	160.5	0.4
SW-13	178.88	29.2	159.4	0.3
SW-14	677.46	92.2	112.9	1.1
SW-15	189.96	29.7	71.7	0.3
SW-16	174.23	29.2	181.4	1.1
SW-17	669.43	89.2	116.4	0.3
SW-18	608.98	92.7	121.3	0.2
SW-19	122.48	13.1	165.7	0.3
SW-20	215.77	17.5	101.8	0.6
SW-21	197.74	82.2	103.2	0.8
SW-22	302.32	37.4	154.2	1.2
SW-23	149.13	95.3	114.2	0.7
SW-24	438.6	85.8	115.3	1.4
SW-25	954.72	64.2	121.4	0.4
SW-26	178.3	37.2	132.1	0.6

7.6 Response of sediment yield to precipitation

Climate change is generally caused by an increase in atmospheric greenhouse gases because of anthropogenic activities. This has some significant impact on land use and land cover land cover type in a given area. Climate changes alter hydrological cycles, which in turn change the land use activities and streamflow regimes (Chen *et al*., 2006). A change in forest cover (Figure 4.4) as a result of change in climatic condition results in increase in soil erosion (Figure 7.4). Hydrological systems can be very sensitive to climate variability and land use activities especially in arid regions (Figure 7.4). Saleh *et al*., (2009) suggested that water resources in arid regions are highly affected by precipitation.

Annual surface runoff generally is generally influenced by change in climate. Increase in precipitation results in increased channel flow, which influences sediment output. It is worth noting that annual sediment yield shows an irregular trend pattern because of variation in precipitation changes and land use activities.

Land use activities in Nzhelele Valley (Agriculture field Figure 4.4) is associated with stream flow especially within irrigation areas. The increase in agricultural practices within riparian land use areas affects the level of soil erosion within the Nzhelele Valley (Figure 7.4). Anthropogenic practices within riparian land use has a significant contribution to soil erosion associated with change in rainfall patterns (Pachauri *et al*., 2014).

7.9 Summary

The study employed a SWAT model assessing soil erosion in land use and land cover of the Nzhelele watershed. The study generated the soil structure of the Nzhelele land-use area. The results show the water balance displaying dominant evapotranspiration accounting for 46% of the total average annual rainfall within the watershed. Furthermore, the study shows an average annual sediment yield of 12.2 tha-^{1}yr-^{1} and with the majority of sub watershed falling under a slight erosion class. However, sub watershed 13 shows the critical stage of soil erosion caused by poor agricultural practices and steep slopes. Our findings show that the Arc SWAT model can simulate the response of the hydrological basin (peak and total runoff) to climate and land use activities. The output from the model provides useful information about the dynamics of land use contributions to sediment output as well as to runoff dynamics due to precipitation. This approach may be useful to analyse future scenario responses to climate change and changes in land use/cover.

The land use, slope, and soil delineation were created from the Arc SWAT model. Based on the river networks and topography of the basin, 25 sub-basins were produced and 301 HRU's were obtained. A total of six land use classes were produced with open deciduous land use having the highest land cover (24.1%) and cropland having the least (7.9%) land use cover. Based on the results concerning meteorological variables, the highest amount of annual precipitation was recorded in 1984 (540 mm), while 1991 recorded the lowest amount of annual precipitation (285 mm) in the study period. Precipitation generally results in higher streamflow, and lower rainfall results in relatively lower streamflow (Figure 7.5 and 7.6).

Extreme high channel flow was observed in the years 1984, 1986. 1989 and 1999. The results show the highest sediment output (16400 t/ha^{-1} yr^{-1}) in 1984 while the lowest values of sediment output (536 t/ha^{-1} yr^{-1}) were observed in 2004. Fluctuation in sediment output is observed within different years influenced by variation in land use. However, a drastic decrease in sediment output is observed from 1989 up to 1991 (Figure 7.8). Based on the results, the majority of the sub-basins fall within the slight erosion category.

The results show high erosion-prone areas within the sub-basins are 38.14% while moderate erosion-prone areas are 34.06% (Figure 7.9). Subbasin 5, 6, and 11 demonstrate high erosion-prone classes with average sediment yield of 15.3%, 11.26%, and 11.57% respectively (Figure 7.9). The highest sediment yield (15.30%) is observed in sub-basin 5 showing a high soil erosion class category. The sediment output decreased over the years from 1980 going up to 2010 with a decrease with increase in years. The high rates of soil erosion from the results are mainly caused by high land use activities within the sub-basins, high slope in some parts of the study area, and abandonment of land that contributes to more sediment output.

CHAPTER 8: CONCLUSIONS, AND RECOMMENDATIONS.

8.1 Introduction

This chapter presents recommendations and conclusions as informed by the research discussions and data interpretation.

8.2 Conclusions

8.2.1 Addressing land use and land cover on soil erosion in Nzhelele Valley

One key challenge on land use and cover in Nzhelele Valley is the need to address spatial changes that contribute to soil erosion in most villages. Spatial changes that occur over time demonstrates that land cover changes based on land-use changes have a connection to soil erosion. The overall change in cover and land use including an increase in bareland/built-up areas contribute to soil erosion (Figure 7.4) with an increase in spatial settlement (Figure 4.4). Based on the research findings, changes in land use and land cover (agriculture 11%) has resulted in encroachment of other land use and land cover (Forest cover, 5%).

Consequently, in a bid to address spatial land use and land cover change and problems of soil erosion in Nzhelele Valley, it is observed that land use activities change over time (Table 4.1) and this results in soil erosion (Figure 7.4). This submits that increase in land use activities results in variation of change in land use and land cover over time. Solutions such as combined ownership of land and community responsibility require much more effort and piloting before acceptance and implementation. Inadequate support and funding to support land use research and land management also have a major role in unplanned changes of land use/cover, which causes environmental problems.

In areas such as bare land, woodlands, and forestry, there is need for better conservation methods that creates solutions to soil erosion (Nunes *et al*., 2011). The rate of change of uncovered area (bare land/built up areas 3%) over the 14-year period (Table 4.1) indicates the vulnerability of Nzhelele Valley to soil erosion. Soil erosion and land degradation increases in marginal areas during the farming season due to change in land use and land cover. Overall synthesis of the findings illustrates that land-use changes significantly impacts soil erosion (Figure 7.4)

8.2.2 Land use-management strategies on soil erosion.

The findings of the Factor analysis show major strategies of farm management that affects farmers on soil erosion decision with effects in various land use areas. The farmers with better resources endowment (related to land and livestock holdings) invest more in land management. Farmers invest in land management when they have financial surplus from their primary needs such as food. Given this result and limited financial resources of farmers in the Nzhelele Valley, there is a need to involve government strategies while land management strategies are planned.

This study also shows that farmers' investments in land management are enhanced by available social capital in Nzhelele Valley. This suggests the need to find approaches for farmers to access a wide network of information and technical support from different sources and advice to strengthen social networks. The farmers' investments in land management investments are influenced by the availability of family labour; especially in Nzhelele Valley where soil erosion control required high labour demand which is of key importance for agricultural production.

The diversity of determinant factors across Nzhelele Valley is due to differences in social, economic, cultural and biophysical characteristics of the study area. This shows that the current blueprint (one size fits all) approach to sustainable land management in the government agricultural practice is not useful. Land management strategies designed at macro level should be adapted to the local circumstances in the specific local villages, based on their local situation.

