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ASSESSMENT OF SPATIAL AND TEMPORAL SOIL LOSS IN AND OUT OF LESOTHO USING RUSLE MODEL AND GIS

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ASSESSMENT OF SPATIAL AND TEMPORAL SOIL LOSS IN AND OUT OF LESOTHO USING RUSLE MODEL AND GIS

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A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Integrated Water Resources Management at the University of Zimbabwe

NOVEMBER 2013

DECLARATION

I, **Mamabitsa Makara**, declare that this research report is own work. It is being submitted for the partial fulfillment of the degree of Master of Science in Integrated Water Resources Management (IWRM) in the University of Zimbabwe. It has not been submitted for any degree or any examination in any other University.

Date: ___________________________________

Signature: ________________________________

DEDICATION

To my parents, Ntšohli and Mamokatja, my dear sisters: Mamatakane and Mantšohli and my lovely nieces Refiloe, Reitumetse and Shoeshoe, I love you all so dearly.

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ABSTRACT

Lesotho is one of the major sources to rivers that drain the southern part of southern Africa through Senqu and Sabi-Sand River. However severe soil erosion is the major environmental problem that has left the landscape dissected with deep gullies and dongas. Fertile soil, that should be supporting food production is washed in billions of tons as sediments in lakes, reservoirs and rivers reducing the aesthetic appearance of water bodies with high sediment loads leading to low agricultural productivity and high costs of water treatment for water supply. There is inadequate current information as to how much soil has been lost or is being lost in and out of Lesotho. Studies of the last four decades are still cited in policy formulations while the earth and its constituents are dynamic and ever changing. The objective of this study was to assess the spatial and temporal (1986, 1997 and 2009) soil loss in and out of Lesotho using the RUSLE model and GIS techniques.

The annual soil loss computed from RUSLE model was compared with the observed sediment yield of gauged rivers that are leaving Lesotho for the duration of the study (1980 – 2012). Data used consisted of DEM of 90m x 90m resolution to calculate the slope length-steepness factor (LS) and the soil map was used to calculate the soil erodibility factor (K). The temporal factor, used to compute rainfall erosivity (R) for 1986, 1997 and 2009. Then Landsat images were used to come up with the land cover management factor and conservation practices for 1986, 1997 and 2009. Flow and sediment data from 1980 to 2012 were used to determine relationships, trends and total amounts of soil that left Lesotho for the three decades. To identify critical areas/ hotspots for future management from the results predicted by RUSLE model and observed sediment yields.

The results of land classification for 1986, 1997 and 2009 indicate a steady increase of area under rock outcrop respectively from 24.4% to 38.4% and 42.42%, however a fluctuating decrease of percentage area under Alpine grassland and cropland. The result from the RUSLE model indicates that average annual loss of 9,079,499.29 ton ha^{-1} $year^{-1}$, 7,785,643.78 ton ha^{-1} $year^{-1}$ and 26,711,616.90 ton ha^{-1} $year^{-1}$ for 1986, 1997 and 2009 respectively. The observed sediment loads result indicates that 12,977,905.35 ton $year^{-1}$ was lost 1986, 10,148,969.26 ton $year^{-1}$ in 1997 and 21,151,804.37 ton $year^{-1}$ in 2009. The north eastern highland and southern lowland districts are identified critical areas/ hotspots for future management.

There is a strong relationship between the observed and predicted soil loss for the RUSLE model. The study discovered that there is a positive the correlation between the RUSLE model results and the observed sediments loads. In conclusion there is a tremendous soil loss in in Lesotho both spatially and temporally.

TABLE OF CONTENTS

DECLARATION i
DEDICATION iii
ACKNOWLEDGEMENTS iv
ABSTRACT v
TABLE OF CONTENTS vi
LIST OF TABLE ix
LIST OF FIGURES x
LIST OF ABBREVIATIONS AND ACRONYMS xi
Chapter 1 INTRODUCTION 1
1.0 BACKGROUND 1
1.1 PROBLEM STATEMENT 3
1.2 OBJECTIVES 4
1.2.1 Main Objectives 4
1.2.1. Specific Objectives 4
1.3 SCOPE AND LIMITATIONS 4
1.4 JUSTIFICATION OF THE STUDY 4
1.5 REPORT LAYOUT 5
Chapter 2 LITERATURE REVIEW 6
2.1 INTRODUCTION 6
2.2 OVERVIEW OF LAND DEGRADATION 6
2.2.1 Causes of land degradation 7
2.2.2 Effects of land degradation 7
2.3 SOIL EROSION 9
2.3.1 Causes of soil erosion 9
2.3.2 Impacts of soil erosion 10
2.4 SEDIMENTATION 11
2.5 METHODS FOR ASSESS SOIL EROSION 12
2.6 SEDIMENT LOADING 13
2.6.1 RUSLE and soil erosion modeling 13
2.6.2 Using GIS in modeling spatial and temporal soil erosion 15

Chapter 3 STUDY AREA DESCIPTION 17
3.1 LOCATION OF STUDY AREA 17
3.2 CLIMATE 18
3.3 GEOLOGY 19
3.4 SOILS 19
3.4 VEGETATION 20
3.5 POPULATION 22
3.6 LAND USE AND LAND COVER 22
Chapter 4 MATERIALS AND METHODS 23
4.1 INTRODUCTION 23
4.2 DATA COLLECTION 23
4.2.1 Data Collection for assessing Soil Loss out of Lesotho 23
4.2.2 Data Collection for Identifying Critical Areas/ Hotspots using RUSLE Model and Spatial soil Loss 23
4.3 METHODS FOR DATA ANALYSIS 24
4.3.1 Determining of the spatial and temporal variation of soil erosion Lesotho 24
4.4 COMPUTING THE RUSLE FACTORS 25
4.4.1 Slope Length and Slope Steepness Factor (LS) 25
4.4.2 Rain Erosivity (R factor) 27
4.4.3 Soil Erodibility (K factor) 30
4.4.4 Crop management (C factor) 32
4.4.5 Conservation Practice (P factor) 33
4.5 DETERMINING THE AMOUNT OF SOIL LOSS OUT OF LESOTHO FOR THE LAST THIRTY YEARS 34
4.6 DETERMINING RELATIONSHIPS BETWEEN FLOW AND SEDIMENT LOAD 34
Chapter 5 RESULTS AND DISCUSSIONS 35
5.1 INTRODUCTION 35
5.2 Temporal variation in trends of sediments loads in Lesotho 35
5.3 TRENDS IN THE SEDIMENT LOAD AND FLOW REGIMES. 38
5.3.1 Sediment Load per Gauged Rivers Networks 39
5.4 TOTAL AMOUNT OF SEDIMENT LOST THROUGH GAUGED RIVERS 42
5.5 RUSLE FACTORS – VALIDATION FOR OBSERVED DATA 42

5.6 SPATIAL AND TEMPORAL VARIATION SOIL LOSS 53
5.7 IDENTIFIED CRITICAL AREAS/ HOTSPOTS FOR MANAGEMENT 60
5.8 CONCLUSION FROM THE FINDINGS 62
Chapter 6 CONCLUSION AND RECOMMENDATIONS 63
6.1 INTRODUCTION 63
6.2 KEY FINDINGS FROM THIS RESEARCH 63
6.3 RECOMMENDATIONS 64
REFERENCES 69
APPENDICES 73

LIST OF TABLE

Table 1: Direct and cumulative effects of land degradation on different sectors 8
Table 2: m values for computing LS) 26
Table 3: LMS Manual Rainfall Gauge Station Locations 28
Table 4: Annual Precipitation Computed for All LMS Stations in Lesotho (mm) from 1986 to 2012.. 29
Table 5: C factor values estimates for different crops in Lesotho 33
Table 6: Total Amount of Sediments that have Lesotho for the Last Three Decades (1980 to 2009) 42
Table 7: Derived Erodibility Factor for Lesotho 44
Table 8: LS factor ranges for Lesotho 46
Table 9: Percentage area changes of different Land use Classes between 1986, 1997 and 2009 51
Table 10: Predicted RUSLE Soil Loss for 1986, 1997 and 2009. 57
Table 11: Management Plan for Critical Areas/ Hotpots for Lesotho 65

LIST OF FIGURES

Figure 1: Global Rivers Sediment loading statues (Source: Syvitsk, et al, 2005) 12
Figure 2: Confluence of Hololo and Mohokare *Figure 3: Makhaleng Sand Deposits* *Figure 4: Senqu/ Orange River Appearance*.. 17
Figure 5: Location of the Study Area... 18
Figure 6: Soil Map of Lesotho and Elevation Map for Lesotho 20
Figure 7: Gullies dissecting terraced slope cultivation *Figure 8: Dongas in duplex soils* 21
Figure 9: Conceptual framework for quantifying surface soil erosion using GIS technique (Arghius and Arghius, 2011: Teh, 2011). 25
Figure 10: Schematic procedure to produce LS factor Map 27
Figure 11: Nomograph for computing K factor values, Source: (Teh, 2011: Schmitz and Rooyani, 1987: Rooyani and Badamchian, 1986).. 31
Figure 12: Temporal Variations in Sediment Loads for Senqu Period 1986 (a), 1997 (b) and 2009 (c)... 35
Figure 13: Temporal in Trends of Sediments Loads for Northern Mohokare Catchment for the Period 1986 (a), 1997 (b) and 2009 (c) 36
Figure 14: Temporal Sediment Load For Makhaleng for the Periods: 1986 (a), 1997 (b) and 2009 (c) .. 37
Figure 15: Relationship between Annual average Flow and sediment Loads for Sediment Loads for Mohokare (a), Makhaleng (b) and Senqu (c) from 1980 1o 2012 38
Figure 16: Sediment Loads in Three Major Rivers (ton.ha^{-1}yr^{-1}) Load *Figure 17: Percentage Sediments* 39
Figure 18: Sediment Magnitudes per Catchment 40
Figure 19: Location of Dams within the Senqu Catchment (Source: Land info Worldwide Mapping)...... 41
Figure 20: Soil erodibility factor Map for Lesotho 43
Figure 21: LS factor Map for Lesotho... 45
Figure 22: K factor for Lesotho (a), 1986; (b), 1997 and (c), 2009; (d) Graph showing trends of R factor 47
Figure 23: NDVI map and C factor map for 1986 49
Figure 24: NDVI (a), (c): 1997 and 2009, Crop Management factor (b), (d): 1997 and 2009................. 50
Figure 25: Percentage Cover Changes for 1986, 1997 and 2009... 52
Figure 26: Conservation Practice factor Map 1986... 52
Figure 27: RUSLE equation maps to produce annual average soil loss 54
Figure 28: Annual Soil Loss Estimate for Lesotho (a), 1986; (b), 1997 and (c), 2009 and (d) Summarized Estimates for Lesotho.. 55
Figure 29: Estimation of Annual Soil for Lesotho, (a), 1986; (b), 1997 and (c), 2009 56
Figure 30: Hydrometric Station Area Influence 58
Figure 31: Correlation between Observed Sediment Yield and Derived Sediment fro RUSLE 59
Figure 32: Observed sediments and Derives Sediment for three years for Lesotho................................. 60
Figure 33: Critical areas/ Hotspots... 61

LIST OF ABBREVIATIONS AND ACRONYMS

DEM	Digital Elevation Model
DWA	Department of Water Affairs
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
LAA	Land Administration Authority
LEAM	Land use Evaluation and Impact Assessment Model
LG	Local Government
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
LMS	Lesotho Meteorological Services
LWP	Lowlands Water Development Authority
METC	Ministry of Environment Tourism and Culture
MFLR	Ministry of Forestry and Land Reclamation
MLGC	Ministry of Local Government and Chieftainship
MTID	Ministry of Trade and Industry Development
NDVI	Normalized Difference Vegetation Index
NUL	Nation University of Lesotho
RSA	Republic of South Africa
RUSLE	Revived Universal Soil Loss Equation
SLEMSA	Soil Loss Estimation for Southern Africa
SWAT	Soil and Water Assessment Tool
TIN	Triangulated Irregular Network
UNCED	United Nations Conference on Environmental Development
USLE	Universal Soil Loss Equation

Chapter 1 INTRODUCTION

1.0 BACKGROUND

The Kingdom of Lesotho is a small mountainous country, completely surrounded by the Republic of South Africa (RSA). It lies between latitudes 28º 35' and 30º 40' south of the equator, 27º 00' and 29º 39' east of the Greenish Meridian Time. It covers an area of about 30,355 km². Described by many, (Rooyani and Badamchian, 1986; Schmitz and Rooyani, 1987; Chakela and Stocking, 1988; Chakela and Seitlheko, 1995; Mokuku, 2002) Lesotho is characterized by high mountains with deep valleys. Its altitude ranges from 1388 meter above mean sea level in the southwest at the confluence of the Senqu (Orange) and Makhaleng Rivers to over 3482 meter above sea level on the Drakensberg escarpment with a peak, Thabana Ntlenyana 3482 m above sea level.

Lesotho is a source to major rivers that drain the southern part of Africa through the Senqu (Orange) River through RSA and Namibia into the Atlantic Ocean and the Sabi-Sand River through RSA and Mozambique into the Indian Ocean, (Nel, 1999). Consequently Lesotho is a watershed to southern Africa with unique wetland habitats housing mostly endemic species. The first French Protestant missionaries to Lesotho namely Arbouset, Casalis and Daumas had this to say about Lesotho in the 1830s "since our entrance in this Country of Basuto we hav10e encountered little springs and streams almost at every step, and we were able to quench our thirst as well as to freshen up and refresh ourselves". Arbouset, Casalis and Daumas were further amazed at the splendor of lush valleys, perennial rivers and clear pools and brooks that were continuously fed by water that come from the mountains, and ubiquitous springs that offered crystal clear water and grass as tall as to reach a horse's breast just like our magnificent European pasture in richness and vastness (Germond, 1967). Three quarters of Lesotho is rangelands located within the three mountain ranges, Maluti Range, Machache Range and Drakensberg Range, and being the only country in the world with its lowest point above 1000 meter above sea level. Three main rivers systems run through Lesotho, Senqu (Orange), Makhaleng and Mohokare (Caledon). Nevertheless, Sabi River originates from the Drakensberg range but does not constitute part of Lesotho drainage network however disturbance from its source which is partly in Lesotho may influence its flow because river flow does not know administrative boundaries but its hydrological boundary.

Severe soils erosion is a major environmental problem in Lesotho reducing the aesthetic beauty of the Mountain Kingdom. Missionaries of the Paris Evangelical Missionary Society first arrived in Lesotho in 1833 and with them came the first signs of modernization into traditional ways of life. Missionaries on their arrival were allocated land in various areas in the lowlands where they could access fertile soil, firewood and timber to establish their stations, using ox-wagons to travel going in any direction they wished (Germond, 1967). Pre-arrival of Missionaries in Lesotho, the mode of transport was neither equine (horse and donkey) nor wagon but foot tracks nor required neither planned nor engineered roads. However the introduction of modernized mode transport such as ox-wagons and equines, in the topographic nature Lesotho purses led to the introduction of soil erosion in Lesotho (Showers, 1989). Into their third year of arrival in Lesotho, the missionaries set out to explore the valley of the Caledon river in their ox-wagons and horses, travelling through mud and bog and wagon wheel would get stuck hence pick-axe and spade would be used to dig out the mud around them, summer rains resulted in roads being plagued with gullies and becoming unusable by wagons (Germond, 1967; Gay, 1999).

At around the same time trade increased in the region and the use of animal transport became popular even among Basotho as they acquired horses and donkeys. Virgin grassland was tilled for crop cultivation, introduction of new grain varieties for extensive food production and ox-drawn plough were used to minimize labour for intensive crop production to meet the growing demand (Marake and Phororo, 1999). Demand for agricultural land resulted in loss of the best rangeland, livestock grazing is limited to marginal lands with limited resources which in turn led to overgrazing (Tainton, 1999). With population growth increase and increased life span, exerted pressure on resources utilization. According to Gay, (1999) in 1833 there were less than 30,000 Basotho and roughly 2,000,000 in 1997 and less than one hectare of arable land per person hence there is over exploitation of available land for food production leading to excessive soil erosion in Lesotho. Nhapi (2013) adds that Sub-Saharan African is headed for a population emergency where fragile ecosystems cannot be protected unless peoples' lives are made secure. In the original farming of Lesotho there was abundant fallow land which made it possible to practice rotation cultivation. However with population pressure, migration and development has led to land scarcity as a result over cropping has intensified leading to reduction of period for fallowing. With this increase in population and increased intensive farming, systems are changing from semi-permanent to continuous cropping thus making the traditional ways of restoring soil fertility through fallow impractical, consequently resulting in reduced agricultural productivity, increased soil loss and decreased land cover. Absence of vegetation has been attributed to high soil erosion rates which result in land degradation (Chakela, 1998).

The extent of soil erosion and land degradation in Lesotho stems since the arrival of missionaries and the colonial era (1833 to 1966) demands a focused, integrated and coordinated approach to land rehabilitation and environmental preservation. The State of the Environment 2002 Report (Mokuku, 2002), recommended and justified the benefits for establishing the Ministry of Forestry and Land Reclamation. The Ministry was established in 2003 and focuses most of resources and energy towards land rehabilitation that can be through policy direction and legislature, physical construction conservation (silt trap dam, gully structures, gabion, terracing, runoff diversion furrows, etc.) or biological (rangeland management, grass reseeding, conservation agriculture and afforestation programmes) and intensified extension and outreach programmes (radio, television or publication fliers and brochures) in order to bring back the beauty of the Mountain Kingdom.

1.1 PROBLEM STATEMENT

Alarming soil erosion in Lesotho has left the landscape dissected with deep gullies and dongas. Fertile top soil is washed in tons of sediment into lakes, reservoirs and rivers resulting in strong environmental impact of high land degradation and soil erosion rates leading to high economic cost in agricultural production and water quality treatment which has left Lesotho still amongst the poorest countries in world. However, there is lack of current information on spatial and temporal quantities of soil lost through erosion to facilitate informed decision-making in Lesotho. Studies of the last three to four decades are still used to inform planning, policies and decision-making, when the earth and its constituents are ever dynamic. This study seeks to quantify the amount of soil loss, trends and identify critical areas/ hot spots for monitoring in Lesotho.

1.2 OBJECTIVES

1.2.1 Main Objectives

To assess the spatial and temporal soil loss using the Revised Universal Soil Loss Equation (RUSLE) model and Geographic Information System (GIS) and compare with the recorded losses in gauged river networks in Lesotho.

1.2.1. Specific Objectives

1. To determine how much soil has been lost through gauged river networks for the last thirty years (1980 to 2012) and computed RUSLE model soil loss for the same period
2. To establish the trends and relationships between river flow and sediment loads.
3. To establish the relationship between observed sediment loads and computed RUSLE model soil loss.
4. To identify soil erosion critical areas/ hot spots for future monitoring.

1.3 SCOPE AND LIMITATIONS

Soil can only leave Lesotho through the major rivers namely Mohokare (Caledon), Orange/Senqu and Makhaleng river systems. Mohokare River collects its load from the southern Drakensberg through northern lowlands to the southern lowland. Orange/Senqu River collects its load from southern Drakensberg through the mountain ranges down through the southern lowland and out of Lesotho whistle the Makhaleng River collects its load from the northern foothills through the central foothills into the Orange just before the Orange leaves Lesotho. The study will focus on the soil lost from gauged rivers that feed the Mohokare River especially from the Lesotho side, Makhaleng and Senqu/ Orange River.

1.4 JUSTIFICATION OF THE STUDY

In Lesotho, like other places worldwide, there is inadequate current information on how much soil has been lost or is being lost. Centralized administration systems lack of interaction and integration by players has led to low or lack of information dissemination. Hence studies of the last three to four decades are still cited in many reports for planning or policy direction. These studies from the past have shown an increasing trend in the amount of soil erosion. Chakela, (1981) mention that 23.4 million tons/hectare• annum of soil loss on average across the country, while Schmitz and Rooyani, (1987) illustrate that 40 million tons/hectare•annum of soil loss on average across the country. But in view of the fact that there are anthropogenic factors stirring the processes and natural processes cannot go on to infinity is the trend still the same?

1.5 REPORT LAYOUT

The study will be presented in six chapters. Chapter 1 is the introduction of the study which emphasizes the background of the origin of soil erosion in Lesotho. The chapter further presents the problem statement, objectives and justification for the study. Chapter 2 provides a review of literature on land degradation, soil erosion and sediment loading and their causes and impact. Chapter 3 describes the study area, location, climate, geology, soils, vegetation and land use. Chapter 4 consists of data collection methods and materials in order to achieve each objective. Chapter 5 presents results and discussion for each objective. Finally Chapter 6 gives the conclusion and recommendations derived from the findings of the study.

Chapter 2 LITERATURE REVIEW

2.1 INTRODUCTION

In recent years landscapes in the world and in Africa are characterized by significant amount of land degradation and conversion (Barbie, 2000). There are many drivers to the world's environmental degradation today. Chen, *et al*., (2000), highlight that inappropriate land use is one of the main reasons for soil erosion. Others (Renard, *et at*.,1997) add that soil erosion by water is another major contributor of degradation of the earth's environment. Schmitz and Rooyani, (1987) point out that for the effectiveness of these processes such as rain splash erosion and sheet erosion to occur, this depends on the size of the rain drop, the terminal velocity, the soil cover, and on the erodibility of the soil. However splashes may seal off soil pores on the soil surface thus reducing infiltration rates causing plopping resulting in runoff and leading to transportation of particles.

Dube (2011) further mentions that soil erosion by rainfall and runoff is also recognized as the major cause of land degradation worldwide and is increasingly becoming a major problem in many communal lands of southern Africa which leads to 'tragedy of the commons' in most communal lands of Africa. During the last two decades, studies have been undertaken to determine the spatial occurrence of soil erosion (Chakela, 1981; Schmitz and Rooyani, 1987; Makhoalibe, 1997; Chakela, 1998; Chen, 2000; Mokuku, 2002; Dube, 2011). Nevertheless relatively few studies have been focused on quantifying amount of soil lost through soil erosion (Quinn and Bever, 1993; Renard, 1997; Arghius and Arghius, 2011; Teh, 2011).

2.2 OVERVIEW OF LAND DEGRADATION

Land degradation is a term used to describe the process of depletion or continual loss of potentially renewable resources such as soil or vegetation at a faster rate than they can replenish (UNCED, 1992). Alternatively, this is the process that occurs when the economic and biological productivity of land is lost, essentially through human activities (Roseburg, 2003). Land degradation described by (Chakela and Seitlheko, 1995) as reduction of resources' productive potential by a combination of one or more processes acting on the land manifesting itself in events such as soil erosion, sedimentation, reduction in natural vegetation and salinization of soil.

