SOIL EROSION RISK ANALYSIS IN MUBI SOUTH LOCAL GOVERNMENT AREA, ADAMAWA STATE, NIGERIA

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MAY 2017

DECLARATION

I declare that the work in this thesis entitled SOIL EROSION RISK ANALYSIS IN MUBI SOUTH LOCAL GOVERNMENT AREA, ADAMAWA STATE, NIGERIA was conducted by me, it has not been presented in the department of Geography or anywhere for a degree. All quotations and source of information are duly acknowledged by means of references.

RICHARD Sunday Thlakma_____ _____

Name of Student **Signature** **Date**

CERTIFICATION

This thesis entitled SOIL EROSION RISK ANALYSIS IN MUBI SOUTH LOCAL GOVERNMENT AREA, ADAMAWA STATE, NIGERIA, by Thlakma Sunday RICHARD meets the regulations governing the award of the degree of Ph.D (Geograpgy) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to God Almighty for His love, guidance and protection throughout my education career, and to my late father Mr. Richard Wada, my sponsor Mr. Daniel Richard, my beloved mother Mary Richard Wada, my sister Miss Serah Richard Wada and brother Emmanuel Wada.

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ABSTRACT

The study analyzed soil erosion risk in Mubi South. The data used are:land use andland cover map derived from Satellite data of 2016. Slope map, derived from ASTER data, rainfall map derived from 2016 rainfall data of Nigeria and masked to the watershed area. RUSLE and RMMFM model parameters were derived from satellite imageries and laboratory analysis for the analysis of soil erosion risk computation in the watershed area. The methods employed include use of RUSLE and RMMF models with the aid of Geospatial techniques using ArcGIS 10.3 Software. The result showed that gully erosion range between 3m to 20m deep, 20–50m wide and mostly more than 100 m long. It was found that sandy soil covered about 65% of the study area, 18% of silt and 17 % clay particles.About 29% of the area was covered by agricultural activities, 19% covered by forest, and 25% not cultivated and covered by bare land. The study area has about 0.58 to -0.07 normalized difference vegetation index (NDVI) with majority of the area within the lower topography of 570m above sea level. The estimated soil loss in the study area was 3.5 t/ha/yr as at the time of this research. The result of the study also showed that average rate of soil detachment is 1 t/ha/yr. The average transport capacity of overland flow is 1.5 t/ha/yr. Average soil per detachability by raindrop is 69.6 t/ha/yr and total soil particle detachment is 69.66 t/ha/yr and average soil erosion of 3.52 t/ha/yr was estimated. The areas of high soil resistivity had soil aggregate stability ranges from 0.29 to 0.41. Predicted soil particle detachability in the watershed are; 24.2 to 37.2 t/ha/yr (low), (37.2 to 49.7) t/ha/yr (medium) and between 49.71 and 69.6 t/ha/yr(high) respectively. Those areas that had low soil particle detachment were attributed to the high soil resistance. Again, Predicted soil Transport Capacity of Overland Flow indicated about 98% of the study area had about 1.57 t/ha/yr soil transport capacity rate of overflow in the watershed. Predicted total soil particle detachment in the study area was high(about 69.66 t/ha/yr of annual total soil particle detachment) and about 25.26 t/ha/yr low values. It was also found that the south east of the study area had about 25.26 t/ha/yr of the (total low soil particle detachment). It was found that about 50% of the watershed has very low soil erosion risk which was mostly covered by vegetation, some part of agricultural area and hilly regions. About 17% of the study area is covered by low soil erosion risk, 12% moderate, 6% moderately high, 11% high and 4% very high. The moderate and low soil erosion risk classes of the watershed were found along the foot of the hills and mountainous area. Very high to high erosion classes were characterised by gully and rill erosion in the study area. It was found that the highest annual soil loss occurred in an urban area. RMMF and RUSLE models showed performance best test for the goodness-of-fit measure. It was recommended that other soil erosion models be applied in the study area for further comparism and analysis of soil erosion.

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CHAPTER ONE
INTRODUCTION

1.1BACKGROUNDOF THE STUDY

Erosion is a morphological operation during which an object is decreased in size by the removal of materials from around its total mass. Soil erosion is defined as the detachment of materials from earth surface, from its original assemblage and position, and transported to other places by various agents, including water and wind (Osman, 2014). Soil erosion refers to the detachment of soil particles from the surface and also to large mass movements like landslides (Osman, 2014).

Soil erosion is facilitated by numerous factors and processes such as land use, topography, climate, and types of soil. Thus, the actions of man such as encroachment of agricultural activities on forest areas, deforestation for commercial and industrial purposes, urbanization and general misuse of land, as well as the effect of climatic changes; such as high rainfall regime, drought, and desertification, tend to exacerbate impact of soil erosion on the environment,United Nations Educational, Scientific and Cultural Organization (UNESCO, 2009).

Water induced soil erosion can be seen as a spectrum of processes ranging from those which are dominantly fluvial with relatively high water content under low gradient at one extreme, to those which are gravitational with less water under gradient at the other (Horton and Smith, 2006). They form at the following sequence; stream flow, mud flow, overland flow, soil creep, land slum and land slide.Soil erosion by water can be observed as rill, inter-rill erosion and gully formation. Horton and Smith (2006) categorized the first two as rill and sheet erosion, the third as gulling and the last three as mass movement. All causes damage, both by the removal and

deposition of materials. They may occur singly or in combination and there is clearly some overlap among them. Rills are small gullies and sheet erosion is a shallow form of mass movement, while heavy rain storms and runoff water enlarge rill into deep channels called gullies erosion (Wandida, 2006).

Sheet erosion is a process caused by surface runoff, where runoff actually is concentrated in many small rivulets of water (Toy, Foster and Renard, 2002). Rill erosion is a process caused by the concentration of surface runoff. It is of less frequency but higher magnitude than sheet erosion. Rills are channels that are so small that they can be obliterated by normal tillage operations (Toy*et al.,* 2002). Areas of both rill and inter-rill erosion make up the overland flow areas of landscapes (Toy*et al.*,2002). The moment rill erosion concentrates, gully erosion can start to develop. Hudson (1995) defined a gully as 'a steep-sided eroding watercourse which is subject to intermittent flash floods'. Gullies are relatively permanent steep-sided water courses that experience ephemeral flows during rainstorms. Gullies are characterized by a headcut and various steps or knick-points along their course (Morgan, 2005).

Soil erosion is a natural process of soil material removal and transportation through the action of erosive agents such as water, wind, gravity, and human disturbance (Aksoy*et al.*,2009; Asdak, 2009; Kefi*et al.*,2009; Hacısalihoglu*et al.*,2010). However, if soil erosion is occurring faster than necessary due to human disturbance, it will cause negative impacts on the environment and economy (Kefi and Yoshino, 2010).

Soil erosion potential risk is determined by all natural phenomena, which could cause erosion damages (Auerswald, 1993). Soil erosion actual risk is the potential risk plus human induced

intensification of the potential risk. The actual erosion and soil erosion risk is determined by all natural and human caused phenomena, which lead to soil erosion (Auerswald, 1993).

Figure 1.1 shwn the process of soil erosion and their influencing factors Duttmann (2001 cited in Brady and Weil, 2010), soil erosion consists of three processes; detachment, transportation and deposition as shown in Figure 1.1. Detachment of soil particles occur by the impact of raindrops in two ways (Le Bissonais, 1996). Firstly, moistening provokes a breakdown of aggregates. Secondly, raindrops can lead to a mechanical breakdown of soil aggregates. Besides that, soil particle detachment can occur by the flow of running water (Duttmann, 2001). The detached soil particles, mostly fine particles, can lead to surface sealing and crust formation (Osman, 2014). Concerning transportation, the detached soil particles are transported either by a strike of the raindrop or by runoff (Duttmann, 2001). The last step of an erosion process is the deposition of soil particles which occurs at some place lower in elevation (Zuazo*et al.*,2011). Soil particle yield, runoff and soil moisture play a key role concerning interrill erosion and therefore this study terms them as interrill erosion parameters.

Rainfall erosivity {(eroding capacity of the rain (Boardman and Poesen, 2006)} can be described by the variable rainfall intensity, kinetic energy and amount of rainfall (Toy*et al.*,2002). Rainfall intensity determines the number of drops per unit surface (Angulo-Martinéz Beguería, *et al.*2012). Kinetic energy is related to size of raindrops: smaller raindrops strike the soil with a lower velocity and therefore exert a lower force on soil which results in reduced soil particle yields, regardless of rainfall amount and intensity. The kinetic energy of a rainfall event is the

sum of kinetic energies of individual raindrops (Toy*et al.*, 2002). The amount of rainfall is mainly important for the total amount of runoff (Toy*et al.*, 2002).

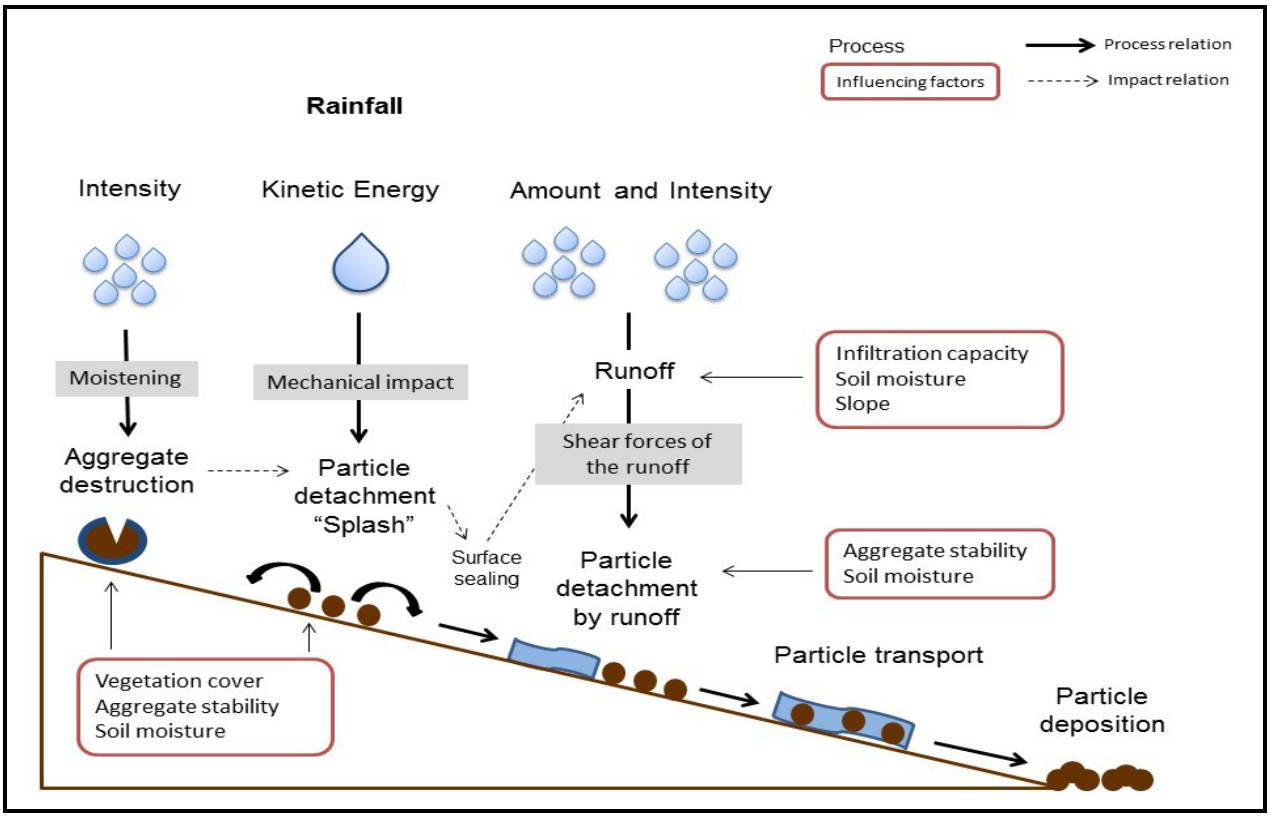


Figure 1.1: Process of Soil Erosionand their Influencing Factors
Source:Adopted from Duttmann,(2001)

Soil erosion by wateris estimated as the most extensive erosion type and results from excess surface runoff. The scope of water erosion is influenced by type of soil, slope and land cover (Verheijen*et al.*,2009). Through the removal of surface soil (including organic matter and nutrients) from soil mass, effective soil functioning is affected. About one-third of land used for agriculture at global level has been affected by soil degradation. Most of this damage was caused by water and wind erosion (Braimoh and Vlek, 2008).

In twenty-firts century, soil erosion by water has become a worldwide issue because of progressive decrease in the ratio between natural resources and population and to climate change. Soil erosion negatively impacts on ecology and can lead to reduced crop productivity, worsened water quality, lower effective reservoir of water levels, flooding and habitat destruction (Park*et al.*,2011). In both the past and present days, soil erosion is one major and most widespread environmental threat. Risk assessment of soil erosion caused by water is indispensable to the creation of effective policies and measures on water and soil resource conservation.

Although soil erosion is a physical process with considerable variation globally in its severity and frequency, where and when erosion occurs is also strongly influenced by social, economic, political and institutional factors. Prevention of soil erosion; which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation. This in turn, requires a thorough understanding of the processes of erosion (Morgan, 2005). Undesirable effect of erosion may not be significant in a short time, but it could be clear in a long time.

Soil erosion is perceived as a major and widespread form of soil degradation and it has large environmental and economic impact at different scales (Zhang*et al.*,2009). Though erosion originally is a natural process, influenced by physical factors, current human interventions in the landscape often accelerate natural erosion rates tremendously (Karydas,Sekuloska and Silleos, 2009). Consequently, social, economic and political factors are decisive in determining soil erosion risk (Eckelmann *et al.*, 2006). The anthropogenic pressure is essentially reflected in land cover, where land use change and -intensity and cultivation practices; such as tillage and

implementation of conservation strategies, determine vulnerability to soil erosion (Lesschen*et al.*,2007). In order to effectively formulate mitigation strategies and implement conservation measures to counteract soil erosion, it is essential to objectively identify and quantify areas at risk (European Commission, 2006).

Human activities continue to put pressure on the world's natural resources and ecosystems. Many of these natural systems can withstand this pressure only up to a certain thresholdcalled tippingpoint,beyond which serious negative and possibly irreversible consequences occur. As the exact thresholds are often unknown, prudence requires identifying danger zones before the threshold is reached, or safety zones in which humanity can safely operate. It is therefore important to find out where environmental thresholds exist, what values they have and to measure distance to this threshold. This should help to alert policy makers. In due time before a danger zone is reached and enable them to respond effectively to avoid unsustainable consequences. Ordinal and scalar scales threshold is usually used and the erosion rate is expressed in qualitative (e.g. 'low erosion risk', 'moderate erosion risk', 'moderate high erosion risk', 'high erosion risk', 'very high erosion risk', as modified in the system of Norway)and quantitative terms (t/ha/y)(Verheijen*et al.*, 2009).

In Nigeria, World Bank(1990) estimated that soil erosion affects over 50 million people and accounts for loss of resources that amount to US 3000 million dollars per year. For decades, soil erosion has been a major environmental problem in Nigeria (Olofin, 1994). Erosion is the most serious natural hazard in Nigeria, affecting several parts of the country. It has killed people,

destroyedroads, destroyed homes, schoolsand farmlands and displaced poor people (Federal Republic of Nigeria, 2007).

Soil erosion of various types and extent arealso found in various parts of Adamawa state but most especially where man's activities have stripped off vegetation that normally holds and protects the soil. In Adamawa state, researches have shown that the different causesof soil erosion sprang fromhuman activities for various purposes such as; intensive cultivation, over grazing, bush burning and deforestation. These are the principal determinants of variation in typesand intensity of soil erosion; such as sheet erosion, rill erosion and gully erosion (Tekwa*et al.*,2014).Mubi Local Government Area like any other part of Adamawa State, is still witnessing various types of soil erosion. The most spectacular and probably most destructive type of soil erosion in Mubi area is gullyerosion.This isfollowed by rill erosion;which is heightened by rapid population increase and lack of alternative sources of employment, thereby exerting pressure on the land, leading to increased use of marginal land (Tekwa, Laflen and Yesuf, 2014).

Tekwa*et al.*(2014)stated that the problem of soil erosion has persistedin these areasover years. In some placessuch as V-vally, Digil and Lamurde (Mubi area), rill erosion is common in the foothills.Soil conservation measures were put in place since 1960s, but still soil erosion is at alarming rate hence the need to assess and predictthe rate of soil erosion and risk in the study area.

During the last decade (2010), many different models and theories had been proposed to describe and anayse soil erosion by water and associated sediment yield.The models and theories

wereused to predict soil loss and to assess soil erosion risk. GIS isalso used as basis for interpolating spatial variability of hydrophysical parameters for soil erosion model (Tesfahunegn*et al.,* 2011b). It is against this background this study was carried out in order to analys, estimate and predict soil erosion risk in the Mubi South Local Government Area of Adamawa State, Nigeria.

1.2 STATEMENT OF THE RESEARCH PROBLEM

The study area (Mubi South) was reported as being exposed to erosion of varied intensities as a result of inappropriate agricultural practices, deforestation, overgrazing, construction activities and variation in climatic condition (Tekwa*et al.,*2014).As a result of this, ithas led to reduction in crop productivity, flooding, ecological destruction and environmental degradation(Tekwa*et al.,*2014).

Previous research(Tekwa*et al.,*2014) observedthat soil erosion in the study area also alters vegetation cover, ground slope, slope length and shape, thereby influencing soil erosion rateand leading to the formation of gullies and rills. Ithas also led to significant soil loss and degradation, destruction of physical infrastructures such as buildings, drainages, roads andculverts; especially around Barama, Anguwan Barkono, Digil, Lamurde and Tudun Wada of the study area(Tekwa*et al.,*2014). These were also confirmed by the present researcher during reconnaissance surveys of 2015 and January 2016.Thus, the needfor assessment andpredicting soil erosion risk in the study area using geospatial techniques become imperative,so as to provide preventive and conservation measures in order to reduce the menaces of soil erosion risk in the study area.

Tekwa*et al.* (2014)estimated monthly soil loss from ephemeral gully erosion features in some parts of Mubi North and Mubi South. They found that soil particles in the study area were mainly sandy; with silt content range of 18-25% and clay contents in the range of 19-26% that did not differ significantly among selected sites. Organic matter content was low. The monthly area of soil loss ranges from 1.5 to 143 m^2, and volume of soil loss was 0.4 to 131 m^3, that were significantly higher in the months of August and September than in the monthsof June, July and October. Ephemeral gully erosion rates for Muvur and Digil sites were greater than at other sites. The monthly rates of ephemeral gully erosion ranged from 35 to 132 m^3, and 15 to 79 m^3 in terms of surface area and volume of soil loss respectively. The soil loss rates thereafter decreased from 18 $m^2$to 5 m^2 and 11 $m^2$to 2 m^2 in terms of surface area and volume of soil loss respectively. The authors recommended that future researches should consider developing empirical soil loss predictor model(s) for Mubi and environs.The authors concentrated on only gully erosion for selected sites and concentrated mainly on their chemical properties. Also, the authors took soil samples only in gully areas and did not employGIS techniques to estimate and predict spatial distribution of soil erosion risk. This is one of the researched gap filled.

Interest in soil erosion risk was triggered by a growing awareness of off-site impacts of soil erosion. These impacts are predominantly associated with movement of eroded soil, sediment particles and changes in water flows (both through and across the soil). The off-site problems are often more evident, and include loading and sedimentation of watercourses and reservoirs, increases in stream turbidity; all of which can disturb aquatic ecosystems and upset the geomorphological functioning of river systems (Owens, 2005).

To reduce such limitations; geostatistic techniques that interpolate data for an entire watershed from appropriately sampled point measurements, are readily available (Tesfahunegn*et al.*,2011a and b). Mapping through conventional methods demand intensive data collection, which is often difficult to practice in complex terrains (Tesfahunegn*et al.*, 2011b). The Geographic Information System (GIS) techniques are easy and time effective tools for mapping and analyzing erosion input data of hydrophysical parameters (Tesfahunegn *et al.*,2011b).

However, no research has explored the power of Revised Morgan, Morgan and Finney and RUSLE with Geospatial Techniques for estimation and prediction of soil erosion risks in Mubi south of Adamawa State, Nigeria, to the researchers best of knowledge despite the high rate of soil erosion in the area.Though, Tekwa*et al.* (2014)attempted to predict soil erosion in some parts of Mubi North and South,but only focused their attention at the chemical properties of some selected gully erosion sites in the area using EGEM model.The study did not consider hydrophysical properties of the soils which play a major role in predictions of soil erosion risk. They also failedto map areas that were vulnerableto soil erosion risk. Moreover, they did not apply geospatial techniques to show patterns, spatial distribution andmaps ofsoil erosion risk in the study area.

Research conducted by Gebreyesus*et al.* (2014) on soil erosion prediction using Morgan-Morgan-Finney model in a GIS environment brought the need because is flexible, itrequired less data and easy integration with GIS environment to conduct such research in Mubi South Local Government area in order to test the performance of the RMMF and RUSLE model. Hence, the quest for integrated models of Revised Morgan-Morgan Finney model, RUSLE, remote sensing

and GIS techniques to analyze soil erosion risk in Mubi South Loclal Government Area gave rise to the current study.

The research provided answered the following research questions:

i. What are the types and observed effects of soil erosionin the study area?
ii. What are the characteristics ofhydrophysical parameters that enhancesoil erosion within the study area?
iii. How spatiallydistributed are the hydrophysical parameters in the study area?
iv. What is the pattern ofdistribution of soil loss, in the watershed area?
v. Which areas are morevulnerable to soil erosion risk in the study area?
vi. To what extent canRMMF and RUSLEModels predict soil loss in the study area?

1.3AIM AND OBJECTIVES

The aim of this study is to analyze soil erosion risk in Mubi Southwatershed area with the aid of RMMF, RUSLE models andGeospatialtechniques.

The stated aim was achieved through specific objective which include to:

i. map types of soil erosion andobservetheir effectsin the study area.
ii. characterize hydrophysical parameters forsoilerosion types in the study area.
iii. assessthedistribution patternsof hydrophysical parameters in the study area.
iv. estimatesoil loss in the watershed areas.
v. predict areas that are vulnerable to soil erosion risk in the study area.
vi. validate the performance of RMMF and RUSLE Model in the study area.

1.4 THE SCOPE OF THE STUDY

This research was carried out in Mubi south watershed area, Adamawa State and focused on analysis of soil erosion risk using Revised MMF and RUSLEmodel with GIS techniques. The watershed area consists of the following fourteen (14) villages and Local Government Headquarters, namely: Sebbore, Gude, Gudere, Wafa, Chaba, Masuwa, Lunguwa,Gyakwar, Wuro Babbowa, Gavayi, Gella 2DH, Gella, Giranburum and Uro Gella which is the Local Government Headquarters of Mubi South. The hydrophysical parameters used as input data were collected from different sources such as empirical relations,rainfall data, land use (forest land, protected area, cultivated, bare fields, grazing land, mixed-forest and residential), digital elevation model (DEM), soil texture, soil moisture, soil detachability index, bulk density, cohesion of soil surface, soil moisture storage capacity, organic matter content effective hydrological top soil depth, and ratio of actual to potential evapotranspiration and cropparameter (mainly maize, beans and sorghum)from erosion plots. The research covered soil erosion data as atJuly to Aujust,2016.

1.5 SIGNIFICANCEOF THE STUDY

Soil erosion is a very dynamic spatial phenomenon. The information on spatial extent of erosion risk area and its severity are pre-requisites for soil conservation planning and watershed management programmes. Spatial patterns of erosion risk are too complex and conventional method of mapping these lands based on field survey does not provide spatially explicit information. Erosion models can be used and analysedas predictive tools for assessing soil loss and soil erosion risk for conservation planning (Popp*et al.*,2000).

Soil erosion and related degradation of land resources are highlysignificant spatio-temporal phenomena in many countries(Pandey*et al.*,2009). Soil problems have become a threat to sustainable agriculturalproduction and water quality.In many regions, uncheckedsoil erosion and associated land degradation have made vast areaseconomically unproductive. Often, a quantitative assessment isneeded to infer extent and magnitude of soil erosion riskso that effective management strategies can be resorted to. Thecomplexities of variables make precise estimation or predictionof soil erosion difficult. The latest advances in spatial informationtechnology have augmented existing methods and provided efficient methods of monitoring, analysis and managementof earth resources. Digital elevation model (DEM) alongwith remote sensing data and GIS can be successfully used toenable rapid, as well as detailed, assessment of soil erosion risk/hazards(Kouli*et al.*,2009).

Spatial and quantitative information onanalysis and prediction of soil erosion risk on a watershed and sub-watershed scale contributes significantly to the planning for soilconservation, erosion controland management of the watershed environment. The results of estimation of soil loss in sub-watersheds were carried out on an experimental basis in manytropical regions using different analysis and prediction techniques (Van De*et al.*,2008).The analysed amount of soil loss and its spatial distribution can provide a basis for comprehensive management and sustainable land use for the watershed.

Thus, the present study wascarried out with theaim to analyse and predict soil erosion risk using revised Morgan-Morgan-Finney, RUSLE modeland GIS techniques; which in turn,wasused as a scalable model for watershed in the Mubi South Local Government Area

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 CONCEPTUAL FRAMEWORK

2.1.1 Processes and Mechanics of Erosion

Soil erosion is a two-phase process consisting of detachment of individual soil particles from soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available to transport the particles, a third phase; deposition, occurs (Morgan, 2005).

Tables 2.1 show the efficiency of forms of water erosion. Rainsplash is the most important detaching agent. As a result of raindrops striking a bare soil surface, soil particles may be thrown through the air over distances of several centimeters. Continuous exposure to intense rainstorms considerably weakens the soil. The soil is also broken up by weathering processes, both mechanical, by alternate wetting and drying, freezing and thawing, frost action and biochemical processes. Soil is disturbed by tillage operations and by the trampling of people and livestock. Running water and wind are further contributors to detachment of soil particles. All these processes loosen the soil so that it is easily removed by agents of transport (Morgan, 2005).

The transporting agents comprise those that act spatiallyand contribute to the removal of a relatively uniform thickness of soil, and those that concentrate their action in channels. The first group consists of rainsplash, surface runoff in the form of shallow flows of infinite width, sometimes termed sheet flow but more correctly called overland flow, and wind. The second group covers water in small channels; known as rills, which can be obliterated by weathering and ploughing, or in the larger more permanent features of gullies and rivers. A distinction is

commonly made for water erosion between rill erosion and erosion on the land between the rills by the combined action of raindrop impact and overland flow. This is termed interrill erosion. To these agents that act externally, picking up materials from and carrying them over the ground surface, added and transported by mass movements; such as soil flows, slides and creep, in which water affects the soil internally, altering its strength (Morgan, 2005).

Severity of erosion depends upon the quantity of material supplied by detachment over time and capacity of the eroding agents to transport it. Where the agents have capacity to transport more material than is supplied by detachment, the erosion is described as detachment-limited. Where more material is supplied than can be transported, the erosion is transport limited (Morgan, 2005).

According to Morgan(2005), the energy available for erosion takes two forms: potential and kinetic. Potential energy (*PE*) results from the difference in height of one body with respect to another. It is the product of mass (*m*), height difference (*h*) and acceleration due to gravity (*g*), so that:

$$PE = mhg$$

2.1

Table 2.1 Efficiency of forms of water erosion

Form	Mass*	Typical velocity (ms^{-1})	Kinetic energy†	Energy for erosion‡	Observed sediment transport§ (gcm^{-1})
Raindrops	0.6R	6.0	18*R*	0.036*R*	20
Overland flow	0.5R	0.01	2.5 \ 10-5*R*	7.5 \ 10-7*R*	400
Rill flow	0.5R	4¶	4*R*	0.12*R*	19,000

Source: Morgan (2005)

* Assumes rainfall mass of *R* of which 50 per cent contributes to runoff.

† Based on $1/2mv^2$.

‡ Assumes that 0.2 per cent of the kinetic energy of raindrops and 3 per cent of the kinetic energy of runoff is utilized in erosion.

§ Totals observed in mid-Bedfordshire, England, on an 11° slope, on sandy soil, over 900 days. Most of the energy of raindrops contributes to soil particle detachment rather than transport.

¶ Estimated using the Manning equation of flow velocity for a rill, 0.3m wide and 0.2m deep, on a slope of 11°, at bankfull, assuming a roughness coefficient of 0.02 which, in units of kg, m and ms-2 respectively, yields a value in Joules. The potential energy for erosion is converted into kinetic energy (*KE*), the energy of motion. This is related to the mass and velocity (n) of the eroding agent in the expression

$$KE = m\ 1/2mv^2 \qquad 2.2$$

Which, in units of kg and m s^{-1}, also gives a value in Joules. Most of this energy is dissipated in friction with the surface over which the agent moves so that only 3–4 % of the energy of running water and 0.2 per cent of that of falling raindrops is expended in erosion (Pearce, 1976). An indication of the relative efficiencies of the processes of water erosion can be obtained by applying these figures to calculations of kinetic energy, using equation 2.2, based on typical velocities (Table 2.1). The concentration of running water in rills affords the most powerful erosive agent but raindrops are potentially more erosive than overland flow. Most of the raindrop energy is used in detachment; however, so that the amount available for transport is less than that from overland flow. This is illustrated by measurements of soil loss in a field in mid-Bedfordshire, England. Over a 900-day period on an 11° slope on a sandy soil, transport across a centimeter width of slope amounted to 19,000 g of sediment by rills, 400 g by overland flow and only 20 g by rainsplash (Morgan *et al.*, 1986).

2.1.1.1 Hydrological basis of erosion

According to Withers and Vipond (1974), processes of water erosion are closely related to the pathways taken by water in its movement through vegetation cover and over the ground surface. During a rainstorm, part of the water falls directly on the land, either because there is no vegetation or because it passes through gaps in plant canopy. This component of the rainfall is known as direct throughfall. Part of the rain is intercepted by canopy, from where it either returns to the atmosphere by evaporation or finds its way to the ground by dripping from leaves; a component termed leaf drainage, or by running down the plant stems as stemflow. The action of direct throughfall and leaf drainage produces rainsplash erosion. The rain that reaches the ground

may be stored in small depressions or hollows on soil surface or may infiltrate the soil; contributing to soil moisture storage, to lateral movement downslope within the soil as subsurface or interflow or, by percolating deeper in to groundwater. When the soil is unable to take in more water, the excess contributes to runoff on soil surface, resulting in erosion by overland flow or by rills and gullies.

Figure 2.1 typical infiltration rates for various soils. The rate at which water passes into soil is known as infiltration rate and this exerts a major control over the generation of surface runoff. Water is drawn into soil by gravity and by capillary forces, whereby it is attracted to and held as a thin molecular film around the soil particles (Withers and Vipond, 1974). During a rainstorm, spaces between soil particles become filled with water and capillary forces decrease so that the infiltration rate starts high at the beginning of a storm and declines to a level that represents maximum sustained rate at which water can pass through the soil to lower levels (Figure 2.1).

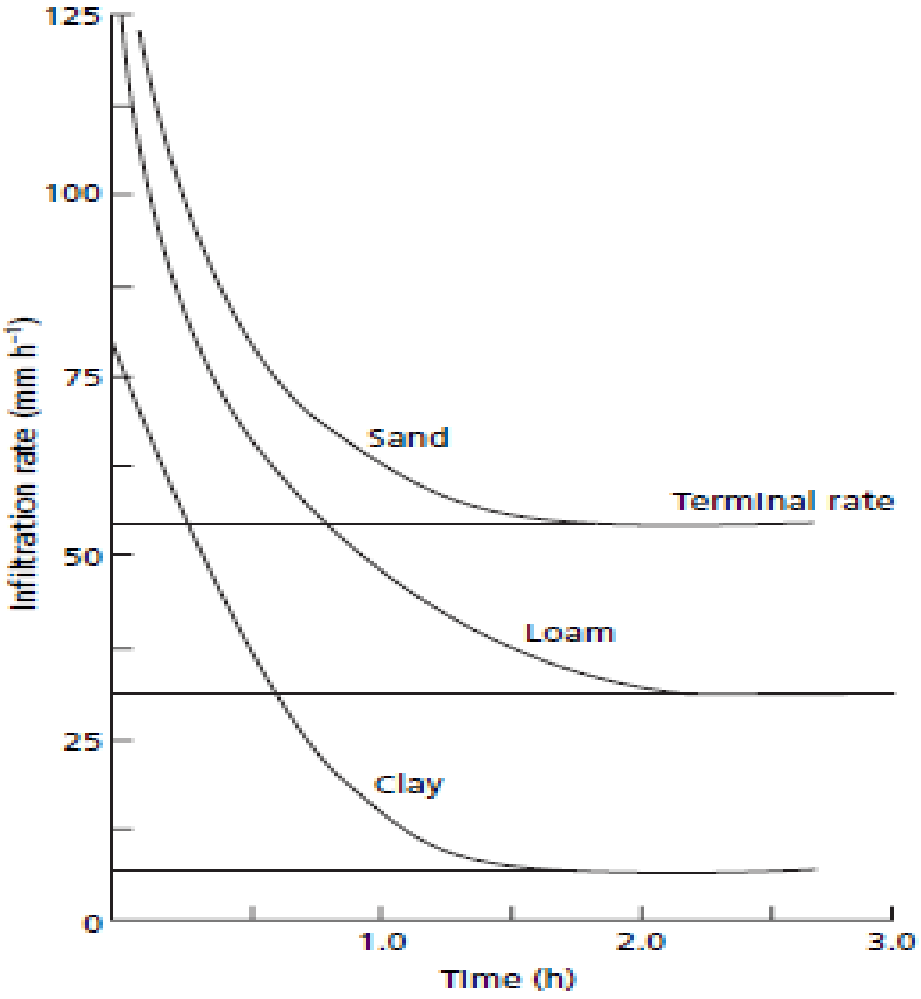


Figure 2.1 Typical infiltration rates for various soils

Source: Adopted after Withers andVipond (1974)

The level of the infiltration capacity or terminal infiltration rate as shown in Figure 2.1 corresponds theoretically to saturated hydraulic conductivity of the soil (Withers and Vipond, 1974).

In practice; however, infiltration capacity is often lower than the saturated hydraulic conductivity because of air entrapped in soil pores as the wetting front passes downwards through the soil horizons (Withers andVipond, 1974). Infiltration rates depend upon the characteristics of the soil types. Generally, coarse-textured soils such as; sands and sandy loams have higher infiltration rates than clay soils because of the larger spaces between pores in sand (Withers and Vipond, 1974). Infiltration capacities may range between or from more than 200mmh^{-1} for sands to less than 5mmh^{-1} for tight clays as shon in Figure 2.1. In addition to the role played by inter-particle spacing or micropores, larger cracks or macropores exert important influence over infiltration rate. They can transmit considerable quantities of water so that clays with well-defined structures and it can have infiltration rates that are much higher than e expected from their soil texture.

The local variability in infiltration rates can be quite high because of differences in structure, compaction, initial moisture content and profile form of the soil and vegetation density. Field determinations of average infiltration capacity using infiltrometers may have coefficients of variation of 70–75%. Eyles (1967) measured infiltration capacity on soils of the Melaka Series near Temerloh, Malaysia, and obtained values ranging from 15 to 420mmh^{-1}, with a mean of 147mmh^{-1}.

According to Horton (1945), if rainfall intensity is less than the infiltration capacity of the soil, no surface runoff occurs and the infiltration rate equals the rainfall intensity. If the rainfall intensity exceeds the infiltration capacity, infiltration rate equals the infiltration capacity and the excess rain forms surface runoff. As a mechanism for generating runoff; however, this comparison of rainfall intensity and infiltration capacity does not always hold. Studies conducted

by Morgan *et al.* (1986) in Bedfordshire,England on a sandy soil show that measured infiltration capacity is greater than 400mmh^{-1} and that rainfall intensities rarely exceed 40mmh^{-1}. Thus, no surface runoff would be expected, whereas, in fact, the mean annual runoff is about 55mm from a mean annual rainfall of 550mm. The reason runoff occurs is that these soils are prone to the development of a surface crust(Boiffin, 1985). Two types of crust can be distinguished. Where a crust forms 'in situ'on the soil, it is termed a structural crust; where it results from the deposition of fine particles in puddles, it is called a depositional crust (Boiffin, 1985).

Also, studies by Boiffin and Monnier (1985)and Martin *et al.* (1997) on loamy soils in north-east France, show that crusting can reduce infiltration capacity from 45–60 6mmh^{-1}to about 6mmh^{-1} with a structural crust and 1mmh^{-1} with a depositional crust. Reductions in infiltration of 50 (Hoogmoed and Stroosnijder, 1984) to 100 per cent (Torri *et al.*, 1999) can occur in a single storm. The importance of crusting and sealing was also emphasized by Poesen (1984), who observed that infiltration rates were higher on steeper slopes where higher erosion rate prevented the seal from forming. This mechanism explains why infiltration rates sometimes increase with rainfall intensity (Nassif and Wilson 1975). Bowyer-Bower (1993) noted that for a given soil, infiltration capacity was higher with higher rainfall intensities because of their ability to disrupt surface seals and crusts that would otherwise keep the infiltration rate low.

2.1.2Strategies of Erosion Control

Since erosion is a natural process, it cannot be prevented. But, it can be reduced to a maximum acceptable level or soil loss tolerance. This should be considered as a performance criterion that erosion-control measures are expected to achieve (Morgan, 2005).

2.1.2.1 Soil loss tolerance

Theoretically, soil erosion should be maintained at a rate that equals or is below the natural rate at which new soil forms. Unfortunately, it is difficult to recognize when this balance exists. Although rates of soil loss can be measured, rates of soil formation are so slow that they cannot be easily determined. According to Buol *et al.* (1973), rates of soil formation throughout the world range from 0.01 to 7.7mmyr^{-1}. The fastest rates are exceptional however, and the average is about 0.1 mmyr^{-1} (Zachar, 1982).

An alternative approach that avoids need to measure the rate of new soil formation directly is to estimate rate required to match rate of removal by erosion and solution in areas where an equilibrium condition might be presumed to exist. Using data from small watersheds under forest and grassland, Alexander (1988) noted that required rates to be between 0.3 and 2 t ha^{-1} annually with majority being below 1t ha^{-1} which; assuming a bulk density for the soil of 1.0Mgm^{-3} is equivalent to 0.1mmyr^{-1}. Such a rate, however, may be a rather conservative indicator for development of an agriculturally productive soil.

Hall *et al.* (1979) suggested that in soils of medium to moderately coarse texture on well managed crop land, the annual rates of formation of A horizon can exceed 11 t ha^{-1}. This could be because the subsoil can be improved by incorporating it with top soil during tillage and by

adding fertilizers and organic matter. It is against this background that values for soil loss tolerance are set so as to maintain an adequate rooting depth and avoid significant reductions in yield while the surface layer of soil is removed by erosion (McCormack and Young, 1981).

Soil loss tolerance is then defined as the maximum permissible rate of erosion at which soil fertility can be maintained over 20–25 years(Hudson, 1981). A mean annual soil loss of 11 t ha^{-1} is generally accepted as appropriate but values as low as 2 t ha^{-1} are recommended for particularly sensitive areas where soils are thin or highly erodible (Hudson 1981).Where soils are deeper than 2m, subsoils are capable of improvement and reductions in crop yield are unlikely to be brought about by erosion over the next 50 years or more, some scientists favour increasing the tolerance to 15–20 t ha^{-1} (Schertz, 1983)

2.1.2.2 Principles of soil conservation

Looking on mechanics of the detachment and transport of soil particles by rainsplash, runoff and wind, strategies for soil conservation must be based on; covering soil to protect it from raindrop impact; increasing the infiltration capacity of the soil to reduce runoff; improving aggregate stability of the soil; and increasing surface roughness to reduce the velocity of runoff and wind (Morgan, 2005).

Agronomic measures utilize the role of vegetation to protect soil against erosion. Soil management is concerned with ways of preparing soil to promote plant growth and improve its structure so that it is more resistant to erosion. Mechanical or physical methods, often involving engineering structures, depend on manipulating the surface topography for example, installing

terraces or windbreaks to control flow of water and air. Agronomic measures combined with good soil management can influence both detachment and transport phases of erosion, whereas mechanical methods are effective in controlling the transport phase but do little to prevent soil detachment (Table 2.2).

Table 2.2Effect of Various Soil Conservation Practices on the Detachment and Transport Phases of Erosion.

Practice	**Control over**					
	Rainsplash		**Runoff**		**Wind**	
	D	T	D	T	D	T
Agronomic measures						
Covering soil surface	*	*	*	*	*	*
Increasing surface roughness	-	-	*	*	*	*
Increasing surface depression storage	+	+	*	*	-	-
Increasing infiltration	-	-	+	*	-	-
Soil management						
Fertilizers, manures	+	+	+	*	+	*
Increasing surface roughness (tillage)	-	-	*	*	+	*
Subsoiling, drainage	-	-	+	*	-	-
Mechanical measures						
Contouring, ridging	-	+	+	*	+	*
Terraces	-	+	+	*	+	+
Shelterbelts	-	-	-	-	*	*
Waterways	-	-	-	*	-	-

D, detachment, T, transport; – no control; + moderate control; * strong control.

Source: Adopted from Morgan (2005).

As shown on Table 2.2, agronomic measure is always given preference as the major means of soil conservation practices for soil erosion. It is so because these are less expensive and deal

directly with reducing raindrop impact, increasing infiltration, reducing runoff volume and decreasing wind and water velocities. They are more easily fitted into existing farming systems and more relevant to maintaining or restoring biodiversity and plant communities. Mechanical measures are largely ineffective on their own because they cannot prevent the detachment of soil particles. Their main role is in supplementing agronomic measures, being used to control flow of any excess water and wind that may arise. Many mechanical works are costly to install and maintain. Some; such as terraces, create difficulties for farmers. Unless the soils are deep, terrace construction exposes the less fertile subsoils and may therefore result in lower crop yields (Morgan, 2005). On irregular slopes, terraces will vary in width, making for inefficient use of farm machinery, and only where slopes are straight terraces can this problem be overcome with parallel terrace layouts. Also, there is a risk of terrace failure in severe storms. When this occurs, the sudden release of water ponded up on the hillside can do more damage than if no terraces had been constructed. For all these reasons, terracing is often unpopular with farmers Morgan (2005).

2.1.2.3. Drivers and constraints

Globally, soil erosion associated with agricultural land is more widespread than that associated with other land uses. Erosion control is therefore strongly influenced by factors that encourage or discourages farmers from adopting soil conservation. In non-agricultural areas, erosion is important wherever it threatens the integrity of a resource. For example, destruction of roads, track ways and footpaths, sedimentation of water bodies or exposure of buried pipelines. The driver for erosion control is to protect the resource and prevent liability for environmental damage, particularly in societies that adopt principle of the ‘polluter pays. Moreover,

organizations like highway agencies, engineering companies and pipeline companies should install protective measures because they want to retain their reputations for sensitive management of the environment (Morgan, 2005).

Perceptions of Erosion: The relevance of conservation measures to a farming system depends in part on how farmers and others perceive erosion problem and its consequences. Most farmers are aware of the problem and its effects. The notion of peasant farmer damaging land through ignorance is severely mistaken. Both small-scale and commercial farmers are more concerned with profit than conserve the land. Farmars are more concerned with maximized yield than maximizing input to optimized yield (Hudson, 1981). Farmers who work marginal land because there is no other land available are generally well aware of the damage they cause but have poor economic and knowledge, power to help the situation. Surveys of small-scale farmers in Sierra Leone showed that the majority correctly perceived erosion problem on their land and associated it with high rainfall, steep slopes and lack of vegetation cover (Millington, 1987). Since farmers appreciate erosion mainly through its effects on yield, sediment accumulation on foot slopes and formation of gullies, they underestimate its seriousness compared with more scientific assessments based on reductions in the depth of soil (Stocking and Clark 1999; Holden and Shiferaw, 1999). Generally, the farmer is not unwilling to change practices but will do so only if substantial benefits arise and the investment costs can be recovered (Hudson, 1981).

Land Tenure:The arrangements by which tenure is granted to land user can influence attitudes towards soil conservation. Where farmers own the land, they are more likely to consider the long-term consequences of their actions or in actions and adopt soil-protection measures unless

the need for short-term survival dictates otherwise. Tenure systems based on short-term cultivation rights, sharecropping and collectives generally lead to poor management because of uncertainty about whether conservation work carried out on the land will be rewarded. Legal title to the land however, may be less important than a guaranteed long-term right to use the land, as seen in Vietnam and China, where soil conservation is practised even though private ownership of the land is not allowed (Phien and Tu Siem, 1996; Li *et al.*, 1998).

The overall size of a farm does not necessarily influence the frequency or type of soil conservation measures employed. Hallsworth (1987) cites data from Nyasa, Rift Valley and Western Provinces of Kenya that show that 51 percent of farmers with holdings of less than 1 ha use fertilizers to maintain productivity, whereas on farms of over 10 ha holding only 68 per cent. Equivalent figures for the use of terracing are 24 per cent and 21 per cent respectively. For mulching however, the figures are 5 and 17 per cent respectively; the lower figure reflecting difficulty of supplying mulch material on very small holdings. More important than farm size is the layout of farm and; in particular, its degree of fragmentation, since many conservation measures; such as terraces, become impractical when the land is held in small and scattered parcels. Mulching is more difficult because there may be a considerable distance between the strip of land from which the mulch is taken and the strip on which it needs to be appliedHallsworth (1987). Land consolidation programmes may not improve erosion status; because, as seen in northern France, the reorganization of holdings into larger fields means the removal of field boundaries and increases in the length over which surface runoff can flow.

External Factors:The causes of soil erosion rarely relate only to the existing physical and socio-economic conditions of a farming system but arise also from inability to adapt to changing circumstances brought about by drought or dry spell, increases in population, fragmentation or enlargement of farms, economic pressures to grow cash crops rather than food crops and new technologies (Franke and Chasin, 1981). Erosion in much of Europe reflects the breakdown of farming systems formerly based on a rotation of cereals, root crops and grasses, or a combination of tree crops, cereals and pastures. With economic incentives to grow continuous cereals and roots, all essentially soil-degrading crops, the loss of grass has led to a decline in organic matter and deterioration in the aggregate stability of the soils (Franke and Chasin, 1981).

If soil erosion as a response to changes in farming systems is to be avoided, soil conservation must be a dynamic process capable of adjusting to future change. It is insufficient to develop a strategy that merely solves an immediate problem. The need for adaptability in soil conservation systems is likely to increase because the global impacts on erosion and agriculture expected to arise from climatic change will be far greater than those hitherto associated with changes in land use (Franke and Chasin, 1981).

Technological Transfer:Though the principles of soil conservation are transferable, conservation strategies developed in one area will not necessarily work elsewhere. What is feasible on a 100–200 ha farm with a high level of mechanization in the Midwest of the USA is unlikely to be applicable to a smallholding of less than 0.5 ha in the tropics. The non-transferability of soil conservation measures is perhaps best illustrated by the failure of channel terraces within the small-scale farming systems of Africa. Borrowed from the USA, where they were successfully

developed and implemented in the 1930s and 1940s, such terraces formed the nub of soil conservation programmes proposed by the European colonial administrations in much of central and eastern Africa (Wood, 1992). In nineties, many exist examples throughout Africa where channel terraces and bench terraces implemented by governments, pre-independence and post-independence, have not worked, whereas indigenous, often highly labour-intensive systems, have been successful (Roose, 1992; Cheatle and Njoroge, 1993; Tiffen *et al.,* 1994).

Traditional bench terrace systems like those built by the Incas in Peru, also encompassed contour bunds to promote infiltration of water and increase soil moisture, applied mulching to conserve water and soil fertility. It encompassed burying of weeds and trash to improve fertility and weed control, crop rotation and weed fallows (Critchley *et al.,* 1994; Reij *et al.,* 1996; Tengberg *et al.,* 1998). A characteristic of these indigenous systems is that they are not standardized; vary from area to area and often from farm to farm, their designs do not conform to the technical standards proposed by soil conservation services (Humbert-Droz, 1996). Indigenous systems are not without problems however. Structural measures require large inputs of labour to construct and maintain. Trash lines and mulching enhance the survival and spread of insect pests and disease pathogens (Tengberg *et al.,* 1999).

Economic Evaluation:A major problem with applying economic analysis to soil conservation is that many aspects, such as benefits related to minimizing adverse environmental impacts, are difficult to quantify in monetary terms. Although this may be of limited importance in a farm budget, it can be vital at a project scale for deciding on the size of financial incentives given to farmers to promote soil conservation for the benefit of the community. An analysis directed at

the community should take account of costs of not controlling the erosion, including downstream or downwind sedimentation, benefits in terms of crop production and employment. However, at this level, analysis generally suffers from inadequate information on: how to price labour when much of it is in the form of unpaid inputs from farmers and their families; how to take account of the effects of different currency exchange rates where a black currency market exists alongside the official exchange; and how to cost differences between a project with soil conservation and one without, when the impact of continuing erosion on productivity cannot be quantified (Bojö, 1992).

Detailed information on the economics of households and their decision-making processes can be difficult to obtain, with many farmers unwilling to provide it or supplying misleading data (Ellis-Jones and Mason, 1999). Different views exist on whether projects should be evaluated in terms of: their net present value (NPV), i.e. sum of discounted benefits less the sum of discounted costs; their internal rate of return (IRR), i.e. rate of interest that the project can afford to pay to cover resources required or their benefit–cost ratio, defined as the sum of discounted benefits divided by the discounted costs. Decisions on appropriate discount rate can seriously affect results of NPV analysis. Disagreement also exists on whether evaluation should be made over 10, 20, 30 years or longer. Extending the time horizon to 50 years can have a detrimental effect on the outcome, especially if discount rates of 10 per cent or more are used (Bojö, 1992).

If the analysis is applied to an individual farmer, costs and benefits can be more easily quantified and yearly cash flows calculated (Hedfors, 1983). Benefit–cost ratios to farmers in Acelhuate Basin, El Salvador, from adopting a system of contour cultivation, contour grass strips and

contour ditches to grow maize, sorghum and beans on steep slopes ranged from 1.0 to 2.8, depending on slope steepness and the depth of soil (Wiggins, 1981). Greatest returns were predicted for the gentler-sloping land with deeper soil, whereas benefits were very limited or neutral for farmers working slopes of 25–51° with no top soil and renting the land on annual leases. Therefore, these last farmers have no economic accessibility to soil conservation. At both 5 and 20 per cent discount rates contour grass barriers were uneconomical for farmers in the Cochabamba region, Bolivia, unless they brought about a 20 per cent increase in productivity (Ellis-Jones & Mason, 1999).

For Konto River Watershed Development Project, Indonesia, weightings were developed to express: expected income to local population; particularly the landless; changes in rates of runoff and erosion; and the preservation of natural forest (De Graaf, 2001). In practice, multicriteria analysis can be somewhat complex, with difficulties in deciding what the weightings should be and how their values should be determined, especially when, unlike measures of erosion and runoff, they cannot be easily expressed numerically. A better approach, which is yet to be widely used in soil conservation studies, would appear to be cost-effectiveness analysis (De Graaf, 2001).

2.1.2.4 Cultivated lands

A risk of erosion exists on cultivated land from the time trees, bushes and grasses are removed. Erosion is exacerbated by attempting to farm slopes that are too steep, cultivating up-and-down hill, continuous use of land for the same crop without fallow or rotation, inadequate use of fertilizers and organic manures, compaction of the soil through the use of heavy machinery and pulverization of the soil when trying to create seed-bed. Least protection of the soil is afforded by crops grown in rows, tall tree crops and low-growing crops with large leaves. As a result, crops like maize, rubber, oil palm, grape vines, cassava and sugar beet can all give moderate to serious erosion problems. Small grain cereals, such as wheat and barley, afford better protection provided they are planted at sufficient density (Morgan, 2005).

Erosion control is dependent upon good management, which implies establishing sufficient crop cover and selecting appropriate tillage practices. As a result of this experience, an alternative approach was tried in the village of Kaniko based on existing farming systems, and integrating the ideas of the farmers with those of researchers and extension staff. Greater emphasis was placed on contour grass strips and use of trees and hedges rather than terraces (Hijkoop *et al.*, 1991). Increasingly, it is recognized that strategies for soil conservation must rely on improving traditional systems (Roose, 1992), instead of imposing entirely new techniques from outside, and on enhancing land husbandry (Hudson, 1993b; Hudson and Cheatle 1993; Critchley *et al.*, 1994).

2.1.2.5 Grazing lands

Erosion problems arise when the protective cover of rangeland vegetation is removed through overgrazing. Erosion control depends largely on the use of agronomic measures. These are directed at determining and maintaining suitable stocking rates, although this can be difficult if not impossible in areas where people attach cultural and social value to the size of their herds, and at planting erosion-resistant grasses and shrubs. The latter are characterized by vigorous growth, tolerance of drought and poor soils, palatability to livestock and resistance to the physical effects of trampling. Specialized measures designed to increase resistance of the soil may be required around field gates, watering points and salt boxes (Morgan, 2005).

Traditional grazing systems are often well adapted to local conditions of climate, soils, vegetation and making use of rotational grazing on a nomadic basis. Cattle are grazed in the lowlands immediately after the wet season, taking advantage of the annual flush of grass, moved to slightly wetter hilly areas during the dry season and kept around a permanent homestead in riverine woodland from which dry-season forage can be obtained (Barrow, 1989).

2.1.2.6 Urban areas

Urban development frequently results in intensive soil erosion. The exposure of bare soil during construction phase results in higher volumes of peak runoff, shorter times to peak flow, higher and more frequent flood flows and rapid increases in erosion by overland flow, rills and gullies, producing high sediment concentrations. Residential development started in the Anak Ayer Batu catchment in Kuala Lumpur in the mid-1960s. As in 1970s the river was choked with sediment. Flooding and deposition of sand occurred regularly on the flood plain, with suspended sediment concentrations in the river water of 4–81,230mgl^{-1} (Douglas, 1978). By 1977 the situation had

changed little with sediment concentrations ranging from 3.7 to 15,343mgl^{-1} compared to between 7 and 1080mgl^{-1} in similar channels in rain forest areas. Similar sediment concentrations with peaks between 15,000 and 49,000mgl^{-1} were recorded during construction work on the new campus of the University of Singapore at Kent Ridge and on the old campus at Bukit Timah (Gupta, 1982).

Strategies for soil erosion control in urban areas depend on scheduling developments to retain as much plant cover as possible, but since this is generally feasible to only a limited extent, a much greater reliance is placed on mechanical methods than is the case with other types of land use. Soil Erosion control in the final phase when urban development is complete requires rapid establishment of plant cover and permanent use of purpose-designed waterways and embankment stabilizing structures. On-site erosion is very low at this stage because most of the land is covered in concrete but runoff from impervious surfaces of streets, pavements, roofs, gutters and sewers can cause bank erosion in rivers downstream of the urban area. The instability of roadside slopes often presents an additional problem (Morgan, 2005).

2.1.2.7. Road banks

Road banks on either cut or fill slopes are frequently major sources of sediment. Poor disposal of runoff is an important cause of soil erosion associated with roads. Runoff upslope of the road should be collected in roadside drains or ditches, which are then led into culverts under the road, usually discharging into existing valleys. However, it is common to discharge runoff collected from several small streams into a single culvert, which means that the catchment area of recipient channel downslope of the road is increased. Where adequate protection measures are not put in

place, the increased runoff can enlarge the channel into a gully which, over time, will extend upslope and damage the road (Nyssen *et al.,* 2002). The road shoulder; the land between road surface and side drain, is also vulnerable to soil erosion, particularly where the road surface is metalled and the shoulder is unprotected (Freer-Hewish 1991; Kamalu, 1991).

The methods used for soil erosion control on road bank range from engineering structures such as revetments and retaining walls to stabilization of the slope by vegetation. Grasses will protect slope against soil erosion by raindrop and runoff impact, trap moving sediment, while shrubs and trees will increase strength of the soil through root reinforcement. Trees will also help to support slope by buttressing. Vegetation increases the infiltration of water into the soil, but this can cause problems where rainfall amounts and intensities are very high. While the resulting reduction in runoff will help to control surface erosion, increased moisture content of the soil may exacerbate risk of mass soil failure (Morgan, 2005).

2.1.2.8 Strategies of erosion control in field crops

Several erosion control strategies are already in use in crop production; for example, growing cover crops, contour tillage, wind and water barriers e.g. hedgerows, trees, grassed waterways or conservation tillage (zero and reduced tillage). In general, any soil cover can reduce water runoff and soil loss. Cover crops cover the soil surface by aboveground biomass, which protects the soil from being detached (Langdale, 1983; Hartwig, 1988). Another erosion control measure is the contour ploughing or the cross-slope cultivation, which is wide-spread in the US. This is a tillage practice where the direction of tillage runs across the slope, and often uses contour lines. Water breaks are created, which reduces gully and rill erosion. Wind and water barriers; such as

hedgerows or trees slow down velocity of wind and water, and reduce slope length. The most important and common strategy to control soil erosion is convincingly known as conservation tillage (Erenstein, 2003). Several conservationtillage practicesare known and established for many field crops, such as maize, sugar beet or potatoes. By definition a tillage practice is classified as conservation tillage, if more than 30% of the soil surface is covered by residues (Baker *et al.,* 2002). Soil inversion tillage by moldboard plough is replaced by non-inversion tillage practices and even no-tillage (zero tillage) is possible.

Reduced tillage optionsare widely used particularly for sugar beets or cereals production, with the main objective to prevent soil erosion and avoid soil degradation. The soil is tilled by chisel plough to prepare the soil before sowing. As the soil is not inverted, crop residues from the previous crop cover soil surface as a mulch layer and provide protection against soil erosion. Any tillage leads to faster soil warming in spring, faster nitrogen mineralization and better weed and pest control compared to no-tillage(Mäder and Berner, 2012). Meanwhile the most useful practice to prevent soil erosion is no-tillage, without any soil disturbance (Kay *et al.,* 2009; Prasuhn, 2012).

The high protection capacity against soil erosion stems from mulch layer from previous crop at the soil surface, which results in higher infiltration rates, increased water storage, and lower evaporation compared to conventional, inversion-tillage practices by a mouldboard plough (Govaerts *et al.,* 2009). For temperate climate zones, yield potential tends to be lowering under no-till because of a lower seedbed temperature in spring. This often results in delayed crop emergence and lower emergence rates (Kaspar *et al.,* 1990; Dwyer, *et al.,* 1995; Johnson and

Hoyt, 1999). Moreover, adoption of no-till results in changes in weed infestation and crop diseases which (i) often reduce yields and (ii) possibly require higher application rates with increased costs of pesticides (Ball and Davies, 1997b; Anken *et al.,* 2004). This practice has attracted interest during the last decades, especially for maize production in the US (Vyn and Raimbault, 1993).

Strip-tillage can be considered as a conservation technique, where the straw and mulch residues from the previous crop remain on the soil surface and the latter seeding or planting rows are tilled exclusively in autumn and/or in spring by a striptiller. Several studies have shown high benefits of strip-tillage for maize and sugar beet concerning erosion control, soil quality, water storage and yield (Al-Kaisi and Kwaw-Mensah, 2007; Overstreet, 2009; Nash*et al.,* 2013). Strip-tillage can lead to higher infiltration rates, higher soil moisture content, and a lower evaporation rate compared to conventional tillage (Al-Kaisi and Hanna, 2002). Higher soil temperatures within the tilled strips are valuable assets of strip-tillage compared to no-tillage because of a lower risk of delayed seed germination and plant emergence (Licht and Al-Kaisi, 2005; Celik*et al.,* 2013). Strip-tillage also has economic benefits because of synergies of combining operations (e.g., seedbed preparation, seeding and fertilization) in one pass, and thus results in lower fuel and labour requirements compared to conventional tillage (Crosson *et al.,* 1986).

