University of Nairobi

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USE OF GEOSPATIAL TECHNIQUES IN MODELLING LAND DEGRADATION

CASE STUDY OF KENYA'S LAKE VICTORIA BASIN

BY

SIRO ALI ABDALLAH

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Declaration

I, Siro Ali Abdallah hereby declare that this project paper is my original work. To the best of my knowledge, the work presented here has not been presented for a proposal in any other university.

Signature ……………………………… Date ………………

Siro Ali Abdallah
Reg. No: F56/74950/2014

This project paper has been submitted with my approval as the university supervisor.

Signature: ………………………… Date ………………

Mrs. Tabitha Mukami Njoroge
Lecturer
Department of Geospatial and Space Technology
University of Nairobi

Abstract

The Lake Victoria Basin is facing major ecological challenges that have caused considerable hardship for the population depending on it for their livelihoods and have also reduced the biodiversity of the lake's flora and fauna. According to ICRAF (2000), more than 80% of the population in the basin is engaged in agricultural production. Deforestation coupled with bad agricultural practices has persistently exacerbated the problem of land degradation in the basin and sedimentation in the lake. As a result, land degradation in prime agricultural areas within the catchments has been attributed to food productivity losses. Assessment on land degradation hazard is therefore deemed essential for soil conservation plans in the basin for sustainable development.

The objective of this study was to identify and map the extent and severity levels of land degradation caused as a result of soil erosion by water in the entire Lake Victoria basin (LVB) in order to support informed decisions for prioritizing and combating land degradation menace in the basin. This study achieved this by fusing geospatial techniques and empirical soil erosion modelling techniques mainly the Revised Universal Soil Loss Equation (RUSLE) Model that looked at five key soil erosion control parameters: vegetation cover, rainfall erosivity, slope factor, soil erodibility and population density data as input variables. The results from modelling were subjected to field assessment in one of the identified hot spots in Bolo area in Kisumu County to gather prove of existence of land degradation hazard.

The output of this study was a land degradation index map which was categorised into five quantile of land degradation severity that is: very low, low, medium, high and very high. This made it easy to visualise major land degradation hot spots which were defined by the very high class as well as overall spatial variability of land degradation severities in the basin's context. The finding from analysis of results reviled that majority of the basin is experiencing moderate soil erosion but this is shifting towards high.

Major erosion hotspots were found to be areas surrounding the lake namely: areas around Mumias, Bunyore, Kisumu, Kendu Bay, Ahero and south western parts of Homa Bay. The study further noted that the areas experiencing very low degradation were forested areas in the northern parts and towards the eastern sides of the basin. These are areas occupied by the Mount Elgon forests, Kapsabet forest and parts of the Mau forests in Kericho all of which are reserved natural forests.

This study revealed that the lead contributing factor to soil erosion in the basin and around the identified hotspots was soil erodibility component followed by rainfall erosivity, vegetation cover management, population density and finally slope factor. This contradicted with soil experts rating which ranked slope factor as the main contributor, followed by vegetation cover, soil erodibility, rainfall erosivity and finally population density. Low gravel content of less than 1% was found to influence highly the soil erodibility component as the soils are exposed to easy detachment. High rainfall intensity and depth in the hotspots areas was also a major factor to soil erosion. The other contributing factors were found to be unsustainable agricultural practice in the basin which continually disturbed vegetation cover exposing the top soils to erosion agents.

In conclusion this study acknowledges that the use of the empirical model (Revised Universal Soil Loss Equation model) for assessing soil erosion by surface runoff and its integration with GIS tools proved useful and effective in assessing land degradation in the entire Lake Victoria basin and in achieving the study's objectives. The study recommends comprehensive catchment level degradation assessment to be undertaken and prioritise the most affected / hotspot areas (Mumias, Bunyore, Kisumu, Kendu Bay, Ahero and south western parts of Homa Bay). The study further recommends capacity building of different stakeholders involved in land reclamation and management activities in the basin.

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List of Abbreviations

AHP – Analytical Hierarchical Process
CHIRPS – Climate Hazard Group Infrared Precipitation and Station
CHIRPS – Climate Hazard Group Infrared Precipitation and Station
DEM – Digital Elevation Model
EPIC – Erosion Prediction Impact Calculator
ESRI – Environmental Systems Research Institute
EUROSEM – European Soil Erosion Model
FAO – Food and Agriculture Organisation
FEWSNET – Famine and Early Warning System Network
GIS – Geographic Information System
GOK – Government of Kenya
HWSD – Harmonised World Soil Database
ICPAC – Intergovernmental Climate Prediction and Application Centre
ICRAF – International Consortium for Research and Agroforestry
IPCC - Intergovernmental Panel on Climate Change
KENSOTER – Kenya Soil and Terrain
LD – Land Degradation
LDIM – Land Degradation Index Map
LS – Slope Factor
LULC – Land Use Land Cover
LULC – Land Use Land Cover
LVB – Lake Victoria Basin
LVBC – Lake Victoria Basin Commission
LVEMP – Lake Victoria Environmental Management Program
MOEWN – Ministry of Environment Water and Natural Resource
NALEP – National Agriculture and Livestock Extension Program

NDVI – Normal

NDVI - Normalized Difference Vegetation Index

NPP – Net Primary Productivity

RCMRD – Regional Centre for Mapping of Resources for Development

RD – Rainfall Depth

RE – Rainfall Erosivity

RI – Rainfall Intensity

RS – Remote Sensing

RUSLE – Revised Universal Soil Loss Equation

SE – Soil Erodibility

SLEEK – System for Land Emission Estimation in Kenya

SRTM – Shuttle Radar Topographic Mission

UNEP – United Nations Environmental Program

UNESCO - United Nations Educational, Scientific and Cultural Organization

USGS – United States Geological Survey

USLE – Universal Soil Loss Equation

WEPP – Water Erosion Prediction Calculator

WLC – Weighted Linear Combination

CHAPTER 1: INTRODUCTION

1.1 Background

Land degradation is an enormous environmental challenge, in Africa it is estimated that the annual decrease in productivity due to soil erosion is at 2-40% with an average of 8.2% for the whole continent and also, an average of 19% of reservoir storage volumes being silted (Anderson, 2010). In Kenya, land degradation is widespread and affects millions of people who also experience poverty and repeated natural disasters especially drought and floods. Climate variations, whether natural or anthropogenic in origin, aggravate the resilience of varied ecosystems and the sustainability of livelihoods in these zones. Weak knowledge of the nature, extent and severity of land degradation, and the inadequacy of tools and methods for assessment and monitoring of this phenomenon hamper the adoption of integrated resources use and management policies and rehabilitation programs according to (UNEP, 2002).

Based on assessment by (Bai, et al., 2008), the immediate causes of land degradation are inappropriate land use, erosion of soil, water and vegetation cover and loss of both soil and vegetative biological diversity, affecting ecosystem structure and functions. Intensive forms of land use, including over-grazing, excessive irrigation, and intensive tillage and cropping have been among some of the other causes attributed to this phenomenon by (IPCC, 2001). The primary driving forces of land degradation are policy and institutional distortions or failures in the public or government, private or market, civil or community sectors, as well as civil strife. (Blaike and Brookfield, 1987) believes that the nature of interrelationships and thresholds between these technical, institutional and policy factors at different levels and scales and in their temporal dimensions are poorly understood.

Studies in 1997 by (Olderman et al., 1997) showed that 64 per cent of Kenya's land area was potentially subject to moderate desertification and about 23 per cent was vulnerable to severe to very severe desertification. The study by (Bai and others, 2008) also identified degradation as a potential precursor to widespread desertification. In the early 2000s, approximately 30 per cent of Kenya was affected by very severe to severe land degradation and an estimated 12 million people, or a third of the Kenya's population, depended directly on land that is being degraded. (GoK, 2002) noted that the droughts of 1970-2000 accelerated soil degradation and reduced per-capita food production.

More recent studies extrapolating on local findings of spatial and temporal patterns of land degradation estimate it is increasing in severity and extent in many areas. Studies by (Muchena, 2008) indicate that over 20 per cent of all cultivated areas, 30 per cent of forests, and 10 per cent of grasslands have been subjected to degradation. The expansion of cropping into marginal lands accounts for much of this degradation.

Studies by (Bai and Dent, 2006) identified the dry lands around Lake Turkana and marginal cropland in the Lake Victoria basin region as the areas of sharpest decline. One measure of land degradation is the loss of net primary productivity (NPP), although such losses do not always indicate land degradation, these losses also result in costs related to changes in rural society due to processes such as migration and associated loss of human capital and break up of communities, social costs of poverty and reduced ability to invest in anti-degradation activities.

The increasing demands on land from economic development, expanding cities and growing rural populations are therefore driving unprecedented land use changes and in turn, unsustainable land use change is driving land degradation. Though this is a global development and environmental issue, there have not been serious authoritative measures of land degradation or land improvement in the Lake Victoria basin.

There is therefore the pressing need for basin level land degradation assessment to support policy informed decisions for development of food and water security strategies, environmental integrity and subnational as well as national strategies for economic development and resource conservation.

1.2 Problem Statement

The undermining of the integrity of the ecosystem coupled with poor farming practices have led to persistently growing land degradation in Lake Victoria basin, (UNESCO, 2006) attributes 45 percent of the lake basin to being prone to water erosion leading to soils being deposited in Lake Victoria and mouths of rivers line Nzoia. In supporting this assertion, (WAC, 2008) notes that since 1963, 3.2 million tons of soil (or the equivalent to one million truckloads) have been washed into Lake Victoria. According to (MoEWN , 2014), while inaugurating the Lake Victoria Basin Commission (LVBC) in Kisumu on June 11th, 2007, President Mwai Kibaki, summarized the situation of Lake Victoria basin as follows:

"Regrettably, Lake Victoria and its basin are today seriously threatened due to receding water levels, high land degradation and pollution rates and a growing decline in the health of its ecosystems. As a result, the livelihoods and well-being of over 30 million people who live around its basin are at risk. It is imperative that we act urgently and decisively to halt further decline of the lake and the surrounding environment."

The need to quantify the amount of erosion in a spatially distributed form has become essential at the basin scale and in the implementation of conservation efforts (Fernandez et.al, 2003). In many situations, land managers and policy makers are more interested in the spatial distribution of soil erosion risk than in absolute values of soil erosion loss (Lu et.al, 2004).This study thus tries to answer the problem by assessing and mapping land degradation severity levels in the Lake Victoria Basin using geospatial techniques that will lead to production of land degradation severity maps. It is envisaged that putting land degradation in the spatial context will form basis for decision and policy support in managing the hazard in the basin.

1.3 Objectives

The general objective of this project is to model land degradation by assessing soil erosion by surface runoff in the entire Lake Victoria basin.

The specific objectives are:

i. To map the geographical variation of land degradation severity at the Lake Victoria basin.
ii. To establish the contributing factors to land degradation in the basin
iii. To identity and recommend land degradation hotspots for further assessment at sub basin level.

1.4 Justification for the Study

Despite the fact that most studies in the region point at alarming status of land degradation (LD) in the Lake Victoria basin, this study has noted that very little and /or insignificant land degradation assessment and mapping efforts have been carried out to identify key intervention areas in the basin. The study has also learned that the methods used to derive land degradation indices in the region have leaned towards assessing only sedimentation which in essence is a week analogy to assessing LD. With this shortcoming in mind, this study purposes to utilise approved empirical methods of estimating LD that will fuse multiple critical indicators in a GIS modelling environment in order to assess and map land degradation severity in the entire basin at finer spatial scale. It is envisaged that this approach will result to finer resolution land degradation index maps covering the entire basin.

1.5 Scope of work

The scope of this project is to identify and map the extent and severity levels of land degradation by assessing soil erosion hotspots as a result of surface runoff in order to support informed decisions for combating land degradation in LVB. The study utilised the following variables: vegetation cover; rainfall erosivity; slope factor; soil erodibility and population factor to assess degradation. All the factors were compiled in a GIS model as illustrated by the RUSLE empirical equation for estimating soil loss. Field survey was carried out to validate selected land degradation hotspots. The study area for this research is the Kenyan part of the Lake Victoria basin which was selected because of its agricultural and economic significance and the fact that it is one of the regions in Kenya that has suffered massive losses of productive land attributed to persistent land degradation which has also had direct implications to the Lake Victoria aquatic ecosystem and livelihoods.

1.6 Limitations of the Study

The concept of land degradation is quite wide and includes all aspects that lead to reduction of lands quality to produce to its full potential including chemical, wind and other forms of erosion. This study tries to model land degradation in the entire Lake Victoria basin by focusing only on soil erosion by surface run-off.

1.7 Report Organisation

This report has been structured into five chapters. Chapter 1 contains the background, problem statement, objectives, justification of the study, scope of work and the limitations of the study. Chapter 2 provides the literature review on documented studies related to land degradation globally, regionally and in the context of the efforts at the basin. It also touches on the RUSLE model and use of geospatial tools. Chapter 3 introduces and discusses the methodological framework used in the study and gives a detailed explanation into the processing workflow adopted. Chapter 4 discusses and analyses the results obtained from the study while linking this to the study objectives. It goes on to relate the findings to key drivers of soil erosion in the basin. Chapter 5 serves as the last chapter; it provides the conclusions and key recommendations of the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Land degradation by soil erosion is defined as a process in which topsoil on the soil surface is carried away from the land by water or wind and transported to other surfaces. It is considered the second prevalent environmental problem the world faces after population growth. (Pimentel et al., 2009) revealed shocking figures about the erosion phenomenon, that is, most of the soil from farmlands is washed away about 10–40 times faster than it is being replaced, citing examples that United States and Africa were losing soil 10 times faster than the regular replacement rate, China and India are said to be losing soil 30–40 times faster. Soil erosion trend has increased throughout the 20th century.

(Angima et al.,2003) also notes that land degradation in the world stands at about 85% and this is associated with soil erosion, most of which occurred since the end of World War II, causing a 17% reduction in crop productivity . The extent of soil erosion shows that it's a worldwide environmental problem with some areas such as the great horn of Africa and majority of sub – Saharan region being extremely prone to erosion due to prolonged dry periods and heavy erosive rainfall, falling on steep slopes with fragile soils, causing in considerable amounts of erosion (Onori et al., 2006).

(Onyando et al., 2005) in explaining the process of soil erosion denotes that it is a natural geomorphic process occurring persistently over the earth's surface, he goes on to state that common problems associated with soil erosion include loss of fertile topsoil for agriculture, siltation of streams and lakes, eutrophication of surface water bodies and loss of aquatic biodiversity.

Lake Victoria, with a surface area of 68 000 km^2, is the world's second largest fresh water lake and is a main source of the River Nile. Accelerated soil erosion and nutrient runoff, urban and industrial pollution and atmospheric deposition have induced a rapid rise in nutrient levels in the lake. This has in turn led to changes in the lake ecology and prolific growth of aquatic weeds dominated by the invasive water hyacinth (Bullock et al, 1995). As a result, the fishery industry, the direct economic mainstay for half a million persons in the lake basin through fishing and fish processing, is in decline (Scheren, 1995).

2.2 Need for soil erosion Assessment in the context of Land Degradation

Soil erosion by water refers mainly to erosion by surface run-off and it is one of the major causes of land degradation. Management practices to minimize these problems can be effectively carried out if the magnitude and spatial distribution of soil erosion are well mapped (Souchère et al., 2005). Soil erosion models can simulate erosion processes in the watershed and may be able to take into account many of the complex interactions that affect rates of erosion. Therefore, it is necessary to establish soil conservation measures to reduce the land degradation and ensure development of a sustainable management of soil resources.

The implementation of effective soil conservation measures has to be preceded by a spatially distributed erosion hazard and risk assessment. A soil erosion hazard map is therefore essential and erosion hazard mapping can be a starting point of any regional intervention policy for land degradation control and conservation (Moussa et al., 2002).