2.2.1 Causes of land degradation

Improper farming practices, overgrazing, the conversion of rangeland to cropland in marginal areas and uncontrolled expansion of urban and rural settlements at the cost of cultivable land are the major causes of land degradation (Khresat, *et al.*, 1998; Barbie, 2000). Furthermore, Khresat, *et al.*, (1998) concluded that loss of soil fertility and productivity were the cause of degradation of north western Jordan, however, rainfall pattern, soil morphological properties, vegetation and land use determine the extent of land degradation where increase in silt content lead to unfavourable soil properties.

Temporally and spatially erratic character of rainfall frequently leads to general or localized drought combined with soil type. Spatial pattern of land use result in lowering of primary productivity below the Normalized Difference Vegetation Index (NDVI) values which exposes soil to hazards of degradation (Thaim, 2002). African pastoralist and farming household respond to declining land productivity by abandoning their existing degraded pasture and cropland to new lands for grazing due to lack of investment in their activities, eventually overgrazing and over-cultivation leading to once again land degradation of the new area (Barbie, 2000).

2.2.2 Effects of land degradation

Suitable soil is limited, necessary for food production, where globally 30% is soil surface that can be used as arable land (Gerbens-Leenes and Nonhebel, 2002). However, arable land is becoming scarcer and scarcer due to ongoing industrialization, urbanization, infrastructure development and land degradation and as a result, food prices are on the increase (Barbie, 2000; Gerbens-Leenes and Nonhebel, 2002). According to Schere, and Yadar, (1996), it is difficult to assess the actual extent and impact of land degradation. More often, the effects are masked by converting or increasing the level of compensating inputs and the relationship is rarely one-to-one between magnitude and the effects of the output. Table 1 describes some direct and cumulative effects of land degradation in different sectors.

Table 1: Direct and cumulative effects of land degradation on different sectors

Sector	Direct effects	Cumulative effects
Soil Management	✓ Crusting ✓ Compaction ✓ Sealing ✓ Wind erosion ✓ Water erosion ✓ DE shrubbery ✓ Over tillage	➢ Reduction in crop yield ➢ Overexploitation of natural resources ➢ Increased in alteration of land use ➢ High conversion of land use ➢ Increase in poverty
Soil and Water management	✓ Impeded drainage ✓ Waterlogging ✓ Reduction water holding capacity ✓ Reduced infiltration	➢ Reduction in water quality ➢ Reduction water quantity ➢ Increased water treatment costs
Soil nutrient and organic matter management	✓ Alkalization ✓ Acidification ✓ Nutrient leaching ✓ Removal of organic matter	➢ Loss cover ➢ Increased denuded ➢ Exposure to soil erosion ➢ Reduction in livestock farming
Soil biology management	✓ Overapplication of agricultural chemical	➢ Soil and water pollution ➢ Increased treatment caused
Vegetation management	✓ Decline in vegetation ✓ Decline biological diversity ✓ Decline in species composition ✓ Decline in availability of valued species	➢ Intrusion of invasive alien species ➢ Extinction of native species

(Source: Pitmental et al., 1995; Schere and Yadar, 1996)

2.3 SOIL EROSION

Soil is a non-renewable natural resource and once it is lost it cannot be replaced within a short period. Soils are however washed away with their nutrients that can be used to support plant growth whereby a group of processes detaches, dissolves, removes and transports soil or geologic material from their place of original setting either by wind, water or gravity (Rooyani and Badamchian, 1986; Teh, 2011). Soil erosion is an element of land degradation where soil is removed through action of wind or water at a faster rate than it is formed. According to Boardman, (2000) soil erosion is a natural process that wears down topographic high areas (hills and mountains) to fill topographic low areas (valleys, lakes, bays) through deposition of eroded materials. Therefore natural bodies such as rivers, hillsides, valleys, soils and lakes are not static but they are dynamic, that is ever changing. Erosion is a geomorphic process occurring continually over the earth's surface and largely depended on topography, vegetation and climate (Jain and Kothyari, 2000) (Jain, *et al.*, 2009).

2.3.1 Causes of soil erosion

Although soil erosion has occurred throughout history, it has been intensified by human population growth coupled with the diversity of activities intruded further into the natural ecosystems (Jain and Kothyari, 2000). Soil erosion by water is one of the most important land degradation problems and critical environmental hazard for modern time worldwide (Ewsanan *et. al*., 2001). Recently soil erosion by water is accelerated by human-induced environmental alteration. At global scale, this causes extravagant increase of geomorphic process activity and sediment fluxes in many parts of the world (Turner *et al.*, 1990). However in African and least developed nations, lack of investment, capital deficiency, unsustainable intensification, that is this season the area is under commercial farming with more investment and management and the next season it finds its under subsistence farming with less on no investment in management becomes the major forces behind farmland soil erosion especially in Africa and developing countries (Barbie, 2000). On the contrary, the Second World War marked the turning point in yield per hectare of arable land in the Western World and the continued increase in production per unit of land area and per unit livestock has led to significant increase in the agricultural productivity subject to high investment security, including rehabilitation methods undertaken through researches (Gerbens-Leenes and Nonhebel, 2002).

However, apart from rainfall and runoff, the rate of soil erosion from an area is depended strongly upon soil vegetation and topographic characteristics which are found to vary greatly within various sub-catchments (Jain and Kothyari, 2000). Though topography, soil type and rainfall erodibility are the factors that trigger soil erosion, and vegetation and anti-erosion works factors are the factors that control erosion (Arghius and Arghius, 2011). Pimental, *et al*., (1995) further adds that soil erosion drastically increases on steep cropland yet steep slopes are continually converted from forests and grassland into agriculture: In Nigeria, cassava fields on steep (12%) slope experienced loss of 220 tons ha^{-1} $year^{-1}$ compared with 3 tons ha^{-1} $year^{-1}$ on flat land whereas in the Philippines and Jamaica, over 58% and 52% of land area respectively have slopes of over 11% and 20% with the subsequent loss as high as 400 tons ha^{-1} $year^{-1}$. Runoff and flowing water in mountainous areas and agricultural lands are the major sources of sediment transport by streams and deposited in reservoirs (Teh, 2011). However the geological soil erosion in Lesotho is accelerated by overstocking, overpopulation, over cultivation, poor roads construction and management lead to gully erosion, channel erosion, sheet erosion, rill erosion, and deterioration of pastures and lack on well-planned soil conservation measures (Chakela, 1981).

2.3.2 Impacts of soil erosion

Soil erosion has been taking place slowly in natural ecosystems throughout geological time, however its cumulative impacts over billions of years is only significant (Pimental, and Kounang, 1998). There are *onsite* and *offsite* soil erosion impacts. *Onsite* has a substantial economic loss of nutrients and water and ecological damage depleting soil depth, crop yield. Studies on reduced soil depth reported crop yield reduction of 0.13 % to 0.39% per centimeter of soil lost (Pimental, 2011). On the other hand *offsite* impact of soil erosion do not only damages immediate agricultural areas but also affect negatively on the surrounding environment (Barbie, 2000). These include roadway, sewer, and basement siltation, drainage disruption,, undermining of foundations, and pavements, gully roads, earth dam failures, eutrophication of water ways siltation of harbors and channels, loss of habitat and disruption of stream ecology flooding zone, loss of ecosystem resilience, damage to public health plus increased water treatment (Pitmental, Harvey *et al*., 1995; Schere and Yadar, 1996; Gerbens-Leenes and Nonhebel, 2002). Furthermore Chakela and Stocking (1988) highlighted that since the 1930's soil erosion has been implicated as the most important factor in decline of agricultural productivity in Lesotho, however, there has been little done to this effect in trying to understand the processes and extent of soil erosion in Lesotho.

2.4 SEDIMENTATION

Drift of unstable pro-glacial or postglacial fluvial environment resulting in heightened sediment movement that continues as long as there is drift material that are easily accessible for fluvial erosion and transportation (Church and Ryder,1972). The problem of sedimentation comprises of detachment, transportation and deposition of sediment away from their original positions in the soil mass (Chakela, 1981). Humans have simultaneously increased the sediment transport by global river through erosion by 2.3 +/- 0.6 billion tons per year but because of retention by reservoirs, over 100 billion metric tons of carbon is now sequestrated in reservoirs constructed within the past 50 years: African, and Asian rivers carry reduced sediment load whereas Indonesian rivers deliver much nutrient to coastal areas (Rogeve, 1990). These sequestrated nutrients in reservoirs and rivers are the reasons for in-land water bodies productiveness, because in stratified lakes, during turn-over, nutrients are unlocked from the benthic zone to the surface waters which gives rise to high productivity of water bodies that could lead to eutrophication and disturb aquatic food chain hierarchy while in hype-eutrophic lakes they experience fish kills during turnover and mixing. Moreover, the runoff constitutes one of the biggest potential sources of reef degradation (Rogeve, 1990), and one of the major problems in hydropower schemes and rivers in mountainous places (Teh , 2011). Chakela (1981) estimated a total sediment soil yield of about 1400 million tons in reservoirs per annum.

Though Syvitsk *et al*., (2005) have the view that, there is increased sediment transport by global rivers including the Orange/ Senqu through soil erosion, though there is reduction of sediments reaching the worlds' coasts because of retention within reservoir constructed for the last 50 years, Orange/ Senqu displays a reduction from ton per second to one tenth of a ton per second, (see Figure 1).

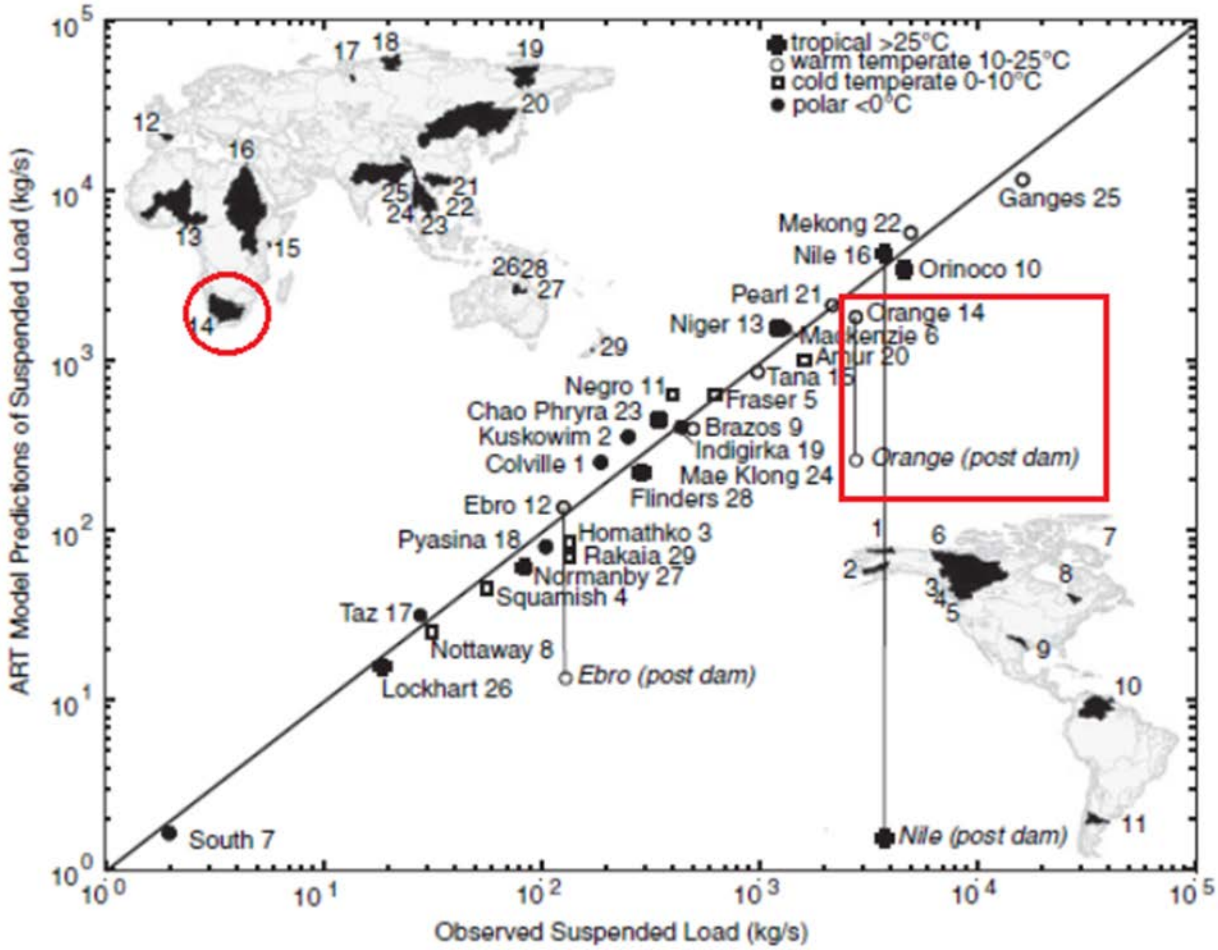


Figure 1: Global Rivers Sediment loading statues (Source: Syvitsk, et al, 2005)

2.5 METHODS FOR ASSESS SOIL EROSION

Due to the complexities or processes involved during erosion, many ways have been devised to assess, predict or quantity the rate and magnitude of soil erosion. Amongst these methods different mathematical models have been devised. The first soil erosion prediction method was developed in the United State of America and many other equations followed (Teh, 2011). According to Dube, (2011) soil loss modeling is a way of bringing various factors and processes in a way to predict or reproduce what is occurring in reality. These models include the earliest model of soil loss, the Universal Soil Loss Equation (USLE) developed by Wischmeier & Smith (1965), modified by Renard *et al.*, 1997, (Arghius and Arghius, 2011; Dube, 2011; Teh, 2011). Other modified models include Soil and Water Assessment Tool (SWAT), Soil Loss Estimation for Southern Africa (SLEMSA) (Chakela and Stocking, 1988; Dube, 2011). However these other models other than the USLE, are more complex to be used by layman due to a combination of factors (Dube, 2011). Therefore USLE still remains the widely used and accepted model to date even with its known shortcomings, like a huge margin of error if one input if over specified, (Teh, 2011). While on the other hand SLEMSA Model above its the complex mathematical equations it also assumes that each factor in erosion has equal weight and importance which is not true under tropical conditions where erosion rate is more sensitive to change in vegetation than soil type (Dube, 2011).

2.6 SEDIMENT LOADING

Sedimentation is a process whereby particulate matter is transported by fluid flow and eventually deposited as a layer of solid particles on the bed or bottom of water (Mavima *et al.*, 2011). Fraley, (2000) adds that river flow regime and sediments transport are correlated, sediment is defined as the total amount of material passing through a given channel cross-section per unit time

2.6.1 RUSLE and soil erosion modeling

This study adopted the Revised Universal Soil Loss Equation (RUSLE), which overcomes the shortcoming of the Universal Soil Loss Equation (USLE) through incorporating improvement of factors with their level of significance and importance but kept the basis of USLE (Teh, 2011). The first rational soil erosion equation was used to estimate soil loss from fields of clay-pan soils, USLE (Smith and Whitt, 1947).

A= **S • C • L ••K•• P** (Equation 1)

A = Annual soil loss, in tons ha^{-1} y^{-1}

C = Average annual soil loss, from clay-pan soils for a specific rotation slope length, slope steepness and row direction

S = Slope steepness

L = Slope length

K = Soil erodibility

P = Support practice (Rooyani and Badamchian, 1986; Schmitz and Rooyani, 1987; Arghius and Arghius, 2011; Teh, 2011).

The new version, Revised Universal Sol Loss Equation developed by Renard *et al.,* (1997), improved the method for calculating the terms with this equation.

$E = R \bullet S \cdot \bullet L^m \bullet i^n \bullet C \bullet C_s$ ***Equation 2***

Where:

E = The average annual rate of the surface erosion (t ha^{-1} y^{-1})

K = The rainfall erosivity factor evaluated based on rainfall aggressiveness obtained as the result of H·I ((H is amount of precipitation fallen during the entire rain event, I is the intensity of the torrential nucleus lasting 15 minutes)

S = The soil erodibility coefficient

L = The slope length factor, is derived using

L^m function, where m=0.3 for straight slope, m = 0.6 for the slope with a concave profile and m = 1.2 for convex slope. L^n, where I represent the slope angle (%) and n = 1.4

C = The cover management factor

C_s = The correction coefficient for the effect of the erosion

(Arghius and Arghius, 2011; Teh, 2011)

Furthermore modified RUSLE for Romania by Motoc and Sevastel, 2002 coded by Arghius & Arghius (2011) highlights that erosion processes can be group into two groupings. That is factors that triggers soil erosion processes and factors that controls soil erosion processes, where rainfall erosivity (AP), topography (R), and soil (S) being triggers while vegetation (C) and anti-erosion works (Cs) controls soil erosion.

The combined action AP, R and S factors represent the potential erosion (Ep), while all factors represent the effective erosion (Eef).

$Ep = AP \bullet R \bullet S$ ***Equation 3***

$Eef = AP \bullet \cdot R \bullet S \bullet C \bullet C_s$ ***Equation 4 (Arghius and Arghius 2011)***

The best equation to determine rainfall erosivity still used to date was developed by Wischmeier and Smith, (1965), (Schmitz and Rooyani, 1987; Teh, 2011).

$$R = \frac{1}{n}\sum_{j=1}^{n}\sum_{k=1}^{m}(EKI_{30})_K$$ ***Equation 5***

Where:

R = Rainfall erosivity factor

E = The total storm Kinetic energy (MJ/ ha)

I_{30} = Maximum 30 minutes rainfall intensity

j = The index for the number of years used to compute the average

k = The index for the number of storms

n = The number of years to obtain the average

m = The number of storm in each year

E = (210 + 89 log I) ***Equation 6***

tm$\leq 7.6\frac{cm}{hr}$ or tm$>7.6\frac{cm}{hr}$ (Teh, 2011)

E = The energy of rain

I = Rainfall intensity measured in 30 minutes (Schmitz and Rooyani, 1987; Teh, 2011).

According to Schmitz and Rooyani, (1987), attempts have been made to compute the R-factor for southern Africa and Lesotho, where the value of R is 200 for the lowlands and 150 for the foothills and due to lack of long term data for the mountains there has been no attempt to compute the R-factor for the mountains.

2.6.2 Using GIS in modeling spatial and temporal soil erosion

Spatial analysis of soil erosion at a watershed scale have been limited to cartographic techniques or overlaying of thematic map, however researchers has since dealt with these complexities through the use and the advancement in geographic information system (GIS), global positioning system (GPS) and remote sensing not only to facilitate cartography but also dynamic modeling of time and space dependent hydrological processes (Paningbatan, 1995).

The advantageous elements of the Geographic Information System (GIS) is that it displays all attributes in one, that is, it captures, stores, integrates, analyses, visualizes data that are linked with coordinate or locality (Teh, 2011). Jain, *et al.*, (2009) add that use of grid cell approach in remote sensing and GIS is adaptive for a collection of inputs on a regular pattern with the use of and accounts for variation in topography. Further the advantage of GIS is that it is suited for quantification heterogeneity in topography and drainage features of the catchment (Jain and Kothyari, 2000). Warren, *et al.*, (2004) highlights that slope steepness is a fundamental parameter in most soil erosion models' where in GIS environment is the most efficient method to determine slope is through the use of digital elevation model (DEM).

DEMs represent topography either by series of regular grid points with assigned elevation values or triangulated irregular network (TIN) where each point is stored by coordinates and the surface is represented by triangular facets (Warren *et al*., 2004). It is a breakthrough in the geomorphological analysis because of its ability to portray elevation and topography and its ability to demonstrate changes in landscape with time (Teh, 2011). However the degree to which DEM grid size affect the representation of the land surface and hydrological modeling has been examined systematically (Zhang and Montgomery, 1994). Flow accumulation factor represent the number of cells contributing to flow in a given territory, represented by flow accumulation bases:

$$\mathrm{L} = 1.4\left[\frac{As}{22.13}\right]0.3$$ ***Equation 7 (Arghius and Arghius, 2011)***

Whereby using DEM spatial analysis of Arc Hydro Tool expression in Raster calculation is calculated as the follows:

1.4*Pow ([flowacc]/22.13, 0.3)) (Arghius and Arghius, 2011): Teh, 2011).

Chapter 3 STUDY AREA DESCIPTION

3.1 LOCATION OF STUDY AREA

The study area is Lesotho, situated at the highest part of the Drakensberg escarpment of the eastern rim the southern Africa plateau occupying elevations 1388 m above sea level to 3482 m above sea level (Marake and Phororo 1999). Lesotho lies between 28˚35' and 30˚40' south of the Equator and 27˚00' and 29˚39' east of the Greenish Meridian Times longitude (Figure 3. 4). Lesotho is divided into four physiographic region based on elevation and agro-climatology. The *Lowlands* with elevation ranging from 1500 to 1800 m above sea level and forms a narrow strip (20-50 km wide) along the western border with the Republic of South Africa (RSA) (Chakela and Stocking, 1988; Mokuku, 2002). *Senqu River Valley* also has a similar elevation as the lowland however is in the rain shadow of the Drakensberg hence receives the least rainfall therefore it sparsely vegetated.

Foothills form a narrow strip (8%), rising from 1800 to 2000 m above sea level running north-east to south-west adjacent to the mountain ranges. *Mountains* ranges from 2000 to 3482 m above sea level and constitutes 61 percent of the total land area of Lesotho (Chakela, 1981; Chakela and Stocking, 1988; Marake and Phororo, 1999).

Lesotho is drained by four river networks of which three take water out of Lesotho. Senqu/ Orange and Mohokare/ Caledon River originate from the Mount-Aux-Sources in the north-east Drakensberg and the Makhaleng and Maphutseng river networks originated from the central Maluti ranges and flow westerly in the direction on RSA. Mohokare, Makhaleng and Senqu are the rivers that this study focuses on as they are the rivers that carry loads out of Lesotho. Photos below show the appearance of rivers of Lesotho.