2.1.2.9 Strategies of erosion control in field grown vegetables

The project on Development of erosion control strategies for field grown vegetables used two approaches to develop, test and improve strategies to control soil erosion. The first approach was the use of row covers, and the second was the adoption and improvement of the strip-tillage system for field grown vegetables. Row covers belong to the group of agrotextiles, cover the soil and reduce the impact of rainfall energy which minimizes the risk of soil erosion. Two frequently used row covers are insect netting; which is used in organic agriculture for pest control, and fleece or non-woven fabrics which serve as frost protection in spring and accelerate plant growth (Rekika *et al.,* 2009; Olle and Bender, 2010). However, there are unresolved issues regarding the microclimate under the covers and the influence on crop growth. The air temperature and relative humidity increases significantly especially under fleece (Mermier, *et al.,* 1995; Gimenez*et al.,* 2002), which can result in better growing conditions on the one hand, but also in a higher risk of plant diseases on the other hand (Jenni *et al*., 2003).

For vegetable production, conservation tillage practices such as strip-tillage are not widely utilized. Vegetable seedlings are dependent on a fine crumbled seedbed, which is hardly achieved by no-tillage. Due to the less promising results attained in vegetable experiments with conservation tillage practices, there are currently no adequate technical solutions on the market (Phatak *et al.,* 2002; Price and Norsworthy, 2013). Nonetheless, due to existing knowledge and the success of striptillage in maize and sugar beet, it appears plausible to adapt and improve strip-tillage for field grown vegetables. Some studies have shown that strip-tillage is possible for tomato (*Solanum lycopersicum* L.), sweet corn (*Zea mays* convar. *saccharata* var. *rugosa*) and cucumber (*Cucumis sativus*; Hummel *et al.,* 2002; Luna J., 2003; Overstreet *et al.,* 2010).

However, many challenges still remain regarding suitable planting, fertilization, herbicide management and the integration of the system in a vegetable crop rotation.

Strip-tillage for vegetable production offers several options with different tillage intensities and fertilizer applications. The general procedure for a temperate climate with field grown vegetables can be considered as follow:

i. Stubble tillage (optional) after cereal harvest is recommended, particularly if harvest residues are not homogeneously distributed.

ii. Weed control by a non-selective herbicide around 10 days before the tillage operation is conducted.

iii. First strip preparation in autumn/winter (September equinox to the December solstice): On heavy soils (> 10% clay), the strips should be prepared in autumn/winter to expose the soil to frost over winter. On sandy soils, it is possible to till the strips in spring. For vegetables, such as cabbage, the strips are 20 cm deep and 20 cm wide. For high strip quality and to guarantee an exact transplanting process, it is important to use a Real Time Kinematic-Global Positioning System (RTK-GPS) guidance system for strip preparing with a precision of ± 2.5 cm.

iv. Weed control in spring by second use of a non-selective herbicide around 10 days before transplanting.

v. Second, shallower strip preparation (optional) in spring can be conducted shortly before transplanting. It is especially recommended if the soil structure in the tilled area is not sufficiently fine-structured for vegetable transplants. It can be combined with a band-placed, fertilizer application through the coulters of the strip-tiller.

vi. Transplanting of vegetable plantlets with a total-controlled planting machine.

The second, band-placed fertilizer application can be conducted during the transplanting process through the coulters (optional). Saved tracks of the RTKGPS guidance system from the strip-tillage process are used, to make sure that the transplants are placed in the tilled area.

Step 1) and step 5) can be omitted for a standard, non-intensive strip-tillage. In this case, the fertilizer application has to be undertaken via broadcast. For an intensive strip-tillage, all steps are included with the option of bandnitrogen fertilization during the second tillage pass and during transplanting in spring. Based on these working steps, in the current study, different striptillage intensities and different fertilizer application techniques were investigated, tested and adapted to specific requirements of white cabbage.

Soil conservation strategies designed considering average weather conditions of a place can provide adequate erosion control in most years but unacceptable sediment yield can occur for the largest erosion-producing events (Gonzales-Hildalgo *et al.*, 2010, 2012). Therefore, it seems reasonable to suggest that conservation strategies should be developed taking into account large storms rather than average weather conditions (Bagarello *et al.*, 2010; Strohmeier *et al.*, 2016). If a sufficiently large historical sequence of soil loss values is available then a frequency analysis can be developed and the soil erosion variable having a given return period can be estimated (Baffaut *et al.*, 1998; Mannaerts and Gabriels,2000). Notwithstanding the knowledge of return period of an erosion event can be considered relevant information to design soil conservation systems, use of frequency analysis in soil erosion studies is relatively limited (Mannaerts and Gabriels, 2000; Bagarello *et al.*, 2010, 2011), probably because of the difficulty to collect a

number of measurements large enough for developing statistical inference analysis for soil erosion.

2.1.3 Erosion Control in Nigeria

According toAdegoke*et al.* (2015), the mission statement is:

i. Arrest all major active erosional gullies and sites nation-wide through appropriate scientific and engineering actions and enforce management practices aimed at preventing/controlling activities which provoke the incidence of erosion and gullying.

ii. Inventorize and categorize incidence of erosion nation-wide, determine their extent and recommend appropriate amelioration programmes and projects.

iii. Quantify losses sustained especially with respect to: soil nutrient losses; agricultural land losses; impact on surface and groundwater losses to human settlements and other infrastructures.

iv. Strengthen capacity building in erosion control programmes through establishment of Environmental Management Support Systems (EMSS), Remote Sensing and Geographical Information Systems (GIS).

v. Prepare comprehensive national and regional Master Plans for the management of soil erosion and floods; Initiate scientific research on soil texture, erodibility and other physicochemical characteristics of soils and use the findings as input in engineering

design of appropriate control measures; Codify and enforce sustainable land-use, agricultural, mining and construction practices that least provokes erosion.

vi. Execute community-based model erosion-control projects such as terraced farming on hill slopes, tree planting, afforestation and re-forestation and slope stabilization projects aimed at inculcating good house-keeping practices in the citizenry.

vii. Establish contingency plans for tackling the socio-economic and health problems resulting from coastal and other erosional disasters.

viii. Encourage the adoption of an integrated approach to problem solving through the involvement of soil scientists, geoscientists and engineers in the containment of erosion and proffering solutions to erosional problems.

2.1.4Soil Conservation Programme in Nigeria

Adegoke*et al*. (2015) pointed out that there is a need to conserve these soils from being degraded, either by soil and wind erosion or intensive activities of man in the area of uncontrolled deforestation. One of the technologies being used to monitor this problem is sheet erosion control trials, which are aimed at monitoring occurrence, intensity and mode of control of sheet erosion on farmlands. Trials of this nature have been successfully completed in some parts of the Eastern States, while similar trials are being initiated in the North-western part of the country.

According toAdegoke*et al.* (2015), the Lead Coordinating Agency isFederal Ministry of Water Resources and Rural Development. Other Participating Agencies/Departmentsare: Federal Environmental Protection Agency, Federal Department of Forestry, Federal Ministry Agriculture and Natural Resources, River Basin and Rural Development Authorities, Agricultural Development Programmes (ADB), Geological Survey Department of the Federal Min. of. Solid Mineral Development, Tertiary Institutions with programmes in geology, agriculture and soil science, Department of Petroleum Resources (DPR), State Environmental Protection Agencies Women Groups, NGOs and Federal Ministry of Works and Housing

2.1.5Concept of Soil Erosion Threshold

Soil loss tolerance is a criterion for establishing if a soil is potentially subjected to erosion risk, productivity loss and if a river presents downstream over-sedimentation or other offsite effects are present at basin scale. Soil degradation implies a long-term decline in its productivity and it determines reduction in some attributes of soil having specific functions of value to humans (Alexander, 1988).

Soil degradation by accelerated erosion is a serious problem and will remain so during the 21st century and its severity and economic impacts and environmental impacts are debatable (Lal, 2001).Soil erosion on cultivated lands has received much concern since it is considered to be one of the most critical forms of degradation (Montgomery, 2007; Cerdà *et al.*,2009; Zhao *et al.*, 2013).

Soil erosion has both on-farm and off-farm impacts. Reduction of soil depth can impair land's productivity and sediment transport can degrade streams and lakes (Uri, 2000). When soil

particles wash off a field, they may be transported by runoff until it is discharged into a water body. Not all agricultural constituents (produced from man made chemicals that are applied directly to agricultural systems or in activated sludge/irrigation water) that are transported from aagricultural land reach water systems but a significant quote of finer particles which are the most chemical active transported from land. Once agricultural pollutants enter a water system, they lower water quality and impose economic losses on water users.

Studies confirm that agricultural soil erosion substantially outpaces soil production under non-conventional agricultural practices around the world. Specifically, Wilkinson and McElroy (2007) reported that an average erosion rate of 0.6 mm yr^{-1} from modern farmlands greatly exceeds the estimated average erosion rate of 0.016 mm yr^{-1} over the past 500 years based on the preserved volumes of sedimentary rocks.

Soil loss tolerance value is a concept useful to judge if a soil has potential risk of erosion, productivity loss and off-site damages as river over sedimentation or reservoir sedimentation (Li *et al.*, 2009). Soil loss tolerance is also a useful criterion to design conservation practices and works for erosion controll or can be used as an indicator of soil quality (Johnson, 2005; Bagarello and Ferro, 2006). The term tolerable soil erosion is used when referring to soil lost by erosion in the context of soil conservation, soil loss tolerance or tolerable soil loss is the variable measured as t ha^{-1} $year^{-1}$. Again, the concept of tolerable soil loss based on soil productivity is reductive and neglecting the off-site effects does not reach a comprehensive environmental approach (Bazzoffi, 2009). According to Verheijen *et al.* (2009) reviewing available definitions for tolerable soil loss two different approaches emerge:

i. Establishing T_{SL} as the value able to maintain dynamic equilibrium of soil quantity (as mass or volume) in any site and under any circumstances.

ii. Relating tolerable soil loss to the biomass production function of soil.

The first approach focuses on soil quantity while the second one focuses only on the biomass (particularly crops) production function of soil. The first definition considers "tolerable" a soil loss, which does not exceed the soil formation rate while the second definition links tolerated value to the performance of a particular soil function. Verheijen *et al.* (2009) suggested to integrate both approaches and proposed a more holistic definition of tolerable soil erosion as any mean annual cumulative (all erosion types combined) soil erosion rate at which a deterioration of one or more (primary) soil functions (e.g. habitat, production, storing, filtering) does not occur.

Soil functions can generally be judged not to deteriorate when soil erosion corresponds to *geological* or *normal* conditions. The USDA (1956) defined the following top ten influencing factors of tolerable soil loss for a particular soil (Li *et al.*, 2009) the rate of soil formation from parent material, the rate of topsoil formation from subsoil, reduction of crop yield by erosion, soil depth; changes in soil properties favorable for plant growth caused by erosion; loss of plant nutrients by erosion, the likelihood of rill and gully formation, sediment deposition problems within a field, sediment delivery from erosion site, availability of feasible, economic, culturally and socially acceptable, as well as sustainable soil conservation practices.

2.1.5.1 Threshold conditions

The main cause of gully formation is too much water, a condition that may be brought about by either climatic change or alterations in land use. In the first case, increased runoff may occur if rainfall increases or if less rainfall produces a reduction in the vegetation cover. In the second case, deforestation, burning of vegetation and overgrazing can all result in greater runoff. If the velocity or tractive force of runoff exceeds a critical or threshold value, gullying will occur. The threshold values however, can show a very wide range. For example, t*c* varies from 3.3 to 32.2Pa on cultivated silt-loam soils in Belgium and from 16.8 to 74.4Pa on cultivated stony sandy loams in the Alentejo area of Portugal (Nachtergaele, 2001).

Where the exceedance of threshold relates to changes in climate or land use, the threshold is described as extrinsic (Schumm, 1979) because changes are external to the processes operating within the gully. Attempts to relate gullying solely to changes in external factors have not proved entirely successful however, because not all gullies in an area appear to respond in the same way. In order to explain onset of instability in one gully while its neighbours remain stable, Schumm (1979) examined the role of intrinsic thresholds, which are related to the internal working of the gully. From a review of studies in Wyoming, Colorado, New Mexico and Arizona, a discriminant function was established between stable and unstable conditions in terms of the size of catchment area (*a*), which controls discharge, and the channel slope (*s*), which controls the velocity of runoff. When, for a given catchment area, channel slope exceeds a critical value, incision occurs, creating a channel characterized by one or more head scarps. Subsequent scouring causes gully to become very active: the channel widens, deepens and extends

headwards. Over time, the channel slope is reduced, promoting a consolidation phase as the gully stabilizes, the channel fills in, the sides and head wall become flatter and vegetation regrows. Deposition steepens the slope again and triggers a new phase of gullying. Thus gullies pass through successive cycles of erosion and deposition. It is not uncommon for the head of a gully to be extremely active while the lower section of the gully is stabilizing or for gullies to contain a sequence of alternating stable and unstable sections.

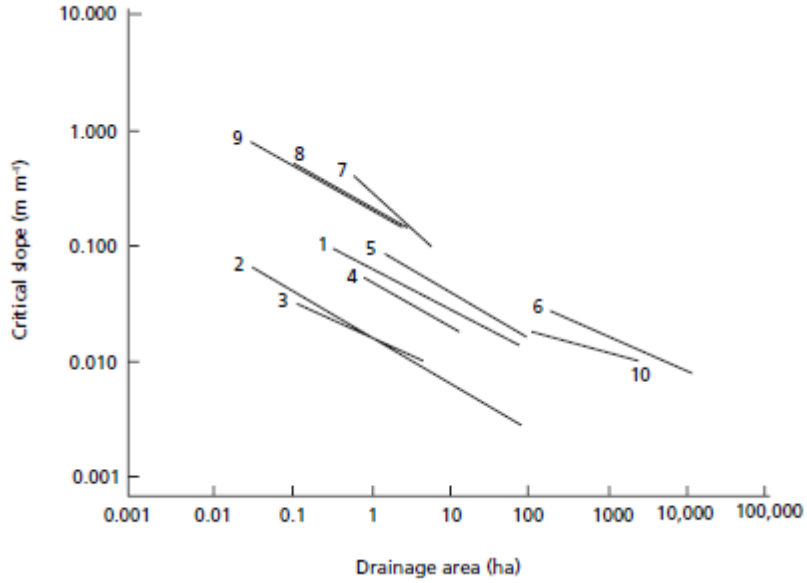
Begin and Schumm (1979) and Moore *et al*. (1988) have established critical *s–a* relationships to the effect that gullies form when:

$$sa^b > t \qquad 2.3$$

Where *t* is the threshold value. Threshold values are higher for non-cultivated land than for croplandand also vary with the type of vegetation cover, differences in soil structure and soil moistureand type of tillage (Poesen *et al.,* 2003).

Figure 2.3 shown the lines plotted in are best-fit regression lines passing through data obtained for gulliedcatchments. The threshold values also depend on the methodology. As a result, some gullied catchments will plot below the lines. Begin and Schumm(1979) however, proposed defining line below which gullied catchments did not occur andwhich could therefore be interpreted as defining the condition at which all valley floors werestable. There will however, be some ungullied catchments, which will plot above the line. Also, Morgan and Mngomezulu (2003) showed that discriminant functions relating *s* to *a*could be used to separate gullied from

ungullied catchments in four areas of Swaziland. Out of asample of 201 catchments, only 8 per cent were incorrectly classified by this method.



1=Central Belgium, 2=Central Belgium, 3=Portugal, 4=France, 5=United Kingdom (South Downs), 6=Colorado and USA, 7=Sierra Nevada and USA, 8=California and USA, 9=Oregon and USA, 10=New South Wales and Australia.

Figure 2.3 Relationship between critical slope and drainage area for development of Gullies

Source: Adopted after Poesen *et al.* (2003)

The value of *b* in eqn 2.35 is generally interpreted in relation to processes operating in the catchment. Values >0.2 are associated with erosion by surface runoff and those <0.2 as indicating sub-surface processes and mass movement (Montgomery and Dietrich, 1994; Vandekerckhove *et al.*, 2000). For three of the four study areas in Swaziland, the values were <0.2, which was surprising, since low saturated hydraulic conductivity of the soil and subsurface material would inhibit development of subsurface channels or pipes (Scholten, 1997). Further, there is no evidence of piping in the headwalls and sidewalls of the gullies. It was proposed that

the low values may reflect increasing importance of groundwater seepage in contributing to undermining and collapse of headwalls in the later stages of gully evolution after the channels have cut down to bedrock. This change in dominant process over time was observed in similar gully systems in Madagascar (Wells and Andriamihaja, 1991).

2.1.5.2 Threshold of soil erosion risk

The Threshold was implementation of Cross Compliance (CC)-erosion classification in 2010 (ErosionsSch, 2010). For this regulation, all field parts were divided into soil erosion hazard classes according to the soil erosion risk. Basis for classification is the RUSLE (Renard *et al.*, 1991), and the adapted version for European soil and environmental conditions, Allgemeine Bodenabtragsgleichung; Schwertmann *et al.*(1987) (ABAG). All equations evaluate the long term average annual soil loss by sheet and rill erosion and are defined by:

$$A = R \times K \times L \times S \times C \times P \qquad 2.4$$

Where *A* stands for the potential long-term average annual soil loss in tons perhectare and year, *R* is the rainfall and runoff factor, *K* is the erodibility factor (soiltexture is the main factor affecting *K*), *L* is the length-factor and *S* represents thegradient-factor. *C* stands for the vegetation and management factor and *P*represents the support practice factor (e.g. cross-slope cultivation). The CC-soilerosion hazard classes depend on the soil type (K-factor) and the steepness (slope;S-factor) of the field parts. There are three classes for water erosion and two forwind erosion (Table 2.3).

Table 2.3: Soil erosion hazard classes according to the Cross Compliance regulations

Water erosion hazard class	Description	K (soil type) x S (slope)
CCwater0 (CCWa0)	Low erosion risk	< 0.3
CCwater1 (CCWa1)	Erosion risk	0.3 < 0.55
CCwater2 (CCWa2)	High erosion risk	≥ 0.55

Source: **Modified according to Dölz, (2010)**

The time period, during which inversion tillage (e.g. mouldboard ploughing) is permitted, is fixed according to the factor of soil type and steepness. On fields prone to erosion (CCWa1), the use of mouldboard plough is only permitted if the following crop is sown before 1stDecember and immediately after the harvest of the previous crop while in the case of Nigeria is sown before end of March depending on the time of raining seasons of the regions. In all other cases, moldboard ploughing is prohibited during winter (from 1 December to 15 February). For field areas, which are classified in CCWa2, mouldboard ploughing is prohibited for row crops with a row distance of more than 45 cm. For all other crops moldboard ploughing is prohibited over winter. The use of mouldboard plough from 16 February to 30 November is only allowed, if the sowing or planting follows immediately after soil tillage (ErosionsSch, 2010).

2.2 THEORY/MODELS

2.2.1 Theory of Fluvial Process on Hillslope

Kirkby (1980) observed that when a soil particles is struck by a raindrop, its initial velocity and probability of movement is largely determined by its mass and raindrop momentum. Once in motion, it is slowed by frictional forces and movement is encouraged by its downslope weight

component, assisted by hydraulic tractive forces from the flowing water. Rainsplash has been observed to move 4mm stones up to 20cm downslope, 2mm stones up to 40mm downslope (Kirkby, 1976). At any given rainfall intensity, the distance of movement decrease with increasing particles size, but the mass transport, defined as the product of mean distance travelled and particle mass, increasing with particles size for particles of up to 50mm diameter.

literature by Kirkby (2004) revealed that rain drops at speed up to 20mph, each drop has kinetic energy which is released to splash soil particles upon hitting the ground, it can show soil particles as much as 1.2 meter horizontally and 0.3 vertically. Raindrop impact breaks up clumps of soil. The lighter materials such as sand, salt, clay, and organic materials that are detached by raindrops are more readily carried away by runoff. Yound and Weirsma (1973) pointed out that the importance of raindrops energy has been confirmed by many empirical studies and is reflected by the dominant role assigned to rainfall erosivity in most soil erosion model.

Kirkby (2004) observed that raindrop impact moves particles in form of random exchange, rather than in one direction. Surface runoff occurs widely over slope when rainfall intensity exceeds infiltration capacity and was believed to be the sole motor of fluvial erosion. A considerable number of studies have carried out to investigate this relationship. Ofomata (1965) noticed that in part of Nigeria for instance Enugu area, the relief is not very high but in accentuated by sandstone escarpment, which is relatively broken. Thus, favouring concentrated runoff a necessary factor in gullies erosion. According to Ofomata (1965), these phenomenons attest what has led the occurrence of badlands structure (landscape) on the Nsukkaudi-plateau behind Enugu escarpment.

Krikby (2004) noticed that hill slopes essentially cover the whole landscape, some are steep others are gentle under natural condition, water sediment and rock more down slope. Surface run-off on upland areas such as hill slope is often accompanied by soil erosion. Soil particle may be detached when the impact of raindrops exceed the soil ability to withstand the impulse at soil surface. Once detachment has occurred, sediment particle are transported by raindrop splash and by overland flow. Obviously, the steepness, shape and length of slope affect both flow pattern and resulting sediment transport capacity. In many places, sheet, rill and interill erosion dominate erosion on hill slope. However, the unabsorbed water beginning flowing downhill in form of sheet erosion, carry away the soil particles that have been loosened by the raindrop bombardment, this process is called sheet erosion. Rain splash and sheet erosion generally account for more than 70% of down slope erosion. Sheet erosion, turn into rill erosion when the runoff beginning cutting small, separate channels as it travel down hills gradually increasing the size of the rill. Gully erosion can be dramatic and can dump large amount of sediment into nearby streams and river (Morgan*et al.,* 2001)

Runoff is the most important direct driver of severe soil erosion processes which influence runoff, must therefore play an important role in any analysis, measuring and assessing intensity of soil erosion which reduce runoff are critical to effective soil conservation. Many erosion process are active on hill slope, focus on run-drop and run-off. The velocity and amount of runoff increase as the slope length increases. Measurement of soil loss from hill slope in West Africa (Roose, 1971, as cited in Morgan, 1995) ranging in steepness from 0.3 degree to 4 degree yield mean annual rate of erosion of 0.15, 0.20 and 0.03 t/ha under natural condition of open savanna grassland, dense Savanna grassland and tropical respectively.

2.2.2 Models of Soil Erosion

Erosion models are used to predict soil erosion. Soil erosion modeling is able to consider many of the complex interactions that influence rates of erosion by simulating erosion processes in the watershed. Model is a representation of reality. Also, it never claims to be reality but attempts to mimic reality as much as possible (Breetzke, 2004). In dynamic and ever expanding science of soil erosion, models are the closest and only aspects that are useful to predict soil loss. Over the years, researchers have developed several models for soil erosion to describe how an erosion system functions and the system responds to change over time. These models are used for hill slope planning, farm planning, site-specific assessments, project evaluation and planning and policy decisions making. Also, the model is used as research tools to study processes and the behavior of hydrologic, soils and erosion systems (De Roo, 1996).

Erosion models are of two types, namely; process based models and mathematically/empirically based ones (Agada, 2014). Both the process based and empirically/mathematically models are available for predicting soil erosion and sediment transport at different scales. Empirically based technology means regression or lumped mathematical models, which were developed using the experimental data of plot studies on erosion by water. Universal Soil Loss Equation, USLE, later revised as Revised USLE or RUSLE is one such model developed in the USA with over 10,000 plot years of research data and experience of soil scientists (Renard *et al.*, 1996). It is the most widely used model for soil erosion estimation because of the simplicity, it required less data and easy integrated in GIS environments. It is based on the set of mathematical equations that estimate average annual soil loss from inter-rill, rill and sheet erosion. Also others models such as Chemical, Runoff and Erosion from Agricultural Management Systems (CREAMS) model

(Kinsel, 1980), Agriculture Non-point Source Pollution model (AGNPS) model (Young *et al.*, 1987), and Soil and Water Assessment Tool (SWAT) model (Arnold *et al.*, 1998) are the examples of hybrid models which are based on USLE/MUSLE/RUSLE for the erosion estimation but use the sediment transport approach on the basis of continuity equation for estimation of sediment yield. Process based models are intended to represent the essential mechanisms controlling soil erosion and sediment transport process. These models are the synthesis of individual component that affect the soil erosion and transport process. The process based models includes European Soil Erosion model (EUROSEM) model (Morgan *et al.*, 1998), Aerial Non-point Source Watershed Environmental Response Simulation (ANSWERS) model (Beasley, Huggins and Monke, 1980), Kinematic Runoff and Erosion model (KINEROS) model (Woolhiser, Smith, and Goodrich, 1990) and Water Erosion Prediction Program (WEPP) (Nearing *et al.*, 1989). Although physically based models try to emulate the physical processes involved in soil erosion and sediment transport, the weakness of these models is numerous parameters they need for calibration, they suffer from the problem of equifinality and not compactible to GIS environment (Beven, and Freer, 2001). The European Soil Erosion Model (EUROSEM) (Morgan *et al.*, 1991, 1992) is a single process–based model for assessing and risk prediction of soil erosion from fields and small catchments. Morgan, Morgan and Finney (MMF) model is an empirical model developed for mean annual soil loss estimation from field-sized areas on hill slopes (Morgan *et al.*, 1984) having strong physical base.

To analyse soil erosion and suggest appropriate management plans, Revised Morgan Morgan and Finney (RMMF) and Revised Universal Soil Loss Equation (RUSLE) Models were selected for this research.Revised Morgan Morgan and Finney model endeavors to retain simplicity of

RUSLE and also encompasses the understanding of erosion processes into water and sediment phases (Morgan*et al.,*2005). Also, RMMF and RUSEL were chosen in this research over other model such as; Water Erosion Prediction Project (WEPP), Soil and Water Assessment Tool (SWAT), European Soil Erosion Model (EUROSEM), and Annualized Agricultural Non- Point Source (AnnAGNPS) because these models applied worldwide to soil loss prediction and their convenience in application and compatibility with GIS (Kouli*et al.,* 2009; Pandey*et al.,* 2009; Bonilla*et al.,* 2010).

Again, RMMF and RUSLE models were selected and applied in this present study because of their simplicity and flexibility in use as compared to the empirical models and needs less data than most of the other erosion predictive models. Revised Morgan Morgan and Finney and Revised Universal Soil Loss Equation Models were easy in integration with GIS and their performance at a watershed/catchment level in Mubi South is not yet known to the best of the researcher's knowledge; hence, need to apply two models in this study in order to analys, estimate and predict soil erosion risk in the Mubi South Local Government Area of Adamawa State, Nigeria.

4.5 LITERATURE REVIEW

2.3.1 Types and Effects of Soil Erosion

Worldwide, Soil erosion is regarded as one of the most critical environmental problems (Meadows, 2003; Wei *et al.,* 2007; Schönbrodt-Stitt *et al.,* 2013; Ma *et al.,* 2014). Although soil erosion is a natural process, it has been accelerated by human impact on the landscape due to

agriculture, grazing, mining and fire (Giménez-Morera *et al.*, 2010; Lieskovský and Kenderessy, 2012; Leh *et al.*, 2013; Mandal and Sharda, 2013; Zhao *et al.*, 2013). The agricultural activities, construction of buildings, roads, railways and other infrastructures also result in soil degradation and changes in the landforms (Cheng *et al.*, 2013; Jimenez *et al.*, 2013; Lee *et al.*, 2013; Villarreal *et al.*, 2014). The soil erosion mainly occurs in the form of sheet, rill and gully erosion (Morgan, 2005; Le Roux et al., 2008).

Rill erosion is a process in which numerous small channels of several centimetres up to about 30 cm are formed (Bergsma *et al.*, 1996). Amongst the three forms of soil erosion, rill erosion remains the main cause for concern since it is a precursor of gully erosion. Rill erosion mainly occurs as a result of concentrated overland flow of water leading to the development of small well-defined channels (Haile and Fetene, 2012). These channels act as sediment sources and transport passages, leading to soil loss (Wirtz *et al.*, 2012). Sheet erosion involves the detachment and transport of soil particles by raindrop impact (rainsplash erosion) and transport by shallow overland flow (Lal and Elliot, 1994).

The process of gully erosion generates 20–30 cm to 20 m deep gullies (Bergsma, 1996). Although there are contradictory views about the share of gully erosion in the total amount of soil loss our experiences show that gully erosion processes have a bigger share than those of sheet erosion (Jakab, *et al.*, 2006).

According to the Hungarian classification gully erosion is one of the processes of linear erosion (Jakab, 2008). Linear erosion is a logical scientific name for this group of processes but it is not used worldwide. Microrill, rill and gully erosion belong to the group of linear erosion

processes.Poesen, *et al.* (2003) define gully erosion "as the erosion process whereby runoffwater accumulates and otenrecurs innarrow channels and, over short periods, removes the soil from this narrow area to considerable depths". The definitions of various forms of linear erosion (rill and gully erosion) are given by Jakab (2006) in Hungarian language. In this classification the value of 50 cm (width and depth) separates rills from gullies and deep-cut tracks are defined as a special group of gullies. They were dealt with in detail by Kertész (1984). Kerényi (1991) applied also the 50 cm value to differentiate between rills and gullies. Various Hungarian and foreign authors use different threshold values and definitions.

Soils of the loess covered areas are generally highly erodible because the parent material of the soil is a loose sediment. The initiation and development of gullies is in some cases promoted by subsurface erosion, for example by piping (called also suffosion in Hungarian literature, Jakab *et al.* 2005). Gully erosion is more frequent under arid conditions and less frequent under humid climatic conditions (Poesen, *et al.,* 1996). Must research concentrates the occurrence of erosive rainfall events. In most cases the role of rainfall characteristics in SL Gully percent (the percentage of soil loss caused by gully erosion in the total soil loss of the catchment. Evidently the amplitude and frequency of rainfall events are the most important rainfall characteristics. It is also evident that any change in rainfall regime (because of climate change) will lead to the change of the value of SL Gully percents.

Gullies are relatively permanent steep-sided water courses that experience ephemeral flows during rainstorms. Compared with Stable River channels, which have a relatively smooth, concave upwards long profile, gullies are characterized by a headcut and various steps or knick-

points along their course. These rapid changes in slope alternate with sections of very gentle gradient, either straight or slightly convex in long profile. Gullies also have relatively greater depth and smaller width than stable channels, carry larger sediment loads and display very erratic behaviour, so that relationships between sediment discharge and runoff are frequently poor (Heede, 1975a). A widely recognized definition used to separate gullies from rills is that gullies have a cross-sectional area greater than 1 m^2 (actually 929 cm^2) (Poesen, 1993). Gullies are almost always associated with accelerated erosion and therefore with instability in the landscape.

Gully formation**:** At one time it was thought that gullies develop as enlarged rills, but studies of gullies or *arroyos* of the southwest USA revealed that their initiation is a more complex process. In the first stage, small, depressions or Knicks form on a hillside as a result of localized weakening of vegetation cover by grazing or fire. Water concentrates in these depressions and enlarges them until several depressions coalesce and incipient channel is formed (Poesen, 1993). Erosion is concentrated at the heads of the depressions, where near-vertical scarps develop over which supercritical flow occurs. Some soil particles are detached from the scarp itself but most erosion is associated with scouring at the base of the scarp, which results in deepening of channels and undermining of headwall, leading to collapse and retreat of the scarp upslope. Sediment is also produced further down the gully by bank erosion. This occurs partly by scouring action of running water and sediment it contains and partly by slumping of the banks. Between flows sediment is made available for erosion by weathering and bank collapse.

The sequence of gully formation, described by Leopold *et al.* (1964) in New Mexico, is shown in Figure 2.4. Not all gullies develop purely by surface erosion, however. Berry and Ruxton

(1960), investigating gullies in Hong Kong that formed following clearance of natural forest cover, found that most water was removed from the hillsides by subsurface flow in natural pipes or tunnels, and when heavy rain provided sufficient flow to flush out the soil in these, the ground surface subsided, exposing the pipe network as gullies.

Tunnel erosion has been widely reported in many hilly and rolling areas of Australia, where it is associated with duplex soils. These are soils characterized by a sharp increase in clay content between the A and B horizons so that the upper layer, 0.03–0.6 m in depth, varies from loamy sand to a clay loam and the lower layer ranges from a light to heavy clay. According to Downes (1946), overgrazing and removal of vegetation cover cause crusting of the surface soil, resulting in greater runoff. This passes into the soil through small depressions, cracks and macropores but, on reaching the top of the B horizon, moves along it as subsurface flow.Figure 2.4 showed the stages in the surface development of gullies on a hillside

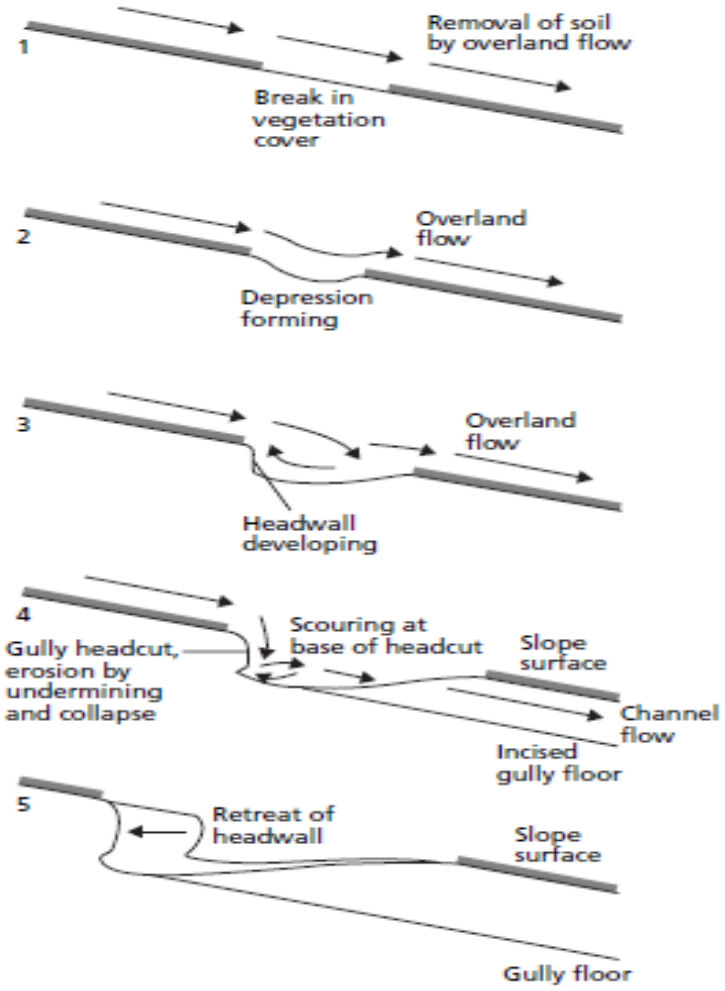


Figure 2.4Stages in the surface development of gullies on a hillside
Source: Adopted from Leopold *et al.* (1964)

Localized dispersion of the clays in areas of subsurface moisture accumulation is followed by piping. Heavy summer rains cause water in pipes to break out on to the surface. Eventually, roofs of pipes collapse and gullying occurs. In the Loess Plateau of China, tunnel erosion contributes 25–30 % of the catchment sediment yield (Zhu, 2003). Most of this relates to the development of new tunnels rather than enlargement of existing ones and takes place in single storms with return periods of 50 years or more. In a storm of 107 mm over 7.5 hours, 67 new tunnels were created; another storm of 37 mm in 115 minutes resulted in the formation of 123 new inlets. Sediment

concentration in tunnel flow ranges from 8.2 to 893.2 g l^{-1}, which was very similar to channel flow (Zhu *et al.,* 2002). Once formed, the tunnels continue to erode both during and between storms through earth falls, slumps, water erosion and roof collapse; in some cases, slumps and earth falls lead to their temporary blockage.

A third way in which gullies are initiated is where linear landslides leave deep, steep-sided scars, which may be occupied by running water in subsequent storms? This type of gully development has been described in Italy by Vittorini (1972) and in central Värmland, Sweden, by Fredén and Furuholm (1978). In the latter case, a 3–20 m deep, 20–40 m wide and 100 m long gully formed in glaciofluvial deposits following the 1977 spring snowmelt, which caused the removal, as mass flow, of 20,000 m^3 of saturated silt and sand in less than three days.

The damages resulting from soil erosion is also classified: definition of gullies and explanation of gully development is given by Morgan (1996), as well as Hudson (1995) who additionally focuses on individual causes of the development of gullies. Toy *et al.*(2002) give detailed definitions of soil erosion features and processes such as sheet erosion and inter-rill erosion, rill erosion, as well as ephemeral and permanent gully erosion. They also describe the influence of changing land-use on stream channel erosion. Hogg (1982) defines sheet-flood, sheet-wash and sheet-flow in terms of a hydrologic and geomorphic based classification system: a) sheet-flood is unconfined floodwater moving downhill; b) sheet-flow is a high -frequency, low magnitude overland flow; c) sheet-wash is superseded by the more meaningful term rain-wash, which is defined as the washing action of rain on slopes.

The varying erodibility of different soils causes different erosion and soil erosion damages. Renschler and Harbour (2002) provide an overview of soil erosion assessment tools from point to regional scales. Gobin *et al.*(1998) present an assessment of soil erosion in south-eastern Nigeria, Bewket and Sterk (2003) report results of a field scale erosion soil moisture, in addition to infiltration rates, also depends on evaporation rates.

2.3.2 Hydrophysical Parameters

Research on rainfall intensities and erosivity was conducted by Nyssen *et al*. (2005) for the north-western Ethiopian Highlands. Lal (1998) measured rainfall erosivity, drop size distribution and kinetic energy for two rainy seasons in Nigeria. Rainfall variations by ground measurements as well as by satellite radar data were measured and discussed.Seleshi and Demaree (1995), Nicholson*et al.*(1997), Hulme (2001), Schumacher and Houze (2002), Giannini *et al.*(2003) and Fernandez-Illescas and Rodriguez-Iturbe (2004) provide different methods of assessment and appraisal of rainfall variations in Sahelian and sub-Sahelian areas.

Causes for inter-annual rainfall variability are discussed by numerous authors such as Thompson (2000), Gasse (2000), Mayewski *et al.*(2004), Adams and Piovesan (2005).

The prediction of rainfall totals for mountainous areas has been investigated by Goovaerts (2000), who presents multivariate geostatistical algorithms for incorporating a digital elevation model into the spatial prediction of rainfall. Prudhomme (1999) introduces a method similar to Goovaerts (2000) for predicting spatial rainfall volumes in mountainous areas in Scotland. He also uses the relationship between precipitation and topography. The erosivity factor R, known

from USLE or RUSLE, was focus of a study by Wang*et al.*(2002). The authors predicts the development of new isoerodent maps, since the uncertainty of the R-factor values estimated from isoerodent maps is unknown.

Erosivity by rainfall drops ('splash-effect'), forces by surface runoff ('overland flow`) are part of the erosivity. Saturated overland flow and Horton's surface runoff occur both in tropical semi-arid and semi-humid landscapes. Zehetner and Miller (2006) studied the runoff-erosion behaviour of soils developed from volcanic ash bedrock and Rockstrom *et al*. (1998) pursued water balance modelling with a special focus on runoff producing surfaces for sandy soils in Niger. For Vertisols, Freebairn*et al.*(1986) monitored surface runoff on agricultural fields and its influence on soil surface cover and soil moisture, whereas Dubreul (1985) gives a general overview of runoff generation in the tropics.

Veihe (2002) examines the spatial variability of erodibility of soil types based on a case study in Ghana. The estimation of K-factors from soil types can in general be problematic because soil classifications are often not based on parameters reflecting erodibility.

Erodibility of tropical soils is highly dependent on grain size distribution, clay content and organic carbon content, which influence the stability of soil aggregates. Le-Bissonais (1996) identifies four main mechanisms by which soil aggregates break down: slaking, differential swelling, raindrop impact and physio-chemical dispersion caused by osmotic stress. Barthes and Roose (2002) analyse topsoil aggregate stability and compared these results to susceptibility to erosion. Mbagwu and Bazzoffi (1998) investigate the resistance of dry soil aggregates against rain drops. Valmis *et al.*(2005) correlate inter-rill erosion to aggregate instability, rainfall

intensity and slope gradient.Macro-cracks, as the result of shrinking soils, react to soil moisture changes by opening and closing, as well as by the reorganisation of the clay particles. In heavy clay soils infiltration and lateral water flow are dominated by macro-pore flow. Thus, three components of porosity of this soil influence water infiltration: matrix, structural and macro-cracks (Ruy et al., 1999). Martinez-Casasnovas *et al.*(2004) reveal that gully sidewall processes are influenced by either potential energy changes associated with variations in soil moisture content or, in unsaturated conditions, by the development of undercut hollows.

Infiltration rates of soils are also influenced by the morphometric characteristics of the land surface. Yair and Raz-Yassif (2004) investigated the influence of slope length and gradient on soil erosion. Arid and semi-arid areas assumes an increasing soil erosion with increasing slope length, whereas the gradient is a minor factor. Montgomery (2003) and Park and Van De Giesen (2004) contribute research on spatial soil hydrological properties and their relation to landscape characteristics. Wang *et al.*(2001) show that heterogeneity of soil in time and space tends to support the concept that soil erodibility depends dynamically and spatially on specific soil properties.

Andréassian*et al.*(2004) highlight that sensitivity studies of rainfall-runoff models with regard to the uncertainty of their inputs have focused quite exclusively on rainfall and only few studies consider the sensitivity of potential evapotranspiration estimation. Research on actual and long term potential evapotranspiration summarizes that ‘average annual evapotranspiration curves appear to be as meaningful as any readily available discrete information’ (Burnash, 1995). Ayenew (2003) quantifies actual evapotranspiration from spectral satellite data for the Rift

Valley Lake Region, Ethiopia. Jhorar *et al.*,(2003) highlight the positive effect of using evaporation when estimating soil hydraulics in semi-arid to arid areas and Auerswald*et al.*,(1994) explain the influence of soil moisture content changes on soil erosion.

Where runoff rates are relatively high over most of the hillside, overland flow, or, more strictly, the combined action of overland flow and raindrop impact as interrill erosion, can be the dominant erosion process on upper and middle slopes, with deposition of material as colluvium on the footslopes. This appears to be true for many agricultural areas on non-cohesive soils type. On loose, freshly ploughed soils on colluvial deposits on 18–22° slopes in Calabria, Italy, Van Asch (1983) found that overland flow accounted for 80–95% of the sediment transport. On unvegetated sandy soils in Bedfordshire with an 11° slope, it accounts for 50–80 per cent (Morgan et al., 1986). On a loam soil on a 14° slope in northern Belgium it accounts for 22–46 per cent of the total soil loss, with rates ranging from 24 to 100 t ha^{-1} (Govers and Poesen, 1988). Interrill processes can also be the main agent of erosion on well vegetated slopes if the rainfall is very high.

2.3.3Soil Loss Influencing Factors

The major factors controlling soil erosion are erosivity of the eroding agent, erodibility of the soil, slope of land and nature of plant cover.

2.3.3.1 Erosivity

i. Rainfall

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking soil surface and partly through the contribution of rain to runoff. This applies particularly to erosion by overland flow and rills, for which intensity is generally considered to be the most important rainfall characteristic. The effect of rainfall intensity is illustrated by the data for 183 rain events at Zanesville, Ohio, between 1934 and 1942, which show that average soil loss per rain event increases with the intensity of the storm (Fournier, 1972).

The role of intensity is not always so obvious however, as indicated by studies of erosion in mid-Bedfordshire, England, taking data for the ten most erosive storms between May 1973 and October 1975. While intense storms; such as the one of 34.9mm on 6 July 1973, in which 17.7 mm fell at intensities greater than 10mmh^{-1}, produce erosion, so do storms of long duration and low intensity, like the one of 19 June 1973 when 39.6mm of rain fell in over 23 hours (Morgan *et al.,* 1986). It appears that erosion is related to two types of rain event, the short-lived intense storm where infiltration capacity of the soil is exceeded, and prolonged storm of low intensity that saturates the soil.

Many of these studies show that at intensities greater than 75 mmh^{-1}, kinetic energy levels off at a value of about 0.29 MJha^{-1}mm^{-1} (Kinnell, 1987). However, much higher values of 0.34–0.38 MJha^{-1}mm^{-1}have been obtained in northern Nigeria (Kowal & Kassam 1976; Osuji 1989), Carter *et al.* (1974) found that in the southern USA the kinetic energy increased to a maximum value at about 75mmh^{-1}, decreased with further increases in intensity up to about 175mmh^{-1} and then increased again at still higher intensities. In contrast, other studies in Japan (Mihara, 1951)

recorded rainfall energies some 6–20 % lower than those calculated. Rainfall energy also varies with the density of the air raised to the 0.9 power; as a result, energy increases with altitude.

ii. Rainsplash

The action of raindrops on soil particles is most easily understood by considering momentum of a single raindrop falling on a sloping surface. The downslope component of this momentum is transferred in full to soil surface but; only a small proportion of the component normal to the surface is transferred, the remainder being reflected(Huang *et al.,* 1982). The transfer of momentum to the soil particles has two effects. First, it provides a consolidating force, compacting the soil; second, it produces a disruptive force as the water rapidly disperses from and returns to the point of impact in laterally flowing jets(Huang *et al.*, 1982). Whereas the impact velocity of falling raindrops striking the soil surface varies from about $4ms^{-1}$ for a 1mm diameter drop to $9ms^{-1}$ for a 5mm diameter drop, the local velocities of these jets are about twice these (Huang *et al.*, 1982). These fast moving water jets withhold velocity to some of the soil particles and launch them into the air, entrained within water droplets that are themselves formed by break-up of the raindrop on contact with the ground (Mutchler & Young, 1975). Thus, raindrops are agents of both consolidation and dispersion.

The actual response of a soil to a given rainfall depends upon its moisture content and therefore, its structural state and intensity of the rain. Le Bissonnais (1990) describes three possible responses:

i. If the soil is dry and rainfall intensity is high, the soil aggregates break down quickly by slaking. This is the breakdown by compression of air ahead of the wetting front.

Infiltration capacity reduces rapidly and on very smooth surfaces, runoff can be generated after only a few millimeters of rain. With rougher surfaces, depression storage is greater and runoff takes longer to form.

ii. If the aggregates are initially partially wetted or rainfall intensity is low, micro-cracking occurs and the aggregates break down into smaller aggregates. Surface roughness thus decreases but infiltration remains high because of the large pore spaces between the micro aggregates.

iii. If the aggregates are initially saturated, infiltration capacity depends on the saturated hydraulic conductivity of the soil and large quantities of rain are required to seal the surface. Nevertheless, soils with less than 15 per cent clay content are vulnerable to sealing if intensity of the rain is high.

Over time, percentage area of soil surface affected by crust development increases exponentially with cumulative rainfall energy (Govers & Poesen, 1985), which, in turn, brings about exponential decrease in infiltration capacity (Boiffin & Monnier, 1985). Crustability decreases with increasing contents of clay and organic matter since these provide greater strength to the soil. Thus, loams and sandy loams are the most vulnerable to crust formation.

Studies of kinetic energy required to detach one kilogram of sediment by raindrop impact show that minimal energy is needed for soils with a geometric mean particle size of 0.125mm and that soils with geometric mean particle size between 0.063mm and 0.250mm are the most vulnerable to detachment (Poesen, 1985). Coarser soils are resistant to detachment because of the weight of the larger particles. Finer soils are resistant because the raindrop energy has to overcome the

adhesive or chemical bonding forces that link the minerals comprising clay particles.The wide range in energy required to detach clay particles is a function of different levels of resistance in relation to the type of clay minerals and the relative amounts of calcium, magnesium and sodium ions in the water passing through the pores (Arulanandan and Heinzen 1977).

Rain does not always fall on to a dry surface. During a storm it may fall on surface water in the form of puddles or overland flow. Studies by Palmer (1964) show that as the thickness of surface water layer increases, so does splash erosion. This is believed to be due to the turbulence that impacting raindrops impart to the water. No increase in splash erosion with water depth has been observed however, on sandy soils (Ghadiri and Payne, 1979; Poesen, 1981). Govers and Poesen (1988) noted that although raindrop impact detached 152 t ha^{-1} of soil over one year on a bare loam soil on a 14° slope in Belgium, splash transport accounted for only 0.2 t ha^{-1} of the soil loss.

iii. Subsurface Flow

The lateral movement of water downslope through the soil is known as interflow. Where it takes place as concentrated flow in tunnels or subsurface pipes its erosive effects through tunnel collapse and gully formation are well known. Less is known about the eroding ability of water moving through the pore spaces in the soil, although it has been suggested that fine particles may be washed out by this process. Pilgrim and Huff (1983) measured sediment concentrations as high as 1 g l^{-1} in subsurface flow through a silt-loam soil on a 17° slope under grass in California in storms of 10mmh^{-1} intensity or less. The sediment material were mostly fine particles ranging from 4 to 8mm in diameter, was being detached by raindrop impact at the surface and then

moved by the flow through the macropores in the soil. Under tropical rain forest on 8–14° slopes at Pasoh, Negeri Sembilan, Malaysia, where erosion rates are very low, material removed as dissolved solids in the subsurface flow can amount to 15–23% of the total sediment transport (Leigh, 1982). Subsurface flow is enhanced where subsurface drainage systems have been installed, which can then serve as important pathways for sediment movement. On a 30.6 ha catchment with silty clay loam soils at Rosemaund, Herefordshire, flows through tile drains account for up to 50 per cent of the annual sediment loss of 0.8 t ha^{-1} (Russell *et al.*, 2001).

Studies by Merritt (1984) on the hydraulic characteristics of the flow show that change from overland flow to rill flow passes through four stages: unconcentrated overland flow; overland flow with concentrated flow paths; microchannels without headcuts; and microchannels with headcuts. The greatest difference exists between the first and second stages, suggesting that flow concentrations within overland flow should strictly be treated as part of incipient rill system. In the second stage, small vortices appear in the flow and, in the third stage, develop into localized spots of turbulent flow characterized by roll waves (Rauws, 1987) and eddies (Savat & De Ploey, 1982). At the point of rill initiation, flow conditions change from subcritical to supercritical (Savat, 1979). The overall change in flow conditions through the four stages seems to take place smoothly as the Froude number increases from about 0.8 to 1.2, rather than occurring when a threshold value is reached (Torri *et al.*, 1987b; Slattery and Bryan, 1992).

Since rill flow is non-selective in the particle size it can carry, large grains, even rock fragments up to 9 cm in diameter (Poesen, 1987), can be moved. Meyer *et al*. (1975) found that 15 % of the particles carried in rills on a 3.5° slope of tilled silt loam were larger than 1 mm in size and that 3

per cent were larger than 5mm. On a 4.5° slope of bare untilled silt loam, 80 per cent of the sediment transported in rills was between 0.21 and 2.0 mm in size and most of the clay particles were removed as aggregates within this size range (Alberts *et al.*, 1980).

2.3.3.2 Erodibility

Erodibility defines resistance of soil to both detachment and transport. Although a soil's resistance to erosion depends in part on topographic position, slope steepness and amount of disturbance, such as during tillage, properties of the soil are most important determinants. Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity, organic and chemical content.

Soil texture with large particles are resistant to transport because of the greater force required to entrain them while fine particles are resistant to detachment because of their cohesiveness. The least resistant particles are silts and fine sands. Thus soils with silt content above 40 per cent are highly erodible (Richter and Negendank, 1977). Evans (1980) prefers to examine erodibility in terms of clay content, indicating that soils with clay content between 9 and 30 percent are the most susceptible to erosion. The use of clay content as an indicator of erodibility is theoretically more satisfying because clay particles combine with organic matter to form soil aggregates or clods and it is the stability of these that determines resistance of the soil. Soils with a high content of base minerals are generally more stable, as these contribute to the chemical bonding of aggregates.Wetting of soil weakens aggregates because it lowers their cohesiveness, softens cements and causes swelling as water is adsorbed on clay particles.

Rapid wetting can also cause collapse of the aggregates through slaking. The wetting-up of initially dry soils results in greater aggregate breakdown than if the soil is already moist because, in the latter case, less air becomes trapped in the soil (Truman *et al.,* 1990). Aggregate stability also depends on type of clay mineral present. Soils containing kaolinite, halloysite, chlorite or finegrained micas; all of which are resistant to expansion on wetting, have a low level of erodibility, whereas soils with smectite or vermiculite swell on wetting and therefore have a high erodibility; soils with illite are in an intermediate position.

However, the interactions between moisture content of soil and the chemical composition of both clay particles and soil water are rather complex. This makes it difficult to predict how clays; particularly those susceptible to swelling, will behave. The erodibility of clay soils is highly variable (Chisci *et al.,* 1989). Although most clay lose strength when first wetted because free water movement from clay releases bonds between clay particles of some clays under moist condition but unsaturated conditions of clay regain strength over time. This process, known as thixotropic behaviour, occurs because hydration of clay minerals and adsorption of free water promote hydrogen bonding (Grissinger and Asmussen, 1963). Strength can also be regained if swelling brings about a reorientation of the soil particles from an alignment parallel to the eroding water to a more random orientation (Grissinger, 1966).

Grissinger (1966) noted that increases in the moisture content of a soil decrease its shear strength and bring about changes in its behaviour. At low moisture contents soil behaves as a solid and fractures under stress, but with increasing moisture content it becomes plastic and yields by flow without fracture. The point of change in behaviour is termed plastic limit. With further wetting,

soil will reachits liquid limit and start to flow under its own weight. The behaviour of a compressible soil when saturated depends on whether the water can drain. If drainage cannot take place and soil is subjected to further loading, pressure will increase in the soil water, the compaction load will not be supported by the particles and the soil will deform, behaving as a plastic material. If drainage can occur, more of the load will be supported and the soil is more likely to remain below the plastic limit and retain higher shear strength (Grissinger, 1966).

The mechanism of soil particle detachment by surface flow involves different failure stresses on soil surface compared with those generated by raindrop impact. Rauws and Govers (1988) show that these can be represented by measurements of strength of the soil at saturation, made with a torvane.

Infiltration capacity, the maximum sustained rate at which soil can absorb water, is influenced by pore size, pore stability and the form of soil profile. Soils with stable aggregates maintain their pore spaces better, while soils with swelling clays or minerals that are unstable in water tend to have low infiltration capacities. Although estimates of infiltration capacity can be obtained in the field using infiltrometers (Hills, 1970), actual capacities during storms are often much less than those indicated by field tests. Where soil properties vary with profile depth, horizon with the lowest infiltration capacity is critical. For sandy and loamy soils, the critical horizon is often the surface where a crust of 2 mm thickness may be sufficient to decrease infiltration capacity enough to cause runoff, though the underlying soil may be dry.

The organic and chemical constituents of soil are important because of their influence on aggregate stability. Soils with less than 2% organic carbon, equivalent to about 3.5% organic

matter content, can be considered erodible (Evans, 1980). Most soils contain less than 15% organic matter content and many sands and sandy loams have less than 2%. Voroney *et al.* (1981) suggested that soil erodibility decreases linearly with increasing organic content over the range of 0–10%, whereas Ekwue (1990) observed that soil detachment by raindrop impact decreased exponentially with increasing organic mattercontent over a 0–12%. These relationships cannot be extrapolated, however, because some soils with very high organic mattercontents, particularly peats, are highly erodible by wind and water, whereas others with very low organic content can become very hard and therefore stronger under dry conditions. The role played by organic material depends on its origin. While organic material from grass leys and farmyard manure contributes to stability of e soil aggregates, peat and undecomposed haulm merely protect the soil by acting like a mulch and do little to increase aggregate strength (Ekwue *et al.*, 1993). Thus peat soils have very low aggregate stability.

Many attempts have been made to devise a simple index of erodibility based on either properties of soil as determined in the laboratory or field, or response of soil to rainfall and wind (Table 2.2). In a review of indices related to water erosion, Bryan (1968) favoured aggregate stability as the most efficient index. Unfortunately, there is no agreement between researchers on the most appropriate method to evaluate aggregate stability. Indices like instability index (*Is*) and pseudo-textural aggregation index (*Ipta*) (Table 2.2) are based on breaking up aggregates by wet-sieving a sample of the soil. But some researchers consider that wet-sieving does not adequately simulate processes of breakdown as they occur in the field and prefer to measure proportion of aggregates that can be destroyed by impact of water drops (Bruce-Okine and Lal, 1975).

Different researchers also follow different methods for the duration and speed of oscillation of sieves in wet-sieving tests, and for the size and height of fall in water-drop tests. Further work on developing appropriate tests probably needs to take account of factors that contribute to stability of the aggregates. These are, respectively: for aggregates >10 mm in size, binding and adhesive effects of plant roots; for aggregates of 2–10mm, calcium carbonate and organic matter content; for aggregates of 1–2mm, the network of roots and hyphae; for aggregates of 0.105^{-1}.0mm, organic matter, roots and hyphae; and for aggregates <0.105mm, clay mineralogy and cementing agents derived from microbiological activity (Boix-Fayos *et al.*,2001).

2.3.3.3 Effect of Slope

Erosion would normally be expected to increase with increases in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff. Further, while on a flat surface raindrops splash soil particles randomly in all directions, on sloping ground more soil is splashed downslope than upslope, the proportion increasing as slope steepens (Morgan, 2005).

a. Exponents for slope steepness: Working with data from experimental stations in

Zimbabwe, Hudson and Jackson (1959) observed that *m* was close to 2.0 in value, indicating that the effect of slope is stronger under tropical conditions where rainfall is heavier. The effect of soil is illustrated by laboratory experiments of Gabriels *et al.* (1975), who showed that *m* increases in value with grain size of the material, from 0.6 for particles of 0.05mm diameter to 1.7 for particles of 1.0mm. The value also changes with slope, decreasing from 1.6 on slopes of

0–2.5° to 0.7 on slopes between 3 and 6.5°, to 0.4 on slopes over 6.5° (Horváth and Ero" di, 1962). On steeper slopes, the value may be expected to decrease further as soil-covered slopes give way to rock surfaces and soil supply becomes a limiting factor.

In a detailed study of soil loss from 33 road-cut slopes on the Benin–Lagos Highway in Nigeria, Odermerho (1986) noted values of m = 1.09 for slopes between 1.4 and 6°, 1.80 for slopes between 6 and 8.5°, -2.18 for slopes between 8.5 and 11° and -1.39 for slopes between 11 and 26.5. The results of these studies suggest a curvilinear relationship between soil loss and slope steepness, with erosion initially increasing rapidly as slope increases from gentle to moderate, reaching a maximum on slopes of about 8–10° and then decreasing with further increases in slope. Such a relationship would apply only to erosion by rainsplash and surface runoff; it would not apply to landslides, piping or gully erosion by pipe collapse.

D'Souza and Morgan (1976) obtained values of m = 0.5 on convex slopes, 0.4 on straight slopes and 0.14 on concave slopes. No studies have been made of effect of changes of slope in plain as at 1984, but Jackson (1984) observed from erosion surveys and laboratory experiments that discharge varies with an index of contour curvature to the power of 5.5.

Table 2.4a and b showed the indices of soil erodibility for water erosion.