8.2.3 Effect of Soil fertility on soil erosion

One key find of the study is that soil degradation in Nzhelele Valley imposes environmental cost and soil erosion as well as a decrease in crop production. The results highlighted that different soil fertility (organic matter, soil pH, nitrogen, and phosphorus) are major components that are associated with soil erosion. A decrease in soil organic matter within the study area in Table 6.1, (OM-1.3% and SL-1.4%) shows the vulnerability of the agricultural land to soil erosion (Figure 7.4). Decrease in soil fertility allows soil erosion to take place as this decrease the forest cover increasing surface runoff.

Soil fertility is mostly affected by loss of topsoil caused by various land use activities resulting in a decrease in soil pH thus making the soils acidic. Low soil fertility as indicated by organic matter, nitrogen, soil pH, and phosphorus (Table 6.1) are caused by continuous cultivation. It also indicates the intensity and duration of land use in specific areas. The continuous cropping over years without soil replenishment decreases the availability of organic matter, phosphorus, and organic matter. Soil erosion (Figure 7.4) disturbs the soil's chemical properties through loss of organic matter minerals and exposure of subsoil with low fertility and high acidity

Solutions that address soil deficiency are key components necessary to address the soil parameters and soil erosion in this study. Soil chemical structure affects the soil productivity of farmers as well as plant growth, which in most instances pave way for environmental problems such as soil erosion (Figure 7.4). this is shown in the study findings that in Nzhelele Valley, (soil pH 5.15) in forest area, (phosphorus (18.81 mg/kg) in old maize field and (nitrogen 0.059%) shrubland, low fertility forest cover, decrease in agricultural land use (Figure 4.4) increasing soil erosion.

8.2.4 Addressing soil erosion in land use area

Land use and climate are two factors that contribute to hydrological responses of the river and sediment output. Variability in climate has an impact on the peak flow and volume, which affect the spatial distribution of sediment output and the rate of soil erosion. Land use affects the mean annual discharge and severity of sediment output.

The overall trend in climate change since 1968, there have been a decline in precipitation (Walter et al., 2020) and relative humidity in the Nzhelele catchment. The reduction has resulted in vulnerability in food security to the residents in the river catchment as they depend on the rain fed agriculture. Of note, high precipitation in 2000 due to extreme weather event Cyclone Leon-Eline (Walter, et al., 2020). However, despite the decline in overall precipitation, there has been an increase in extreme weather events such as, Cyclone Domonia in 1984 (Manyatsi, 2011), Tropical Storm Irina in 2011–2012 (Fitchett, and Grab, 2014) and Cyclone Dineo in 2017 (Moses, and Ramotonto, 2018). These cyclones and tropical storms have high-speed winds and precipitate large rain downpours in a short period of time which increases soil erosion (Figure 7.4) thus increasing the vulnerability of food security and causes flooding (Manyatsi, 2011). For example, the cultivation on slopes and the clearing of forest exacerbated the soil erosion (Table 5.1) in the study area as a result of storm intensification such as Cyclone Leon-Eline (Fitchett, and Grab, 2014). Consequently, settlements and agricultural fields are vulnerable, and this calls for better disaster preparedness and coping land use management strategies (Table 5.1) to mitigate the impact of soil erosion (Figure 7.4) in Nzhelele catchment area.

SWAT analysis illustrates that sediment output is influenced by climate variability and soil type as well as the slope of an area. From these factors, SWAT simulated variations in sub basins' sediment output over time. The levels of sediment output demonstrate the levels of soil erosion as well as land-use change over time. Sediment output based on the land use classes is potentially influenced by cropland with the study. A gradual increase in sediment yield demonstrates the change in land use as well as levels of precipitation on soil erosion

8.3 Recommendations

This section presents the research recommendations as informed by the research results. This is important because it ensures that recommendations are an outcome from the research objectives and the researcher's critique based on the literature review of land use/cover change on soil erosion.

8.3.1: Closing the knowledge gaps and mitigating the challenges of soil erosion on land use land cover change in the Nzhelele Valley.

8.3.2 Land use and land cover change management

Based on the conclusion made, recommendations were suggested as following:

- The land use change that is mostly affected by agricultural activities needs to be projected to figure out where the land use change leads in the future. It is useful to plan strategies in land rehabilitation and to anticipate the possibility of erosion risk triggered by land use changes.

- High soil erosion in Nzhelele Valley watershed is potential to remove most of top soil surfaces and affect soil quality as explained previously. Even though farmers have not yet felt the influence of soil erosion on crop productivity, however a more detailed research scale should be conducted, especially in area that experienced intolerable soil loss, to figure out how bad soil loss has affected soil quality.

- A suitable soil conservation technique should be formulated in Nzhelele Valley watershed considering the high soil loss and the irreplaceable agricultural practice. Setiawan, (2012) suggested two kinds of soil conservation techniques: terrace risers with stone and terrace riser with grass. These two conservation techniques can be a good start to formulate the best technique for Nzhelele watershed

8.3.3 Tackling management strategies as a means of solving soil erosion

- Addressing and education of economic cost will help farmers and local District officers to emphasize surface erosion control over other aspects of degradation and productivity improvements.
- Implementation of educational programs that motivate old and young to conserve land and better ways to manage productive land through government departments might assist participants in better management strategies.
- Concisely, a mixture of better implementation plans and support from the department of agriculture will improve the management strategies and implementation mechanism.

8.3.4 Degradation of soil fertility

- Prevision of monetary value of the lost nutrient could ignite the local farmer if awareness creation would be conducted for sustainable nutrient management and soil conservation activities.

- The need to have solutions generated in collaboration with the local community for local farmers in Nzhelele to understand and provide input to prevent problems of soil erosion.

- Stand-alone solutions can be implemented using organic fertilizers and consultation with the department of agriculture efficiently and effectively based on the severity of the problem within the area of concern.

8.3.5 Improving soil erosion with SWAT model within South Africa.

- In order to understand better, similar studies must continue in the catchment including event-based sediment hysteresis assessment in order to compare it with the weekly

- More-so there is a need for the establishment of catchment management agencies throughout South Africa, which will provide informative and relevant data that will establish a good framework and availability of data for research

- There is a need to have a large base user of SWAT developed in South Africa to have a viable possibility of availability of data that can assist future researchers. More attention should focus on green water (soil water, evapotranspiration processes, and crop dynamics) which are essential for sediment output within croplands.

8.4 Summary

In conclusion, it is important to point out that land use has become one of the global problems to soil erosion especially in areas where people depend much on agriculture. We found that land use/cover change between the years 2005 and 2015 for agriculture decreased by 16% followed by the encroachment of forest into agricultural land use by 12%. This land-use change resulted in land abandonment leading to high surface runoff and soil erosion within encroached areas by forest cover. On the other hand, a change in settlement by 1% illustrated a shift in the rate of soil erosion in settlement areas, which influenced a significant increase in surface runoff, and soil erosion. An increase by 5% of grassland illustrates the increase in surface runoff and soil erosion as all the grassland are bare and uncovered. This increase demonstrated an increase in soil erosion and surface runoff over time. Results from our study also illustrated those areas with high broad change patterns may be used for subsequent analysis of soil erosion and nutrient variability.