2.3 Efforts in Modelling and Assessing Soil Erosion

2.3.1 Regional Soil Erosion Assessment Models:

Soil erosion prediction and assessment has been a challenge to researchers since the 1930s and several models have been developed (Lal, 2001). These models are categorized as empirical, semi-empirical and physical process-based models. The most commonly adopted empirical models are the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) and Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991). Other models like the Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1990), European Soil Erosion Model (EUROSEM) (Morgan et al., 1992) and Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995) are also used to estimate the status of soil loss. These methods analyse soil erosion by attempting to estimate the volumes or masses of soil loss.

These models are used, modified and improved within years of research for quantitative and qualitative evaluation of soil erosion by water. The USLE/RUSLE model have stood the test of time and given results useful for a general estimation of the erosion phenomena. However, the outputs are strictly dependent to the single parameter estimation and the model does not permit the simulation of the erosive rainfall events (Flanagan and Nearing, 1995).

2.3.1.1 Traditional Methods of Soil Erosion Loss using RULSE

The historical background of erosion-prediction technology started with analyses as reported by (Renard et al., 1997) to find the major variables that affect soil erosion by water. They listed three major factors: potential erosivity of rainfall and runoff, susceptibility of soil to erosion, and soil protection done by plant cover. According to (Moore and Burch, 1986), the first equation published described mathematically the effects of slope steepness and slope length on erosion. (Smith, 1976) also gives additional factors for support practices and cropping system to the equation. The concept of specific annual soil- loss limit and the resulting equation to develop a graphic method for selecting conservation practices for certain soil conditions in the Midwestern United States were added.

(Browning and associates, 1947) as reported by (Renard et al., 1997) added soil erodibility and management factors to the Smith equation and prepared extensive tables of relative factor values for different soils, crop rotations, and slope lengths. The approach emphasized the evaluation of slope-length limits for different cropping systems on specific soils and slope steepness with and without, terracing, contouring, or strip- cropping. (Moore and Burch, 1986) reported a method for estimating soil losses from fields of clay pan soils. Soil-loss ratios at different slopes were given for contour farming, strip-cropping, and terracing.

The recommended limits for slope length were presented for contour farming. Also, the equation is of limited value since it cannot provide information on the fate of sediment once it is eroded. The USLE model is not able to predict deposition or the pathways taken by eroded material and sediments as it moves from hill slope sites to water bodies. Similarly, the design of strategies to control pollution associated with erosion runoff and on agricultural land requires knowledge of what happens in individual rainstorms, seldom on a minute-by- minute basis, in order to forecast the size and timing of peak discharges of water and sediment from hill slopes to rivers. The USLE cannot provide this because it predicts only mean annual soil loss. The need for an alternative approach was recognized by improving on the USLE.

2.3.1.2 Developments in the USLE and RUSLE

Recent developments in assessing soil erosion have recommended fusing of statistical techniques with the existing empirical techniques like USLE and RUSLE to effectively assess the sensitivity to soil erosion (Li et al., 2006). Multi- criteria analysis has largely been applied in producing and combining spatial data for describing the causal factors. Other studies have favoured the use Analytical Hierarchial Pairwise (AHP) Comparison Methods through Weighted Linear Combination (WLC) Approach in GIS environment (Rahman et al., 2009).

According to (Wenfu et al., 2008) the advent of remote sensing and GIS technologies accompanied with their integration with the USLE/RUSLE method has led to a simpler, cost-effective and efficient perception of erosion, and this integrated application was applied by many researchers in the whole world. The prime input required for soil erosion modelling are terrain, slope gradient and slope length which can be generated by processing of DEM in GIS. Multi-temporal remote sensing data (satellite imageries) provide valuable information related to seasonal land use dynamics. Satellite data can be used for derivation of erosional and depositional features, such as gullies, point bar, braided channel, abandoned channel, and vegetation cover factor (Surjit et al., 2015).

Several studies have also presented the potential of GIS technique for quantitatively assessing soil erosion hazard based on various empirical models .(Rahman et al.,2009) notes that soil erosion is a complex issue with many related factors, and investigators face great challenges for quantifying the relationships between soil erosion and these factors. He goes on to advice that an integrated and systematic approach utilising the essential Geospatial techniques is adopted in soil based erosion studies.

In order to provide an effective result for soil erosion hazard assessment, remote sensing (RS) and geographical information system (GIS) technologies should be adopted, and an appropriate empirical model utilised particularly in determining the spatial dynamics of soil erosion vulnerability by water (Surjit et al., 2015).

2.3.2 Soil Erosion Related Assessments at the Lake Victoria basin:

Despite the alarming manifestation of land degradation risk in the Lake Victoria basin, not much effort has been put in place to counter the hazard. Until now the following soil erosion assessment methodologies mostly by World Agroforestry Centre (ICRAF) have been utilised by different actors in some sections of the basin:

2.3.2.1 River monitoring and sediment core analysis: By routinely monitoring the sediment and nutrient load in the Nyando, Nzoia, Yala and Sondu-Miriu rivers since 1999, the International Consortium for Research and Agroforestry (ICRAF) managed to document the magnitude of the soil erosion problem and compare the Nyando to other Kenyan rivers. Analysis of sediment cores extracted from the mouth of the Nyando River also allowed the quantification of the magnitude of the sediment load and the changes in magnitude over the last 100 years (Swallow et al., 1999). This study finds approach useful in soil erosion assessments although the overall argument is that its scope is so limited sedimentation and when considering the overall parameters and scope of soil erosion, the approach still leaves a lot to be desired.

2.3.2.2 Use of reflectance spectrometry to integrate soils' results across scales : Reflectance spectrometry technique of soil erosion assessment was utilised and found to be a very useful tool for developing inferences about the chemical and physical properties of soil that determine fertility, erosion and hydrologic function, as well as the history of dominant plant type. By building a library of spectra for well-characterized soils from across the Nyando watershed, the World Agroforestry Centre (ICRAF) through the Trans Vic2 project used this approach to construct watershed level profiles and maps of soil fertility (devising a spectral fertility index), hydraulic conductivity (Omuto, 2003), erosion/deposition status, and historic land use (Shepherd and Walsh , 2001). Further studies have however shown that this approach is quite intensive and can only be applied at a very small geographical scale.

2.3.2.3 Plot and catchment scale studies: These coarse resolution studies applied by Joint implementation with the National Agriculture and Livestock Extension Programme (NALEP) of the Kenya Ministry of Agriculture were complemented by studies of the effects of land use and agroforestry technologies on soil erosion, infiltration, hydraulic conductivity and runoff during the 1999 – 2002 periods at Nyando catchment. Plot-level measurements were aggregated to the catchment scale through spatially-based hydrological models to derive inference on levels of soil erosion within the Nyando sub-catchment (Swallow et al., 1999). This study found this approach to be effective although the entire process could be dimmed tedious hence only applicable to a small scale assessment.

2.4 Remarks and conclusion from Literature Findings

The outcome from this literature survey has drawn some pointers towards the need for use of empirical models to abstract the land degradation and specifically soil erosion hazard in the entire basin. The advantage being that empirical models allow for the integration of several parameters and indicators that contribute to manifestation of soil erosion. The study backs this up by the understanding that the different approaches currently used in assessing soil erosion in the lake Victoria basin as pointed out in section 2.3.2 have had limitations in either the narrowed scope of assessment e.g. By focusing on one variable like the River monitoring and sediment core analysis approach or by undertaking tedious procedures that although accurate can only be carried out at small geographical extents e.g sub-catchments to measure soil erosion.

The study has also noticed that existing methodologies of assessing soil erosion in the basin so far have been constrained to small geographical units like the Nyando sub-catchment and related drainage systems. It is apparent that soil erosion is a complex issue requiring multitude factors (Rahman et al., 2009) and in order to assess the aspect of soil erosion in the entire lake Victoria basin, there is the dire need for a model that can integrate the GIS tools as well as remote sensing inputs and statistical methods in order to quantitatively assess soil erosion hazard. It is for this reason that this study settled with the Revised Universal Soil Loss Equation (RUSLE) empirical model which integrates the remote sensing inputs in a GIS environment in assessing soil erosion by surface runoff.

2.5 The RUSLE Model

2.5.1 The Model Equation

As it has been highlighted above, several models and methods had been suggested to predict soil erosion. Empirical erosion prediction models continue to play an important role in soil conservation planning and are widely used to predict soil erosion. In this study, the revised and improved version of the Universal Soil Loss Equation model which is the Revised Universal Soil Loss Equation (RUSLE) as shown below by equation (2.1) was adopted for the assessment of soil erosion in the Lake Victoria Basin

$$A = R \times K \times L \times S \times C \times P \qquad (2.1)$$

Where:

A is the spatial average soil loss in tonnes per hectare per year (t/ha·yr); R is the rainfall runoff erosivity factor in millimetres per hour per year mm/ha·h·yr; K is the soil erodibility factor in t/ha per unit R; L is the slope length factor; S is the steepness factor; C is the cover management factor; and P is the support practice factor defined by population density These factors (RKLSCP) are combined via the RUSLE in a GIS environment for soil erosion prediction and, for these factors, individual maps can be prepared in raster GIS.

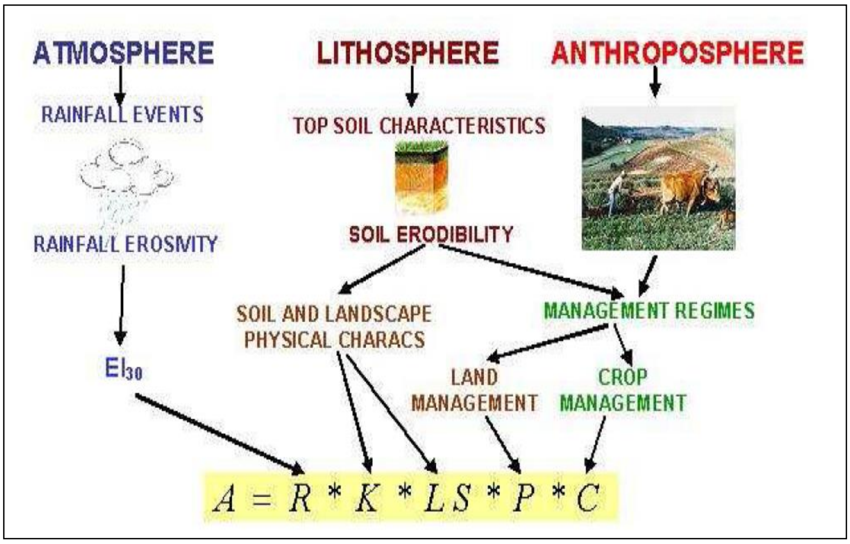


Figure 2.1: Illustration of Universal Soil Loss Equation (RCMRD, 2015)

2.5.2 Use of Geospatial tools for Indicator mapping and Combination in RUSLE

Within the frame work of RUSLE, individual indicators as pointed in figure 2.1 above affecting soil erosion are mapped separately, and later combined into a single scale, by adding or multiplying suitably weighted indicators for each individual factor. An overlay mathematical analysis in a geographical information system (GIS) as a factor-based assessment of risk is then performed. Input factors are then combined to estimate different categories of actual soil erosion risk as shown in figure 2.2.

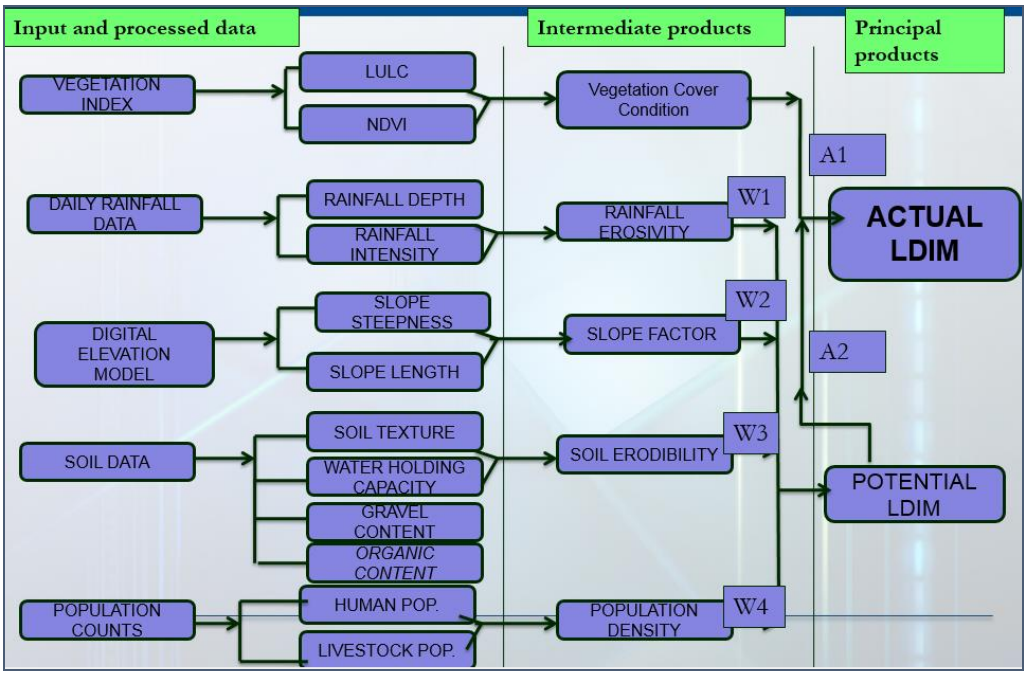


Figure 2.2: Soil erosion modelling flow process (indicator mapping and combination)

The final data processing is performed in a GIS model environment. For this study, the ArcGIS Model Builder and a global scheme as presented in figure 3.3 is used. Each of the input layers (e.g. Rainfall Erosivity, Soil Erodibility, Slope factor, population densities etc.) is explained well in the model developed. Notice that potential soil erosion index is made distinct from the actual soil erosion index by eliminating the vegetation cover component

2.5.3 Variable Ranking and Weighting

The basic pre-requisite for the assessment is the determination of weights and rating values representing the relative importance of factors and their categories. For this study, the importance of classes was determined before assigning weights to the layers, and a suitable rating scale for each factor defined from expert's opinion.

Assigning weights of influence or importance to the 5 land degradation assessment input requires comparing alternatives with respect to a set of criteria. Saaty Pair wise comparison (as shown in table 2.1) enables ranking criteria in order of importance and to assign to the criteria some relative ranking indicating the degree of importance of each criterion with respect to the other criteria (GITTA 2016). This study utilized this approach by seeking assistance from two expert institution's teams (RCMRD and MOEWN) to subject all the 5 land degradation input parameters to ranking in order to derive individual weights leading to actual land degradation index.

The land degradation assessment inputs

1. Population Density (Human and Livestock)-**P**
2. Rainfall Erosivity-**R**
3. Soil Erodibility- **K**
4. Slope Aspect- **S**
5. Vegetation Index- **VI**

Actual Land Degradation Index

Table 2.1: Pairwise Comparison Matrix for Land Degradation

	R	**P**	**S**	**K**	**VI**
R		**R**	**S**	**K**	**VI**
P			**S**	**K**	**VI**
S				**S**	**S**
K					**VI**
VI					

2.5.3.1 Assigning Weights

Finally weights are associated with the output from the pairwise ranking criteria (table 2.2 and table 2.3) so that the relative ranking from the pair wise comparison is satisfied. There are two basic constraints on how to assign the weights (RCMRD, 2015):

I. The total of all the weights must be 1 (100%)
II. The weights must obey the relative ranking given by the pair wise comparison.