Figure 2: Confluence of Hololo and Mohokare

Figure 3: Makhaleng Sand Deposits

Figure 4: Senqu/ Orange River Appearance

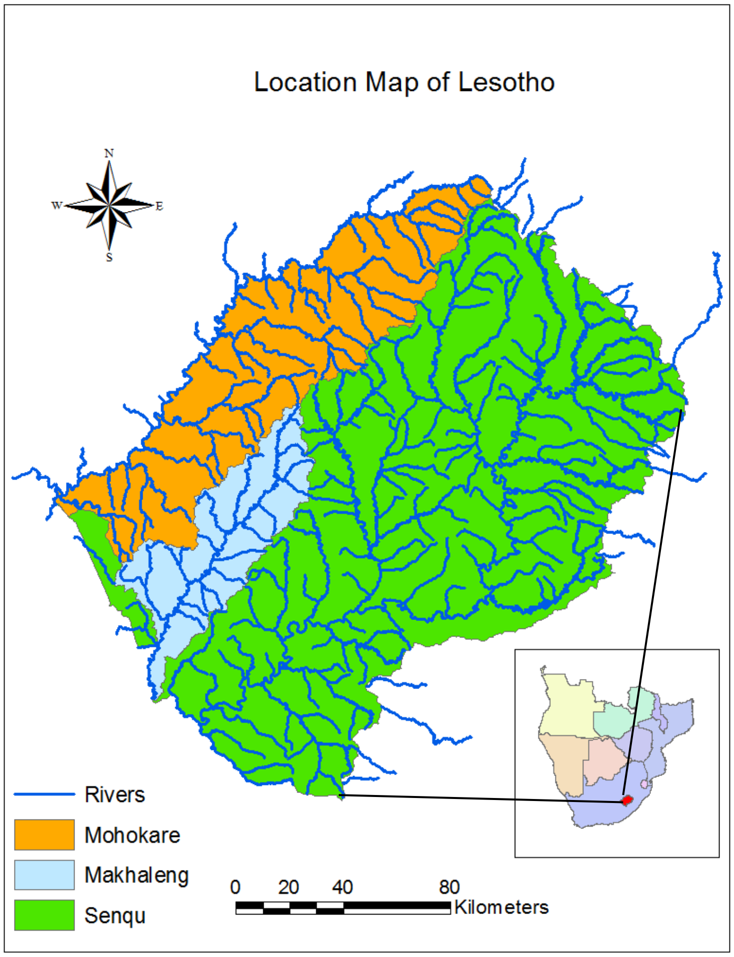


Figure 5: Location of the Study Area

3.2 CLIMATE

The Drakensberg Ranges is thought to abruptly cut off Lesotho from the influence of the south Indian Ocean current enjoyed by the South Africa province of KwaZulu Natal. However the mountain tops and the east-facing slopes still receive rainfall influenced by the Indian Ocean current (Tseki and Sekoli, 1999). The highest precipitation in the country is recorded over high altitudes closer to the effects of the Indian Ocean such as Oxbow region whereas the lowest recorded precipitation is recorded within the Senqu River Valley which coincides with the rain shadow of the Drakensberg. The precipitation in Lesotho is customary in the form of rain, snow, hail and frost. The annual precipitation is unevenly distributed ranging from 500 mm in the Senqu River Valley to over 1000 mm in the northern eastern Highland (Oxbow) (Chakela, 1981; Schmitz and Rooyani, 1987; Tseki and Sekoli, 1999). However it is characterized by fluctuating trends from year to year, of which 85 percent normally falls between October and March in the northern part of the country while 75 percent falls during the same months in the southern part of the country. Temperature on the other hand varies heavily from diurnal monthly and annually from -20 ˚C to 36 ˚C (Tainton and Hardy, 1999).

3.3 GEOLOGY

The structural development of the African continent was marked by several periods (Palaeozoic and Mesozoic) of mountain building blocks, where large areas became folded, metamorphosed and was subject to deep seated intrusions, thus fused together to form African shield (Schmitz and Rooyani, 1987). During the late Paleozoic and early Mesozoic era, the African Continent was part of the Gondwanaland supercontinent, whose break up resulted in Africa and South America (Anderson and Schwyzer, 1977).

Within the African Continent Lesotho lies in the cratonic margin between the older (2700 million years) and more stable KaapVaal Craton in the northern part of the country and younger (1100 million year) Namaqualand-Natal Mobile Belt in the south (Barthelemy and Dempsterm, 1975). Schmitz and Rooyani (1987) further interpolated that in general, this belt consists largely of gneisses and contains rocks which have been metamorphosed more strongly than those of the KaapVaal Craton, the host belong to the Swaziland system depicted by complex folded schist belt of sediment (granite) and volcanic (greenstone belt) origin.

Lesotho adjoins northern-eastern part of the Orange Free State underlined by Triassic and Jurassic basalt of Lesotho Formation and Triassic sand and mud rock of the Karoo Sequence (Van Rooy and Van Schalkwyk, 1993). Schmitz, and Rooyani (1987) describes the Karoo basin as a tectonic-sedimentary basin of terrain of tectonic origin that measures several for hundred square kilometers. In Lesotho the Karroo system consists of four main geological groups namely Dwyka, Ecca, Beaufort, and Stormberg, however Ecca group in Lesotho may be expected to occur at depth while the Stormberg group in Lesotho consists of Molteno, Elliot, Clarens and Lesotho Formation (Beukes, 1970; Chakela, 1998).

3.4 SOILS

Most soils in Lesotho are mineral (Schmitz and Rooyani 1987) and a small fraction of organic matter as well as decomposed matter, where plant residues contribute greatly to sources of organic matter (Rooyani and Badamchian, 1986). Soils formed at elevations more than 3000 meters (mountains) are formed in basalt controlled terrain and they have relative amount of organic matter most soil in foothills and the lowlands (Chakela, 1981). Furthermore, shale and sandstone of sedimentary formations of Clarens, Elliot and Molteno form the geologic material for most of the foothills and lowlands (Schmitz and Rooyani, 1987). However, not all soils of Lesotho tend to reflect the mineralogy of the geologic material underlying them (Chakela 1998).

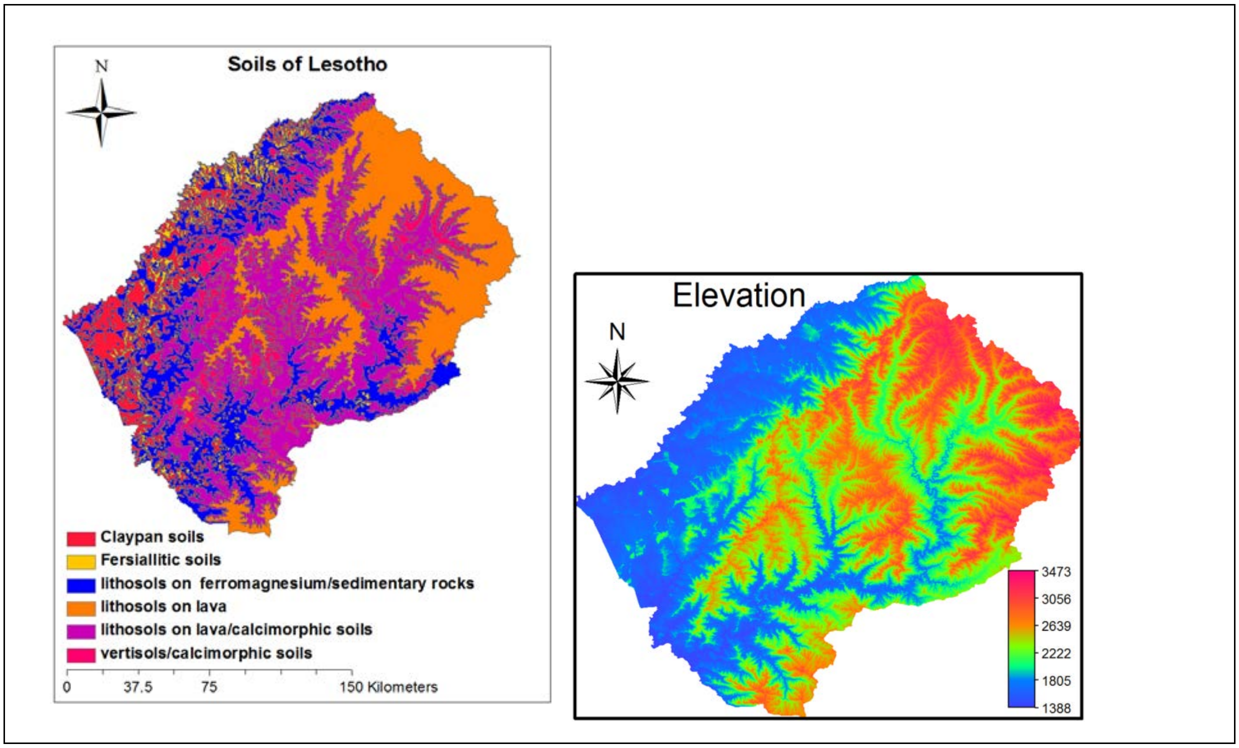


Figure 6: Soil Map of Lesotho and Elevation Map for Lesotho

Furthermore basalt parent material helps in growth of grass, and these grasslands occupy the large part of higher-lying eastern region of Southern Africa where Lesotho is situated, and partly these areas are relatively cool (Tainton, 1999). Moreover, soils formed in basalt terrain contain high organic matter (Marake and Phororo, 1999) compared to soil in found in the lowlands and foothills.

3.4 VEGETATION

Lesotho is a grassland country and treeless almost completely devoid of natural tree growth (Marake and Phororo, 1999). Germond (1967) had a different view. According to the First European Missionaries to Lesotho they found abundant water, fertile soil, firewood, timber, and a picturesque situation though trees were never abundant in Lesotho, but their presence along the Caledon River has been recorded and land was characterized by abundant grass on hillside and this prevented soil erosion (Showers, 1989). However climate in a broad sense is a major determinant of the geographic distribution of species and vegetation types, in agricultural terms, within any particular region there are microclimate habitats which are greatly influenced by local topography suitable for plant growth (Tainton and Hardy, 1999).Temperature further contribute to productivity and survival of plant life. Lesotho weather is highly remarkable, with harsh cold winters, below freezing and snowfall experienced especially during the month of July ending with hot rainy summers (Showers, 1989).

The coldest recorded winter in Lesotho was recorded in 1902 which resulted in the loss of the already small trees population (Chakela and Seitlheko, 1995; Tseki and Sekoli, 1999). The poor recovery of the tree growth was due to the high demand for firewood under the cold weather conditions hence the start of land degradation in Lesotho (Showers, 1989). Consequently Lesotho over the years has lost most of its wildlife that used to inhabit the country (Germond, 1967). In late 1830's the Boers trekkers from the Cape Colony arrived on the western border of Basutoland subsequently claimed land rights and displaced people from the area which led to treaty of 1869 defining the boundaries referred to as "Lost or Conquered territory: however the west of the Caledon remained in the hand of the Boers, this effectively reduced Lesotho by half (http://en.wikipedia.org/wiki/Moshoeshoe_I, 5/11/2013). This loss of arable land to the Free State resulted in Basotho people occupying the fragile mountain areas and forced by circumstances in cultivating those steep slopes. Farming below the escarpment thereof accelerated soil erosion resulting in loss of valuable soil. As a result, rills developed into gullies and gullies developed into dongas, and this is how the Mountain Kingdom has been perceived over the years (see Figure: 7 and 8).

Figure 7: Gullies dissecting terraced slope cultivation

Figure 8: Dongas in duplex soils

Where land use is set aside for livestock grazing, grassland is important, often it is the only, source of food for animals in the Karoo region (Tainton, 1999). However, there has been a radical change in the vegetation of the Karoo during the last century, such as loss of perennial climax species like *Fingerhuthia sesleriaeformis, Pennisetum sphacelatum, Themeda triandra* as well as palatable shrub such as *Felicia ovata, Helichrysum dregreanum, Limeum aethiopicum* and *Osteospermum scariosum* (Vorster and Roux, 1983) and these species survive in protected patches. The adaptation by species differs at successional gradient (Tainton, 1999) moreover grasslands are potentially by far more productive ecosystems where carrying capacity can be reduced with declining rainfall.

3.5 POPULATION

In 1997, according to Gay and Tshabalala (1999) there were roughly 2,000,000 Basotho and fifteen years down the line there are 1,894,194 Basotho (Lesotho Bureau of Statistics, 2013) The growth rate indicate a declining trend but the birth rate is 2.665 % (CIA World Factbook, 2012). This decline in population growth rate can only be attributed to a pandemic wiping people (HIV and AIDS). Gay and Tshabalala (1999) furthermore highlighted that there has been a strong movement of people from the mountains to the *foothills* and *lowlands* and from rural areas to towns and out of Lesotho. Where these areas constitute about 26 percent of the total land surface of Lesotho, as a result this has led in the reduction of arable land per person leading to overexploitation of land resources.

Due to prevalence of droughts especially in the southern lowlands the pressure has attributed to land degradation.

3.6 LAND USE AND LAND COVER

Seitlheko*, et al.*, (1999), views land as the complex dynamic combination of actors geology, topography, hydrology, soils, micro-climates and communities of plant and animals as they are continually interacting in under the influence of climate and human activities. Land use is human use of land and involves the management and modification of natural environment or wilderness into the built environment such as fields, pastures and settlements (http://wikipidia.org, 15/11/2013). FAO/ UNEP (1999) further defined land use as the arrangement activities that input people's undertake in a certain land cover type to produce change or maintain it.

Chapter 4 MATERIALS AND METHODS

4.1 INTRODUCTION

This chapter describes the data collected, methods, analysis used to quantity for spatial and temporal soil loss lost out of Lesotho, identify soil erosion drivers and hotspot of erosion for future monitoring.

4.2 DATA COLLECTION

4.2.1 Data Collection for assessing Soil Loss out of Lesotho

Secondary data of flows and sediment loads was obtained for all terminal stations of rivers leaving Lesotho from the Department of Water Affairs in Lesotho. Field visits were also undertaken to validate location of all station where GPS coordinates were obtained. The soil map for Lesotho was obtained from the Department of Soil and Water Conservation in Lesotho. Rainfall data for all meteorological stations in Lesotho was obtained from the Lesotho Meteorological Services (LMS). Aerial photos and topographic sheets (1: 50,000) were acquired from Land Administration Authority (LAA).

4.2.2 Data Collection for Identifying Critical Areas/ Hotspots using RUSLE Model and Spatial soil Loss

Landsat TM 4-5 image (Path 169-170 and Row 080-081) for 1986 March, 1997, 2006 and 2009 were obtained from the Glovis website (http://glovis.usgs.gov/). The images were classified to come up with land use – land cover maps and the cover management factor. SRTM Digital Elevation Model (DEM) of 90 m resolution was obtained from the Earth Explorer website (http://EarthExplorer.com). DEM was to be used in determining slope-length factor. Digitized Soil Map for Lesotho was obtained from the Department of Soil and Water Conservation in Lesotho to be used to obtain the erodibility factor. While referenced rainfall stations and rainfall data collected from LMS were used to obtain the rain erosivity factor map.

4.3 METHODS FOR DATA ANALYSIS

4.3.1 Determining of the spatial and temporal variation of soil erosion Lesotho

In order to determine the spatial and temporal variation of soil erosion in Lesotho, Reversed Universal Soil Loss Equation (RUSLE) was uses as shown below.

A= LS • R • K • P • C *Equation 1*

A Annual soil loss, in tons ha^{-1} y^{-1}

C Average annual soil loss, from clay-pan soils for a specific rotation slope length, slope steepness and row direction

S Slope steepness

L Slope length

K Soil erodibility

P Support practice (Arghius, and Arghius, 2011: Teh, 2011: Schmitz and Rooyani, 1987: Rooyani, and Badamchian, 1986).

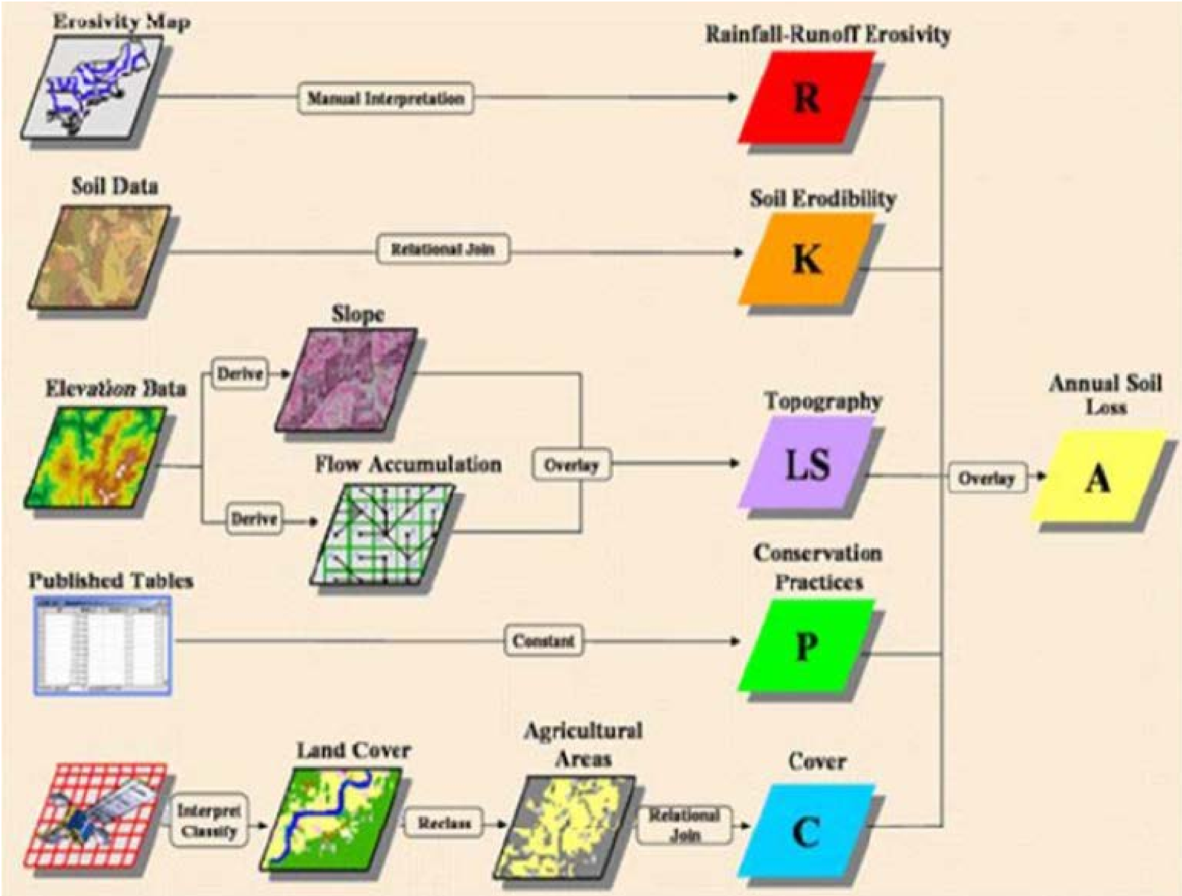


Figure 9: Conceptual framework for quantifying surface soil erosion using GIS technique (Arghius and Arghius, 2011: Teh, 2011).

4.4 COMPUTING THE RUSLE FACTORS

4.4.1 Slope Length and Slope Steepness Factor (LS)

The effect of topography on soil erosion is influenced by the LS factor in Revised Universal Equation (RUSLE), where the combination of slope length L and slope steepness factor S increases runoff as steepness of slope and length of slope increases (Rooyani and Badamchian, 1986). This is given by the equation 2.

$$LS = \left(\frac{X}{22.13}\right) m\ (0.0065 + 0.0045 + 0.00065S^2) \qquad \textit{Equation 2}$$

Where:

X – Sheet flow path length (m)

22.13 – Constant

s – Average slope gradient (%)

m – Refer to Table 1

Table 2: m values for computing LS)

m- Value	% Slope
0.6	> 5
0.5	3 - 5
0.4	3 - 1
0.3	< 1

(Source: Schmitz and Rooyani, 1987)

The procedure entails use of GIS to determine LS based on topography map. For this study digital elevation model (DEM) of resolution 90 m was imported into ArcGIS 9.2 software and for better visualization purpose hillshade was computed. The DEM in this study was only used to determine the RUSLE factor (LS), but not used on its own as a standalone method to determine soil erosion rates due to some limitation of this study. There was lack of continuous observation of recorded points to determine change in landscape.

The program calculated slope in degrees from the DEM. Then the computed slope in degrees was then converted to percentage slope. The DEM was further was used to calculate separately the flowaccumulation. This was performed through this command Flow Direction (elevation). Then flow direction was used in computing flowaccumulation. The computed percentage slope and flowaccumulation were further used to calculate the LS factor. Given by this command;

*"1.6*Power(([Flowacc}* Resolution)/ 22.13, 0.6) * Power (Sin([Slope]*0.01745)/ 0.09, 1.3) (Aghius and Aghius, 2011: Teh, 2011).*

Steps are indicated by figure 10.

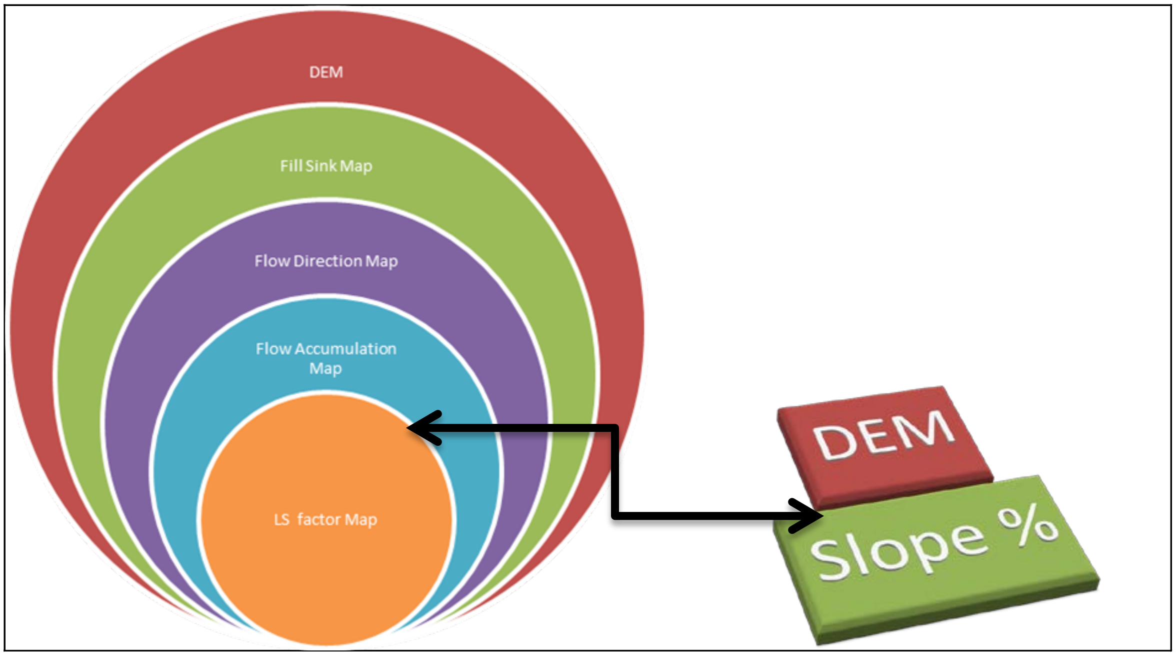


Figure 10: Schematic procedure to produce LS factor Map

4.4.2 Rain Erosivity (R factor)

Rainfall erosivity R factor reflects the power of rainfall pattern (Schmitz and Rooyani, 1986). Smulyan (2010) further adds that rainfall erosivity is the product of storm kinetic energy and maximum 30 minutes intensity rainfall energy to remove or transport materials and is given by this equation below:

E = (210 + 89LogI) *Equation 3* where:

E = The energy of rain

I = The rainfall intensity measured in 30 minutes (Rooyani and Badamchian, 1986)

However rainfall data available in most meteorological stations is not in the form of rainfall intensity or storm kinetic energy but is available as mean monthly or mean annual rainfall. Due to absence of rainfall intensity or storm kinetic energy data for Lesotho, this study will generate the R factor from the available monthly and annual rainfall data adopted from Armoldus (1978) (Wordofa, 2011).