Table 2.4aIndices of Soil Erodibility for Water Erosion

Static laboratory tests		
Dispersion ratio	$\frac{\%\text{silt} + \%\text{clay in undispersed soil}}{\%\text{silt} + \%\text{clay after dispersal of the soil in water}}$	Middleton (1930)
Clay ratio	$\frac{\%\text{sand} + \%\text{silt}}{\%\text{clay}}$	Bouyoucos (1935)
Surface aggregation ratio	$\frac{\text{surface area of particles} > 0.05\text{mm}}{(\%\text{silt} + \%\text{clay in dispersed soil}) - (\%\text{silt} + \%\text{clay in undispersed soil})}$	André and Anderson (1961)
Erosion ratio	$\frac{\text{dispersion ratio}}{\text{colloid content/moisture equivalent ratio}}$	Lugo-Lopez (1969)
Instability index (*Is*)	$\frac{\%\text{silt} + \%\text{clay}}{Ag_{air} + Ag_{alc} + Ag_{benz}}$ where Ag is the % aggregates >0.2mm after wet sieving for no pretreatment and pretreatment of the soil by alcohol and benzine respectively	Henin *et al.*(1958)
Instability index (*Is*)	$\frac{\%\text{silt} + \%\text{clay}}{(\%\text{aggregates} > 0.2\text{mm after wet sieving}) - 0.9(\%\text{coarse sand})}$	Combeau and Monnier (1961)
Pseudo-textural aggregation index (*Ipta*)	$\frac{MWDw - MWDt}{X - MWDt} \times 100$ where $MWDw$ is the mean weight diameter of the wet-sieving grain-size distribution (mm), $MWDt$ is the mean weight diameter of the primary particle grain-size distribution (mm) and X is the maximum average grain-size diameter of the particles in the given grain-size distribution	Chischi *et al.* (1989)

Table 2.4bIndices of Soil Erodibility for Water Erosion

Static field tests		
Erodibility index	$\frac{1}{\text{mean shearing resistance} \times \text{permeabilty}}$	Chorley (1959)
Soil cohesion	direct measure of soil cohesion at saturation using a torvane	Rauws and Govers (1988)
Dynamic laboratory tests		
Simulated rainfall test	Comparison of erosion of different soils subjected to a standard storm	Woodburn and Kozachyn (1956)
Water-stable aggregate (*WSA*) content	%*WSA* > 0.5 mm after subjecting the soil to rainfall simulation	Bryan (1968)
Water drop test	% aggregates destroyed by a pre-selected number of impacts by a standard raindrop (e.g. 5.5 mm diameter, 0.1 g from a height of 1 m)	Bruce-Okine and Lal (1975)
Erosion index	$\frac{dh}{a}$ where d is an index of dispersion (ratio of % particles >0.05 mm without dispersion to % particles >0.05 mm after dispersion of the soil by sodium chloride); h is an index of water-retaining capacity (water retention of soil relative to that of 1 g of colloids); and a is an index of aggregation (% aggregates >0.25 mm after subjecting the soil to a water flow of 100 cm min^{-1} for 1 h)	Voznesensky and Artsruui (1940)
Dynamic field tests		
Erodibility index (K)	mean annual soil loss per unit of EI_{30}	Wischmeier and Mannering (1969)

If soil loss is assumed to vary with the square of discharge, value of *m* becomes 3.5. Contour curvature is here defined as the proportion of a circle centered on a point on a hillside that lies at a higher altitude than that point (Jackson, 1984). The index ranges from 0 to 1 in value with values <0.5 indicating diverging slopes, on value of 0.5 a straight slope and values >0.5 on converging slopes.

b. Exponents for Slope Length

The value of 0.6 for exponent *n* applies only to overland flow on slopes about 10–20 m long, with steepnesses greater than 3°.Wischmeier and Smith (1978) proposed values of $n = 0.4$ for slopes of 3°, 0.3 for slopes of 2°, 0.2 for slopes of 1° and 0.1 for slopes of less than 1°. Kirkby (1971) suggestsed that $n = 0$ for soil creep and splash erosion, ranges between 0.3 and 0.7 for overland flow and rises to between 1.0 and 2.0 if rilling occurs. This implies that the value of *n* will vary with distance along a hillside as for example; soil creep close to the summit gives way first to overland flow and then to rill flow. Without rills, *n* may become negative on slopes longer than about 10m. The increasing depth of overland flow downslope protects soil from raindrop impact so that, though the transporting capacity of overland flow increases, erosion becomes limited by rate of detachment, which decreased with slope length (Gilley *et al.,* 1985). Once rills form, soil loss will either increase with slope length (Meyer *et al.,* 1975), particularly if the density of rills is very high, or decrease because, as the flow becomes concentrated, there is no longer sufficient flow on the interrill areas to remove all the material detached by rainsplash (Abrahams *et al.,* 1991). Erosion may also decrease with increasing slope length if, as the slope steepens, the soil becomes less prone to crusting and infiltration rates remain higher than on the gentler-sloping land at the top of the slope (Poesen, 1984). Similarly, if the slope declines in angle as length increases, soil loss may

decrease as a result of deposition. Clearly, with such a great range of possible conditions, a single relationship between soil loss and slope length cannot exist.

2.3.3.4Effect of plant cover

Vegetation acts as a protective layer or buffer between atmosphere and soil. The aboveground components; such as leaves and stems, absorb some of the energy of falling raindrops, running water and wind, so that less is directed at the soil, while below-ground components, comprising the root system, contribute to mechanical strength of the soil.

Plant covers where leaves and stems are not in contact with the soil but form a canopy at some height above the soil surface, soil loss ratio is conventionally considered to reduce in a linear relationship with increasing percentage cover (Wischmeier and Smith, 1978; Dissmeyer and Foster, 1981). Moreover, for adequate protection at least 70 per cent of ground surface must be covered (Elwell and Stocking, 1976) although reasonable protection can sometimes be achieved with between 30 and 40 per cent cover. The effects of vegetation however, are far from being straightforward.Under certain conditions, a plant cover can exacerbate erosion, depending on how it interacts with the erosion processes.

3.3.4 Estimate Soil Loss

Soil erosion by water is an important form of land degradation. It is estimated that one sixth of the world's soils are affected by water erosion. Globally, humans impact on around 1,094 million hectares; of which 43% suffer from deforestation and removal of natural vegetation, 29% from overgrazing, 24% from improper management of agricultural land and 4% from over-exploitation of natural vegetation (Walling and Fang, 2003). Human-induced land degradation is one of the more destructive phenomena relating to natural resources in the

world, and is recognized as a key issue for conservation in the 21st century (Reich, *et al.*, 2000). In mountain environments of developing countries, soil erosion regularly constrains rural development and exacerbates poverty by undermining the productive capacity of highland agriculture and livestock raising (Zimmerer, 1993; Lal, 2001).

Erosion embodies the processes of rainfall and flow detachment, entrainment or transport and deposition of soil particles. The processes controlling sediment detachment, transport and deposition are complex and interactive (Toy *et al.*, 2002). This complexity results in the lumping of many sub-processes under erosion process in many erosion models. The difficulty in observing, monitoring and measuring erosion processes during erosion events; owing to the scales at which the processes occur, necessitates use of erosion models for prediction of erosion in catchments (Jetten *et al.*, 2003).

Soil loss is normally estimated with empirically and physically-based models (Jha and Paudel, 2010). The well-known physically-based models include Water Erosion Prediction Project (WEPP) (Flanegan and Nearing, 1995), Limburg Soil Erosion model (LISEM) (De Roo, Wesselingsnd Ritsema, 1996), European Soil Erosion Model (EUROSEM) (Morgan *et al*., 1998), and Revised Morgan, Morgan and Finney model (RMMF) (Morgan and Finney, 2001). Empirically based models include SLEMSA (Soil Loss Equation Model of Southern Africa), and Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Universal Soil Loss Equation (USLE) was successfully applied in the tropics in Kenya (Burrough and McDonnell, 1998). In its original form USLE was applied to a plot of land (Wischmeier and Smith, 1978) and in recent year's application of distributed USLE is wide spread (Beskow*et al.*, 2009).

Over the years, there has been remarkable reports on progress in development of mathematical tools for erosion transport modelling, with a tendency towards physically or process-based model development (Young*et al.,* 1989; Jetten *et al.,* 2003). Most of the current process-based erosion models can be roughly divided into three main groups namely: plot, field or hillslope scale; catchment scale; and complex landscape models (Merrit, *et al.,* 2003). But field and catchment scale is chosen in this present research because of data availability, nature of the study area and choice of models used. Meanwhile there are numerous models that combine more than one of the above concepts; as a number of important issues for effective erosion assessment at catchment and regional scales remain unsolved. For example, many current methods require a large number of experimental input data unavailable in ungauged catchments, important effects of terrain shape are not taken into account, numerical methods used for the model implementation exhibit instabilities when used at high resolutions and detailed spatially variable outputs are limited (Perrin, *et al.,* 2001).

Numerous research conducted by Hill and Schütt (2000), Ranieri*et al.* (2002), Van Oost*et al.* (2004), King*et al.* (2005) and Metternicht and Gonzalez(2005) demonstrates that geo-information and remote sensing techniques in combination with erosion models are powerful tools for generating and supporting such understanding. Therefore, emphasis has been put on use of geo-information techniques for geospatial data monitoring, handling and processing and use of remote sensing as sources of data for GIS inputs. At the most basic level, estimates of erosion risk can be derived by classifying pixels according to percentage of bare soil (Paringit and Nadaoka, 2003). Mathieu*et al.* (1997), Haboudane*et al.* (2002) and Singh*et al.* (2004) modified this scheme by estimating vegetation parameters from Medium Resolution Imaging Spectrometer (MERIS), Landsat-TM and SPOT-4 satellite imagery and

combining them with slope factors generated from a DEM to produce an erosion rate map. On the other hand, empirical soil erosion models in combination with soil, climate, vegetation and topography information have been implemented using remote sensing technology (Fu*et al.*, 2005). Classification of Landsat-TM imagery has been used over the years to estimate crop management factor of USLE (Millward and Mersey, 1999; Zhang, 1999).

There are different strategies for linking erosion models with GIS, ranging from loosely coupled to tightly coupled arrangements. Pullar and Springer (2000) categorized three levels of integration:

i. Loose coupling: GIS system and erosion model are separated, and the files must be transferred back and forth externally between GIS and the model.
ii. Tight coupling: GIS (typically) provide the shared interface to move spatial data between GIS and separated modelling program.
iii. Embedded: model is fully integrated as a component in the host GIS application.

Most current integrations of soil erosion models with GIS are examples of the first two approaches. In the third approach, linkages are problematic owing to lack of a temporal dimension in most GIS systems.

Kabir *et al.* (2016) estimated soil erosion dynamics in Koshi Basin Using GIS and Remote Sensing to Assess Priority Areas for Conservation. This study used remote sensing (RS) data and a geographic information system (GIS) to estimate spatial distribution of soil erosion across entire Koshi basin, to identify changes between 1990 and 2010 and to develop a conservation priority map. The revised universal soil loss equation (RUSLE) was used in an ArcGIS environment with rainfall erosivity, soil erodibility, slope length and steepness,

cover-management and support practice factors as primary parameters. The estimated annual erosion from the basin was around 40 million tonnes (40 million tonnes in 1990 and 42 million tonnes in 2010). The results were within the range of reported levels derived from isolated plot measurements and model estimates.

Erosion risk was divided into eight classes from very low to extremely high and mapped to show spatial patterns of soil erosion risk in the basin in 1990 and 2010. The erosion risk class remained unchanged between 1990 and 2010 in close to 87% of the study area, but increased over 9.0% of the area and decreased over 3.8%, indicating an overall worsening of the situation. Areas with a high and increasing risk of erosion were identified as priority areas for conservation.

2.3.5 Soil Erosion Risk

Erosion risk assessment is the process of estimating or judging the value or functional status of ecological processes in a location at a moment in time (Pellant *et al.,* 2005). Monitoring is the orderly collection, analysis and interpretation of resource data to evaluate progress toward meeting management objectives (Pellant *et al.,*2005).

Obinna *et al.*(2013)assessed and mapped long term erosion hotspots in South East Nigeria. The study is aimed at assessing level of erosion across the entire region and map areas vulnerable to erosion, over an extended period of time. Erosion hotspots in the region have been identified through field observations with obvious; limitations such as being time consuming, expensive and tedious. The Revised Universal Soil Loss Equation (RUSLE) was implemented in a GIS, in conjunction with remote sensing techniques as an alternative method of identifying erosion hotspots. The research identified five levels of erosion risks in

the region, ranging from extreme to very low risk areas, and highlighted spatial distribution of erosion hotspots in the region. The hotspots are mainly located in most parts of Ebonyi State, some parts of Enugu State (Northwest axis), Anambra State (South East and Central axis), and most parts of Abia State. Results from the spatiotemporal variations analysis carried out revealed that there are increasing levels of erosion risk in Ebonyi State from 1986 to 2011.

Yahya *et al.*(2013) conducted research on spatial estimation of soil erosion risk using RUSLE approach, RS, and GIS Techniques: A Case Study of Kufranja Watershed, Northern Jordan. Wadi Kufranja catchment (126.3 km^2), northern Jordan, was selected to estimate annual soil loss using the Revised Universal Soil Loss Equation (RUSLE), remote sensing (RS), and geographic information system (GIS). RUSLE factors (R, K, LS, C and P) were computed and presented by raster layers in a GIS environment, then multiplied together to predict soil erosion rates, generate soil erosion risk categories and soil erosion severity maps. The estimated potential average annual soil loss is 10 $ton \cdot ha^{-1} \cdot year^{-1}$ for the catchment, and potential erosion rates from recognized erosion classes ranged from 0.0 to 1850 $ton \cdot ha^{-1} \cdot year^{-1}$. About 42.1% (5317.23 ha) of the catchment area was predicted to have moderate risk of erosion, with soil loss between 5 - 25 $ton \cdot ha^{-1} \cdot year^{-1}$ and31.2% (3940.56 ha) of the catchment has severe to extreme soil erosion with about 25 - 50 and >50 $ton \cdot ha^{-1} \cdot year^{-1}$ soil loss. Apart from gentle slopes of the alluvial fan (Krayma town and surroundings), the lower and middle reaches of the watershed suffer from severe to extreme erosion risk. High terrain, slope steepness, removal of vegetation, and poor conservation practices were the most prominent causes of soil erosion. This investigation demonstrates that remote sensing (RS) and GIS technologies were effective tools in modeling erosion,

thus enabling extraction of significant information for implementing soil conservation plans in the north Jordan highlands.

Thomsen *et al.*(2015) measured soil surface roughness, comparing old and new measuring methods and application in a soil erosion model in southern Norway. Quantification of soil roughness such as the irregularities of soil surface due to soil texture, aggregates, rock fragments and land management, is important as it affects surface storage, infiltration, overland flow and ultimately, sediment detachment and erosion. Subsequently, the values were used as input for LISEM soil erosion model to test their effect on simulated hydrograph at catchment scale. Results show that statistically significant differences between the methods were obtained only for fields with direct seeding on stubble; for the other land management types, the methods were in agreement. The spatial resolution of the contact methods was much lower than for the sensor methods (10,000 versus at least 57,000 points per square metre). In terms of costs and ease of use in the field, the Xtion Pro method is promising. The results from LISEM indicated that especially the roller chain overestimated the Random Roughness (RR) values and the model subsequently calculated less surface runoff than measured.

Lopez-Vicente *et al.*(2015) assessed soil redistribution at catchment scale by coupling a soil erosion model and sediment connectivity index (central Spanish prepyrenees). Catchment scale both in field and numerical simulation studies was for the study. Also, two different predictive models and a sound field-based dataset were used in assessing the potential soil redistribution in a Mediterranean rain-fed agricultural and mountainous catchment. (La Reina gully catchment, Cino Villa's region, NE Spain). The models employed were; enhance Modified-RMM-2014 version of the Modified RMMF Model (Morgan and Finney,

2001; Lopez-Vicente*et al.,*2010) of soil erosion and the Index of Connectivity model of sediment connectivity. The authors first ran the IC model under six different scenarios of runoff pathways and results were compared with field observation of soil redistribution in a cereal experimental plot (1.9 ha; 1x1m of cell size). IC model was run at La Reina gully catchment (231 ha; 5 x 5 m) and IC values were analyzed. Predicted rates of both models were correlated 613, control points and three areas were identified at the plot; erosive, stable and depositional-prone areas, affecting 30%, 22% and 48% of the soil surface. They noteed that the average erosion rates in each area were3.3, 1.5 and 1.1 Mg ha^{-1} yr^{-1} with standard deviation values of 20.3, 19.0 and 8.3 Mg ha^{-1} yr^{-1}. The best performance was obtained with IC model when the map of geomorphic features (rill, ephemeral gullies and fan deposits) was used in the simulation. The results of predicted showed clear differences in the index of connectivity along catchment though extension of area with predominant processes of about 11% soil loss within the catchment area.

Haile and Fetene (2012) estimated that about 97.04 % of Kilie catchment, East Shoa, have 0–10 Mg $ha^{-1}yr^{-1}$ erosion rate. In Borena district of south Wello, the rate of soil loss estimated between 10 Mg and 80 Mg $ha^{-1}yr^{-1}$(Abate, 2011).

2.3.6 Predicting of Soil Erosion Loss

There has been a number of model-based studies of soil erosion in small individual watersheds in the Nepal Himalayas. Satisfactory results were also obtained using the Revised Morgan, Morgan, and Finney (RMMF) model in Pakhribas Sherchan, Gurung and Chand, 1992) and Likkhu Khola valleys (Shrestha, 1997) and RUSLE in Bagmati basin (Jha and Paudel, 2010). The RUSLE-GIS interface has several advantages in terms of easy

updating, integration of spatially referenced data and the facility to present mapping results in different forms. A number of studies have shown good results using RUSLE together with GIS methods and RS data to model soil erosion (Pandey Chowdary and Mal 2007; Adediji *et al.*, 2010; Perovic*et al.,* 2013). RUSLE and RMMF have also been applied to the Kalchi Khola watershed to predict soil loss rates and spatial erosion pattern (Jha and Paudel, 2010). In the present study, the RUSLE and RMMF model were used together with remote sensing (RS) data and GIS to predict erosion risk dynamics in Mubi South watershed and determine priority areas for soil conservation to erosion prevention.

Owusu (2012) carried out a research on GIS-Based estimation of soil loss in Densu Basin in Ghana. The Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) were used to estimate soil loss. Input data include soil, rainfall, digital elevation model (DEM) and its derivative slope map, land use map and cultivation parameter (C). A PC Raster GIS soil loss risk maps was developed for Densu basin using models of Universal Soil Equation (USLE) and Revised Universal Soil Equation (RUSLE). The model predicted average, minimum and maximum annual soil loss rates of 2.2, 0, and 63 t ha^{-1} yr^{-1}, respectively, indicating that some areas in the basin were above tolerance level of 5.0 t ha^{-1} yr^{-1}. The total soil loss was 756,507 tonnes per hectare per year. Among the soil types Lixisols experienced the highest soil loss of 402,080 t ha^{-1}yr^{-1} with Plinthosols experiencing the lowest soil loss of 64 t ha^{-1} yr^{-1}. Among the administrative districts in the basin, Suhum, Kraboa and Coaltar experienced the highest absolute soil loss of 216,957 t ha^{-1} yr^{-1} while Fanteakwa experienced highest average soil loss of 4.5 t ha^{-1} yr^{-1}. Mountainous areas of the basin exhibited high risk of soil loss that exceeded tolerance level of 5 t ha^{-1} yr^{-1}, and districts found on mountainous part of the basin are more erodible. Channel erosion dominates in the valleys of Densu River while there are also evidence of splash and rill

erosion occurring upstream. Proper soil management can use these risk maps to make decision on soil conservation.

Lu*et al.*(2004) mapped soil erosion risk in Rondônia, Brazilian Amazonia using RUSLE, remote sensing and GIS. Soil map and soil survey data were used to develop the soil erodibility factor (K), and a digital elevation model image was used to generate the topographic factor (LS). The cover management factor (C) was developed based on vegetation, shade and soil fraction images derived from spectral mixture analysis of a Landsat Enhanced Thematic Mapper Plus image. A soil erosion risk map with five classes (very low, low, medium, medium-high, and high) was produced based on the simplified RUSLE within the GIS environment. The results indicate that most successional and mature forests are in very low and low erosion risk areas, while agroforestry and pasture are usually associated with medium to high risk areas.

Amore *et al.*(2004)applied two soil erosion models both spatially distributed, to three large Sicilian basins upstream of reservoirs. In the study, each basin was subdivided into hillslopes, using three different classes of average area, in order to estimate the scale effect on sediment yield evaluation.The first model was the empirical Universal Soil Loss Equation (USLE) and the other one was the physically based model of the Water Erosion Prediction Project (WEPP). A Geographical Information System was used as a tool to handle and manage data for application of model.Computed sediment yields were compared with each other and with measurements of deposited sediment in the reservoir, and for these cases the WEPP estimates better approximated the measured volumes than did the USLE. Neither of the models appeared to be particularly sensitive to area of hillslopes, at least within the range of values considered. This suggests that a finer subdivision; although it may better define the

experimental conditions (plot or field areas) for calibration of model, may not result in a better estimate of erosion.

2.3.7 Empirical Literature Review

From the litereture reviewed, Odunze (2002) studied mulching in a semi-arid zone of nigeria for soil erosion control and grain yield of maize in Zaria, Kaduna State. The method employed includes; sediment collected in 94 liter capacity drums in each treament of selected herbaceous legumes which was intecropped with maize.

A sole maize and maize/straw mulched treatment were also maintained and evaluated for soil loss control potentials. Sediments were obtained in each year of 1993 and 1994. In 1993, ten and seven soil loss events were monitored in July and August while in 1994, both July and August were saperately monitored for six and five sediment events in September under the treatment. Universal Soil Loss Equation was used to determine potential annual soil loss. The research revealed that water erosion is a major factor degrading soils of Nigerian Semi-Arid ecoregions and making agriculture less sustainable. The results obtained show that there was generally higher sediment yields in 1993 and 1994 under legume live mulch and sole maize treatment than straw much. The researcher also found that straw mulch followed by Stylosanthes and Macrotyloma live mulch treatments resulted in significant maize grain yields than sole maize and Mucuna live much treatment. The researcher recommended the need for measured and estimate soil loss, and suitable management practices that will ensure sustained productivity of the soil.

Joris*et al.* (2003) in their research titled application of semi-quantitative methods and reservoir sedimentation rates for the prediction of basin sediment yield in Spain. The authors

explored the use of semi-quantitative approaches to predict mean annual area-specific sediment yield (SSY) at the scale of small to medium-sized basins. Factorial Scoring Model (FSM) and PSIAC model was employed. Some variations of these models were applied to predict SSY for the 60 reservoirs, using reservoir sedimentation rates, Sediment yield at Spanish reservoirs and its relationship with the drainage basin area. Based on the research, FSM explained 72% of variability found in reservoir sedimentation rates, which was significantly better than estimates based on basin area alone, explaining only 22%. The PSIAC explained 58% of the variation in SSY. The researches only concentrated on reservoir and failed to cover the entire catchment area.

Iguisi (2003) conducted a research on validation of soil loss estimation model for two location in Zaria, Nigeria. The research was aimed at validating the model for two sub-basins near Zaria, Nigeria. Morgan, Morgan and Finney model was used and the soil loss was measured at multiple points within each sub-basin using Garlac erosion troughs to collect overland flow and vacuum filtration techniques to determine amount of soil loss contained in the collected overland flow. The result showed that in sub-basin 1, measured soil loss ranged from 0.441 to 4.396 mt/ha/yr with a mean of 2.197 mt/ha/yr. In sub-basin 2, soil loss ranged from 1.71 to 12.789 mt/ha/yr with a mean of 5.643 mt/ha/yr. It was also observed that soil loss generated by the model indicates that sub-basin 1 lost about 0.38 mt/ha/yr while sub-basin 2 lost about 2.19 mt/ha/yr. Result of statistical analysis which compared measured soil lost with estimated soil loss shows that estimated soil loss amount was not significantly different from measured soil loss in the two experimental sub-basins. Morgan Morgan Finnery model was employed in the research; but not the revised MMF model. The researcher also did not used GIS techniques. Hence, the need for the present

research to use GIS techniques to derive some input parameters for revised model and also to show the spatial distribution of hydrophysical parameters for ongoing research and produce maps of predicted soil erosion risk.

Ande *et al.*(2009)predicted soil erosion using MMF model on highlydissected hilly terrain of Ekiti environs in southwesternNigeria. Their aim was to assess the potential of Morgan, Morgan and Finney (MMF) model in predicting soil erosion in an agrarian Ekiti environment. Results showed that erosion was low in the area in spite of the landscape. The highest soil loss was 1.275 kgm^{-2} $yr^{-1}$from rock, hill with slope greater than 15%. The lowest was 0.942 kgm^{-2} yr^{-1} at lowlands covered with riparian forest. The average estimated annual soil loss of the study area was 1.112 kgm^{-2}, which was less than tolerable standard of 1.33 $kgm^{-2}yr^{-1}$ or 3 tons $acre^{-1}yr^{-1}$. The MMF model shows that the current land-use/cover in the area was sustainable because erosion risk was below the critical level. Despite use of MMF model by the researchers, it was not done or conducted with the revised version. Also, the research failed to look at spatial distribution of hydrophysical parameters of soil erosion. Thus, the research was not GIS inclined, which triggered ongoing research in Mubi South assupported by Tamene (2005); Tesfahunegn *et al.*(2011a).

Park*et al.* (2011) assessed soil erosion risk in Korean watersheds, using the Revised Universal Soil loss Equation and GIS. The result showed that most mountainous areas are at high risk of soil erosion caused by water while lowlands in river basin areas suffer lower risk. They found that soil erosion at p=0.1 is less than that at p=0.02. Further, the difference of soil erosion modulus between p=0.1 and p=0.02 will increase as average rainfall increases. The authors also noticed that slopes in the region ranged from 0.0 to 24.1°, among

which slopes steeper than 30% only take 1.3% of the total area. The research failed to consider some hydrophysical parameters from GIS techniques, hence the need for the present research to use RMMF model with GIS techniques to ascertain such problems and predict soil erosion risk. Also, revised universal soil loss equation has many limitations for application at catchment-scale and in applicability due to intensive data and computation requirements as pointed out by Fox and Bryan (2000) and Kinnell (2000).

Qi (2011) assessed soil erosion risk in the hilly-gullied area for Luoyugou watershed in Tianshui, Loess Plateau, and North China. The research attempted to simulate distribution of soil erosion risk in a small watershed named Luoyugou (Tianshui, North China) by an uncertainty inference model based on Subjective Bayes and GIS. It was observed that the impact on soil erosion from vegetation cover is obvious and soil erosion risk will plummet from 56.98% without vegetation cover to 10.5% with vegetation cover. Again, the probability of soil erosion possesses the trend of exponential growth along with the slope enlargement and has increased to about 0.497%, 1.834%, 10.232%, 27.987%, 41.665% or 55.639% separately, compared with only considering vegetation factor under various slope classifications. The research only concentrates on gully erosion and fails to assess major hydrophysical parameters that lead to formation of gully erosion in the areas. Also, the research failed to predict areas that are vulnerable to gully erosion basedon the hydrophysical parameters.

Prasannakumar *et al.*(2011) estimated soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. A comprehensive methodology that integrates Revised Universal Soil Loss Equation (RUSLE) model and Geographic Information System (GIS) techniques

was adopted to determine soil erosion vulnerability of a forested mountainous sub-watershed in Kerala, India. The spatial pattern of annual soil erosion rate was obtained by integrating geo-environmental variables in a raster based GIS method. Geographic Information System data layers including rainfall erosivity (R), soil erodability (K), slope length and steepness (LS), cover management (C) and conservation practice (P) factors were computed to determine their effects on average annual soil loss in the area. The resultant map of annual soil erosion shows a maximum soil loss of 17.73 t h^{-1} y^{-1} with a close relation to grassland areas, degraded forests and deciduous forests on the steep side-slopes (with high LS). The research concentrated on mountainous area with the aid of RUSEL only without integrating it with RMMF Model in order to know the best model suited for the environment.

Vieira*et al.* (2013) modeled runoff and erosion and their mitigation in burned Portuguese forest. The method employed was using revised Morgan Morgan Finney model. It observed that revised MMF model can easilyprovide a set of simple criteria for management decisionsfor runoff and erosion in burned areas. The successful predictions of runoff and erosion at the validation site attestto its applicability to other eucalypt and pine sites in Portugal and suggest that it may well have wider applicability topost-fire conditions for other vegetation types elsewhere inthe Mediterranean.They mainly concentrated on wildfire and mulching in plantations for the study area and not soil erosion and also fail to involve geospatial techniques.

Gebreyesus *et al.*(2014), soil erosion prediction used Morgan-Morgan-Finney model in a GIS environment in Northern Ethiopia catchment. The study aimed to derive spatial distribution of hydrophysical parameters and applied them in Morgan-Morgan-Finney

(MMF) model for estimating soil erosion in Mai-Negus catchment, northern Ethiopia. Major data input for the model include climate, topography, land use, and soil data. The method employed was MMF model. The results show that rate of soil detachment varied from <20 t $ha^{-1}y^{-1}$to >170 t $ha^{-1}y^{-1}$, whereas soil transport capacity of overland flow (TC) ranged from 5 t $ha^{-1}y^{-1}$to >42 t $ha^{-1}y^{-1}$. The average soil loss estimated by TC using MMF model at catchment level was 26 t $ha^{-1}y^{-1}$. Also in most parts of the catchment (>80%), the model predicted soil loss rates higher than the maximum tolerable rate (18 t $ha^{-1}y^{-1}$) estimated for Ethiopia. This is the method to be adopted in the present research but using revised MMF model of the year 2014 because the study area has a similar characteristics with ongoing research and also it requires less input data unlike the other models put forward by other scholars.

Moreover *et al.*(2014) evaluated soil erosion risk in the basement complex terrain of Akure Metropolis, Southwestern Nigeria. They employed the method of principal component analysis (PCA) and using weighted index overlay raster tool in ArcGIS software. Composite erosion index map of the study area was produced. The erosion index map classified the Akure Metropolis into three zones – very low risk (57.5%); low risk (33.9%) and moderate risk (8.6%). The results showed that most parts (91.4%) of the metropolis fell within the very low to low risk zones with tendency for sheet/rill erosional features. Areas with moderate risk with tendency for gully erosion were located on the high slope region. They only concentrated on GIS based soil erosion risk but failed to apply any model to ascertain spatial variability of other parameters.

Augustine and Chima (2015) mappedpotential soil erosion risk areas in Imo State using the Revised Universal Soil Loss Equation (RUSLE), Remote Sensing (RS) and Geospatial

Information System (GIS) Techniques. The Revised Universal Soil Loss Equation (RUSLE) was implemented in a GIS, in conjunction with remote sensing techniques. The study identified five levels of severity in the state, ranging from extreme to very low risk areas, as well as spatial distribution of erosion risk areas in the State. It was observed that long and continuous human disturbance and deforestation; with combined effect of K, LS and C factors, accounted for high level of soil loss across the area. Most of the hotspots were located in north eastern part of the State, which correlated with areas of steep slopes. The research did not integrate RUSEL with RMMF Model to compare for best model suited for the environment.

Based on review of previous literature in chapter two of this work, various erosion-focused studies were carried out by researchers in the country (Odunze, 2002; Iguisi, 2003; Ande*et al.*, 2009; Tekwa *et al.*, 2014; Augustine and Chima, 2015). However, some of these studies largely focused on different parts of the world (Park *et al.*, 2011; Prasannakumar *et al.*, 2011; Gebreyesus *et al.*, 2014), using RUSLE and RMMF model. Most of the predictions of soil erosion risk for the region were largely produced through ground surveys of affected sites, looking into the areas of gullying and their physio-chemical properties, especially in some parts of the study area (Mubi South). The menace of erosion has drawn attention of researchers at local, national and global research community, and has led to studying of various effects and aspects of soil erosion in various parts of the world.

2.3.8 Summary of Literature Review

Based on the review of previous literature in this chapter, it was observed that soil erosion risk assessment is the process of estimating value or functional status of ecological processes

in a location at a moment in time and it also involved monitoring which are the orderly collection, analysis, and interpretation of resource data to evaluate progress toward meeting management goals. However, Obinna *et al.*(2013) conductedlong term assessment and mapping of erosion hotspots in South East Nigeria. The study only aimed at assessing level of erosion across the entire region and map areas vulnerable to erosionover extended period of time without looking at the hydrophysical parameters which play a measure role is assessing soil erosion risk. Yahya *et al.* (2013) analysed spatial estimation of soil erosion risk using RUSLE approach, RS, and GIS techniques, but also failed to considered hydrophysical parameters. Thomsen *et al.* (2015) only measured soil surface roughness, comparing old and new measuring methods and application in a soil erosion model in southern Norway without using geospatial technology. Lopez-Vicente *et al.* (2015) assessed soil redistribution at catchment scale by coupling a soil erosion model and sediment connectivity index (central Spanish prepyrenees) without assessing spatial distribution of the soil hydrophysical parameters.

On the same note, there has been a number of researches conducted on model-based studies of soil erosion in small individual watersheds in the Nepal Himalayas. Satisfactory results were also obtained using Revised Morgan, Morgan, and Finney (RMMF) model and RUSLE in the Bagmati basin using RUSLE together with GIS methods and RS data to model soil erosion. Revised Universal Soil Loss Equation and Revised Morgan, Morgan, and Finney have also been applied to watershed to assess and predict soil loss rates and spatial erosion pattern as pointed out by (Jha and Paudel, 2010). Owusu (2012) carried a research on GIS-Based estimation of soil loss in the Densu Basin in Ghana but only used RUSLE without

using hydrophysical parameters of soil erosion. This is Similar to the research conducted by Lu *et al.*(2004).

Perrin*et al.* (2001) pointed out that numerical methods used for the model implementation exhibit instabilities when used at high resolutions and detailed spatially variable outputs are limited. Research conducted by King*et al.* (2005) and Metternicht and Gonzalez(2005) demonstrates that geo-information and remote sensing techniques in combination with erosion models are powerful tools for generating and supporting such understanding. It was noted by Paringit and Nadaoka (2003) that at most basic level estimates of erosion risk can be derived by classifying pixels according to percentage of bare soil which is also supported by Singh *et al.* (2004) and (Fu*et al.*, 2005). It is also stated that since 1999 classification Landsat-TM imagery had used over the years to estimate crop management factor of RUSLE as poined by Tateishi*et al.* (2004) that the normalized difference vegetation index (NDVI) was the most useful in estimating of soil erosion. On a similar note, Kabir *et al.* (2016) estimated soil erosion dynamics in Koshi Basin using only RUSLE with GIS and Remote Sensing to Assess Priority Areas for Conservation only and results were within the range of reported levels derived from an isolated plot measurements and model estimates.

Moreover, Odunze (2002) studied mulching in a Semi-Arid Zone of Nigeria for soil erosion control and grain yield of maize in Zaria, Kaduna State. Conventional method such as Universal Soil Equation Loss was used to determine potential annual soil loss without the use of geospatial technigues. Though Joris, Jean and Gert (2003) in their research explored use of semi-quantitative approaches to only predict mean annual area-specific sediment yield (SSY) at the scale of small to medium-sized basins of reservoir and fail to cover the entire catchment area.

Again, Iguisi, (2003) validated soil loss estimation model for two locations in Zaria, Nigeria, using old version of MMF model that did not involve GIS techniques. On the same note Ande, Alaga and Oluwatosin (2009)predicted soil erosion using MMF model on highlydissected hilly terrain of Ekiti environs in southwesternNigeria; meanwhile the research was not GIS inclined. Park *et al.*(2011), Qi (2011) and Prasannakumar *et al.*(2011) used Revised Universal Soil Loss Equation (RUSLE) and Geo-information technology without integrating it with RMMF Model in order to know the best model suited for the environment. On the same note, Vieira*et al*. (2013) modeled runoff, erosion and their mitigation measures, but failed to involve geospatial techniques.

Gebreyesus, Tesfahunegn and Paul (2014) assessed and predicted soil erosion using Morgan-Morgan-Finney model in a GIS environment This method is adopted in my research; but by using Revised MMF model of the year 2014, because the study area had a similar characteristics with the ongoing research and also require less input data unlike the other models put forward by other scholars. Though John *et al.*(2014) evaluated soil erosion risk but concentrated on GIS based soil erosion risk and failed to apply any model to ascertain spatial variability of soil hydrophysical parameters. On the same manner, Augustine and Chima (2015) mapped potential soil erosion risk areas but also failed to use RUSEL with RMMF Model to compare for best model suited for the study area.

CHAPTER THREE
STUDY AREA

3.1 THE STUDY AREA

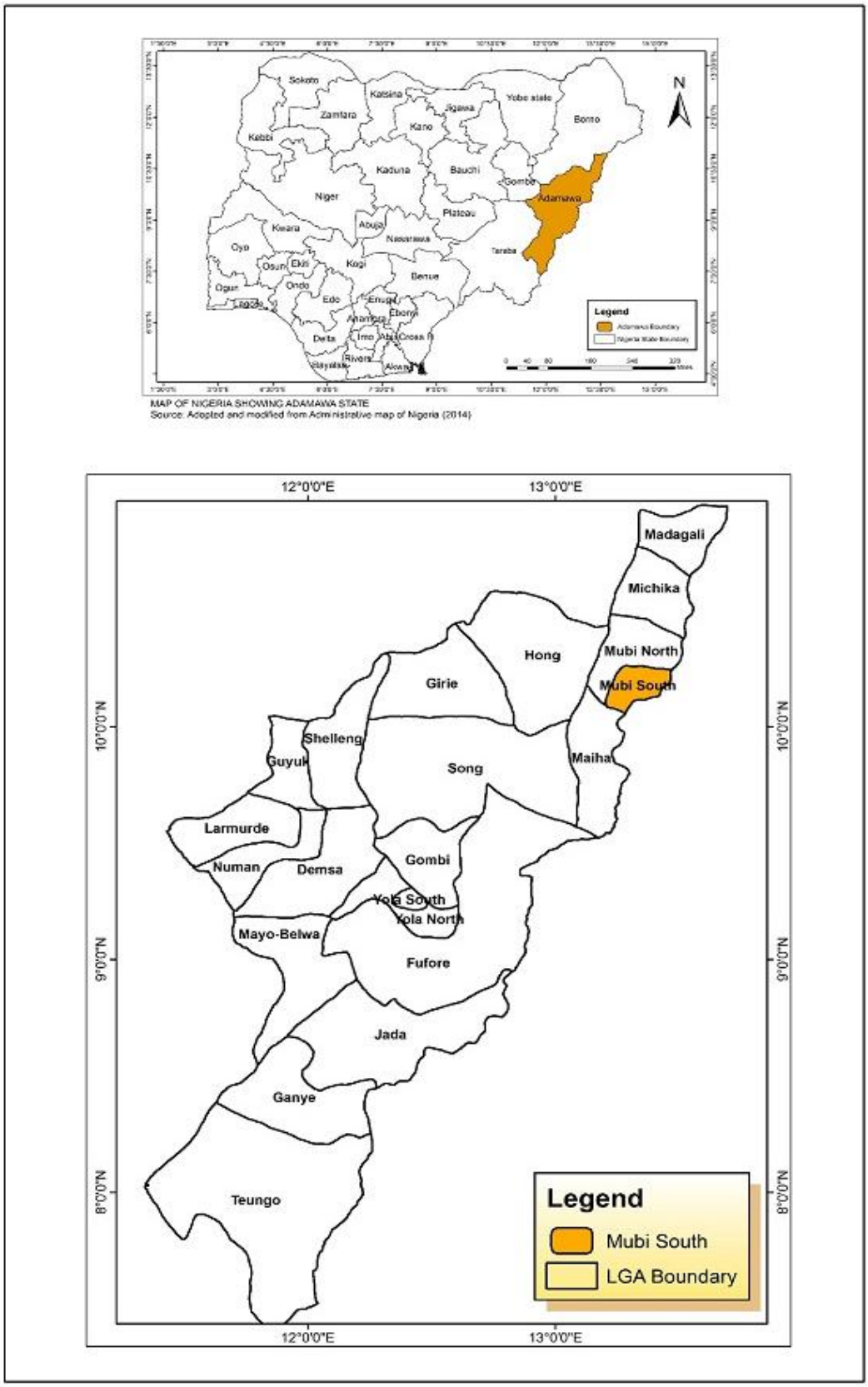
3.1.1 Location

Mubi south Local Government Area is located in Northeastern Nigeria between latitudes 10º 4′ 30”N - 10º 15′ 0” N, and Longitudes 13º 20′ 0” E - 13º 27′ 0”Eofthe Greenwich Meridian (watershed is located 10º 4′ 30”N - 10º 15′ 30” N, and Longitudes 13º 16′ 30” E - 13º 25′ 30”E). The study watershedarea covered about 148.43 km^2 (sq km). The study area is bordered by Lamurde from North-East, Gella Local Government Area to the East, Wuro Bobbowa and Girgi in the South-West. The map and location of study area is shown in Figure 3.1.

3.1.2 Climate

The climate of the study area is typical of the tropical savanah climate count 2431 of Aw koppen-Geiner classification. Temperature in this climatic region is high because of the radiation income, which is relatively evenly distributed. However, there is usually a seasonal change in the temperature. There is gradual increase in temperature from January to April. There is also a distinct drop in temperature at the onset of rains due to the effect of cloudiness. A slight increase after the cessation of rain (October to November) is common before the onset of harmattan in December the temperature in Yola reach 40^oC particularly in April and while minimum temperature can be as low as 18^oC in the south to 27.8^oC in the northeastern part in December (Adebayo and Tukur, 1999). Rainfall Erosivity ranges

between 481m to 192m with about 15.5mm to 15.8mm rainfall per day and 4.5mm to 4.6mm rate of potential evapotranspiration.



MAP OF NIGERIA SHOWING ADAMAWA STATE
Source: Adopted and modified from Administrative map of Nigeria (2014)

Figure 3.1: Map of Adamawa State Showing Mubi and Nigeria Showing Adamawa
Source: Modified from the Administrative Map of Adamawa and Nigeria (2015)

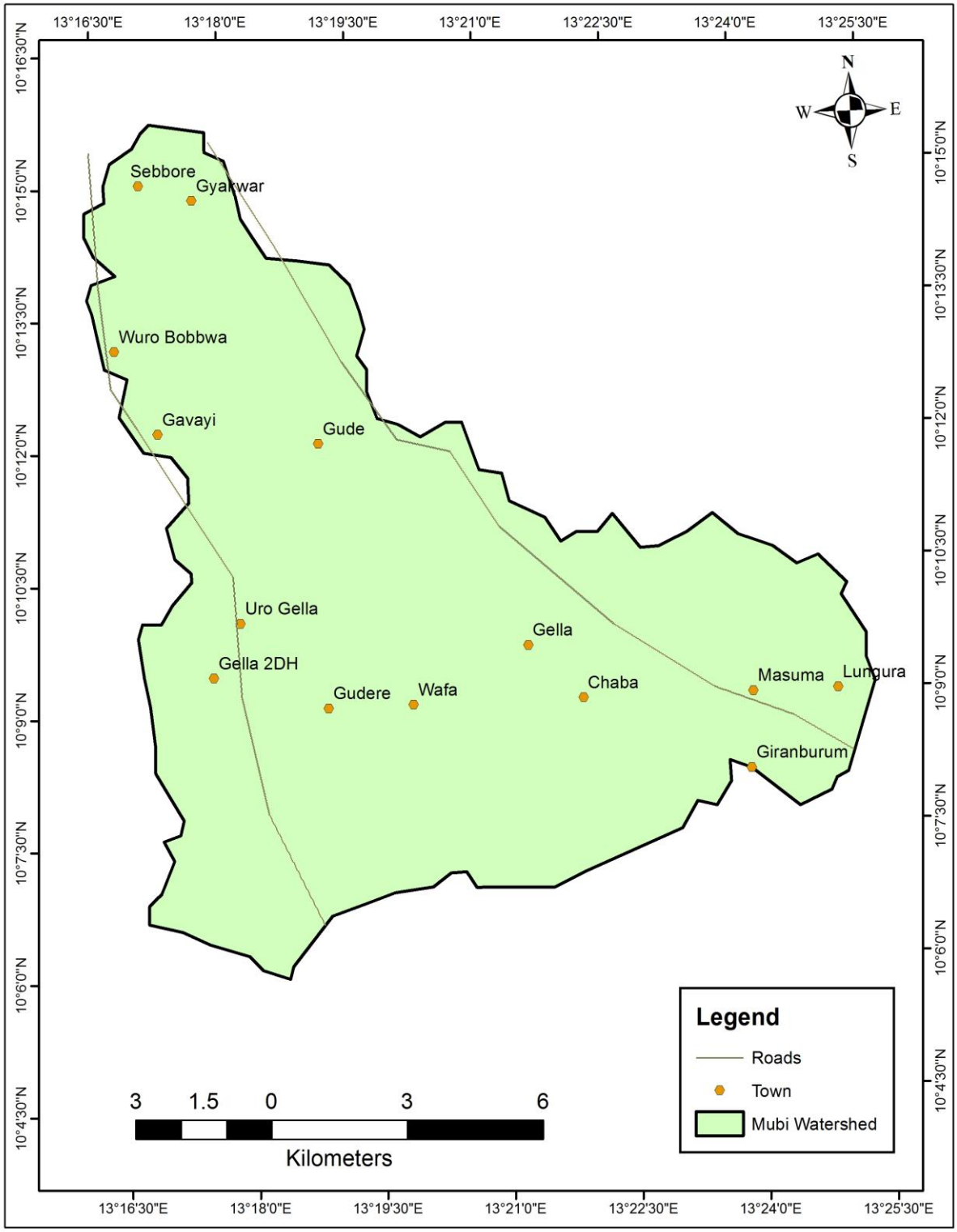


Figure 3.2: Map of the Study Area
Source: Modified from the Administrative Map of Adamawa State(2015)

The area is characterized by a typical tropical wet (April-October) and dry (November-March) climate with a mean annual rainfall ranging from 700mm to 1,050mm (Adebayo, 2004). The vegetation is a typical Sudan savanna with short grasses interspersed with shrubs and few trees (Adebayo, 2004; Tekwa and Usman, 2006). The variation in climatic variables in the hilly areas affects the rate of runoff that influenced the rates of soil erosion in the study area.

3.1.3 Vegetation

The study area is usually characterized by orchard-type vegetation due to its limitation in inherent fertility (Nwaka *et al.*, 1999). The major vegetation formations in the Mubi South are the Sudan Savannah. Within each formation is an interspersion of thickets, tress savannah, Open grass savannah and fringing forest in the river valleys. It is however necessary to note that large scale deforestation resulting from indiscrimination extraction of wood for fuel and expansion of agricultural land areas have left large area within each vegetation type with few indigenous woody plant species. Most areas especially those close to settlements are covered with exotic species such as the neem and eucalyptus trees. However, the original forest type could still be found in patches in each zone and particularly along the Nigerian – Cameroon borders where there has been little or no disturbance on the forest ecosystem.

Sudan Savannah zone has a mean annual rainfall ranging from 700 to 900mm and the rainy season last for about 3-4month. This zone covers Gulak, Michika and parts of Mubi and Hong Local Government Areas. The dominant woody plant spices in this zone are *Acacia seneegal Acacia nilotica, Adonsonia digitata, Borassu aethiopum, Ziziphus Spina-christi,*

Selerocarcya birrea, and *Terminalia avicennioides*. Species of Southern and Northern Guinea Savanna zones may be found in the zone. More abundant grass species of the zone including *Aristida longiflora, Cenchrus biflorus pennisetum pedicellatum* and *Eragrostis spp.* The open grass savannah and fringing forest in the river valleys of the study area led to the surface runoff because the land are not covered by vegetation and this led to the accelerated runoff lead to the foemation of the various soil erosion types in the study area.

3.1.4 Soils

Soils of the study area belong to the order lithosols (Agboola, 1979; Adebayo, 2004; Tekwa and Usman, 2006). Lithosols constitute one of the upper categories of FAO/UNESCO soil classification system (Aduayi*et al.,* 2002). They refer to soils with rock-basements within shallow depths from the soil surface and this implies shallowness and stoniness of the surface soil depths.

Luvisols: These are derived from basement complex and have a typical clay-ended horizon with high base saturation of more than 50%. They are the most common soils after Regosols in Adamawa State and cover the 213, 222, 28, 229 and 240 units. They have high ferric properties with iron oxides concretions, and are most of the time red to deep brown in colour in the B Horizons. They are lateritic, hydromorphic and in semi-arid places like Mubi and Madagali area, lime enriched and called calcic luvisols. They could be plinthic, calcic, gleyic or chronic. These soils are moderately acid, and are shallow to moderately deep and well drained. They have gravel to loamy sand surface horizons, and have a high pH of about 5.1 to 6.1 and organic matter is moderate to high, FAO (2006).

Arenosols and Regosols: There are relatively young soils or soils with very little or no profile developments, or very homogenous sands, are grouped together. These are found on

mountain sites within the 213 and 232 units. On these types of soils, weathering is slight and involves no accumulation of the products of weathering. The B. horizon may not be very clear and reddish in colour, while the original carbon content is most of the time leached out. The proportion of weathered minerals in the type of soils is greater than 30%, and they are strongly acid in reaction. They are also deep poorly drained with medium texture and have loam, sandy loam, silly loam or loamy sand surface horizons, and the lower horizons are usually sandy clay loam. The study area have soil moisture 0.072 %, bulk density of 1.63 Mgm^{-3}, 2.33 gkg^{-1} soil particle densities, 6.66 gkg^{-1} organic carbon, 0.68 of soil porosity and 11.46 gkg^{-1} organic matter (FAO, 2006). This soil type, moisture conted and bulk density of the study area is still at the state of development and as the result, is is poorly drained and this led to the surface runoff and formation of rill and gully erosion.

3.1.5 Relief

It has mixed assemblage of scattered granitic outcrops on gentle (0-4%) to steep (18-22%) slopes with dissected soil surfaces. Geomorphology of the area consists of dissected uplands, pediment slopes and narrow valleys. The hard Crystalline basement are ancient Precambrian rocks formed from series of orogenic cycles within the middle belt of Central Africa. The various ages obtained from its absolute dating revealed Liberian – (2500 200 Million years – My), Eburnean – (1800± 200My), and Kibarian (1200±200My) orogenic events (Bessoles and Laserre, 1977 and Holt *et al.*, 1978). The rocks of these events are commonly the Gnesses, Migmatites and Quartzites. However, many of the structural traces were obliterated by the Later Proterozoic and Pan-African thermotectonic events that spanned from 750My to 500My (Rahaman, 1988). Granitisation by intrusion of Granites, Granodiorites and Syenites during this period transformed the older rocks into oriented Biotite-granite, BIotite and

porphyroid-granite, and alkaline granite.These recycled crystalline rocks are located in the northern and southern fringes of the State. They outcrop at Mubi, Song, Garkida Jada, Ganye and Toungo as prominent ridges consequent to compression during the orogenic events. The hilly nature of the study area facilited the movement and transportion of sediments which affects the velocity of the surface water flow leading to distruction of agricultural productivity, decline in soil nutrients and formation of rill and gully erostion at the dediplain.

3.1.6 Geology

Geology of the area consists of Precambrian Basement rocks, while parent material of the soil is undifferentiated Basement Complex, represented by migmatite-gneisses, schists, quartzites aplite, medium and coarse-grained granites, pegmatite, diorite, and amphibolites (Adebayo, 2004). Most prominent physical feature in the area is the Mandara Mountain that spans the length of Mubi area. Industrial Minerals include Clay, gypsum, limestone, Benthonite, Trona, Graphite, Feldspar, and Quartz. Clay rocks are found in Mubi, Garkida, Gombi, Numan and Ganye areas. The deposit at Mubi had been exploited for the manufacturer of brunt bricks. The undifferentiated Basement Complex allowed free movement of water, especially groundwater movement and this help in reducing the intensity of soil erosion in the study area because the water easily infiltrated in at the hilly areas and flow down the slope.

3.1.7 Drainage

The drainage basin is the part of the earth surface, which is drained by main stream and its tributaries, the geomorphic unit flow of land surface is governed by its properties and it is an open system in which energy flows (Jayakumar and Siraz, 1997). The major river that flows through the area is the River Yedzeram, and it is one of the rivers that drain into Lake Chad. It has a total length of about 330 km. It takes it source from the Hudu Hills south-east of Mubi and flows northward into the Chad (Adebayo and Umar, 2004). The present of the river as well as its tributaries facilited the rate of soil erosion in the study area. Also, redused the rate of soil erotion in the study area especially in the hilly part of the study area where water easily drained in to the tributaries thereby redusing soil sealing and crust formation in the study area.

3.1.8Landuse

The land-use type is basically arable farming and animal production. Mubi is geographically well placed and functions not only as center of commerce in the region but also extends its sphere of influence to countries such as Cameroun, Central Africa Republic and Chad. Numerous banks, filling stations and hotels exist in the town to support commercial activities. Another factor that led to growth of the town is rural-urban migration experienced from surrounding villages (Adebayo, 2004). The dominant landuses in the study area are; agricultural land, forestry/vegetation, water body, builtup Area and bareland. Moreover, the town has become center of learning with numerous tertiary and secondary institutions established in the metropolis. Bareland and builtup area reduces the infiltration rates wich

inturn led to surface runoff leading to formation of sheet erosion and results to rill and gully formation.

3.1.9 Population

The study area has a total projected population of 126,378 people (National Population Census, 2009) in 2015. The growth of Mubi town is traced to agricultural, administrative, and commercial functions it performs. By 1902, Mubi was a German base from where neighbouring tribes (i.e Fali, Gude, Kilba, Higgi, Margi and Njanyi) of the region were subjugated (Adebayo, 2004). On 1st April 1960, Mubi was made Native Authority headquarters (Adebayo, 2004). The same year, July 1960, the town became provincial headquarters of the defunct Sardauna province (Adebayo, 2004). In 1967, Mubi was made L.G.A Headquarters while in 1996, the town was split into Mubi-North and Mubi-South local government areas. Currently, the town is the seat of Mubi Emirate Council and headquarters of Adamawa-North Senatorial District. The population of the study area facilited human activities and led to high agriculture activities, overgrazing, deforestation leading to the distructions of vegetation and forest in the study area. These anthropogenic activities make the study area vulnerable to soil erosion risk.

CHAPTER FOUR

METHODOLOGY

4.1 RECONNAISSANCE SURVEY

Reconnaissance surveywas carried out by the researcher to get acquainted with the study area in terms ofsoil erosion sites, selections of coordinate location points, choice for major land use classes,ground thruthing and major crop types selected for the study in April 2015. Also in July 2016, focus group interview was carried out with head of farmer (Sarkin Noma) in the study area in order to get information on type of soil conservation practices in the study area. These help the researcher to familiarized with the terrain and the land uses of the study area for better filedwork and choised for supervised classification.

4.1 TYPES AND SOURCES OF DATA USED

The types and sources of data used for this research are summarized in Table 4.1.

Table 4.1: Types, Sources and uses of Data

S/NO	Types of Data	Sources of Data	Uses
1	Landsat thematic mapper of 2015 with 30m resolution,	Download from Global Land Cover Facility web	Input Parameter for the Model as land use type
2	Quickbird image of 2015 with 0.5 resolution	eHealth Africa Kano	Mapping of soil erosion types
3	ASTER Image (DEM)(Advanced Spaceborne Thermal Emission and Reflection Radiometer)	Download from Global Land Cover Facility web web	Input Parameter for the RMMF and RUSLE Model
4	Coordinates for the 80 soil sampling points	Field survey	Input Parameter for the RMMF and RUSLE Model
5	rainfall data	Geography NIMET (department ADSU Mubi)	Input Parameter for the RMMF and RUSLE Model
6	Organic matter Content	Laboratory Analysis	Input Parameter for the

			RMMF and RUSLE Model
7	Soil texture (Particle size distribution)	Laboratory Analysis	Input Parameter for the RMMF Model
8	Soil moisture (gravimetric)	Laboratory Analysis	Input Parameter for the RMMF Model
9	Soil detachability index	empirical relations	Input Parameter for the RMMF Model
10	Bulk density	LaboratoryAnalysis	Input Parameter for the RMMF Model
11	Cohesion of soil surface (aggregate stability)	Laboratory Analysis	Input Parameter for the RMMF Model
12	Soil moisture storage capacity	Field and laboratory Analysis	Input Parameter for the RMMF Model
13	Effective hydrological top soil depth. (porosity/particle density) Milting points at 0, 0.3 and 15 bars.	Laboratory Analysis	Input Parameter for the RMMF Model
14	Ratio of actual to potential evapotranspiration	empirical relations	Input Parameter for the RMMF Model
15	Crop types cover	Field survey	Input Parameter for the RMMF and RUSLE Model
16	Vegetation cover	Landsat imagery of 2015 in ArcGIS 10.3	vegetation cover conditions for RMMF
17	Slope steepness	From ASTER image	Input Parameter for the RMMF and RUSLE Model

Source: Author (2016)

4.3 MATERIALS USED FOR THE RESEARCH

4.3.1 Field instruments used

i. Handles Single Auger of 1.5mwas used to drill soil sampling locations.

ii. Shovels, single spiral hand augers, bucket augers, perhaps power-driven coring tubeswasused to take soil samples of about 500 g each from the field.

iii. Core sampler was used for taking and determinationofsoil bulk density and soil moisture.

iv. Mettler Electronic Scalewasused for measurements of soil moisture content at field capacity.

v. Cloth Tape of 30 meters lengthwasused for measurements of various soil erosion types in the study area.

vi. Soil Thermometerwasused to take soil temperature at field capacity.

vii. Garmin Dakota 10 Global Positioning System (GPS) Receiverwasused along with Open Data Kit form (ODK) for soil sapling point navigation, data collection and soil location description.

4.3.2 Laboratory Materialsused

i. Sieve of 2mm wasused to sieve 10g air dried soil for laboratory analysis.

ii. Bouyoucos hydrometerwas used as measurement cylinder to determine soil texture.

iii. Capillary action in KR boxwasused to determine soil moisture content in the laboratory in 1500F1 20 Bar Pressure Plate Extraction.

iv. Pipette and sievingwasused to determine soil particle size.

v. Erlenmeyer flaskwasused to weigh soil organic matter.

vi. 1500F1 20 Bar Pressure Plate Extractionwasused to determine soil moisture retentions.

vii. Soil sampling Retaining Ringwas used inside Pressure Plate hold sample during the extraction process.

viii. Soil psychrometer wasused toestimation of effective soil hydraulic properties by top soil moisture.

ix. Pocket penetrometerwasused to measure Cohesion of soil amongst others.

See Plates 1 to 8(see appendix I)for the some Laboratory Instruments used for the analysis.

4.4 FIELD WORK

i. Soil Sampling

Franzen *et al.,* (1998) pointed out that grid soil sampling areused as basesto dividethe field into soil units (zone sampling) in order to determinesoil variability in the sampling zone and provide more information about the soil hydro-physical parametersfor the samples collected from the entirethe sampling area. Grid Sampling by zone was chosen because it was assumed that sampling areas are likely to remain temporally stable (Birrell, Sudduth and Kitchen, 1996; Franzen *et al.,*1998). See appendix II for grid sampled location.

ii. Soil Sample Collection

A total of 65out of the proposed soil samples was collected based on grid sampling points generated in ArcGIS 10.3. Figure 4.1 shows the location of samplingpoints in the study area. Each sampledsoilwascollected at 1.4km (l,240m) intervals along transects which were also 1.4km (l,240m) at a map scale of 1:100,000 apart using the grid method in Figure 4.1 and using spiral auguring (see Plates 11 to 12). This helped in taking unbiased soil samples at equal intervals and in taking the soil coordinates. Since soils are heterogeneous in nature, there was a need to take the coordinates at equal interval (Birrell, Sudduth and Kitchen, 1996; Franzen, *et al.*, 1998).All the composite soil samples werecollected at a soil depth of

0-20 cm (the plough depth) since this is the most vulnerable depth to soil erosion, long-term land use change, and soil management practices.