For this study the weights must be developed considering the pair-wise comparison of the two expert teams (e.g. table 2.2 and table 2.3):

Table 2.2: Ranking the inputs by different teams

Expert Opinion			**AVERAGE RANKS**
Land Degradation Input	**Team A**	**Team B**	
Vegetation Index- **VI**	1	4	2.5
Slope Aspect- **S**	2	2	2
Soil Erodibility- **K**	4	1	2.5
Rainfall Erosivity-**R**	3	2	2.5
Population Density-**P**	0	1	0.5
TOTAL RANKING			10

To get weights this formula is used: Weight=Rank/Total Weight

Table 2.3: Weighting the inputs

Land Degradation Input	Calculation	Weights (%)
Vegetation Index- **VI**	2.5/10 *100	25
Slope Aspect- **S**	2/10 *100	20
Soil Erodibility- **K**	2.5/10 *100	25
Rainfall Erosivity-**R**	2.5/10 *100	25
Population Density-**P**	0.5/10 *100	5
Total		**100**

2.6 Soil Erosion Process Controlling Parameters (Input Variables)

Rain erosivity (RE): Both rainfall and runoff factors may be considered in assessing a rainfall erosion problem. Rain may move soil directly, which is known as rain splash erosion. Splash is only effective if the rain falls with sufficient intensity. If it does, then as the raindrops hit bare soil, their kinetic energy is able to break down soil aggregates, disperse the aggregate material, and move soil particles a short distance. So, soil movement by rain splash is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Although the erosion caused by long-lasting and less-intense storms is not as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time. High rainfall quantities are indicative of important soil loss quantities (Lancaster N, Helm P, 2000).

Vegetation Cover: Different land use types in terms of area size and pattern influence the soil erosion risk. The Land Cover Management Factor (C) is used to express the effect of plants and soil cover. Plants can reduce the runoff velocity and protect surface pores. The C-factor measures the combined effect of all interrelated cover and management variables, and it is the factor that is most readily changed by human activities (Karaburun, 2010). It is mainly related to the vegetation's cover percentage and it is defined as the ratio of soil loss from specific crops to the equivalent loss from tilled, bare test-plots (Gitas et.al, 2009). The value of C depends on vegetation type, stage of growth and cover percentage. The vegetation cover has a big impact in the erosion by intercepting the rainfall thus increasing the infiltration and reducing the rainfall energy (Rojas-González, 2008).

Soil Erodibility (SE): Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Tillage and cropping practices which lower soil organic matter levels, cause poor soil structure, and the result of compaction contribute to increases in soil erodibility. Decreased infiltration and increased runoff can be a result of compacted subsurface soil layers. A decrease in infiltration can also be caused by a formation of a soil crust (Wischmeier, 1971)

Slope: Slope plays a major role in erosion control. Generally, wherever steeper the slope, chance of soil erosion was high due to increased Kinetic energy fostering surface run-off.

Population Density: Both for livestock and human have a direct pressure on land and the existing vegetation. Heavily occupied region are highly susceptible to erosion than scarcely populated. This may include grazing and pressure for settlements and agriculture.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This section introduces and discusses the entire workflow used to achieve the study results. Specifically, it looks at the entire workflow used from study area identification, data acquisition, data processing, intermediate products derivation, ranking of variables, weighted overlays in model builder, development of land degradation index maps, and field validation all the way to the final product which is the land degradation map. The flow chart below summarises the methodological workflow.

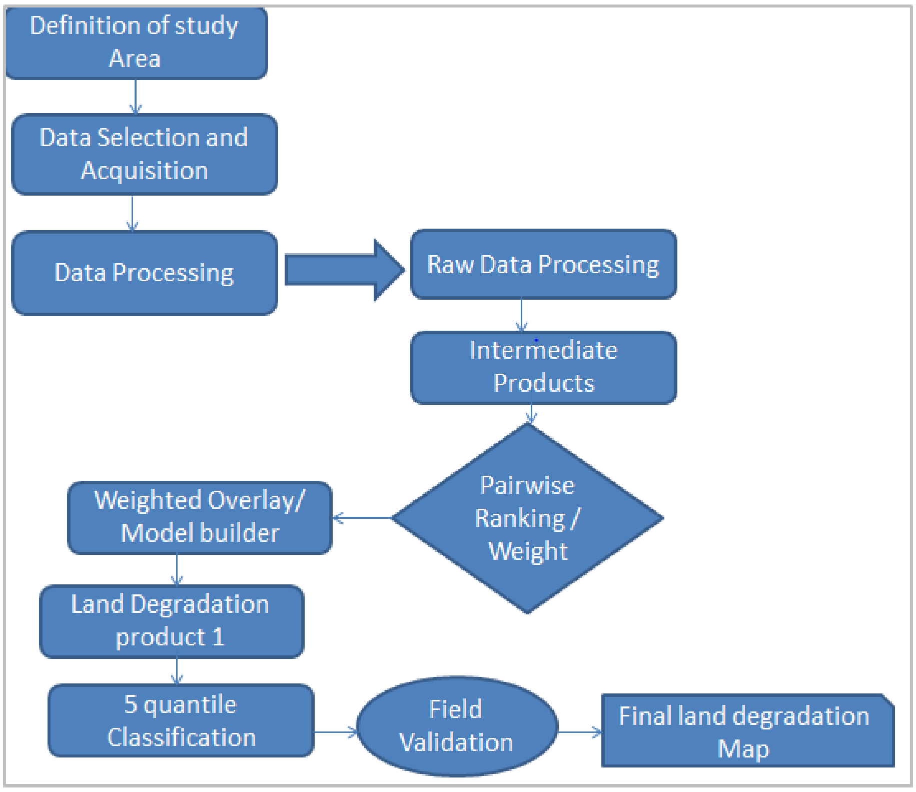


Figure 3.1: Summary of the methodology

3.2. The study area

The Lake Victoria Basin (LVB) is one of Africa's largest trans boundary water resources covering an area of about 194,200 km2, and surrounding the second largest freshwater Lake in the world (68,800 km^2), with the largest freshwater fishery resources.

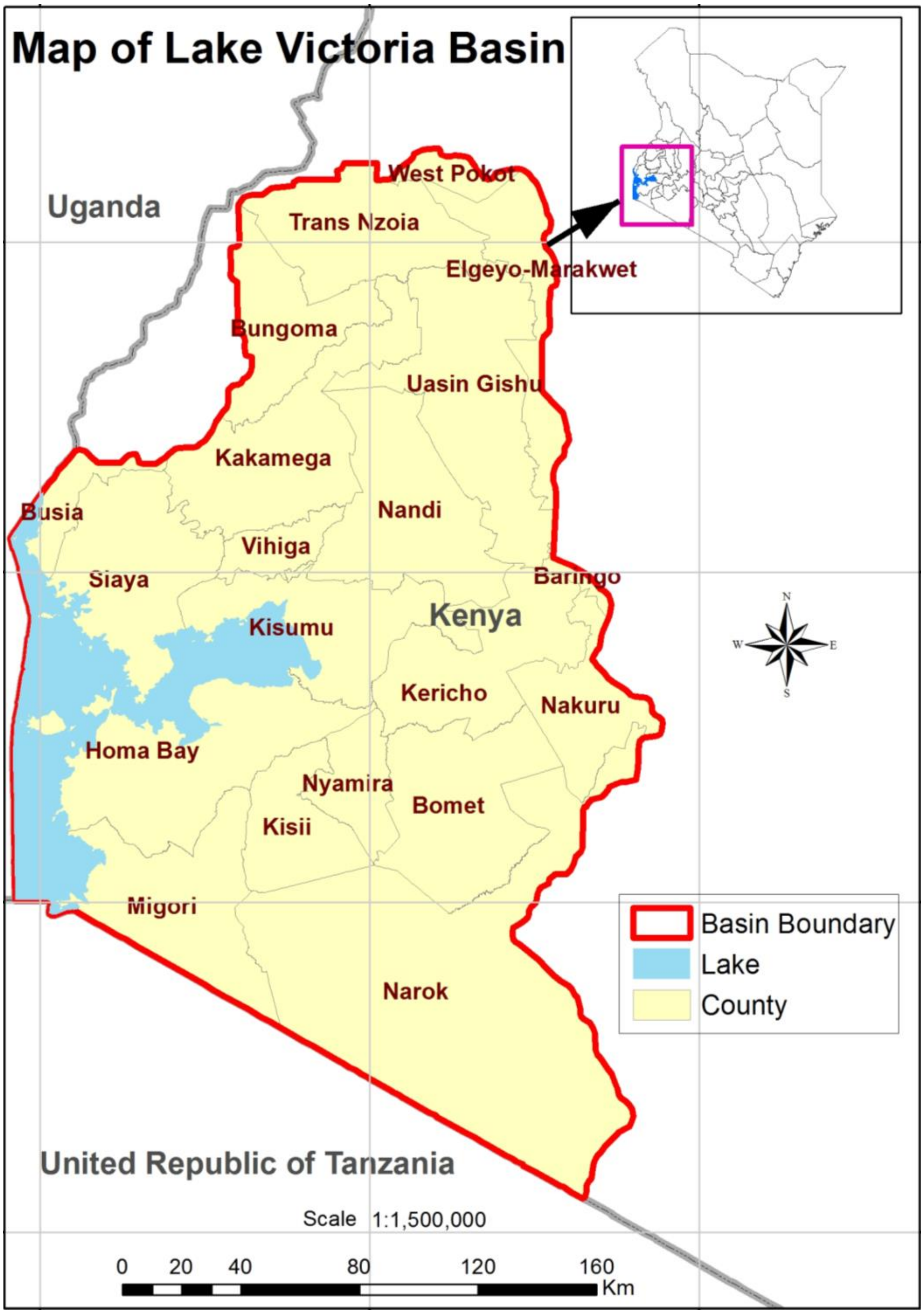


Figure 3.2: Study Area (Kenyan part of the LVB)

The Kenyan part of the basin covers 42,724 km^2. According to LVBC's regional Trans boundary diagnostics report of 2007, the basin's geographical area was delineated by the watershed limits of the systems of water including surface and underground waters flowing in Lake Victoria which consists of the following rivers: the Nzoia, Sio, Mara, Yala, Awach, Gucha, Migori and Sondu as shown in table 3.1.

Table 3.1: Surface water resources within LVB and their contribution to Lake Victoria (Source: MoEWN, 2014)

Country	Drainage Basin	LVEMP Study (1950-2000)		LVEMP (2001-2004)		Long Term (1950-2004)	
		Flow in Cumecs	%	Flow in Cumecs	%	Flow in Cumecs	%
Kenya	Sio	11.4	1.4	9.8	1.4	11.3	1.4
	Nzoia	116.7	14.5	107.4	15.7	116.1	14.6
	Yala	37.7	4.7	47.9	7.0	38.4	4.8
	Nyando	18.5	2.3	41.9	6.1	20.3	2.6
	North Awach	3.8	0.5	3.3	0.5	3.7	0.5
	South Awach	5.9	0.7	5.5	0.8	5.9	0.7
	Sondo	42.2	5.2	43.9	6.4	42.4	5.3
	Gucha	58.0	7.2	39.9	5.8	56.6	7.1

The basin falls under the equatorial hot and humid climate with a bi-annual rainfall pattern, where the long rains are experienced from March to May and short rains from October to December. July is the coolest month of the year and the warmest month is variable and fluctuates in the period from October to February. Rainfall varies considerably from one part of the Basin to another between 1,350 mm - 2,447 mm annually. The temperature in the Basin is maximum in February, just before the March equinox and reaches its lowest records in July after the June equinox maximum and range from 28.6˚ C – 28.7˚ C. The minimum temperature varies from 14.7˚ C to 18.2˚ C. Comparison of temperatures records for the period 1950-2000 to 2001-2005 show that maximum temperatures have increased by an average of 1˚ C. (LVEMP, 2005).

The Basin is characterized by different types of soils suitable for a variety of crops. Ferrosols are dominant within the lower parts of the Basin which are characterized by strong acidity and low in base saturation. Vertisols, which are also common, are dark-coloured-clays that expand and contract markedly with changes in moisture content and develop deep drying cracks. There is intensive cultivation in these soils. Acrisols, characterized by an argilic B horizon, containing alluvial clay and clay skin. Nitosols and cambisols are also common in the lower parts of the Basin (WAC, 2008).

The vegetation cover around Lake Victoria basin comprises savanna and wetlands (MoEWN, 2014). Most of the natural vegetation of Lake Victoria Basin has disappeared because of intensive agricultural activities. Areas unsuitable for crop cultivation are planted to various species of trees, eucalyptus and cypress. Some areas within the lake basin are covered with shrubs. The biodiversity and ecosystem of the Lake Victoria basin provide a wide range of species of aquatic life, plant and forest cover. The soils, vegetation and landscapes vary widely with rainfall and altitude giving four main agro-ecological zones.

The elevation of the entire lake Victoria basin falls within 1078m to 4061m above sea levels with the lowest sides being around lake Victoria while the highest regions being the North Western sides of the basin around mount Elgon.

Increased population pressures around the Lake have reduced vegetation cover and exposed soils to water erosion, which is extensive in many parts of the Lake Victoria Basin; about 45 per cent of the land is prone to water erosion (UNESCO 2006). Since 1963, 3.2 million tonnes of soil (or the equivalent to one million truckloads) have washed into Lake Victoria (WAC 2008). Erosion has led to the siltation of dams and increased the risk of river and estuary flooding. For example, erosion-related processes have led to periodic flash floods on the Budalangi and Kano plains (UNEP 2006). In Kenya each year, the value of soil lost due to erosion is three to four times as high as the annual income from tourism (WAC 2008).

3.3 Materials for the study

The materials for the study included the following:

3.3.1 Data

Assessment of basin wide degraded lands utilised five input data layers required to compute the required principal products. Most of these input layers were computed from a combination of two or more other data layers, as described below:

i) Vegetation covers type and condition: This data consisted of two data layers: Land use land covers (LULC) of 2015 and decadal Normalize Difference Vegetation Index (NDVI). The LULC data was sourced from existing land cover datasets of 2015 from RCMRD archive courtesy of the System for Land-based Emissions Estimation in Kenya (SLEEK) program. Decadal NDVI data was acquired from the eStation based at Inter Governmental Climate Prediction and Application Centre (ICPAC), specifically, this was time series data derived from the SPOT VGT Normalized Difference Vegetation Index (NDVI) and it consisted of 1km resolution Proba-V decadal NDVI data. The two layers LULC and NDVI were combined to characterize the vegetation condition.

ii) Rainfall: since the principal rainfall product i.e. rainfall erosivity required high temporal and spatial resolution rainfall data to calculate both rainfall depth and intensity, 5km decadal Climate Hazard Group Infrared Precipitation and Station (CHIRPS) rainfall data was found to be most representative. The CHIRPS dataset was further processed to provide the variability of the intensity and also characterize the potential erosive capacity of rainfall in the land degradation assessment.

iii) Soil erodibility: Soil erodibility data layer is a composite indicator that was derived from soil mineralogy and texture. This data layer was sourced from soil sample analyses available at Food and Agricultural Organization (FAO) and Kenya Soils and Terrain (KENSOTER) databases.

iv) Slope Factor: Slope was computed from the corrected Shuttle Radar Topographic Mission (SRTM) DEM at a resolution of 90 m. The slope length and slope steepness were computed from the same data source.

v) Population Density: Population density layer was used as an indicator of Population pressure which is the major socio-economic variable that is continuously changing. Human population density layer of 2010 was sourced from AfriPop project website, which is one of the most up-to-date detailed 100m gridded spatial population density dataset that is calibrated with Kenya National census data for 2009.

vi) Livestock population: Livestock population density data was derived from Food and Agricultural Organization's (FAO), gridded livestock density population data of 2008 which provides livestock population density at 8 km^2.