Table 3 presents the list of station names and location of 13 manual rain gauge stations in Lesotho. These stations are managed by the Lesotho Meteorological Services (LMS). For the purpose of this study, thirty years of monthly rainfall data was availed from all LMS stations. The location and annual amount of rainfall analyzed in Excel for each station was therefore used to produce rainfall point map. Then inverse wetness was used to compute the R factor for ten year-three year periods. The choice of years was determined by availability of free Landsat complete scene images for Lesotho from Glovis website. The R factor was therefore computed for 1986, 1997 and 2009.

Table 3: LMS Manual Rainfall Gauge Station Locations

STATION NAME	X DEGREE	Y DEGREE
BOTHA-BOTHE	28.70	-28.77
LERIBE	28.05	-28.88
PHUTHIATSANA-TY	27.78	-29.13
MEJAMETALANA	27.50	-29.30
MOSHOESHOE I	27.57	-29.45
MAFETENG	27.25	-29.82
MOHALE'S HOEK	27.47	-30.15
QUTHING	27.72	-30.42
QACHA' NEK	28.70	-30.12
THABA-TSEKA	28.58	29.55
MOKHOTLONG	29.07	-29.28
OXBOW	28.62	-28.72
SEMONKONG	28.10	-29.83

(Source: Lesotho Meteorological Services)

Table 4: Annual Precipitation Computed for All LMS Stations in Lesotho (mm) from 1986 to 2012

Station No.	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	MEAN
BB	651.9	799.6	956.0	912.2	623.7	926.8	607.6	732.9	661.6	640.9	721.5	925.2	930.7	598.1	1188.4	805.9	773.4	588.7	755.4	781.0	1147.3	758.6	791.8	929.8	929.8	929.8	818.6	810.6
Ler	624.9	673.1	1037.3	735.5	637.6	674.3	458.9	628.6	502.3	640.3	940.8	856.9	794.6	730.9	879.9	771.8	859.2	591.8	700.0	842.5	992.3	738.4	581.6	304.7	611.2	869.7	697.4	717.6
Phuth	672.1	693.9	851.5	756.2	656.5	945.8	533.9	712.1	730.6	658.9	700.5	696.6	685.3	694.2	845.0	710.5	716.1	450.8	590.9	806.0	987.4	643.2	534.3	867.6	491.4	1135.5	822.2	725.5
Meja	674.5	773.9	970.0	576.1	641.5	798.5	400.8	597.8	603.1	642.4	784.6	699.6	926.0	587.4	858.6	1032.7	732.3	460.8	581.2	722.4	915.2	538.7	648.6	752.0	999.0	863.1	707.2	721.8
Mosh l	743.3	688.4	1022.3	663.1	735.5	1233.1	358.6	617.4	532.3	742.8	807.0	767.1	940.0	546.7	739.4	1006.2	999.7	609.2	666.9	836.7	1126.1	610.6	746.4	763.6	998.6	971.9	674.0	783.2
MFT	787.1	482.8	907.3	750.8	589.4	1048.0	327.1	583.8	555.1	617.8	788.3	612.5	815.5	530.4	887.4	1159.9	894.4	507.2	471.0	595.6	996.1	544.2	627.4	658.2	588.9	840.4	663.4	697.4
M'Hoek	617.8	934.1	1283.6	749.1	678.6	948.1	404.4	809.3	292.0	415.3	716.0	661.9	858.6	613.4	886.2	1159.3	827.9	522.7	699.0	641.0	1324.3	629.5	810.7	784.6	806.7	799.3	931.6	770.6
QTG	537.9	771.2	1203.3	681.9	713.8	965.7	499.2	804.6	526.3	620.1	835.2	615.2	919.2	596.5	921.5	1292.4	1042.4	495.2	760.2	631.8	1125.5	667.8	741.9	834.1	965.1	984.8	756.6	796.6
Q'Ne k	847.0	837.1	1002.2	764.8	400.8	846.0	499.4	812.7	645.6	1026.4	991.6	772.4	893.1	796.9	986.9	1017.5	820.5	730.2	889.4	675.2	757.7	721.1	741.1	828.4	791.1	809.2	916.9	808.2
TT	519.2	525.4	784.9	613.4	514.9	541.8	391.2	586.5	538.9	776.0	631.1	717.2	723.5	493.9	676.6	837.6	445.7	525.6	637.9	577.4	874.0	560.2	641.2	578.7	783.3	810.3	519.0	623.2
MKG	626.5	747.1	652.2	534.3	437.0	431.1	473.9	772.2	430.8	617.8	794.1	694.7	652.6	857.1	690.5	658.1	460.8	597.0	786.6	837.9	499.9	638.4	515.6	520.5	583.3	650.7		621.6
OXB	948.2	1279.3	1482.2	1139.8	1085.8	1229.4	908.0	1151.1	993.1	1164.0	1184.8	1371.9	1421.8	988.1	1513.9	1285.9	1340.1	1020.0	1062.1	1206.4	1311.3	1183.4	927.6	1185.1	1300.5	1384.1	1176.7	1194.2
SEM	577.8	608.3	548.6	412.8	583.6	254.5	0.0	0.0	444.4	489.8	638.3	795.5	636.4	831.0	1047.4	781.6	606.3	763.6	608.6	1093.4	757.7	862.2	826.4	1001.2	867.7	729.4		644.9
Mean	679.1	754.9	977.0	714.6	638.4	834.1	451.0	677.6	573.5	696.3	810.3	783.6	861.3	681.9	932.4	963.0	809.1	604.8	708.4	788.3	985.8	699.7	702.7	769.9	824.4	906.0	789.4	763.6

In order to compute the Rainfall erosivity factor (R), the annual rainfall for each station was used to and its computation was made with ArcGIS software. With the aid of GIS the table was converted into a point map. Then to determine the influence of each station an inverse wetness was performed for each point/ station. Then the R factor map was calculated using this function (R =-0.0334(P annual) + 0.006661 (P annual) square) (MJ*mm/ha*hr*yr) (Aghius and Aghius, 2011) in ArcGIS command calculator.

4.4.3 Soil Erodibility (K factor)

Soil erodibility factor represents the susceptibility of soil to erosion (Wordafa, 2011). Soils purses different physiochemical properties thus different soils have different erodibility (Rooyani & Badamchian, 1986). The K for a given soil series can be determined by using of standard Nomograph adopted from Wischmeier and Smith, 1958 (Schmitz and Rooyani, 1987) as in Figure 11. The nomograph follows the information of topsoil particular soil series.

Where:

$$K = \left(\frac{[1.0*10^{-4}\ (12-OM)M^{1.14}+4.5\ (S-3)+3.0\ (p-2)]}{100}\right) \qquad \text{Equation 4}$$

K -- Soil structure factor

M -- (% silt + % fine sand) * (100- % clay)

OM -- % of organic mater

S -- Soil structure

P -- Permeability (Teh, 2011)

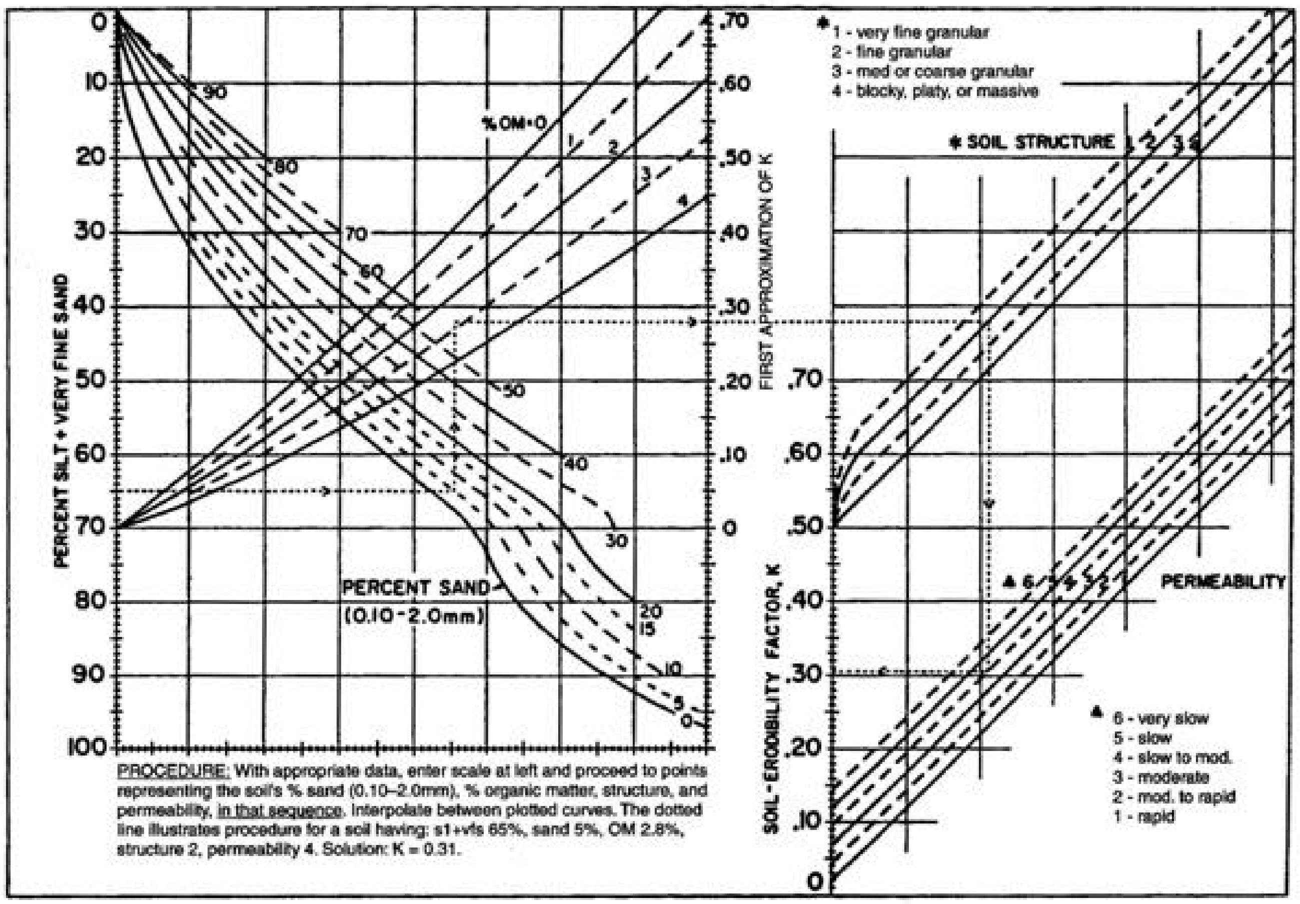


***Figure 11: Nomograph for computing K factor values, Source: (Teh, 2011: Schmitz and Rooyani, 1987: Rooyani and Badamchian, 1986*)**

The soil erodibility factor (K) present the long term soil profile response to erosive power associated with rainfall (ArcGIS and ArcMap manual). To come up with K value in ArcGIS, Lesotho Soil_shapefile and soil attribute table were examined to follow the Lesotho soil type = the various soil in the drainage Basin. (K_factor = the erodibility index of various soil). Then Lesotho soil map was opened, Lesotho_soil.shp then performed using this algorithm (*Categories > Unique Value* and *K factor* as the field and *Add.all value).* Then Lesotho_ soil shapefile is converted to grid using the same procedure for R to derive the K factor.

4.4.4 Crop management (C factor)

This is the factor reflecting the effects of land use and management on soil loss (Rooyani and Badamchian, 1986; Arghius and Arghius, 2011). It is measured as a ratio of soil loss from the corresponding land use (Renard, *et al*., 1997).To determine the changes in land use, GIS ability to provide the spatial and distribution of different feature based on the fact that different objects have different reflectance and absorbance Near-Infra-Red wavelength. Landsat images are integrated in to GIS software's to produce a composite image build from band 5, 4, and 3 respectively which enables segregate different features in accordance to their classes like water, vegetation, settlements and soil can be identified, because they have different reflectance values.

Lesotho falls within Landsat TM image of Path 169-170 and Row 080-081. For this study, all downloaded images with complete scenes availed from Glovis website for Lesotho were available for the following years: 1986, 1997, 2006 and 2009. However images for 2006 were not used sorely due the fact that not much change can be depicted within a space of three years in land use land cover between 2006 and 2009, therefore 2009 was chosen relatively because it was much closer to the study time. Therefore Band 5, 4, 3 for each scene were imported into Ilwis software to produce composite images for Lesotho, whereby four scenes cover Lesotho and were merged. Lesotho is found in four different scenes (Path 170 and 169, Row 080 and 081). The composite map for Lesotho was obtained by gluing and merging the bands from the different scene (Bands 3, 4 and 5) which was performed using Ilwis software. The merged composite images were therefore imported to ENVI software to run unsupervised classification to come up with land use and land cover for Lesotho/ NDVI map. Then the NDVI map was imported to ArcGIS 9.2 to compute the C factor through these following commands.

1- $NDVI = \frac{(NIR-Red)}{(NIR+Red)}$

2 - Ave – NDVI (NDVI)

3- C factor map = 102 – 1.21 * NDVI (Arghius & Arghius, 2011)

4 Then the above equation was adjusted using output statistics from NDVI to:

5 1.2078*NDVI + 0.2585

4.4.5 Conservation Practice (P factor)

This is the factor that reflects the influence of conservation on soil loss based on the ratio of soil loss under certain conservation practice and soil loss from clean up and down hill farm (Teh, 2011: Renard *et al.*, 1997: Rooyani and Badamchian, 1987). P values ranges from zero, and the value zero is given to area of maximum conservation support and the value 1 is given to areas with minimal conservation practices (Renard e*t al.*, 1997). Where zero is the P value for 100% conservation practice and 1 is for no practice implemented. To obtain the P factor the involved that the classified land use land cover map to be further reclassified brought in the P values.

Table 5: C factor values estimates for different crops in Lesotho

	ROTATION	LOW YIELD	MEDIUM YIELD	HIGH YIELD
1.	Maize or Sorghum – clean – continuous	0.64	0.54	0.47
2.	Maize or Sorghum – weedy –continuous	0.50	0.45	0.38
3.	Maize or Sorghum – weeds – maize/ sorghum weeds	0.31	0.29	0.23
4.	Maize or Sorghum/ beans – semiweedy-continuous	0.57	0.50	0.43
5.	Maize/ Beans - Maize/ Beans(Clean)	0.67	0.56	0.50
6.	Maize or sorghum with beans (4 yr)- Fodder (4 yr)	0.26	0.23	0.20
7.	Beans clean continuous	0.69	0.59.	0.52
8.	Beans weedy continuous	0.57	0.52	0.45
9.	Beans – Fodder – four year rotation (clean)	0.17	0.13	0.08
10.	Wheat continuous	0.24	0.23	0.20
11.	Wheat Fodder – Wheat Fodder	0.05	0.45	0.04
12.	Wheat/ Beans (1 yr) – continuous	0.45	0.38	0.31
13.	Wheat (4 yr) – Fodder (perennial) (4 yr)	0.16	0.14	0.12
14.	Potatoes – Maize – Beans – Wheat – Fodder	0.34	0.26	0.23
15.	Potatoes – Wheat – Beans – Fodder – Fodder	0.27	0.24	0.14
16.	Potatoes – Maize – Beans – Wheat (clean)	0.41	0.35	0.20
17.	Wheat/ Peas – Maize – Potatoes – Fodder (4 yr)	0.27	0.25	0.23
18.	Lucerne (4yr) – Ma – Pot- Sunf- Wheat –Fod – Maize Sunf- Soy – Wheat - Fod	-	-	0.17

Source: (Rooyani and Badamchian, 1986)

4.5 DETERMINING THE AMOUNT OF SOIL LOSS OUT OF LESOTHO FOR THE LAST THIRTY YEARS

Statistical analysis was performed using excel spreadsheet to reveal the trends of sediment load per catchment. Then sediment loading was compared between and amongst different catchments. The quantification of sediment loads per catchment was performed through summing per catchment per the duration of last three decades (1980 – 2012) to give the overview of the total amounts of soil lost out of Lesotho through its gauged rivers networks.

4.6 DETERMINING RELATIONSHIPS BETWEEN FLOW AND SEDIMENT LOAD

To establish relationships between flow and sediment load through correlation analysis. Flow regime and sediment transport are correlated temporally and spatially over the changes of river geometrics (Fraley, 2004).

H_0: Sediment is not correlated to flow

H_1: Sediment is correlated to flow

Chapter 5 RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

This chapter presents the findings from the study whose main objective was to assess the spatial and temporal soil loss in and out of Lesotho and to identify the critical areas/ hotspot for monitoring. The results and discussions are presented per specific objective in four sections and the summary of the chapter is given as the fourth section of the chapter. The first section provides the spatial and temporal variation of soil loss in Lesotho and identifies critical areas or hotspot for future monitoring with aid of the RUSLE model. The first part of the section gives the results of the five RUSLE factors used in calculating the RUSLE soil loss and second part gives the results of the RUSLE model. The second section gives results and discussions on trends and relationship between sediment loading and flow regimes within and amongst rivers that takes water out of Lesotho. The third section provides the relationship between observed sediment yields and RUSLE yields. The fourth section provides results and discussions for the quantities of soil lost from Lesotho through rivers from 1980 to 2012 as given by Excel statistical analysis.

5.2 Temporal variation in trends of sediments loads in Lesotho

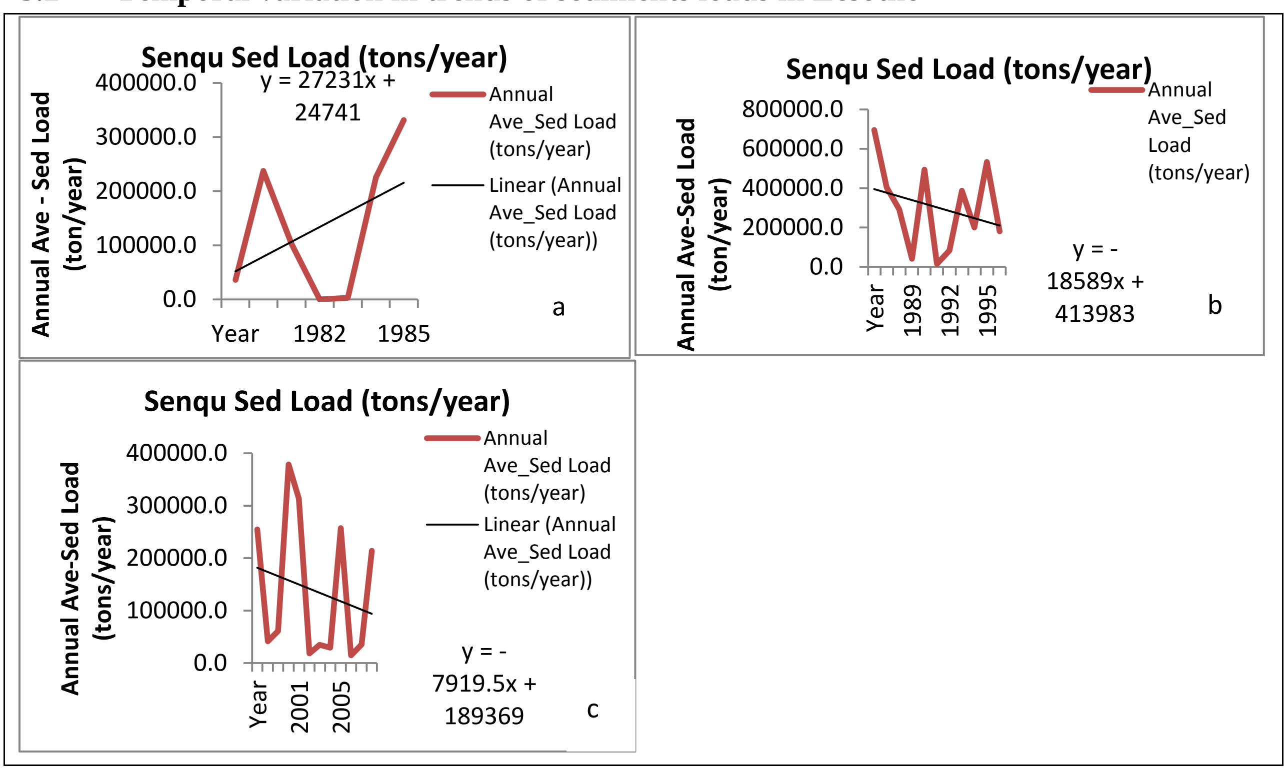


Figure 12: Temporal Variations in Sediment Loads for Senqu Period 1986 (a), 1997 (b) and 2009 (c)

The three graphs for Senqu depict variation in trend of sediment loading of this river supported with Figures 12 (a), (b) and (c). The temporal variation shows that during the period 1980 to 1986 the sediment trend was on the increase though there was not data for part of 1982 to part of 1983. The period 1997 and 2009 experienced declining trends. The trends also agree with the declining trends of soil loss from the RUSLE Model maps where 1997 experienced -30,642,734 which further tallied with the increase in percentage of area classified as rock outcrop especially in the Senqu River Valley. It can further be concluded that the potential for erosion remains high due to increase in barrenness, lowering of erosivity and high slopes. Also the area is known for its sparsely vegetated area amongst the four agro-ecological zones of Lesotho which have low NDVI values supported by increase in rock outcrop. The Senqu River valley also receives the least rains as it is the rain shade on the Drakensberg. However the valley has low LS factor, higher erosivity factor and low erodibility factor which makes the area less prone to erosion.