Soil sample of 500g from the pits samples was taken. The soil samples of about 500 g was removed from the field with the best available tools (shovels, spiral hand augers, bucket augers, perhaps power-driven coring tubes) (see Plate 9 for the equipment used), disturbing the sample soil structure as little as possible (Dirksen, 1999). Also core sampler of 5cm height and 4.5 cm radius was used to take the reading for Soil Moisture Content at field Capacity with the aid of Mettler Electronic Scale (precision weighing Balance) as shown on Plate 10. Open Data Kit form server platform (ODK) was used for soil sampling location description as show in Appendix III Form. Soil samples were air dried and sieved through 2mm mesh sieves, before analysis for soil textures. On the other hand, undisturbed soil samples were collected from each soil sampling point for bulk density and soil moisture determination using core sampler. In addition, field level observation and measurement for parameters; such as effective hydrological top soil depth (m), ground cover and cover factor was carried out from the geospatial sampling points.

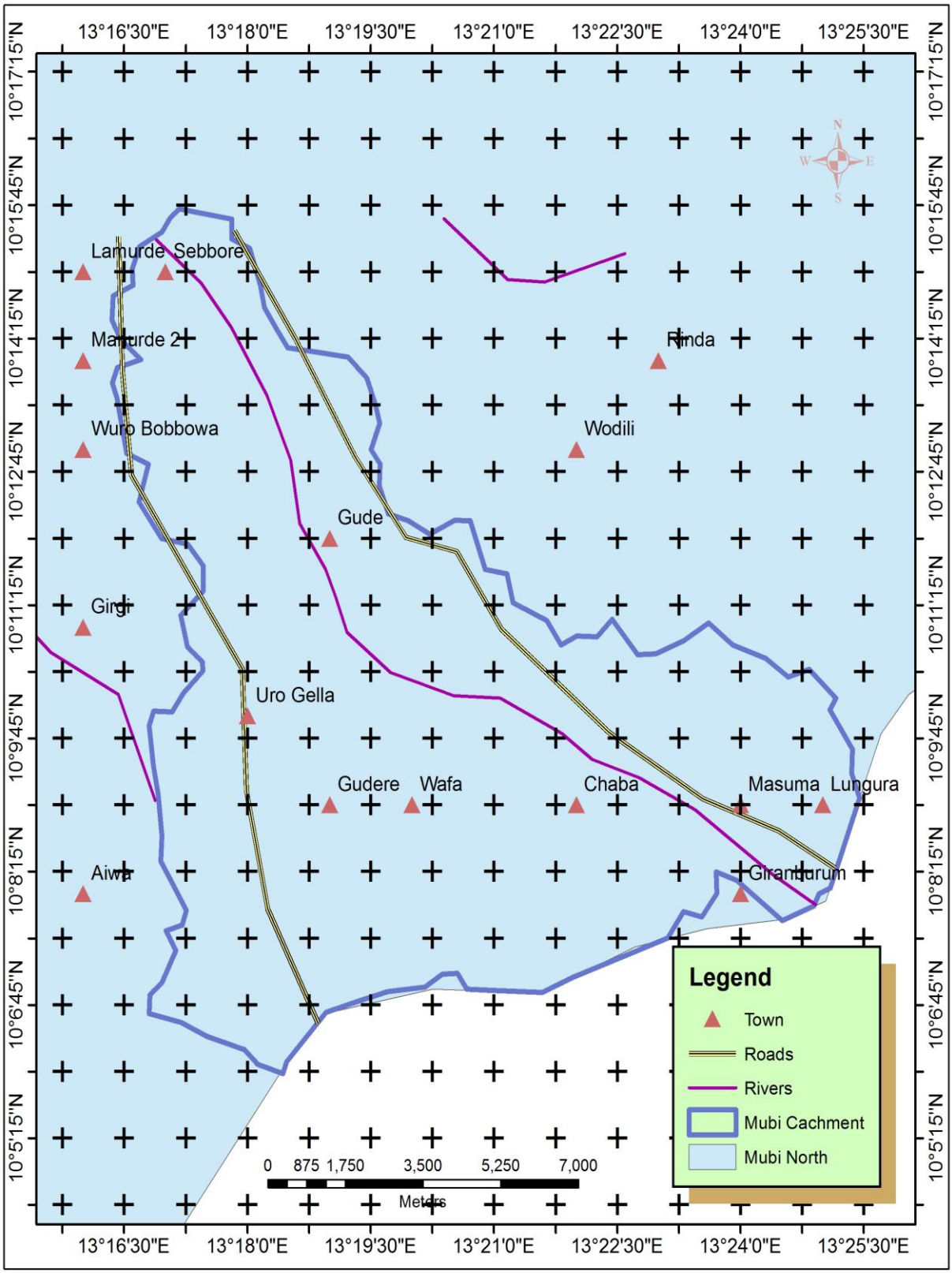


Figure 4.1: Mubi South showing 80 Grid SamplingPoints within the Watershed Area
Source: (Generated from Advanced Spaceborne Thermal Emmission and Reflection) (ASTER) Imagery of (2015)

Three (3) soil profile pitsweredug on the high slope, medium slope and low slope. The soil profilepits (shallow pits) were dug at 100cm wide, 100cm long and 200cm deep respectively (see Plate 13 to Plate 14) and ODK form wasused for soil profile description (see Appendix II).Soil sampling pointscoordinates and data description obtained from the field was downloaded from ODK server and imported into ArcGIS software environment as way point to show their distribution in the study area and for further analysis and discussions. Moreover, Plates 9 to 10(see appendix I)shows the pictures of field assistance.

4.5 INPUT PARAMETERS FOR THE RMMF MODEL

The Input Parameters used for the RMMF Model are presented in Table 4.2.

Table 4.2: Input Parameters for the RMMF Model

Factor	Parameter	Definition and Remarks
Rainfall	R	Annual or mean annual rainfall (mm)
	R_n	Number of rain days per year
	I	Typical value for intensity of erosive rain (mm/h); use 10 for temperate climates, 25 for tropical climates and 30 for strongly seasonal climates (e.g. Mediterranean type and monsoon)
Soil	MS	Soil moisture content at field capacity or 1/3 bar tension (% w/w)
	BD	Bulk density of the top soil layer (Mg/m^3)
	EHD	Effective hydrological depth of soil (m); will depend on vegetation/ crop cover, presence or absence of surface crust, presence of impermeable layer within 0.15 m of the surface
	K	Soil detachability index (g/J) defined as the weight of soil detached from the soil mass per unit of rainfall energy
	COH	Cohesion of the surface soil (kPa) as measured with a torvane under saturated conditions
Landform	S	Slope steepness (°)
Land cover	A	Proportion (between 0 and 1) of the rainfall intercepted by the vegetation or crop cover
	E_t/E_o	Ratio of actual (E_t) to potential (E_o) evapotranspiration
	C	Crop cover management factor; combines the C and P factors of the Universal Soil Loss Equation
	CC	Percentage canopy cover, expressed as a proportion between 0 and 1
	GC	Percentage ground cover, expressed as a proportion between 0 and 1
	PH	Plant height (m), representing the height from which raindrops fall from the crop or vegetation cover to the ground surface

Source: Morgan (2014)

4.6INPUT PARAMETERS FOR THE RUSLE MODEL

The Input Parameters used for the RUSLE Model are presented in Tabble 4.3.

Table 4.3: Inputs Parameters for RUSLE

Factor	Parameter	Definition and remarks
Rainfall	R	Rainfall-runoff erosivity factor (MJ.mm/ ha.hr.year) (Arnoldus, 1980)
Soil	K	Soil texture/ erodibility in ton.ha.hr/ (MJ.mm.ha) (USDA, 1978)
Topographic	LS	Slope length and slope steepness (m) (Moore and Burch, 1986a,b)
Cover management	C	Ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow conditions (Zhou*et al.*, 2009).
Conservation practice	P	Soil conservation operations or other measures that control the erosion. The values of P-factor ranges from 0 to 1 (Renard*et al.*, 1997).

Source: Compiled by the Author (2016)

i. Empirical Relations in Deriving Inputs of RMMF Model.

Some intermediate input parameters were used estimated fromobserved data in the watershed using the empirical relationsdescribed in (Morgan, Morgan and Finney, 1984) as:

$$E = R\,(11.9 + 8.7\log_{10}{}^{(I)}),$$

$$R_c = 1000 * \mathrm{MS} * \mathrm{BD} * \mathrm{EHD} * (Et/E_o)^{0.5},$$

$$\mathrm{SR} = R\exp(-RC/R_o) \qquad 4.1$$

$$R_o = R/R_n,$$

Where $E=$ is annual kinetic energy of rainfall (Jm^{-2}),

$I=$ is intensity of rainfall which is assumed to be 25mmh^{-1}in tropical conditions,

SR= is surface runoff/overland flow (mm),

$Rn=$is number of rainy days,

$R=$ is average annual rainfall (mm),

$Rc=$is soil moisture storage capacity (mm),

Ro=is annual rain per day,

MS= is soil moisture content at field capacity (ww^{-1}),

BD= is bulk density of the topsoil layer (Mgm^{-3}),

EHD= (m) is effective hydrological topsoil depth defined as the depth of soil from the surface to an impermeable or stony layer to the base of A horizon or to the dominant root base, and

Et/Eo=is the ratio of actual (Et) to potential (Eo) evapotranspiration.

EHD= is the top soil depth within which the storage of water affects the generation of runoff.

Intermediate maps derived on the basis of land use/cover map included ratio of actual to potential evapotranspiration (Et/Eo), permanent rainfall contributing to permanent interception and stream flow (A) and crop cover management factor (Cf).

Intermediate layers were generated from hydrophysical soil map (soil texture) including; soil detachability index (K) and cohesion of topsoil (COH) using ArcGIS 10.1 software. According to Morgan, Morgan and Finney (1984) and Dinka (2007) K is defined as the weight of soil detached from soil mass per unit of rainfall energy. Inputs such as plant related (e.g., EHD, A, CC) and soil related (e.g., K, COH) parameters were adopted from Revised Morgan *et al.*(2001) and Dinka (2007), in which such values corresponded to crop type, cover conditions and soil textures were observed in the field.

ii. Deriving Inputs of RUSLE Model

The RUSLE Model equation is a function of five input factors in raster data format: rainfall erosivity, soil erodability, slope length and steepness, cover management and support

practice. These factors vary over space and time and depend on other input variables. Therefore, soil erosion within each pixel was estimated with the RUSLE. The RUSLE method is expressed as:

$$A = R \times K \times LS \times C \times P \quad 4.2$$

where A is the computed spatial average of soil loss over a period selected for R, usually on yearly basis (t $ha^{-1}y^{-1}$); R is the rainfall-runoff erosivity factor (MJ mm t $ha^{-1}y^{-1}$); K is the soil erodability factor (t $ha^{-1}y^{-1}MJ^{-1}$ mm^{-1}); LS is the slope length steepness factor (dimensionless); C is the cover management factor (dimensionless, ranging between 0 and 1.5); and P is the erosion control (conservation support) practices factor (dimensionless, ranging between 0 and 1) as show on Table 4.2.

Rainfall erosivity (R): The rainfall factor, an index unit, is a measure of the erosive force of a specific rainfall. This was determined as a function of the volume, intensity and duration of rainfall and can be computed from a single storm, or a series of storms to include cumulative erosivity from any time period. Raindrop/splash erosion is the dominant type of erosion in barren soil surfaces. Rainfall data of 11 years (2004 to 2015) (see appendix VI) collected from Department of Geography Meteorological unit Adamawa State University Mubi was used for calculating R-factor using the following relationship developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 \log_{10}\left(\frac{P_i^2}{P}\right) - 0.08188\right)} \quad 4.3$$

Soil Erodability Factor (K): Different soil types are naturally resistant and susceptible to more erosion than other soils and is a function of grain size, drainage potential, structural integrity, organic matter content and cohesiveness. Erodability of soil is its resistance to both detachment and transport. Soil texture map of the study area was used for the preparation of K factor map and soil types were grouped into major textural classes. The corresponding K values for soil types were identified from soil erodability nomograph (USDA, 1978) by considering particle size, organic matter and permeability class.

Slope length and steepness factor (LS): Length and steepness of a slope affects total sediment yield from the site and is accounted by the LS-factor in RUSLE model. In addition to steepness and length, other factors; such as compaction, consolidation and disturbance of the soil were also being considered while generating LS-factor. Erosion increases with slope steepness but, in contrast to L-factor representing effects of slope length. The combined LS-factor was computed for the watershed by means of ArcGIS Spatial analyst extension using DEM, as proposed by Moore and Burch (1986a, b). The flow accumulation and slope steepness was computed from the DEM using ArcGIS Spatial analyst.

$$LS = (\text{Flow accumulation} \times \text{Cell size}/22.13)^{0.4} \times (\sin \text{slope}/0.0896)^{1.3} \quad 4.4$$

Where flow accumulation denotes the accumulated upslope contributing area for a given cell, LS=combined slope length and slope steepness factor, cell size=size of grid cell (for this study 30 m) and sin slope =slope degree value in sin.

Cover management factor (C): The C-factor represents effect of soil- Cover management factor (C). The C-factor represents effect of soil-disturbing activities, plants, crop sequence

and productivity level, soil cover and subsurface bio-mass on soil erosion. Due to the variety of land cover patterns with spatial and temporal variations, satellite remote sensing data sets were used for the assessment of C-factor (Karydas, 2009; Tian *et al.*, 2009). The Normalized Difference Vegetation Index (NDVI), an indicator of the vegetation vigor and health was used along with the following formula (eq. 5) to generate C-factor value image for the study area (Zhou *et al.*, 2009; Kouli *et al.*, 2009).

$$C = \exp\left[-\alpha \frac{\text{NDVI}}{(\beta - \text{NDVI})}\right] \qquad 4.5$$

Where a and b are unitless parameters that determine shape of the curve relating to NDVI and the C-factor. VanderKnijff *et al.*(2000) found that this scaling approach gave better results than assuming a linear relationship and values of 2 and 1 were selected for parameters a and b, respectively. This equation was applied for assessing C-factor of areas with similar terrain and climatic conditions (Prasannakumar *et al.*, 2011a; Prasannakumar *et al.*, 2011b).

Conservation practice factor (P): The support practice factor (P-factor) is the soil-loss ratio with a specific support practice to the corresponding soil loss with up and down slope tillage (Renard *et al.*, 1997). In this study, the P-factor map was derived from the land use/land cover and support factors. The values of P-factor ranges from 0 to 1, in which the highest value is assigned to areas with no conservation practices (deciduous forest); the minimum values correspond to built-up-land and plantation area with strip and contour cropping. The lower the P value, the more effective the conservation practices.

4.7 SOIL LABORATORY ANALYSIS

Table 4.4 shows the hydrophysical parameters for analyzing and predicting soil erosion and analytical method to be employed. Soil samples collected in the soil sampling zones were used to determine the parameters(see appendix IV for the laborotery results).

Table 4.4: Hydrophysical Parameters

S/NO	Hydrophysical Parameter	Determination Method	Source
1	Soil texture	Bouyoucos hydrometer method	Gee and Bauder (1986)
2	Soil bulk density (BD)	Core method	Blake and Hartge (1986)
3	Soil moisture content	Capillary action in KR box	Baruah and Barthakur (1999)
4	Soil particle size	Pipette and sieving	Gee and Bauder (1986)
5	Soil PH	PH meter	ASTM (1995)
6	Aggregation of soil	Pocket penetrometer	O'sullivan and Ball, (2006)
7	Efective of hydrological top soil.	soil psychrometers	Gardner, (2001)

Source: Compiled by the Author (2015)

4.7.1 Soil particle size analysis (Bouyoucos Hydrometer Method)

Reagent:

Calgon (Sodium hexametaphosphate) 37g/lt

Procedure:

i. Weight 50g of 2mm sieved soil (if soil is little clay or more) and 100g if the soil is sandy only into a 250ml plastic beaker.
ii. Add 100ml of 50% calgon into the beaker and stir with a glass rod. Add about 100ml calgon into a 250ml plastic container with cover and shake on a reciprocating shaker for 20 minutes.

iii. Transfer the sample into a mixing cup, washes every content of the soil in beaker into the cup and stir for five minutes or transfer into a 250ml plastic contasiner and shake on an end to end shaker for ten minutes.

iv. Transfer the nixture or shaken sampled into a 1000 cm^3 measuring cylinder, make sure that the contents in the containers are washed completely into the cylinder. Make to 1000 cm^3 mark with water.

v. Before starting hydrometer reading, mix the suspension vigorously using a long handle plunger and making sure that the sediment at the bottom is thoroughly disturbed.

vi. Take the hydrometer readings for 40 seconds and 2 hours (these are the times recommended by Bouyoucos for the 20μm and 2μm fractions respectively).

vii. Before reading is due, gently lower the hydrometer slowly into the suspension. Take readings at the top of the meniscus.

viii. Prepare a blank cylinder by making 100ml of the 50% calgon solution up to 1 litre mark with water. Take also the blank hydrometer reading at each of the readings.

ix. Take the temperature of the suspension and blank.

x. After the last reading pour the suspension through a 0.2mm or 72 mesh sieve. Wash the sand grains retained on the sieve with water and then transfer the washing into a beaker and dry in an oven at 105^0C.

Calculations:

The corrected hydrometer readings C(g/l) are obtained by subtracting the blank reading RL (g/L) from the hydrometer readings in the soil suspensions R(g/L) and adding 0.36g/L for every degree above 20^0C.

$C = R – RL + (0.36T)$

Where T = Room temperature minus 20

The percentages by weight of the SILT + CLAY and SAND fractions are given by:

$$\% \, clay = \frac{Corrected \ 2 \ hrs \ reading - Blank \ x \ 100}{Weight \ of \ soil \ taken}$$

$$\% \, Silt = \frac{Corrrected \ 40 \sec reading - Blank \ x \ 100 - \% \ clay}{Weight \ of \ soil \ taken}$$

% Sand = 100 - % Clay + % Silt

The samples can now be classified according to the USDA or International Systems of Textural Classification.

4.7.2 pH determination

Reagents:

i. Distilled water
ii. 0.01M $CaCl_2.2H_2O$
iii. Dissolve 1.47g of salt in distilled water and make to 1 litre.
iv. 1N KCl: Dissolve 74.56g of salt in distilled water and make to 1 litre.
v. Standard buffer solution pH 4, 7, 9.

Soil to water ratio:

pH in soil is usually determined in the following soil to water ratio:

1:1 – 10g of soil to 10 mls of distilled water

1:2.5 – 10g of soil to 25 mls of distilled water

Procedure:

Put the 10g of 2mm sieved air dry soil in a 50ml plastic beaker, add 25ml of distilled water and stir the suspension several times during the next 30 minutes. Then let the soil suspension stand for about 30 minutes more undisturbed. Calibrate the pH meter using pH

buffer 2, 7, 9. Immerse the electrode into the soil but it should not touch the bottom of the beaker. Read the pH after 30 seconds. Repeat the above using 0.01M $CaCl_2$ and 1N KCl solutions. Record your reading as pH in water, 0.01M $CaCl_2$ and 1N KCl.

4.7.3Organic carbon determination (Walkley-Balck)

Reagents:

i. Potassium dichromate ($K_2Cr_2O_7$) 1N dry $K_2Cr_2O_7$ (Analar) at 105^0C. Cool in a dessicator and weigh out exactly 49.04g into 1 litre vol. flask, dissolve with distilled water. Make up to 1000ml volume.
ii. Concentrated H_2SO_4
iii. O-phenanthrolien ferrous sulphate indicator.
iv. Ammonium ferrous sulphate 0.5N
Dissolved 196gm of $NH_4^-Fe^{++}$ - 50 in distilled water into which 10 mls of concentrations H_2SO_4 has been added. Shake well to dissolve completely and then make to mark of 1 litre.
O-phenanthrolien-ferrrous complex – 0.025M
Dissolve 7.435g of O-phenanthrolein and 3.475g of $FeSO_4.7H_2O$ in water and dilute the solution to 500ml.
Phosphoric acid.

Procedure:

i. Weigh in 1 g of soil into 250ml Erlenmeyer flask. Reduce the weight of soil if soil is very high in organic matter.
ii. Add 5ml or 10ml of 1N $K_2Cr_2O_7$ using a pipette, and then swirl the flask gently to disperse the soil.
iii. Rapidly add 10ml of concentrated H_2SO_4 from a measuring cylinder and swirl for 1 min. again. (If colour turns greenish reduce the amount of soil taken to half).
iv. Allow the flsk to stand on asbestos sheets for 30 minutes (End point easier if suspension is cold).
v. Add 100ml of distilled water to the flask. Let it cool.

vi. Add 5 drops of indicator.

vii. Titrate with ammonium ferrous sulphate solution with a white background.Change in colour: blue – green – dark green – red.

viii. Make blank determination in same manner but without soil.

ix. Repeat with less soil if more than 75% of the dichromate is used.

$$Org\ C\ \% = \frac{(meq\ \mathrm{K2Cr2O7} - \mathrm{meq\ FeSO4})\ x\ 0.003\ x\ 100\ x\ F}{Weight\ of\ air\ dry\ soil\ taken}$$

Where f = correction factor 1.33 or

$$Org\ C\ \% = \frac{(blank\ titre\ -\ actual\ titre)\ x\ 0.3\ x\ m\ x\ f}{Weight\ of\ air\ dry\ soil\ taken}$$

Where m = Conc. Of ferrous ammonium sulphate

F = correction factor

%OM = %OC x 1.724

4.7.4 Soil Bulk Density (BD) using Core Method by Blake and Hartge (1986)

Procedure:

i. Separate 3 peds from each sample (make the volume of each ped ~3-5cm3)

ii. Tie a string around each ped with thread so that it can hang freely from a 2" length of thread with a loop on the end.

iii. Place each ped in a numbered and weighed beaker, recording the sample and beaker number on the data sheet.

iv. Place the beakers containing the peds in the oven and allow them to dry overnight, remove the beakers, cool in the dessicator, weigh the beakers containing the peds,

and record the data (subtracting the weight of the beaker from the combined weight of the ped and beaker).

v. Melt a cup of paraffin (wax), stabilizing it between 55 to 60.

vi. Dip each ped in the paraffin and allow to dry, making sure that the ped is entirely sealed. If there are any holes noticed, dip a rod in the melted wax and apply a drop of hot wax to patch the hole. Do not redip the whole ped, because the wax coating will be too thick.

vii. Weigh the coated ped without the beaker and record its weight.

viii. Immerse the ped in water and weigh the beaker and ped on a triple beam balance using a ring stand to hold the beaker of water positioned just above the balance pan. (note: if bubbles appear on the surface of the coated ped and then break free and rise to the surface, note this on the data sheet by writing "BBL" next to the "submerged weight". If the ped floats, write "Floater" in the space for "submerged weight").

ix. Peel the coating off each ped and return it to its beaker. Fill each beaker with water so that the peds will get soggy and fall apart.

x. Wet sieve the contents of each beaker through a >2mm sieve. Discard all but the >2mm fraction. Return portion to the beaker and place in the oven to dry.

xi. Weigh the >2mm contents of each beaker and record the weights on the data sheet.

Calculations

Adjusted dry weight = (dry weight of the ped) - (dry weight >2mm fraction) 2. Weight of paraffin = (weight of dry ped) + (paraffin) - (dry weight of ped) 3. Adjusted immersed weight = (weight of ped with paraffin in water) + 0.1 (weight of paraffin) - 1.65 (weight of

the >2mm material/ 2.65)* 4. Specific gravity = (adjusted weight)/ ((adjusted dry weight)-(adjusted immersed weight))

Record the dry weight of the ped, ped with paraffin weight, ped with paraffin in water weight, and >2mm weight.

*Note: 0.1(ped with parafin weight-dry weight ped) ----corrects for the buoyant force of the wax 1.65(>2mm weight/2.65)---- corrects for the >2mm material assuming a density of 2.65 g/cm3 for that material.

4.7.5 Soil Moisture Content using Capillary action in KR box by Baruah and Barthakur (1999)

i. Determine purpose of sampling a. Known soil moisture samples using Soil Water Characteristics model. Soil texture only needed from field b. Known moisture samples and field moisture determination. Soil is collected at moisture level of interest. c. Known moisture samples from field sampled soils at field capacity. Take soil after a soaking irrigation or rain event.
ii. Collect 500cm3 (1/2 gallon) of moist soil in air-tight container at appropriate soil moisture level.
iii. Obtain estimate of percent sand and clay to use Soil Water Characteristics model.
iv. Transfer data from Soil Water model to Soil Moisture Calculation Worksheet Part A (blue cells).
v. Weigh approximately half of wet soil collected. Carefully weigh and record wet weight. Dry at about 220º Fahrenheit for 24 hours or until weight is stable on reweighing. Reseal and save remainder of wet soil.

vi. When weight is stable on reweighing, record dry weight.

vii. If interest is only known soil moisture samples using model, weigh 100 grams of oven dry soil and place in zip lock bag. Add water in amounts shown in percent water by weight cells from Section A of Worksheet 1.

viii. If interest is field moisture determination, enter weights of wet and dry soil in Section A cells. Worksheet will calculate AWC and percent water of sample.

ix. If interest is determination of soil field capacity, use Section B of Worksheet 1. Enter weights of wet and dry soil in Section B of worksheet.

x. Using worksheet calculated percent water by weights from Section B, rewet oven dry soils to make known moisture samples.

xi. A set of samples at field capacity, 75 percent of FC, 50%, 25%, and WP can provide a reference for estimating when to irrigate and provide calibration for soil moisture instrumentation.

4.7.6Cohesion of soil using Pocket penetrometer by O'sullivan and Ball, (2006).

i. Holding the sleve of the penetrometer, slide the indicator ring towards the sleeve until the ring touches it.

ii. Hold the shaft at right angles to the concrete mortar surface. Then force the shaft onto the mortar to a depth of one inch (inches are scribed on the shaft).

iii. After pulling the penetrometer out, take the reading at the low-reading edge of the indicator ring on the scale.

iv. Return the indicator ring to the edge of the sleeve before running another test.

v. Take multiple readings and calculate the average value in psi.

The pocket penetrometer measures the compressive strength of the soil. Most penetrometers available today contain units of tons/ft^2 or kg/cm^2, and the compressive strength is read directly from the gauge. Some common conversions are:

1 ton/ft^2 = 2000 psf = 13.9 psi

1 kg/cm^2 = 98.1 kPa

4.8 IMAGE PROCESSING

The Satellite image of the study area was corrected geometrically to remove distortions and subsequently enhanced to improve visual interpretation. This was followed by classification into different landuse types. Supervised and object based image analysis classification was employed because of its high accuracy and the researcher's knowledge of the training areas. Accuracy assessment of the image was done using ten coordinates location for each landuse class was collected with the aid of GPS during ground thruthing. This was done to aid supervised classification. This is to identify sets of pixels that accurately represent spectral variation present within each information region. The datasets were classified into classes of water body, vegetation, bareland, built-up area and Agriculture. These are adopted from Anderson *et al.*,(2001), to suit the study area.

4.9 TECHNIQUES OF DATA ANALYSIS

The stated objectives were achieved through the following:

i. To identify the types and observed effects of soil erosion in the study area:

This was carried out using high-resolutionquickbird image of 0.6 resolutions and 2015 landsat thematic mapper satellite imagery of the study area. The 2015 landsat thematic mapper image was imported in to ArcGIS 10.3 environment. Then coordinates of the

gullies, rills and sheet erosion taken in the field were added to the high resolution image in order to identify and map various soil erosion spots in the study area. The landsat thematic mapper of 2015 with 30m resolution was also used along with hydrological tool in ArcGIS in order to map other soil erosion types.This study concentrated on gully, rill,inter-rill and sheet erosion. Visual observation was used in assessing the probable effects of soil erosion in the study area and the results were presented in plates.

ii. To characterize hydrophysical parameters for soilerosion sites in the study area:

The hydrophysical parameters for each of the soil sampling sitesin the study area was analyzed from laboratory and characterized based on the each type of soilunder study.Techniques of data analysis. Following the procedures, results were characterized and presented in Tables.

iii. To assess distribution patterns of hydrophysical parameters:

This was carried out using Geostatistical Interpolation in ArcGIS 10.3 software environment**.** The point data and their corresponding coordinateswere downloaded from Open Data Kid (ODK) Form entered into ArcGIS 10.3software; maps of hydrophysicalmodel, input parameters were developed using Kriginginterpolation technique (Utset, L´opez and D´ıaz, 2000). This was done in ArcGIS environment with the aid of Kringing method using geostatistical tool for all sample locations. Map of the characterized hydrophysical parameters based on soil erosion were produced.Ordinary kriging was selectedas the preferred interpolation method for RMMF and RUSLE model spatialinputs derivation because it was morereliable than the otherinterpolation methods based on the mean squared errorwhich compares measured values with the predicted ones.

Moreover, since the spacing to be measured for hydro-physical input parameters were relatively sparse and randomly chosen for each subsampling zone, ordinary kriging is the best unbiased predictor at specific unsampled locations (Cressie, 1993). Ordinary kriging also has an additional advantage of minimizing the influence of outliers (Triantafilis *et al.*, 2001). The semivariogram analyses were conducted before application of ordinary kriging interpolation of the input parameters. This is because semivariogram model determinesthe interpolation function (Tesfahunegn *et al.*,2011b). Semivariogram models were chosen by using the cross-validation technique that compares statistical mean square error values estimated from the semivariogram models and actual values.

iv. **To estimate rate soil loss in the watershed area:**This was done using spatial distribution of the rate of soil detachment by rain drop (F) and spatial data layers of unchanneled and channeled flows (erosion) as input to RUSLEmodel in ArcGIS 10.3 software environment and predicted annual pixel level soilloss using Equation 4.2 in raster calculator of ArcGIS 10.3 software environment.

$$A = R \times K \times LS \times C \times P$$

v. To predict soil erosion risk in the study area. The soil erosion amount was predicted using the RMMF model as shown in Equation 4.1.

The RMMF model separates soil erosion process in two phases: the water and sediment phases (Morgan *et al.*,1984). In the erosion phase, rates of soil particle detachment by rainfall and runoff are determined along with the transporting capacity of runoff. Using the procedure proposed by Wischmeier and Smith (1978), predictions of total particle detachment and transport capacity was compared and erosion rate is equated to the lower of

the two rates. The list of input parameters needed to run the revised version of RMMF model is shown on Table 4.2.

The water phase mainly comprises of prediction of soil detachment by rain splash. It thus requires data related to intensity of rainfall (I, mmh^{-1}), number of rainy days (Rn), and average annual rainfall (R, mm). After developing the different input spatial maps (layers), the rate of soil detachment by rain drop impact (F, kgm^{-2}), rate of soil detachment by runoff (H, kgm^{-2}), and transport capacity of overland flow (runoff) (TC, kgm^{-2}) are calculated and overlay in the GIS environment and using raster calculator of ArcGIS 10.3 software environmentas follows:

F (rate of soil detachment by rain drop impact) = $10^{-3} * K * (E * e^{-0.05A})$ 4.6

H (rate of soil detachment by runoff) = $10^{-3} * (0.5\text{COH})^{-1}(\text{SR})^{1.5}\sin(S)(1 - \text{GC})$ 4.7

TC (transport capacity of overland flow (runoff)) = $10^{-3} * Cf * \text{SR}^2 * \sin(S)$ 6.8

where $K$is soil detachability index (g J−1), $E$is annual kinetic energy of rainfall (Jm−1), $A$is percentage of rainfall contributing to permanent interception and stream flow (%), COH is cohesion of the soil surface (KPa), GC is fraction of ground (vegetation) cover (0-1), $Cf$is the crop cover management factor, and $S$is the steepness of the ground slope expressed in degree. Total particle detachment ($D = F+H$) is finally computed as sum of soil particle detachment by runoff (H) and soil particle detachment by raindrop (F) impacts. The model compares predicted rate of splash detachment (D), the transport capacity for overland flow (TC), and the minimum value is taken as the erosion rate (annual soil loss) estimated for the study watershed area.

Predicted soil erosion rate was classified intosoil erosion risk classes (Singh, Ram, Narain, Bhusan and Abrol, 1992): i.e.; verylow, low, moderate, moderately high, high and veryhigh. Average annual soil loss ofvarious land use/land cover types was estimatedand analyzed to understand causes of erosion inthe watershed in context to spatial distribution oferosion factors together with RMMF Model.

vi. Validation of RMMF and RUSLE Model in the study area:

In order to validate the model,percent difference (D) was used as methods for goodness-of-fit measure of model prediction. The model estimate soil loss rate in this study and was evaluated with respect to result obtained for rate of soil detachment by rain runoff. The percent difference (D) was used to measure average difference between simulated and measured values as $D = (p - q/q)\ 100$.

Where $p$is model simulated value and $q$is measured value. A value close to 0% is best for D. However, higher values of D will be acceptable if the accuracy in which the observed data to be gathered is relatively poor (Chekol, 2006). Also, the soil profile data were used to validate estimated erosion result by RMMF and RUSLE model. With regard to the soil profiles (shallow pits) identified based on soil types and dug (100cm wide, 100cm long and 200cm deep), then compared to the corresponding models spatial soil erosion risk results. For this purpose, areas vulnerable to soil erosion were selected. The data werecompared with soil loss prediction made by the two models.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 TYPES AND OBSERVED EFFECTS OF SOIL EROSION

Various types of soil erosion such as; gullies, rills, interrill and sheets erosion were identified and mapped. Their patterns were assessed based on visual interpretations using pictorial representatives of the erosion types obtained during fieldwork as indicated on the plate. Figure 5.1 to Figure 5.4 show the location of all the soil erosions in the study area. The location of the soil erosion types is shown in appendix vii.

5.1.1Gully Erosion

Gullies are often blamed for enhanced drainage and accelerated aridification processes (Eitel *et al*., 2002; Daba, 2003). The location of gullies in the study area is presented on Figure 5.1. Plates 18 to 21(see appendix I)show the pictorial nature of soil erosion within the watershed. The location of the gully soil erosion is shown in appendix vii.

Gullies are found in the hilly area of the watershed with steep slopes which was as similar as reported by Esteves *et al.* (2005) and Mathys *et al.* (2005) from the French Alps. It wasalso noticed that gully erosion results not only from surface flow but also often from sub-surface flow as in the Northern part of the study area and mostly around foot of the mountains/hills. It can be observed in Figure 5.1 that in the highlands (mountainous area), development of gullies has led to an enlarged drainage of the intergully areas, resulting in soil moisture decrease and a corresponding crop yield reduction on farmland located near gully walls and this is similar to research finding by Nyssen *et al.* (2004c). The present nature of gully

erosion was accelerated by land use change that commonly triggered soil erosion as also pointed out by Chaplot *et al.* (2005a) and/or extreme climatic events.

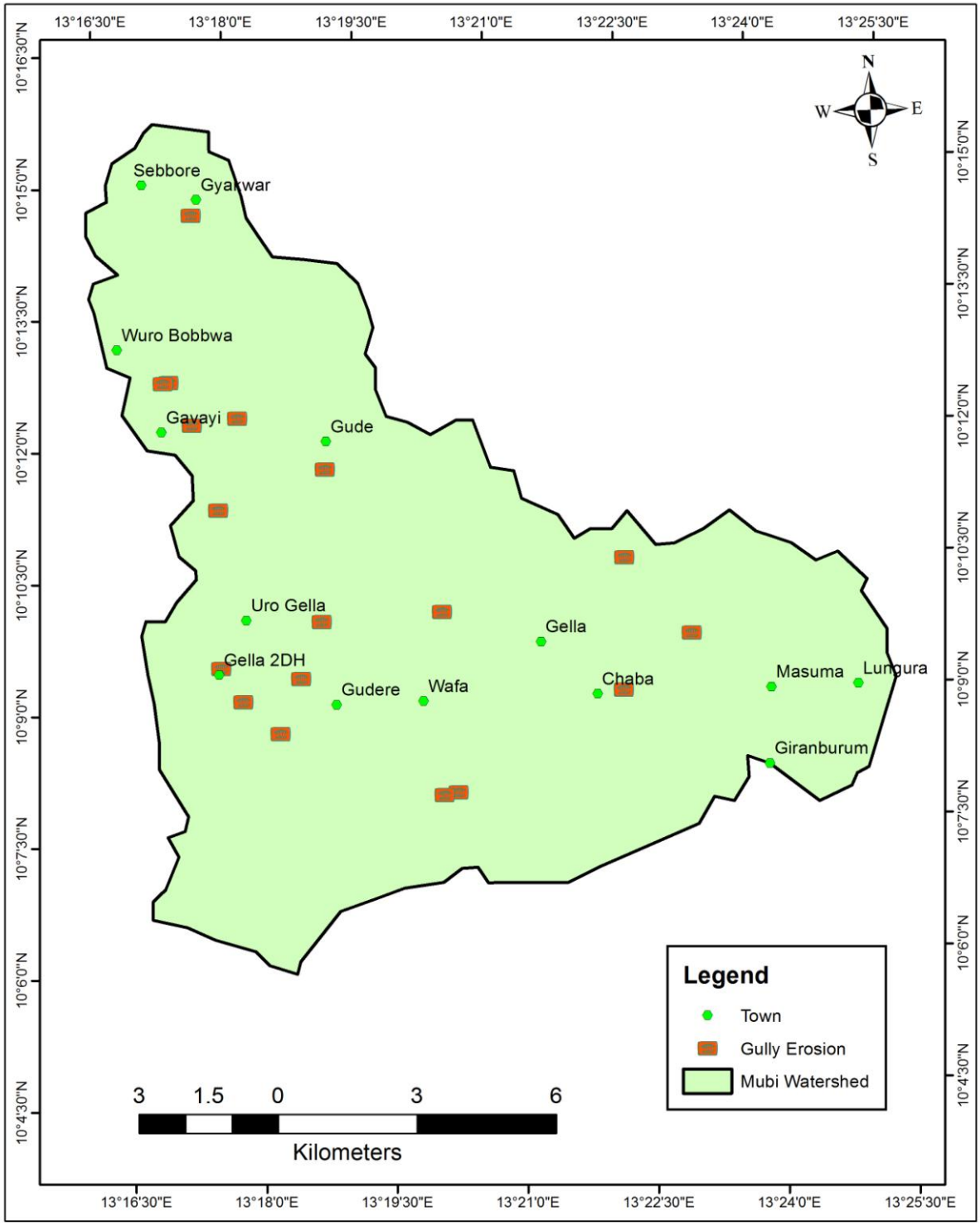


Figure 5.1: Location of Gully Erosion
Source: Author's Analysis (2016)

Also, the gullies grow initially rapidly to large dimensions; making effective control technically difficult or prohibitively expensive, for people of the study area to control as supported by Thomas *et al.* (2004) and Vanwalleghem *et al.* (2005a). Chaplot *et al.* (2005a) pointed out that annual cropping in mountainous regions like in the study area, has been reported as intensifying rill and gully erosion processes as well as in vineyards in Mediterranean regions (Martinez-Casasnovas *et al.*,2003). Overgrazing is also often reported as one of the main drivers of gully erosion in rangelands (Gomez *et al*., 2003b; Nyssen *et al.*, 2004c).

As presented in Plate 19, the lateral bank erosion occurred where bank erosion migrates laterally from a channel forming a gully in which it becomes waterway in its own right. The lateral bank soil erosion is triggered by an increase in flows entering a stream from adjacent floodplain, exposure of weak subsoil layer by surface runoff spilling laterally into a stream, and removal of bank vegetation as a result of soil crusting and sealing by the high infiltration rate in the study area especially in the steeper slope. This is similar to the findings by Poesen (1984), who stated that infiltration rates were higher on steeper slopes, where higher erosion rate prevented seal from forming. Also supported by Bowyer-Bower (1993) whose pointed out that for a given soil, infiltration capacity was higher with higher rainfall intensities because of their ability to disrupt surface seals and crusts that would otherwise keep infiltration rate low.

Undercut bank gully erosion as show on Plate 20 was as the result of migrates of gully erosion up the valley, the high and less stable the gully banks become.

As shown on Plate 21, the gully erosion was triggered by exposure of a weak subsoil layer beneath a streambed and this gully erosion is one of the processes of linear erosion (Jakab,

2008).This reveal that gully sidewall processes are influenced by potential energy changes associated with variations in soil moisture content and in unsaturated conditions, by the development of undercut hollows as supported by Martinez-Casasnovas *et al.* (2004). It was found that most of gullies in the study area range between 3m to 20m deep, 20–50m wide and mostly more than 100 m long as in the case of research finding by (Bergsma, 1996).

This is similar to the case of Fredén and Furuholm (1978) in glaciofluvial deposits following the 1977 spring snowmelt, which caused the removal, as a mass flow, of 20,000m^3 of saturated silt and sand in less than three days which formed 3–20m deep gullies, 20–40m wide and 100 m long gully. Gullies were observed to have relatively greater depth and larger/smaller width than stable channels, carry larger sediment loads and display very erratic behavior (Heede, 1975a).

Gullies in the study area were formed following clearance of natural forest cover. It was noted that most water was moved from the hillsides by subsurface flow and flow into natural tunnels. Heavy rain provided sufficient flow to flush out the soil; ground surface subsided, exposing the tunnel network as gullies (Berry and Ruxton, 1960). Overgrazing and removal of vegetation cover in the study area resulted in distrucion of soil structure, compaction, reduced infiltration and hydraulic conductivity and crusting of the surface soil and consequently high runoff. This proved findings of Albert*et al. (*2006) which stated that soil erosion has been identified as the most threatened environmental hazards in the Nigeria.

5.1.2 Rill Erosion

Figure 5.2 presents location of rill erosion in the study area. As runoff rates are relatively high over most of the hillside, overland flow and more strictly, combined action of overland

flow and raindrop impact as interrill erosion are the dominant erosion process on the upper and middle slopes, with deposition of material as colluvium on the foot slopes. This appears to be true for many agricultural areas on non-cohesive soils type. All the rill erosion was linked with locations in the study area using hyperlink tool in ArcGIS 10.3 software environment. The result for nature of rill erosion within the watershed is presented on Plates 21 to 24(see appendix I). The location of the rill soil erosion is shown in appendix vii.

As shown on Figure 5.2, rill is caused by the lower crusting in the study area on steep slopes as compared to lower slopes due to a lower impacting kinetic energy and a continuous soil erosion of the surface seal (Poesen, 1986). Because soil crusts mainly develop on gentle slopes generating higher runoff, the slope threshold for rill initiation can be very low for seriously crusted soils. It was observed that most rill erosion in the study area was located in association with gully erosion. They were also found in virtually all aspects of the slope in the study area as indicated on Figure 5.2. The dimensions of rills erosion extended continuously from top to bottom changed significantly downslope. The changes in rill dimensions are determined by soil detachment and deposition along the length of rills as supported by Bennett *et al.* (2000).

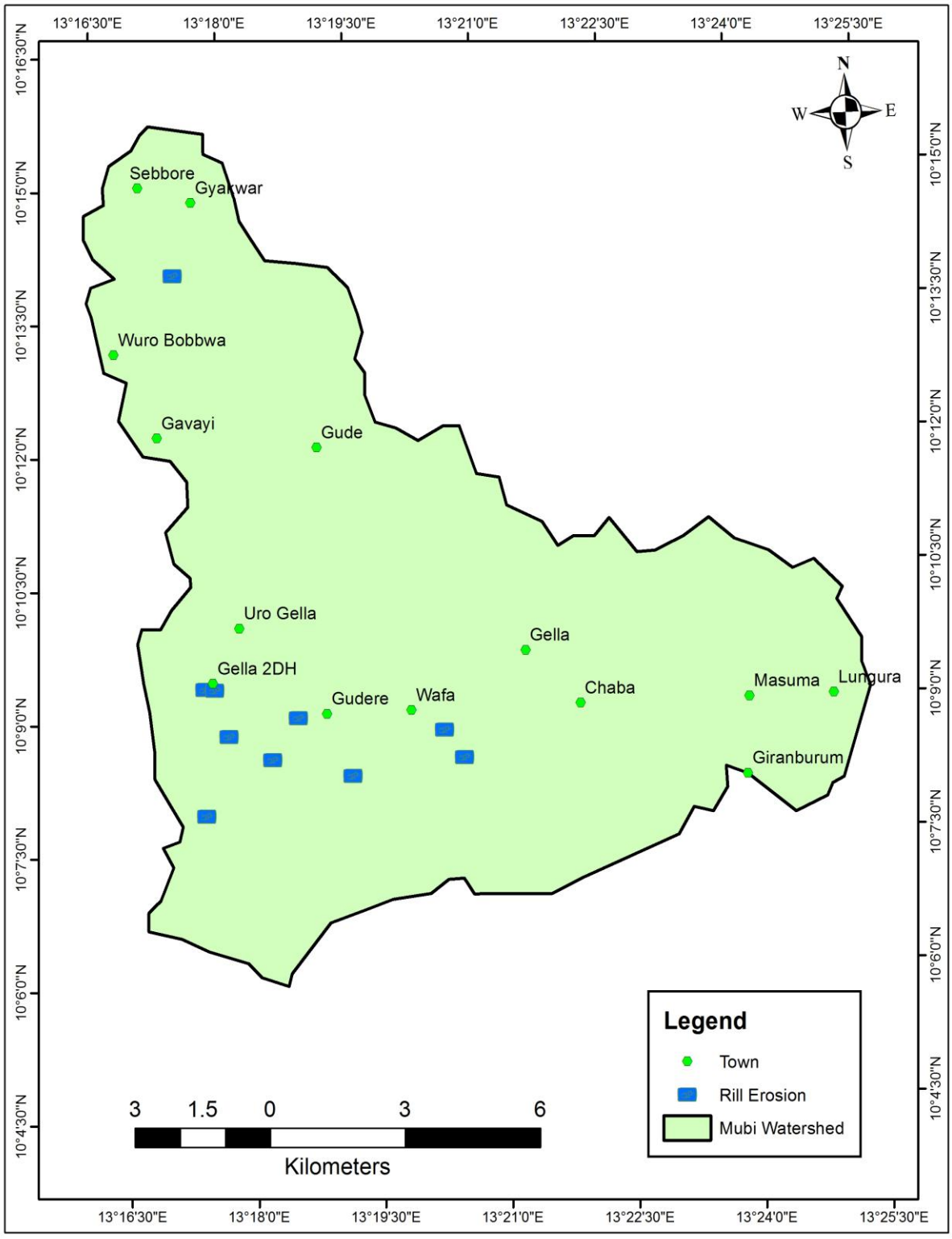


Figure 5.2: Location of Rills Erosion
Source: Author's Analysis (2016)

Also observed was decrease in rill width downslope implyimg that scouring of the rill side walls decreased as a result of limited scouring capacity of flow, due to increase in sediment load downslope and confirmed by Bewket and Sterk (2003). It was also noted that rill erosion was less towards Northern part of the study area, which was predominant; high in clay content and higher percentage of clay content for non-degraded land could be an indication of the role of clay in reducing soil erosion. An increase in clay content of the soil has been associated with the increase in aggregate stability, thereby decreasing soil erodibility (Dlamini *et al.,* 2011).

5.1.3 Sheet Erosion

Sheet erosion involves uniform loss of soil over large areas caused by action of water or wind. This form of erosion is not always obvious but it results in significant loss of productive soil. However in some arid areas, all of the topsoil may be removed, leaving a scalded appearance. Sheet erosion is the erosion of surface soil layers over a large area. This type of erosion is the start of erosion and often not easily recognized. See Figure 5.3 for location of sheet erosion. Also, some of the pictorial representatives of sheet erosion in the study area are shown on Plates 25 to 27(see appendix I).The location of the sheet soil erosion is shown in appendix vii.

The Presence of sheet erosion on Figure 5.3 and Plates 25 to 27 indicates lower porosity and microbial activity in the study area. Most of the rill areas were found to be around pediplain and especially the agricultural lands. From Plates 25 to 27 it was noticed that there was a removal of soil in thin layers by raindrop impact and shallow surface flow, which resulted in loss of the finest soil particles that contain most of available nutrients and organic matter in

the soil. No increase in sheet erosion with water depth observed around sandy soil zones as in the case of Ghadiri, Payne (1979) and Poesen (1981).

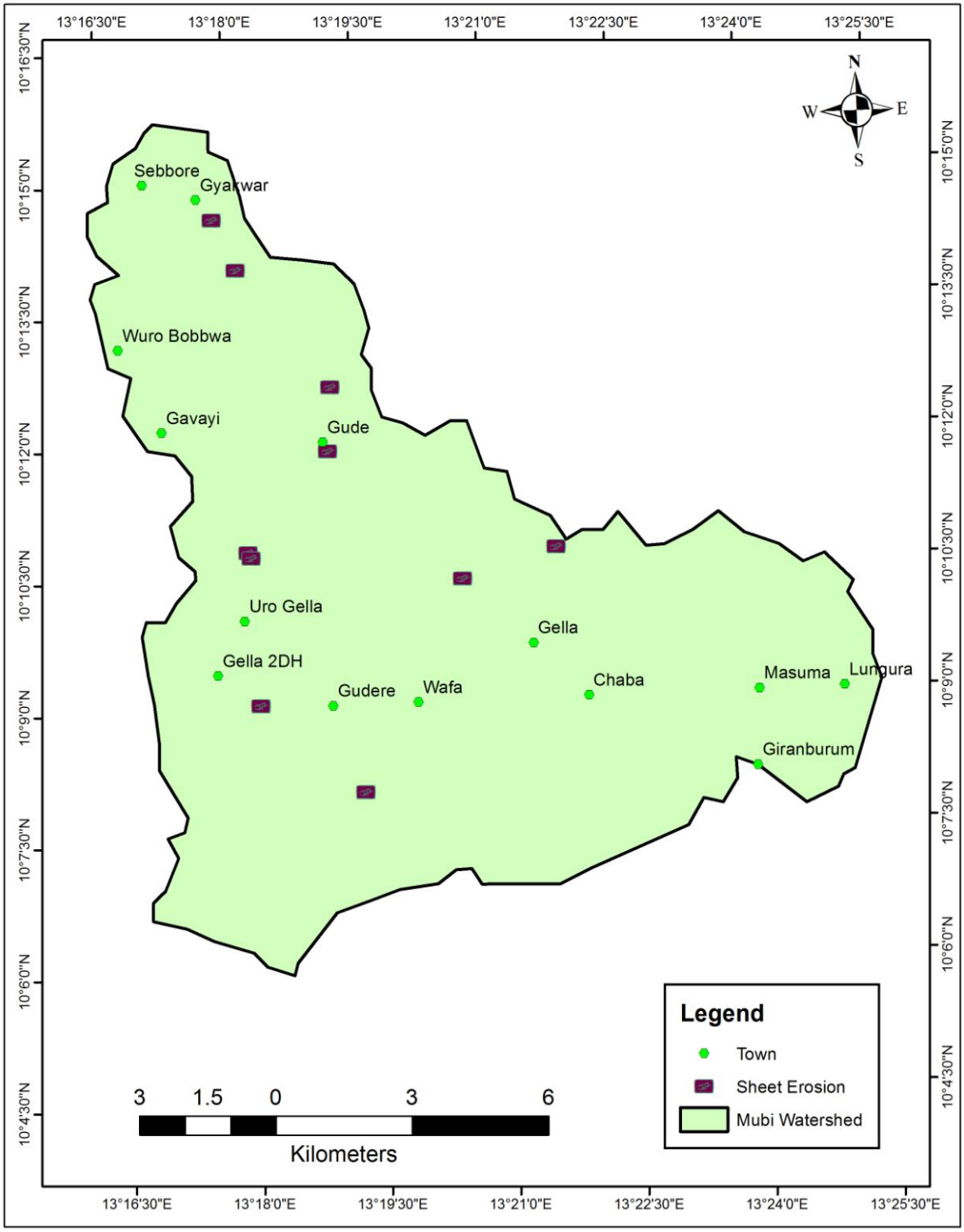


Figure 5.3: Location of Sheets Erosion
Source: Author's Analysis (2016)

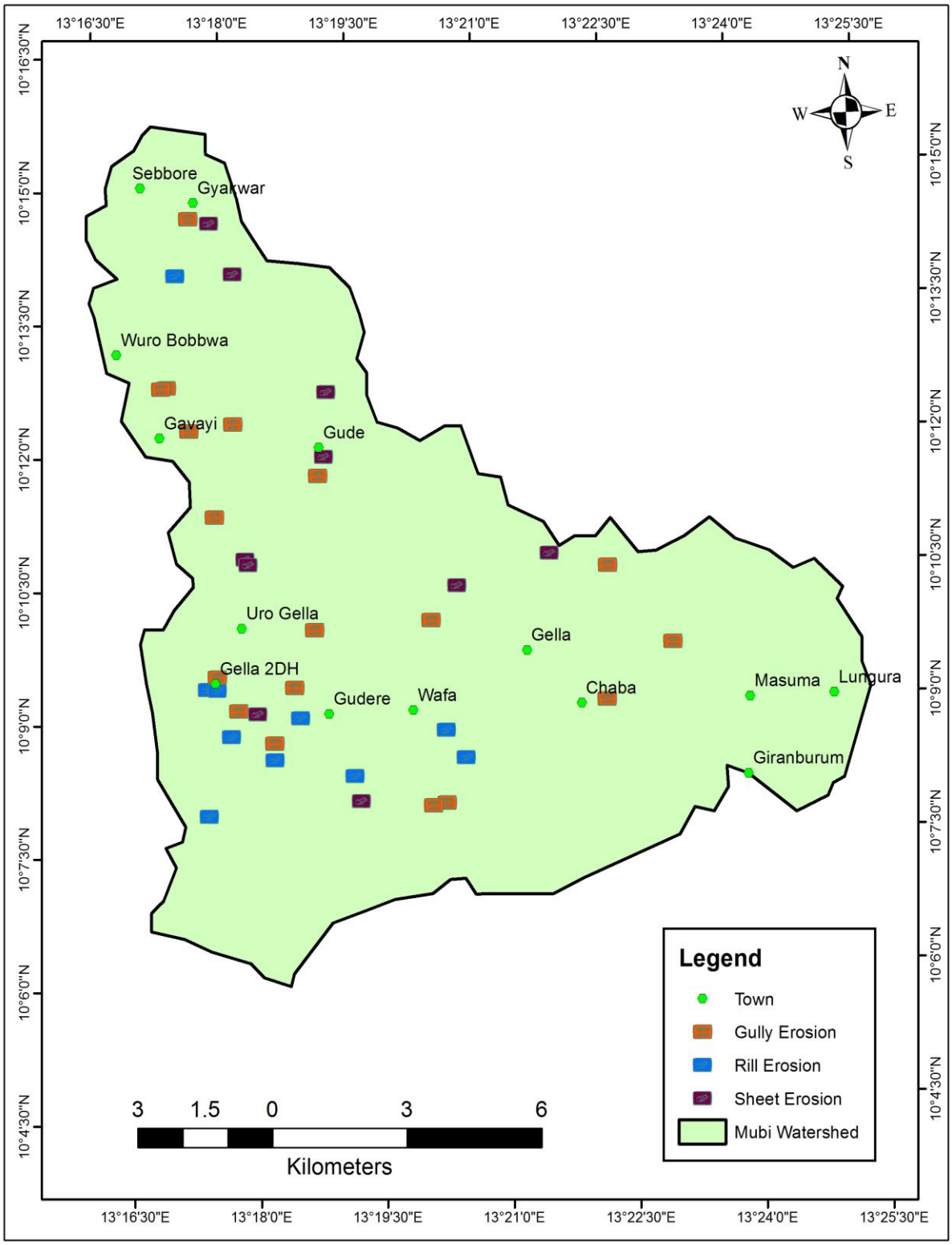


Figure 5.4: Location of Sheets, Rill and Gully Erosion
Source: Author's Analysis (2016)

It was noticed from Figure 5.4 that all the soil erosion types were randomly distributed in the study area, despite the nature of their geomorphology.

5.1.4 Observed Effects of Soil Erosion

The human impacts such as agricultural activities, construction of buildings and roads in Mubi South result in soil degradation and changes in the landforms as supported by findings of Cheng *et al.*(2013), Jimenez *et al.*(2013), Lee *et al.*(2013) and Villarreal *et al.*(2014) in their countries. This lead to the occuranced of soil erosion in the form of sheet, rill and gully erosion in Mubi South as supported by the findings of Morgan (2005) and Le Roux *et al.* (2008) elsewhere.

Soil erosion affected agricultural lands, builtup areas, forestry and social amenities such as road and destroyed electricity facility within the study area. Plates 28 to 34(see appendix I)show some representatives of the effect of soil erosion in the study area.

As indicated in Plates 28 to 34 (see appendix I), effect of soil erosion in the study area is very profound hence the urgent need of soil erosion conservation in the study area so as to reduce the menace of soil degradation in the study area. However, the effects were mostly on agricultural land which in turn affect outputs of production as affirmed by Sarkin Noma during the interview.

5.2 HYDROPHYSICAL PARAMETERS FOR SOIL EROSION

The hydrophysical parameters of soils in the study area are characterized based on the soil types in Mubi South Watershed. Laboratory results for soil texture, aggregate stability, soil

moisture and Bulk density were characterized base onsoil types of the study area. The results are shown in Table 5.1 to Table 5.8.

5.2.1 Soil Perticle Sizes of Mubi South Watershed

Based on the outcome of laboratory analysis for soil in the study area, the soil were categorised into three major types; namely sandy, silt and clayed. Average number of soil types in the study area is presented on Table 5.1.

Table 5.1: Average Number of Soil Types in Mubi South Watershed

Soil Type	Average (mm)	Percentages (%)
Sandy	652.963	65.28
Silt	184.815	18.47
Clay	162.5926	16.25
Total	**1000.37**	**100.00**

Source: Author's Analysis (2016)

The results from Table 5.1 show that sandy soil is the dominant soil type in the watershed which covered about 65% of the study area, followed by silty with about 18% and clayed soils of less than 17 %. On the basis of the result, it can be inferred that soils of the study area are predominated by sandy. This is because therelief and geologyof the study areawhich has mixed assemblage of scattered granitic outcrops on gentle with dissected uplandsand soil

surfaces resulted to soil classes. Moreover, Precambrian basement rocks of Mandara Mountain play a vital role on the soil types of the area (Adebayo, 2004).

5.2.2 Soil Erodibility in Mubi South Watershed

The resulting soil erodibility variables found in the study area is presented in Table 5.2. Loamy sand covered more than 28% of soil erodibility of the study area, which constitutes the highest percentage amongst the other soil textural type, followed by sandy loam soil while others constitute between 20% to 25% with sandy clay loam having the least amongst them with about 21%. These facilated the movement of soil particle sizes which result to soil erosion types and sediments transportation down to the slope.These affect the nature of soil erosion from the hilly areas down the slope and led to the formation of rill and gully erosion.

Table 5.2: Soil Erodibility in Mubi South Watershed

Soil Texture Classes	Erodibility (mm)	Percentages (%)
Sandy Loam (SL)	0.237	25.26
Sandy clay loam (SCL)	0.202	21.54
Loamy Sand (LS)	0.27	28.79
Loamy	0.229	24.41
Total	**0.938**	**100.00**

Source: Author's Analysis (2016)

5.2.3 Soil Related Hydrological Parameter Value in Mubi South Watershed

The result of soil related hydrophysical parameter value of the study area obtained from laboratory analysis is shown on Table 5.3.

As presented in Table 5.3, soil texture has differences on soil detachment factor, moisture content, bulk density and Cohension of soil (COH, aggregate stability). As in the case of loamy sand, the higher the detachment factors of soil, the higher the soil moisture the higher the COH of the soil.