Table 3.2: List of data and data sources

Data	**Source**	**Access Link**	**Principal Product**
Soil	Harmonized World Soil Database (FAO HWSD, 2008, KENSOTER)	http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HWSD_Viewer/HWSD_viewer_setup.exe	Soil Erodibility
Rainfall	USGS Chirps (5km, Pentadol) gridded data.	ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/africa_pentad/tifs/	Rainfall Erosivity
Slope	Shuttle Radar Topography Mission (SRTM) 90m	http://srtm.csi.cgiar.org/	Slope Factor
Population	Livestock Population : GLiPHA-FAO 2008 Cows, Goats, sheep density raster's were used. Human Population: Afri-pop, 1km	http://www.fao.org/Ag/againfo/resources/en/glw/GLW_dens.html http://www.afripop.org/	Population Factor

Vegetation	LULC (RCMRD) NDVI (Spot VGT/ Proba V)	Rcmrd SLEEK program eSTATION ICPAC	Vegetation Index
Baseline Data	Boundaries, towns, other (RCMRD)	http://geoportal.rcmrd.org	Baseline / Ancillary data

3.3.2 Tools

The tools used in this study included the following;

Hardware – Personal computer.

Software – ArcGIS and QGIS Software, Microsoft Office.

3.4 Data Processing and Analysis

3.4.1 Introduction

This section describes the entire workflow used to process soil erosion leading to land degradation severity map. Since the empirical model adopted for assessing soil erosion by surface runoff in this study is RUSLE, this section describes the processing stages of the 5 parameters i.e. Vegetation cover condition, Rainfall erosivity, Slope factor, soil erodibility and Population density. The five parameters summarise the atmospheric, lithospheric and anthropogenic interactions that are considered responsible for soil loss. It is worth noting that the soil erosion assessment was based on the rainy season for the entire basin which covered the months of March to September 2015 (RCMRD, 2015).

The soil erosion model (RUSLE) was conceptualized theoretically as illustrated in figure 3.3 below. Such conception enabled the structuring of the system, the understanding of the logical order of transfers of energy and matter through the system, and the interactions between the variables to be defined (RCMRD, 2015). These parameters were then computed and integrated through spatial overlays and weighting made possible by use of ESRI’s ArcGIS 10.1 model builder. The eventual land degradation severity map was also produced in ArcMap.

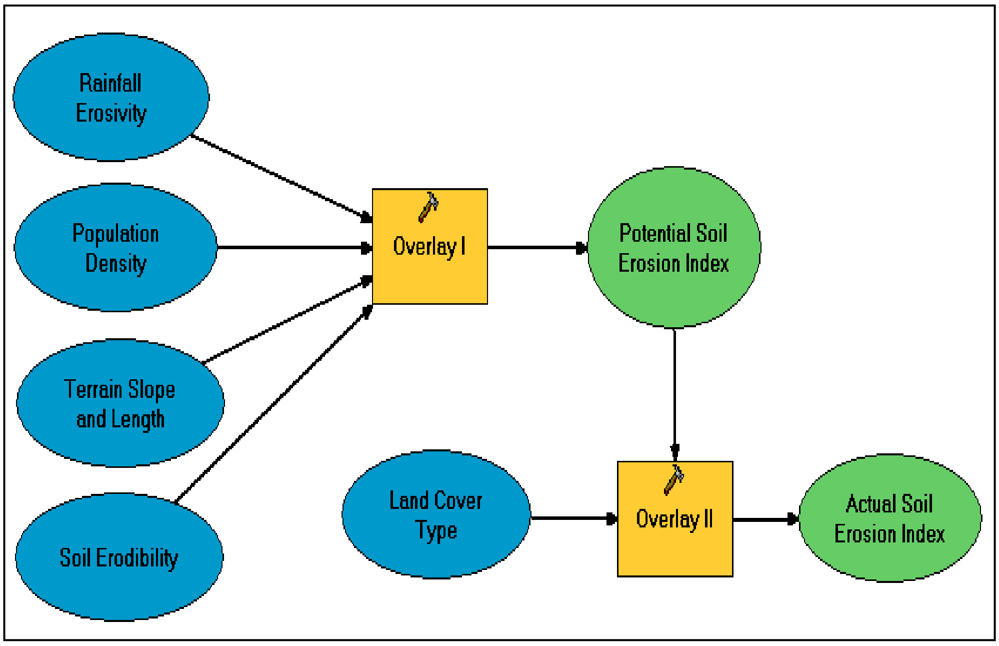


Figure 3.3: Summary Land degradation modelling approach.

The revised Universal Soil Loss Equation is presented in the form:

$A = R \times K \times L \times S \times C \times P;$ (3.1)

Where:

A is the spatial average soil loss in tonnes per hectare per year (t/ha·yr); R is the rainfall runoff erosivity factor in millimetres per hectare per hour per year mm/ha·h·yr; K is the soil erodibility factor in t/ha per unit R; L is the slope length factor; S is the steepness factor; C is the cover management factor; and P is the support practice factor defined by population density. These factors (RKLSCP) were combined via the RUSLE in ArcGIS model builder for soil erosion prediction and, for these factors, individual maps were prepared in raster GIS.

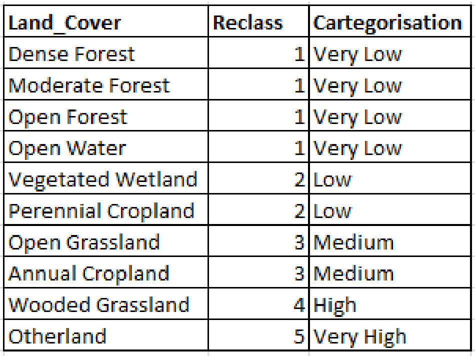
3.4.2 Vegetation Cover Management (C)

As noted earlier in chapter 2 (section 2.6) on vegetation cover, the Land Cover Management Factor (C) is used to express the effect of plants and soil cover. Plants can reduce the runoff velocity and protect surface pores. Since the satellite image data provide up to date information on land cover, the use of satellite images in the preparation of land cover maps is widely applied in natural resource surveys (Karaburun, 2010). More so, Since the Normalized Difference Vegetation Index (NDVI) values have correlation with C factor many researchers fuse both land cover data derived from satellite imagery interpretation and NDVI to estimate C-factor values in erosion assessment (RCMRD, 2015).

In this research, Land cover data for 2015 sourced from RCMRD was combined with NDVI data obtained from SPOT VGT satellite system. The two datasets were first processed and aggregated separately in 5 classes ranging from 1 to 5 with 1 being very low potential for soil erosion and 5 being very high potential for soil erosion then later converted to raster grids resampled to 100m before being combined in a weighted environment.

i) **Processing Land cover:** The different land cover types covering the entire basin were categorised into 5 classes of soil degradation susceptibility as shown in the table 3.3 and figure 3.4 below, after which the land cover data was exported to raster grid of 100m spatial resolution using the reclass field as the export field:

Table 3.3: Aggregation of land cover types into 5 classes summarising their influence on soil erosion (very low (1) to very high (5))



Land_Cover	Reclass	Cartegorisation
Dense Forest	1	Very Low
Moderate Forest	1	Very Low
Open Forest	1	Very Low
Open Water	1	Very Low
Vegetated Wetland	2	Low
Perennial Cropland	2	Low
Open Grassland	3	Medium
Annual Cropland	3	Medium
Wooded Grassland	4	High
Otherland	5	Very High

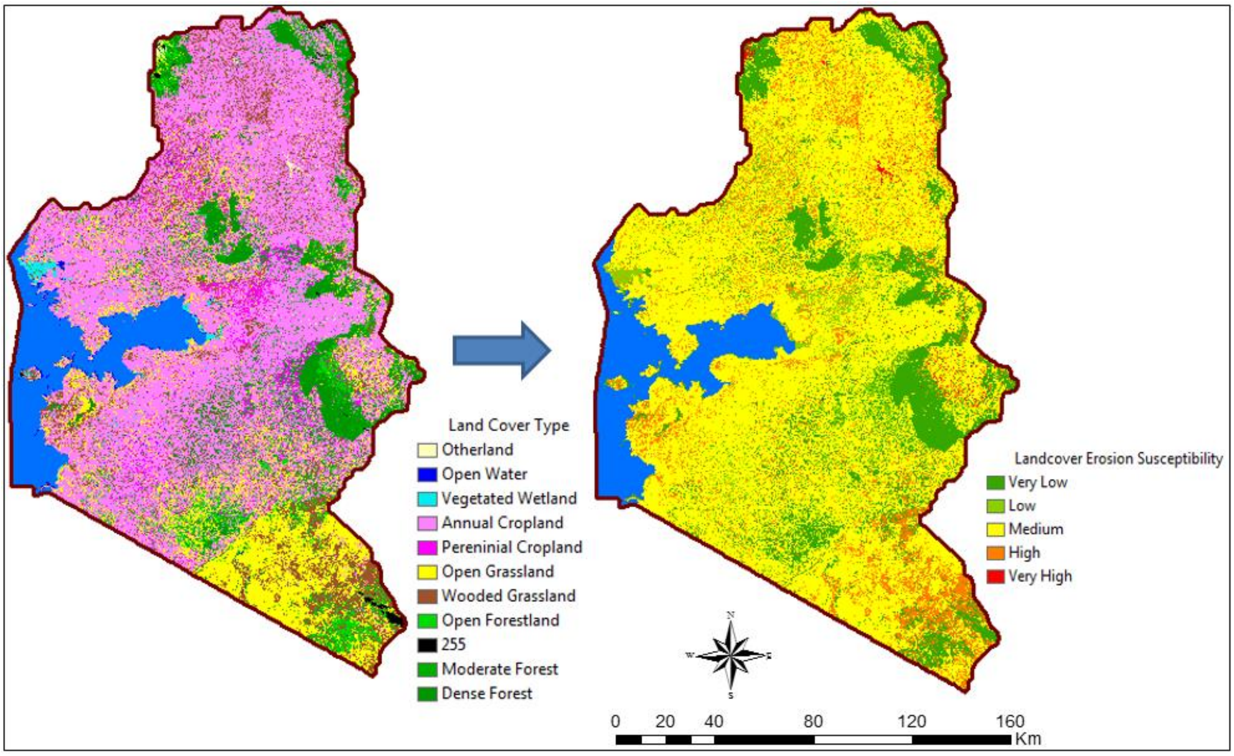


Figure 3.4: Aggregation of land cover to the 5 classes relating land cover type to its soil erosion susceptibility

ii) **Processing NDVI:** Since NDVI dataset received had been organised into 10 day (decadal) means, the first processing step was to obtain seasonal average NDVI (March to September)for the entire basin. This was achieved by obtaining the MEAN for all the decadal NDVI data in the season using cell statistics by MEAN functionality in ArcGIS Spatial analyst. The final seasonal NDVI_mean data was classified into the 5 classes of erosion susceptibility as specified in the classification below (RCMRD, 2015) :

1.	0.68-0.98	Very Good
2.	0.5-0.68	Good
3.	0.3-0.5	Normal
4.	0.15-0.3	Poor
5.	0.1-0.15	Very Poor
6.	= or < 0	Water bodies: needs to be masked out

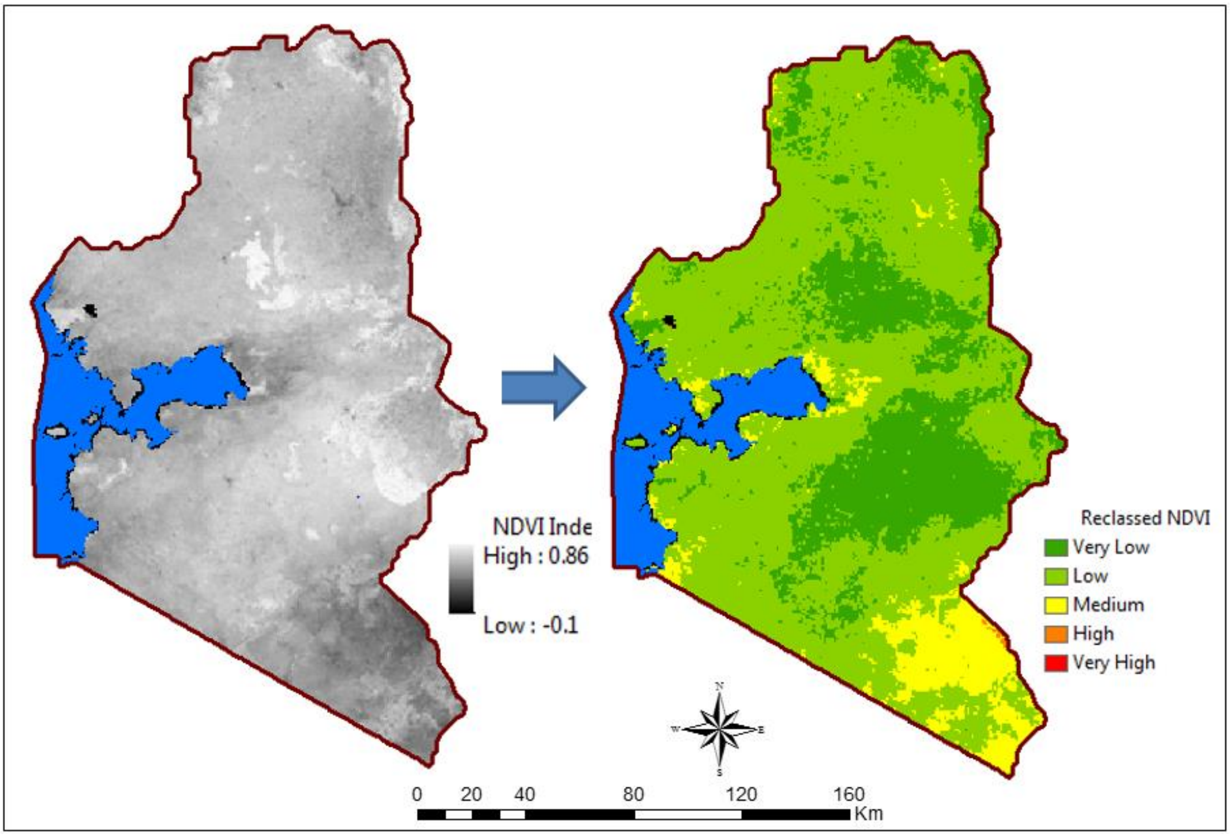


Figure 3.5: The processing of mean NDVI and the subsequent reclassification to the 5 classes relating land cover type to its soil erosion susceptibility.

The final vegetation cover management (C) was obtained by combining LULC and NDVI using the weighted sum tool in Spatial Analyst. Both LULC and NDVI had equal weights 1:1.

3.4.3 Processing Rainfall Erosivity (R)

Rainfall and runoff play an important role in the process of soil erosion and are together usually expressed as the R factor. The greater the intensity and duration (depth) of the rain storm, the higher the erosion potential(Stone et.al, 2000).The RUSLE rainfall- runoff erosivity factor (R) for any given period is obtained by summing for each rainstorm the product of total storm energy (E) and the maximum 40mm intensity (RCMRD , 2015). Unfortunately, the values of these factors are rarely available at standard meteorological stations. Fortunately, long-term average R-values are often correlated with more readily available satellite rainfall estimates values (Sadeghi et.al, 2011). For the computation of R factor two components were computed from the CHIRPS rainfall data: Rainfall depth and Rainfall intensity.

i) **Computing rainfall depth:** rainfall depth calculation was meant to provide the total seasonal storm energy (E) in the basin. It was computed by summing up all the pentadol (5day rainfall average) CHIRPS gridded rainfall data for the entire season (March - May) using ArcGIS raster calculator. The cumulative seasonal rainfall depth (D) was then classified using natural breaks to 5 classes of erosion susceptibility (as shown in figure 3.6) whereby very high rainfall totals implied very high susceptibility to soil erosion and vice versa.