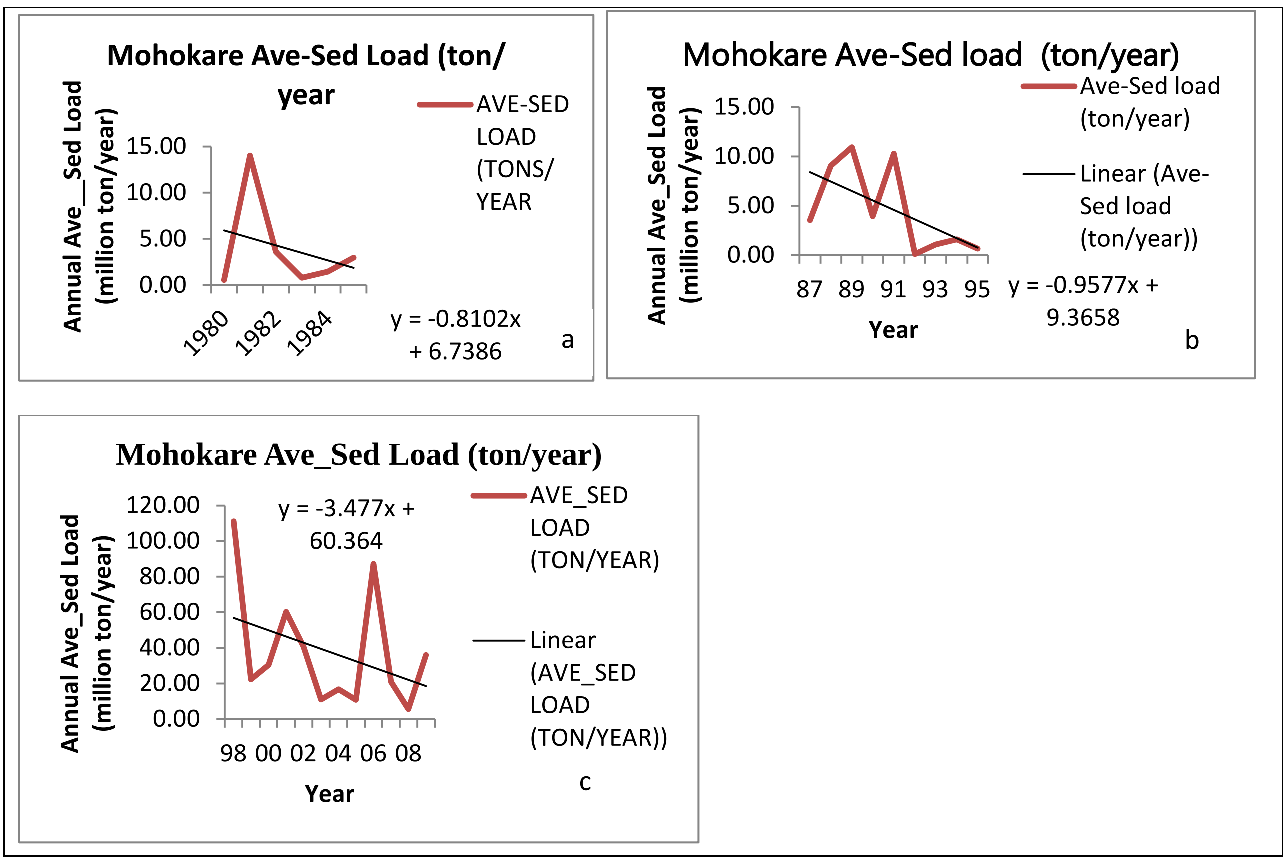


Figure 13: Temporal in Trends of Sediments Loads for Northern Mohokare Catchment for the Period 1986 (a), 1997 (b) and 2009 (c)

Mohokare River is represented by its upper gauged rivers: Hololo, Hlotse, North Phuthiatsana and South Phuthiatsana depicting a decline in trends in the magnitude of sediment loads for the three periods supported by Figures 13 (a), (b) and (c). The scenario for this area is true as it falls within low erodibility, low Length Slope (LS) factor and high erosivity, and high cover management factor hence the low prone area. However, the river continue from north to south through ungauged rivers which experiences high erodibility, sparse vegetation of the Karoo and clay-pan soil, which exposes or form crust hence increasing runoff rates which makes soil more prone, vulnerable or susceptible to erosion thus creating many gullies and dongas which are found in the area Mafeteng and Mohale's Hoek.

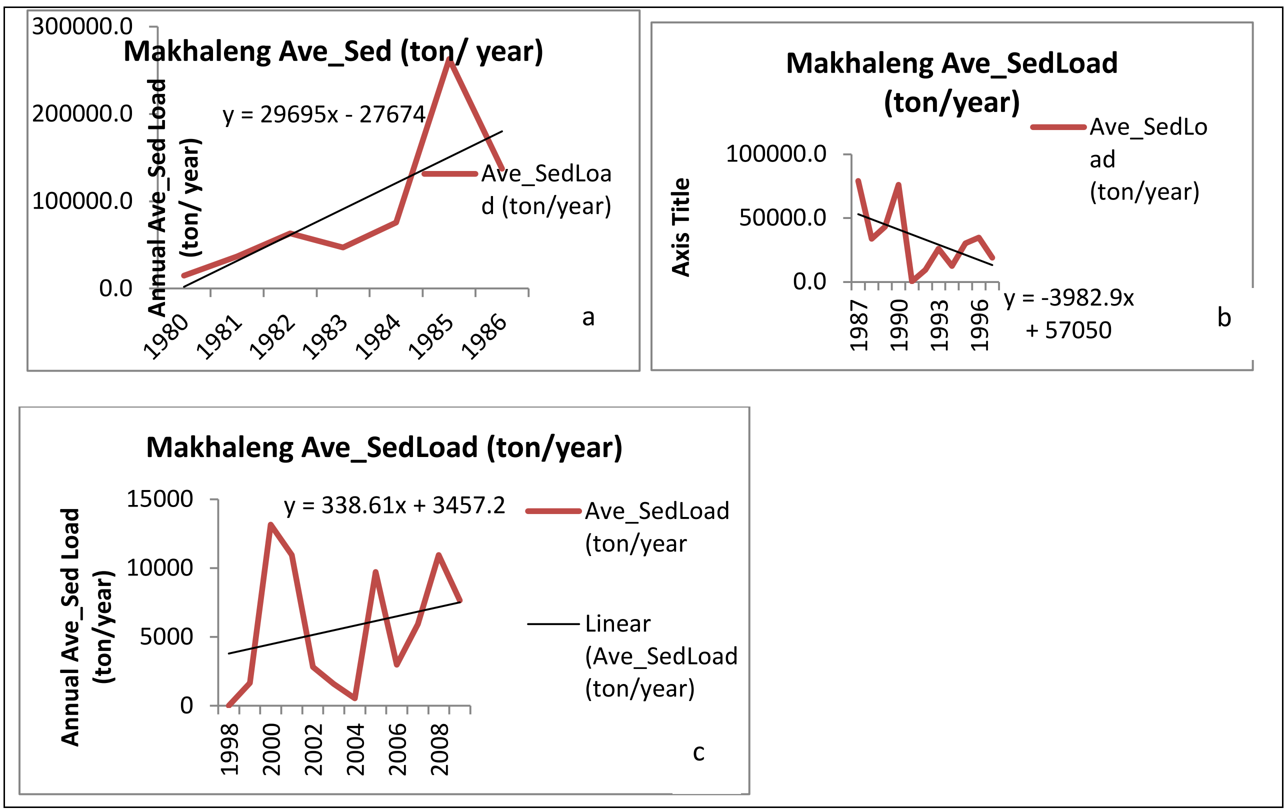


Figure 14: Temporal Sediment Load For Makhaleng for the Periods: 1986 (a), 1997 (b) and 2009 (c)

Makhaleng sediment trends for the period 1986 increased drastically (See Figure 14 (a)) and the high increase was experienced in the year 1984 and 1986 which could be linked to lowering of law enforcement on steep hill, slope cultivation due to instability that led to the toppling of the then ruling government by the Military force, however the soil depth are low in the area hence why the decrease in the period: 1997 (Figure 14 (b)), moreover resettlement of villages within the Lesotho Highlands Water Project (LHWP) could be some of the reasons for the second phase increase. Villages that were relocated to the lowland or foothills start pursuing their style of living not bearing in mind that places where they are relocated are steeper hence require high skill of terrace cultivation Hence the second increase of in the trend of 2009 see Figure 14 (c).

5.3 TRENDS IN THE SEDIMENT LOAD AND FLOW REGIMES.

Three major river network systems are responsible in carrying sediments out of Lesotho, namely Orange/ Senqu with an area of 20,485 km^2, Makhaleng with an area of 2,911 km2 and Mohokare/ Caledon River which subsequently forms the western border between Lesotho and the Republic of South Africa with an area of 6,890 km^2 (Mokhothu *et al.*, 1999). Mohokare River is not gauged anywhere in Lesotho and to account for its load, terminal station of rivers that leaves Lesotho and discard into Mohokare were used in this study name Hololo, Hlotse, North Phuthiatsana and South Phuthiatsana River. Figure 15 (a), (b) and (c) show the relationship between the annual average flow and sediment loads for Mohokare, Makhaleng and Senqu Rivers respectively for 1980 to 2012.

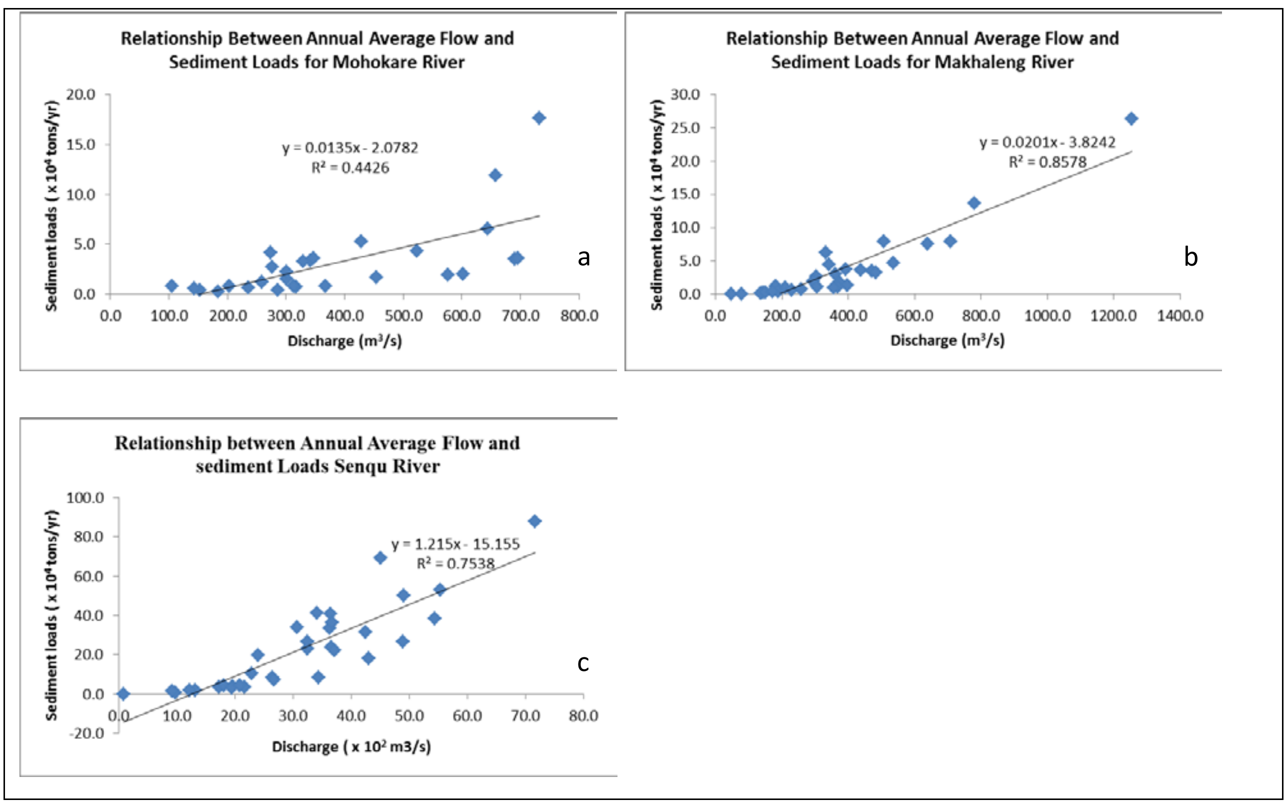
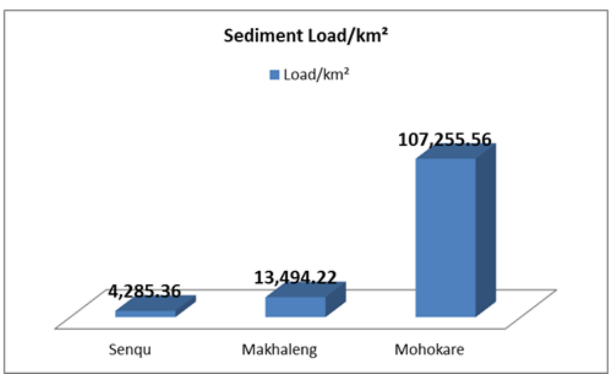


Figure 15: Relationship between Annual average Flow and sediment Loads for Sediment Loads for Mohokare (a), Makhaleng (b) and Senqu (c) from 1980 1o 2012

Figure 15 (a), (b) and (c) show the correlation analysis between annual average flow and sediment loads performed for Mohokare, Makhaleng and Senqu Rivers. The relationship indicates respectively a weak coefficient of determinacy ($R^2 = 0.44$) between the annual average flow and sediment loads for Mohokare River, while there is a strong coefficient of determinacy ($R^2 > 0.75$) between sediment loads and for Makhaleng and Senqu. However regression analysis revealed that there is a significant difference ($P = 0.00$) between the two variables all rivers (Appendix 1).

The same regression values for the three rivers could probably due to the fact that sediments loading are depended on flow. However the differences in correlation value of Mohokare with respect to the other two river displaying similar strong correlation value could also due to the heterogeneity tributaries of Mohokare river: Hololo is found within the northern foothill were soils are shallow, Hlotse and North Phuthiatsana South Phuthiatsana are found with the lowland where soils are well developed however South Phuthiatsana falls with high soil erodibility areas while North and Hlotse Rivers fall within low soil erodibility areas hence low correlation. While Makhaleng and Senqu rivers are constituted by homogenous catchment thus they are strongly correlated.

5.3.1 Sediment Load per Gauged Rivers Networks



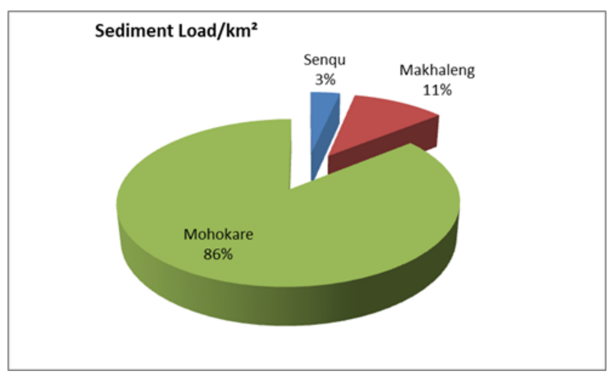


Figure 16: Sediment Loads in Three Major Rivers (ton.ha^{-1}yr^{-1})Figure 17: Percentage Sediments Load

The figures above show that there are tremendous sediments loads within the Mohokare Catchment as compared to Makhaleng and Senqu measured in load per km^2. Mohokare contributed 86% of the total average sediment loads, Makhaleng 11% and Senqu with 3 % (Figure 16 and 17). Even though Senqu contributes less sediment than the other two catchments in loads per square kilometer Senqu has more load than Makhaleng in terms of magnitude recorded (Figure 18).

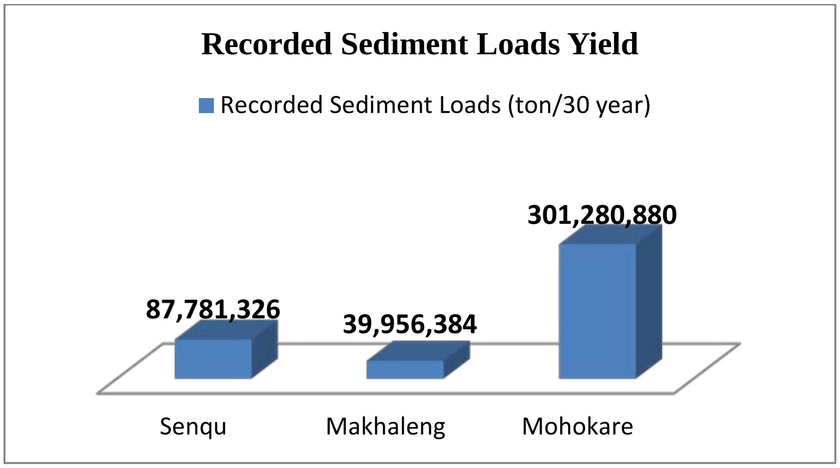


Figure 18: Sediment Magnitudes per Catchment

Senqu bears low sediment yields per square kilometer than Mohokare and Makhaleng due the fact that it is three times the area of Mohokare catchment and about ten times the area of Makhaleng catchment. Secondly Senqu River runs its three quarters length through the mountain ranges exhibiting well drained shallow soil. However the area especially in the east, Mokhotlong have low soil erodibility, but the slope steepness factor ranges between 692 to 3,464 which increase the susceptibility of the area to erosion, where soils are trickled down and find their way into streamlets, streams, rivers and reservoirs. Also the area enjoys more rainfall due to the effects of the warm Indian ocean currents and further experiences lowing of rainfall erosivity factor from 1,778.83 in 1986 to 9,978.40 in 1997 to 610.93 MJmm/ha.hr.yr in 2009, which means less and less rainfall energy power is being required to initiate the effect of erosion in the area which make the area more prone to erosion. Therefore shallow saturated soils become more prone to landslides. This threatens the planned construction of Lesotho Highlands Water Project (LHWP) dam in the area unless drastic rehabilitation measures are taken immediately. Teh, (2011) highlighted that the life span of a reservoir is determined by the reservoir storage capacity divided by the mean annual sediment loads. If no measures are taken in to account the new dam might silt before its sister dams. Furthermore the sister dams are within places that requires higher rainfall erosivity coupled with low soil erodibility and high NDVI values as compared to the negative values displayed in the east due to the fact that most of the area has increased in rock outcrop.

The low vegetation cover in the area might inhibit infiltration and latter percolation of rainfall which will therefore results prevention of underground recharge hence the dam could be prevent it from filling as opposed to its sister dams which filled up earlier that it was anticipated by the designs (Wortz, 2005- http://en.wikipedia.org, 31/10/2013). Katse Dam was completed in 1996 and the reservoir filled in 1997 with the dam wall of 185 m and being the second highest in Africa *(ibid).* Therefore underground recharge played a significant role towards its filling which cannot be enjoyed by Pulihali Dam which has negative NDVI values.

Figure 19 shows the current locations of LHDP dams. However Senqu is used as flood escape exits to secure millions of dollars infrastructure dam walls leading to environmental hazards. In order sequestrate sediments within dams are silt trap dams can be constructed within the Mohokare tributaries. Then alluvial sediments of Lesotho can be trapped in these dams the load and increase the transparence of river.

Figure 19: Location of Dams within the Senqu Catchment (Source: Land info Worldwide Mapping)

5.4 TOTAL AMOUNT OF SEDIMENT LOST THROUGH GAUGED RIVERS

Table 6: Total Amount of Sediments that have Lesotho for the Last Three Decades (1980 to 2009)

NAME OF RIVER	TOTAL AMOUNT OF SEDIMENT IN 30 YEARS (ton/30year)	TOTAL (ton/30 year)	PERCENTAGE CONTRIBUTION %
Makhaleng	39,956,384.4	39.4 X 10^6	9.3
Mohokare	301,280,880.0	301.3 X 10^6	70.2
Senqu	87,781,326. 0	87.8 X 10^6	20.5
GRAND TOTAL	427,226,263.9	427.2 X 10^6	100

Table 6 summarizes the total amounts of sediments that have been lost through Lesotho's major river networks. However this amount could be more as the amount only comes from the gauged catchments. Mohokare contributed 70.2 % of the total sediments lost out of Lesotho but the contribution is only from the northern part of the catchment where there is low soil erodibility. This implies that if there was data from the ungauged river networks from the southern lowlands where the erodibility is very high the scenario would even be worse. In addition, Mohokare falls within well-developed soils, hence more sediment loss. Makhaleng contributed the least amount of sediments lost because the catchments area of Makhaleng is the smallest and the soils depth is shallow, even though there is steep gradient. Although, Senqu has the largest catchment area, it contributes less sediment than Mohokare, because Senqu is within the mountain where the soils are not deep (see Figure 21).

5.5 RUSLE FACTORS – VALIDATION FOR OBSERVED DATA

In order to come up with the spatial and temporal changes of soil and to identify critical areas/ hotspots for future monitoring for Lesotho, RUSLE model was used. For RUSLE model to be able to run effectively its results in assessing soil erosion, the model employs five different factors derived from varies inputs: Slope length-steepness factor (LS) derived from DEM, Rainfall erosivity (R) from rainfall data, soil erodibility (K) derived from soil map, Crop management factor (C) derived from land use land cover changes and conservation practices (P) factor.

5.5.1 Soil erodibility factor (K factor)

Figure 21 present the soil erodibility map for Lesotho derived as per described in methods.