Table 5.3: Soil Related Hydrological Parameters Value for Soil Texture in in Mubi South Watershed

Soil Texture	MS	BD	COH
Sandy Loam (SL)	46.64	1.65	2.67
Sandy clay loam (SCL)	46.74	1.68	2.43
Loamy Sand (LS)	48.3	1.70	2.44
Loamy	45.4	1.48	2.00

MS=Moisture Content, BD=Bulk Density and COH=Cohension of soil (aggregate stability)

Source: Author's Analysis (2016)

Reserve was the case in the respect of sandy clay loam which showed that the lower the soil detachment factor the high the soil moisture, bulk density and COH. From these result, it was inferred that types and nature of soil detachment factors did not significantly determine its hydrophysical parameters.This could be as the results of other topographical factor such as; nature of vegetation and climatic variables.

5.2.4 Soil Aggregate Size Distribution

The result of soil aggregate fraction of the study area is presented on Table 5.4.

Table 5.4 shows result of soil aggregate fractionobtained from the study area at different size, though only the aggregate stability fraction of 2mm sieve size wet-sieved were dfor use in this study based on the recommendation made by Morgan (2005).

Table 5.4: Soil Aggregate Size Distribution/Fraction in Mubi South Watershed

	SIEVE SIZE					
Soil Texture	**>2mm**	**1-2mm**	**0.5-1mm**	**0.25-0.5mm**	**<0.05mm**	**Total**
Sandy Loam (SL)	0.51	0.21	0.19	0.07	0.004	0.984
Sandy clay loam (SCL)	0.41	0.17	0.23	0.16	0.005	0.975
Loamy Sand (LS)	0.47	0.21	0.21	0.09	0.004	0.985
Loamy	0.55	0.23	0.17	0.04	0.002	0.992

Source: Author's Analysis (2016)

Observed in the result also was the fact that loamy soils have high soil aggregate fraction of about 0.55g/g in the study area, followed by sandy loam with about 0.51g/g aggregate fraction. As a result of these, the study with sandy loam and loamy soil were less vulnerable to soil erosion risk and these also show that the watershed area was vulnerable to soil erosion risk but the magnitude varied because of the several factors that made-up the study area.

5.2.5 Soil Moisture and Bulk Density

In assessing soil erosion factors, the relationship between soil moisture and bulk density can never be overemphasis, so theneed of their hydrophysical parameters in analysed soil erosion. Result of soil moisture and bulk density base on the textural classes of soil in the study area is show on Table 5.5.

Table 5.5 Soil Determinat Factor of Moisture and Bulk Density

Soil Texture	Detachment Factor	Soil Moisture	Bulk Density
Sandy Loam (SL)	0.24	0.08	1.65
Sandy clay loam (SCL)	0.20	0.08	1.68
Loamy Sand (LS)	0.27	0.07	1.70
Loamy	0.23	0.06	1.48

Source: Author's Analysis (2016)

From Table 5.5, it was discovered that the loamy sand has the higher the soil detachment factor and sandy clay loam with the lowest. The lower the soil moisture and the higher the bulk density as in case of loamy sand. Reverse was the case in case of sandy loam, sandy clay loam and loamy which show higher soil moisture and bulk density contents in the watershed. Moreover, it was observed that sandy loam and sandy clay loam had high soil moisture content in the study area (0.8%) than loamy sand (0.07%) and Loam soil (0.06%) respectively. A variation of these results was due to nature of watershed which comprised hills, mountainous, vegetation and water bodies. The results was also as the results of

variations in the spatial distribution of hydrophysical parameters, climate change and as well as vegetation types of the study area as supported by Adebayo (2004).

5.2.6Soil Laboratory Analysis for RMMF Model Parameter

Table 5.6 presents summary of all hydrophysical parameters discussed and used as an input for deriving RMMF model. Also, spatial distribution of these parameters were presented and discussed with relation to geomorphology of the watershed under objective three of this present research work.

Table 5.6 Soil Laboratory Analysis for RMMF Parameters

	Detachment Factor (K)	SM	BD	MC at LC			PD	OC	Moisture Storage	Gmc_1 mlc	Porosity	OM	COH
				0.0g	0.3g	15g							
Sandy Loam	0.202	0.08	1.68	0.251	0.186	0.077	2.67	4.50	46.74	0.213	0.429	7.70	2.67
Sandy clay loam	0.229	0.08	1.48	0.341	0.196	0.082	2.271	8.02	45.4	0.339	1.479	13.83	2.43
Loamy Sand	0.237	0.07	1.65	0.256	0.182	0.083	2.399	6.79	46.64	0.161	0.709	11.71	2.44
Loamy	0.27	0.06	1.70	0.242	0.152	0.064	2.00	7.33	48.3	0.161	0.140	12.60	2.00

SM=Soil Moisture, BD=Bulk Density, MC at LC=Moisture Content at Lab Capacity, PD=particle Density, OC=Organic Carbon, OM=Organic Matter, COH=Cohension os Soil (aggregate fraction)

Source: Author's Analysis (2016)

5.2.7 Landuse and Landcover in the Watershed

Table 5.7 presents result of land use land and cover of the study area. The land uses were categorized based on five Major land uses in the study area, which were: Agricultural land, forestry, water body, built up and bare land.

Table 5.7: Landuse Landcover of the Study Area

S/No	Land use type	Area Sqkm	Percentage %
1.	Agriculture	42.32	28.6%
2.	Forestry/Vegetation	28.05	19.0%
3.	Water body	14.72	10.0%
4.	Built up Area	25.30	17.1%
5.	Bareland	37.33	25.3%
Total		**147.72**	**100**

Source: Author's Analysis (2016)

As shown on Table 5.7, about 29% of the watershed was covered by agricultural activities, 19% was covered by forest, and 25 % was not cultivated and covered by bare land while 17% was covered by built up areas and 10% by water bodies. From the result it was inferred that major land use of the watershed was agricultural activities, followed by bare land where neither agricultural activities is taking place nor covered by forest.

5.3 SPATIAL DISTRIBUTION OF HYDROPHYSICAL PARAMETERS

Before assessment of spatial distribution of hydrophysical parameters of soil in Mubi South watershed, there was need to assess the physical land morphology which plays a vital role in determining soil hydrophyscial parameters. Land geomorphology such as land use type, NDVI, Digital elevation model, soil type, flow accumulation, flow direction and Hillshed were considered for the purpose of this research as major determining factors that lead to soil erosion in the study area.

5.3.1 Spatial Distribution of Land Geomorphological Factors

Land morphological factors are those features which are considered to be important determinant factors in soil development and also affect soil erosion of an area. The spatial distribution of land use of Mubi South watershed is show in Figure 5.5.

5.3.1.1 Land uses land cover within the watershed

Figure 5.5 and Table 5.7 shown that Mubi South watershed is predominantly covered by Agricultural activities with agricultural land followed by bare land, also show that built up area covered lesser of land use followed by water bodies and forest land used. On the basis of the analysis,it can be inferred that Mubi South is a dominant agricultural area with most of the forest cleared and cultivated as on agrarian land(Figure 5.5 and Table 5.7). It was also observed that there was a higher rainfall in the study area.

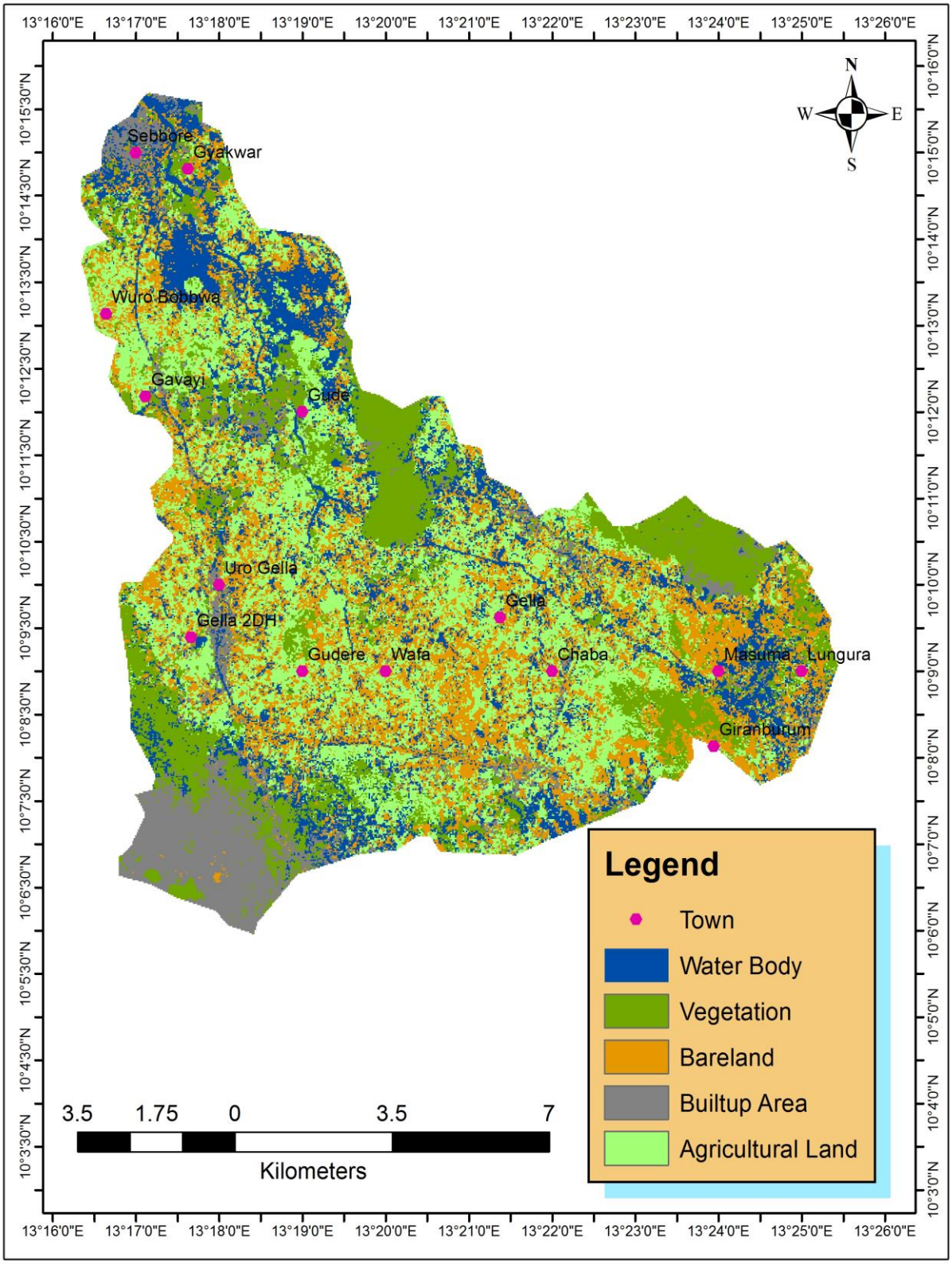


Figure 5.5: Land Use within the Watershed

Source: Author's Analysis (2016)

5.3.1.2 The normalised difference vegetation index (NDVI)

The Normalised Difference Vegetation Index (NDVI) is an indicator of vegetation vigor and health used in determining cover management factor (c), which represents effect of soil disturbing activities, plants, crop sequence and productivity level, soil cover and subsurface biomass on soil erosion risk. Figure 5.6 shows spatial distribution of NDVI in the study area.

It reveals that majority of the watershed area was covered by higher vegetation vigor, which was about 0.58 with a lower value of -0.07. These show that the target area being observed contains live green vegetation at the ground cover. Yellow colour on Figure 5.6 represents bare soil which reflects moderately in both the red and infrared portion of the electromagnetic spectrum as supported by Holme *et al*. (1987).

This study noted that some part of the watershed area has dense vegetation because the NDVI takes value between -1 and 1, with values 0.5 indicating dense vegetation and value less than 0 indicating no vegetation as shown in Figure 5.6. Symeonakis and Drake (2004), and Tateishi, *et al.,* (2004) studies were compared using satellite imagery to produce maps of vegetation-related variables for soil erosion and found out that the NDVI was the most useful in parameter/factor for determining the cover management facto (C-factor) wich is used in estimating and predicting soil erosion. These results showed that there is less cover management practices in the study area and this facilitates the rate of soil erosion expecially around the builtup area and bared surfaces.

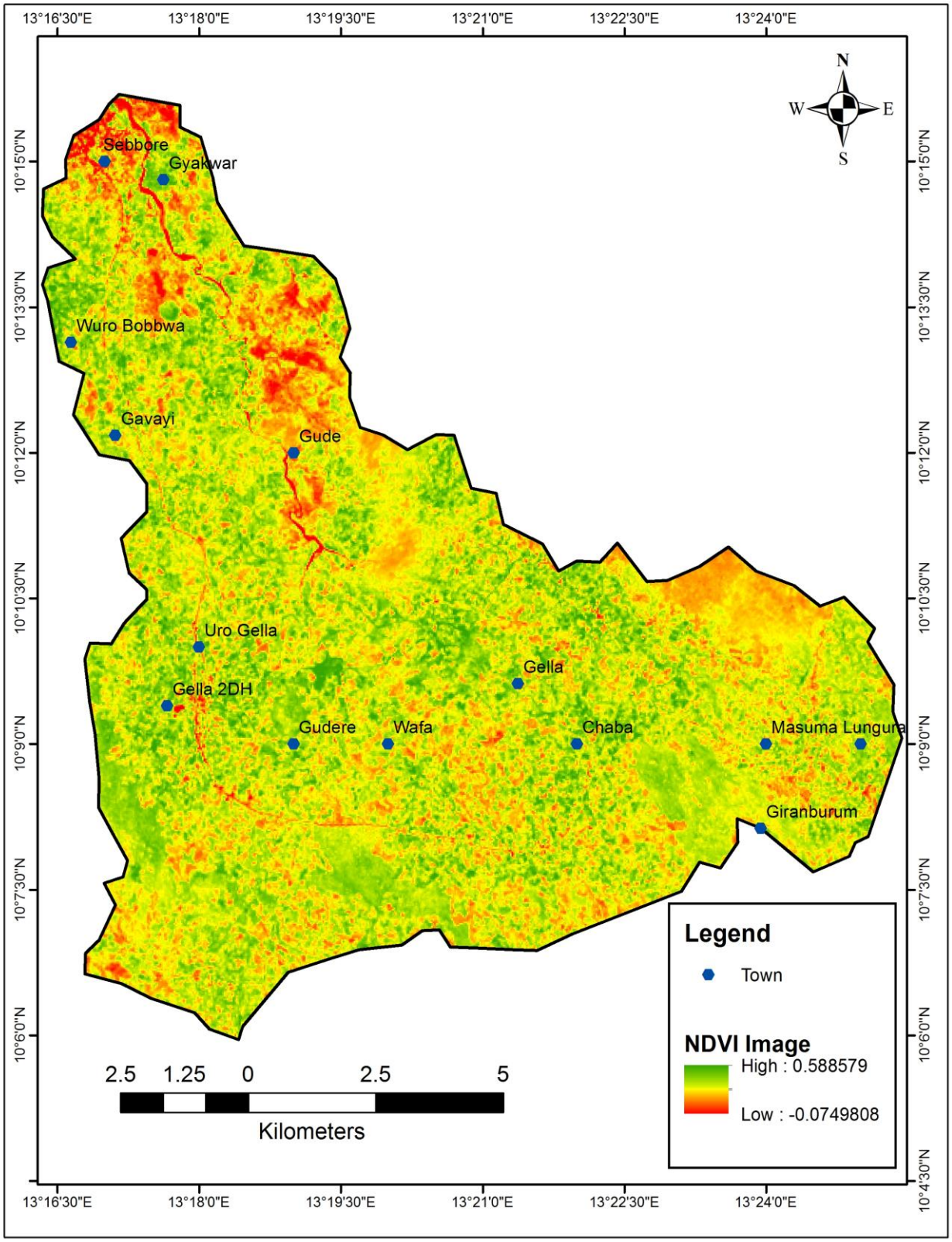


Figure 5.6: NDVI within the Watershed
Source: Author's Analysis(2016)

5.3.1.3 Digital elevation model

The digital elevation model contains information derived from long-track, 15m ASTER optical data acquired in near infrared bands 3N and 3B. The topographic data used to derive slope and slope aspect are basic to all aspects of land surface. The DEM of Mubi South watershed is shown on Figure 5.7.

From Figure 5.7, it was inferred that spatial distribution of DEM in the study area ranges from higher value of about 1261 m tolower value of about 570 m. Figure 5.7 shows that majority of the study area haswithin the lower topography of 570m above sea level and also all settlements of the study area were located within the lower topography with the exception of Giranburum town which is located in higher elevation area. The evidence of higher elevation of about 1261m is the Mandara Mountain that serves as a border between Nigeria and Cameroon.

The area covered by high elevation or mountainous area has mixed up vegetation as shown in Figure 5.5and this is attributted agricultural activities taking place in the area and people from the communities engaged in deforestation in the area for domestic fuel and selling them to solve their financial problems as it were. The hilly areas facilited the rate of surface runoff which results to mass movemet of sedimets thereby leading to surface sealing and crustining and led to formation of the rill and gully erosion in the study area.

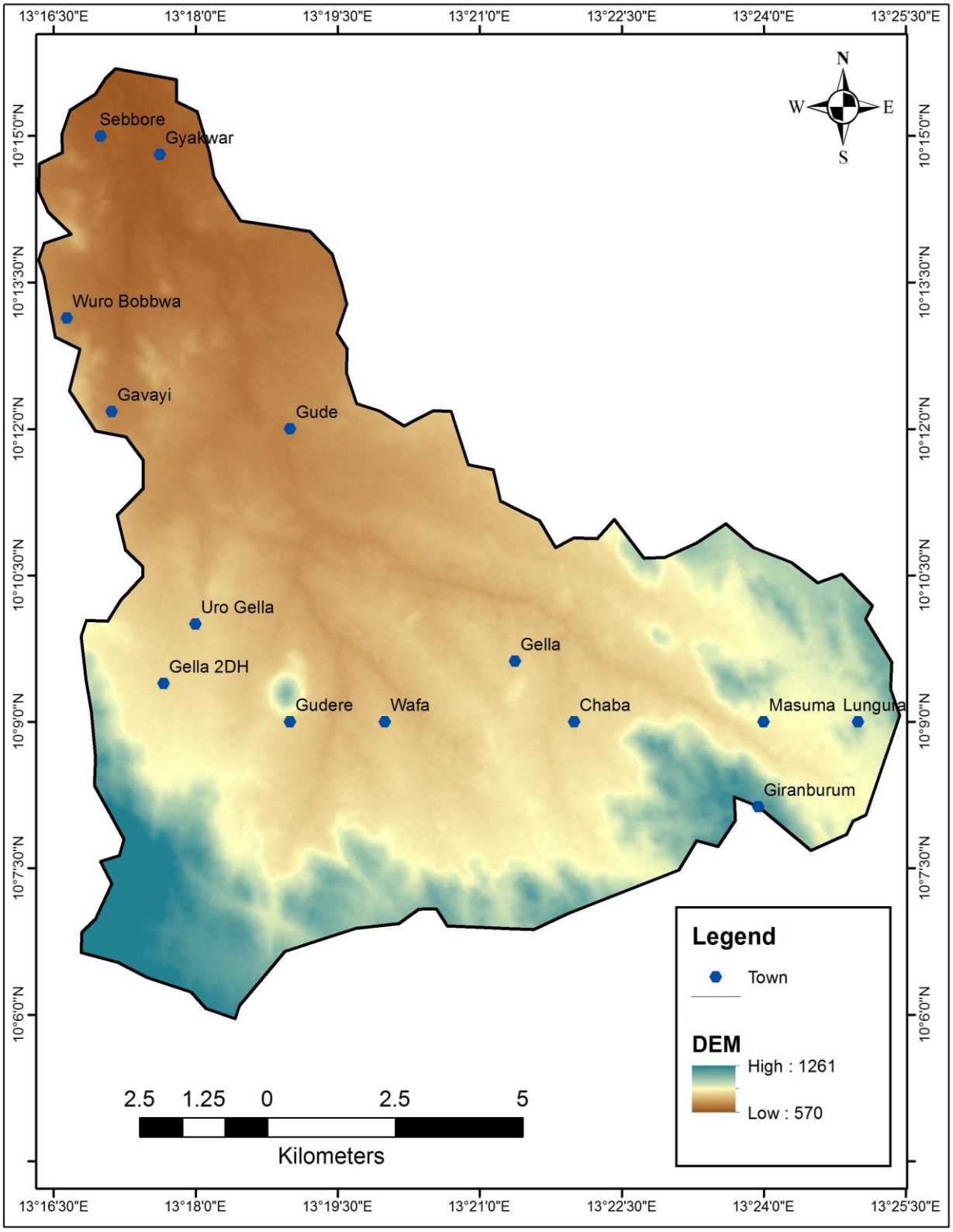


Figure 5.7 DEM within the Watershed

Source: Author's Analysis (2016)

5.3.1.4 Soil of Mubi South

Soil of the Mubi South watershed is shown on Figure 5.8. The soil map was produced for the soil sample collected from the study area during fieldwork. Laboratory analysis was conducted and the result obtained from the laboratory was used as basis for producing soil map of the study area and compared with FAO (1978) global soil data result. From Figure 5.8, it was observed that there are three dominant soil classes in the study area which comprised of Luvisols, Regosols and Arenosols. Luvisols constitute about 30% Regosols 35% and Aresonols 35%.

The Luvisol was in pediplain of the watershed, which has about 570m above sea level as shown in Figure 5.7, along Sabbore, Gyakwa, Wuro Babbwa, Gavayi and some part of Gude town of the study area. Lowland and low vegetation in the study area resulted to the presence of Luvisols in the watershed. Also, Regosol and Arenosol were located between mixed vegetation in the study area and also agricultural areas.

The movement of soil from highland area contributed to the presence of Regosol and Arenosol, because the nature of topography, time, climate and vegetation types plays a major role on soil formation and Mubi south watershed area is not exception from the influence of the factors. Dominant soil groups of the study area is shown in Appendix VI as well as their sequence, dominant soil association and inclusion supported by FAO (2006). The soil group of the study area is further divided into soil types. The result of soil types analyzed from the laboratory is presented in Figure 5.9 to Figure 5.11.

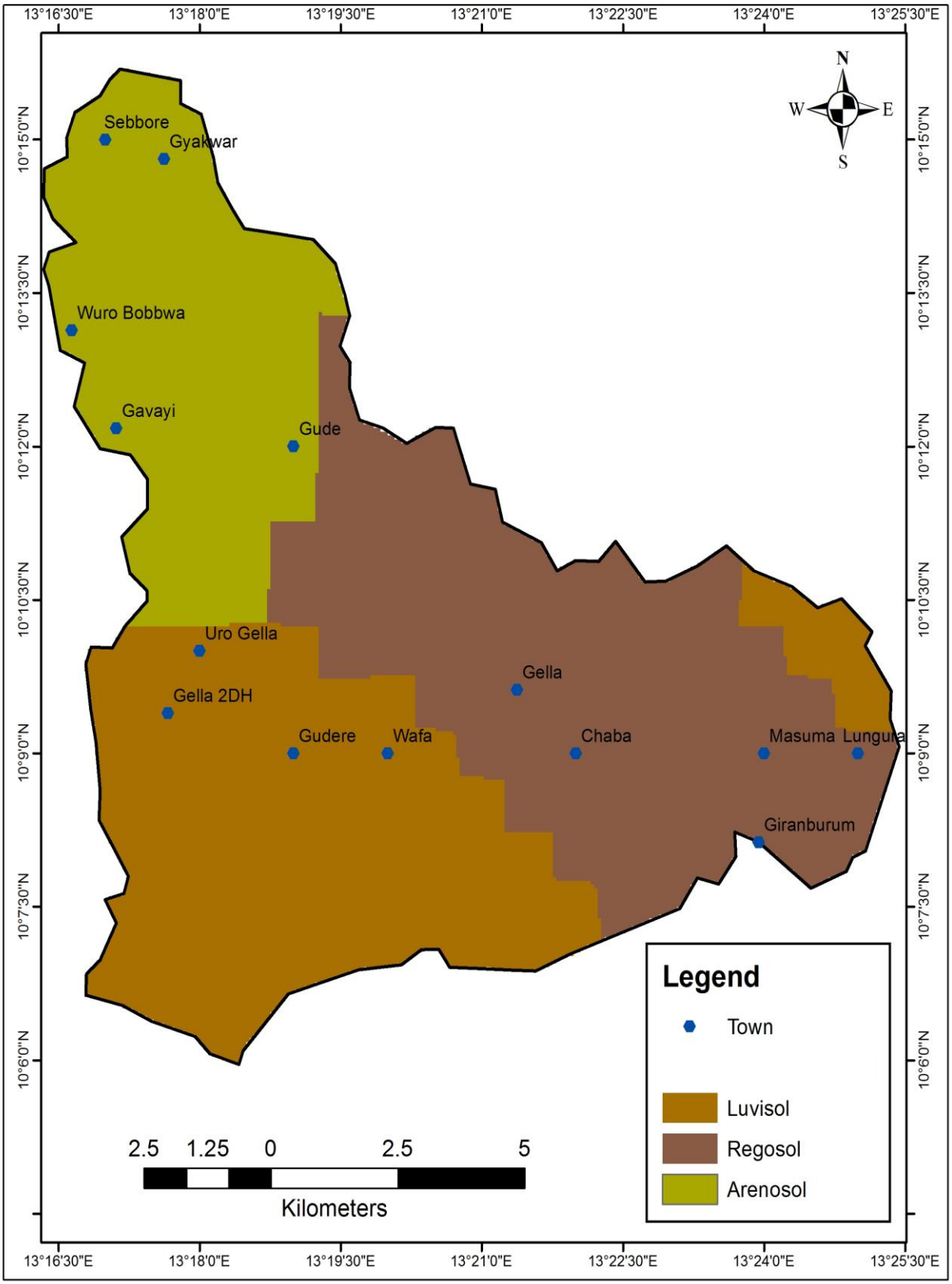


Figure 5.8: Soil within the Watershed

Source: Author's Analysis (2016)

5.3.1.5 Spatial distribution of soil particle sizes

The Figures show spatial distribution of the soil types which ranged from Sandy soil on Figure 5.9, silt content on Figure 5.10 and clay contents of the watershed on Figure5.11 respectively. From Figure 5.9, spatial distribution of sandy soil varies in different locations in the watershed. The value of sandparticles ranges from 455.8 kg/$m^3$to 791.5kg/m^3 in the watershed with low contain of the sandy soil in the northern and southern part of the study area and high proportion of between 692.7kg/m^3 to 791.5 kg/m^3in the central part of the study area.

From Figure 5.9, it was observed that low concentration of sandy particles in the study area was mostly found in mountainous area. Many sand particles were observed at lowland and central part of the study area where agricultural activities was practiced. Again, least value of sandy particleswas observed incentral part of the watershed. The presence of high concentration of sandy particles in the central part of the study area was as the result of movement, transportation and deposition of soil particles from highland areas of the watershed. As shown on Table 5.1, sandy soil has constitute about 65% of the watershed which shows that the study area is vunerable to soil erosion risk.

5.3.1.6 Spatial distribution of silt in study area

On the same note, Figure 5.10 shows spatial distribution of silt in the study area (watershed). Figure 5.10 shows that silt particle was sparsely distributed in the watershed which varied between 53.8 kg/m^3 to 360.1kg/m^3.There was higher concentration of silt content in the Northern part of the study area especially around Sebbore, Gyakwar and Wuro Bobbwa between 223.9 kg/m^3 to 360 kg/m^3 respectively.

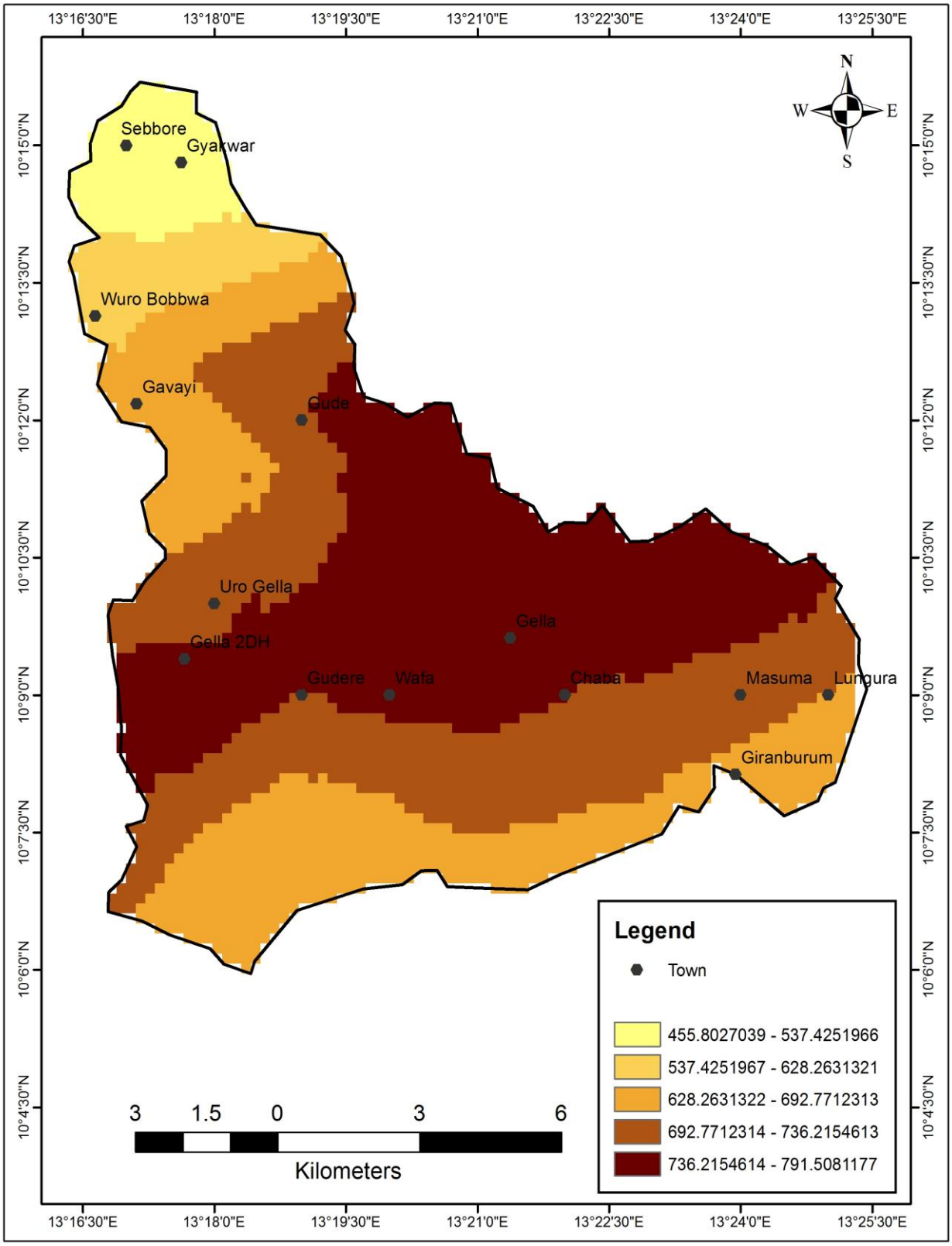


Figure 5.9: Sandy Soil within the Watershed

Source: Author's Analysis (2016)

The higher concentration of silt occured mostly around the Luvisol in the study area whereas between the range of 52.8 kg/$m^3$to 223.9 kg/$m^3$was found around the Regosol and Arenosol soil group respectively. This shows that there was mixed silt and sandy particles at the central part of the study area than any other part. Also noted was silt which constitutes an average of about 18% in the study area as shown on Table 5.1. Figures 5.9 and Figure 5.10 reveal that area of higher silt in the watershed had lower concentration of sandy soilparticles and also shown on Figure 5.9.

5.3.1.7 Spatial distribution of clay content

The result of spatial distribution of clay content is presented on Figure 5.11.From Figure 5.11, clay content range from 130.7 to 182 kg/m^3 in the watershed with the area having mostly clay ranging between 130.7kg/m^3 to 161.1 kg/m^3respectively. Also, clay predominate Northern part of the watershed which was evidentbecause there was higher silt content and low sandparticles in Northern part of the watershed as shown on Figure 5.9 and Figure 5.10. The findings also show that most of the clay was in the lower part of the watershed of study area. Moreover, Table 5.1 shows that clay content of the area constitutes 16 % averagely. This finding also shows that there was less clay content in Regosol and Arenosol in the watershed than in Luvisol soil group (Figure 5.8). This is because the finer soils are resistant because raindrop energy has to overcome the adhesive or chemical bonding forces that link minerals comprising the clay particles as supported by Poesen (1985) in his country which also noted that coarser soils are resistant to detachment because of the weight of larger particles. In the areas of high clayed particle, it affects the rate of surface water infiltration which result to sheet erosion formation thereby affecting the soil nutries and make the areas vulnerable to soil erosion risk.

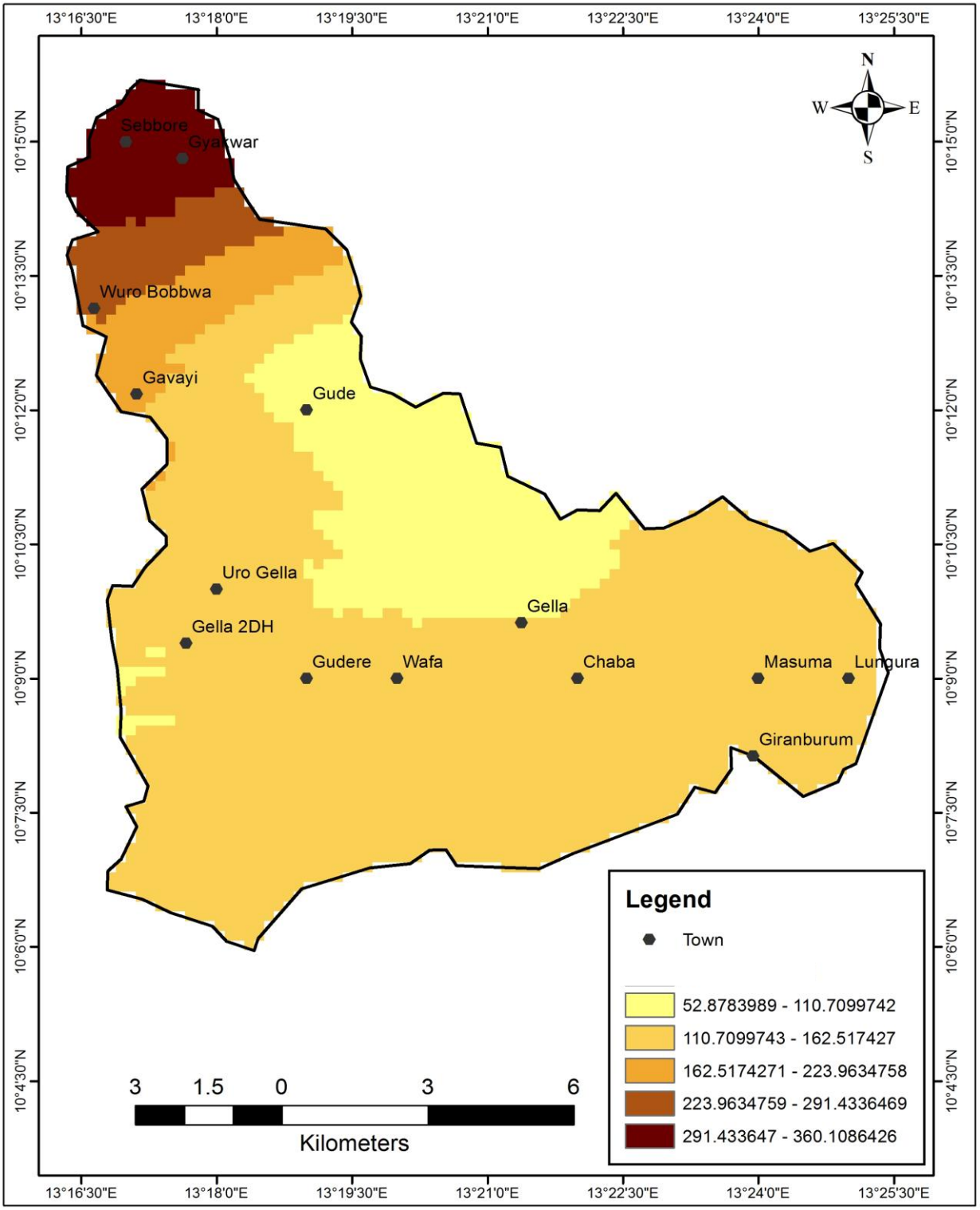


Figure 5.10: Silt Contents within the Watershed

Source: Author's Analysis (2016)

5.3.1.8 Flow accumulation

DEM is important source of information in GIS application. It has been widely used for modeling surface hydrology including automatic delineation of catechment area (Martz and Jong, 1988), erosion modeling or automatic drainage network extraction (Fairfield and Leymaire, 1991).All these computations are linked to the determination of flow accumulation and then flow direction. The flow accumulation is especially important to understand topographic control on water, carbon, nutrient and sediment flows within and over full watershed. Figure 12 shows the flow accumulation of Mubi watershed.

From Figure 5.12, rivers flow from Sabbore and Gyakwar of lower land to Gella. Wafa and Lungurawatershed have high flow accumulation rate of about153906m. it was also noted that the study area has spanning tree type of flow accumulation similar to the findings by Fairfield and Leymarre (1991) in his country. It was also noticed from Figure 5.12 that all flow from a cell goes into one direction and a value of (Zero) and implying that no water flowed throughthe cell.

5.3.1.9 Flow direction

This is the outer part raster that shows the flow direction from each cell to its steepest downslope neighbor. Itis a key factor deriving hydrologic characteristics of a surface to determine the direction of flow from every cell. Figure 5.13 show the flow direction of Mubi South watershed. From Figure 5.13, it was found that water flow from Northern direction down tothe south.

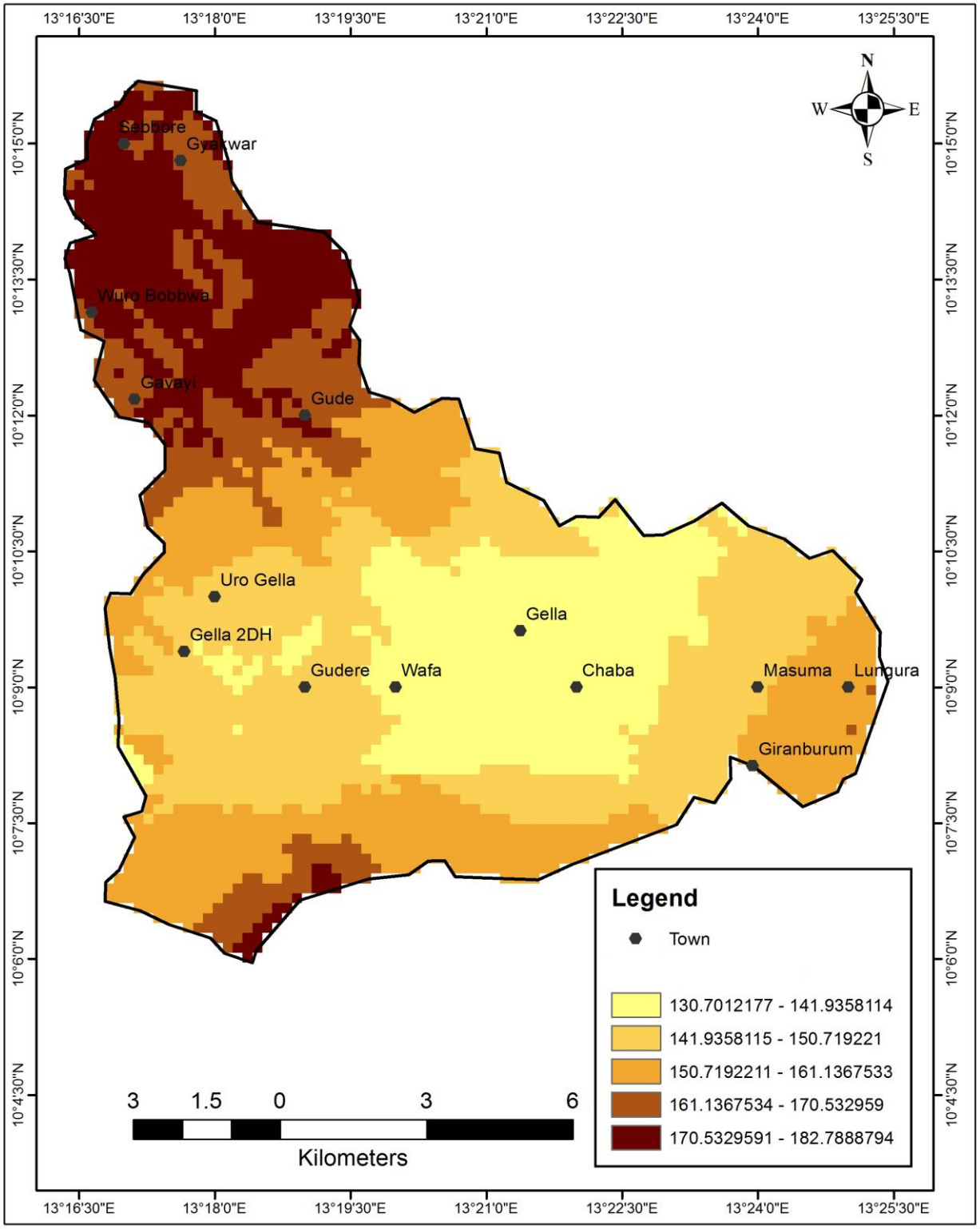


Figure 5.11: Clay Soil within the Watershed

Source: Author's Analysis (2016)

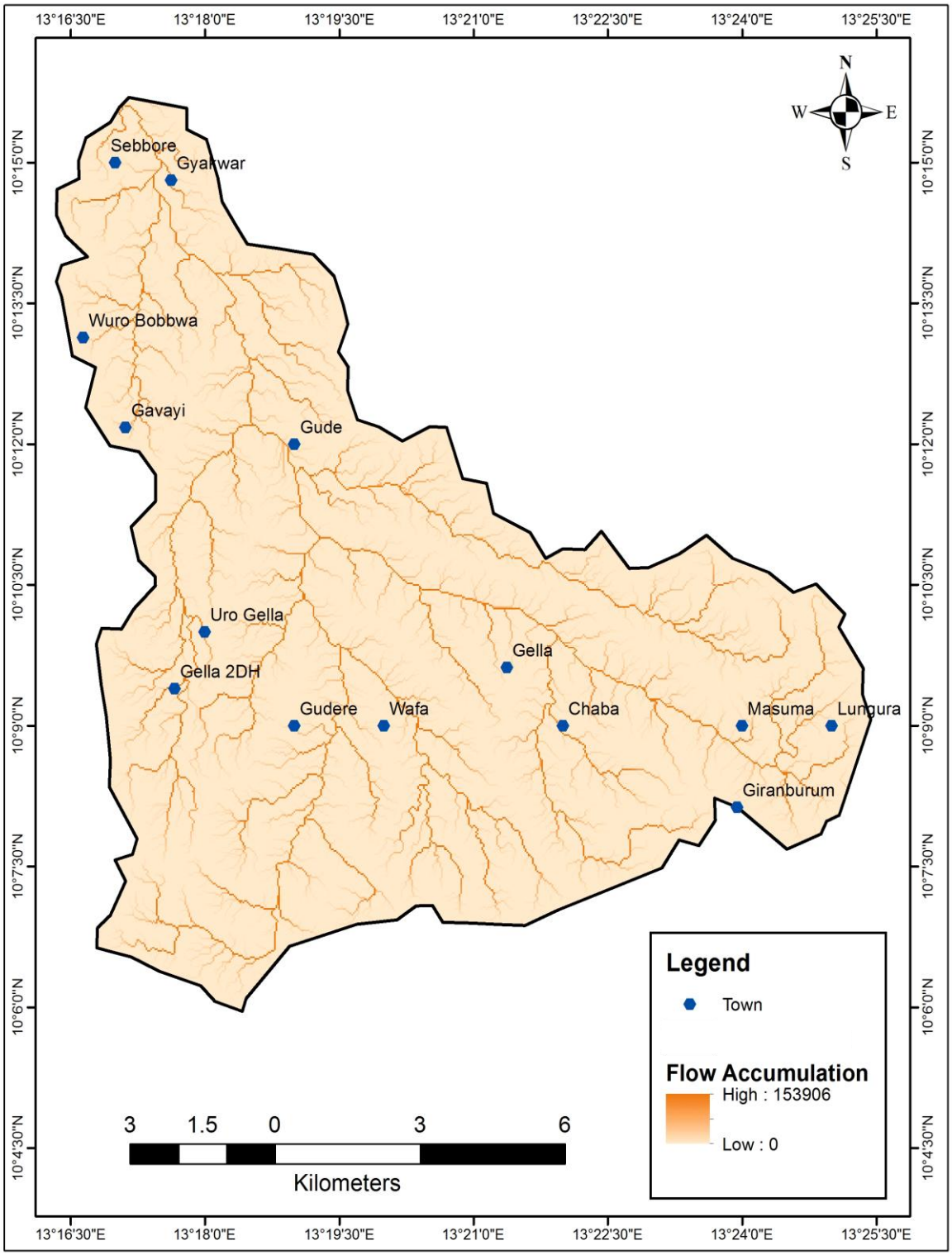


Figure 5.12: Flow Accumulation (Runoff)

Source: Author's Analysis (2016)

Figure 5.13shows that flow direction moves toward southern part of the area from Arenosol towards Luvisol and Regosol, as also shown on Figure 5.8. The movement of flow direction resulted in deposition of high sandy soil in central part of the watershed (Figure 5.9), small concentration of clay content in the central part (Figure 5.11) and larger concentration of silt in the center of the watershed.

5.3.1.10Hillshade

Hillshade Model was created for the watershed of Mubi south in ArcGIS 10.3 to visualize shaded relief of features in the landscape as shown on Figure 5.14.Figure 5.14, reveals that hillshade image illuminates conical hill around Gudere and Gella, and mountains in the southern part of the watershed, which shares boundary with Cameroon Republic. Also noticed was that the hillshades have highest peak of about 180 meters above sea level.

The mountainous area of the hillshade was found to be characterized by low vegetation and high agricultural area (see Figure 5.5). Also noticed was low vegetation index (Figure 5.5)characterized by low flow direction and accumulation in the watershed (see Figure 5.12 and 5.13). The morphological land factor was used in the determination of RUSLE model for assessing soil erosion rate and risk in Mubi south watershed.

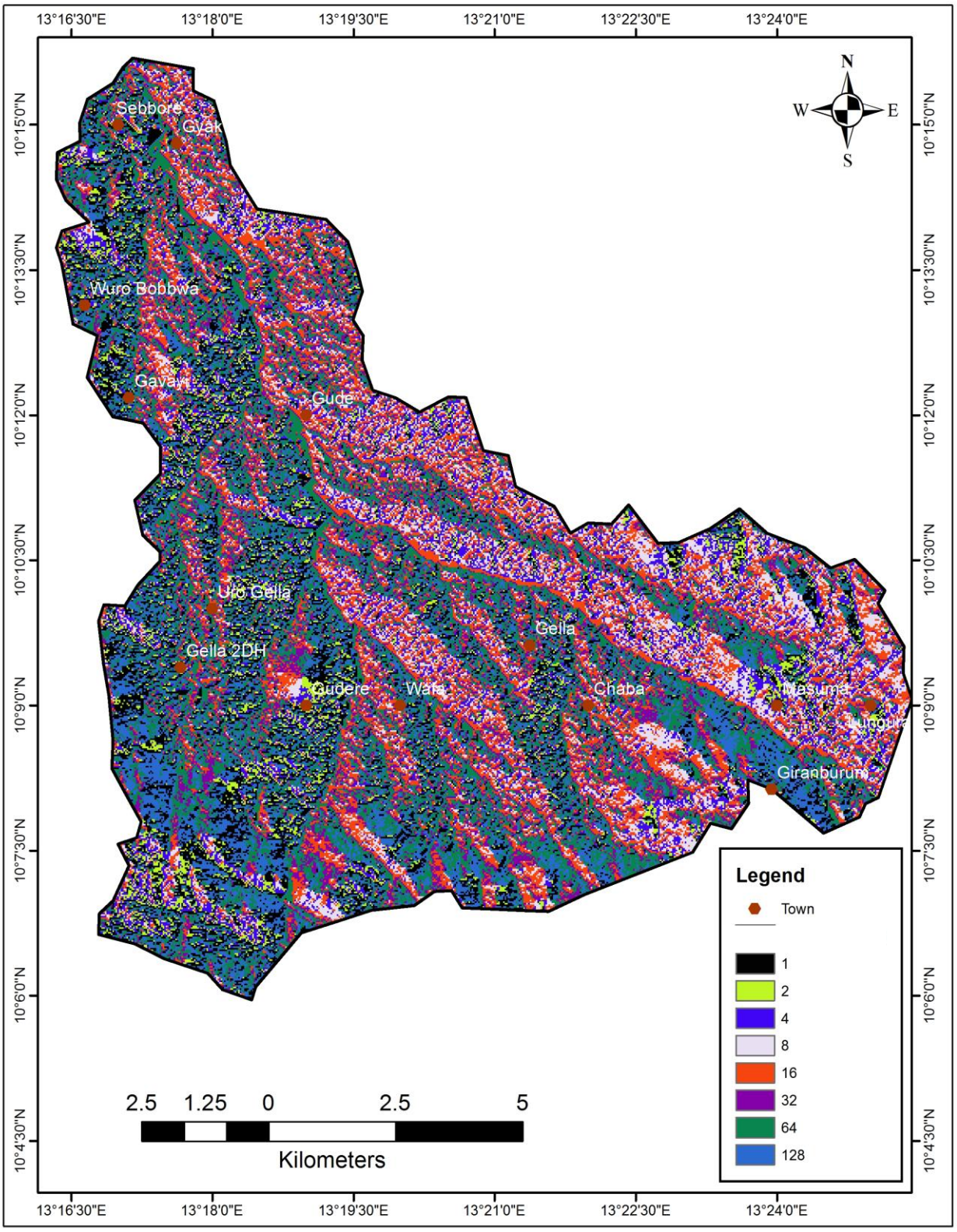


Figure 5.13: Flow Direction (Stream Flow)

Source: Author's Analysis (2016)

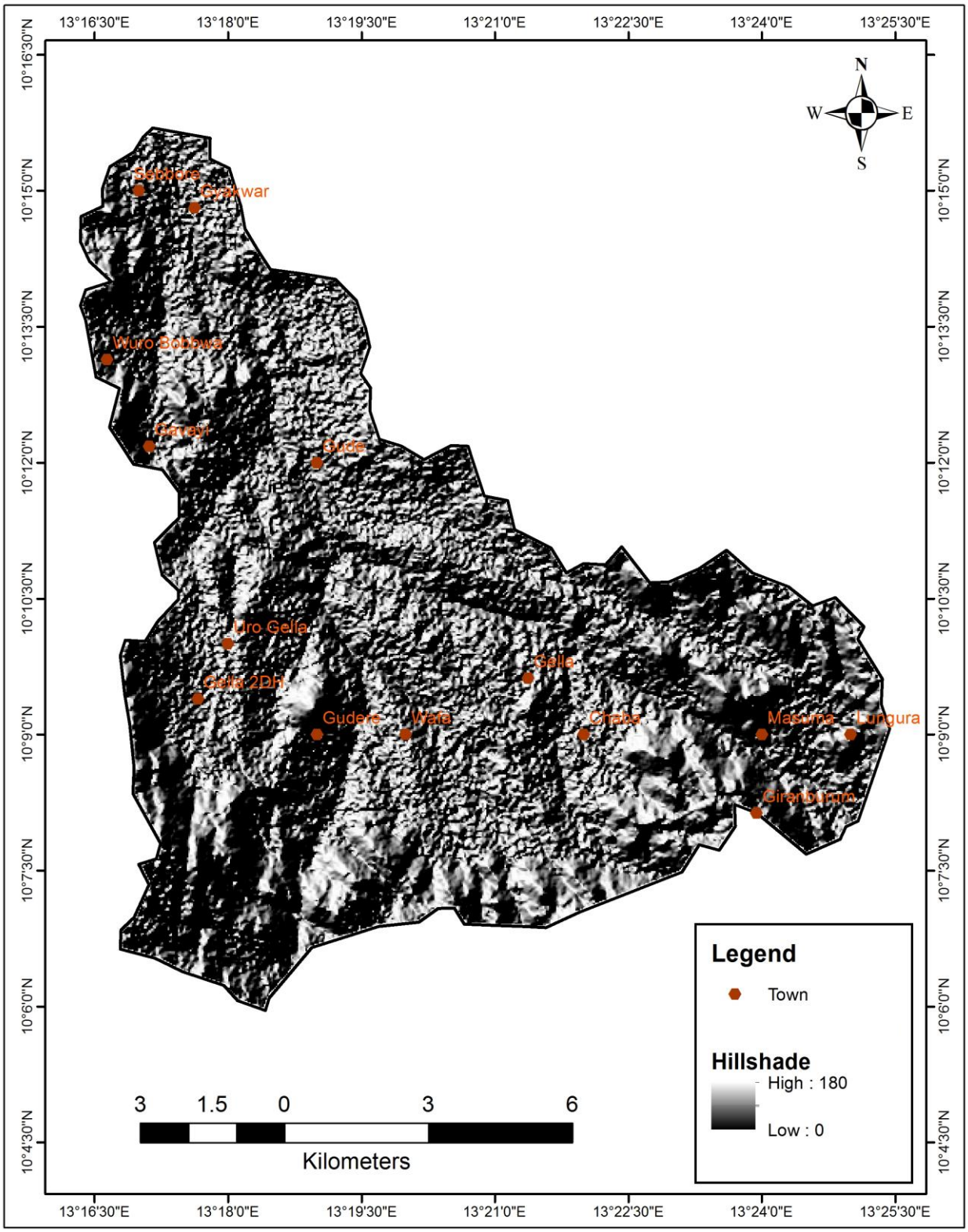


Figure 5.14: Hillshade

Source: Author's Analysis (2016)

5.3.2 Spatial Distribution of Factors used in Assessing Revise Universal Soil Lost Model (RUSLE)

In order to assess spatial distribution of RUSLE, five factors were chosen based on the model which served as input in the equation for assessment of soil loss in the watershed area.

Amongst factors used are: cover management factor (factor), soil erodibility factor (k-factor), slope length and steepness factor (Ls-factor), conservation practice factor (p-factor) and Rainfall erosivity (R-factor). All the factors were derived from land morphological factors; except rainfall factor. That asserts the need for assessment of morphological factors for watershed of the study area for proper analysis and assessment of soil erosion risk in the study area. The factor maps result obtained from analysis is presentedin Figures 5.15 to Figure 5.19:

5.3.2.1 Cover management factor

The result of cover management factor (c-factor) is presented in Figure 5.15 to show spatial distribution of cover management factor that range from higher value of 0.5 to lower value of 0.01 in the watershed.

Result of Figure 5.15was due to land use covered within watershed which shows that most of the vegetation and agricultural activities were around the river. There is an intersection of low and high cover management practices in the study area.High cover management factor wasobserved around mountainous area of the watershed. This finding shows that land use slope and hillshade plays vital role in determining cover management practices in an area.

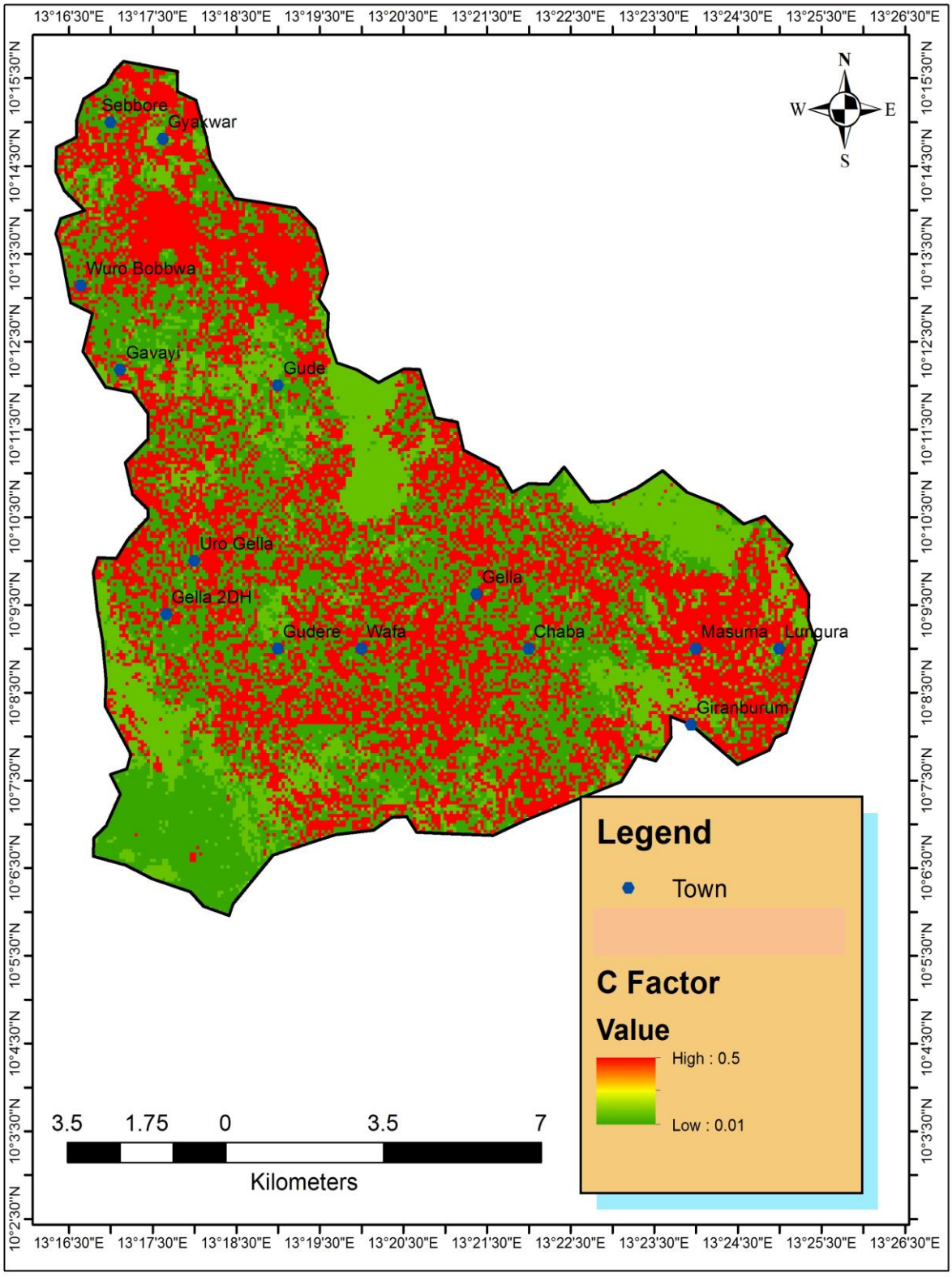


Figure 5.15:Cover Management Factor (C-Factor)

Source: Author's Analysis (2016)

5.3.2.2 Soil erodibility factor

Result of soil erodibility of the watershed is shown in Figure 5.16. The soil erodibility factor (k-factor) measures susceptibility of soil particle to detachment and transport by rain or runoff (Goldman *et al.,* 1986; Mitchell and Bubenzer, 1980).From Figure 5.16, it was inferred that soil erodibility factor reveals that different soils erode at different rates. For axample, comparing this result with soil map on Figure 5.08,it was observed that the rate of soil erodability isheigh (0.69) around areas having Arenosol. Also, Arenosol had highest clay content and lower silt content in the study area. Luvisol had moderate (0.4) erodibility factor and characterized with moderately clay and silt content and sandy soil deposit.