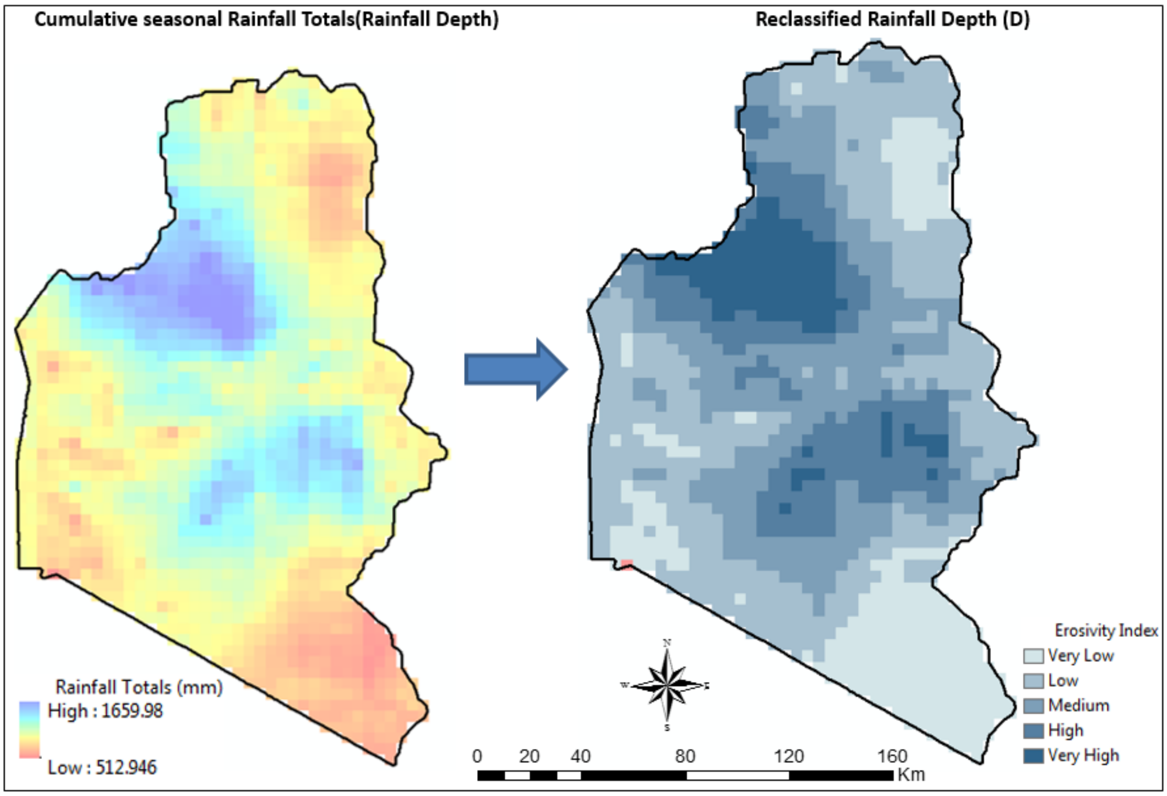


Figure 3.6: Cumulative seasonal rainfall depth

ii) Computing rainfall intensity:

Rainfall intensity is defined as the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period (FAO, 2016). It is expressed in depth units per unit time, usually as millimetre per hour (mm/h). Studies suggest that, on average, around 50 percent of all rain occurs at intensities in excess of 20 mm/hour and 20-30 percent occurs at intensities in excess of 40 mm/hour (Adnan, 1978). This relationship appears to be independent of the long-term average rainfall at a particular location. This study adopted Adnan's assessment which compared with RCMRD (2015) derivation of rainfall intensity by assuming a rainfall intensity threshold of >= 40mm to possess enough kinetic energy to dislodge soil particles thus transporting them in the process initiating soil erosion. To compute rainfall intensity, for each pentadol, areas with rainfall above threshold of 40 mm/pentadol were derived for the entire season. The processed pentadol files were then summed up to generate the cumulative seasonal rainfall intensity (I). The (I) was then classified into 5 classes of erosion susceptibility using the natural breaks as shown in figure 3.7.

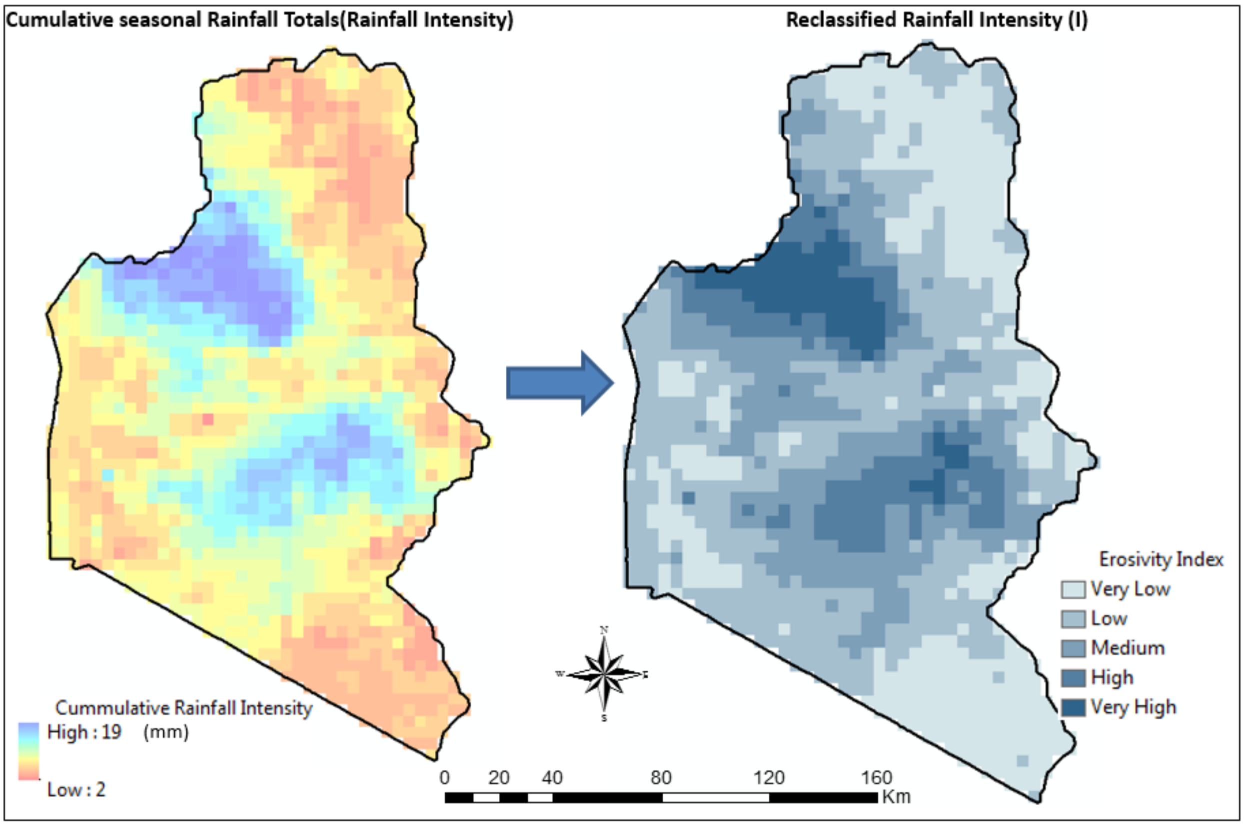


Figure 3.7: Cumulative seasonal rainfall intensity

The final rainfall erosivity (R) was obtained by combining rainfall depth (D) and rainfall intensity (I) using the weighted sum tool in Spatial Analyst using the formula (RCMRD 2015) below:

$$R = (0.4*D + 0.6*I) \qquad (3.1)$$

Where:

R is rainfall erosivity
D is rainfall depth
I is rainfall intensity

3.4.4 Processing Slope Factor (LS)

The L and S factors represent the effects of slope length (L) and slope steepness (S) on the erosion of a slope. The combination of the two factors expresses the effect of topography, specifically hill slope length and steep- ness, on soil erosion. An increase in hill slope length and steepness results in an increase in the LS factor (Karaburun, 2010). The slope length factor (L) is defined as the distance from the source of runoff to the point where either deposition begins or runoff enters a well-defined channel that may be part of a drainage network. On the other hand, the steepness factor(S) reflects the influence of slope steepness on erosion (George et.al, 2013). As already pointed out, the longer the slope length, the greater the amount of cumulative runoff, and the steeper the slope of the land the higher the velocities of the runoff which contribute to erosion. This study utilised the 90m digital elevation model provided by Shuttle Radar Topography Mission (SRTM) as the input elevation for computation of slope factor (LS). For estimation and processing of the LS factor, this study adopted the expression (3.2) since it is integrated within ArcGIS and enables easier manipulation of the DEM (George, 2013).

$$LS = Pow\left([flow\ accumulation] * \frac{resolution}{22.1,0.4}\right) * Pow\left(\sin\frac{([slope\ of\ DEM])}{0.09,1.4}\right) * 1.4 \qquad (3.2)$$

Where *Pow* (which means power) is a function in the ArcGIS spatial Analyst.

Using the Spatial Analyst Extension in ArcGIS, the slope of the catchment area was derived from DEM. Sinks in the DEM were identified and filled. The filled DEM was used as input to determine the Flow Direction (FD) which was used as an input grid to derive the Flow Accumulation (FA). The LS factor was then computed using Raster Calculator in ArcGIS to build an expression for estimating LS (3.2), based on flow accumulation and slope steepness (Mitasova et.al, 1996). The derived LS was then reclassified in the five soil erosion susceptibility classes with very steep areas being classified as very high and vice versa as shown in (figure 3.8) below.

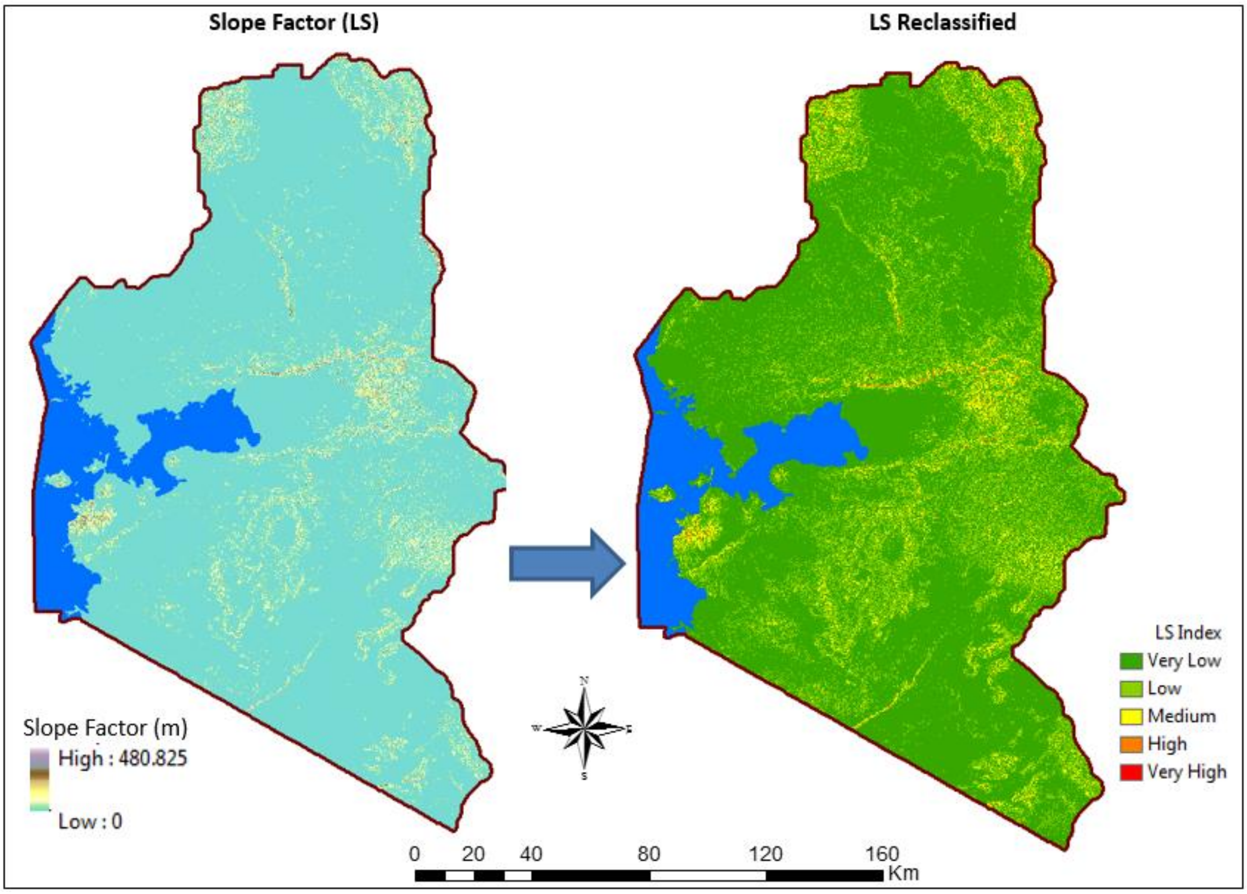


Figure 3.8: Processed slope factor (LS)

3.4.5 Processing Soil Erodibility (K)

The Soil Erodibility (K) factor represents both susceptibility of soil to erosion and the amount and rate of runoff. Soil texture, organic matter, gravel content and permeability (water holding capacity) determine the erodibility of a particular soil (Efe, 2008). The K factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow, and therefore shows the change in the soil per unit of applied external force of energy (Dumas, 2010). It is related to the integrated effects of rainfall, runoff, and infiltration on soil loss, accounting for the influences of soil properties on soil loss during storm events on upland areas (George, 2013).

For computing the K- factor, the most updated version of the harmonized world soil database (HWSD) which integrates inputs from FAO-UNESCO soil map data and soil and terrain database for Kenya (KENSOTER) was selected for use. The advantage with HWSD was that the database had all the four components of soil (texture, organic matter, gravel, water holding capacity) that were of interest for processing (K) factor in this study.

In order to process the four different soil components for soil erodibility (K), this study borrowed from RCMRD's methodology for processing K factor in IGAD region land degradation assessment (RCMRD, 2015). The tables: 3.4, 3.5, 3.6, 3.7 below show the processing and classification of the four soil components. Figure 3.9 shows the map output of the four different soil components:

i) **Processing soil organic content:**

Organic Carbon is together with pH, the best simple indicator of the health status of the soil. Moderate to high amounts of organic carbon are associated with fertile soils with a good structure. Soils that are very poor in organic carbon (<0.2%), invariable need organic or inorganic fertilizer application to be productive. Soils with an organic matter content of less than 0.6% are considered poor in organic matter. The following classes were used to prepare maps of organic carbon status for mineral soils in the entire basin:

Table 3.4: Classification of soil organic carbon from HWSD

Code	Percentage organic carbon - PH	Erodibility Rating
1	< 0.2	Very high erodibility
2	0.2 – 0.6	High erodibility
3	0.6 – 1.2	Moderate erodibility
4	1.2 – 2.0	Low erodibility
5	> 2.0	Very low erodibility

ii) **Processing Soil Texture:**

Table 3.5: Classification of soil texture from HWSD

Texture class	Topsoil Texture Classification (T_USDA_TEX_ CLASS)	Erodibility Rating
1	C(h), SiC, C (HWSD class 1, 2, 3)	Very low erodibility
2	SiCL, CL, SCL (4,5, 8)	Low erodibility
3	L,SCL,LS (9,10,12)	Moderate erodibility
4	SiL, SL (7, 11)	High erodibility
5	Si, S (6, 13)	Very high erodibility

Textural Classification Where S = Sand, C = Clay, Si = Silt and L = Loam

iii) Processing water holding capacity (WHC)

Table 3.6: Classification of water holding capacity from HWSD

Water Holding Capacity (WHC) Class	Available water storage capacity (AWC) -mm	Erodibility Rating
1	> 125 (class 1,2,)	Very low erodibility
2	125-100 mm (class 3)	Low erodibility
3	100-75 mm (class 4)	Moderate erodibility
4	75-50 mm (class 5)	High erodibility
5	< 50 mm (class 6,7)	Very high erodibility

iv) Processing Gravel content

Table 3.7: Classification of soil organic carbon from HWSD

Stoniness class	Topsoil Gravel Content (T_GRAVEL) - %	Erodibility Rating
1	>50	Very low erodibility
2	50-30	Low erodibility
3	30-10	Moderate erodibility
4	10-1	High erodibility
5	<1	Very high erodibility

The four components were then summed together with equal weights in spatial analyst. The summed output raster was then reclassified into five classes of erodibility using the natural breaks classification to generate the final soil erodibility layer (K).