Furthermore, findings showed that land management strategies depend on various factors. Several factors such as age, gender, socio-economic factors as well as education play an important from in land management strategies. The significant correlation (p-value = 0.033 between age and land-use strategies demonstrated that age is an important factor in dealing with soil erosion problems. Results from our analysis on farm equipment for land management illustrate that lack of proper equipment for land management plays an important role in the increase of soil erosion problems in the study area. Respondents (32.65%) from the research regarded investment of profits back into the land management as not important. This illustrates the need for socio-economic empowerment and the need for the implementation of educational programs that can assist in the development of ideas to improve land use management strategies. The role of the agricultural field and income illustrates that income is very vital for people's livelihoods. However, this has resulted in farmers neglecting land management. Strategies on land management require farm holders with a forward-driven attitude, which underline the importance of land management in marginalized areas that will solve erosion problems.

Land use activities are responsible for changes in soil parameters (soil pH, nitrogen, organic matter, and phosphorus. Changes in soil parameters result in environmental problems such as soil erosion over time. A decrease in soil nutrients increases the vulnerability of soil erosion based on the deficiency of soil chemical parameters. Results illustrated acidic soil condition in an old maize field (5.98) that emanates from a deficiency in other soil nutrient availability (organic matter 1.32%). Findings illustrated that long term use of the same area over time tends to reduce the soil fertility of the area (the old maize field had acidic soil 5.98 and low organic matter 1.32 as compared to the new maize field which had a neutral soil pH of 6.98 and 2.97 of soil organic content). Continuous cultivation over a long period with poor land-use management strategies increases the vulnerability of land use to soil erosion and land degradation.

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Appendix 1: Research Ethics Certificate

RESEARCH AND INNOVATION
OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR:
Mr B Mavhuru

Student No:
11605726

PROJECT TITLE: **Modelling the impact of soil erosion on land use/land cover in Nzhelele Valley, Limpopo Province, South Africa.**

PROJECT NO: SES/18/GGIS/02/0405

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Dr NS Nethengwe	University of Venda	Promoter
Dr H Chikoore	University of Venda	Co - Promoter
Prof OBD Odhiambo	University of Venda	Co - Promoter
Mr B Mavhuru	University of Venda	Investigator – Student

ISSUED BY:
UNIVERSITY OF VENDA, RESEARCH ETHICS COMMITTEE

Date Considered: May 2018
Decision by Ethical Clearance Committee Granted
Signature of Chairperson of the Committee: ....
Name of the Chairperson of the Committee: Senior Prof. G.E. Ekosse

UNIVERSITY OF VENDA
DIRECTOR
RESEARCH AND INNOVATION
2018 -05- 07
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"A quality driven financially sustainable, rural-based Comprehensive University"

Appendix 2: Consent form

Department of Geography and Geo-Information Science, University of Venda.

August 2018

I am **Mavhuru Blessing** a Ph.D. candidate in the Department of Geography, University of Venda, would like you to participate in my study. I am carrying out a research entitled Analysis of land use and its impact on soil erosion in Nzhelele Valley, Limpopo Province, South Africa. Your response to form part of this study will bring much-needed conclusions that can assist the community on land use practices and soil erosion. If you would like to form part of this research, please note that your privacy and beliefs shall be of much value to us. The researcher will take full responsibility to protect your privacy and will remain confidential, as you would have participated in the study.

Sign of researcher………………………………. Date…………………………

I ……………………………….. the participant do hear by declare that I have read the contents of this latter and I am going to participate in this study.

Respondent sign …………………………………. Date……………………………

Witness` sign ……………………………………….. Date………………………………

For more information contact Mavhuru B (Researcher)-0710787116 or mavhurublessing3@gmail.com

Appendix 3: Disclosure Form for weather data

South African
Weather Service
ISO 9001 Certified Organisation

DISCLOSURE STATEMENT

The provision of the data is subject to the User providing the South African Weather Service (SAWS) with a detailed and complete disclosure, in writing and in line with the requirements of clauses 1.1 to 2.4 (below), of the purpose for which the specified data is to be used. The statement is to be attached to this document as Schedule 1.

1 **Should the User intend using the specified data for commercial gain then the disclosure should include the following**:

1.1 the commercial nature of the project/funded research project in connection with which the User intends to use the specified data;

1.2 the names and fields of expertise of any participants in the project/funded research project for which the specified data is intended; and

1.3 the projected commercial gains to the User as a result of the intended use of the specified data for the project/funded research project.

2 **Should the User intend using the specified data for the purposes of conducting research, then the disclosure should include the following**:

2.1 the title of the research paper or project for which the specified data is to be used;

2.2 the details of the institution and supervisory body or person(s) under the auspices of which the research is to be undertaken;

2.3 an undertaking to supply SAWS with a copy of the final results of the research in printed and/or electronic format; and

2.4 the assurance that no commercial gain will be received from the outcome from the research.

If the specified data is used in research with disclosure being provided in accordance with paragraph 2 and the User is given the opportunity to receive financial benefit from the research following the publication of the results, then additional disclosure in terms of paragraph 1 is required.

The condition of this disclosure statement is applicable to the purpose and data requirements of the transaction recorded in Schedule 1 on page 2. This statement is effective from October 2017.

SCHEDULE 1

Please note: The South African Weather Service will only act upon customer requirements noted on this disclosure statement and not from any other correspondence.

FULL PERSONAL DETAILS OF USER

Full Names	Mavhuru Blessing
University/school/organisation	University Of Venda
Student Number (if applicable)	11605726
Email address	bmavhuru@yahoo.com
Cellphone	+27710787116
Supervisor	Dr N.S. Nethengwe
Project/Thesis Title	Modelling the impact of soil erosion on land use/land cover in Nzhelele Valley, Limpopo Province, South Africa
Current registered degree (e.g. BSc)	PHDGEO
Expected finalization date (MMYYYY)	31/12/2018

The South African Weather Service reserves the right to request, at any time, from the student proof of registration for the Degree at the University.

THE PURPOSE (*Please indicate a detailed description of the purpose for which the data will be used)*

The purpose of this research is to develop a model to assist in predicting soil erosion rate and impacts of land use in the Nzhelele Valley South Africa. ARCSWAT (Soil and Water Assessment Tool with an interface of ArcView Geographic Information System (GIS)) will be used to model soil erosion on land use land cover. Input data such as topography, land use, soil data and weather components will be required to run the model.