The findings of soil erodibility factor range in value from 0.02 to 0.69 andsupport Goldman *et al*.(1986) and Mitchell and Bubenzer(1980). This result shows that there was lower permeability in Southeast; moderately in Southwest and higher at the Northern part of the watershed. This was as result of soil type, landuse and hillshed of the area which show evidence of resistance of soil to detachment by rainfall impact and surface flow. Research Toy *et al.* (2002) shows that soil with larger sand and silt properties are more vulnerable to water erosion due to lack of stability of the soil particle. Soil texture with large particles are resistant to transport because of the greater force required to entrain them and fine particles are resistant to detachment because of their cohesiveness. The least resistant particles are silts and fine sands. Thus soils with silt content above 40 per cent are highly erodible (Richter and Negendank, 1977)

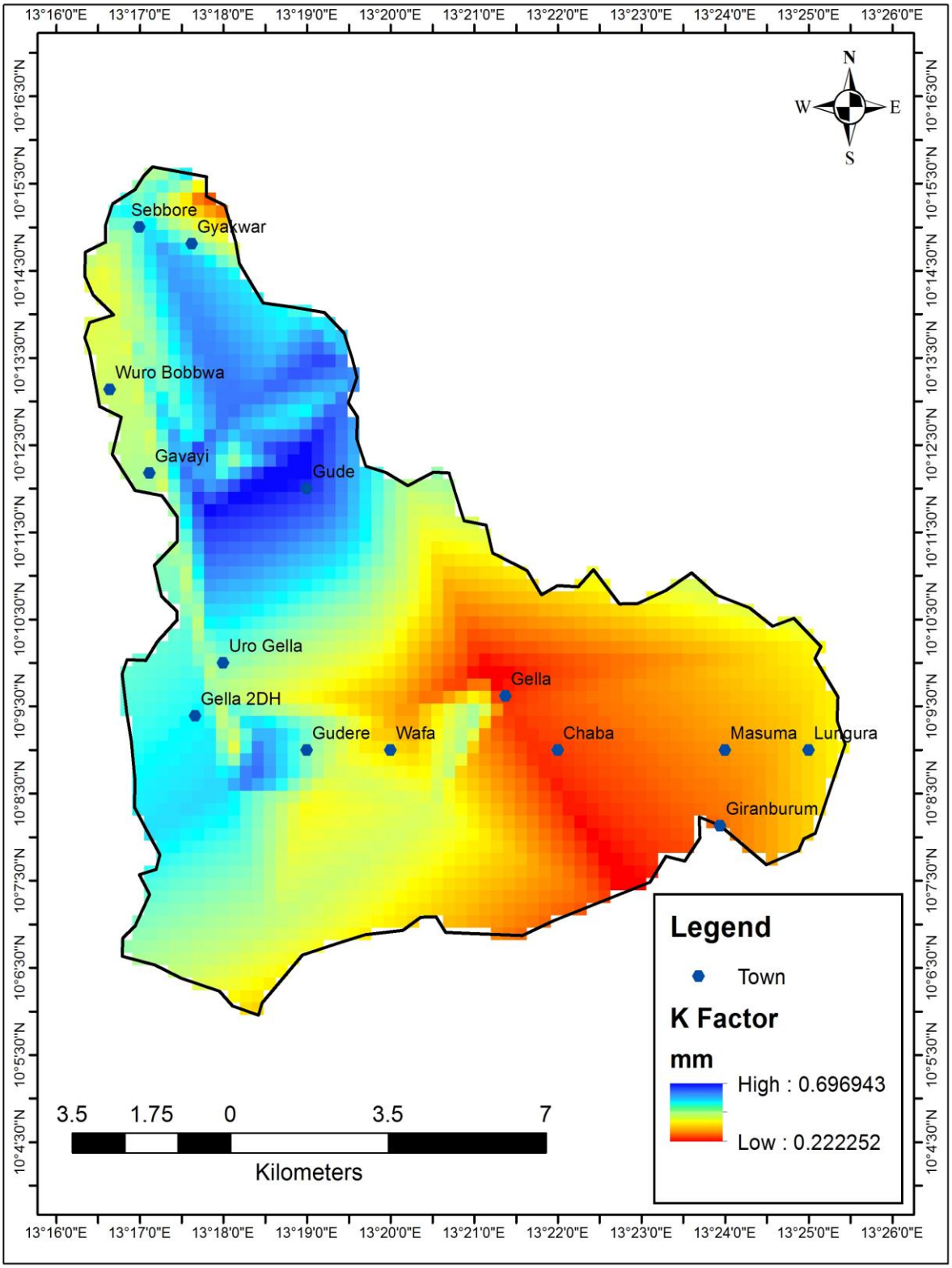


Figure 5.16:Soil Erodibility Factor (K-Factor)

Source: Author's Analysis (2016)

5.3.2.3 Slope length and steepness (Ls-factor)

Slope length and steepness factor represent effect of slope length on soil erosion. The slope length is the ratio of soil loss from field slope length and soil loss increase more rapidly with slope steepness than it does with slope length. The Ls-factor result of the area is presented on Figure 5.17.

From Figure 5.17, the result of Ls-factor shows even distribution of slope steepness along each watershed. Research by Tay *et al.* (2002) shows susceptibility of soil to water erosion depends on soil length and is more prevalent in sloping area (Angima *et al.*, 2003). Also, the result of these studies suggest a curvilinear relationship between soil loss and slope steepness, with erosion initially increasing rapidly as slope increases from gentle to moderate, reaching a maximum on slopes of about 7° and then decreasing with further increases in slope. Such a relationship would apply only to erosion by rainsplash/sheet and surface runoff. It would not apply to landslides, piping or gully erosion by pipe collapse.

Again, studies of Toy *et al.* (2002) show that slope length has effect on soil loss for steep slope. Also reported that greater sensitive of slope had effects on soil loss due to differences in rainfall. Areas having about 7.39m length of cell slope length and steepness in the watershed as show on Figure 5.17, will have greater soil loss as supported by Toy *et al.* (2002), than those areas having 3m and 0m length of cell slope lenght respectively.

5.3.2.4 Conservation practice factor (p-factor) within the watershed

Conservation practice (p-factor) is the support practice factor. Reflect effect of practices that will reduced amount and rate of water runoff; hence reduce the amount of erosion (Renard *et al.*, 1997).

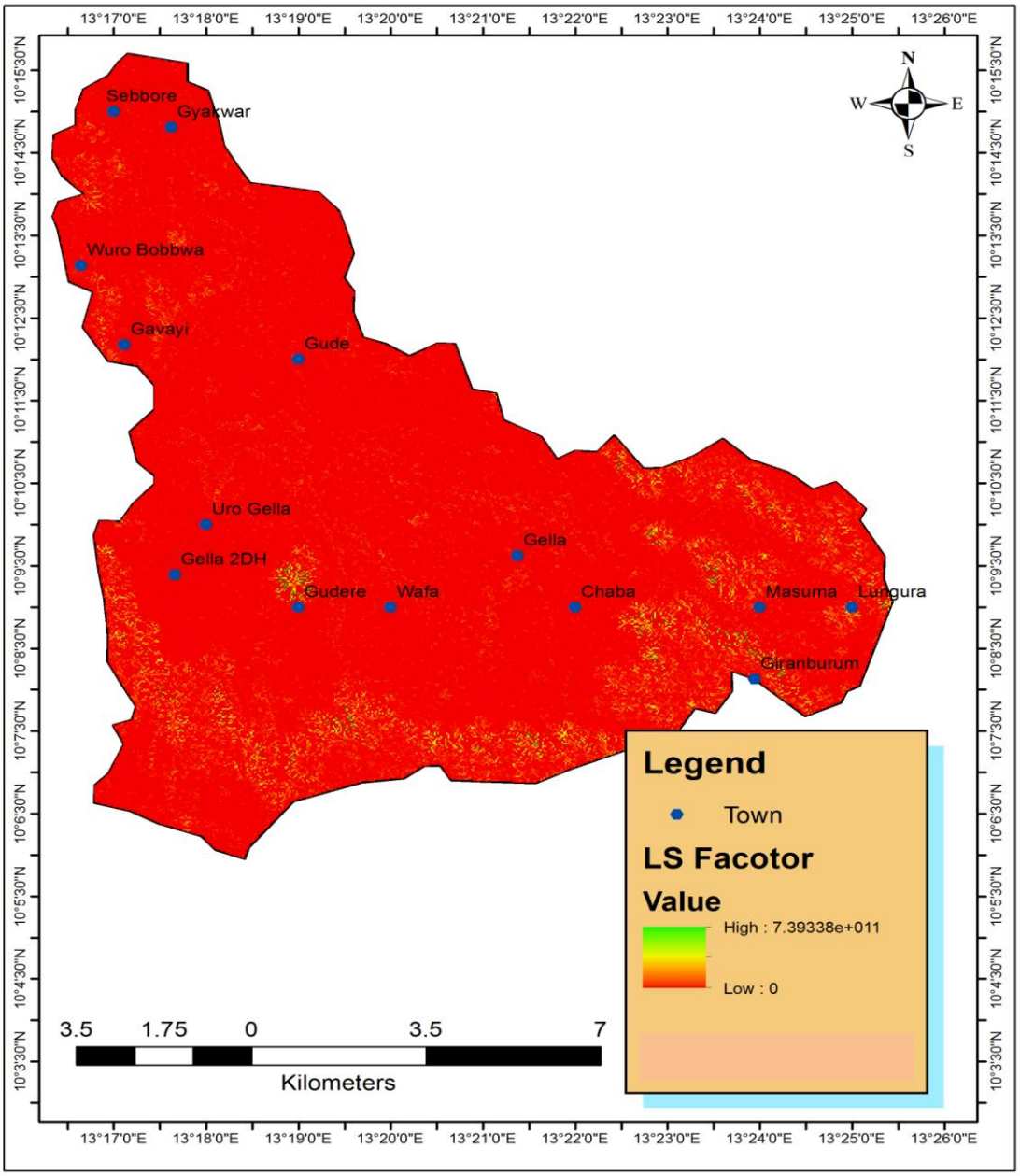


Figure 5.17:Slope Length and Steepness (LS-Factor)
Source: Author's Analysis (2016)

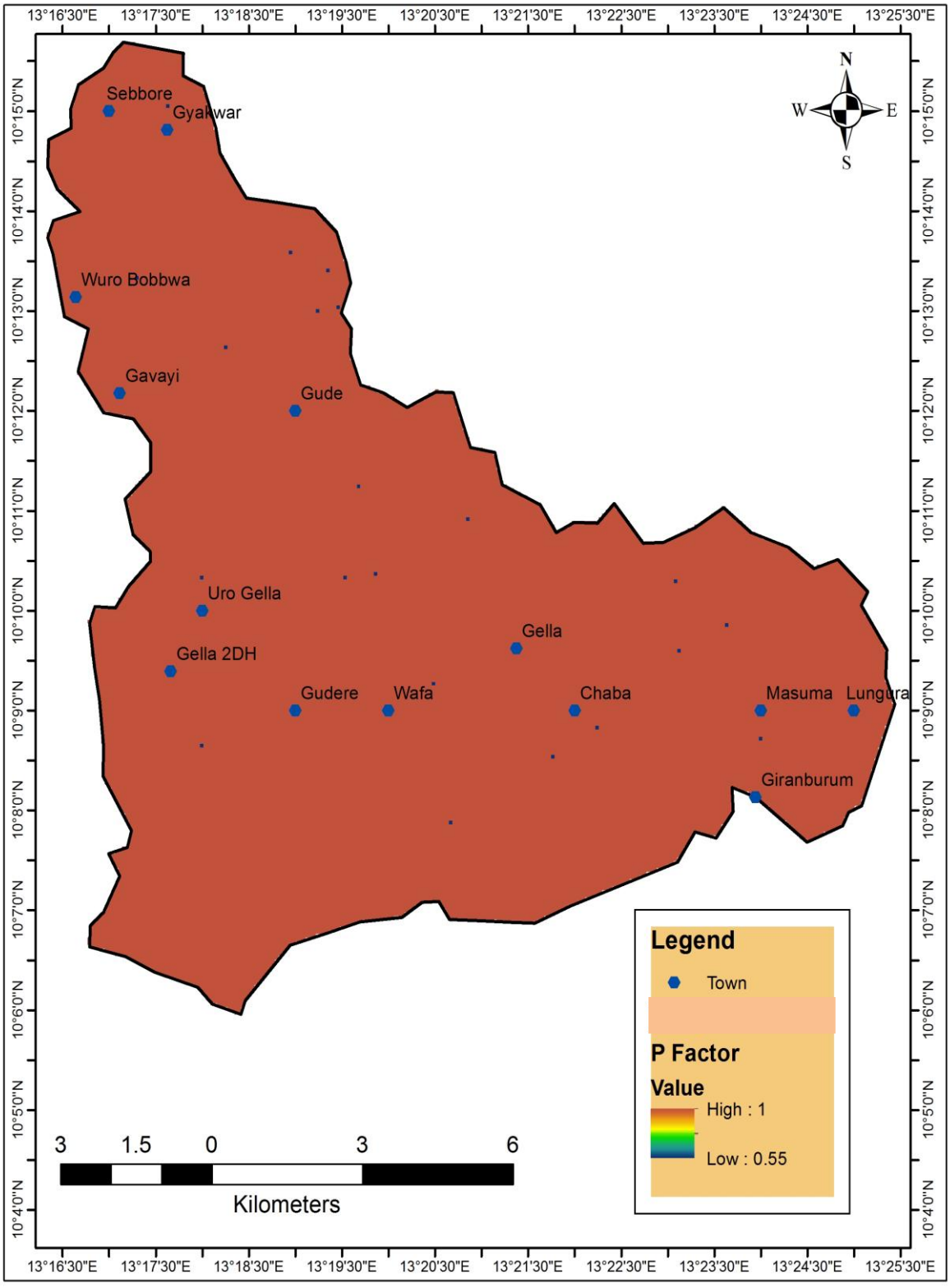


Figure 5.18:Conservation Practice Factor (P-factor)

Source: Author's Analysis (2016)

The p-factor represents ratio of soil loss by a support practice to that of straight-row farming up to down the slope. The result of the p-factor for the watershed is presented in Figure 5.18.

As shown in Figure 5.18, areas which shows the spatial distribution value of 1 from the legend show no conservation practice (deciduous forest) while the minimum value of 0.55 corresponds to built-up with strip and contour cropping as supported by Renard *et al*.(1997).The lower the p-value (0.55) as in the watershed, the more effective is conservation practice in the study area. Also, result of the practice correspond to nature and landuse landcover map of the watershed. The result also proves that practice factors supported in the watershed was contouring and contourstrip cropping with the value ranges between (0.350 – 0.600).

5.3.2.5 Rainfall erosivity (R-factor)

Rainfall erosivity is a measure of the erosive force of a specific rainfall. Rainfall is the main climatic characteristics that influence soil erosion; given the extraordinary importance of soil detachment process due to drop impact and runoff shear (Wischmeier and Smitt, 1978). Rainfall erosivity map of the watershed is shown on Figure 5.19.

As shown in Figure 5.19, spatial distribution of rainfall map of the watershed indicates that it ranges between 481m to 192m. It also shows that the rainfall is higher towards northwest of the watershed and the area of higher rainfall were in the mountainous area of the watershed along Masuma and Lumgura which shares boundary with the Republic of Cameroon.

The spatial distribution of five factors map produced were used as input for derivating GIS-based RUSLE and also served as input for some of the RMMF model.

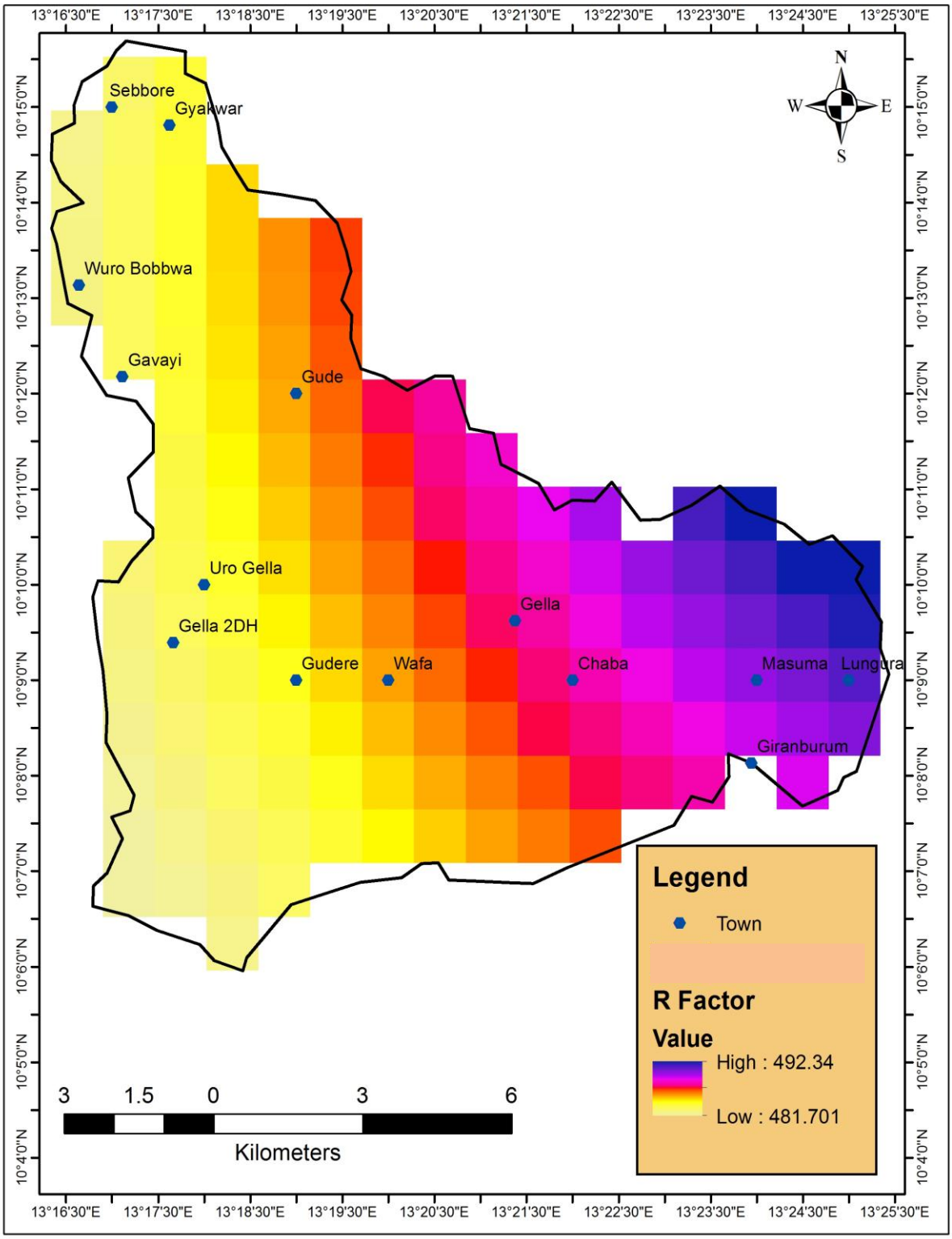


Figure 5.19: R-Factor

Source: Author's Analysis (2016)

These analyses explored the importance of GIS and remote sensing in integrating both spatial and non-spatial data/information; hence the needs for the technique in assessing and analyzing spatial distribution of soil erosion data. Results obtained were used as input in estimating rate of soil erosion in objective four of this study.

5.3.2.6 Spatial distribution of hydrophysical parameters in the watershed

The result of soil analysis obtained from field and analyzed in laboratory were also encoded in ArcGis 10.3 environment so as to assesse spatial distribution of hydrophysical parameters presented as a map for further interpretation and discussions.

The hydrophysical parameters were used as impact for Revised Morgan Finnery model and the results were presented in Figure 5.20 to Figure 5.33. All result obtained from the laboratory were interpolated and presented as a map showing their spatial distribution.

5.3.2.7 Bulk Density

Bulk density is an indicator of soil compaction and soil health, affects infiltration, rooting depth/restriction, available water capacity, soil porosity, plant nutrient availability and soil micro-organism activity, which influence key soil processes and productivity (USDA, 1978). The spatial distribution of bulk density of the study area is presented in Figure 5.20.

As shown of Figure 5.20, spatial distribution of bulk density ranges from 1.38Mgm^{-3} to about 1.88 Mgm^{-3}in the watershed. Most of the study area had bulk density which ranging between 1.47$Mgm^{-3}$to 1.55 Mgm^{-3}, especially in towns like Masuma, Langura, Giranburam,

Gella and Uro Gella. Also, bulk density ranges between 1.47 $Mgm^{-3}$to 1.69 Mgm^{-3}were mostly obtained within Luvisol and Regosol soil group in the watershed.

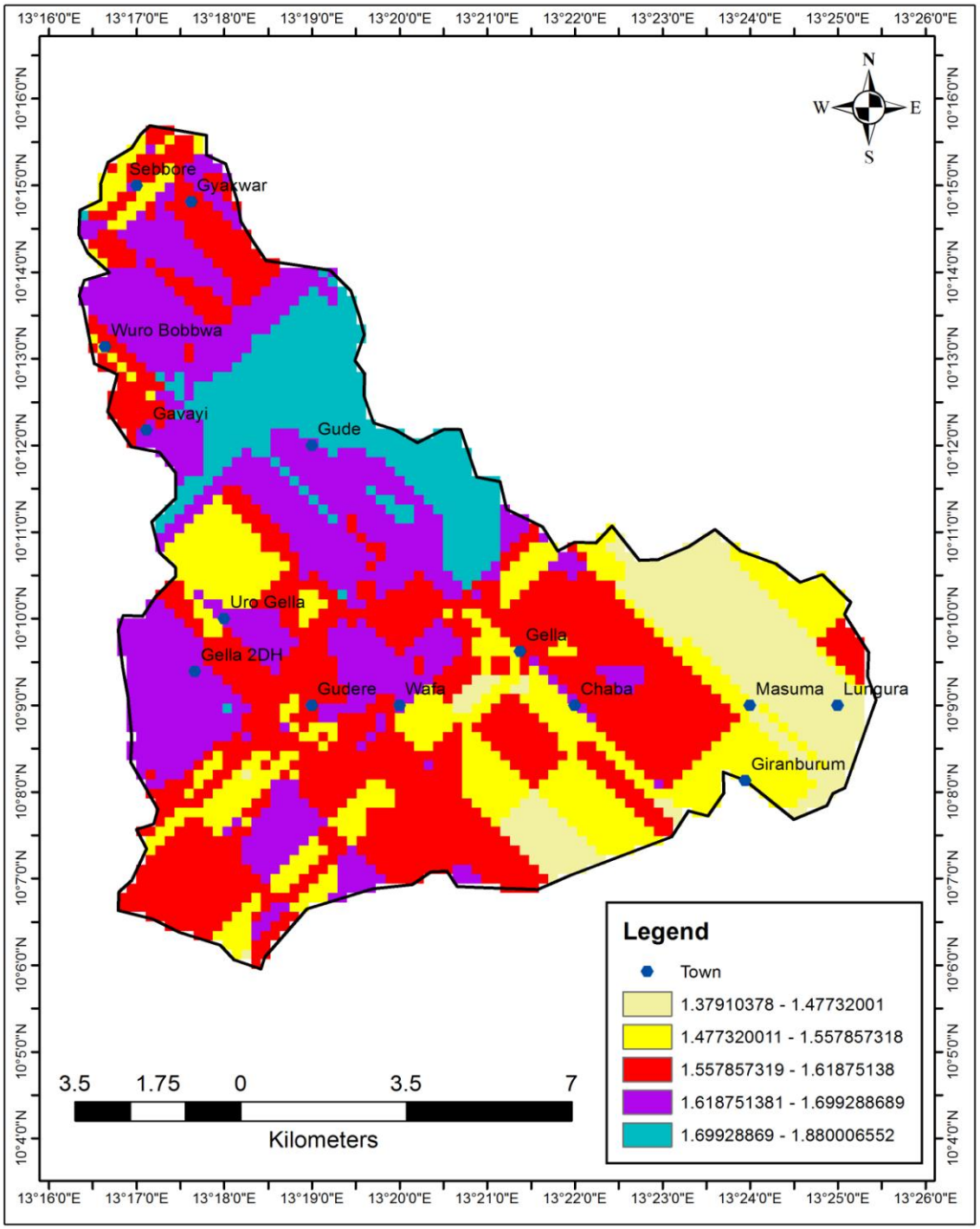


Figure 5.20: Bulk Density

Source: Author's Analysis (2016)

Again, Gude areas had higher concentration of bulk density of between 1.69 to 1.88Mgm^{-3}. This finding attributed to effect of soil type, vegetation, soil texture, in significantly determing bulk density spatial distribution in the study area.

Agricultural land had low density in the watershed and research showed that excessive tillage destroys soil organic matter and weakens natural stability of soil aggregates making them susceptible to erosion caused by water and wind as supported by USDA (1978). Moreover, changes in spatial distribution of bulk density in the study area was due to management practices in the watershed that affected soil cover, organic matter, soil structure, compaction, and porosity as also supported by USDA (1978). Also, the watershed area had average bulk density of 1.64Mgm^{-3}.

5.3.2.8 Soil organic matter content

Soil organic matter served multiple functions in the soil, including nutrient retention, water holding capacity, soil aggregation and is the key indicator of soil quality (Brandy and Weil, 1999)

Figure 5.21 shows spatial distribution of soil organic matter in Mubi South watershed. From result obtained in Figure 5.21, organic matter was higher along the Arenosol; which had higher concentration of clay and ranges from 12.3 gkg^{-1}to 13.7 gkg^{-1}.

The spatial distribution of soil organic matter ranges between 8.4 gkg^{-1}to11.3 gkg^{-1}in Luvisol and Regosol soil group of the study area. Soil erodibility decreased linearly with increasing organic matter content over the range of 0–10% as suggested by Voroney *et*

al.(1981), whereas Ekwue (1990) stated that soil detachment by raindrop impact decreased exponentially with increasing organic content over a 0–12%.

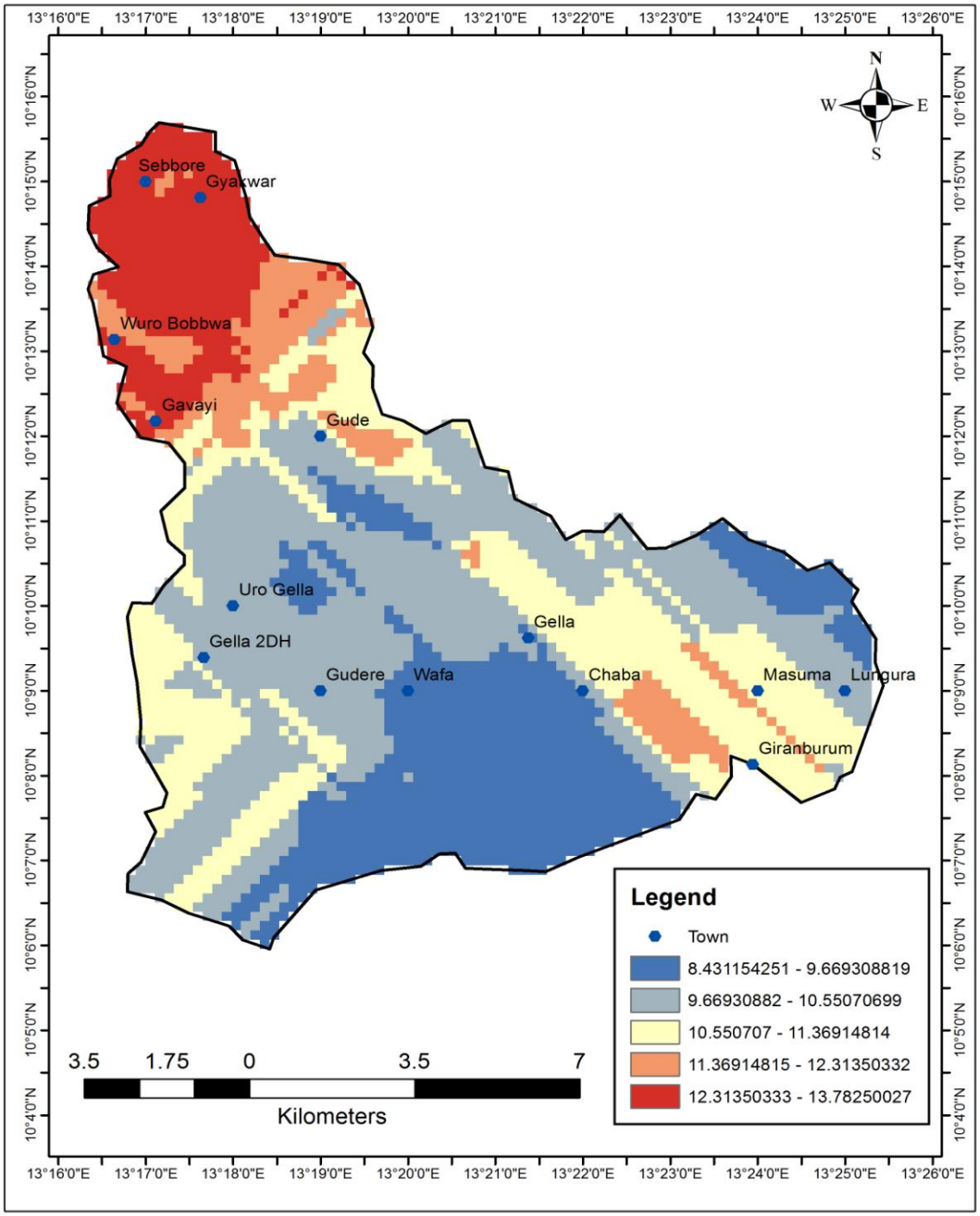


Figure 5.21: Organic Matter Content

Source: Author's Analysis (2016)

Moreover, the low soil organic matter in the watershed was a result of continuous tillage of land for agricultural activities.Landuse and landcover where soil organic matter is low are predominantly agricultural and arable land. This finding was supported by USDA (1978)which stated that the practice of continuous tillage (i.e tillage for six years or more) tend to reduce organic matter content of soil unless appropriate management practices are implemented to reverse this trend. Factors influencing rate of decline of soil organic matter levels include soil type and physical properties, climate, topography, vegetation and land management practices (Brandy and Weil, 1999).

5.3.2.9 Spatial distribution of particle density

The soil particle density represente average density of all mineral composion in the soil.Value obtained was; perhaps because quartz dominates the soil fraction. Particle density of quartz is given as 2.65 Mgm^{-3}.

The spatial distribution of particle density in the study area is shown in Figure 5.22. Figure 5.22 shows that spatial distribution of particle density. Luvisol and Arenosol soil group had particle density ranged between 1.68 $gkg^{-1}$to 2.47 gkg^{-1}towards Northwest and Southwest of the watershed which constitutes a larger proportion of the area.High value range of between 2.47 gkg^{-1} to 3.02 gkg^{-1}were distributed within Regosol soil group of the watershed, mostly found along southeast of the study area.

5.3.2.10 Spatial distribution of soil aggregate stability

The space between aggregate provide pore space for retention and exchange of air and water (USDA,1978). Figure 5.23 shows result of spatial distribution of soil aggregate stability in the study area.

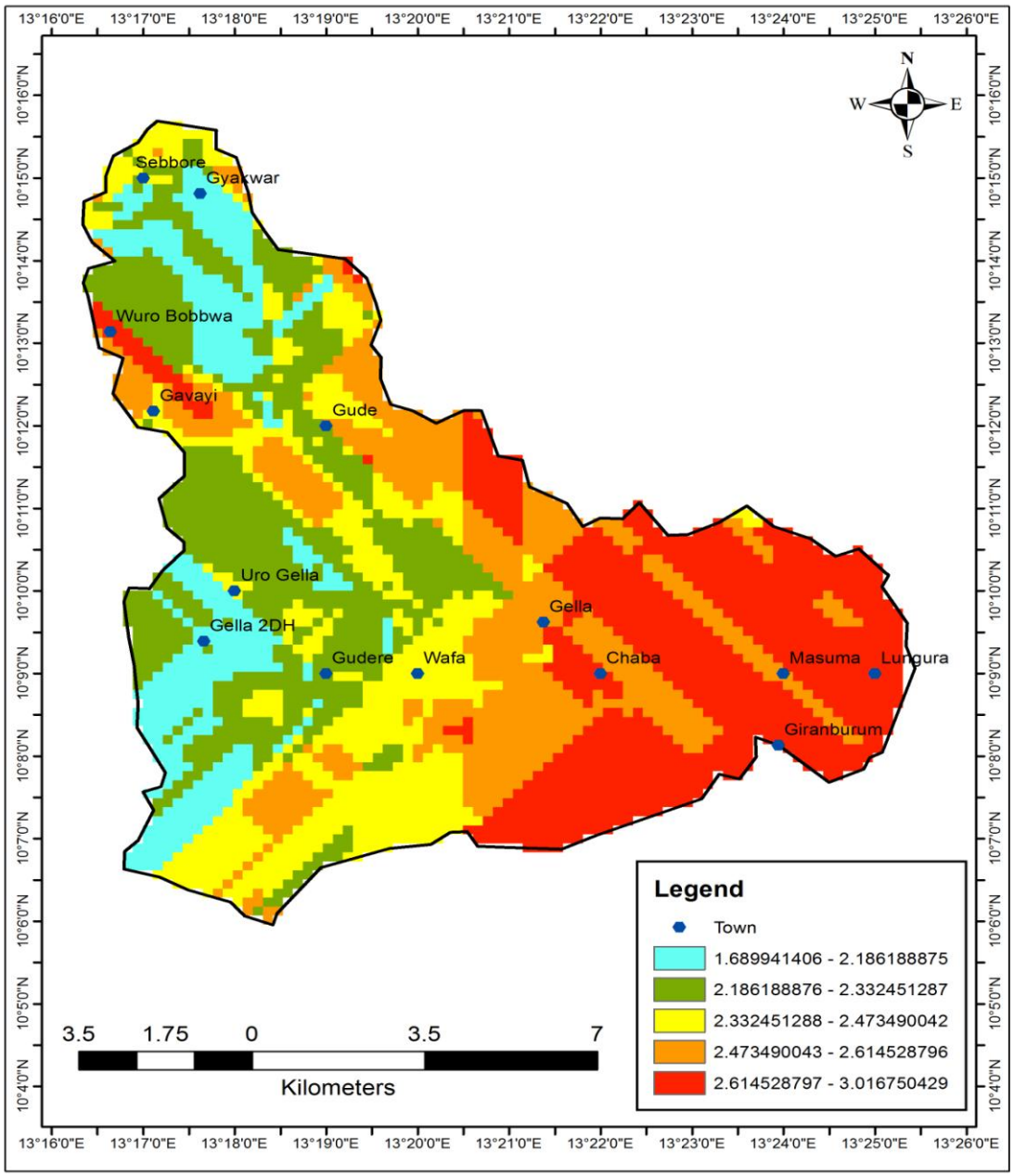


Figure 5.22: Particle Density
Source: Author's Analysis (2016)

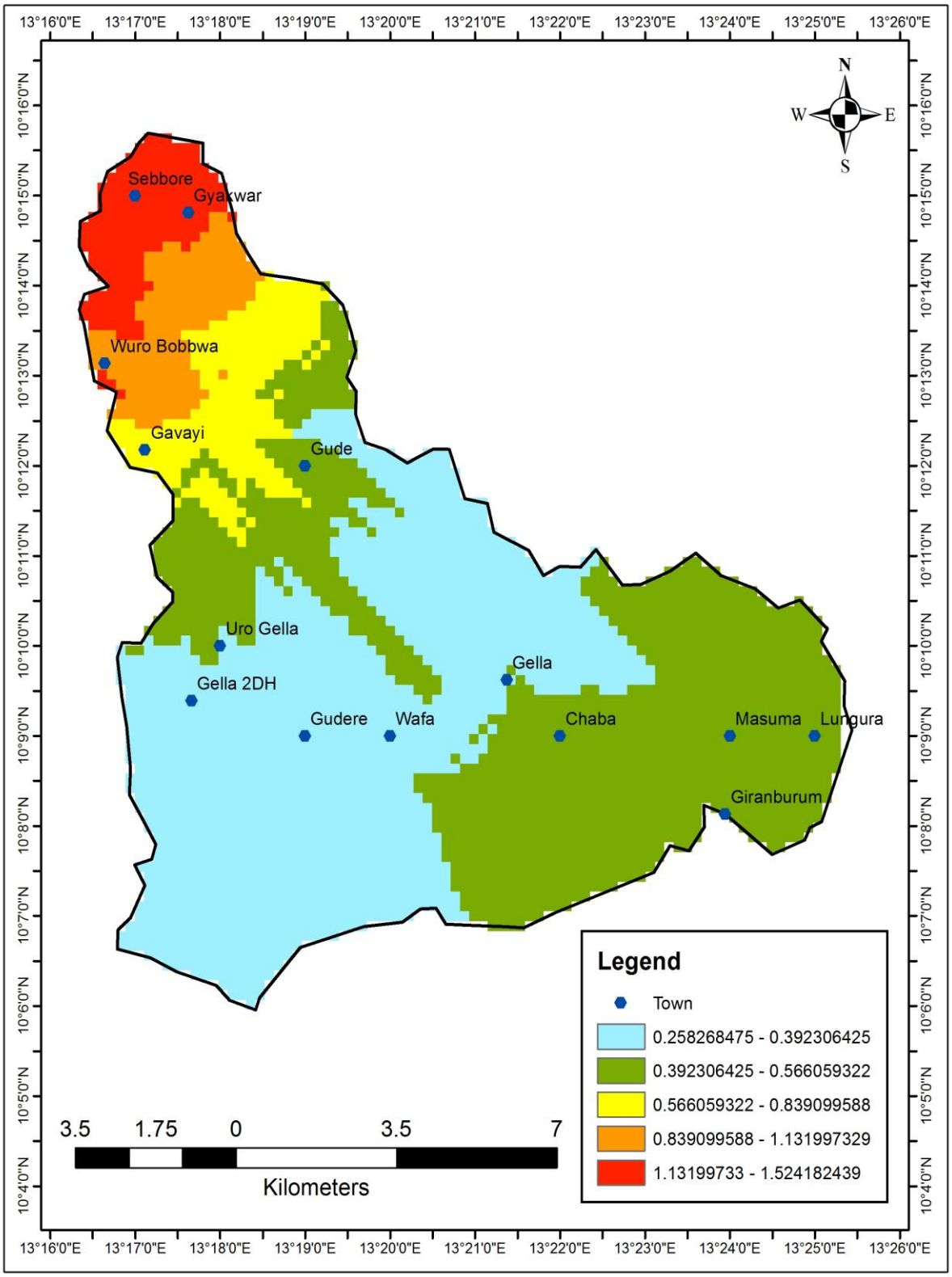


Figure 5.23: Soil Aggregate Stability

Source: Author's Analysis (2016)

As shown on Figure 5.23, the area of higher of aggregate stabilityvalue ranged between 1.13g\cm^3 to 1.52g\cm^3 facilitate free-water drainage, aeration, evaporation, and gas exchange. These higher values were as the result of high clay content in the watershed because research has shown that clays promote aggregation but can also be readily compacted. The presence of the high clay also increases water storage by providing an aboundance of pore space as shown on the southwest and southern part of the watershed of the study area; ranges between 0.25g/cm^3 to 0.56g/cm^3. The study area also shows the evidence of micro pose range between 0.56g/cm^3 to 0.83g/cm^3 which is located at the pour point of the watershed along the Northern part which has the predominant of Arenosol soil group. It was also found that the location/distribution of micro pose is characterized by the Regosols and Luvisols soil group of the watershed area. The concentration of organic matter affects the spatial distribution of porosity through enhancement of soil aggregate.

5.3.2.11 Spatial distribution of soil porosity

Soil porosity is the amount of the pore volume of soil. A medium textured, well aggregated soil contains about 50% pore space and is a good condition for plant growth when pore holds egual distribution of air and water(Lafe-ber, 1965). Figure 5.24 shows soil porosity distribution of the study area.

Figure 5.24 shows that soil porosity of the study area wasstronger between Luvisol and Arenosol soil group and had the valuesbetween 0.29 mm to 0.58 mm, while it were lower in Regosol soil group in the watershed respectively.

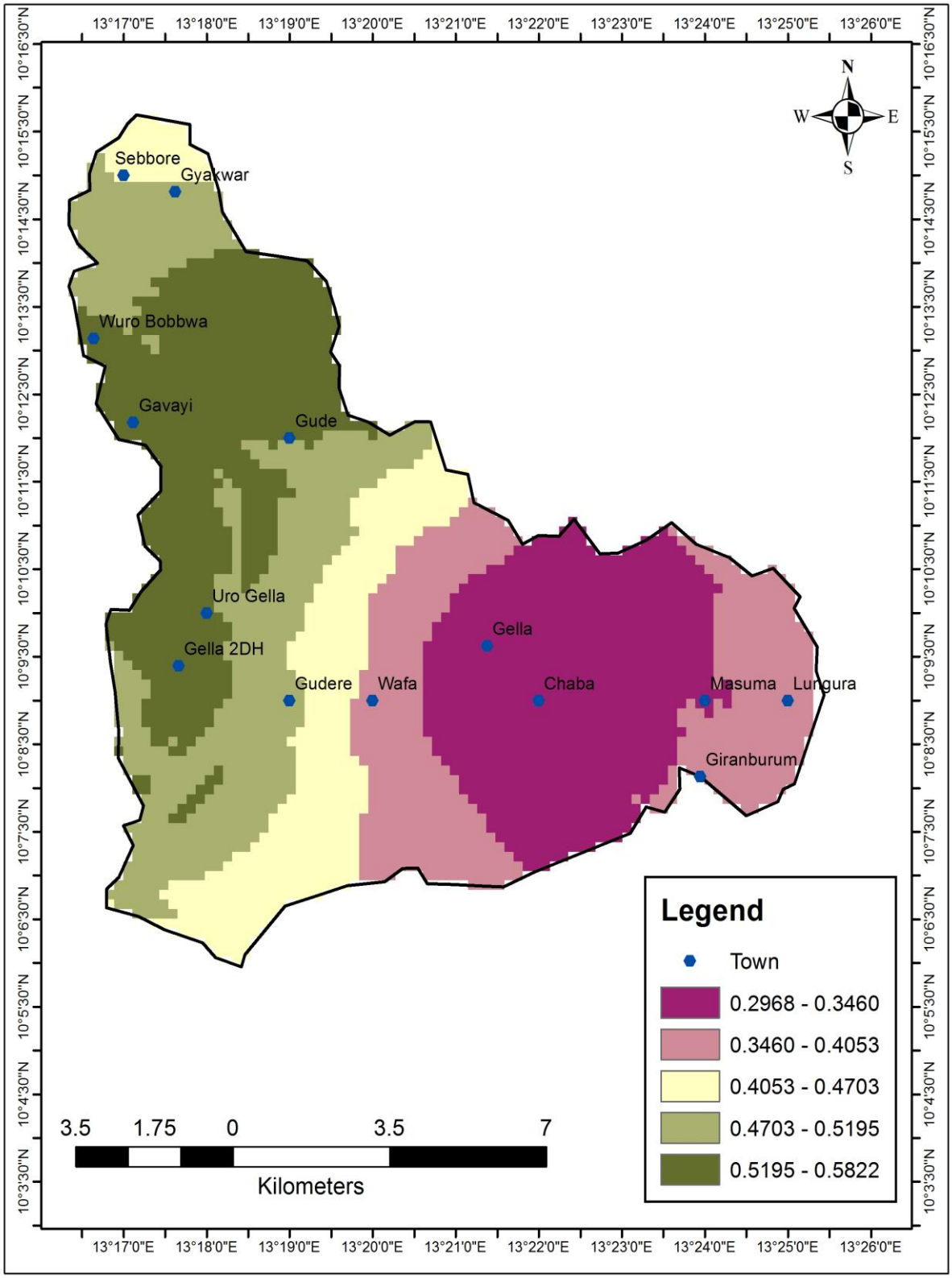


Figure 5.24: Soil Porosity

Source: Author's Analysis (2016)

Also observed was that the soils contained kaolinite and fine-grained mica minerals in the Northern part of the watershed.These were resistant to expansion on wetting, have low levels of erodibility, whereas smectites swell on wetting and therefore have a high erodibility especially at the foot of the mountainous region. The loss of grass cover also led to a decline in organic matter and deterioration in aggregate stability of the soils (Franke and Chasin 1981). Spatial distribution of vegetation as shown in Figure 5.05 affect distribution and concentration of soil aggregate stability in the study area andwas supported by several studies (Burrietal, 2009;Bronick and Lal, 2005). Study by Burri*et al.* (2009) showed that development of vegetation coverhas beneficial effect on the stability of soil aggregation. Plants' roots enmesh soil particles and release exudates, resultingin physical, chemical and biological interactions influencing soil aggregate (Bronick and lal, 2005). Also, Bronick and Lal (2005) pointed out that soil aggregation stability increase root length density, microbal association diversity and percent cover (Rillig *etal.,* 2002).

5.3.2.12 Spatial distribution of soil moisture at field capacity and wilting point

Soil holds different amount of water depending on their texture and structure. The spatial distribution of the laboratory result obtained for soil moisture at field capacity and wilting point is shown in Figure 5.25.

As shown in Figure 5.25, the upper limit of water holding capacity (0.21 to 0.29) is often called field capacity, while the lower limit (0.14 to 0.17) soil moisture content is the permanent wilting point.From Figure 5.25, it could be inferred that there was rapid down word movement (drainage) of soil water due to gravitational force and soil moisture

decreased continuously. This shows that drainage was faster for sandy soils compare to clay soil.

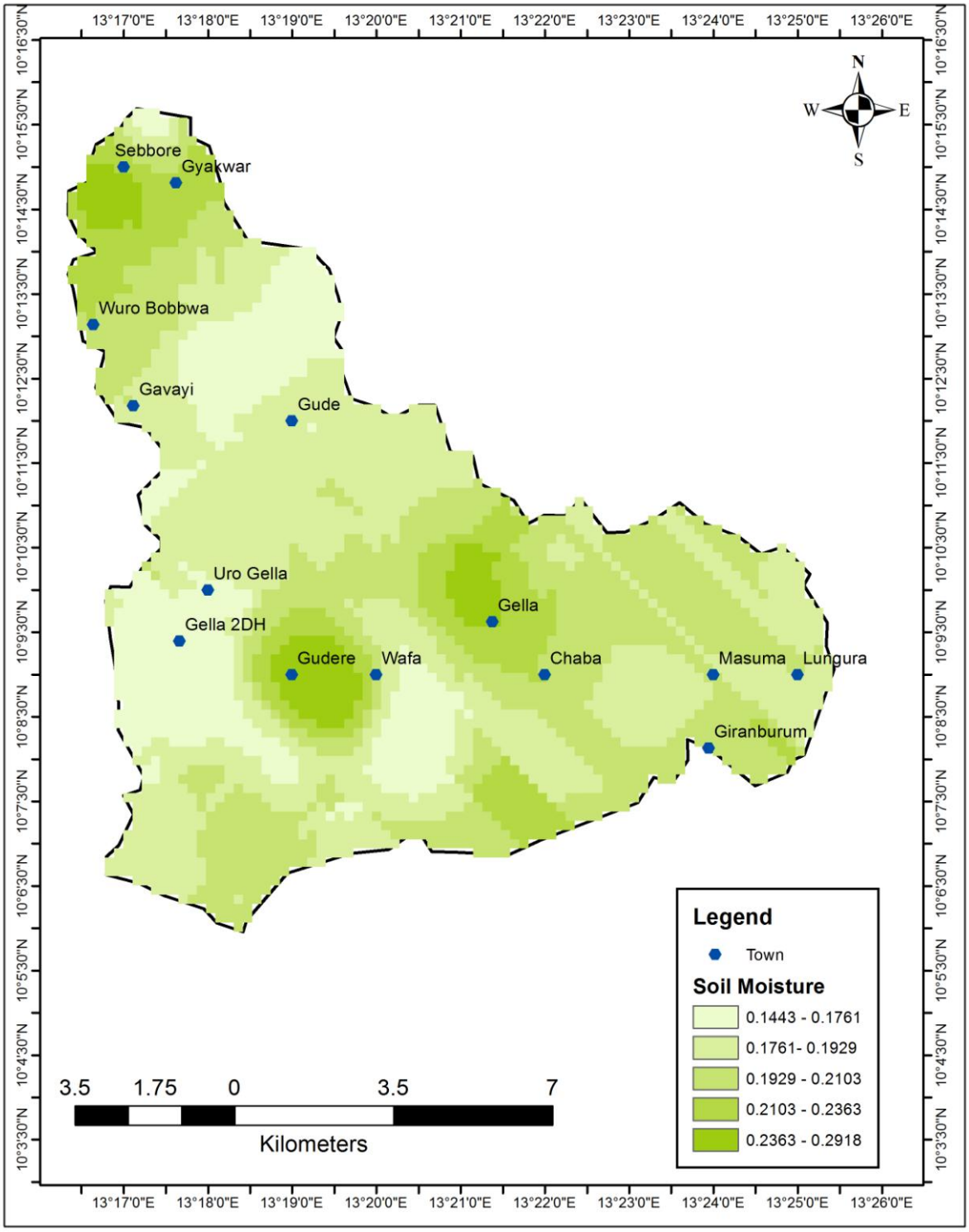


Figure 5.25: Soil Moisture Content at Field Capacity Melting Point
Source: Author's Analysis (2016)

This was also similar to result of soil moisture content as shown in Figure 5.27 of the watershed. Figure 5.27 reveals that higher value of soil moisture were obtained in areas predominated by high clay content in the study area, with about 0.3 %to o.49% moisture content at field capacity in Pediplain of the watershed. Moreover, soil moisture or spatial distribution of soil moisture at field capacity as presented on Figure 5.27 shows that values range between 43.07 %to 47.56%. This shows that soil moisture at field capacity varie due to nature of topography, land use, as well as soil type.

Again, soil moisture content was tested in the laboratory and the result presented in Figure 5.28. Soil moisture content (also referred to as water content) is an indicator of amount of water present is the soil. By definition, is the ratio of mass of water in a sample to the mass of solids in the sample (ASTM, 2001).

The surface soil moisture plays a key role to understand the exchange of water and heat energy between land surface and atmosphere through evaporation to evaluate soil trafficability,characterize plant health (Lambers *et al.*,2008) or soil texture (Nocita *etal.*, 2013).

5.3.2.13 Spatial distribution of rainfall per day

Though rainfall factor has been mapped and used as an input for deriving RUSLE, the amount of rainfall per day is also mapped from rainfall factor map, so as to show their spatial distribution in the watershed and also to be used as input data for deriving RMMF model. The result for spatial distribution of rainfall per day is presented in Figure 5.29.

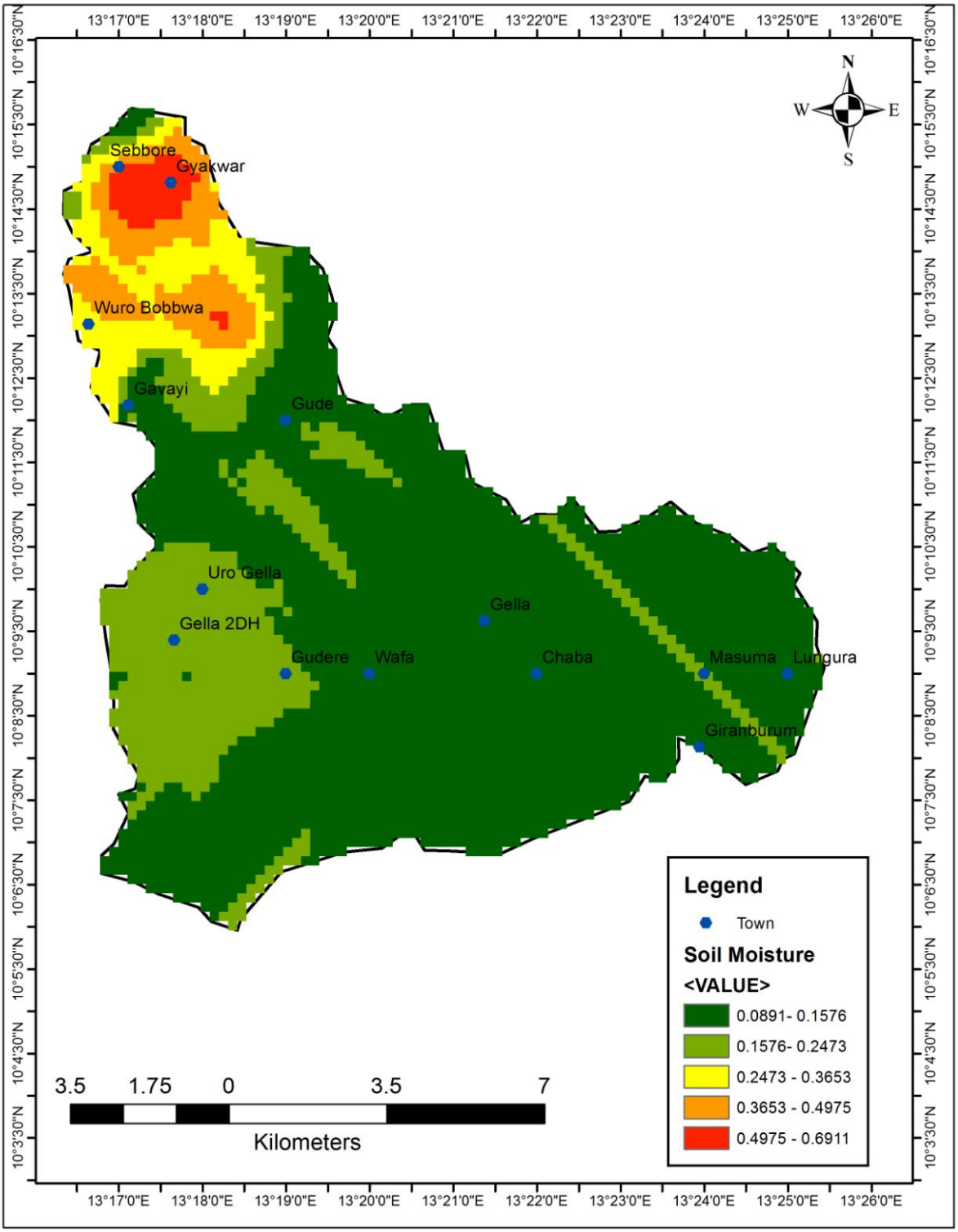


Figure 5.26: Soil Moisture Content Gravitational Capacity

Source: Author's Analysis (2016)

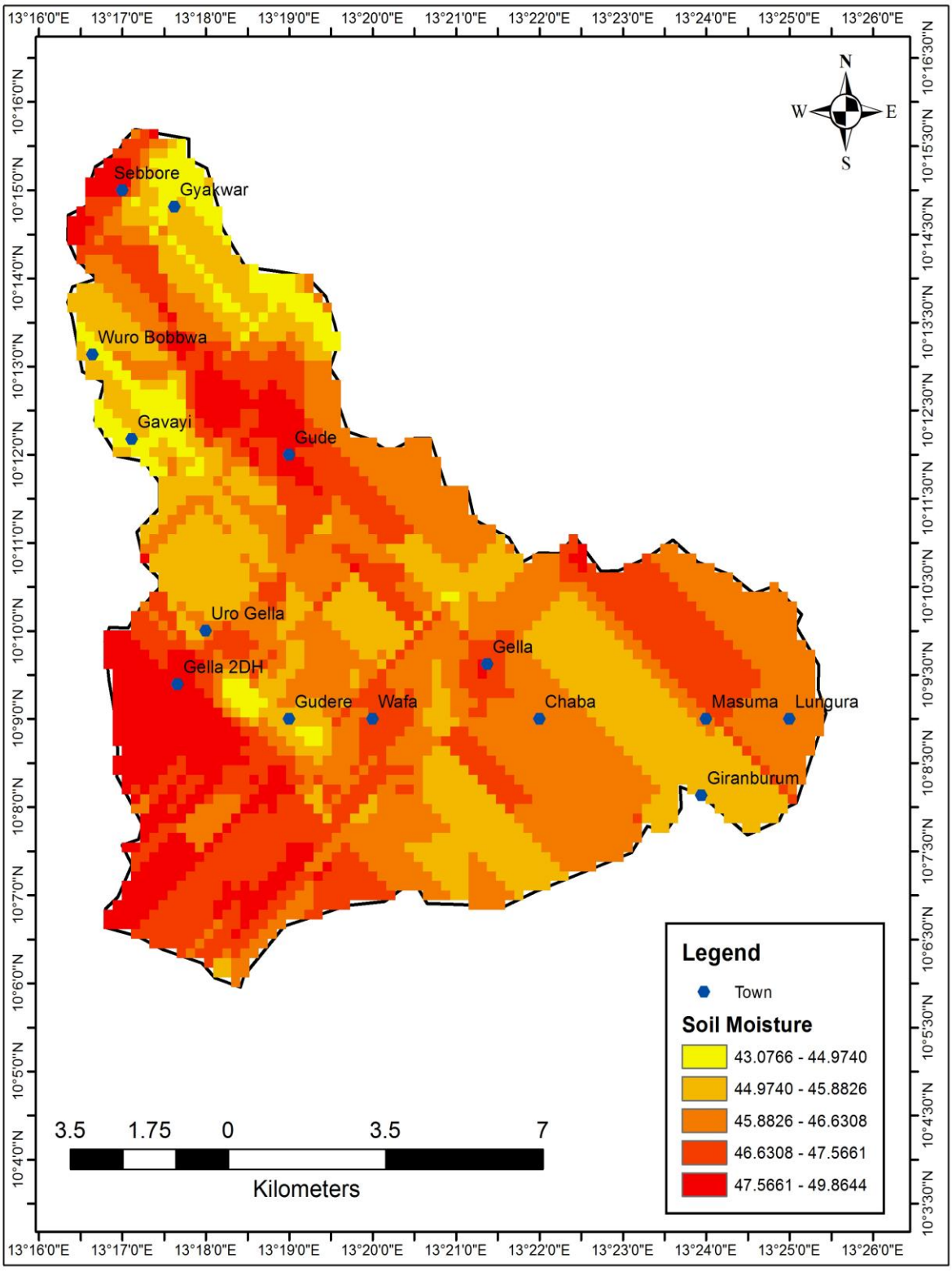


Figure 5.27: Soil Moisture Content at Field Capacity

Source: Author's Analysis (2016)

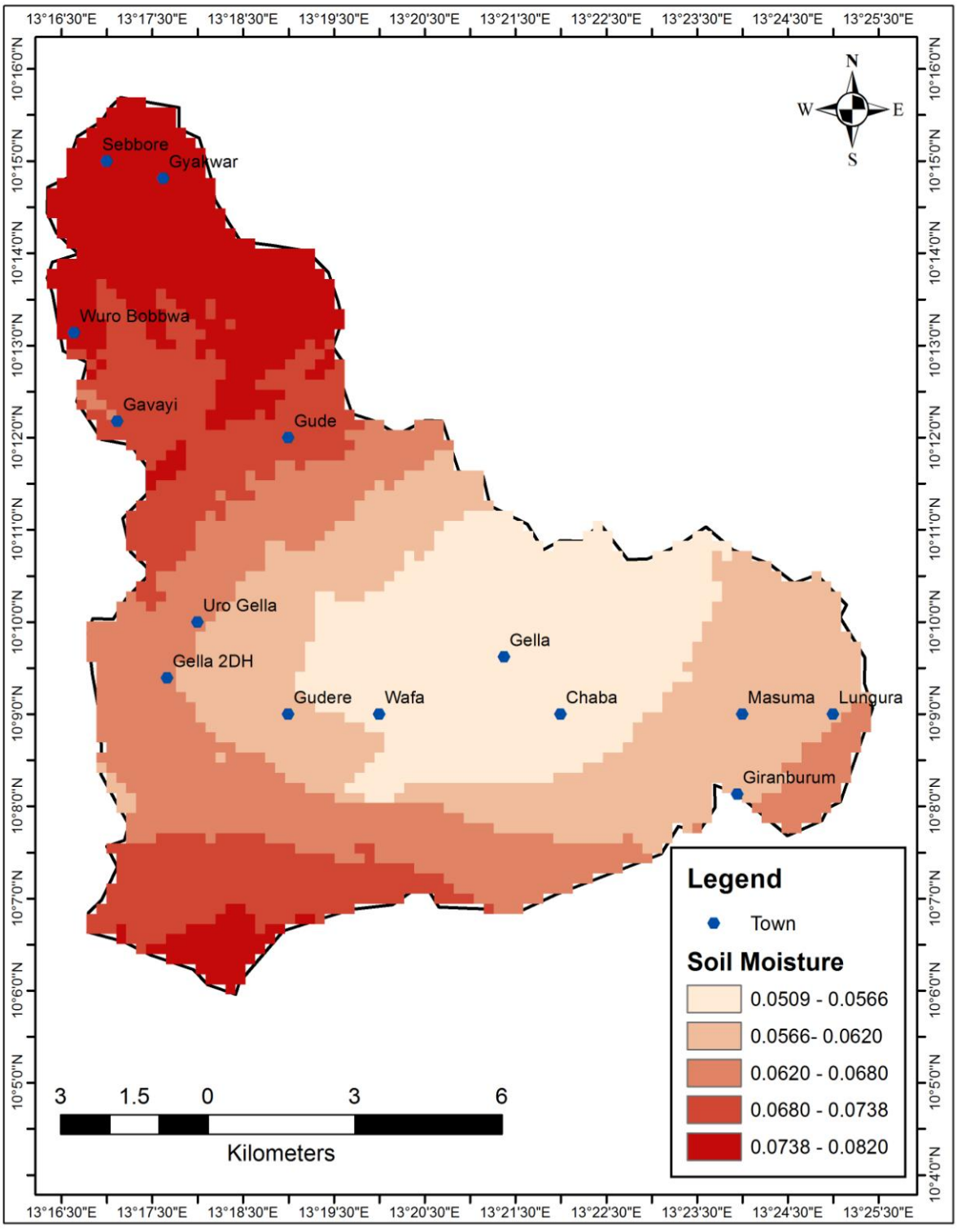


Figure 5.28: Soil Moisture Content Wilting Point

Source: Author's Analysis (2016)

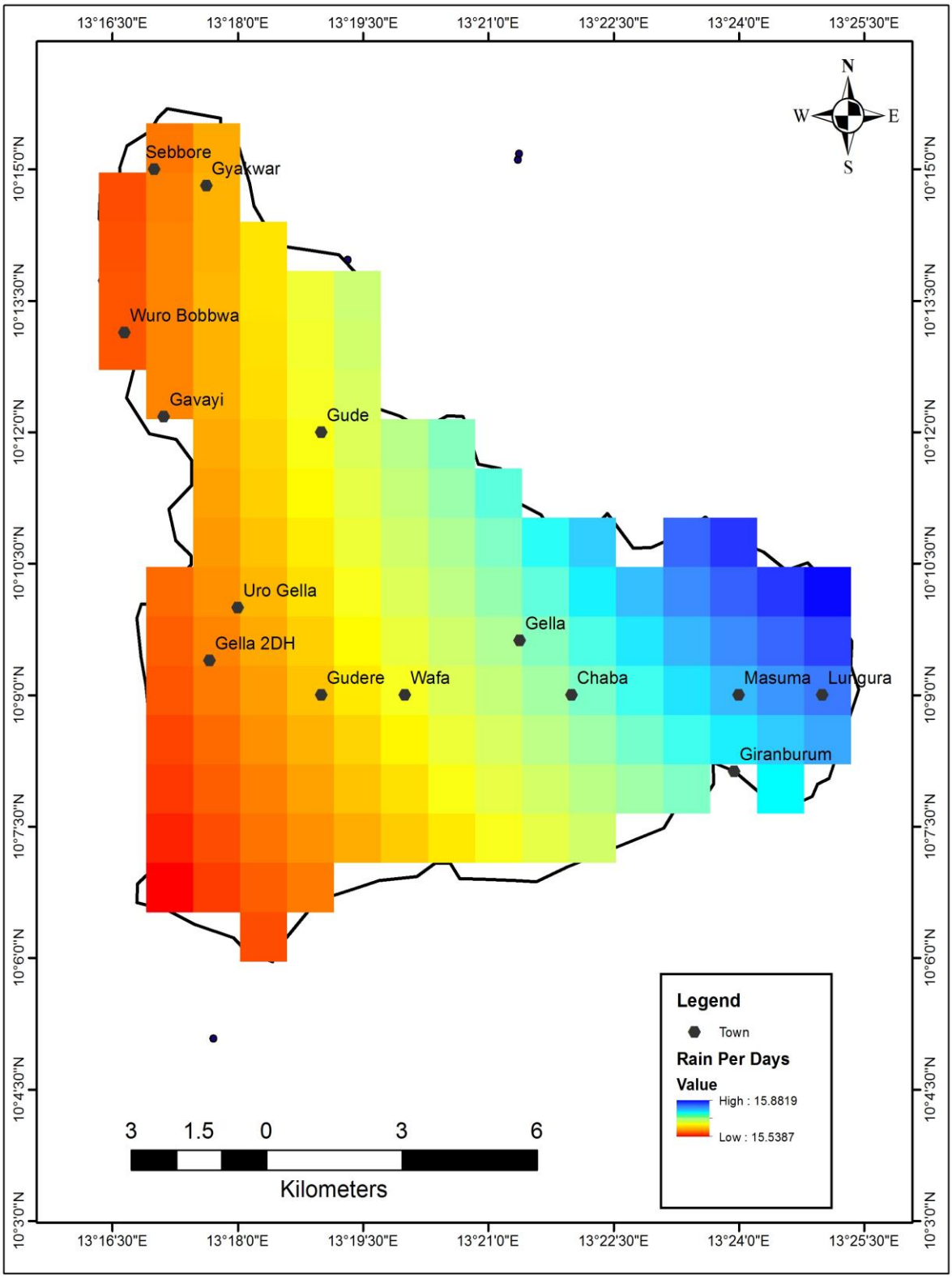


Figure 5.29: Rainfall Per Day

Source: Author's Analysis (2016)

Figure 5.29 reveals that there was high concentration of rainfall in Gella, Ghaba, Masuma, Lungura and Girambunm towns, which are located in the southeast and mountainous region of the watershed. Also,West part of the study area wascharacterized with about 15.5mmlow concentration rainfall daily. These finding shows that the higher the topography, the higher the daily amount of rainfall in the watershed and vis-visa.