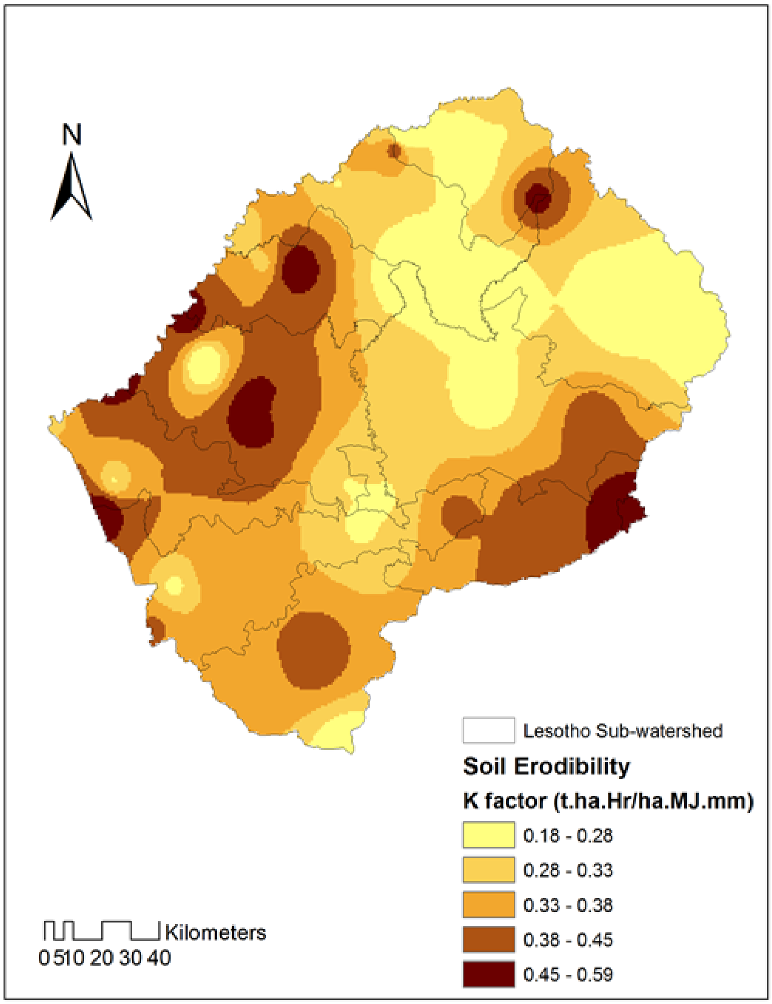


Figure 20: Soil erodibility factor Map for Lesotho

For the soil erodibility factor for Lesotho, the temporal aspect was not taken into account because of the lack of primary data like the soil texture information and knowledge of soil classification. As a result, this aspect was considered as a constant in terms of temporal scale, based on the fact that soils are different in their physiochemical properties and do not change unless there is a reason to explain the changes (Rooyani and Badamchian, 1986). The derived soil erodibility factor(s) are presented into five classes shown in the table 7 below.

Table 7: Derived Erodibility Factor for Lesotho

CLASS	RANGE (ton.ha.hr.ha^{-1}MJmm^{-1})
CLASS 1	0.18 – 0.28
CLASS 2	0.28 – 0.33
CLASS 3	0.33 – 0.38
CLASS 4	0.38 - 0.45
CLASS 5	0.45 – 0.59

The higher K value depicts higher soils susceptibility to erosion. The map shows (Figure 20) that soils in the southern lowlands or southern part of the Mohokare/ Caledon catchment areas, and those in the north-east highlands of Lesotho are more prone to soil erosion. While the central parts of Lesotho constitutes soils with less K values hence the not that prone to soil erosion.

The southern lowland comprises clay-pan and duplex soils which are vulnerable to soil erosion hence the reason of a high K factor values (Rooyani and Badamchian, 1986). However the north eastern part of country comprises shallow Millisols of which the most extensive one is the Popa Series (Hapludolls), well-drained soils. And the area having high K value could only be linked to topography or low rainfall erosivity as the area experiences high rainfall rates coupled with lack of ground cover. Millisols are predominant in the northern latitudes where glaciation has occurred, and many of this soil are young soils (less than 10,000 year) (http://www.soil.usda.gov 17/10/2013). In addition these soils are highly productive hence they are being overexploited for (C_4) grain production. The skim forest bulletin, 17/10/2013 indicates that its subclass Hapludolls are found in very steep areas of slope area greater than 50% which the northern-eastern parts experiences (http://www.sikkimforest.gov.in (17/10/2013).

The north east parts and the central parts of Lesotho exhibits similar attributes such as slope and soils, however the north east displays high soil erodibility than the central parts. Therefore the high erodibility factor of the north east parts of Lesotho could linked to the high rainfall the area experiences due to the effects of warm Indian Ocean currents which the central parts is inhibited by the Drakensberg Ranges. Rainfall erosivity trends in the area have lowered to 610.93 MJmm/ha.hr.yr., which makes the area to become even more vulnerable to soil erosion. And also the eastern parts is bearing more conversional developments than the central parts of Lesotho depicted by its low NDVI values displayed by NDVI maps for 1986 and 1997 and 2009 (see Appendix 1).

5.5.2 Slope length-steepness factor (LS factor)

Figure 21 shows the results of the slope length and steepness factor as described by the schematic procedure summarizes Figure 9.

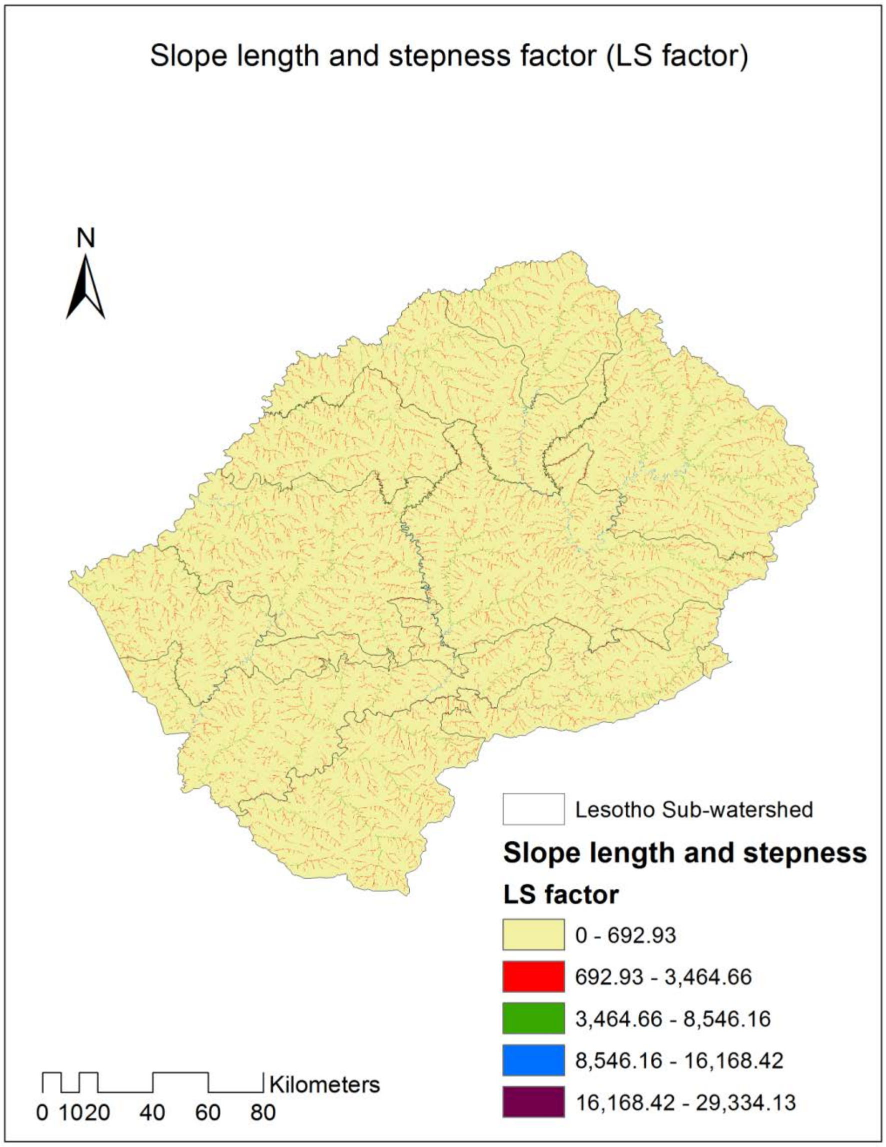


Figure 21: LS factor Map for Lesotho

Length and slope refer to the distance from origin of runoff to the point where slope decreases enough to allow deposition (Rooyani and Badamchian, 1986). From Figure 21 the results of LS factor ranges in five distinguished classes presented in Table 8 below.

Table 8: LS factor ranges for Lesotho

CLASS	RANGE
CLASS 1	0 – 692.93
CLASS 2	692.93 – 3,464.66
CLASS 3	3,464.66 – 8.546.16
CLASS 4	8,546.16 – 16,168.42
CLASS 5	16,168.422 – 29,334.13

Over ninety nine percent of the Lesotho falls within the first class which ranges from 0 to 692.93, hence the dominance of the yellow colour. The next class of LS depicted in the map ranges from 692.93 to 3,464.66 represented by the dotted green lines which reveals drainage networks of Lesotho, (from streamlets, streams to rivers). The other classes are not represented in the LS map and the areas in Lesotho could either fall from LS ranges of 0 to 692.93 or 692.93 to 3,464.66 that is the areas are flat or steep but not 3,464.66 which agrees with the topography of Lesotho.

5.5.3 Rainfall erosivity factor (R factor)

Figure 22 shows the rainfall erosivity factor maps for Lesotho for the three periods considered in this study that is 1986, 1997 and 2009.

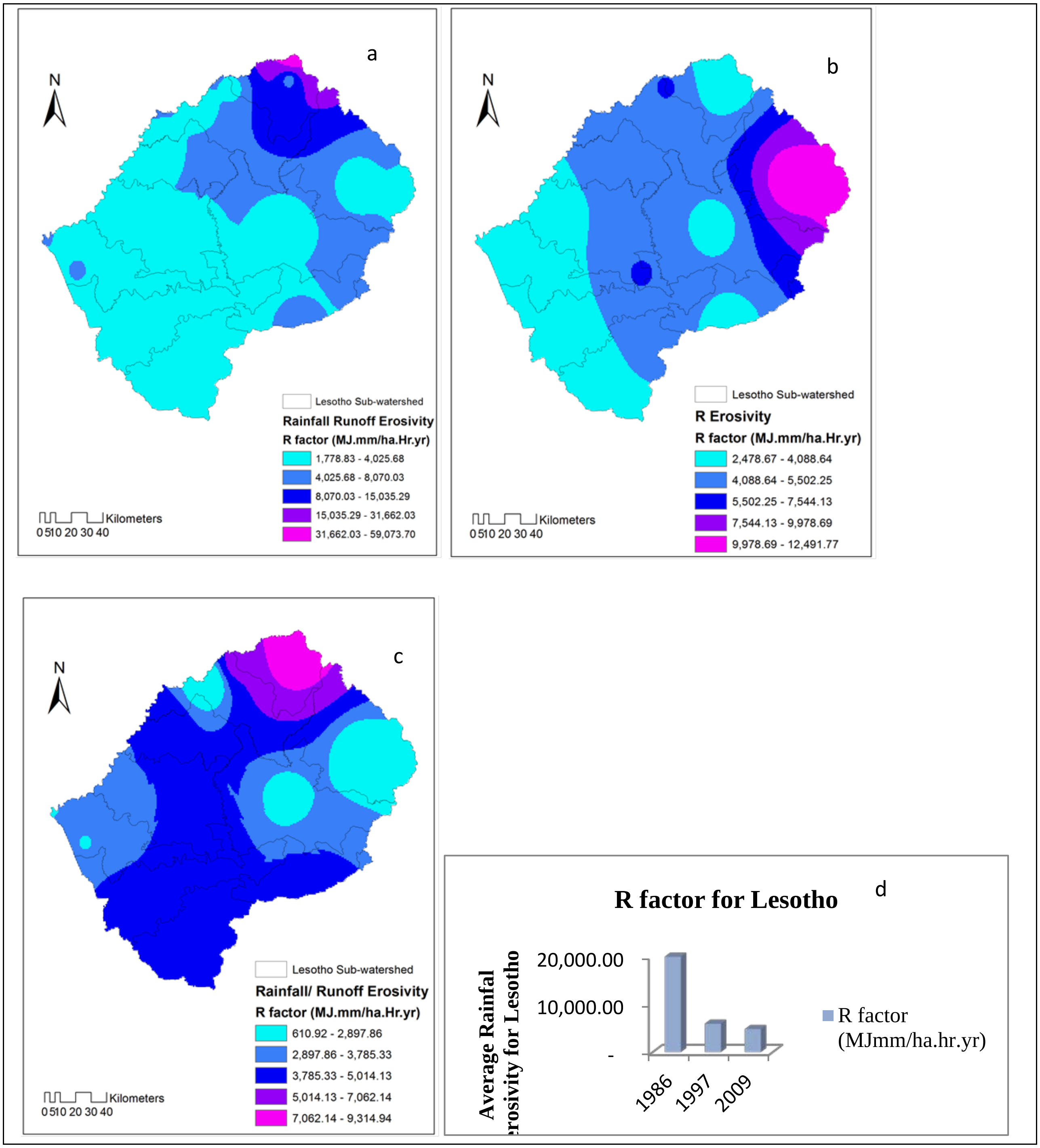


Figure 22: K factor for Lesotho (a), 1986; (b), 1997 and (c), 2009; (d) Graph showing trends of R factor

Figures 22 (a), (b) and (c) present the R factor Maps for Lesotho for 1986, 1997 and 2009 as computed from ArcGIS 9.3. The figures depict drastic decline in rainfall erosivity between 1986 and 1997 to a steady decrease between 1997 and 2009 steady as explained by Figure 12 (d). The declining trends rainfall energy from an average of 19,840.29 to 5,918.93 then 4,780.72 (MJmm/ha*hr* yr) in 1986, 1997 and 2009 respectively imply that less energy is being required to cause soil erosion. Figure 22 (a) indicated that in 1986, high rainfall erosivity energy was required to cause erosion from over half of the total land surface area. However, two-thirds of the total area which comprises part of the northern lowland, all of the southern lowlands and part of the central as well as eastern highlands are more susceptible to erosion since less energy is required to erode the soil, consequently the areas shows occurrence of gullies and dongas which gives evidence of soil erosion (Berea, Maseru, Mafeteng, Mohale's Hoek and part of Quthing and Qacha' Nek). Even though areas have low LS factor in ranging between 0 and 692.93.

There has been further decrease in the rainfall erosivity ranges between 1997 and 2009 (see figure 22 (b) and (c)), indicates that as low as 610 MJmm/ha*hr*yr in some parts of the northern highlands and part of southern lowlands. The area in the north that falls within the low erosivity energy forms the catchment for the Phase II LHWP dam to be built (Pulihali). The dam is therefore already threatened by sedimentation unless drastic land rehabilitation programmes are under taken. This is hotspot for future monitoring, since water is one of the important valuable natural resource and is also sufficient for Lesotho to meet the needs of the current population and future generation (http://www.britannica.com, 17/10/2013). Lesotho has already benefited through income generation from the export of inter-basin transfer to RSA, however dams have led to reduction in downstream flows and sequestration of billions metric tons of carbons in reservoir which has led to loss of nutrient soils for agricultural production that could translate to US$ 2.8 to $4.2 million loss in income annually (Sehoai Santho- http://www.iucn.com, 17/10/2013: (Syvitski, et al., (2005).

5.5.4 Crop management factor (C factor)

Figure 24 present NDVI maps for 1986 derived from the Landsat images (a) cover management factor map (b) for Lesotho for the year 1986 derived from the NDVI map.

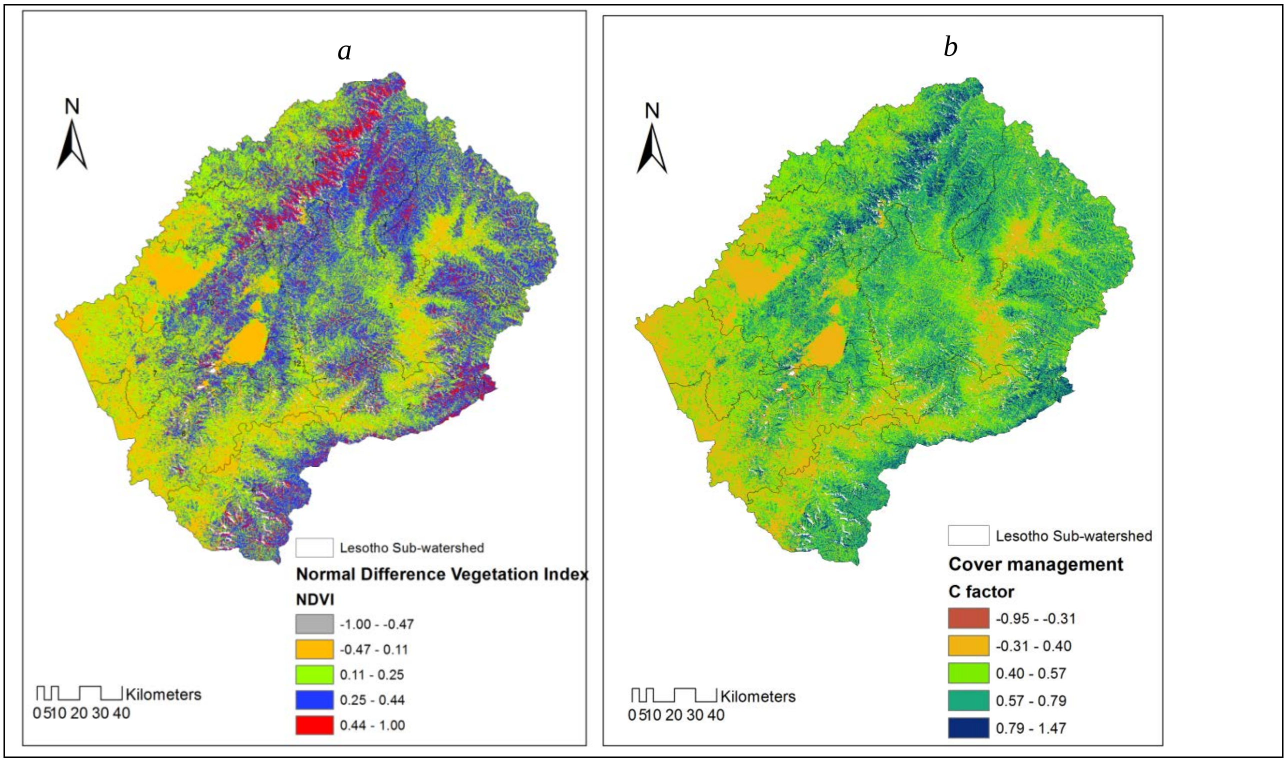


Figure 23: NDVI map and C factor map for 1986

Figure 23 (b) shows that Cover management (P factor) is directly linked to NDVI values (figure 23 (a). According to Pettorelli, *et al*, (2005), NDVI increases with high photosynthesis rate and high values are observed with high vegetation cover. The NDVI values ranges between -1 and 1. The negative values could indicate that the area is not under vegetation hence could be either settlements or bare soils. From the maps above it can be revealed that the central part of Lesotho is consisted of mountain ranged covered by alpine grasses which explains the higher NDVI values for Lesotho in 1997 (see Figure 24 (c)) and could be relatively true due to the efforts of the Lesotho Highlands Water Project (LHWP), as in 1986 was before the implementation of LHWP, so the NDVI values are lower. The reduction in NDVI values in 2009 could be attributed to changes in management and retrenchment of staff of LHWP which was responsible for maintenance of vegetative cover through range management (see Figure 24 (a, b, c. d)).

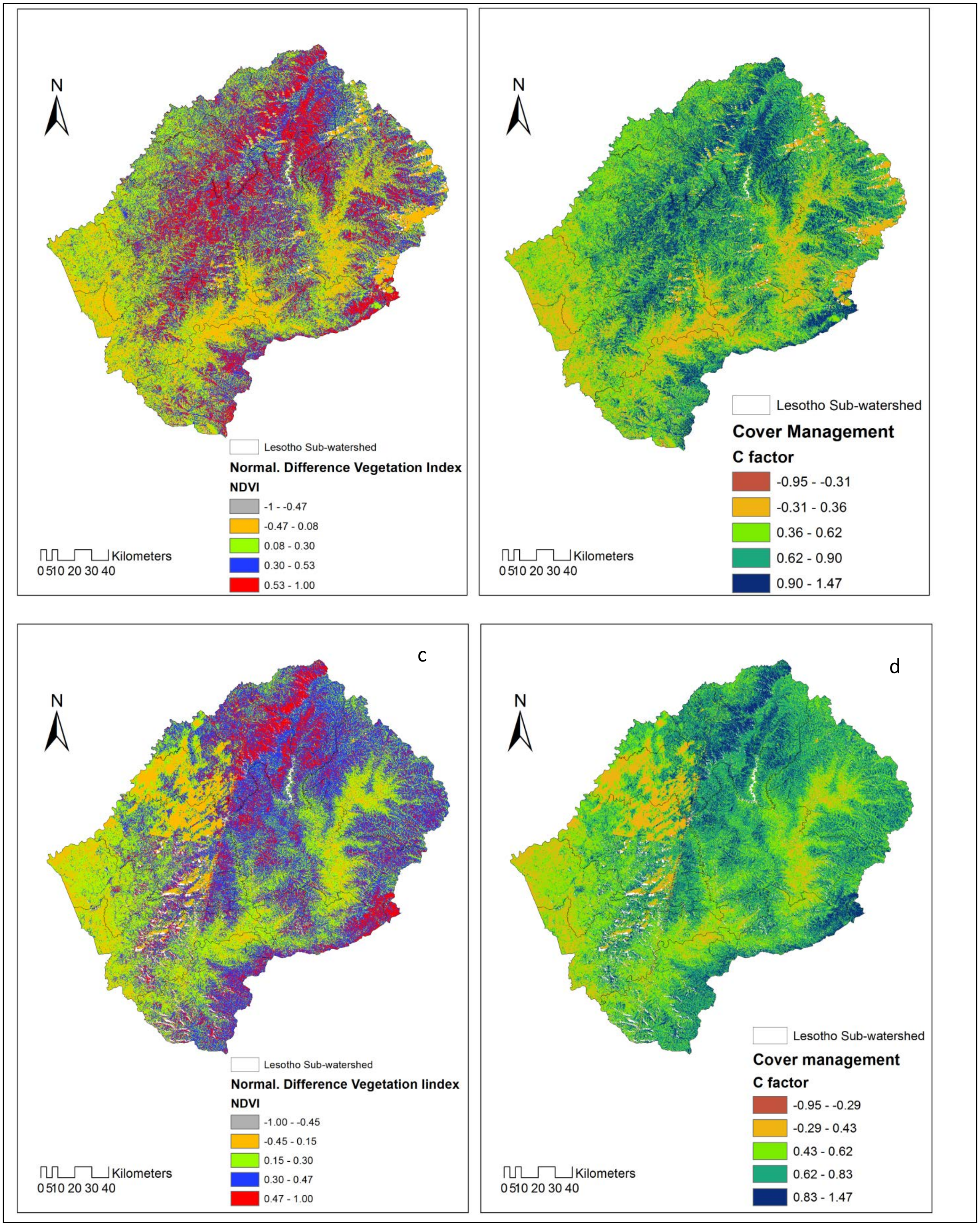


Figure 24: NDVI (a), (c): 1997 and 2009, Crop Management factor (b), (d): 1997 and 2009

5.5.5 Conservation practices factor (P factor)

Land use classification from ENVI software revealed six to seven classes over the years (1986, 1997 and 2009). The area of land use land cover changes over the years is summarized in the Table: 9 below.