DATA REQUIRED *(Please include the <u>weather elements</u> (e.g. rain, temperature), <u>place/s</u> and <u>time period</u>)*

TYPE OF DATA:
Relative Humidity
Rainfall
Temperature
Wind speed
Solar radiation data

PLACE AND PERIOD:
The data should be for Nzhelele Valley South Africa
From 1980 up to 2015

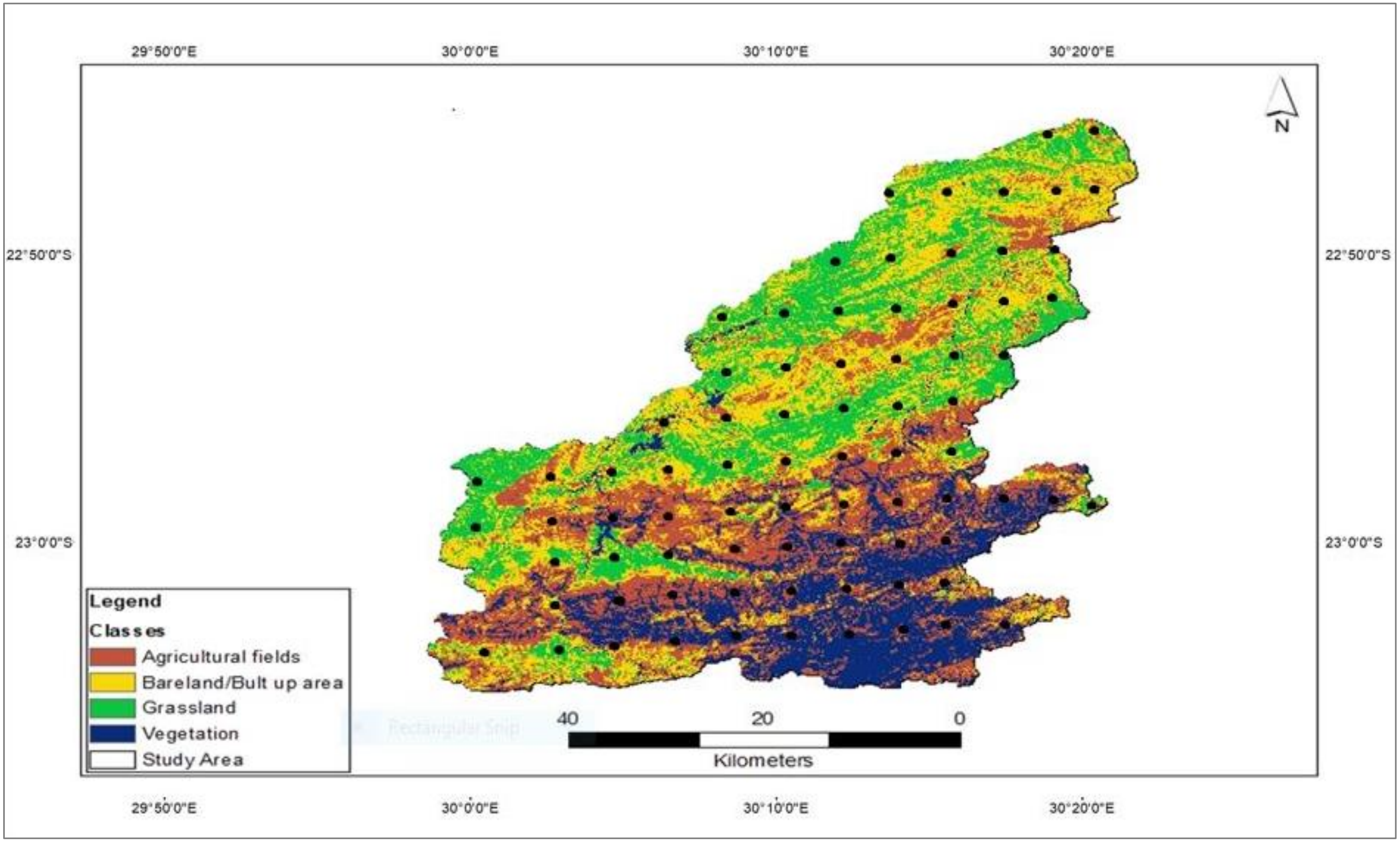
I hereby accept that:

- SAWS will be acknowledged in the resulting thesis/project or when published, for the data it provided.
- SAWS will be provided with a copy of the final results in printed or electronic format.
- The data received shall not be provided to any third party.

Signature of the User: Date: 28/05/18

(*Please sign the document and do not type your name in as this is a legal document and requires a signature*.)

Appendix 4: Distribution of sampling sites in Nzhelele Valley



Appendix 5: Land use and land cover for Nzhelele Valley

a) Nzhelele land use land cover image

b) Nzhelele Valley land use land cover image

Appendix 6: Questionnaire on land use management strategies

Farm land use Questionnaire

This questionnaire is part of a research on modelling the impact of soil erosion on land use/land cover in Nzhelele Valley, Limpopo Province, South Africa at the University of Venda, Department of Geography and Geo-information Sciences School of Environmental Sciences.

Note: Important Information

a) This questionnaire does not require any personal details such as your name etc.

b). Please do not answer or skip questions that you feel might be too personal to you.

c) You can only share what you are only comfortable with.

SECTION A: DEMOGRAPHIC INFORMATION OF HEAD OF FARMLAND (tick appropriate box)

Sex	Male		Female		Age	<20		21 to 30		31 to 40		31 to 50		51 to 60		>60	
	1		2			1		2		3		4		5		6	

Marital Status	Single	Married	Widowed	Separated

Highest educational level	Primary	Secondary	Tertiary		

SECTION B (1): LAND USE MANAGEMENT STRATEGIES

N.B *Please indicate by ticking in the box indicating the answer you choose*

1	2	3
	X	

A) ***Reliance on Farming***

1a. How is the topographic location of your farmland?

1 (<no slope)	2 (gentle slope)	3 (steep slope)

2a. What is the size of your farm land?

1 (<1hec)	2 (1-6 hec)	3 (<6 hec)

3a. How important is market accessibility to your farming activity?

1 (0%)	2 (1-45%)	3 (<45%)

4a. How many total farmland do you have?

1 (<3)	2 (4-6)	3 (>6)

5a. How many workers do you have on your farm?

1 (0)	2 (1-5)	3 (<5)

B) Programs on Land Use Management Strategies (LUS)

1b. Do you have membership in local agricultural institute?

1 1-2	2 3-4	3 <4

2b. How many number of membership in leadership in local institute associated with agriculture?

1 (0)	2 (1)	3 (>1)

3b. How many number of training have you received for the past 3 years?

1 (0)	2 (1)	3

4b. How accessible are training programs within your area pertaining farming?

1 (0 %)	2 (50%)	3 (>50%)

5b. How many visits have you received from the agricultural extension officers?

1(0)	2 (1-3)	3 (>3)

C) Strategies on Soil Erosion

1c. What soil type do you have within your farm land?

1 (<1)	2 (1-3)	3 (>3)

2c. Are you vulnerable to soil erosion within your farm land?

1 (Low)	2 (medium)	3 (High)

3c. What type of soil quality is available in your farm land?

1 (low)	2 (medium)	3 (High)

4c. How many hactres of land do you cultivate per year?

1 (>1)	2 (1-2)	3 (<3)

5c. How deep is the soil that you cultivate in your farm land?

1 (Shallow)	2 (Medium)	3 (Deep)

D) Equipment Used on Farmland

1d. Is you soil type in need of manure?

1 (no)	2 (maybe)	3 (yes)

2d. What kind of equipment do you use in your farm land?

1 (low)	2 (medium)	3 (heavy)

3d. Is manure readily available within your farm land?

1 (no)	2 (maybe)	3 (yes)

4d. What is the topographic location of your farm?

1 (flat land)	2 (medium)	3 (steep slope)

5d. How many livestock per family member?

1 (<1)	2 (1)	3 (>1)

E) Income on Land Use Output

1e. How much of your income from crop production do you invest in LUS?