5.3.2.14 Spatial distribution of effective hydrological top soil depth

The effective hydrological top soil depth is the depth of soil from the surface to an impermeable or strong layer to base of A horizon or to dominant root base. Figure 5.30 shows the result of spatial distribution of effective hydrological top soil depth obtained in the watershed.

Result in Figure 5.30 shows that depth of the soil was mostly low in the study area and range from low to medium in the area dominated by Regosol, while medium to higher value (7.9 m to 8.8 m) dominate the Luvisol and Arenosol soil group. This so because changes in rainfall pattern, changes in the vegetation and chane in agricultural activities influenced effectiveness of hydrological top soil and the study area was not exception of these changes as supported (FAO, 1980). Relationship between soil physical characteristics and soil hydrological properties are the beginning point to simulate or to predict dynamic soil degradation/erosion process and their effects as supported by Larson and Piece (1991).

5.3.2.15 Potential evapotranspiration

The result obtained for potential evapotranspiration was used in mapping its spatial distribution in the watershed as shown in Figure 5.31.

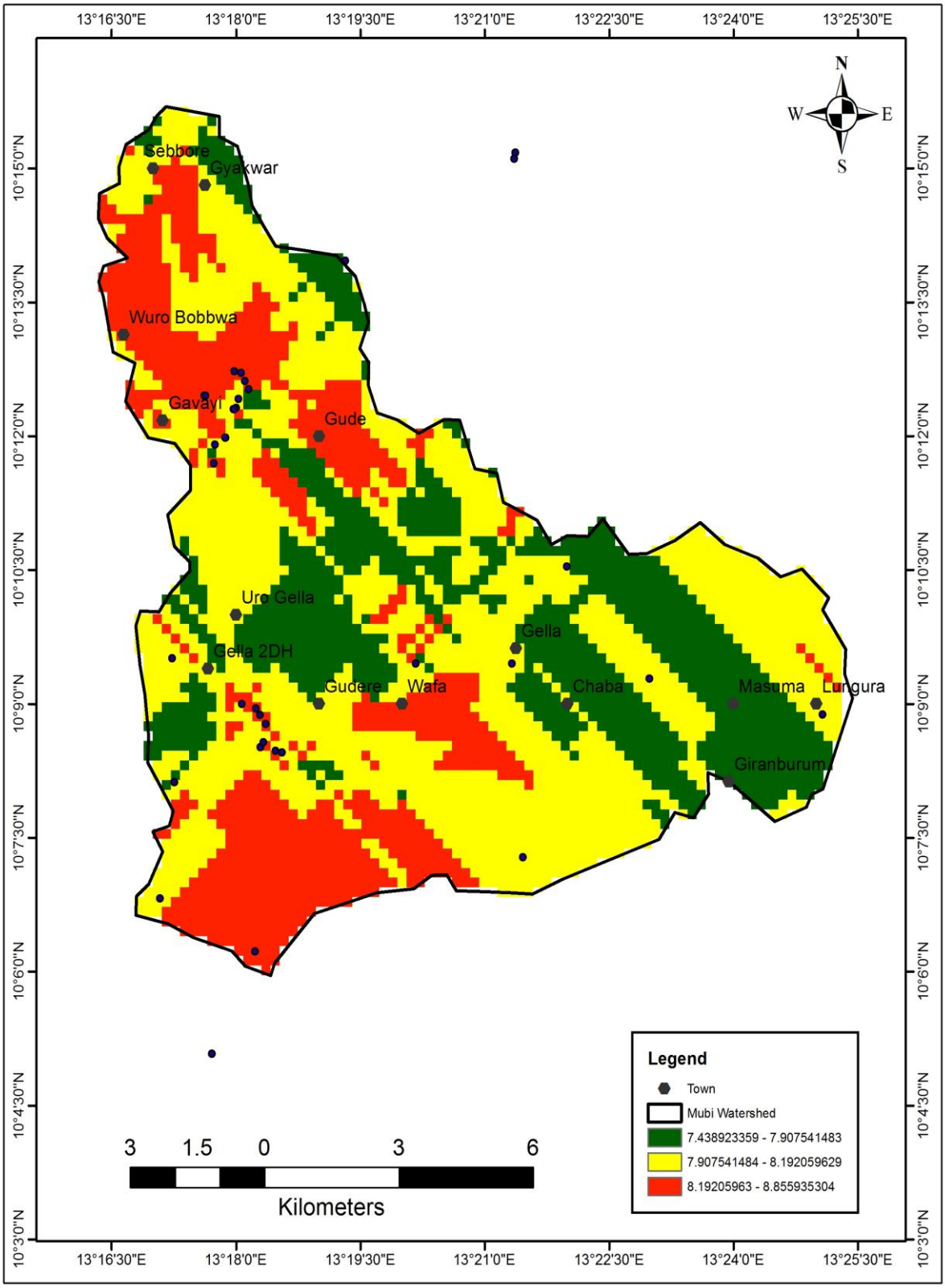


Figure 5.30: Effective Hydrological to Depth of the Study Area
Source: Author's Analysis (2016)

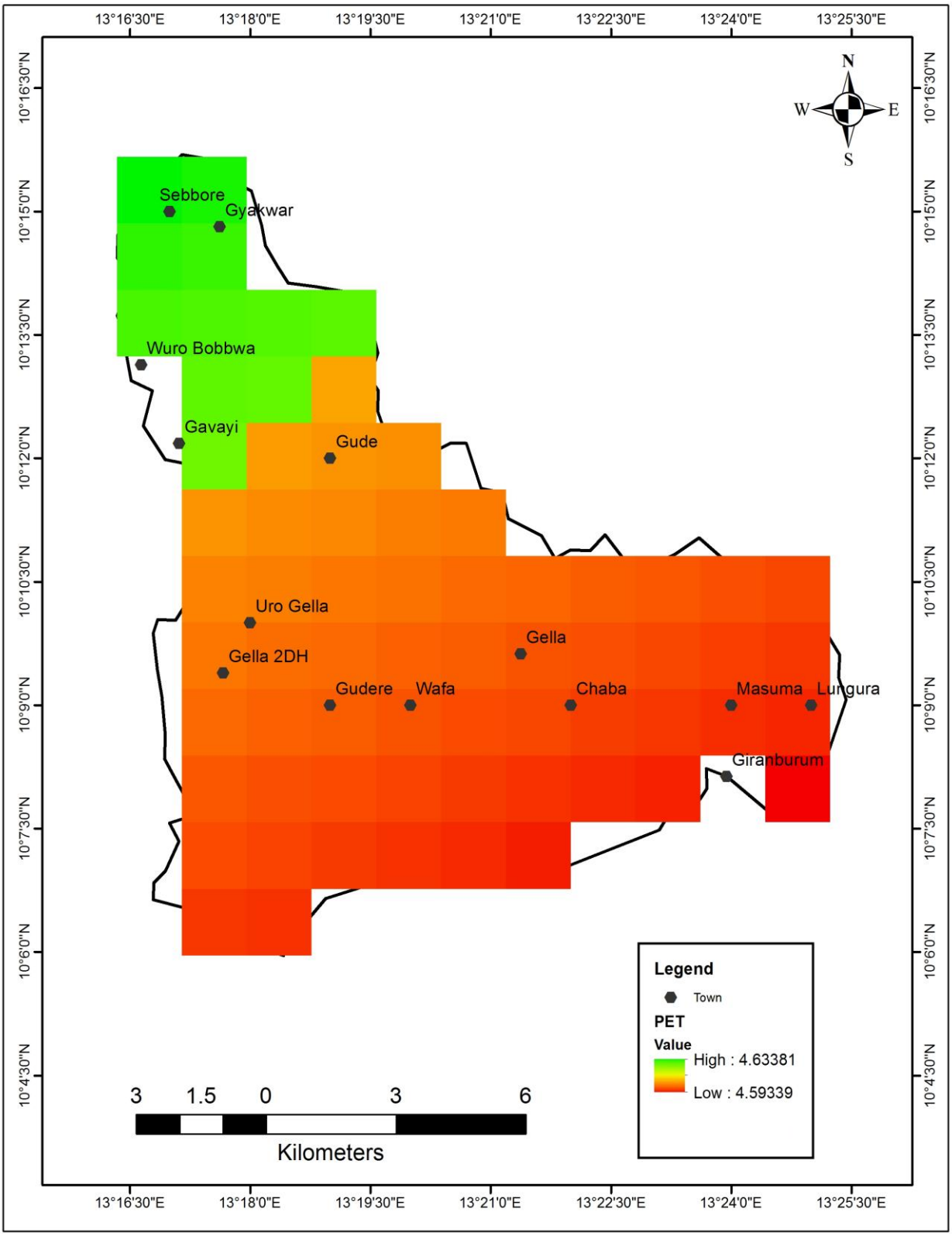


Figure 5.31: Potential Evapotranspiration of the Study Area

Source: Author's Analysis (2016)

As presented in Figure 5.31, it was observed that the study area had 4.5 m to 4.6 m rate of potential evapotranspiration. Most of the study area was characterized with about 4.5 m of everpotranspitaion. The presence of higher value of 4.6 m everpotranspitaion in the Northern part of the study area, this was major source of water in to the watershed.

5.3.2.16 Crop cover management factor

Crop cover management was also used in deriving RUSLE but different approaches were used in obtaining the crop cover management factor used in RMMF model. Result presented in Figure 5.32.The result for spatial distribution of crop cover management factor presented in Figure 5.32 shows that the management factor range from higher value of about 0.5 to lower value of 0.01. The higher value of 0.5 was observed along major water channels of the watershed. Value of 0.01 was found within mountainous areas, built-up areas and bare land surface of the watershed. These show that the nature of land uses and topography determined spatial variability of crop cover management in the study area.

5.3.2.17 Soil moisture storage capacity

The result for spatial distribution of soil storage capacity is presented in Figure 5.33. Figure 5.33 indicates that there is higher moisture storage capacity in the clay soil than in the silt and sandy. Also, high concentration of the soil moisture storage capacity in the Northern part was due to the fact that the area is the major source of water in the reserves, which has some vegetation and forest and not a predominant agriculture land use.All spatial distributions of the geomorphological factors and hydrophysical parameters of soils were

used as major data input in achieving goals of the study. All of these are linked together as cycle of assessing, analyzing and predicting soil erosion risk with geospartial techniques.

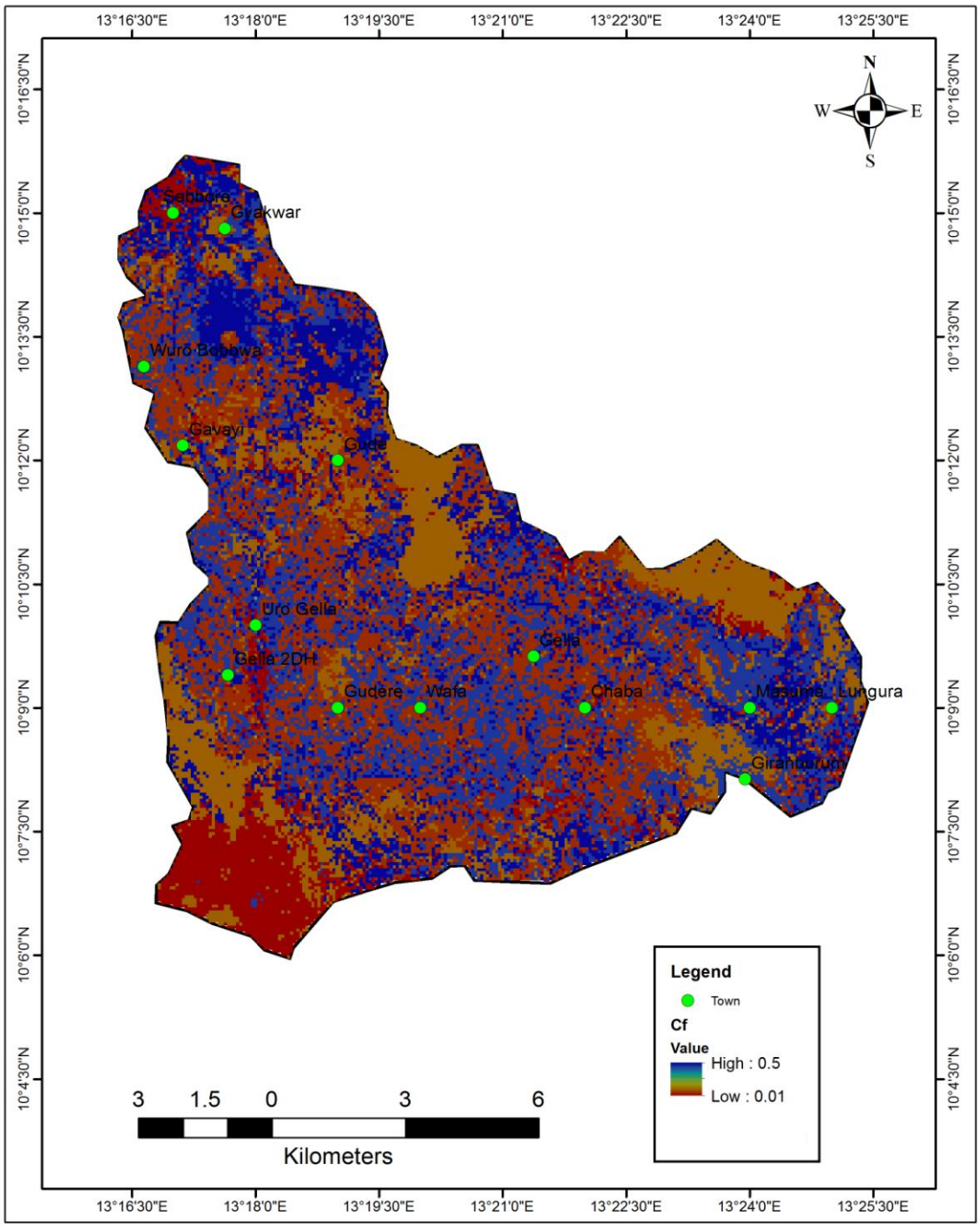


Figure 5.32: Crop Cover Management Factor

Source: Author's Analysis (2016)

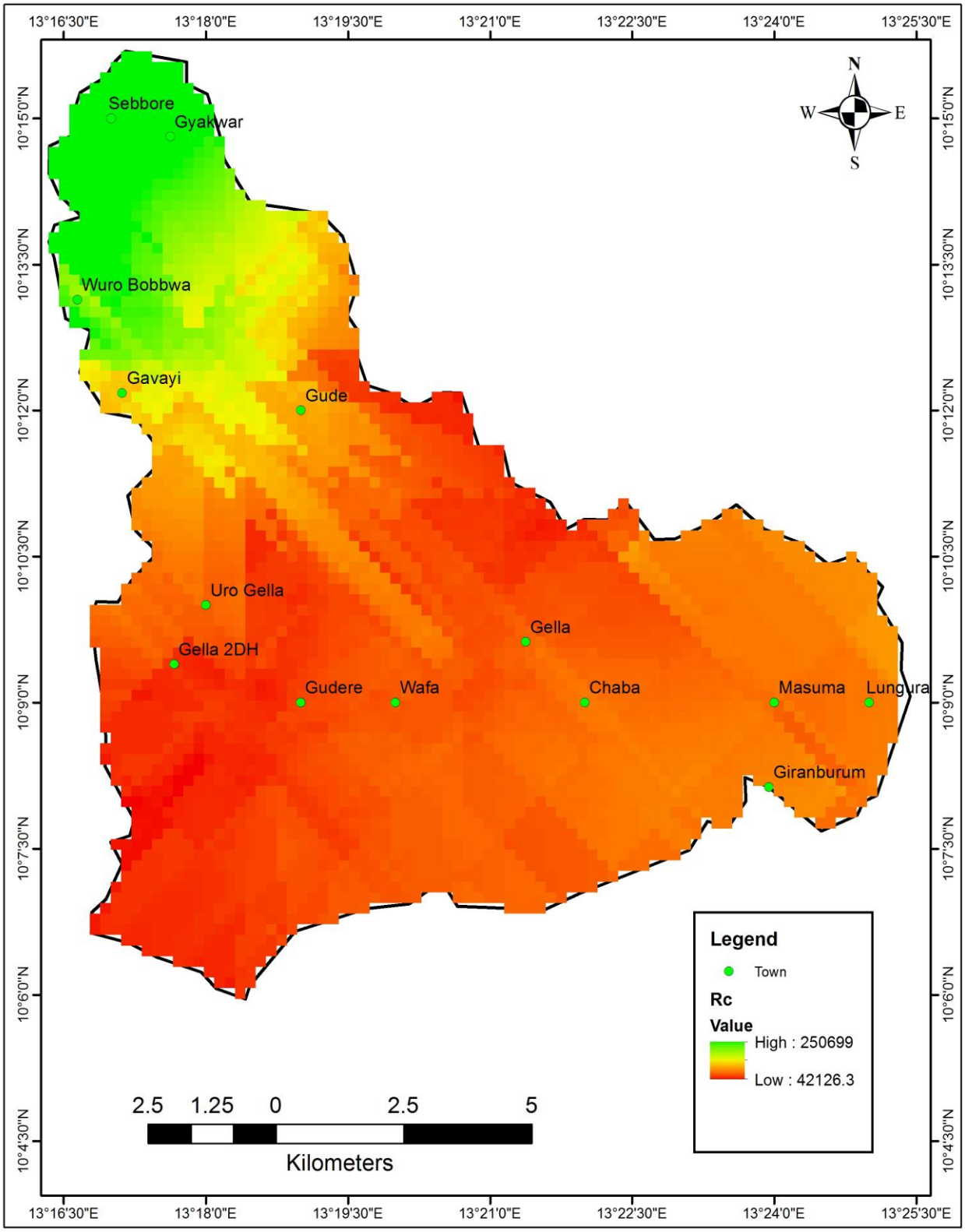


Figure 5.33:Soil Moisture Storage Capacity (Rc)

Source: Author's Analysis (2016)

5.4 ESTIMATED SPATIAL DISTRIBUTION OF SOIL LOSS

The result of the estimated spatial distribution of soil loss in the study area is presented in Figure 5.34.

Figure 5.34 indicates that soil erosion loss in the study area was between 0 - 3.5 t h^{-1} yr^{-1} as at the time of this research. It was observed that higher soil loss was obtained were crop cover management is high; with about 4.5 rate of potential evapotranspiration and between 0.08 to 0.24 high soil moisture. It was also observed that soil loss was high between 15.8 mm to 15.7 mm high to medium occurrences of daily rainfall.

It was also noticed that area with high soil loss was observed within low soil porosity area, except around Sebbore which was located in an area of high porosity with lower slope steepness length mostly having low to moderate silt content (52.8to 223.9) with 1.4 $Mgm^{-3}$to 1.6 Mgm^{-3}bulk density. This finding is similar to the study conducted by Haile and Fetene (2012) which found out that Kilie catchment, East Shoa, have 0–10 Mg $ha^{-1}yr^{-1}$ erosion rate and unlike the case of district of Borena where the rate of soil loss estimated between 10 Mg and 80 Mg $ha^{-1}yr^{-1}$(Abate, 2011). Also similar to the findings by Lopez-Vicente *et al.*(2015) which assessed soil redistribution at catchment scale in Central Spain and noteed that the average erosion rates were 3.3, 1.5 and 1.1 Mg ha^{-1} yr^{-1}. The low mean annual rate of erosion were found under natural condition from hill slope like in West Africa region as stated by Morgan (1995).

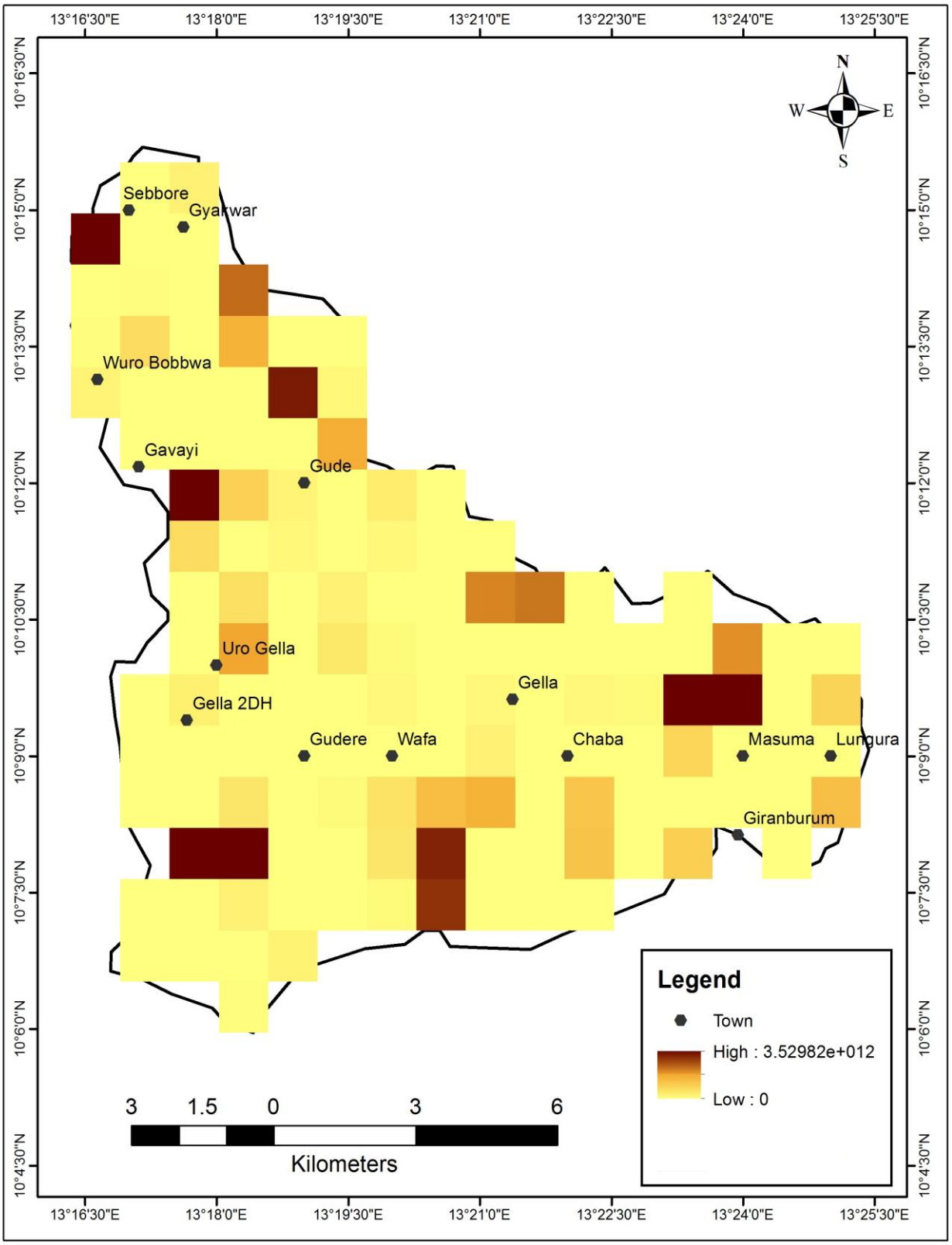


Figure 5.34: Estimated Soil Erosion Using RUSLE

Source: Author's Analysis (2016)

5.5 PREDICTED SOIL EROSION RISK

Soil erosion risk of the study area was predicted using hydrophysical parameters analyzed inDepartment of Soil Science Laboratory Ahmadu Bello University, Zaria.Spatial distributions of soil were discussed under the objective four (4) of this research work. Moreover, in order to predict the rate of soil detachment by runoff, transport capacity of overflow and total particle detachment, there arose need to analyze surface runoff/overland flow (SR) total energy, effective rainfall, soil particle detachable by rain drop and soil resistance of the study area which are shown in Figure 5.35 to Figure 5.38.

5.5.1Surface Runoff/Overland Flow (SR)

Result of spatial distribution of surface runoff/overland flow (SR) is presented in Figure 5.35.

From Figure 5.35, it was noticed that surface runoff at the foot of highland area pronounced in agricultural land having less vegetation cover; especially in areas such as: Gella 2DH, Uro Gella, Masuma and Lungara. Runoff had higher value of about 217.4 mm to – 1.29 mm out of 492.34 mm rainfall to indicate higher increase of runoff along foot of the hills; moderate on lower slopes and less at the mountainous area as shown in Figure 5.35. This is attributed to nature of landuse/landcover management practices in the study area.

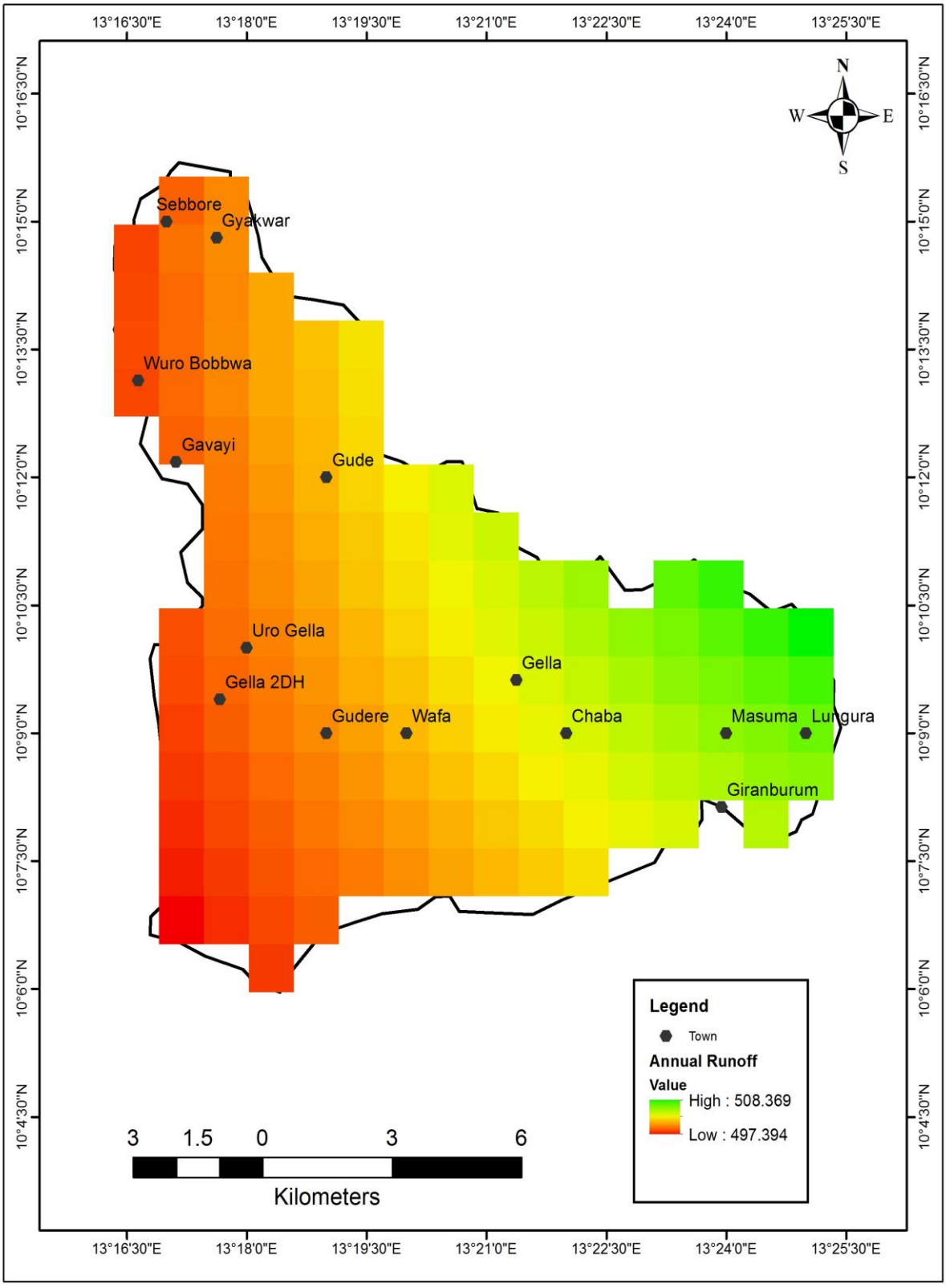


Figure 5.35: Estimated Runoff

Source: Author's Analysis(2016)

5.5.2 Total Energy of Effective Rainfall (KE)

Rainfall characteristics play a vital role in runoff generation and soil erosion risk in the Loess Pleateau (Fang *et al.*,2008). Rainfall characteristics become more variable and stochastic in the context of climate change, which increase the uncertainties and risk of water on soil erosion globally (Wei*et al.*, 2007). The result for effective rainfall of the study area is presented on Figure 5.36.

Effective rainfall (KE) of the watershed tend to be high towards south west of the study with about 10,136 value to about 9917 towards western part of the area. This indicates increase of total effective rainfall energy from western to eastern part of the study area as observed by Groisman *et al.* (2005), who showed that on the global scale, changes in extreme rainfall tend to be larger than changes in mean rainfall totals. Also, increase in rainfall extremes occur in many religions where no change or even decrease in total rainfall was observed (Groisman *et al.*, (2005). The KE can explain more than 78% of variation in runoff and soil loss which suggests that it was the dominant factor that controll runoff and soil loss.

5.5.3 Annual Kinetic Energy of Rain

A rainfall event is a collection of a number of raindrops of various sizes hitting the receiving surface. Each of these possesses specific mass of water. The raindrop will then start to travel at a constant velocity called terminal velocity. This terminal velocity and mass of raindrop constitutes the kinetic energy of rain drop.

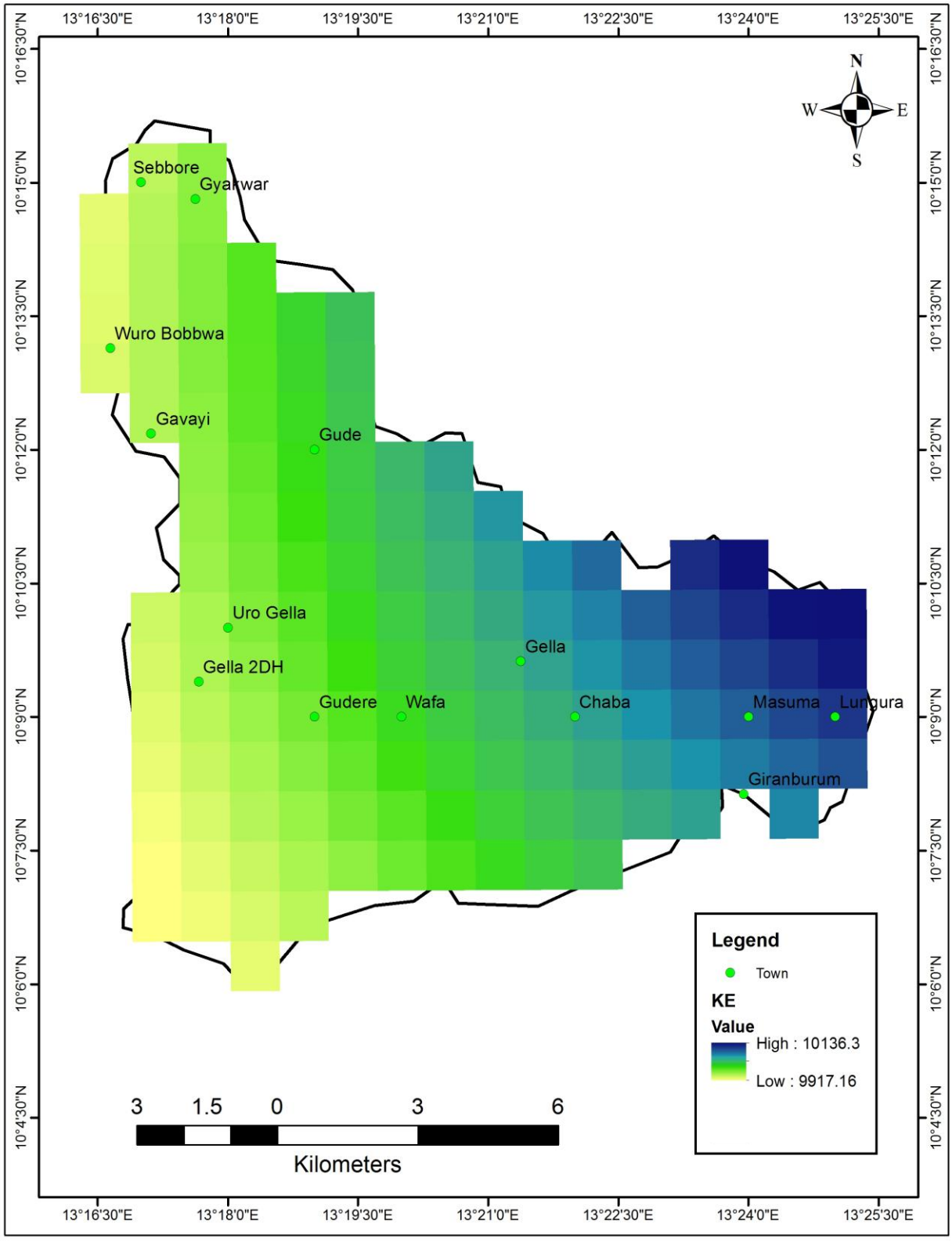


Figure 5.36:Total Energy of Effective Rainfall (KE)

Source: Author's Analysis (2016)

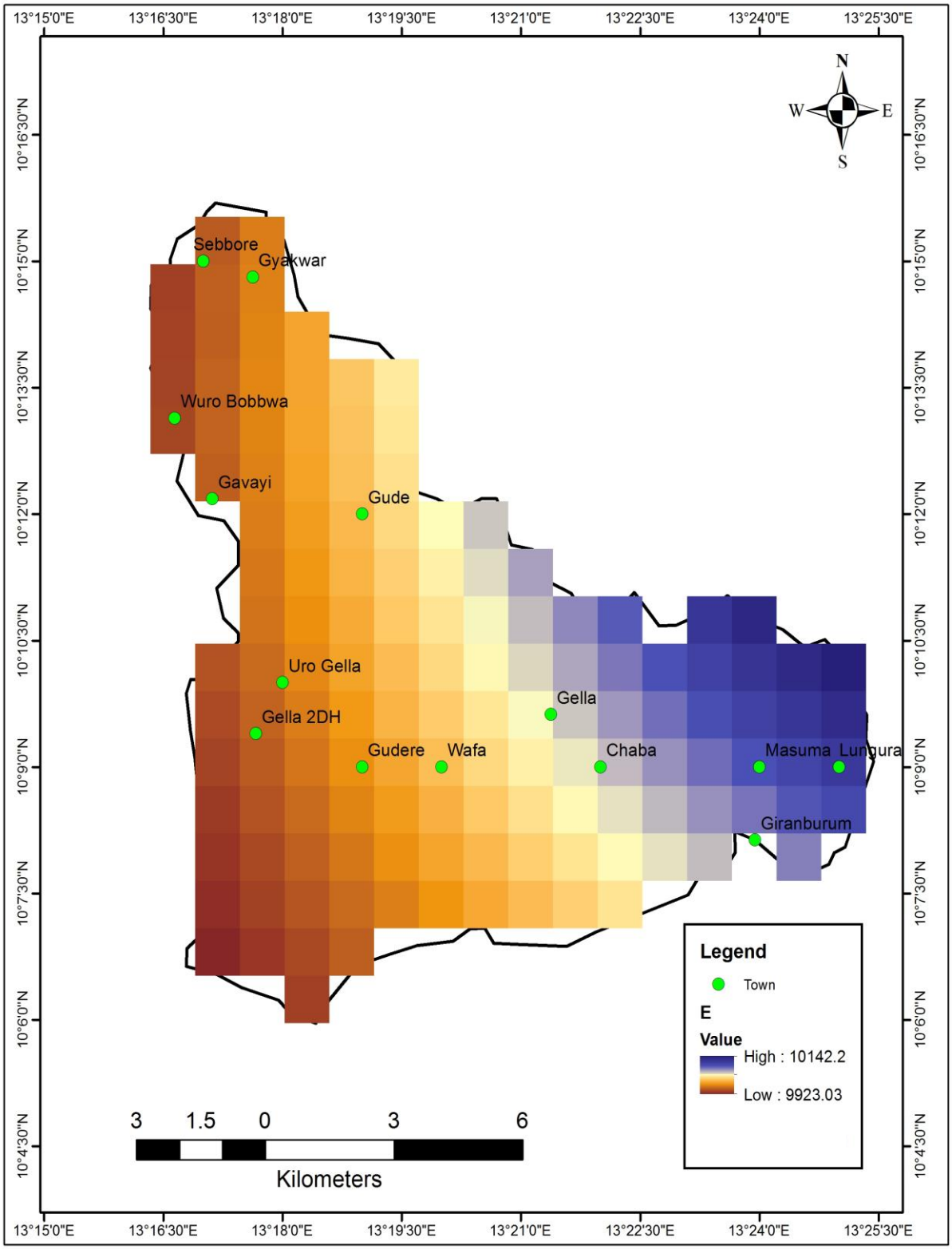


Figure 5.37: Annual Kinetic Energy of Rain Jm^{-2}(E)

Source: Author's Analysis (2016)

The summation of kinetic energy of individual raindrop hitting per unit area over a period of time is known as the kinetic energy of rainfall event. Kinetic energy of a rainfall event is an important agent of soil erosion. Initial detachment of soil particles are caused by impact of raindrop on the soil surface. The amount of soil particles detached depends on a number of parameters including soil characteristics and the amount of kinetic energy. This initial detachment and subsequent transport of soil particles by overland flow is known as splash erosion (Lal, 1990c).

Annual kinetic energy of rain is vital in soil erosion risk analysis. Based on Wischmeier and Smith(1978), annual kinetic energy is the potential ability of rain to cause erosion and could be termed the erosivity index or simply erosivity. The kinetic energy of rainfall is used as an input to determine and predict soil erosion risk of an area. The result for spatial distribution of annual kinetic energy of rainfall for the study area watershed is presented in Figure 5.37.

From Figure 5.37, it was determined that kinetic energy of rainfall increasedtowards upper slope in the watershed area. It had a rainfall total ranged between 10142 mm southeast to 9923 mm western part of the study area which resultedfrom topography and orographic rainfall in hilly areas. This effect of rainfall pattern affects runoff and erosion from the three different soils as supported by Persons and Stone (2006) who stated thatowing to spatial heterogeneity in infiltration characteristics of the soil surface, infiltration would increase with increased rainfall intensity and runoff might decrease.

The peak of the rainfall in southeast; with instantaneous intensity at the end, yielded higher sediment loads and concentration (Kavian and Mohammadi, 2012). These different soil regimes have different effects on runoff and soil erosion risk (Wei *et al.,* 2007).

5.5.4 Soil Resistance

Soil resistance factor is amongst the main factors causing soil erosion after energy and protection factors. Soil resistance factor is the product of soil erodibility, infiltration capacity and soil management. The result obtained for spatial distribution of soil resistance in the watershed is shown in Figure 5.38. The soil resistivity was used as input to determine runoff detachment as shown in Figure 5.39.

Soil resistance as shown in Figure 5.38 ranges between 6.74 Oh-cm to 3.43 Ohm-cm in the watershed. Soil resistivity to soil erosion is high in the watershed areas that are dominated by Regosol and low in and around Arenosol and Luvisol.

The Arenosols and Luvisols soil groups have the same proportion of spatial distribution of soil with low resistivity to soil erosion in the watershed of the study area. It was imferred in this research that areas of high soil resistivity have soil aggregate stability ranges between 0.29 to 0.41. Those areas of low soil resistance wer observed within soil with higher aggregate stability of about 0.47 to 0.58. Again, areas with high soil resistance had high soil particle density as well as high annual Kinetic energy of rainfall, whereas reversee was the case for areas with low soil resistivity. Areas with high soil resistivity affects the infiltration of water and are found to be vulnerable to soil erosion.

5.5.5 Soil Particle Detachable by Rain Drop

Spatial distribution of predicted soil particle detachability of raindrop in the study area is shown in Figure 5.39.

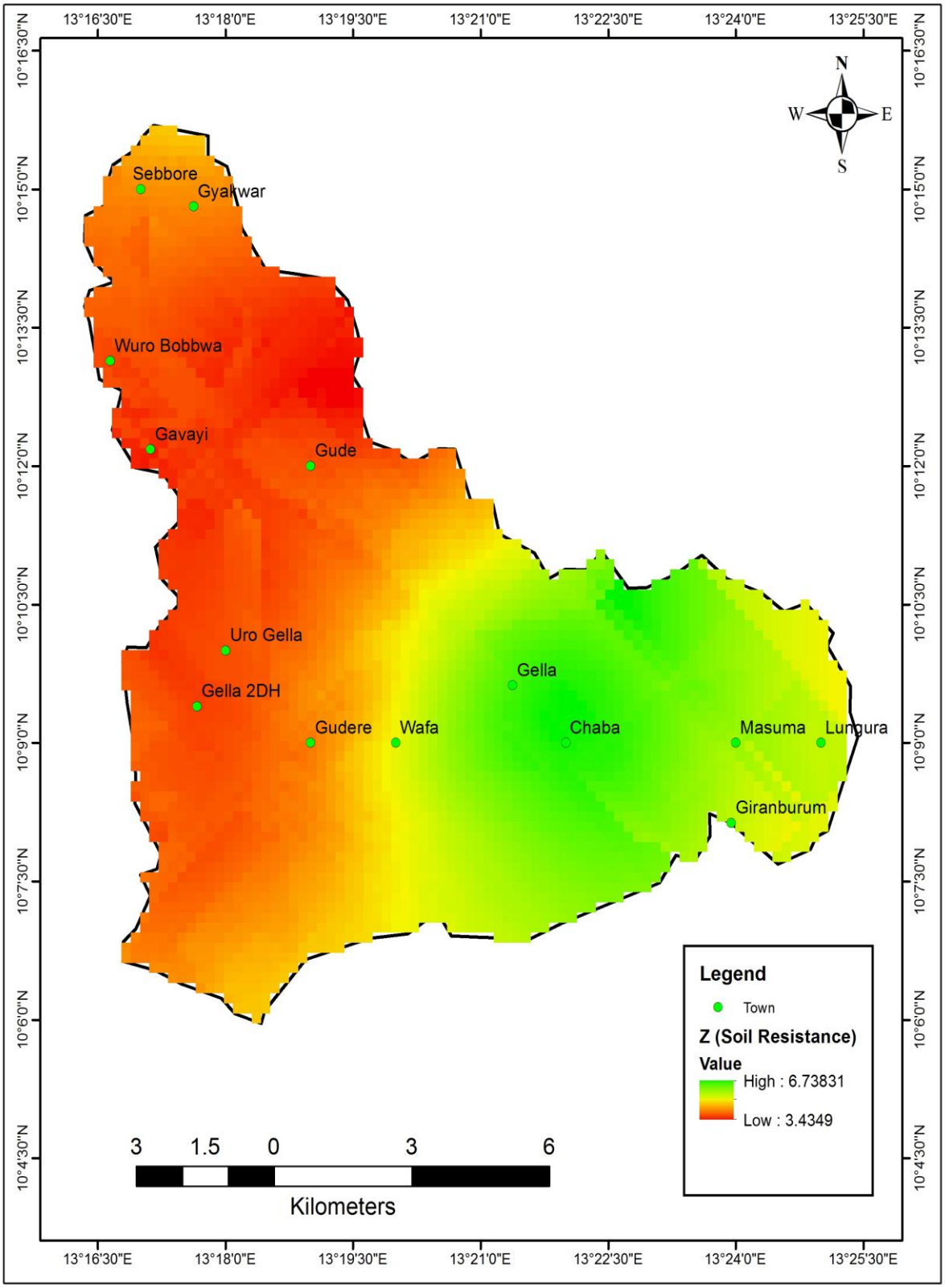


Figure 5.38:Soil Resistance (Z)

Source: Author's Analysis (2016)

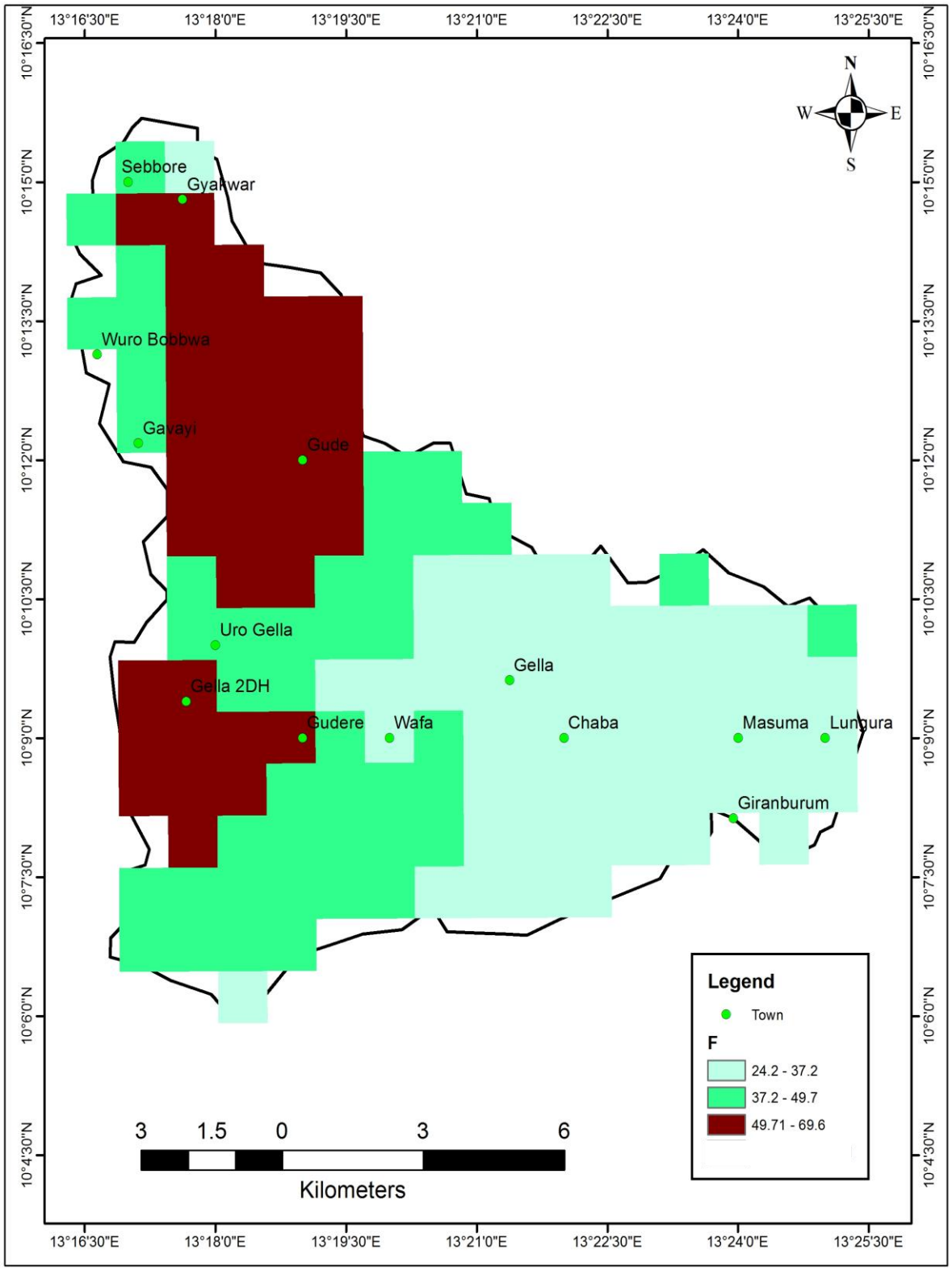


Figure 5.39:Soil Particle Detachable by Raindrop (F)

Source: Author's Analysis (2016)

From the predicted result of soil particle detachability in Figure 5.39, it was inferred that soil particles were categorised into three class such as; 24.2 – 37.2 tha^{-1} yr^{-1} (low), 37.2 – 49.7 tha^{-1} yr^{-1} (medium) and between 49.71 – 69.6 tha^{-1} $yr^{-1(}$ high) respectively. These were as the result of sheet erosion in Mubi South which involves the detachment and transport of soil particles by raindrop impact (rainsplash erosion) and transport by shallow overland flow as supported by Lal and Elliot (1994).

It was observed that those areas that areas with high soil particle detachability had low soil particle detachment and this was due to high soil resistance of the reas (Figure 5.38). Also, observed in areas with high annual kinetic energy, high particle density (Figure 5.22) with high sandy soil content (Figure 5.9). Moreover, high soil particle detachability was due to low soil moisture storage capacity and low aggregate soil stability. Low clay content and low to moderate silt, low soil texture/erodibility and low Regosol soil groupalso attributed to high soil particle detachability within the watershedas supported by FAO (1978) whereas reverse is the case with the areas having moderate to low soil particle.

5.5.6 Predicted Rate of Soil Detachment by Runoff

The result of spatial distribution of predicted rate of soil detachment in the study area is shown in Table 5.8 and Figure 5.40.

Table: 5.8 Rate of Soil Detachment by Runoff

Rate (1 t ha^{-1} yr^{-1}) Based on Grid Code	Area (Km^2)	Area (Hectares)	Percentage (%)
1 (Hegh)	79.17	7917	53.34 %
0 (Low)	69.26	6926	46.66 %
Total	**148.43**	**14843**	**100.00**

Source: Author's Analysis (2016)

As presented in Figure 5.40, watershed area had annual rate of 1 t ha^{-1} yr^{-1} soil detachment which covered an area of 79 Km^2 and constituted about 53 % of the study area. This is as the results of high rate of deforestation, population growth, overgrazing and use of marginal lands intensify erosion (Cerdà *et al.,* 2009). The intensification of the agriculture production in the Mubi South also results in high erosion rates as supported by Cerdà *et al.,* (2009). Meanwhile, the low annual soil rate covered about 69 Km^2 and constituted less than 47% of the area. It was found that rate of soil detachment by runoff occured mostly at the mountainous or hilly areas. This may be as a result of high rate of runoff down the slope from hilly areas. Moreover, it was noticed that predicted soil detachment rate by runoff was more around agricultural areas as well as areas with low vegetal cover. This Study suggested that high rates of soil erosion in in the study area is mainly caused by extensive deforestation due to the prevalence of high demand for grazing in to steep land areas and fuel wood collection as supported by Amsalu *et al.,* (2007) and Haile and Fetene, (2012).

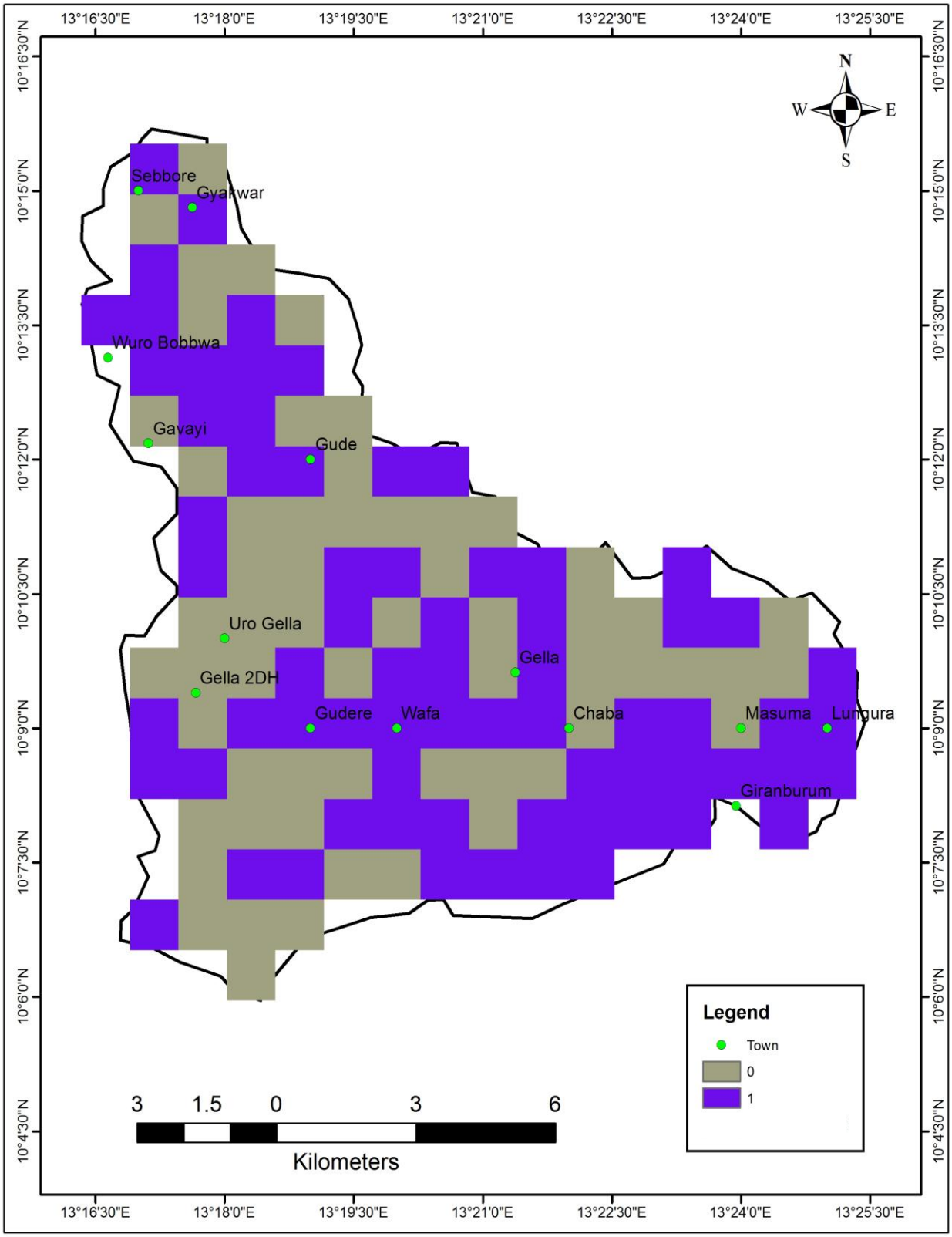


Figure 5.40:Rate of Soil Detachment by Runoff (H)(t ha^{-1} yr^{-1})

Source: Author's Analysis (2016)

5.5.7 Predicted soil Transport Capacity of Overland Flow

Result of spatial distribution of predicted soil transport capacity of overland flow derived from RMMF model with the aid of raster calculation in ArcGIS 10.3 environment is presented in Table 5.09 and Figure 5.41. Table 5.09 show the index to surface runoff/overland flow classes in the study area.To show that,about 55 % of the study area show low soil transport capacity rate of 1.29 t ha^{-1} yr^{-1} which covered 82.98 km^2. The high rate of about 17.43 t ha^{-1} yr^{-1} soil transport capacity rate of overflow covered 45 % of the study area. The areas with low (68.33 km^2) or with increased rate of soil transport capacity were around conical hills; especially, around Gella and Chaba.Most of the areas were located around bare land and cultivated area.These were also as the result of sheet erosion in Mubi South which involves the detachment and transport of soil particles by raindrop impact (rainsplash erosion) and transport by shallow overland flow as supported by Lal and Elliot (1994). Urban development frequently results in intensive soil erosion (Gupta, 1982).