Table 9: Percentage area changes of different Land use Classes between 1986, 1997 and 2009

Class Name	Land use land cover		Land use land cover		Land use land cover	
	%	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**
Rock outcrop	25.63	7780.00	38.40	11656.32	42.42	12876.59
Alpine grassland	57.76	17532.00	35.12	10660.68	47.97	14561.21
Cropland	10.64	3229.77	12.63	3833.84	1.79	543.35
Cropland harvested	2.75	864.76	10.01	3038.34	0.51	154.81
Water	1.40	424.97	0.11	33.39	0.77	233.74
Wetland / Marshy	1.8357	555.50	2.92	886.37	6.55	1988.25
Waste water	-		0.01	3.04	-	
Plantations	-		-		0.59	179.09

Table 9 gives the statistical percentage changes in land use over the three decades. The table shows that in 1986 there was more area under Alpine grassland 56.5% and subsequently became the highest value depicted for any land use class in the three year periods used in this study. The lowest recorded Alpine class was in 1997 with the percentage dropped to 35.12 % and 47.97% in 2009. The second class that accounted for the second highest values is the Rock outcrop class. From 1986 to 2009 there has been a steady increase for percentage area under rock outcrop witnessed by the increase in barrenness of land in Lesotho and the area increased from 24.37 % to 38.40 % and 42.42 % respectively, and the increase in rock outcrop can be linked with the decrease in Alpine grasses.

However the increase in Alpine grassland in 2009 can be subjected to the reduction in percentage area under cropland because bare land or rock outcrop is on its increase (see Figure 26). And the reduction in cropland can be linked to the current scenario of crop failure attributed to land degradation as people abandon their fields and are found in town looking for other sources of livelihoods. However there is an increase in area under wetland/ marshy and water for these periods and this could be related to the increased surface area under water due to LHWP and Lowland Water Projects (LWP).

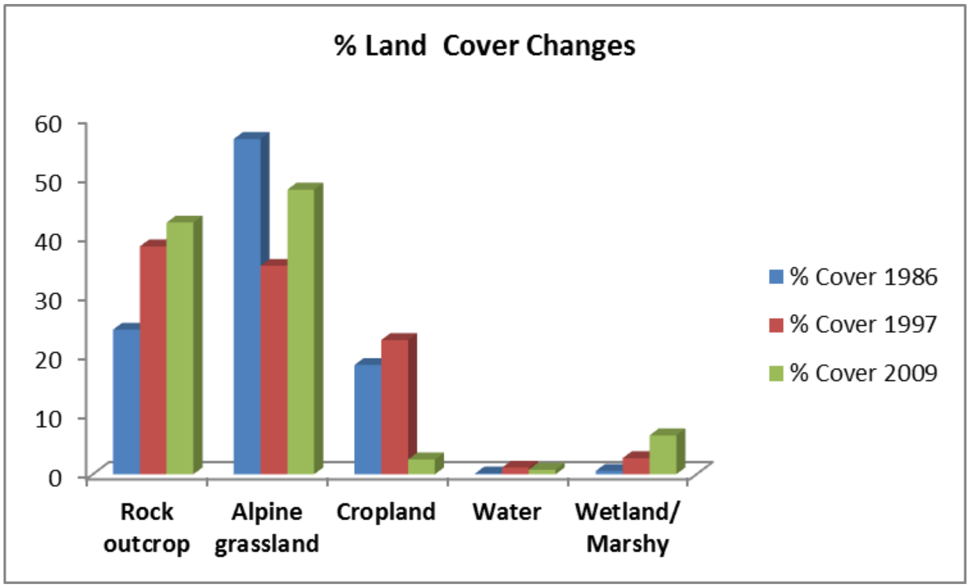


Figure 25: Percentage Cover Changes for 1986, 1997 and 2009

Figure 26 gives the result for the derived conservation practices for Lesotho for 1986, from the land classification map.

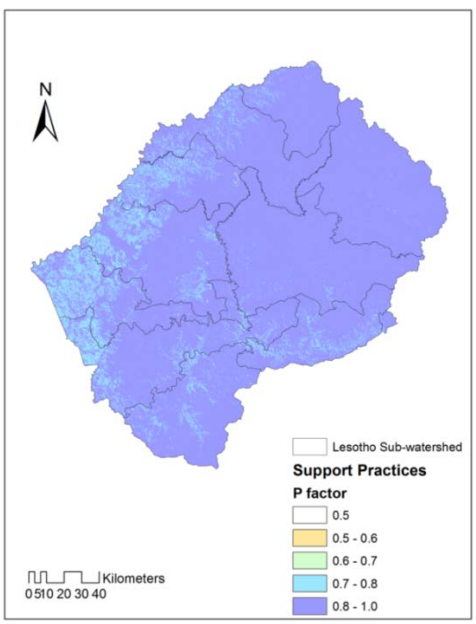


Figure 26: Conservation Practice factor Map 1986

Conservation practice factor reflects the ratio of soil loss under a specific conservation practice and soil loss under a convectional farming practice. When convectional farming practice is use, it leads to high soil loss whereby erosion rates increase with decrease in vegetation (Arghius and Arghius, 2011). The values of conservation practice factor ranges from 0 to 1, and 0 means high conservation while 1 implies that the area is least conserved. For the three year periods considered in this study, the conservation values ranges from either 0.7 to 0.8 or 0.8 to 1 which means that the area is subjected to less conservation activities or the conservation works are minimal; hence efforts cannot be depicted as yet.

5.6 SPATIAL AND TEMPORAL VARIATION SOIL LOSS

The output map of annual soil loss calculated from the RUSLE model were computed for the three year periods, 1986, 1997 and 2006. Where in these three years K and LS factor used were assumed to be constant variables and their changes can be explained. LS is derived from unchanging DEM, however, its changes can be attributed to change in resolution but for this study only 90 m x 90 m resolution was used and R, C, and P factors were derived for each year that for 1986, 1997 and 2006 due their spatial and temporal variability of the attributes that they are derive from. Figure 27 below shows how the RUSLE map of annual soil loss was computed in ArcGIS.

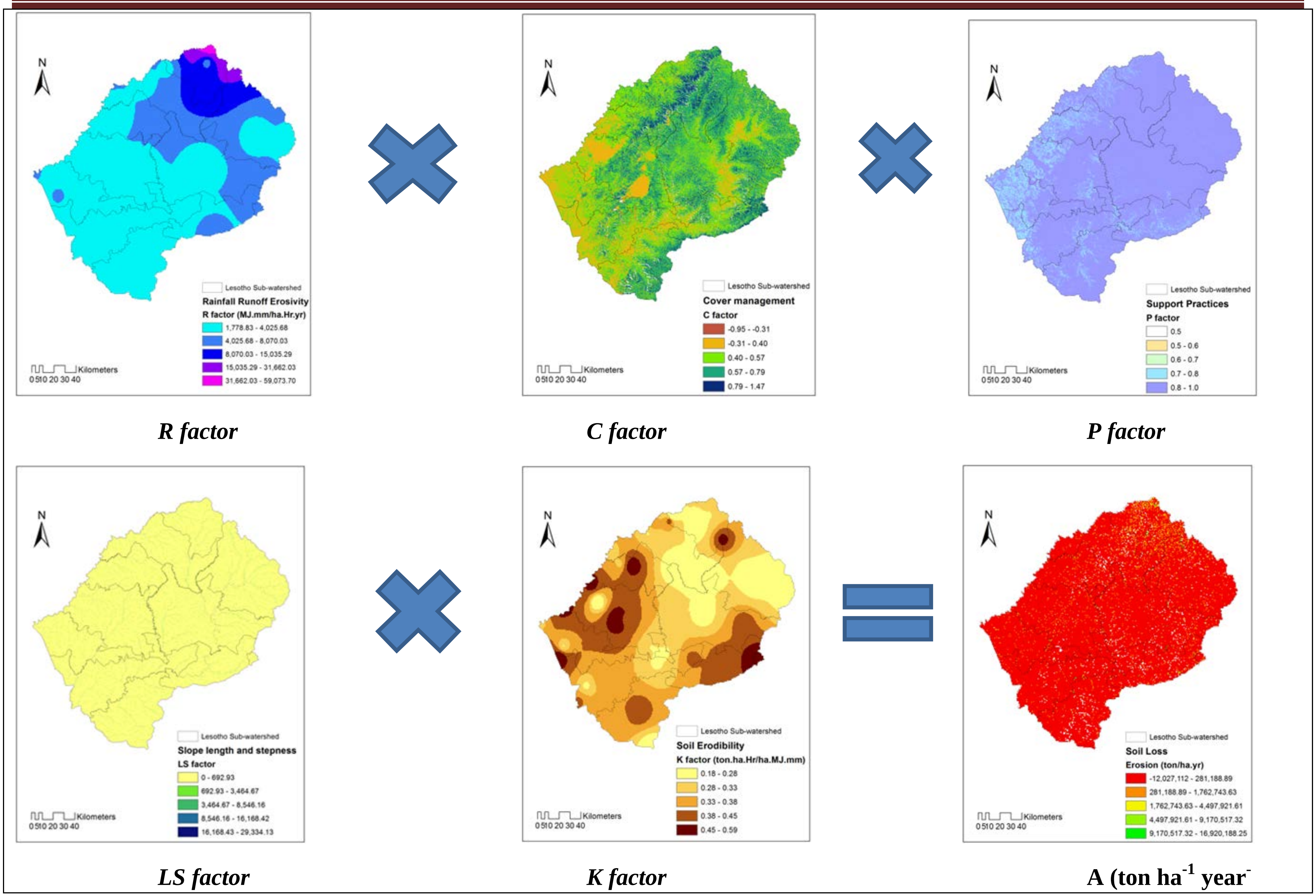


Figure 27: RUSLE equation maps to produce annual average soil loss

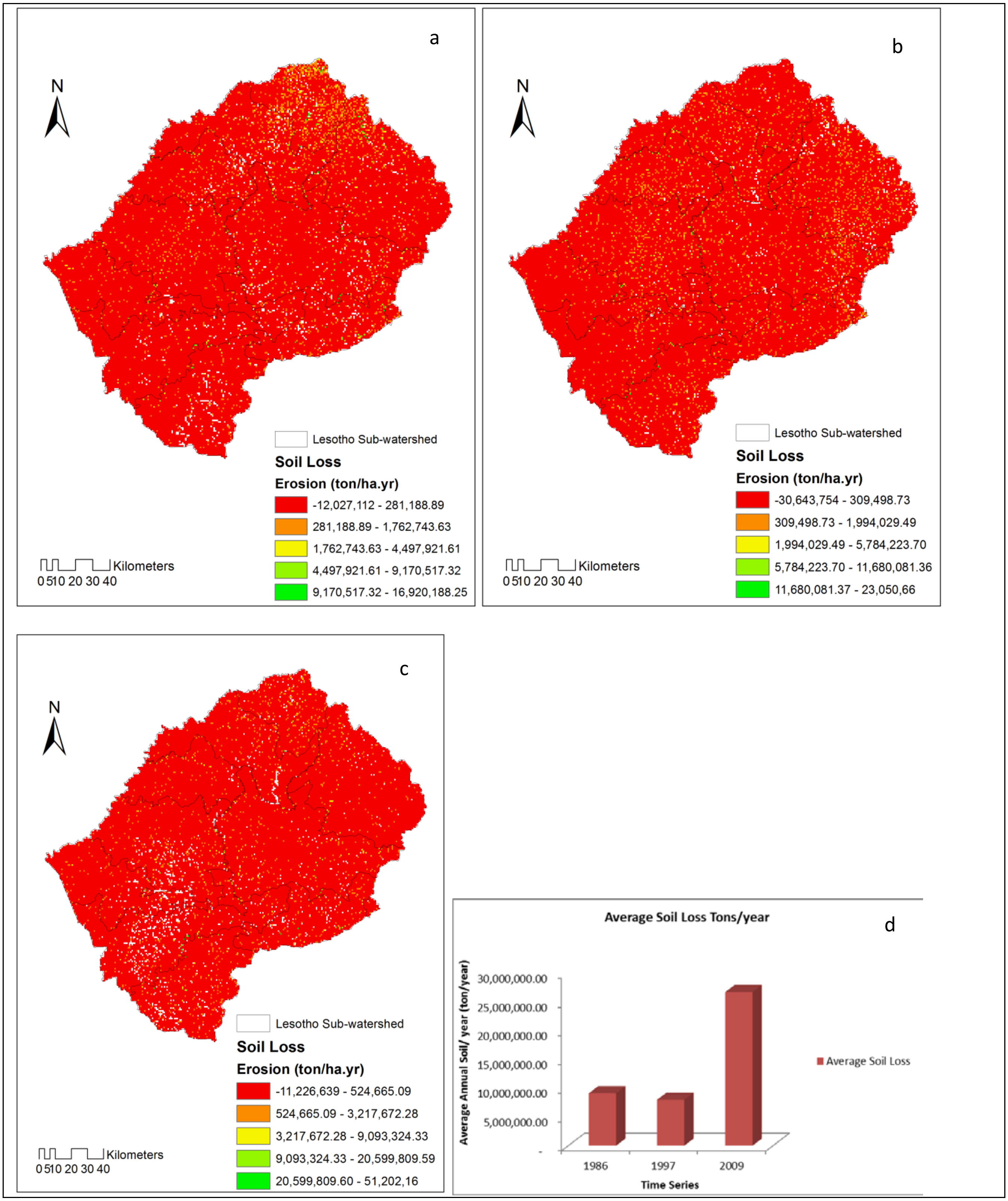


Figure 28: Annual Soil Loss Estimate for Lesotho (a), 1986; (b), 1997 and (c), 2009 and (d) Summarized Estimates for Lesotho

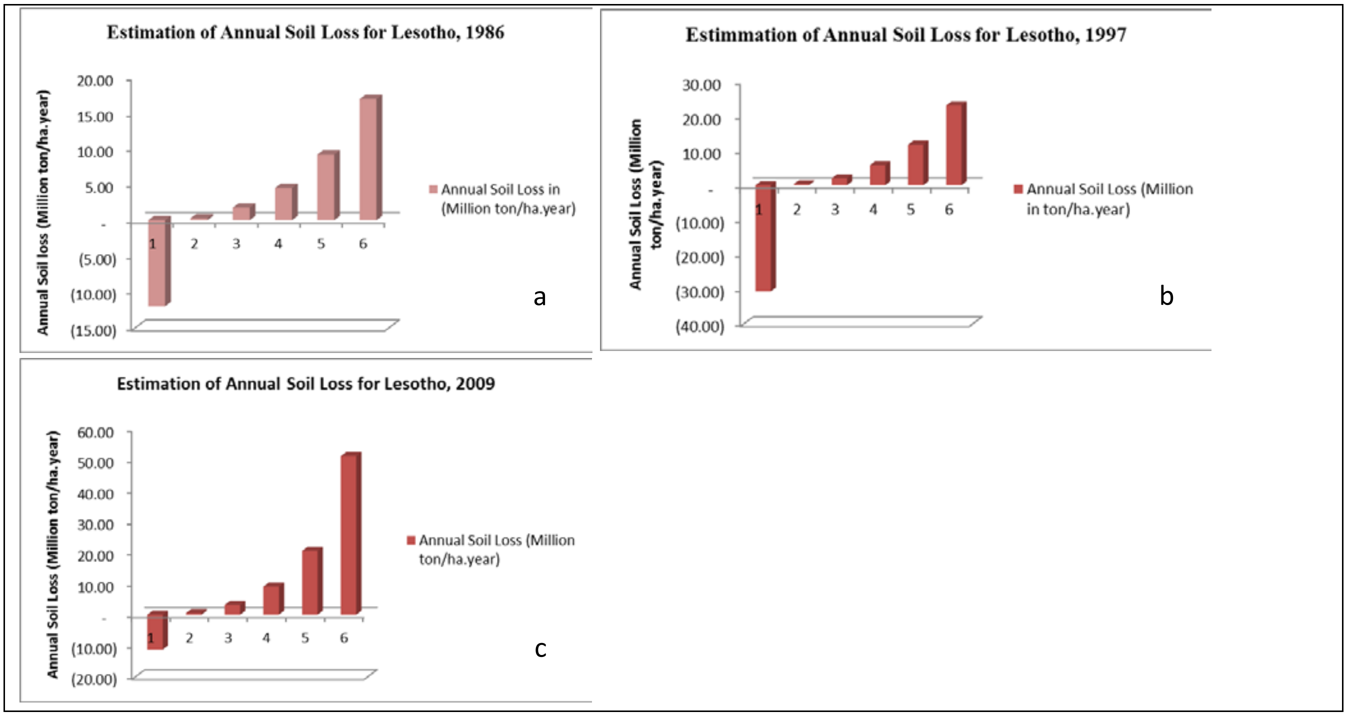


Figure 29: Estimation of Annual Soil for Lesotho, (a), 1986; (b), 1997 and (c), 2009

The results given by the RUSLE model for the three year periods (see Figure, 28 (a), (b) and(c)) predict the negative soil loss ranges and positive soil loss ranges. The negative soils can further be explained by two scenarios; 'half empty concept' and 'half full concept'. The 'half empty concept' scenario can be explained by conservative notion, that is the area is naturally retaining the soils hence less erosion is experienced. The second scenario the "half full concept" can be explained by credit cards notion which lead to extravagant spending beyond capacity or what is available, that is all the soils have been lost and the erosion has hit the bedrock. The positive soil loss on the other hand could imply that the areas are losing soil and that the erosion is still active.

The negative soil loss increased from -12,027,112.00 to -30,643,754.00 ton ha^{-1} $year^{-1}$ in 1986 and 1997 respectively (see Figure 29 (a) and (b)). This negative loss is related to 14% increase in area under rock outcrop in 1997. This implied that the areas are losing beyond their capacity, justified by the "half full notion", that could further be explained by the fact that the areas have hit the bedrock hence there is nothing else to be removed. This decrease in the amount of soil loss coupled with the increase in area under rock outcrop could be triangulated to be amongst the reasons that stimulated the intellectual of Lesotho from all walk of life to sit together and produce the book called "The State of Environment in Lesotho 1997 edited by Chakela, 1999".

From the graphs, it can be deduced that the negative soils losses magnitudes of 1997 doubles that of the 1986, however the positive soil loss magnitudes ranges for the two years bear the similar magnitudes and trends. While in 2009 (see Figure 29 (c)), there was decrease in negative soil loss which implies that the area during this period gained some soil depth and the positive means some areas are still losing soil. In addition, the positive soil losses of 2009 doubled that of 1997. The increase in positive soil loss in 2009 can be supported by the reduction in cropland area by 90%. Cropland areas are found within deeper soil, so indeed the trend of soil erosion in Lesotho is on the increase. Chakela (1981) reported that there is soil loss of 23 million ton per hectare per year where Schmitz and Rooyani, (1987) reported that 40 million ton per hectare is being lost per year. In 2009 the maximum soil loss predicted by the RUSLE model is over 50 million tons per hectare per year the Table 10 gives the average soil losses for the three years.

Table 10: Predicted RUSLE Soil Loss for 1986, 1997 and 2009.

YEAR	1986	1997	2009
RUSLE Average Soil loss (ton ha^{-1} yr^{-1})	9,079,499.29	7,785,643.78	26,711,616.90

Most erosion was experienced in the mountain areas and the southern lowlands districts. The erosion in the mountains could be linked to topography and the high rainfall the area experiences plus lowering of rainfall erosivity. In 1997 high negative soil loss range was experienced which lowered the average soil loss to 7,985,616.78 ton ha-^{1} year^{-1} from 9,079,499.29 ton ha^{-1} year^{-1} (see Table 10).

In 2009, (see Figure 28 (d)) an increase in soil erosion of about three times as that of 1997 was experienced, mostly in the southern lowlands figure 29 (b) and could be linked to the 90% reduction in cropland as due the current scenario of crop failure fields which are abundant. Croplands are found in deep soils of duplex soil types. The soils in this region has the composition of sandy soils (Sephula series), consists of Maseru series clay-pan and Lithosols on sedimentary rock on lava which is rich in ferromagnesian minerals. And this soil structure exhibits poor drainage between soil strata (Schmitz and Rooyani, 1987; Makara, 2001; Loock, 2011). Due to the difference in texture between the strata of duplex soils there is uneven infiltration, rapid in the upper strata and the low infiltration in lower strata, hence the bottom strata exhibit low permeability which leads to the upper strata to be more saturated with water. Therefore sodium and dispersed clay particles become active forming a clayey medium prevents vertical movement of water and therefore the only available space for water to through cracks hence the U-shaped gullies experienced in the area which justifies the high soil loss in the area (Rooyani and Badamchai, 1986).

Over and above there is an existence of salt concretion due to the fluctuating water table which distracts the soil structure which reduces the medium capacity of plant growth (Makara 2001). Hence the area has sparsely vegetation which makes the area more prone to cracks, with high erodibility soil the latter becomes gullies then dongas.