1 (<10%)	2 (10-50%)	3 (>50%)

2e. How much of your income acquired from off farm activities you invest in LUMS?

1 (<1)	2 (1)	3 (>1)

3e. How much of your income from trading livestock do you invest in LUMS?

1 (<10%)	2 (10-50%)	3 (>50%)

4e. How much of your income do you save for future LUMS?

1 (<10%)	2 (10-50%)	3 (>50%)

5e. Have you received support (training and management from government in investing in land use strategies?

1 (no)	2 (maybe)	3 (yes)

Appendix 7: Basic soil fertility of Nzhelele Valley

T	LabNo	SENDER_NR		OM	P	Total N
				%	mg/kg	%
M	1177	B1	a	5.26	0.59	0.143
M		B2	a	0.74	22.23	0.058
M		B3	a	5.25	0.58	0.142
M		B4	a	0.72	0.60	0.051
M		B5	a	0.27	22.22	0.144
M		B6	a	0.76	22.24	0.065
M	1180	D1	a	1.05	6.35	0.054
M		D2	a	1.60	31.28	0.039
M		D3	a	1.03	6.31	0.053
M		D4	a	1.57	31.26	0.037
M		D5	a	1.07	6.39	0.055
M		D6	a	1.63	31.30	0.041
M	1183	H1	a	2.30	28.98	0.062
M		H2	a	0.56	13.11	0.056
M		H3	a	2.28	28.97	0.060
M		H4	a	2.32	28.99	0.054
M		H5	a	0.55	13.90	0.64
M		H6	a	0.57	13.13	0.058
M	1186	M1	a	5.22	5.38	0.129
M		M2	a	9.50	2.53	0.201
M		M3	a	5.19	5.31	0.128
M		M4	a	9.49	2.51	0.200
M		M5	a	5.25	5.45	0.130
M		M6	a	9.51	2.55	0.203
M	1189	T1	a	2.26	33.67	0.077
M		T2	a	3.69	11.37	0.062
M		T3	a	2.22	33.66	0.075
M		T4	a	3.60	11.20	0.063
M		T5	a	2.30	33.68	0.079
M		T6	a	3.76	11.44	0.061
M	1192	TS1	a	1.60	15.74	0.038
M		TS2	a	3.38	68.64	0.161
M		TS3	a	1.58	15.70	0.160
M		TS4	a	3.30	68.20	0.020
M		TS5	a	1.62	15.78	0.162
M		TS6	a	3.46	68.84	0.058
M	1195	TB1	a	5.26	0.59	0.143
M		TB2	a	0.74	22.23	0.058
M		TB3	a	5.25	0.58	0.142
M		TB4	a	0.72	0.60	0.051
M		TB5	a	0.27	22.22	0.144
M		TB6	a	0.76	22.24	0.065

M	1198	MZ1 a	1.05	6.35	0.054
M		MZ2 a	1.60	31.28	0.039
M		MZ3 a	1.03	6.31	0.053
M		MZ4 a	1.57	31.26	0.037
M		MZ5 a	1.07	6.39	0.055
M		MZ6 a	1.63	31.30	0.041
M	1201	TT1 a	2.30	28.98	0.062
M		TT2 a	0.56	13.11	0.056
M		TT3 a	2.28	28.97	0.060
M		TT4 a	2.32	28.99	0.054
M		TT5 a	0.55	13.90	0.64
M		TT6 a	0.57	13.13	0.058
M	1204	QW1 a	5.22	5.38	0.129
M		QW2 a	9.50	2.53	0.201
M		QW3 a	5.19	5.31	0.128
M		QW4 a	9.49	2.51	0.200
M		QW5 a	5.25	5.45	0.130
M		QW6 a	9.51	2.55	0.203
M	1207	ZT1 a	2.26	33.67	0.077
M		ZT2 a	3.69	11.37	0.062
M		ZT3 a	2.22	33.66	0.075
M		ZT4 a	3.60	11.20	0.063
M		ZT5 a	2.30	33.68	0.079
M		ZT6 a	3.76	11.44	0.061
M	1210	BW1 a	1.60	15.74	0.038
M		BW2 a	3.38	68.64	0.161
M		BW3 a	1.58	15.70	0.160
M		BW4 a	3.30	68.20	0.020
M		BW5 a	1.62	15.78	0.162
M		BW6 a	3.46	68.84	0.058
M	1213	HH1 a	1.05	6.35	0.054
M		HH2 a	1.60	31.28	0.039
M		HH3 a	1.03	6.31	0.053
M		HH4 a	1.57	31.26	0.037
M		HH5 a	1.07	6.39	0.055
M		HH6 a	1.63	31.30	0.041

METHODS USED FOR ANALYSIS :