Table 5.9: Surface Runoff/Overland Flow (SR)

Classes of Surface Runoff	**Rate (t ha^{-1} yr^{-1})**	**Area (Km^2)**	**(Hectares)**	**Percentage (%)**
High	217.43	68.33	6833	45.16
Low	-1.29	82.98	8298	54.84
Total		**151.31**	**15131**	**100.00**

Source: Author's Analysis (2016)

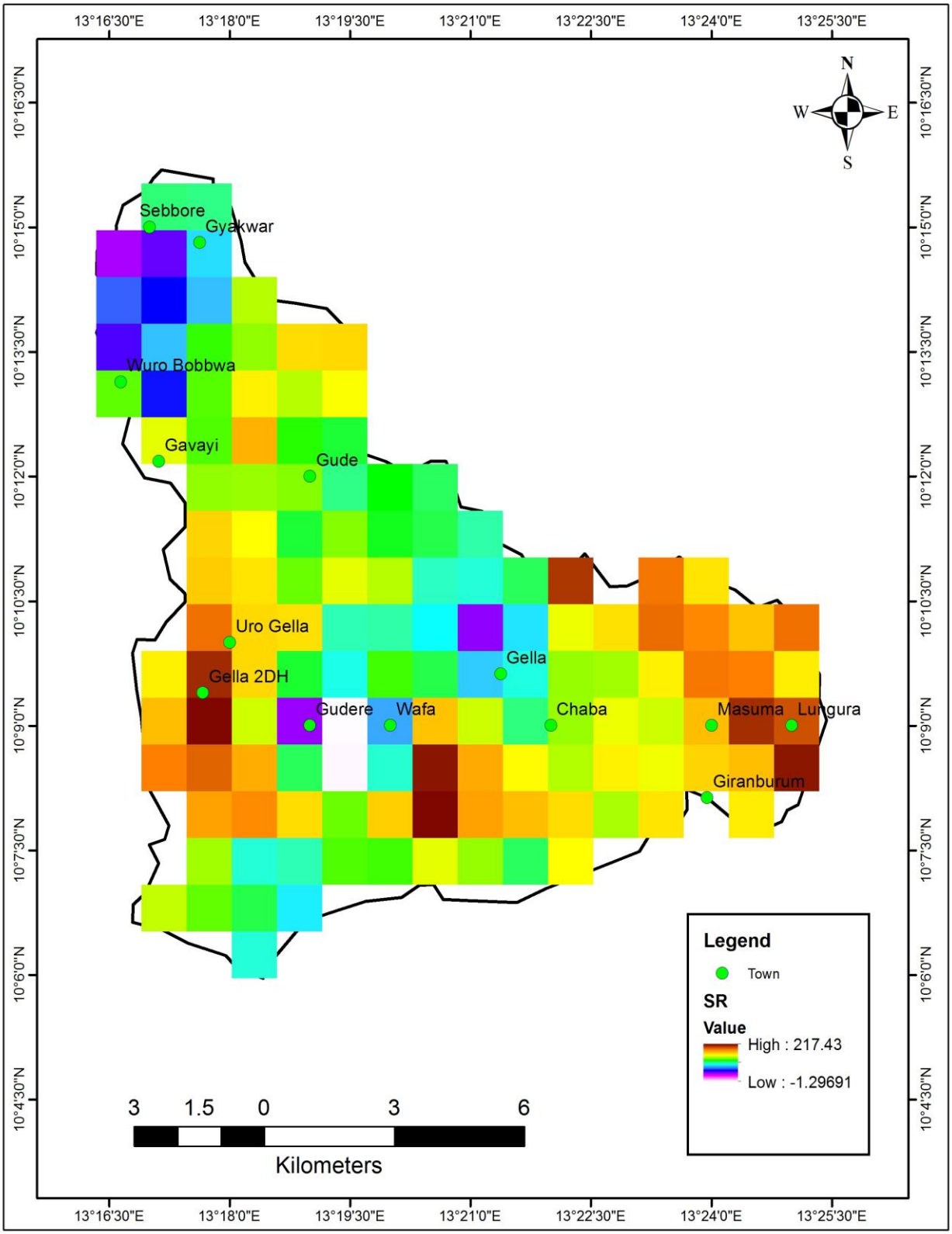


Figure 5.41:Surface Runoff/Overland Flow (SR)

Source: Author's Analysis (2016)

5.5.8 Predicted Total Soil Particle Detachment

Revised Morgan Morgan Finnery was used with the aid of geospatial techniques in order to predict total soil particle detachment obtained from the watershed and the result is presented in Table 5.10 Figure 5.42.

Table 5.10: Total Soil Perticle Detachment (D)

Class	**Detachment(t ha^{-1} yr^{-1})**	**Extent (Hectares)**	**Percentage (%)**
High	69.657	68.21	45.95 %
Low	25.2637	80.22	54.05 %
Total		**148.43**	**100**

Source: Author's Analysis (2016)

Table 5.10 and Figure 5.42 shows that the study area has higher value of about 69.66 t ha^{-1} yr^{-1} of annual total soil particle detachment which covered an extent of 68.21hectares (45%). About 25.26 t ha^{-1} yr^{-1} lower value covering about 80.22 hectares and also constitutes about 54% of the study area.This is as the result of raindrop impact that breaks up clumps of soil. The lighter materials of sand, salt, clay, and organic materials in the study area are detached by raindrops are readily carried away by runoff as supported by kirkby (2004).

It was observed that raindrop impact moves particles in form of random exchange, rather than in one direction and these results to the vations between soil particle detachments as

confirmed by Kirkby (2004). Also south east of the study area had about 25.26 t ha^{-1} yr^{-1} of total low soil particle detachment due to its high content of sandy soil, high soil texture, particle density, low soil porosity, high aggregate stability of soil, low soil moisture content, high total energy of effective rainfall, high annual kinetic energy of rainfall, high soil resistivity and low to moderate soil particle detachable by raindrop.Regosols soil group of the watershed recorded low total particle detachment of soil loss.

Moreover, areas with about 69.66 t ha^{-1} yr^{-1} total soil particle detachment were located around western part of the watershed which was characterized with low soil texture, low particle density, moderate to high soil porosity, moderate to high soil aggregate stability, high moisture content, medium annual kinetic energy of rainfall, low soil resistivity, high soil particle detachable by raindrop and dominated by Luvisol and Arenosol soil group.

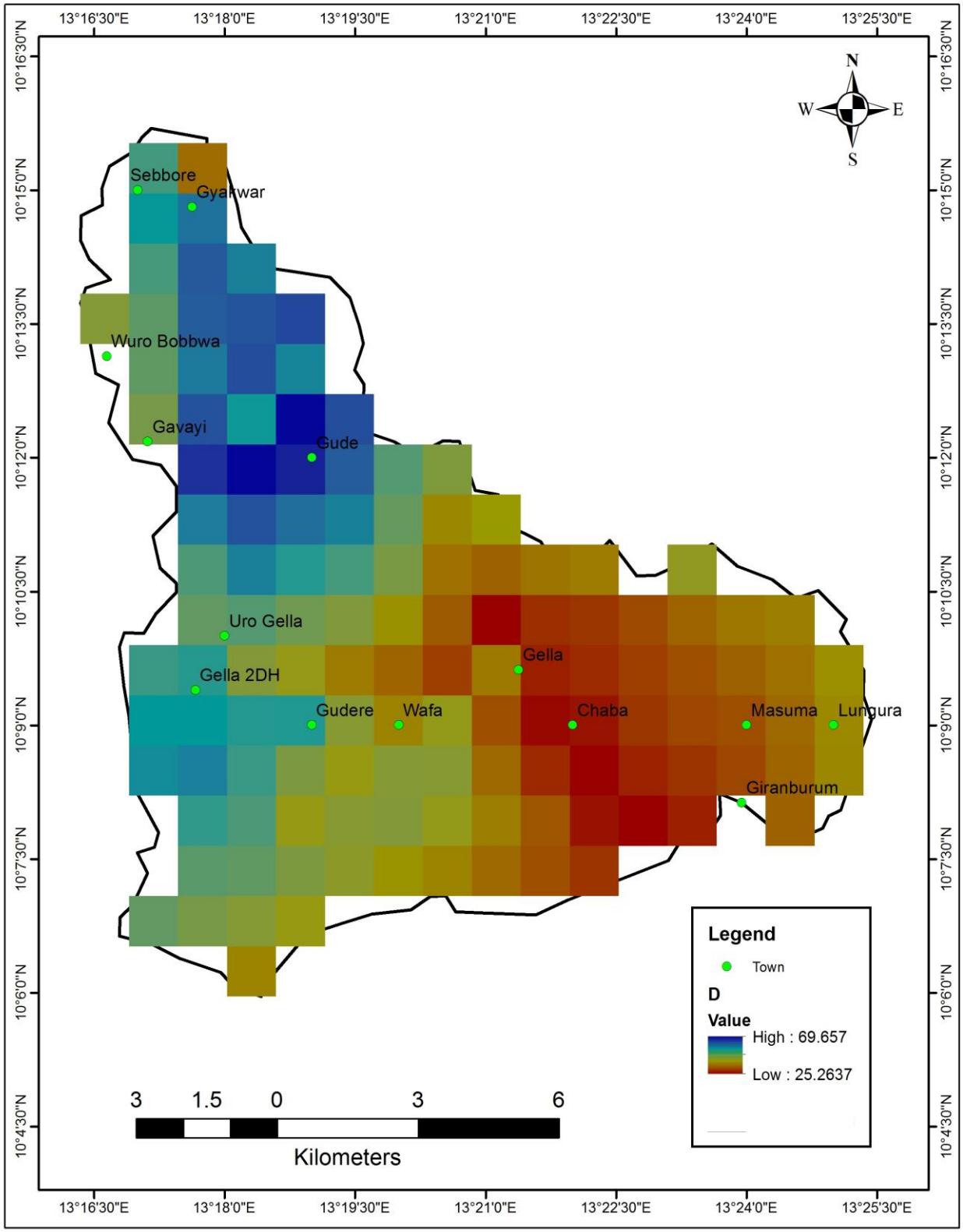


Figure 5.42:Total Particle Detachment (D) (t ha^{-1} yr^{-1})

Source: Author's Analysis (2016)

5.5.9 Soil Erosion Risk

A risk of erosion exists on cultivated land from the time trees, bushes and grasses are removed. Erosion is exacerbated by attempting to farm slopes that are too steep, cultivating up-and-down hill, continuous use of land for the same crop without fallow or rotation, inadequate use of fertilizers and organic manures, compaction of soil and as a result, crops like maize, cassava and sugar beet can all give moderate to serious erosion problems (Morgan, 2005).The result for soil erosion risk classes of the study area is presented in Table 5.11 and Figure 5.43.

Table 5.11: Extent of Soil Erosion Risk Classess

Classess	**Area**		**Percentage (%)**
	Km^2	**Hectares (ha)**	
Very Low	77.53	7753	52.23
Low	22.27	2227	15.00
Moderare	20.24	2024	13.64
Moderately High	8.19	819	5.52
High	8.96	899	6.03
Very High	11.24	1124	7.58
Total	**148.43**	**14843**	**100.00**

Source: Author's Analysis (2016)

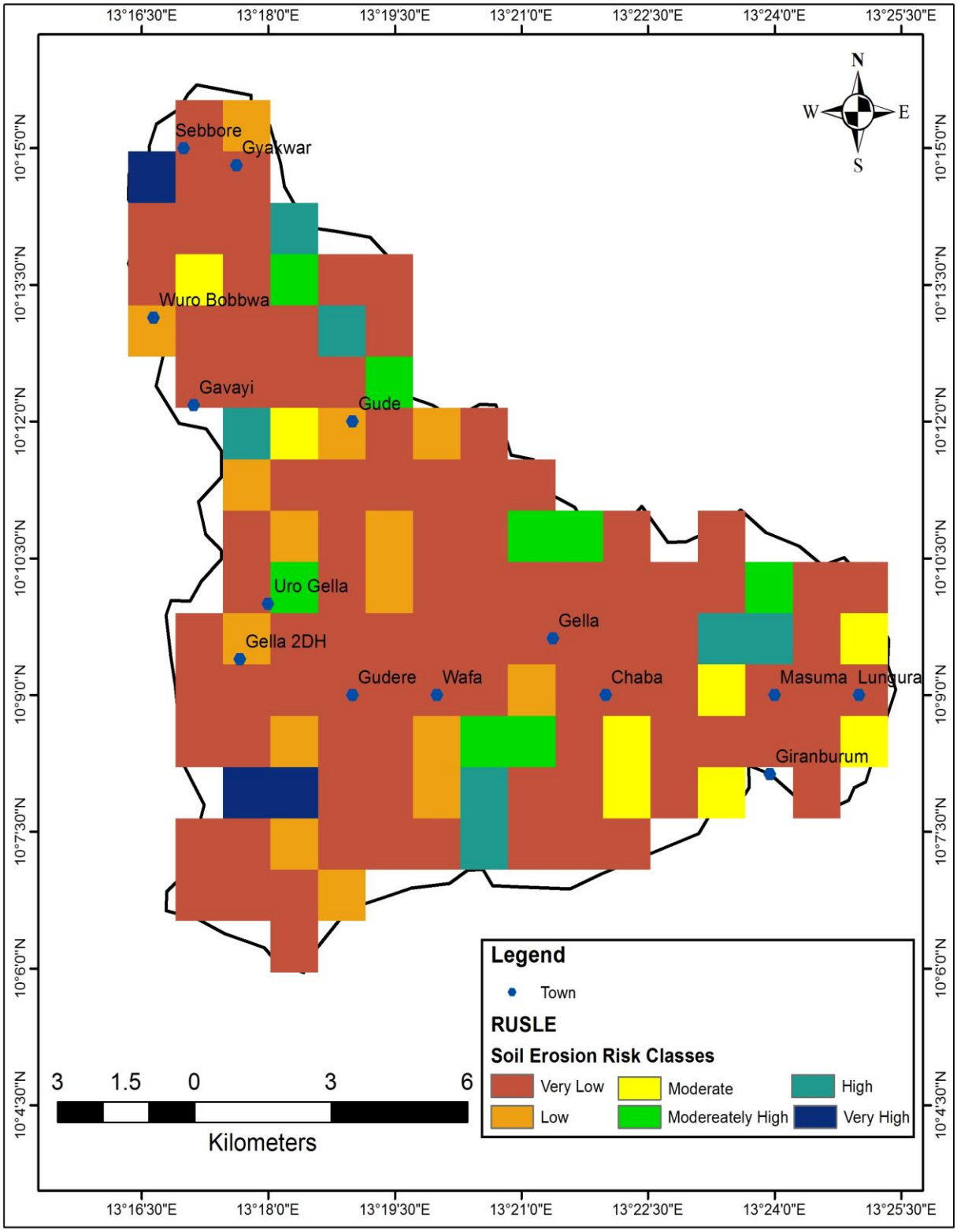


Figure 5.43: Soil Erosion Risk Map

Source: Author's Analysis (2016)

Table 5.11 and Figure 5.43 shows the class as well as spatial distribution of soil erosion risk in the study area. It was noted that about 50% (77.53 km^2) of the study area had very low soil erosion risk, which was mostly covered by vegetation, some part of agricultural area and hilly regions. About 15% of the study area was covered by low soil erosion risk, 13% moderate, 6% moderately high, 11% high and 7% very high. The areas with very high were as the result of clay content between 9 and 30% and are the most susceptible to erosion (Richter and Negendank, 1977; Evans, 1980)

Erodibility of different soils causes different erosion and soil erosion damages (Renschler and Harbour, 2002). Also, Bewket and Sterk (2003) report that soil erosion in south-eastern Nigeria is as the results of a field scale erosion soil moisture, in addition to infiltration rates.Based on this result, it could be said that the study areas has risk to soil erosion as the mountainous areas of the watershed exhibited high risk of soil loss and towns found on mountainous parts were more erodible. The areas of very high erosion risk were around settlements like Sebbore, while others were in areas under intensive agriculture; especially,having high to moderately high erosion risk. The moderate and low soil erosion risk classes of the watershed were located along foot of hills and mountainous area. Very high to high erosion classes were characterized by gully and rill erosion in the study area. This was because gully and rill erosion flow is non-selective in the particle size and can carry and move large grains, even rock fragments up to 9 cm in diameter (Poesen, 1987). Also, arid and semi-arid areas assumes an increasing soil erosion with increasing slope length, whereas the gradient is a minor factor (Yair and Raz-Yassif, 2004)

Meyer *et al.* (1975) stated that 15 % of particles carried in rills on a 3.5° slope of tilled silt loam were larger than 1 mm in size and that 3% were larger than 5mm. On a 4.5° slope of

bare untilled silt loam, 80 per cent of sediment transported in rills was between 0.21 and 2.0 mm in size and most of the clay particles were removed as aggregates within this size range (Alberts *et al.,* 1980). Also, the area covered by moderately to moderately high were characterized by rills and gullies erosion type whereas sheet erosions were occurred around the very low soil risk classes of the watershed area. Human-induced land degradation in the study area was one of the more destructive phenomena relating to natural resources in the world, and is recognized as a key issue for conservation in the 21st century (Reich*et al.,* 2000). In mountain environments of the study area; like in developing countries, soil erosion regularly constrains rural development and exacerbates poverty by undermining productive capacity of highland agriculture and livestock raising (Zimmerer, 1993; Lal, 2001).

This finding is similar to that of Qi (2011), who assessd soil erosion risk in the hilly-gullied area of Luoyugou watershed in Tianshui and observed that the probability of soil erosion had higher growth rate without vegetation cover than that having vegetation cover. Similar to findings by Gebreyesus, Tesfahunegn and Paul (2014) in Northern Ethiopia catchment, the rate of soil detachment varied from <20 t $ha^{-1}y^{-1}$to >170 t $ha^{-1}y^{-1}$, whereas the soil transport capacity of overland flow (TC) ranged from 5 t $ha^{-1}y^{-1}$to >42 t $ha^{-1}y^{-1}$. The average soil loss estimated by TC using MMF model at watershed level was 26 t $ha^{-1}y^{-1}$. Also in most parts of the watershed (>80%), the model predicted soil loss rates higher than the maximum tolerable rate (18 t $ha^{-1}y^{-1}$) estimated for Ethiopia.

Moreover, John *et al.*(2014) evaluated soil erosion risk in the basement complex terrain of Akure Metropolis, Southwestern Nigeria and found that most parts (91.4%) of the metropolis fell within the very low to low risk zones with tendency for sheet/rill erosional features. These research findings confirm findings conducted by Tekwa *et al.*(2014) that soil

erosion in the study area also altered vegetation cover, ground slope, slope length and shape, thereby influencing soil erosion rate leading to the formation of gullies and rills erosion. It also leads to significant soil loss and degradation, destruction of physical infrastructures such as buildings, drainages, roads and culverts especially. This demonstrates the importance of remote sensing data and GIS in successfully enabling rapid, as well as detailed, assessment of soil erosion risk/hazards (Kouli *et al.*, 2009).

5.6 VALIDATING THE PERFORMANCE OF RMMF AND RUSLE MODEL

The model performance was validated using Chekol (2006), formular. The model estimates soil loss rate in the study and was evaluated with respect to result obtained for rate of soil detachment by rain runoff and total soil particle detachment. The percent difference (D) was used to measure average difference between simulated and measured values as;

$D = (p - q/q)\ 100.$

Where $p$is model simulated value and $q$is measure value. A Value close to 0% is best for D. However, higher values of D will be acceptable if the accuracy in which the observed data to be gathered is relatively poor (Chekol, 2006).

$D = (p - q/q)\ 100.$

p=69.66

q=69.6

$$D = \frac{(69.66 - 69.6)}{69.6} \times 100.$$

$$D = \frac{(0.06)}{69.6} \times 100. D = 0.0008 \times 100 = 0.086 \text{ (0.09 approximately)}$$

Result for the performance of RMMF and RUSLE in the study area shows value of 0.08 which indicates that the models were best for the study area because research by Chekol (2006) stated that a value close to 0% is best test for the goodness-of-fit measure of model performance.This finding was as a result of erosion by surface runoff because research conducted by Montgomery and Dietrich (1994) and Vandekerckhove *et al.* (2000) pointed out that values >0.2 are associated with erosion by surface runoff and those <0.2 to indicate subsurface processes and mass movement.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY OF THE STUDY

The study analyzed soil erosion risk in Mubi South watershed area. The aim was achieved through the following objectives to: (i) Map types and pattern of soil erosion in the study area, (ii) Characterize hydrophysical parameters for soil erosion in the study area, (iii) Assess the spatial distribution of hydrophysical parameters in the study area, (iv) Estimate spatial distribution of soil loss in watershed area, (v) Predict areas that are vulnerable to soil erosion risk in the study area and (vi) Validate performance of RMMF and RUSLE Model in the study area.

The research was carried out using Revised MMF and RUSEL model with GIS techniques. The watershed area consists of the following fourteen (14) villages and Local Government Headquarter; namely, Sebbore, Gude, Gudere, Wafa, Chaba, Masuwa, Lunguwa,Gyakwar, Wuro Babbowa, Gavayi, Gella 2DH, Gella, Giranburum and Uro Gella which is the Local Government Headquarters of Mubi South. Sixty five soils samples were takenfromthe proposed 80 soil samples sites. These were collected in July 2016.Coordinates of sample points were taking using grid system in GIS software environment. Only the hydrophysical parameters of the soil were measured in laboratory for this research.

The hydrophysical parameters used as input data were collected from different sources: empirical relationship, rainfall data, land use (forest land, protected area, cultivated, bare fields, grazing land, mixed-forest and residential), digital elevation model (DEM), soil

texture, soil moisture, soil detachability index, bulk density, cohesion of soil surface, soil moisture storage capacity, organic matter content effective hydrological top soil depth, and ratio of actual to potential evapotranspiration and Crop parameter (mainly maize, beans and sorghum) from erosion plots. Focus group interview was carried out with head of farmers (Sarkin Noma) in the study area in order to get information on type of soil conservation practices in the study area.

The results showed that gully erosion results not only from surface flow but also often from sub-surface flow as in the Northern part of the study area and mostly around the foot of hills. Most gully erosions in the study area range between 3m to 20m deep, 20–50m wide and mostly more than 100 m long. The presence of gullies was attributed toovergrazing and removal of vegetation cover in the study area causedby crusting of the surface soil, resulting in greater runoff. Most rill erosion in the study area was located in association with gully erosion. They were also found in virtually all aspects of slopes in the study area. The presence of sheet erosion indicated lower porosity and microbial activity in the study area. No increase in sheet erosion with water depth was observed around sandy soils.

Sandy soil particles were dominant soils of the watershed which covered about 65 % of the study area, followed by silt with about 18% and clay of less than 17%.The soil has different texture, detachment factor, moisture content, bulk density, and COH. Soil erodibility variables in the study area and loamy sand covered more than 28% of soil erodibility, sandy loam soil ranges between 20% to 25 % and sandy clay loam had the least (about 21%). These results showed that the watershed had about 28% of loam sand erodibility in the study area.

Result shows that loamy soil has high soil aggregate stability of about 0.55g/g in the study area, followed by sandy loam with about 0.51g/g. Therefore, sandy loam and loamy soil were vulnerable to soil erosion risk. Again, the higher the soil detachment factor, the lower will be the soil moisture content and the higher the bulk density as in case of loamy sand found in the study area. Observed also sandy loam of the study area it had 0.24 soil detachment factors, 0.08 % soil moisture and 1.65 Mgm^{-3}bulk density. Sandy clay loam had 0.20 soil detachment factor, 0.08 % soil moisture and 1.68 Mgm^{-3}bulk density. Whereas loamy sand is had 0.27 soil detachability, 0.07 % soil moisture and 1.70 Mgm^{-3}bulk density,loamy soil had 0.23 detachability, 0.06 % soil moisture and 1.48 Mgm^{-3}bulk density respectively. Moreover, it was noticed that sandy loam and sandy clay loam had high soil moisture content in the study area (0.8) than loamy sand (0.07) and Loam soil (0.06) respectively.

The land use land cover has about 29% of area covered by agricultural activities, 19% covered by forest and 25% were not cultivated and covered by bare land. Seventeen (17%)percent land was covered by built up areas and 10% water bodies. Therefore majority of the watershed area was covered by higher normalized difference vegetation index (NDVI) of about 0.58 with a lower value of -0.07. These showed that target area being observed contains live green vegetation at the ground cover. Digital Elevation Model (DEM) in the study area ranges from higher value of about 1261 m to the lower value of about 570m respectively. Majority of the study area belong to lower topography of 570m above sea level and all settlement of the study area are located within the lower topography except Giranburum.

Soil of Mubi South show three dominant soil classes which compring of Luvisol, Regosol and Arenosol. Luvisol constitute about 30% Regosol 35% and Aresonol 35% respectively. Luvisol is found in the pediplain of the watershed which has about 570m, along sabbore, Gyakwa, Wuro Babbwa, Gavayi and some part of Gude town. The geomorphic position effect of low land and low vegetation result in the presence of Luvisol in the watershed. Sandy soils have constitutes about 65% of the watershed, which shows that the study area is variable to soil erosion risk. There is higher concentration of sillt content in the Northern part of the study area especially around Sebbore, Gyakwar and Wuro Bobbwa ranges between 223.9kg/m^3 to 360kg/m^3. The higher concentration of salt is found mostly around Luvisol in the study area whereas between the range of 52.8 to 223.9 was found around the Regosol and Arenosol soil group respectively. The watershed area had clay ranges between the ranges of 130.7kg/m^3 to 161.1kg/m^3. Also, clay predominate the Northern part of the watershed which is evidence of the fact that there is higher salt content and low sand particles in the Northern part of the watershed.

It was also observed that the the watershed had spanning tree type of flow accumulation.Flow direction is the outer part raster that shows flow direction from each cell to its steepest downslope neighbor. Hillshade areas were noticed with highest peak of about 180 meters above sea level. The spatial distribution of cover management factor ranges from the higher value of 0.5 to lower value of 0.01 in the watershed.

Soil erodibility factor (k-factor) was 0.69around Arenosol, which had highest clay content and lower silt contain. Luvisols have moderate (0.4) erodibility factor which characteristic of moderate clay and silt content and some sand deposit. Slope Length and Steepness (Ls-factor) shows even distribution along each of the watershed.

Conservation Practice Factor (P-factor) within the watershed ranges between 1(showing no conservation practices deciduous forest) to 0.55 corresponds to built-up areas with strip and contour cropping. Spatial distribution of rainfall map of the watershed indicates that it ranges between 481m to 192m and is higher towards northwest of the watershed. Also, bulk density ranges from 1.38 Mgm^{-3} to about 1.88 Mgm^{-3} in the watershed. It was observed that most of the study area had bulk density ranging between 1.47 Mgm^{-3} to 1.55 Mgm^{-3}; especially, in a towns like Masuma, Langura, Giranburam, Gella and Uro Gella. Spatial distribution of soil organic matter ranges from 8.4 $gkg^{-1}$to 11.3 gkg^{-1}.

Luvisol and Arenosol soil group had particle density ranges between 1.68 $gkg^{-1}$to 2.47 gkg^{-1}towards Northwest and Southwest of the watershed, which constitutes larger proportion in the watershed area whereas high values range between 2.47 gkg^{-1} to 3.02 gkg^{-1}were distributed around Regosol soil group of the watershed which were mostly located along southeast of the study area. Area of higher value of soil porosity ranges between 0.29mmto 0.58mm facilitates free-water drainage, aeration and evaporation. The soil aggregate stability of the study area show value of 1.13g\$cm^3$ to 1.52g\$cm^3$, while the lower value was found among Regosol soil group in the watershed. Soil moisture or the spatial distribution of soil moisture at field capacity shows values ranging from 43.07 to 47.56.

There is low concentration of amount of rainfall per day towards Northwest and Southwest parts of the area. This is characterized by about 15.5mm of rainfall and potential evapotranspiration ranges from 4.6m and lower value of 4.5m. The estimated spatial distribution of soil loss in the study area indicated that high soil erosion loss in the watershed area was 3.5 t h^{-1} yr^{-1} as at time of this research.

It was also noticedthat the study areahas low porosity; except around Sebbore, which was located in an area of high porosity and lower slope steepness length; mostly have low to moderate silt content (52.8 kg/$m^3$to 223.9kg/m^3) with 1.4 $Mgm^{-3}$to 1.6 Mgm^{-3}bulk density. The runoff was higher;ranging from 217.4 to – 1.29 mm out of 492.34 mm rainfall. It was observed that there was higher increase of runoff along the foot of the hills, moderate on lower slope and less at mountainous areas. Effective rainfall (KE) of the watershed tend to be high towards south west of the study area with about 10,136 value to about 9917 lower towards western part of the area. This indicates increase of total effective rainfall energy from western to eastern part of the study area. Kinetic energy of rainfall increase toward upper slope within the watershed area, which ranges from 10142mm in south east.Incresase in rainfall was as result of topography positionwhich experiences orographic rainfall (9923mm) in the western part of the study area mostly located in hilly areas respectively.

Findings fromthis research showedthat areas of high soil resistivity have soil aggregate stability ranges from 0.29 to 0.41. Predicted soil particle detachability in the watershed were 24.2 – 37.2 tha^{-1} yr^{-}(low), (37.2 – 49.7) tha^{-1} yr^{-1} (medium) and between 4.9.7.1 – 6.9.6 tha^{-1} yr^{-1} high. It was observed that those areas that have low soil particle detachment were had high soil resistance with annual rate of soil detachment of 1 t ha^{-1} yr^{-1}. Areas with as low as about 1.57 t ha^{-1} yr^{-1} were recommended for, particularly,erosion control because their soils are thin or highly erodible (Hudson, 1981). High rate of soil detachment by runoff mostly occurs at the mountainous or hilly areas/hilly areas. This may be as a result of high rate of runoff down the slope from hilly areas. Moreover, predicted high soil detachment rate by runoff also occur around agricultural areas, as well as areas with low vegetal cover. Again, Predicted soil Transport Capacity of Overland Flow indicated that about 98% of the study

area was 1.57 t ha^{-1} yr^{-1}. Predicted Total Soil Particle Detachment in the study area show higher value of 69.66 t ha^{-1} yr^{-1} of annual total soil particle detachment and about 25.26 t ha^{-1} yr^{-1} lower value. Also, observed southeast of the study area witnessed 25.26 t ha^{-1} yr^{-1} of total low soil particle detachment. Moreover, the areas with 69.66 t ha^{-1} yr^{-1} of total particle detachment by soil were located around western part of the watershed.

About 50 % of the watershed had very low soil erosion risk and was mostly covered by vegetation, agricultural land and hilly regions. About 17% of the study area was groupedas low soil erosion risk, 12% moderate, 6% moderately high, 11% high and 4% very high. The areas of very high soil erosion risk were found around settlemenst like Sebbore, while others were located where there is intensive agriculture; especially, high to moderately high. The moderate and low soil erosion risk classes of the watershed were located along foot of the hills and mountains. Very high to high erosion classes were characterised by gully and rill erosion in the study area. Also, Soil erosion affects agricultural lands, built-up areas, forests and social amenities: such as road and electricity facility within the study area.

The results showed that runoff of 217.4mm out of 492.34mm rainfall occurred and runoff will occur when daily rainfall is greater than 15mm. Result of the study also shows that average rate of soil detachment is 1t ha^{-1} yr^{-1}, average transport capacity of overland flow is 1.5 t ha^{-1} yr^{-1}. Average soil per detachability by raindrop is 69.6 t ha^{-1} yr^{-1} and total soil particle detachment is 69.66 t ha^{-1} yr^{-1} and average soil erosion of 3.52 t ha^{-1} $yr^{-1}$was estimatedand highest annual soil loss occurred in urban areas.The RMMF and RUSLE model had values of 0.08 which indicates that the models were best test for goodness-of-fit measure of model performance.

6.1.1 Contributions to Knowledge

i. Out of the research, one paper was presented at the Geoinformation Society of Nigeria Conference which took place from 13th to 15th of November 2018, at National Space Research and Development Agency, Obasanjo Space Center, Abuja, Nigeria.

ii. Five Journals articles were derived out of this research in which two have been published in a reputable international journals. The first paper title: Prediction of Soil Erosion Risk in Mubi South watershed Area, Adamawa State, Nigeria.International Organisation of Scientific Research Journal of Environmental Science, Taxiocology and Food Technology. The second Estimation of Soil Erosion Risk in Mubi South Watershed Area, Adamawa State, Nigeria. International Journal of Advance Remote Sensing and GIS. Cloud publications

iii. The outcome of this research provides blueprint showing that estimated spatial distribution of soil loss in Mubi South indicated high soil erosion loss of 3.5 t h^{-1} yr^{-1} in the watershed.

iv. The study area had predicted soil particle detachability of 24.2 – 37.2 tha^{-1} yr^{-} (low), (37.2 – 49.7) tha^{-1} yr^{-1} (medium) and between 4.9.7.1 – 6.9.6 tha^{-1} yr^{-1} (high).

v. This document provides document that shows the extents and nature of watershed area in Mubi South Local Government Area, spatial distribution of soil erosion

hydrophysical parameters, classes and zones of soil erosion risk of the study area which can be used as basis for further research works.

vi. Spatial and quantitative information on analysis and prediction of soil erosion risk on a watershed and sub-watershed scale contributes significantly to planning for soil conservation, erosion control and management of watershed environment.

vii. Results of this study serve as a document that can help town planners, road construction planners, engineers and site constructors to design urban land use plan that are less vulnerable to erosion.

viii. Also, it would serve as a document that will help urban developers, Watershed Management Authority, National Emergency Management Agency, Transport Department and Federal Road Maintenance Agencies in planning for town embankment rehabilitation work.

ix. It also serves as document for sustainable Drainage System for soil erosion risk management with the aim of preventing soil erosion risk within a watershedand urban surface flow (runoff).

x. It serves as document that will help for effective design to facilitate maintenance of gently shelving slopes to allow safe access for maintenance and minimise soil erosion while allowing people contact with landscape features and Identify appropriate operations soil erosion repair (SuDS, 2014).

6.2 CONCLUSION

Studies had shown that recent global land degradation caused by increase in soil erosion risk lead to land degradation and in Mubi South Watershed and Nigeria are not exceptions of

degradation. Several lands, houses, roads, agricultural land, vegetation, forests have been eroded and degraded due to high rate of soil erosion in Mubi, Gombe and other parts of Nigeria.

The occurrence of soil erosion risk in Mubi South Watershed has also been on the increase and is not limited to mountainous and hilly regions; but all part of the watershed to cause serious land degradation affecting a wide variety of soils prone to crusting and/or piping. The widths and depths of soil erosion increase with the increase in slope gradient and decrease with increase in percentage of vegetation cover, especially during the rainy season. This research findings confirm that soil erosion in the study area also alters vegetation cover, ground slope, slope length and shape; thereby influencing soil erosion rate, leading to the formation of gullies, rills and sheet erosion amongst others. It also leads to significant soil loss and degradation, destruction of physical infrastructure, as well as natural features. Remote sensing data and GIS successfully enabled rapid, as well as detailed assessment of soil erosion risk/hazards and show spatial distributions of soil erosion related factors and features. Local government, state, Federal Government, Town Planners as well as relevant organizations such as; highways agencies and engineering companies companies should install protective strategies and measures for sensitive management of the environment on reducing soil erosion rates and increasing water conservation.

6.3 RECOMMENDATIONS

i. It is recommendedthat soil erosion conservation, planning and management in the hill region be prioritized because based on outcome of the research, nature of

flow direction from the mountainous area to the pediplain led to water movement, transportation and deposition of debris down the slope; hence, the need for proper management at the mountainous/hill regions by Mubi local government authorutis and Adamawa state government.

ii. Also,researchers are adviced to use others soil erosion model in the study area to further compares and analyse soil erosion risk.

iii. Vegetation cover in the study area should be prioritized because gully retreat was controlled by the inherent strength of tree root mat that binds surface soils until the undercut trees finally collapse, surpoted by Archibold *et al.*(2003). Increasing effects of plant roots lead to soil resistance and concentrated flow erosion mainly depend on the characteristics of effective roots where they densely distributed at depth of 0–30 cm as surpoted by Li *et al*.(1991). Plant roots reduce gully erosion in improving soil physical properties such as structural stability and infiltrability also surpoted by Li *et al*. (1992 and 1995). Hence the needs by Mubi local government authorutis and Adamawa state government to plants vegetation as a mitigation measure for reducing soil erosion in the study area.

iv. Agronomic measures, combined with good soil management, is also recommended because measures and management can influence both detachment and transport phases of erosion. Whereas mechanical methods are effective in controlling the transport phase, they do little to prevent soil detachment (Morgan, 2005). Mubi local government authorutis and Adamawa state government are also adviced to adopt this method.

v. There is the need for soil conservation supports byindividual or private organizations, Local Government, State and Federal Government so as toprovide

protective measures in order to retain their reputations for management of the environment as recommended by Morgan (2005).

vi. There is the need for constraints for adoption of conservation strategies innovative by Mubi local government authorutis and Adamawa state governmentbecause conservation strategies have proved to be effective in controlling soil erosion risk as also supported by FAO (2002).

vii. Traditional bench terrace systems like those built by contour bunds (Uro Gella and CHaba) to promote infiltration of water and increase soil moisture, mulching to conserve water and soil fertility, burying of weeds and trash to improve fertility and weed control, crop rotation and weed fallows are recommended as supported by Critchley *et al.* (1994), Reij *et al.* (1996) and Tengberg *et al.* (1998). Greater emphasis should be placed on contour grass strips and use of trees and hedges rather than terraces (Hijkoop *et al.,* 1991). Hence the needs by Mubi local government authorutis and Adamawa state government to adopt this method.

viii. The methods used for soil erosion control on road bank range is recommended for engineering structures; such as revetments and retaining walls to stabilization of slopes by vegetation.

ix. In Field Crops, used of hedgerows, trees, grassed waterways or conservation tillage (reduced tillage), contour ploughing or the cross-slope cultivation, which is widely-spread in the US is recommended by Mubi local government authorutis and Adamawa state government.

x. It is recommended for the local indigens to usestriptillage in maize, because it appears plausible to adapt and improve strip-tillage for field grown vegetables (Phatak *et al.,* 2002; Price and Norsworthy, 2013).

xi. Moreover, Mubi local government authorutis and Adamawa state governmentare adviced to vegetative buffers (trees, understory, and groundcover) combat soil erosion as they protect the soil from erosion processes, allow greater infiltration of water and trap sediment entering from cultivated areas. So as reduced on-site impacts of soil erosion. Again, appropriately designed windbreaks can also significantly reduce soil loss from fields byreducing wind velocity as recommended by Salah*et al*. (2008).

6.3.1 Recommendation for Further Research

i. The Mubi South Local Government Area has two Watershed areas. This research concentrated in one watershed area and there is the need for research of this nature to be conducted in the other watershed so as to compare soil erosion risk within the entire local government area for proper erosion control and planning.

ii. This present research did not measure the area coverage of individual soil erosion types; hence, the need for further research to measure the magnitude of all forms of soil erosion.

iii. It is recommended for research to be conducted in the study area by looking at the relationships of hydrophysical parameters as factors that leads to soil erosion risk.

iv. It is recommended for research to be conducted in the study area by looking at the chemical parameters as hindrances for soil erosion risk using chemical related recommended revised models.

v. It is also recommended for comparative research between physical and chemical parameters of soil erosion to be conducted in the study area.

vi. It is also recommended for research like this to be conducted in Mubi North Local Government because it was confirmed during field work that the area is also experiencing soil erosion and there is the needs to know the areas vulnerable to soil erosion risk for proper conservation practices, planning and management.

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APPENDIX 1

PALTES



Plate 1: Sampled Soil ready for Laboratory Analysis (ABU Soil Physics Lab)
Source: Author's Laboratory Work (2016)



Plate 2: Sampled Soil ready for Laboratory Analysis (ABU Soil Physics Lab)
Source: Author's Laboratory Work (2016)

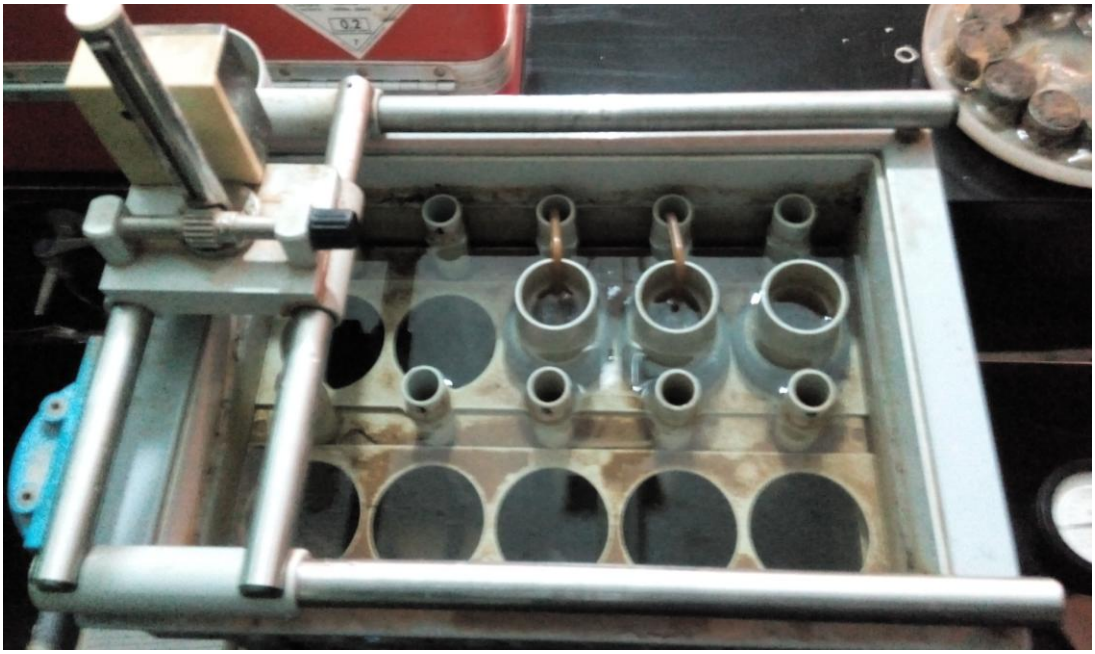


Plate 3: Measurement Cylinder to Determine Soil Texture Using Bouyoucos Hydrometer (ABU Soil Physics Lab)
Source: Author's Laboratory Work (2016)



Plate 4: Bar Pressure Plate Extraction Using Capillary Action in KR Box (ABU Soil Physics Lab)
Source: Author's Laboratory Work (2016)



Plate 5: Weigh Soil Organic Matter using Erlenmeyer Flask (ABU Soil Water Lab)
Source: Author's Laboratory Work (2016)



Plate 6: Determine Soil Particle Size using Pipette (ABU Soil Survey Lab)
Source: Author's Laboratory Work (2016)

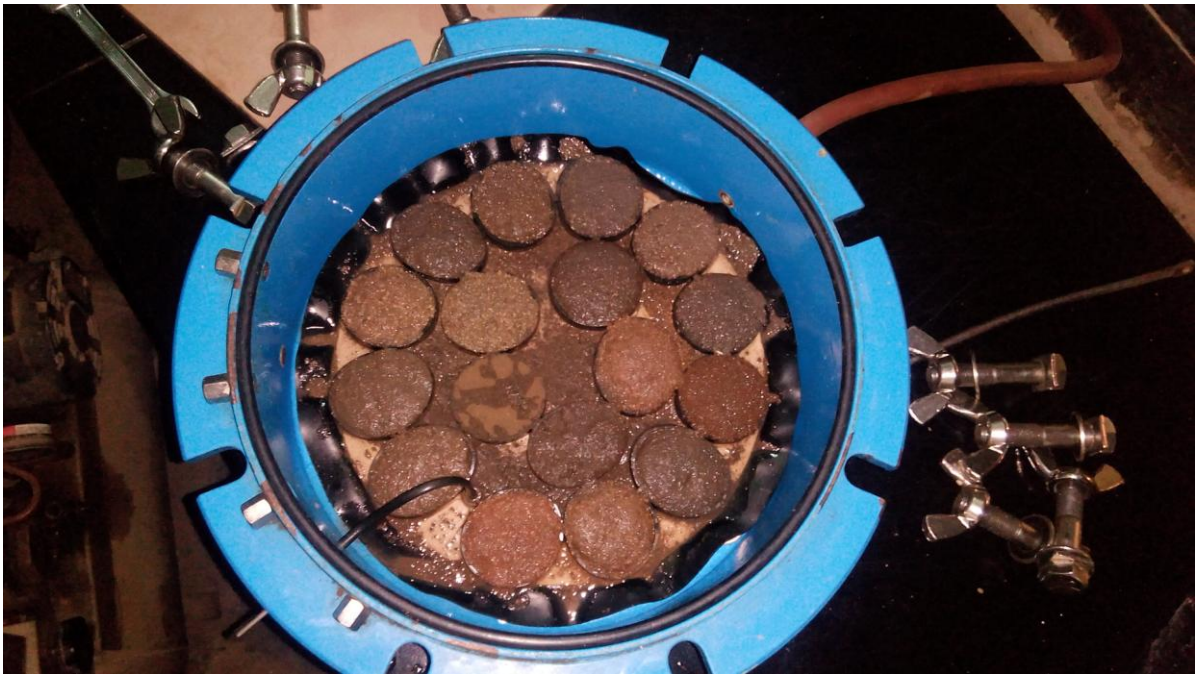


Plate 7: Determine Soil Moisture Retentions using Bar Pressure Plate Extraction (ABU Soil Physics Lab)
Source: Author's Laboratory Work (2016)



Plate 8: Oven dries for Soil Bulk Density (ABU Soil Physics Lab)
Source: Author's Laboratory Work (2016)



Plate 9: Equipment Used for Data Collection During Field Work
Source: Author's Field Work (2016)

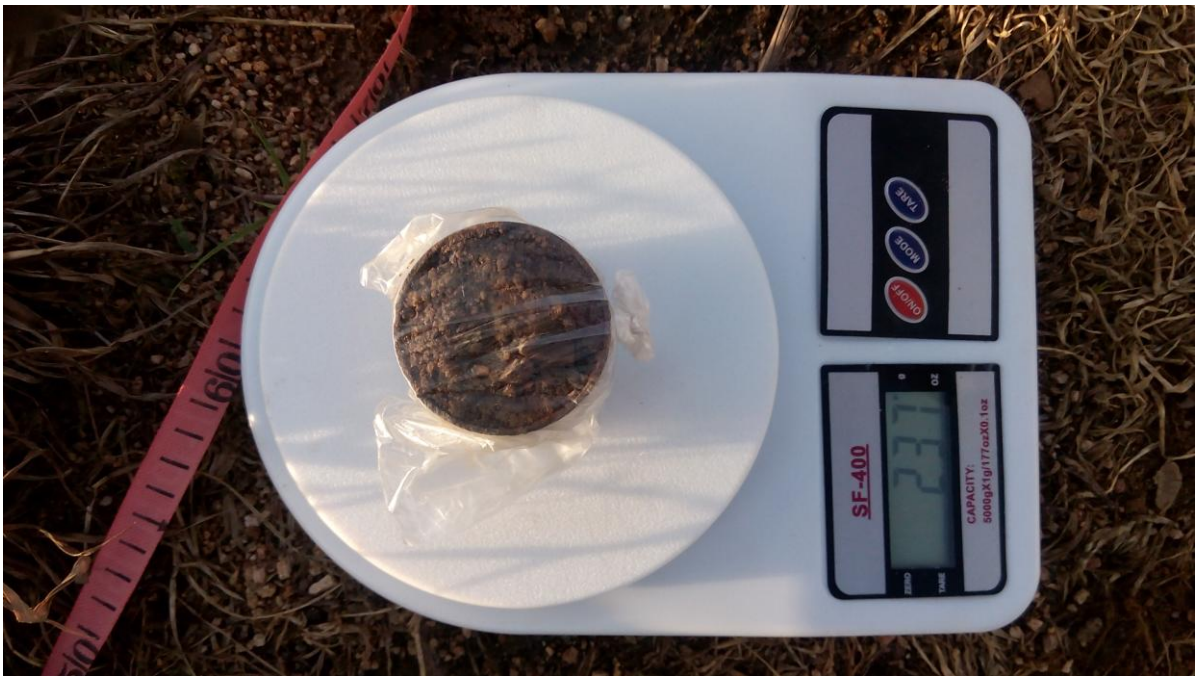


Plate 10: Core Sampler Used to Take Reading for Soil Moisture Content at Field Capacity
Source: Author's Field Work (2016)



Plate 11: Soil data collection along Transectsduring Field Work
Source: Author's Field Work (2016)



Plate 12: using spiral auguring for Soil data collection during Field Work
Source: Author's Field Work (2016)



Plate 13: Soil Profile Pit along Low Slop
Source: Author's Field Work (2016)



Plate 14: Soil Profile Pit along Medium Slop
Source: Author's Field Work (2016)



Plate 15: Field Assistance during research field work
Source: Author's Field Work (2016)



Plate 16: Field Assistance during research field work
Source: Author's Field Work (2016)



Plate 17: One on One Interview with Sarkin Noma
Source: Author's Field Work (2016)



Plate 18: Gully Erosion within the Watershed
Source: Author's Field Work (2016)



Plate 19: Lateral Bank Erosion within the Bank of Gully
Source: Author's Field Work (2016)



Plate 20: Undercutting Bank Gully Erosion
Source: Author's Field Work (2016)



Plate 21: Gully Erosion Migrating through Weak (Slaking) Sandy Subsoil
Source: Author's Field Work (2016)



Plate 22: Formation of Rill Erosion with the Watershed
Source: Author's Field Work (2016)



Plate 23: Rill/Interrill Erosion along bare land within the Watershed
Source: Author's Field Work (2016)



Plate 24: Rill Erosion along Hilly Farmland within the Watershed
Source: Author's Field Work (2016)



Plate 25: Excessive Sheet Erosion within the Watershed
Source: Author's Field Work (2016)



Plate 26: Sheet Erosion on Farmland within the Watershed
Source: Author's Field Work (2016)



Plate 27: Sheet/Interrill Erosion along Pediplain within the Watershed
Source: Author's Field Work (2016)



Plate 28: Effect of Gully Erosion on Builtup Area and Culvert
Source: Author's Field Work (2016)



Plate 29: Effect of Rill Erosion on Tree Roots (Vegetation/forestry)
Source: Author's Field Work (2016)



Plate 30: Effect of small Gully Erosion on Agricultural Farmland
Source: Author's Field Work (2016)



Plate 31: Effect of Sheet Erosion on Electric Pole in Gella Town
Source: Author's Field Work (2016)



Plate 32: Effect of Gully Erosion on Road along Major Road from Mubi Town to Gella
Source: Author's Field Work (2016)



Plate 33: Land Degradation as the Result of Gully Erosion within the Mubi South Watershed
Source: Author's Field Work (2016)



Plate 34: Agricultural Land Degradation as the Result of Gully Erosion within the Mubi South
Source: Author's Field Work (2016)

APPENDIX II

LOCATION OF THESIS SOIL SAMPLE SITES IN MUBI CATCHMENT AREA

S/NO	LOCATION	TEM	SMCFC (G)-WCS		
1	339.088 427.413				
2	339.088 427.413				
3	339.441 408.346				
4	321.786 409.052				
5	357.803 391.043				
6	338.382 391.043				
7	321.433 390.690				
8	321.079 372.682				
9	339.441 371.623				
10	357.096 372.682				
11	375.458 372.329				
12	393.819 372.329				
13	393.819 354.320				
14	375.811 353.967				
15	357.449 353.967				
16	339.088 354.673				
17	339.088 336.312				
18	357.096 336.312				
19	375.811 336.312				
20	393.466 336.665				
21	411.475 336.665				
22	429.483 318.657				

23	411.475 317.597				
24	393.466 317.950				
25	375.811 317.950				
26	356.390 317.950				
27	339.441 317.597				
28	357.096 299.942				
29	376.164 317.950				
30	393.819 300.295				
31	411.475 299.942				
32	429.483 300.295				
33	448.198 299.942				
34	465.853 300.295				
35	484.215 299.942				
36	502.223 299.942				
37	520.232 299.942				
38	520.232 281.934				
39	502.576 281.934				
40	484.215 282.287				
41	466.206 282.640				
42	447.845 281.934				
43	429.483 282.287				
44	411.828 282.287				
45	411.828 282.287				
46	375.811 281.580				
47	357.803 281.580				

48	339.441 281.580				
49	339.040 264.077				
50	357.411 264.077				
51	375.430 264.430				
52	393.448 263.723				
53	411.467 264.077				
54	412.174 263.723				
55	447.857 263.723				
56	466.229 263.723				
57	484.248 263.723				
58	502.266 263.723				
59	520.991 263.723				
60	538.656 264.077				
61	520.232 246.270				
62	502.223 245.917				
63	484.215 245.917				
64	466.206 245.917				
65	447.492 245.917				
66	429.483 246.270				
67	411.828 246.270				
68	393.466 245.917				
69	376.164 245.917				
70	357.449 245.917				
71	339.441 246.270				
72	339.441 228.261				

73	356.743 227.555				
74	375.811 227.202				
75	393.819 227.555				
76	411.828 227.555				
77	429.836 227.202				
78	447.845 228.261				
79	466.206 228.261				
80	375.811 209.900				
81	357.096 209.547				
82	339.088 209.547				

S/NO	LOCATION	TEM	SMCFC		
1	340.046 400.510				
2	375.906 302.963				
3	408.925 232.231				
4					

APPENDIX 111

SOIL PROFILE DESCRIPTION

Soil Profile Number **…….**

A) <u>Information of Soil Profile Site</u>

Date of examination / /

Authors ……

Status Mini-pit description……..

Location (UTM) ……

Elevation (meters) ……

Locality ……..

Landscape ……

Geological unit ……

Position ……

Slope ……

Local Relief ……

Vegetation ……

Land use …….

B) <u>Information on Soil Profile</u>

Classification ……

USDA Soil Taxonomy ……..

Parent material ……

Drainage class …….

Internal drainage ……..

External drainage ……

Rock outcrops ……..

Surface stoniness ……

Evidence of erosion ……

Water table ……..

C) Soil Profile Description

Horizon	Depth (cm)	Description
…….	……	……
		……
…….	…….	…….....
		……
…….	…….	…….
		……
……	……	…….
		……..
……	……	…….....
		…….

APPENDIX 1V

LABOROTERY ANALYSIS FOR SOIL HYDROPHYSICAL PARATEMERS 285

APPENDIX V

POTENTIAL EVAPOTRANSPIRATION (PET)

State station	Latitude	Longitude	Potential Evapotranspiration (PET)
Bauchi	10.7	9.49	44.9
Gombe	11.10	10.15	43.3
Maiduguri	11.51	13.05	53.0
Yola	9.16	12.26	45.0
Mubi	13.30	10.16	43.1
Kaduna	10.42	7.19	40.9
Kano	12.03	8.32	50.7
Yelwa	10.53	4.42	43.2
Yobe (Uguru)	12.53	10.28	49.0
Jos	9.54	8.45	37.7

Source: Modified from Weather/Agricultural Outlook for DEKAD2 (11 to 20) of June 2015

APPENDIX VI

RAINFALL DATA

State station	Latitude	Longitude	Rainfall
Bauchi	10.7	9.49	550.8
Maiduguri	11.51	13.05	309.32
Yola	9.16	12.26	496.49
Mubi	13.30	10.16	539.99
Yobe (Uguru)	12.53	10.28	352.83

Source: Average Rainfall Data from Nigerian Meteorological Agency 2015.

APPENDIX VII

SOIL EROSION LOCATIONS

GULLY EROSION	
Latitude	Longitude
10*12`14.75``N	13*17`27.96``E
10*12`18.15``N	13*17`59.38``E
10*12`44.49``N	13*17`13.09``E
10*12`43.78``N	13*17`9.13``E
10*11`41.10``N	13*18`58.52``E
10*14`37.98``N	13*17`33.17`E
10*9`27.73``N	13*17`41.27``E
10*9`4.54``N	13*17`55.63``E
10*7`56.94``N	13*20`21.30``E
10*10`0.50``N	13*20`14.99``E
10*11`15.91``N	13*17`43.70``E
10*7`55.50`N	13*20`11.62``E
RILL EROSION	
Latitude	Longitude
10*9`19.69``N	13*17`33.92``E
10*9`18.83``N	13*17`40.96``E
10*8`47.06``N	13*17`49.72``E
10*7`54.11``N	13*20`31.73``E
10*8`26.67``N	13*20`36.34``E
10*8`57.70``N	13*18`39.47``E
10*8`30.24``N	13*18`19.98``E
10*8`17.28``N	13*19`16.67``E
10*8`45.80``N	13*20`22.82``E
10*13`59.79``N	13*17`22.50``E
SHEET EROSION	
Latitude	Longitude
10*10`46.53``N	13*18`4.36``E
10*10`42.54``N	13*18`6.31``E
10*9`1.78``N	13*18`9.09``E
10*10`23.02``N	13*20`34.54``E
10*10`42.34``N	13*21`41.00``E
10*14`38.63``N	13*18`19.07``E
10*14`19.75``N	13*18`37.60``E
10*12`53.34``N	13*19`40.85``E
10*8`0.04``N	13*19`20.41``E
10*11`53.43``N	13*19`3.20``E