5.7 RELATIONSHIP BETWEEN OBSERVED SEDIMENTS AND RUSLE ESTIMATED SEDIMENTS

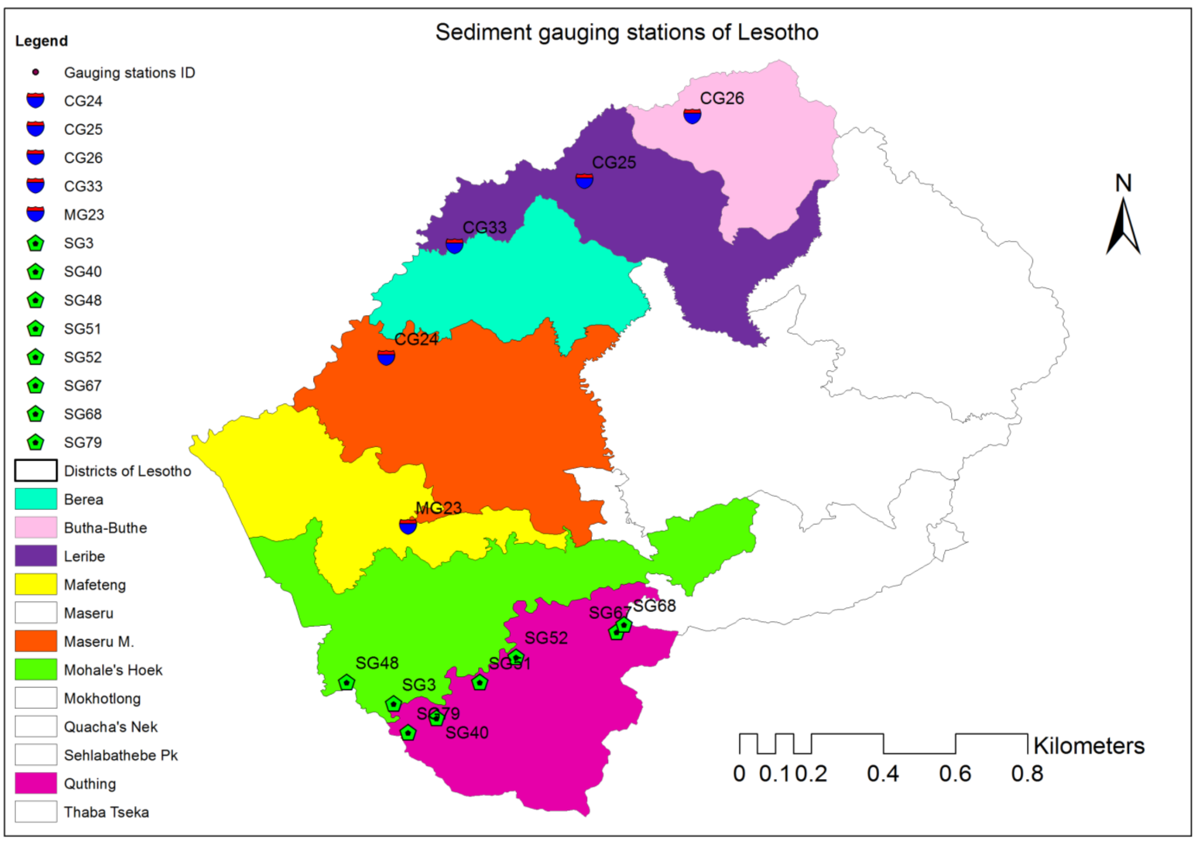


Figure 30: Hydrometric Station Area Influence

In order to establish whether there is a relationship between RUSLE results and observed sediment loads, a correlation between and amongst rivers that take sediment out of Lesotho was done, where the result showed that there is a positive correlation (see Figure 30).Furthermore RUSLE model results were performed for the whole Lesotho as opposed to the observed measured sediments which were taken in terminal stations of major rivers and tributaries of rivers that take sediments out of Lesotho. Therefore to establish the relationship between the model results and observed results, some assumptions were made that each station has an area of influence because the amount of sediment measure whichever outlet articulates its areas' carrying capacity. Figure 30 shows that two-thirds of the area in Lesotho is under the influence of these gauging stations. And the total area under influence by these gauging stations was in square kilometers. Then the area was converted into hectares so as to make a comparative analysis between the attributes since the model was in hectares as well. Because the area was already computed as total area, to avoid over estimation of sediments the sediments yields were expressed as average sediments.

Then sediments from the RUSLE were extracted to be compared through correlation analysis with the actual yields. However RUSLE values are not periodic but absolute therefore there was need to correlate the observed yields (as shown in figure 31) with the respective actual yields for temporal years that the RUSLE was performed for which were 1986 1997 and 2009.

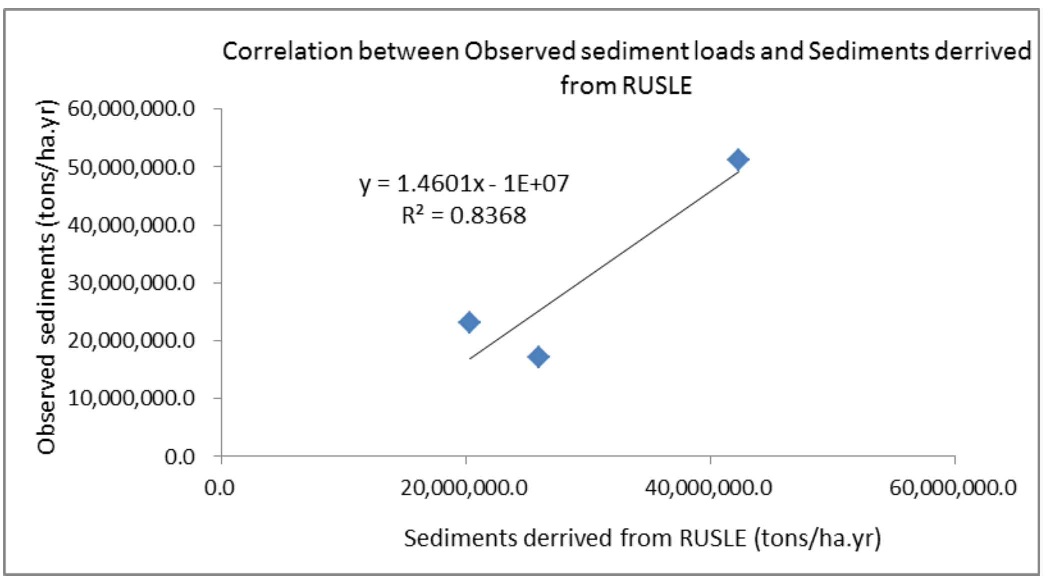


Figure 31: Correlation between Observed Sediment Yield and Derived Sediment fro RUSLE

The results show a strong positive relationship (R^2 = 0.8368), which means that the RUSLE results and observed results are strongly correlated.

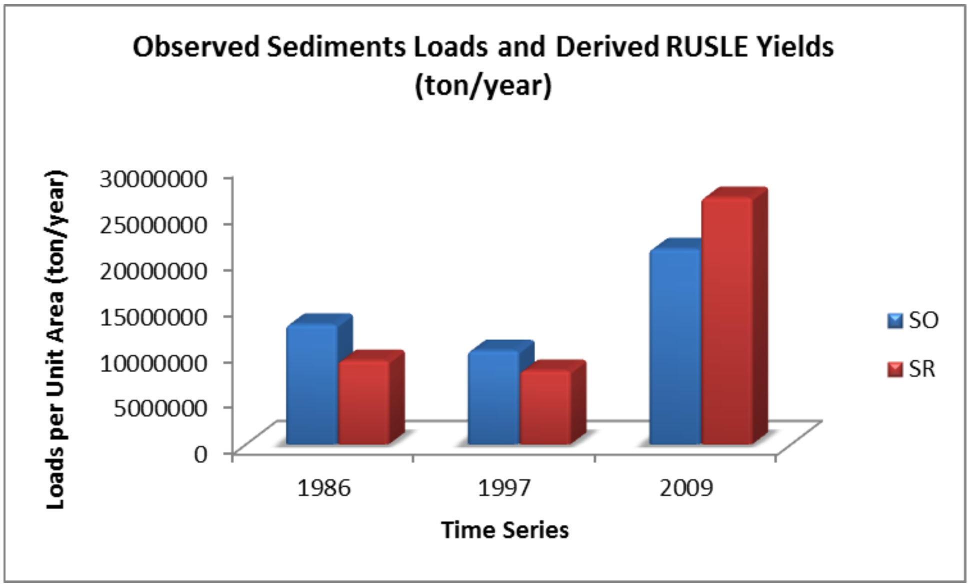


Figure 32: Observed sediments and Derives Sediment for three years for Lesotho

The results for the three years: 1986, 1997 and 2009 for both observed sediments and RUSLE model show fluctuating trend in average sediments. An average of **9,079,499.29** ton ha^{-1} year^{-1} was predicted to be lost in 1986, **7,785,643.78** ton ha^{-1} year^{-1} in 1997 and **26,711,616.90** ton ha^{-1} year^{-1} was predicted to be lost during the year 2009 by RUSLE model. And the observed sediments show a similar trend as the RUSLE model that there was decrease in trend between 1986 and 1997 from **25,955.810.7** to **20,297,938.5** ton ha^{-1} year^{-1}. However an increase was observed in the rates of 1997 and 2009 from **20,297,938.5** to **42,303,608.7** ton/year see Figure 32. Moreover the results derived from either RUSLE or observed gives similar values and the difference between the values are insignificant. Both methods results show that Lesotho is losing its soil if the simulated values are so similar to the observed values, hence a call for massive rehabilitation programmes.

5.7 IDENTIFIED CRITICAL AREAS/ HOTSPOTS FOR MANAGEMENT

The identified critical areas or hotspots for management for this study are divided into three classes. The first class represents areas where erosion is still active (active gullies and dongas), class two represents areas where erosion is managed or minimal and class three represent areas where areas that is barren, bare or rock outcrop. In this study Class 1 is where erosion still active falls within north-eastern highland and parts of Mohokare (Caledon) catchment. These area are mostly comprised by areas where soil are developed or deep, and the southern lowlands is comprised with piping duplex soils which makes the area more susceptible to soil erosion. Or the area is found within north-eastern highlands where there are shallow soils and steep slopes coupled with lowering of rain erosivity hence the negatives soil loss values further explained by the ‘half full” scenario. This makes the area the mostly critical or vulnerable to soil erosion hence becomes a hotspot for management as in Figure 33 represented by brown colour mostly areas in Mokhotlong and Senqu River Valley.

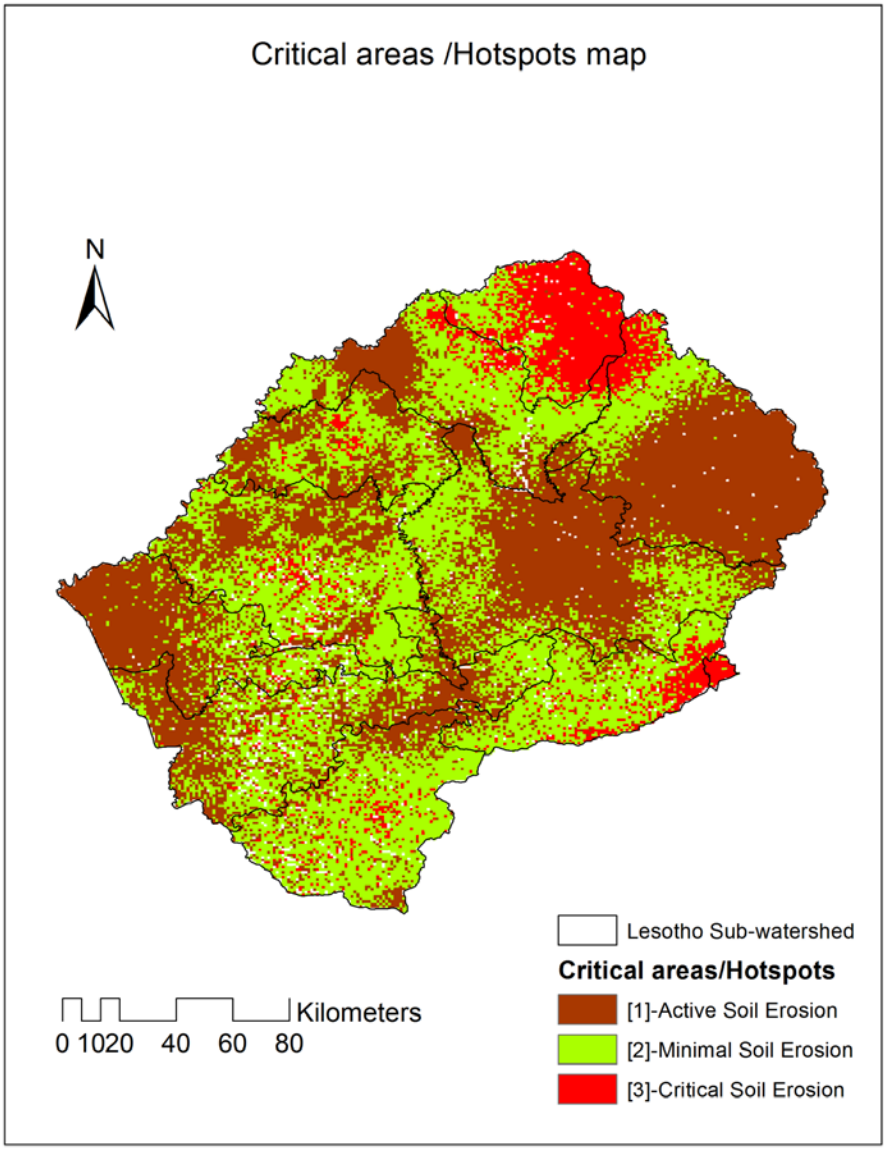


*Figure 33: **Critical areas/ Hotspots***

Class 2 present areas where erosion cases are minimal or erosion is well curbed by the present management practices or the nature of the area. Generally where the areas are flat, erosion levels are also minimal which makes part of the northern lowlands areas except where the soils experiences high erodibility naturally. Three quarter of Lesotho is rangelands, covered by grasses. Within mountain ranges where areas are still left in their natural states even with steep topography the areas experiences less soil erosion, Lejone-Katse, Sehlabathebe, Tšehlanyane reveal the beauty of the Mountain Kingdom. However areas like Sani-Pass, Mahlasela-Moteete are heavily overgrazed.

Class 3 represent areas of rock outcrop or barren, and these areas in Lesotho falls within areas which receives high rainfall in steep terrain couple with lowering of required energy to effect erosion. These places falls within Oxbow and Qacha's Nek and there areas enjoyed the ocean current stimulated precipitation and with low vegetation cover the areas becomes even more prone to erosion.

All these three classes require different management practices in order to curb the rate of soil erosion in Lesotho. The management practices are presented in the recommended management plan below.

5.8 CONCLUSION FROM THE FINDINGS

The relationship between flow and sediments reveals a very significant difference (P = 0.00) for the three river that takes water out of Lesotho; Mohokare, Makhaleng and Senqu River. However Mohokare a weakly correlated (R^2 = 0.44) while Makhaleng and Mohokare displayed a strong correlation (R^2 > 0-75) between average annual flow and average annual sediment loads. The finding provided by both the observed and the validation model (RUSLE) a strong correlation (R^2 = 0.875) between the sediments load and the predicted sediment, therefore any gap can be filled using either methods. There is indeed tremendous soil erosion in Lesotho and the trends are not yet curbed. The study identified three classes of critical areas/ hotspots for future management.

Chapter 6 CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

The Study whose objective was to assess the spatial and temporal soil loss in and out of Lesotho revealed that there is a tremendous soil loss in and out of Lesotho. The revealed trend, relationships and validations results provided evidence of spatial and temporal variations of soil loss in and out of Lesotho. Key findings for this study and recommendations drawn from the findings are presented in this chapter. The proposed management plan is also included in this chapter.

6.2 KEY FINDINGS FROM THIS RESEARCH

The spatial trends found from this study indicated that soil erosion is still on the increase, some parts of Lesotho are predicted by the RUSLE model to losing 51 million tons/ha/year. This finding is in line with the one by Schmitz and Rooyani (1987) reported 40 million tons/ha/year and Chakela (1981) reported losses of 23 million ton/ha/year. And both the trends from observed and simulated indicated fluctuations in the amount and rate of soil loss and the magnitudes are not as steep as between 1986 and 1997.

1. The study identified the following areas Southern lowlands, North Eastern Highland, and Mohokare catchment to be critical/hot spots for soil loss which required monitoring. The north-eastern lowland is critical since it has low erodibility, high LS factor and low cover management factor.
2. There is tremendous soil loss in Lesotho both spatially and temporally. The results show that a total of 427.2 x 10^6 tons for 30 years has been conveyed out of Lesotho for the period of year 30 years which amounted to 14 x 10^6 ton/ year through the major rivers out of Lesotho of which Mohokare contributes over 70% to the total sediment loss.
3. There is a direct relationship within and amongst rivers that drain water out of Lesotho. The higher the flow, the more the sediment loads taken out of Lesotho. These have led to reduction in soil loss from 1980 to 2009. This was also depicted by RUSLE model where the values ranges from negative to positive, furthermore, the study discovered that the correlation between the RUSLE results and the observed sediment loads is positive (i.e. R^2 = 0.875).

6.3 RECOMMENDATIONS

To curb the tremendous soil loss trend and magnitudes, findings from this thesis can be used to inform current and future plans and policies especially within the identified critical area or hotspots for management. These therefore call for immediate catchment transects rehabilitation, where the responsible agencies should be given adequate resources to bring down the rates of soil erosion. It has been the norm that when land deteriorates that it is either abandoned or seized from the people who are the key players for good or bad management. Therefore the management plan suggested by this study should be availed and utilized by the authorities (see Table 11 for the management plan).

Further studies should be carried out in the ungauged catchments in order to quantity the total amount of soil loss as these rivers falls within the high soil erodibility areas. Furthermore this study used remotely sensed data for LS factor therefore further studies should integrate both the remotely sensed data and ground data, especially on the determination of LS factor. The study also proposes use of DEM as a method to quantify the amount of soil loss in order for the two methods (i.e. RUSLE and observed data sets) used in this study to validate the results.

Table 11: Management Plan for Critical Areas/ Hotpots for Lesotho

CLASS DESCREIPTION	ECOLOGICAL ZONE	MEASURES	RESOURCES	TIME-FRAME	KEY PLAYER	RESPONSIBILITY
Class 3 Rock outcrop/ bare areas	Highlands	- Outreach - Set protection plans with the people - Contour stone-line silt traps - Outreach - Grass-seeding - Road furrow maintenance - Wetlands/ marshy land rehabilitation - Outreach	o Skill7 o Expertise o Budget o Material o Research	Short to Long Term	Local Govnt. MFLR, MET, DWF	MET, Local Government
					Local Government & operation ministries	Local Government
					Local Govnt. Public responsible Department	MFLR
					Departments of Roads and Local Govnt.	Local Govnt
					LHDA, DWF, MFLR, MET Local Government	MFLR
	Foothills	- Outreach - Plan - Grass seeding - Tree planting - Protection plan - Outreach - Contour silt	o Skill o Infrastructure o Machinery o Participation	Short to Long Term	LHDA, DWF, MFLR, MET Local Government	MFLR

		traps - Terracing - Storm drains maintenance				
	Lowlands	- Outreach - Protection plan with the people - Tree planting - Outreach - Water harvesting - Diversion Furrows - Terraces maintenance - Fallow/ rotation farming - Silt trap earth dams	o Skill o Expertise o Participation o Machinery o Infrastructure	Short to Long Term	LHDA, DWF, MFLR, MET Local Government	MFLR
Class 1 Active soil erosion	Lowlands	- Outreach - River Bank protection - Storm drainage maintenance - Gully structure construction - Vegetative protection - Constructive protection, gabions - Silt trap dams along the river - EIA's	o Infrastructure (gauge more river networks); southern lowlands o Expertise o Skill o Machinery o Participation o Research	Immediate, to long term	Integration of all stakeholder Participation	Central and Local Govnt.

		enforcement - Research for possible				
	Foothill	- Marginal land cultivation - Plantation	o Skill o Participation o Research	Proper site & species selection	LHDA. LWP, Local Govnt, stakeholders	MFLA
	Highlands	- Silt traps and contour stone-line protection - Fallowing (*Maboella)* - Rotational livestock grazing - Removal of invasive shrubs - Stakeholder participation & - Indigenization - Buttering promotion	o Participation o Enforcement o Skill o Finance o Research	Short to Lon Term	Integrated resources managemen t.	Central Govnt & Local Govnt.
Class 2 Minimal soil erosion	Highlands and Foothills	- Communal grazing frees enforced - Promotion of Stall feeding - Outreach - Rotational grazing management - Promotion of	o Budget o Participation	Short to Medium Term	Integrated Stakeholder Participatio n	Central and local Govnt.

		user associations • Promotion of incentives • Competitions with worthy prices • Exchange visits				
	Lowlands	• Maintenance field grass strips and contour cultivation • Maintenance of diversion Promotion of grain exchanger and buttering	o Participation o Budget o Expertise o Infrastructure (storage facilities)	Short to Long Term	MTMD, Planning, Private Sector	Central Govnt

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APPENDICES

APPENDIX 1: RUSLE Annual Soil Rate in ton per Unit Area for 2009

Regression Mohokare River

Model Summary[b]

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.665[a]	.443	.421	28628.5863	.443	20.645	1	26	.000

a. Predictors: (Constant), CG_ Flow(m3/s)

b. Dependent Variable: CG_Sed (tons/yr)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.692E10	1	1.692E10	20.645	.000[a]
	Residual	2.131E10	26	8.196E8		
	Total	3.823E10	27			

a. Predictors: (Constant), CG_ Flow(m3/s)

b. Dependent Variable: CG_Sed (tons/yr)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-20781.641	12613.278		-1.648	.111
	CG_ Flow(m3/s)	134.988	29.709	.665	4.544	.000

a. Dependent Variable: CG_Sed (tons/yr)

Regression_Makhaleng Rriver (MG23)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.926[a]	.858	.853	20059.0765	.858	174.968	1	29	.000

a. Predictors: (Constant), MG23_Flow(m3/s)

b. Dependent Variable: MG23_Sed(tons/yr)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.040E10	1	7.040E10	174.968	.000[a]
	Residual	1.167E10	29	4.024E8		
	Total	8.207E10	30			

a. Predictors: (Constant), MG23_Flow(m3/s)

b. Dependent Variable: MG23_Sed(tons/yr)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-38241.940	6669.202		-5.734	.000
	MG23_Flow(m3/s)	201.288	15.217	.926	13.228	.000

a. Dependent Variable: MG23_Sed(tons/yr)

Regression_Senqu river

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.868[a]	.754	.746	108429.7874	.754	94.910	1	31	.000

a. Predictors: (Constant), SG03_Sed(tons/yr)

ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.

1	Regression	1.116E12	1	1.116E12	94.910	.000[a]
	Residual	3.645E11	31	1.176E10		
	Total	1.480E12	32			

a. Predictors: (Constant), SG03_Sed(tons/yr)

b. Dependent Variable: SG03_Sed(tons/yr)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-151549.692	42878.116		-3.534	.001
	SG03_Sed(tons/yr)	121.496	12.471	.868	9.742	.000

a. Dependent Variable: SG03_Sed(tons/yr)