Serial	Method	Serial	Method

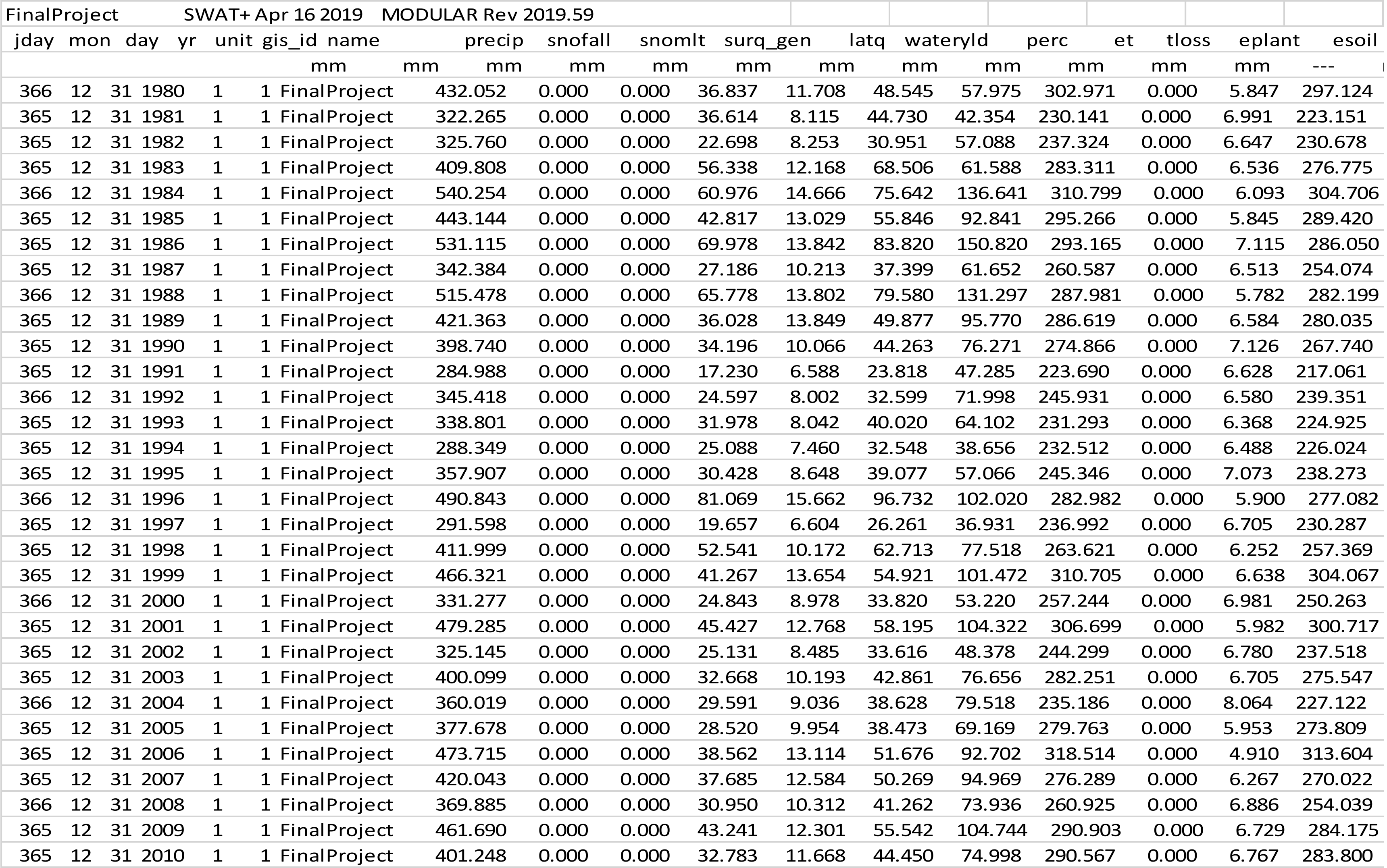
1	% C (LOI)
2	P-Bray1
3	Total N Digest

Appendix 8: Watershed Data used in the study

A. Annual sediment yield

Date	unit	Month	Observed Sediment yield	Simulated Sediment yield
1980	1	31-Dec	0	0
1981	1	31-Dec	1.24E+04	1.14E+04
1982	1	31-Dec	0	0
1983	1	31-Dec	1.02E+04	1.12E+04
1984	1	31-Dec	5.17E+04	5.47E+04
1985	1	31-Dec	7.24E+03	7.34E+03
1986	1	31-Dec	1.04E+05	1.34E+05
1987	1	31-Dec	5.36E+04	5.16E+04
1988	1	31-Dec	1.68E+04	1.48E+04
1989	1	31-Dec	7.11E+03	7.01E+03
1990	1	31-Dec	2.38E+04	2.28E+04
1991	1	31-Dec	0	0
1992	1	31-Dec	9.48E+03	9.48E+03
1993	1	31-Dec	7.80E+03	7.70E+03
1994	1	31-Dec	8.52E+03	8.32E+03
1995	1	31-Dec	0	0
1996	1	31-Dec	2.96E+04	2.76E+04
1997	1	31-Dec	0	0
1998	1	31-Dec	2.80E+04	2.70E+04
1999	1	31-Dec	1.92E+04	1.72E+04
2000	1	31-Dec	6.80E+03	6.90E+03
2001	1	31-Dec	1.03E+04	1.13E+04
2002	1	31-Dec	8.28E+03	8.18E+03
2003	1	31-Dec	1.21E+04	1.51E+04
2004	1	31-Dec	0	0
2005	1	31-Dec	6.97E+03	6.87E+03
2006	1	31-Dec	9.61E+03	9.41E+03
2007	1	31-Dec	7.71E+03	7.51E+03
2008	1	31-Dec	1.10E+04	1.20E+04
2009	1	31-Dec	1.69E+04	1.79E+04
2010	1	31-Dec	2.37E+04	2.47E+04