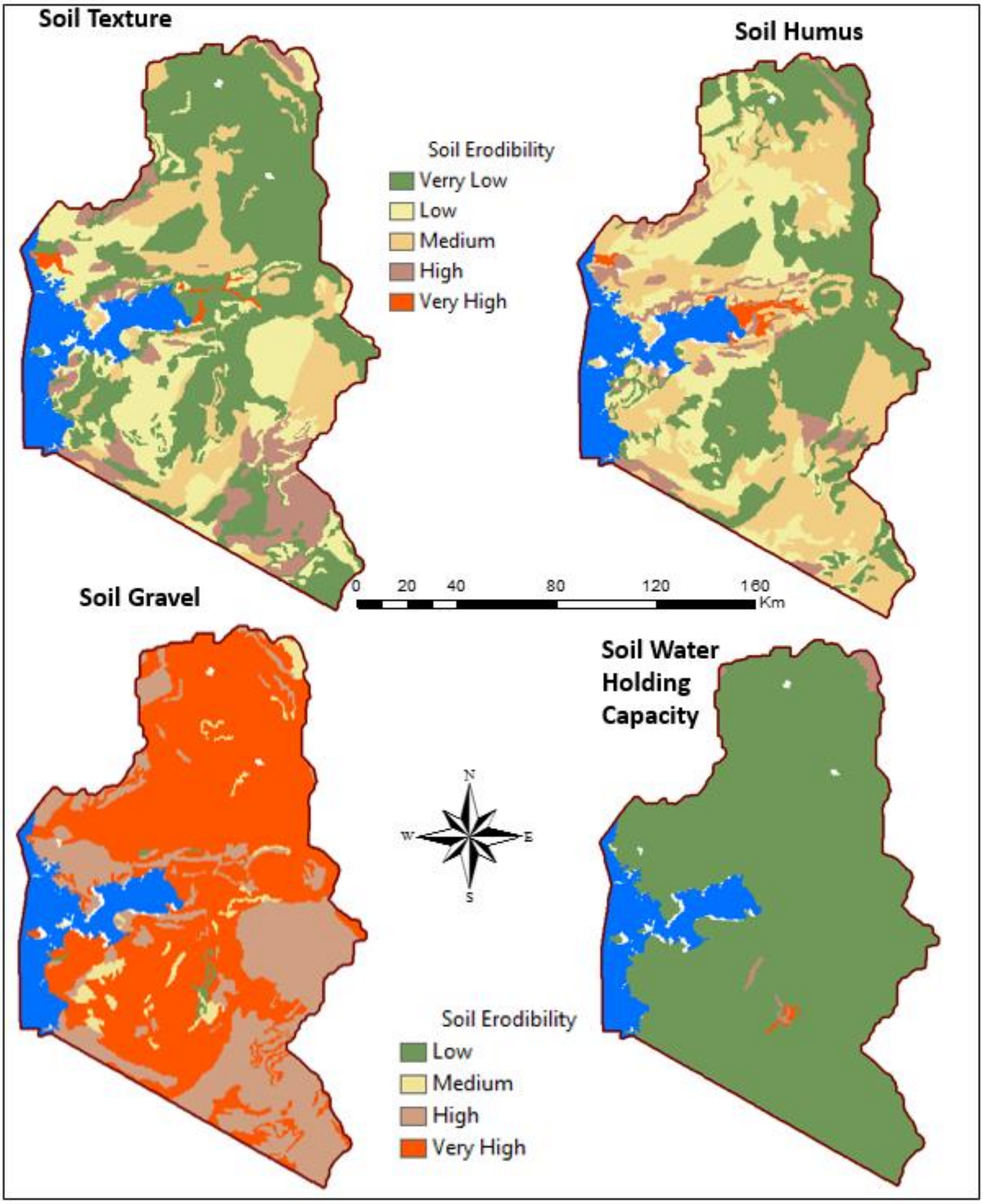


Figure 3.9: Mapped output of the four different soil components

3.4.6 Processing Population Density (P)

The soil conservation practice (P) factor describes the supporting effects of practices like contouring, strip cropping, and terraces other soil conservation efforts. Most often these datasets are not easy to obtain at an extensive geographical coverage and in most cases when computing the (P) factor in RUSLE, many studies have pointed at substituting the conservation data with human and livestock population data which is assumed to provide the indicator on cover management (George, 2013 and RCMRD, 2015).

This study computed (P) by combining livestock density data (for common reared species mainly comprising the cattle, goats and sheep) provided by FAO gridded livestock data with human population density data provided by AfriPop.

i) **Processing human population:**

Since the population data as received had been processed to population density grids, the data was directly reclassified to five classes of erosion susceptability as (shown in table 3.8 and figure 3.10):

Table 3.8: Population density classification

Class	Population Density Classification	Rating
1	0 – 2	Very Low
2	2 – 10	Low
3	10 - 40	Medium
4	40 - 100	High
5	> 100	Very High

ii) **Processing Livestock population:**

This study summed up the population datasets for goats, cattle and sheep since they are the predominant livestock domesticated in the Lake Victoria basin to derive the livestock population. The combined output was then reclassified into five classes of erosion susceptibility same as human population (as shown in table 3.8 and figure 3.10).

The final population density (P) was achieved by combining the livestock and human population data in a weighted ration of 0.6:0.4 respectively (RCMRD, 2015)

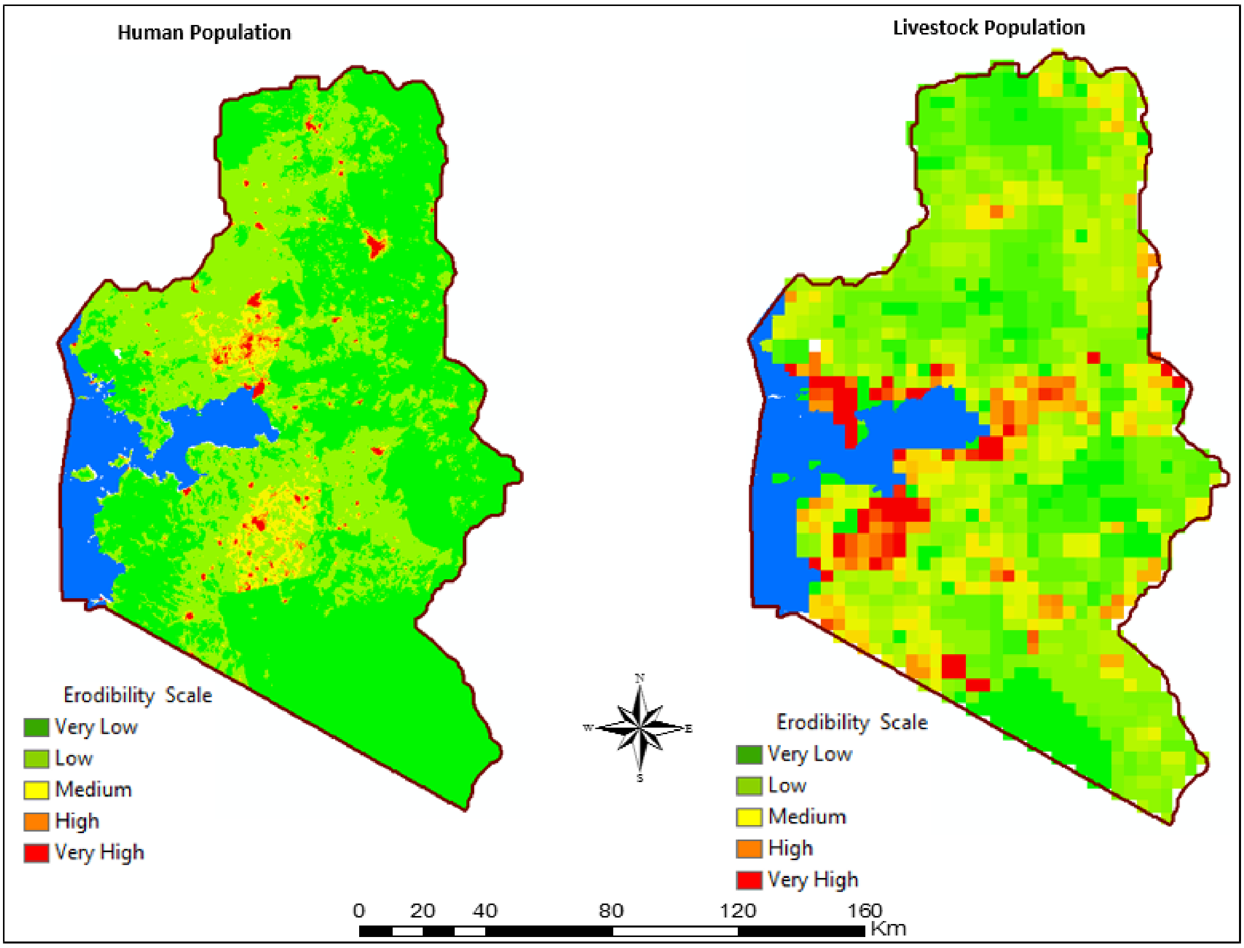


Figure 3.10: The reclassified human and livestock population

3.4.7 Factor weighting and combination (Overlay)

In order to derive the final soil erosion hotspots map, all the five processed soil erosion parameters were combined by summation using specific weights for each parameter as explained in section 2.5.2.1. The decision making framework used for determining weights was multi - criteria analysis. The Weights were assigned to the criteria according to their relative importance based on the experts' judgements and using a pair-wise ranking / preference matrix (see table 3.9) which is a measure to express the relative preference among the factors.

The land degradation assessment parameters

- Population Density (Human and Livestock)-**P**
- Rainfall Erosivity-**R**
- Soil Erodibility- **K**
- Slope Aspect- **S**
- Vegetation Cover Management Index- **C**

} Actual Land Degradation

Specifically for this study, two teams of experts from two different specialised institutions namely: Regional Centre for Mapping of Resources for Development's (RCMRD's) Land degradation modeling team; and the Ministry of Environment, Water and Natural Resources state (MOEWN) department of Water, directorate of Land Reclamation's team) were collected in organised meetings to rank the 5 land degradation input parameters using the pairwise ranking approach. The outcome was a matrix similar to the table 3.9 and the indicator weights as shown in figure 3.11:

Table 3.9: Pairwise Comparison Matrix for Land Degradation

Expert Opinion				
Land Degradation Input	**Team 1 RCMRD Experts**	**Team2 (MOEWN) Experts**	**Average Ranks**	**Weights**
Vegetation Index- **VI**	3	5	4	26.7
Slope Aspect- **S**	5	5	5	33.3
Soil Erodibility- **K**	2.5	3.5	3	20
Rainfall Erosivity-**R**	2	2	2	13.3
Population Density- **P**	1	1	1	6.7
TOTAL RANKING			15	100

To get weights the study used the formula: Weight=Rank/Total Weight * 100

Considering the above outcome the following weights were used for land degradation assessment.

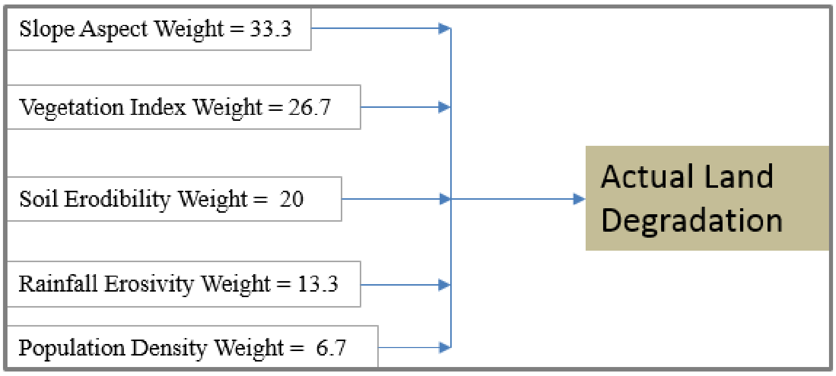


Figure 3.11: Weights used for the LDIM

To generate the final land degradation index, the 5 parameters were combined and specific weights implemented through weighted overlay performed with the model builder in ArcGIS spatial analyst as shown in figure 3.12

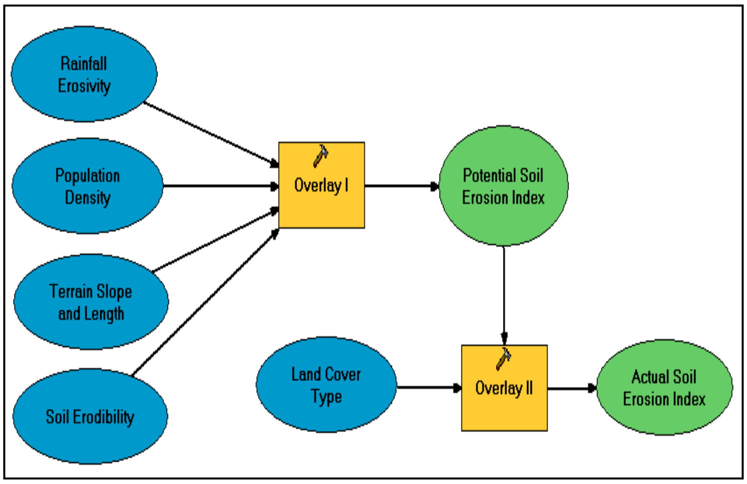


Figure 3.12: Erosion Model in model builder – Spatial Analyst

3.4.8 Field Validation

Field validation was carried out to establish evidence of degradation. Due to budget limitations, field validation was restricted to a small section of Kisumu County which registered massive soil erosion (land degradation) hotspot. The field tools were mainly camera for taking photos of degraded areas, note book and pens for jotting down the characteristics of hotspots based on observations and conversations with local communities and a Garmin GPS for recording the coordinates of degraded spots.

CHAPTER 4: RESULTS AND DISCUSSIONS

The combined use of GIS and erosion models has been integrated to estimate the severity and spatial distribution of land degradation through erosion by surface runoff for the Lake Victoria basin. Five different erosion risk factors including vegetation cover management(C), rainfall erosivity(R), slope factor (LS), soil erodibility (k) and population density (P) were determined. The results of modelling these factors are shown in appendices 1, 2, 3, 4 and 5 respectively. The final land degradation map is shown in figure 4.1 and appendix 6. Figure 4.2 shows the field validation map.