C: Annual precipitation output



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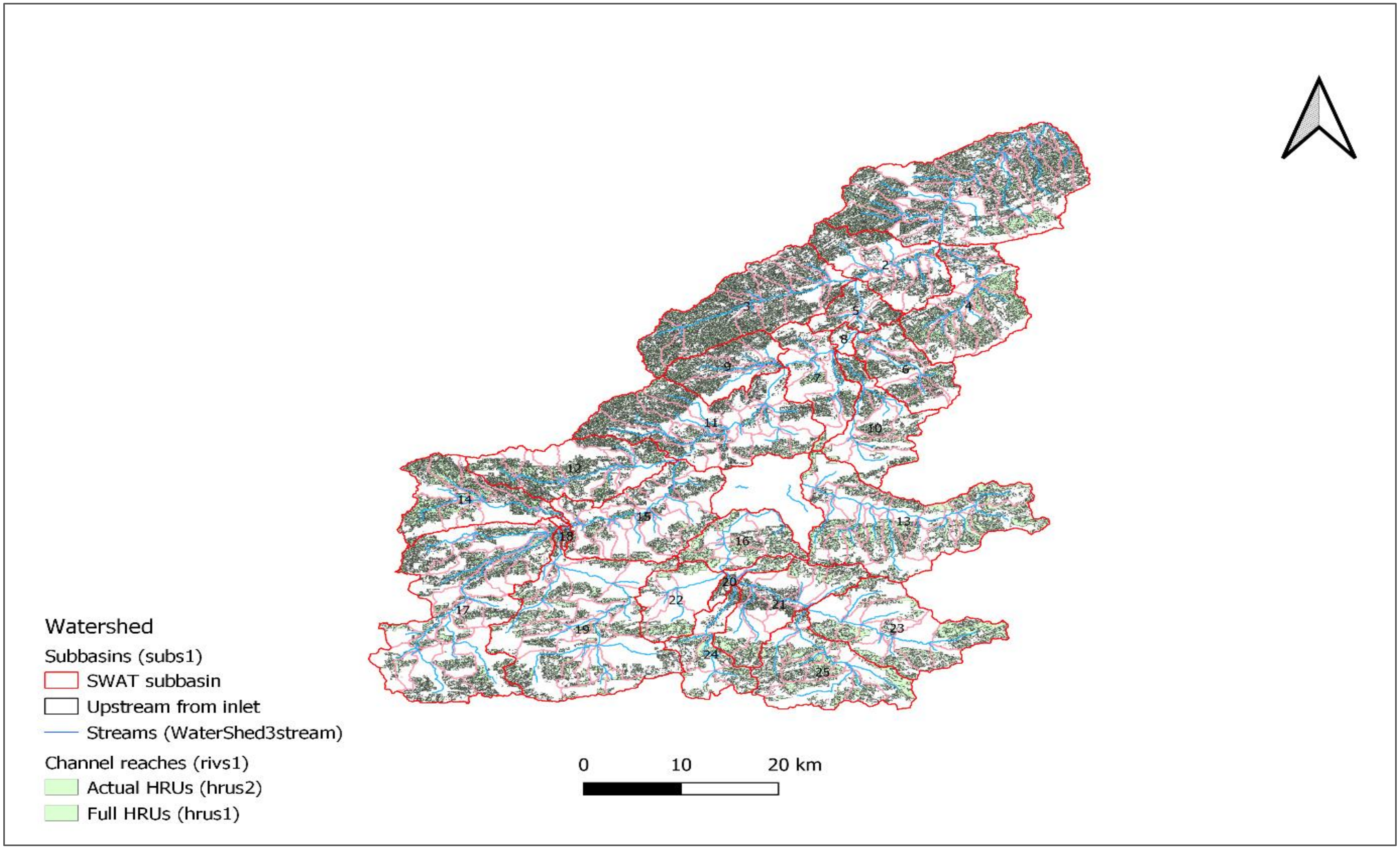
FinalProject        SWAT+ Apr 16 2019    MODULAR Rev 2019.59
 jday  mon  day   yr   unit gis_id  name           precip   snofall    snomlt  surq_gen      latq  wateryld      perc        et     tloss    eplant     esoil
                                         mm        mm        mm        mm        mm        mm        mm        mm        mm        mm        mm        mm       ---
  366   12   31 1980      1      1 FinalProject   432.052     0.000     0.000    36.837    11.708    48.545    57.975   302.971     0.000     5.847   297.124
  365   12   31 1981      1      1 FinalProject   322.265     0.000     0.000    36.614     8.115    44.730    42.354   230.141     0.000     6.991   223.151
  365   12   31 1982      1      1 FinalProject   325.760     0.000     0.000    22.698     8.253    30.951    57.088   237.324     0.000     6.647   230.678
  365   12   31 1983      1      1 FinalProject   409.808     0.000     0.000    56.338    12.168    68.506    61.588   283.311     0.000     6.536   276.775
  366   12   31 1984      1      1 FinalProject   540.254     0.000     0.000    60.976    14.666    75.642   136.641   310.799     0.000     6.093   304.706
  365   12   31 1985      1      1 FinalProject   443.144     0.000     0.000    42.817    13.029    55.846    92.841   295.266     0.000     5.845   289.420
  365   12   31 1986      1      1 FinalProject   531.115     0.000     0.000    69.978    13.842    83.820   150.820   293.165     0.000     7.115   286.050
  365   12   31 1987      1      1 FinalProject   342.384     0.000     0.000    27.186    10.213    37.399    61.652   260.587     0.000     6.513   254.074
  366   12   31 1988      1      1 FinalProject   515.478     0.000     0.000    65.778    13.802    79.580   131.297   287.981     0.000     5.782   282.199
  365   12   31 1989      1      1 FinalProject   421.363     0.000     0.000    36.028    13.849    49.877    95.770   286.619     0.000     6.584   280.035
  365   12   31 1990      1      1 FinalProject   398.740     0.000     0.000    34.196    10.066    44.263    76.271   274.866     0.000     7.126   267.740
  365   12   31 1991      1      1 FinalProject   284.988     0.000     0.000    17.230     6.588    23.818    47.285   223.690     0.000     6.628   217.061
  366   12   31 1992      1      1 FinalProject   345.418     0.000     0.000    24.597     8.002    32.599    71.998   245.931     0.000     6.580   239.351
  365   12   31 1993      1      1 FinalProject   338.801     0.000     0.000    31.978     8.042    40.020    64.102   231.293     0.000     6.368   224.925
  365   12   31 1994      1      1 FinalProject   288.349     0.000     0.000    25.088     7.460    32.548    38.656   232.512     0.000     6.488   226.024
  365   12   31 1995      1      1 FinalProject   357.907     0.000     0.000    30.428     8.648    39.077    57.066   245.346     0.000     7.073   238.273
  366   12   31 1996      1      1 FinalProject   490.843     0.000     0.000    81.069    15.662    96.732   102.020   282.982     0.000     5.900   277.082
  365   12   31 1997      1      1 FinalProject   291.598     0.000     0.000    19.657     6.604    26.261    36.931   236.992     0.000     6.705   230.287
  365   12   31 1998      1      1 FinalProject   411.999     0.000     0.000    52.541    10.172    62.713    77.518   263.621     0.000     6.252   257.369
  365   12   31 1999      1      1 FinalProject   466.321     0.000     0.000    41.267    13.654    54.921   101.472   310.705     0.000     6.638   304.067
  366   12   31 2000      1      1 FinalProject   331.277     0.000     0.000    24.843     8.978    33.820    53.220   257.244     0.000     6.981   250.263
  365   12   31 2001      1      1 FinalProject   479.285     0.000     0.000    45.427    12.768    58.195   104.322   306.699     0.000     5.982   300.717
  365   12   31 2002      1      1 FinalProject   325.145     0.000     0.000    25.131     8.485    33.616    48.378   244.299     0.000     6.780   237.518
  365   12   31 2003      1      1 FinalProject   400.099     0.000     0.000    32.668    10.193    42.861    76.656   282.251     0.000     6.705   275.547
  366   12   31 2004      1      1 FinalProject   360.019     0.000     0.000    29.591     9.036    38.628    79.518   235.186     0.000     8.064   227.122
  365   12   31 2005      1      1 FinalProject   377.678     0.000     0.000    28.520     9.954    38.473    69.169   279.763     0.000     5.953   273.809
  365   12   31 2006      1      1 FinalProject   473.715     0.000     0.000    38.562    13.114    51.676    92.702   318.514     0.000     4.910   313.604
  365   12   31 2007      1      1 FinalProject   420.043     0.000     0.000    37.685    12.584    50.269    94.969   276.289     0.000     6.267   270.022
  366   12   31 2008      1      1 FinalProject   369.885     0.000     0.000    30.950    10.312    41.262    73.936   260.925     0.000     6.886   254.039
  365   12   31 2009      1      1 FinalProject   461.690     0.000     0.000    43.241    12.301    55.542   104.744   290.903     0.000     6.729   284.175
  365   12   31 2010      1      1 FinalProject   401.248     0.000     0.000    32.783    11.668    44.450    74.998   290.567     0.000     6.767   283.800
```

D: Sub-watershed Hydrological Response Units



E: Hydrological Responds Units: (Data presented for the first and last 40 HRU)

name	order	wd	dp	slp	len
hydcha001	first	121.6718	2.693665	0.002601	0.3845
hydcha002	first	120.9852	2.683522	0.002164	3.6964
hydcha003	first	120.5649	2.677303	0.003394	1.1787
hydcha004	first	119.769	2.665506	0.002175	5.5165
hydcha005	first	117.8604	2.637114	0.001786	5.6003
hydcha006	first	116.9083	2.622892	0.003421	2.6309
hydcha007	first	116.0749	2.610411	0.002272	2.6413
hydcha008	first	115.1538	2.596584	0	0.1341
hydcha009	first	114.3696	2.584782	0.003701	2.9724
hydcha010	first	112.2955	2.553437	0.002379	2.943
hydcha011	first	107.0342	2.473044	0.00259	2.3167
hydcha012	first	106.5224	2.465154	0.003404	2.0567
hydcha013	first	105.956	2.456408	0.001246	2.4078
hydcha014	first	105.4567	2.448686	0.003802	0.526
hydcha015	first	104.9569	2.440943	0.0013	1.5381
hydcha016	first	104.4809	2.433557	0.002731	1.4647
hydcha017	first	103.5206	2.418623	0.002624	2.2863
hydcha018	first	97.0504	2.316764	0.002643	4.5409
hydcha019	first	96.0882	2.301425	0.002184	0.4579
hydcha020	first	95.74819	2.295993	0.003618	2.7641
hydcha021	first	92.5251	2.244174	0.002985	3.685
hydcha022	first	88.48032	2.178285	0.006659	0.4505
hydcha023	first	87.02722	2.15437	0.002722	1.8367
hydcha024	first	86.20572	2.140791	0.001111	0.9001
hydcha025	first	85.53561	2.129682	0.003009	3.6556
hydcha026	first	82.2584	2.074931	0.002572	5.4432
hydcha027	first	79.71248	2.031894	0.006279	0.3185
hydcha028	first	79.43445	2.027167	0.004735	4.2236
hydcha029	first	78.8193	2.016687	0.002135	1.8735
hydcha030	first	77.50157	1.994147	0.003002	0.9995
hydcha031	first	77.10439	1.987328	0.004911	1.2217
hydcha032	first	76.3797	1.974856	0.00389	2.8279
hydcha033	first	73.7897	1.929956	0.00365	3.5614
hydcha034	first	67.25278	1.814222	0.002791	3.225
hydcha035	first	65.86378	1.789155	0.001808	2.765
hydcha036	first	64.68446	1.767734	0.004088	2.6908
hydcha037	first	63.16917	1.740018	0.003028	1.6513
hydcha038	first	62.2278	1.722688	0.002179	3.2124
hydcha039	first	61.47455	1.708758	0.004204	0.4757
hydcha040	first	55.4114	1.59447	0	0.1289

Continued Hydrological Responds Units

hydcha262	first	5.020232	0.321637	0.01138	2.6361
hydcha263	first	3.667233	0.260881	0.004736	0.4223
hydcha264	first	5.356661	0.335851	0.00484	3.3057
hydcha265	first	5.843656	0.35591	0.013492	3.4095
hydcha266	first	3.864836	0.27017	0.010383	1.3484
hydcha267	first	6.666683	0.388589	0.006931	3.3183
hydcha268	first	5.629943	0.347179	0.007117	2.8101
hydcha269	first	6.448239	0.380053	0.00432	3.4724
hydcha270	first	4.806401	0.312438	0.008436	1.6596
hydcha271	first	5.784747	0.353514	0.006189	4.0392
hydcha272	first	4.370086	0.293231	0.022629	2.4747
hydcha273	first	4.474718	0.297893	0.029427	0.7816
hydcha274	first	4.209437	0.286	0.008786	0.9105
hydcha275	first	7.973711	0.437848	0.005513	4.5348
hydcha276	first	4.975924	0.319742	0.009115	2.633
hydcha277	first	4.790332	0.311741	0.012043	0.9964
hydcha278	first	5.46652	0.340427	0.012813	4.1364
hydcha279	first	4.535855	0.3006	0.013857	2.3093
hydcha280	first	4.531529	0.300409	0.011326	2.6487
hydcha281	first	5.334232	0.334913	0.002556	2.347
hydcha282	first	3.561555	0.255845	0.011499	0.6957
hydcha283	first	4.860003	0.314756	0.009644	2.5922
hydcha284	first	5.183342	0.328567	0.011436	4.0223
hydcha285	first	3.936239	0.273488	0.005728	1.3966
hydcha286	first	8.124628	0.443356	0.014378	5.1467
hydcha287	first	5.677956	0.34915	0.011581	3.7992
hydcha288	first	7.820865	0.432235	0.010339	7.351
hydcha289	first	3.853481	0.269641	0.016284	1.1054
hydcha290	first	4.99478	0.320549	0.003351	1.4921
hydcha291	first	3.648333	0.259984	0	0.2022
hydcha292	first	7.182614	0.408387	0.007634	5.7639
hydcha293	first	5.793412	0.353867	0.00793	4.54
hydcha294	first	7.778246	0.430663	0.011235	9.524
hydcha295	first	4.036583	0.278116	0.017138	1.6921
hydcha296	first	7.244292	0.410722	0.010409	9.3188
hydcha297	first	6.523697	0.383012	0.012634	5.224
hydcha298	first	4.2528	0.287961	0.011115	2.0693
hydcha299	first	4.018859	0.277301	0.015206	1.7099
hydcha300	first	3.754821	0.265019	0.012794	0.7816
hydcha301	first	3.747458	0.264672	0.018565	0.9157

Appendix 9: Proofreading Report

2021/07/20

Editing and Proofreading Report

This letter serves to confirm that I, Dr Nyete Liberty, Takudzwa from the English Department, Boston Media House have proofread and edited a thesis Titled *"An analysis of land use and its impact on soil erosion in Nzhelele Valley, Limpopo Province, South Africa"* by Mavhuru Blessing (11605726) an independent research project to be submitted in fulfillment of the requirements for the A PhD in Environmental Science Research submitted to the Department of Geography & Geo-Information Sciences, University of Venda.

I carefully read through the thesis, focusing on proofreading and editorial issues. The recommended suggestions were highlighted.

Yours Sincerely

Nyete Liberty (PhD,) PGCE (UNISA)
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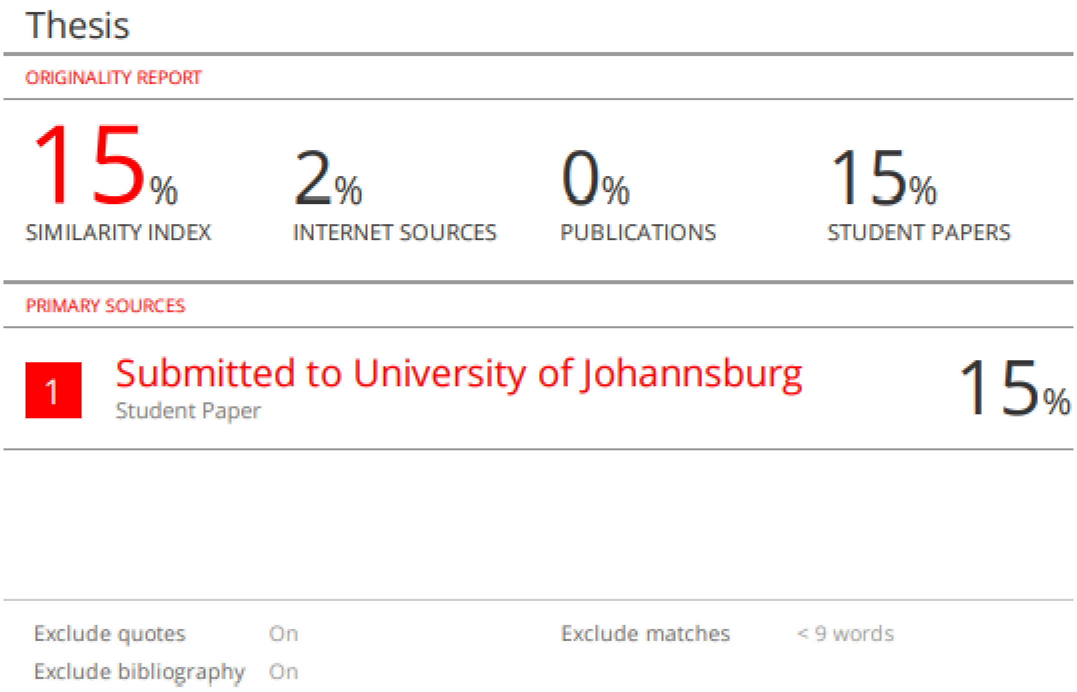
E-mail: Inyete@gmail.com

Appendix 10: Publication

Mavhuru B., Nethengwe N. S., Chikoore H., Odhiambo O. B. D. 2019. *Influence of human management strategies on soil erosion in Nzhelele Valley, Limpopo Province, South Africa.* Proceedings of the IGU Comission of African Studies Annual Conference, 17-19 June 2019, University of Zululand, South Africa, ISBN 978-0-620-82855-0

http://uzspace.unizulu.ac.za/xmlui/handle/10530/1991.

Appendix 10: Turnitin



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