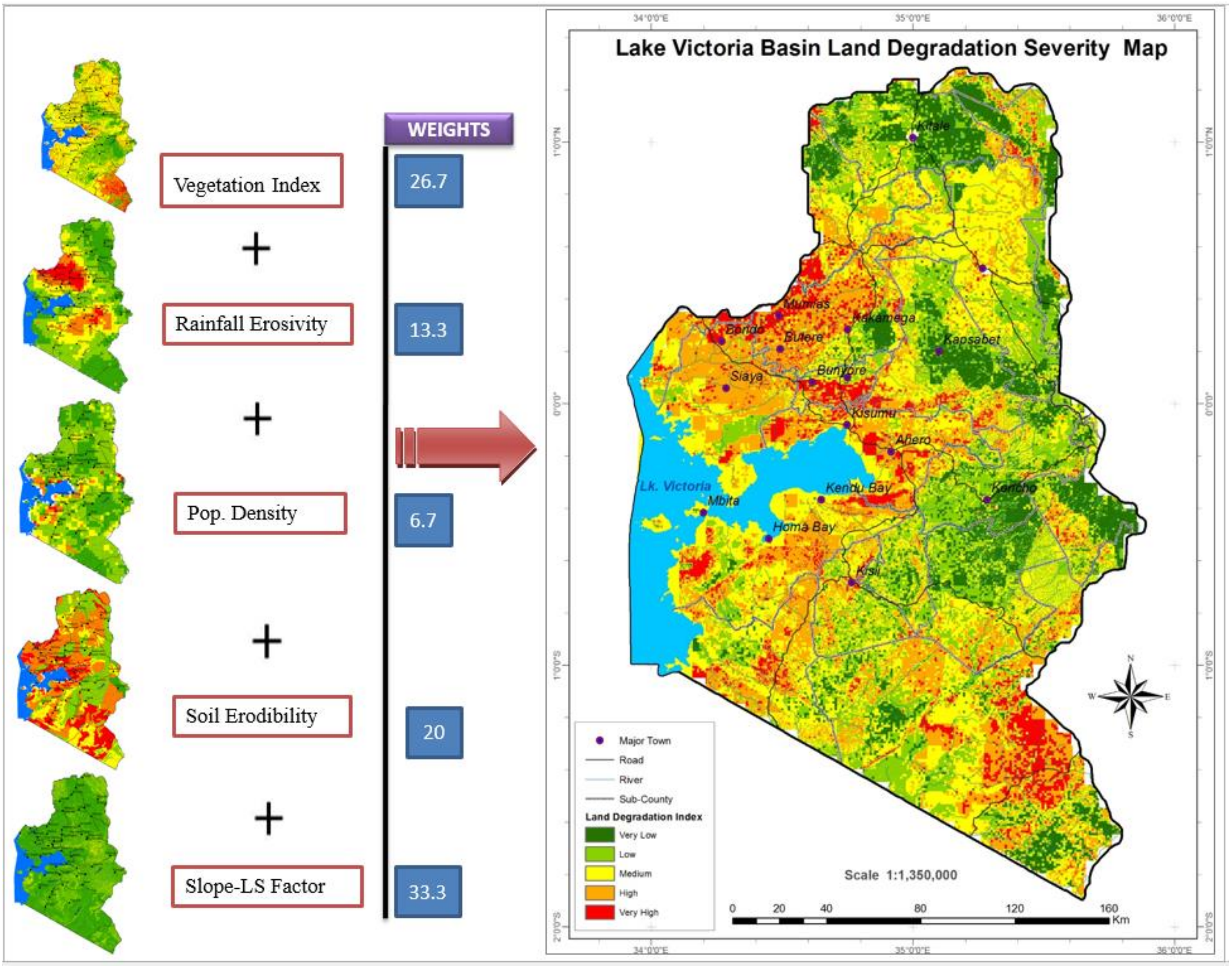


Figure 4.1**:** The RUSLE parameters leading to the final land degradation severity map.

From visual interpretation of figure 4.1 above, this study learned that most parts of the Lake Victoria basin experience medium to high levels of degradation. The areas experiencing very low degradation are notably forested areas (see appendix 1) in the northern parts and towards the eastern sides of the basin. These are areas occupied by the Mount Elgon forests, Kapsabet forest and parts of the Mau forests in Kericho all of which are reserved natural forests. The study also noted that the eastern parts of the basin registered low degradation levels and this could also be attributed to the tea plantations grown around these areas which provide perennial cover to the ground. The major soil erosion hotspots were found to be areas around the lake. Specifically, very high degradation occurs in areas around Mumias, Bunyore, Kisumu, Kendu Bay, Ahero and south western parts of Homa Bay (see figure 4.1 and appendix 6).

This study noted that soil experts rated slope factor as the major contributing factor to land degradation by soil erosion in the basin followed by vegetation cover, soil erodibility, rainfall erosivity and population density simultaneously (see table 3.9). However, while evaluating the key parameters that resulted to final land degradation hotspots map as outlined by RUSLE and as shown in figure 4.1, the leading factor to soil erosion in the basin and around the identified hotspots were found to be : soil erodibility component followed by rainfall erosivity , vegetation cover , population density and finally slope factor in that order.

In Figure 3.9, soil erodibility factor which represents both susceptibility of soil to erosion and the amount and rate of run- off is shown. The results of soil erodibility in the basin (see appendix 4) reflect the ease with which the soil is detached. However figure 3.9 points to the fact that most soils in the basin have very low gravel content of <1% and this contributes highly to their susceptibility to erosion by run-off. There is a very close correlation between the soil erodibility map and the final land degradation severity map where in both cases, the hotspots are around the lake region.

In this study, rainfall erosivity stood out as the second most contributing factor to soil erosion in the basin. In modelling the rainfall erosivity, it can be seen that (as in Figure 3.6, 3.7 and appendix 2) the greater the intensity and depth of the rain storm, the higher the erosion potential. High rainfalls within the basin are received in the western parts of the basin mainly: Bungoma, Mumias and Kakamega region and subsequently this has an inclination in the overall degradation in these regions.

The study further noted that areas practising small holder agriculture (arable and mixed farming) in the basin most notably: Bungoma, Uasin Gishu, Kisii and Narok registered medium to high levels of degradation. The consistent disturbance of land and specifically top soils through tillage combined by unsustainable agricultural practice might be the precursor to growing soil erosion levels in these areas. The aspect of vegetation cover management provides an insight into the need for proper forest and vegetation cover protection and conservation in the basin in order to alleviate soil erosion and preserve the topsoil.

In this paper, population factor (as in figure 3.10 and appendix5) was seen to provide modest impact in overall soil erosion in the basin. The population factor had high impact in the lake regions around Lake Victoria which had most population in the basin especially livestock population. The impact of human population was widely distributed though.

Surprisingly, this study noted that despite the high weight allocated to slope factor (see figure 3.8 and 4.1), this particular parameter had little contribution to the overall land degradation in the basin (see figure 3.6). Further analysis on the slope layer revealed that it is in ridges, river lines and stream areas that flow accumulation was high and that slope factor dictated very high soil erosion. The overall impression is that the gentle to near flat nature of slope in the entire basin bar the isolated mountainous regions of Elgon, Kapsabet and Mau regions meant that slope had little effect on soil erosion in the region.

Overall and as observed by findings from field validation at Bolo location in Kisumu county (see figure 4.2) , massive land degradation through soil erosion by surface runoff in the basin is caused by unsustainable agriculture practice in the basin which results to vegetation clearance and exposure of topsoil to erosion agents. A large part of the basin is occupied by small holder farmers practicing arable and mixed agriculture. Lack of awareness combined by poor agricultural extension services in the marginalised rural setups act as the precursor to the hazard.

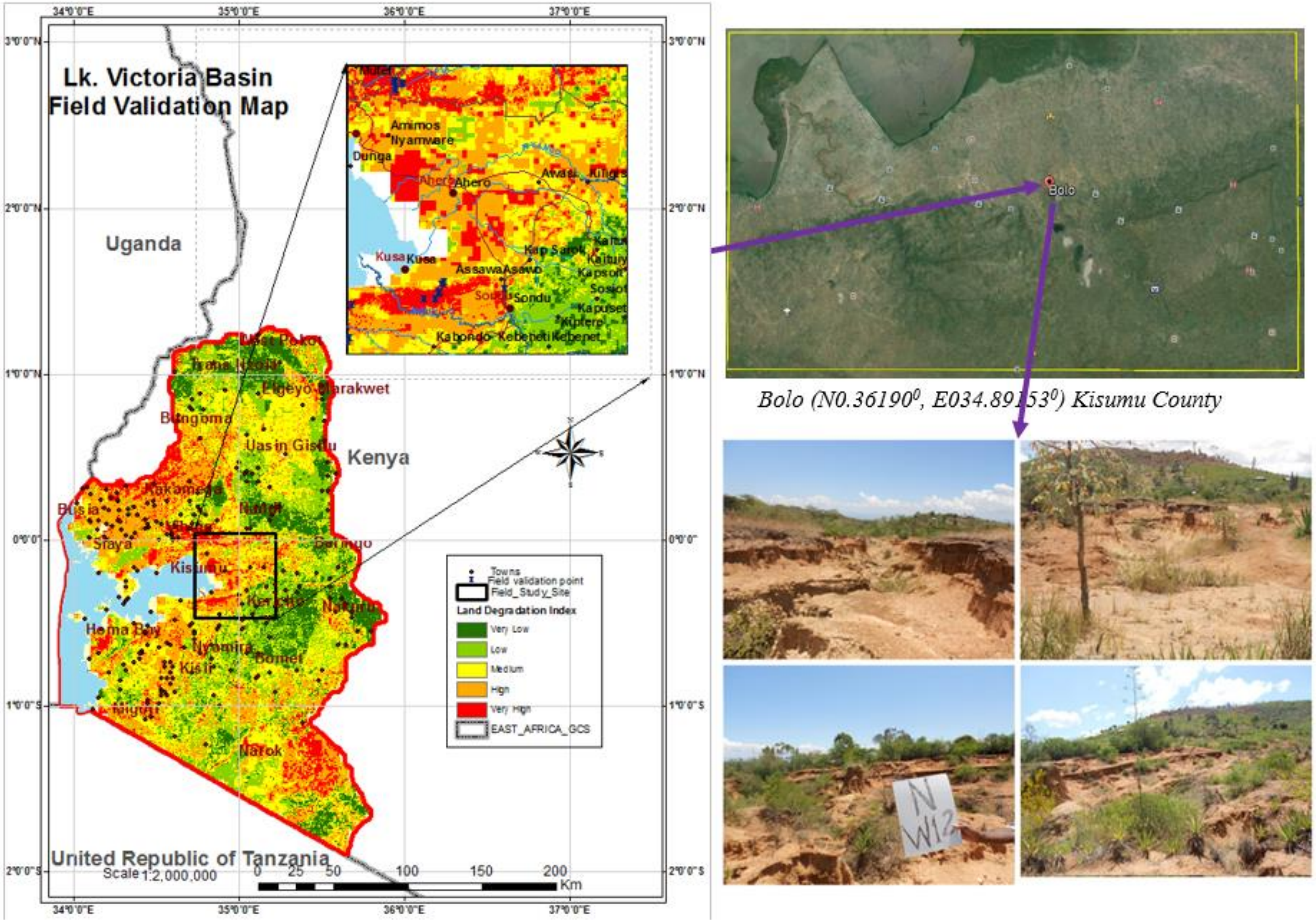


Figure 4.2: Degradation Hotspot at Bolo in Kisumu County

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this paper, empirical land degradation model for assessing soil erosion by surface runoff (RUSLE) and its integration with GIS tools has proved useful and effective in assessing land degradation in the entire Lake Victoria basin. The output which was a land degradation index map has shown the spatial variation in soil erosion severity in the basin enabling the study to point out the major land degradation hotspots in the basin which are mainly found around these areas: Mumias, Bunyore, Kisumu, Kendu Bay, Ahero and south western parts of Homa Bay. The leading factors contributing to soil erosion in the basin have also been analysed and prioritized as follows: soil erodibility component followed by rainfall erosivity, vegetation cover management, population density and finally slope factor. This study hence fully achieved its objectives which were: to map the geographical variation of land degradation severity at the Lake Victoria basin; to establish the contributing factors to land degradation in the basin and to identify and recommend land degradation hotspots for further assessment at sub basin level.

5.2 Recommendations

Following the comprehensive assessment of land degradation in the Lake Victoria basin complemented by carefully executed approach, the study draws the following recommendations to be used by key stakeholders like Lake Victoria Basin Commission (LVBC) and the county governments to contain land degradation and reclaim degraded lands in the basin:

- Undertake comprehensive catchment level degradation assessment prioritizing the most affected / hotspot areas (Mumias, Bunyore, Kisumu, Kendu Bay, Ahero and south western parts of Homa Bay). The information obtained from the assessment would include the level, severity and extent of land degradation as well as sedimentations levels so that the information can be used for catchment conservation.

- Deliberate sensitization and training of policy makers at both levels of government (National and County) on the importance of land reclamation.

- Sensitize and empower existing organizations / stakeholders involved in land degradation and reclamation activities such as the community farmers associations (CFAs) and water resource users associations (WRUAs).

- Conduct tree planting and other soil and water conservation measures to include establishing tree nurseries, tree planting and fencing. This should start by targeting the established hotspots as areas of priority.

- Propose and adopt legislations on county bi-laws to regulate exploitation of natural resources e.g. sand harvesting.

- Adopt effective conservation measures targeting natural resources through afforestation, rain water harvesting, and agro-forestry among others.

- Adopt alternative livelihood strategies such as bee and poultry keeping; gum Arabic and aloe Vera growing and others to safeguard against environmental degradation caused by over reliance on unsustainable agriculture.

- Capacity building for farmers and general community on land carrying capacity and climate change adaption strategies.

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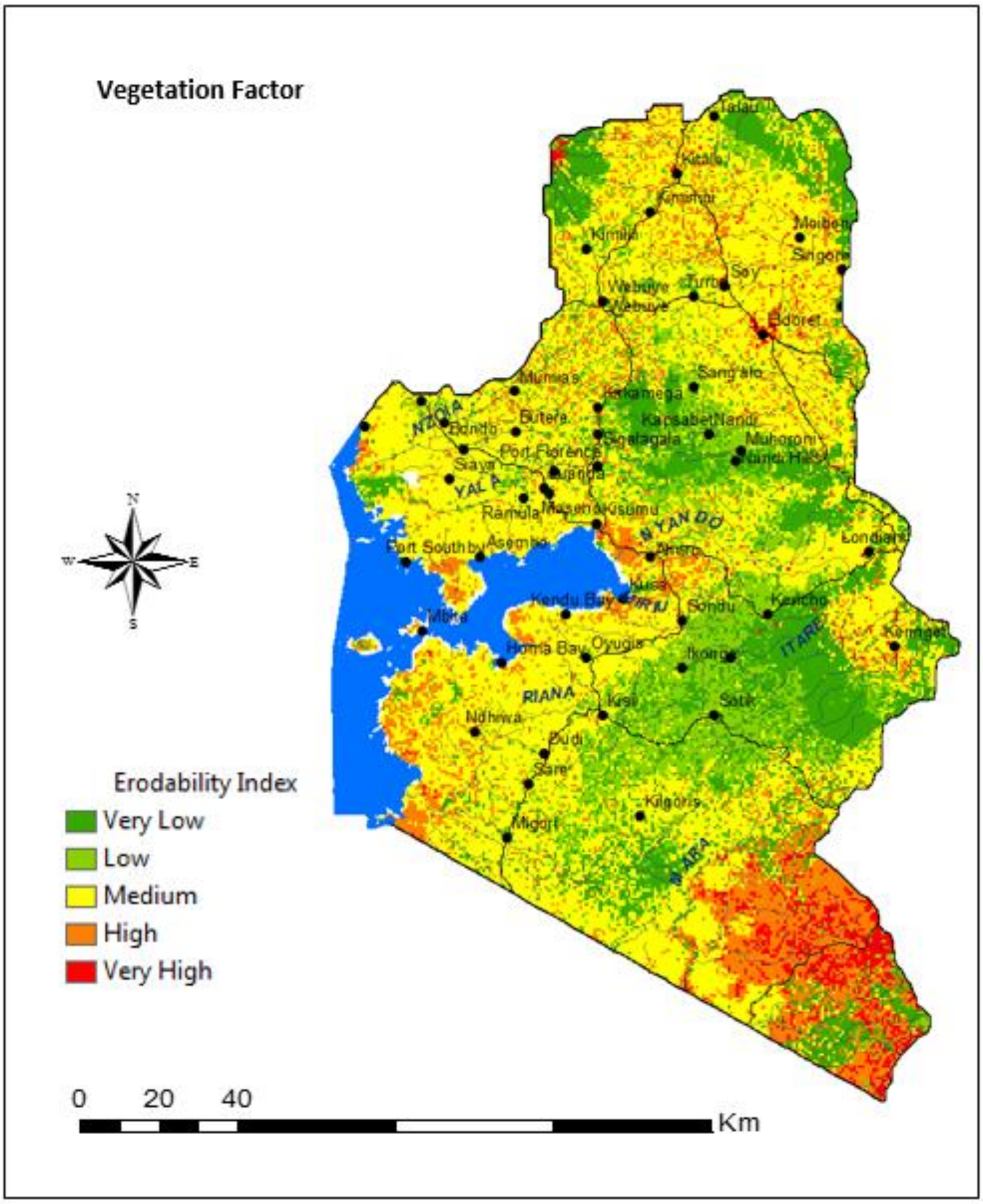
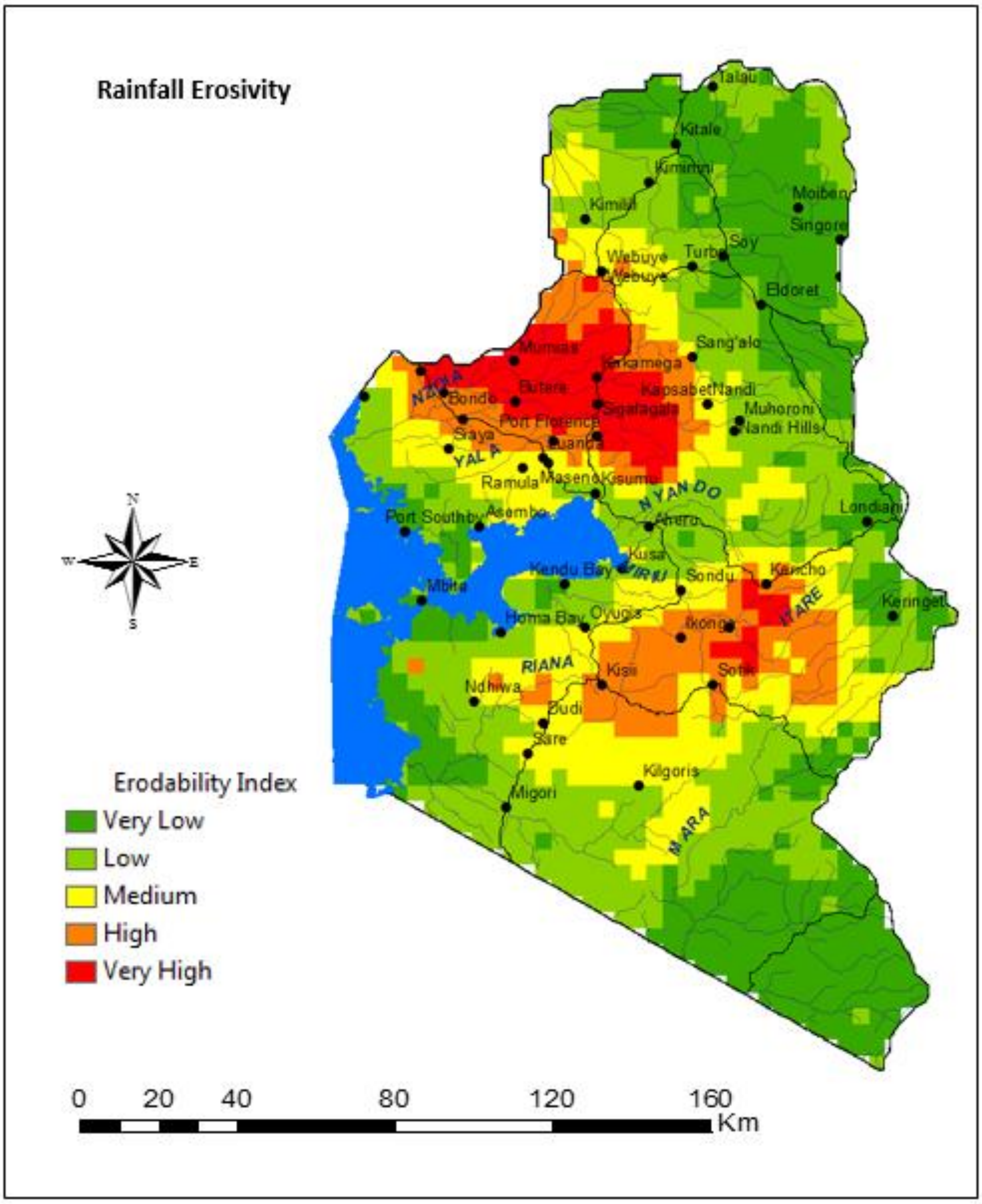
APPENDICES

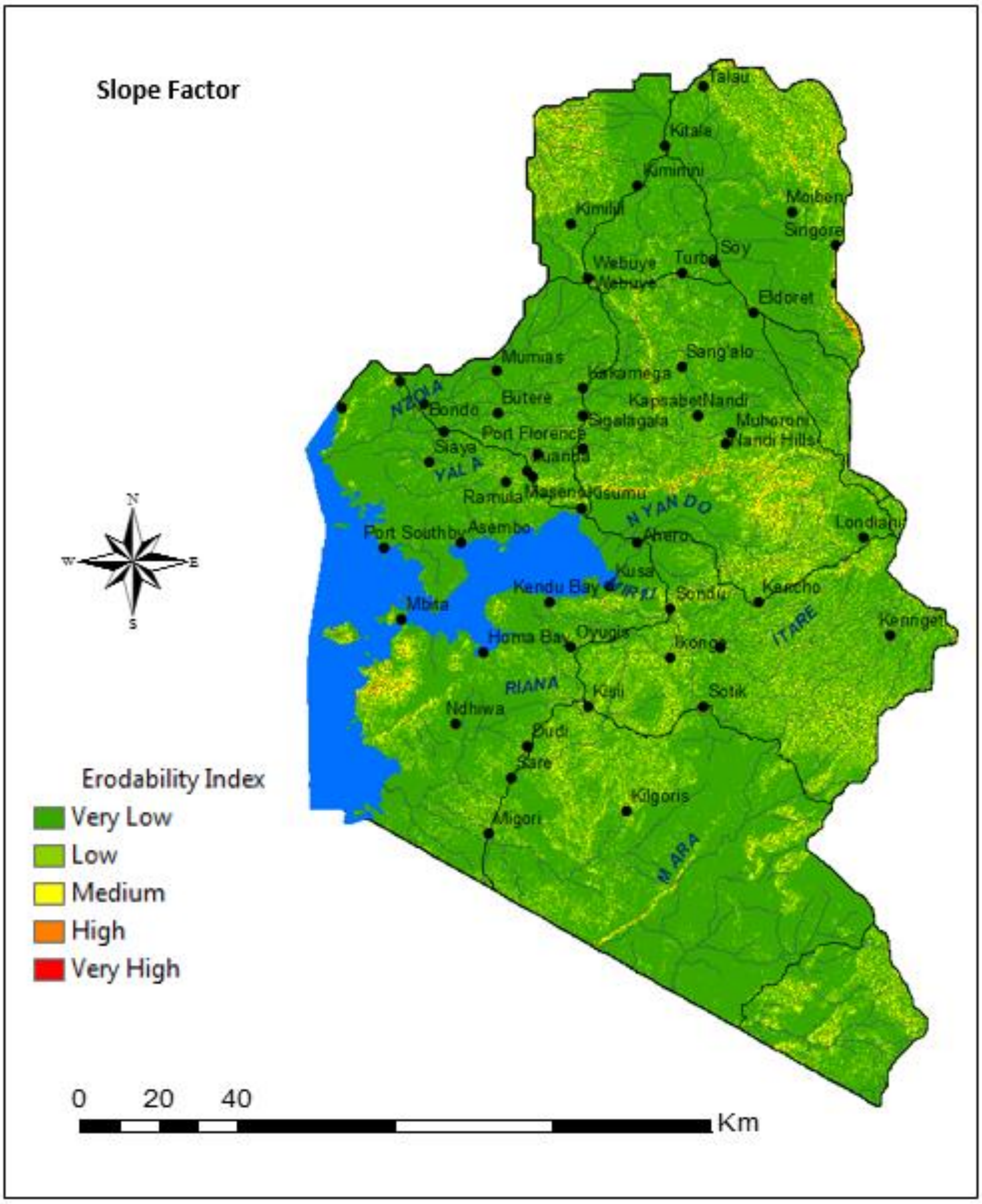
Appendix 1: Vegetation Factor



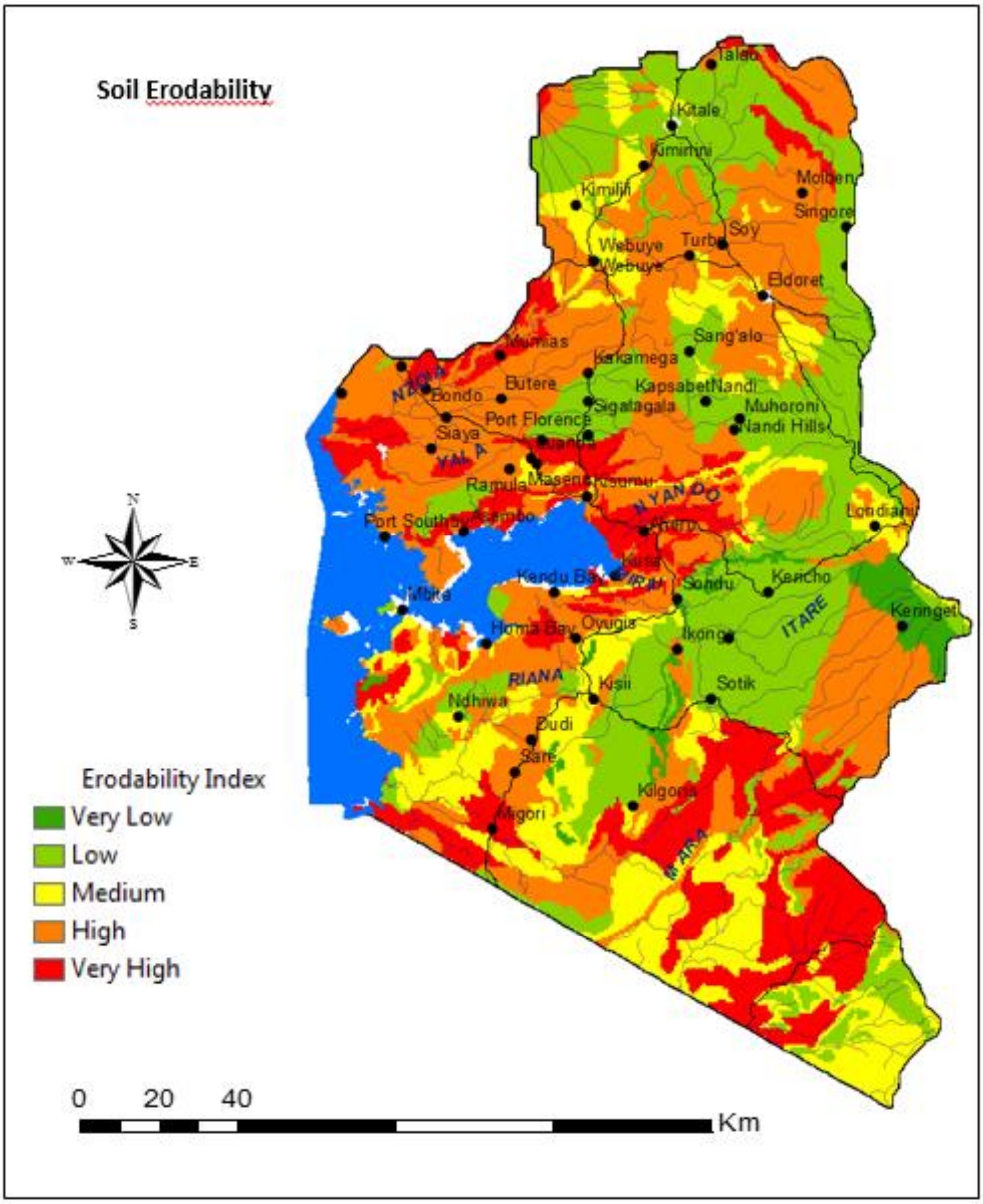
Appendix 2: Rainfall Erosivity



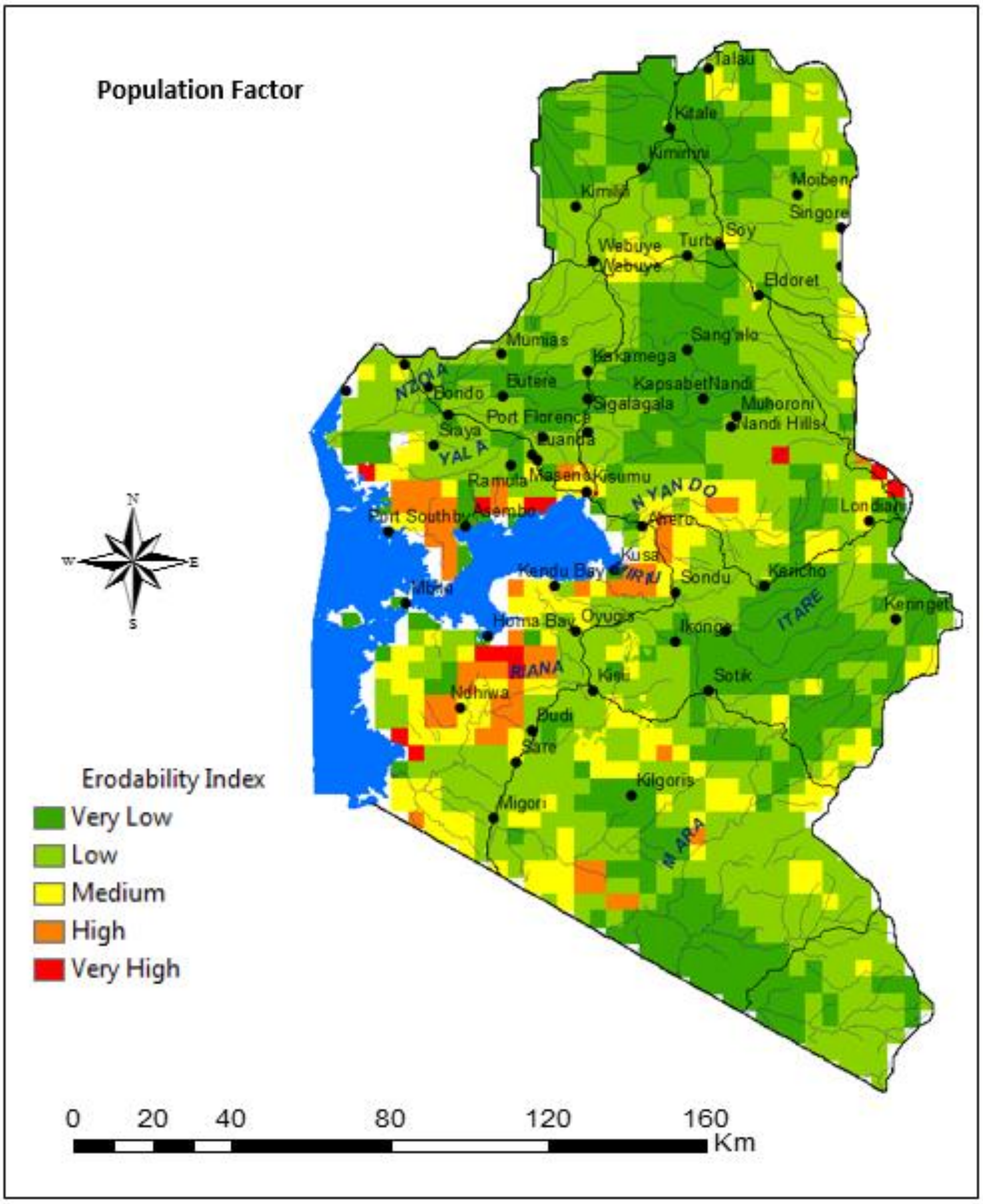
Appendix 3: Slope Factor



Appendix 4: Soil Erodibility



Appendix 5: Population Density



Appendix 6: Land Degradation Map