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Prediction of Soil Erosion Risk in Mubi South Catchment Area, Adamawa State, Nigeria

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Abstract: *The study aims to predicting soil erosion risk in Mubi South catchment area with the aid of RMMF model and Geospatial techniques. In this study, the data used are; land use land cover map derived from Satellite data of 2016. The soil map produced from FAO soil map. The slope map was derived from ASTER GDEM data. The rainfall map was derived from 2016 rainfall data of Nigeria and mask to the watershed area. The RMMFM parameters such as; annual rainfall, soil moisture content at field capacity; agricultural capacity and laboratory capacity, flow accumulation, flow direction, bulk density, effective hydrological soil depth, soil detachability index, ground cover, NDVI, crop cover management factor, slope, interception capacity, canopy cover, soil resistivity, ratio to actual and potential evapotranspiration, surface runoff overland flow and total energy of effective rainfall amongst others were derived for the analysis of soil erosion risk computation in the watershed catchment area. The method employed include used RMMF model with the aid of Geospatial techniques using ArcGIS 10.3 Software, for analysis, presentation of result and laboratory analysis of the sampled soil. The Predicted soil Transport Capacity of Overland Flow indicated about 98% of the study area had about 1.57 t ha^{-1} yr^{-1} soil transport capacity rate of overflow in the watershed. Predicted Total Soil Particle Detachment in the study area was higher (about 69.66 t ha^{-1} yr^{-1} of annual total soil particle detachment) and about 25.26 t ha^{-1} yr^{-1} lower values. It was also found that the south east of the study area were noticed with about 25.26 t ha^{-1} yr^{-1} of 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 areas of very high were found to be around settlement areas like in the case of Sebbore while others are found where there is intensively agricultural area especially in the case of high to moderately 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 characterized by gully and rill erosion in the study area. It is recommended the need for constraints for adoption of conservation strategies innovative because conservation strategies have proved to be effective in controlling soil erosion risk. Also, other soil erosion models be applied in the study area for comparative analysis of soil erosion.*

Keywords: *Soil, Erosion, Risk, RMMFM and Geospatial Techniques.*

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I. Background To 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 but 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 (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) 3. 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 and 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).

According to Brady and Weil (2010), soil erosion consists of three processes; detachment, transportation and deposition as shown in Figure 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).

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). 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).

Ordinal and scalar scales threshold were used and the erosion rate was 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).

Erosion is the most serious natural hazard in Nigeria, affecting several parts of the country. It has killed people, destroyed roads, destroyed homes, schools and farmlands and displaced poor people (Federal Republic of Nigeria, 2007).

Soil erosion of various types and extent are also 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 causes of soil erosion sprang from human activities for various purposes such as; intensive cultivation, over grazing, bush burning and deforestation. These are the principal determinants of variation in types and intensity of soil erosion and Mubi Local Government Area is not exceptional like any other part of Adamawa State (Tekwa, Laflen and Yesuf, 2014).

Soil conservation measures were put in place since 1960s, but still soil erosion is at alarming rate; hence, need to assess and predict rate of soil erosion and risk in the study area.

During the last decade, many different models and theories had been proposed to describe and anayse soil erosion by water and associated sediment yield. The models and theories were used to predict soil loss and to assess soil erosion risk. GIS is also used as basis for interpolating spatial variability of hydrophysical parameters for soil erosion model (Tesfahunegn *et al.*, 2011b).

To predict soil erosion and suggest appropriate management plans, Revised Morgan Morgan and Finney (RMMF) Models was 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, 2005). Also, RMMF was 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 models was 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 is 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, the need of this study in order to predict soil erosion risk in the Mubi South Local Government Area of Adamawa State, Nigeria.

1.2 STATEMENT OF RESEARCH PROBLEMS

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, it has led to reduction in crop productivity, flooding, ecological destruction and environmental degradation (Tekwa *et al.*, 2014).

Previous research (Tekwa *et al.*, 2014) observed that soil erosion in the study area also alters vegetation cover, ground slope, slope length and shape, thereby influencing soil erosion rate and leading to the formation of gullies and rills erosion. It also lead to significant soil loss and degradation, destruction of physical infrastructures such as buildings, drainages, roads and culverts; especially around Barama, Anguwan Barkono, Digil, Lamurde and Tudun Wada of the study area (Tekwa *et al.,* 2014). These were also confirmed by researcher during reconnaissance surveys of 2015 and January 2016. Thus, the need for assessment and predicting 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.

Also, based on literature review and the researchers knowledge, no previous researches has, however, explored the power of Revised Morgan, Morgan and Finney with Geospatial Techniques for prediction of soil erosion risks in Mubi; south of Adamawa State, Nigeria, 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/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 failed to map areas that were vulnerable to soil erosion risk. Moreover, they did not apply geospatial techniques to show patterns, spatial distribution and maps of soil 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 to conduct such research in Nigeria and Mubi South Local Government area in order to test the performance of the RMMF Hence, the quest for integrated models of Revised Morgan-Morgan Finney model, remote sensing and GIS techniques to predict soil erosion risk in Mubi South Loclal Government Area gave rise to the present study.

1.3 AIM

The aim of this study is to predict soil erosion risk in Mubi South watershed area with the aid of RMMF models and Geospatial techniques.

1.4 THE SCOPE OF THE STUDY

On the basis of spatial extent, the research was carried out in Mubi south catchment area, Adamawa State and focused on prediction of soil erosion risk using Revised MMF model 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. On content, 80 soil samples were collected in July 2016 and coordinates of the sample points were derived using grid system in GIS software environment as shown in Figure 2. Coordinates and soil samples for all of gully, rill and inter-rill erosion of the study area collected. Only their hydrophysical parameters were measured in laboratory.

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 crop parameter (mainly maize, beans and sorghum) from erosion plots. The research covered soil erosion data as at July, 2016.

1.5 THE STUDY AREA

1.5.1 Location and Description of the Study area

Mubi south Local Government Area is located in Northeast Nigeria between latitudes 10º 4′ 30”N - 10º 15′ 0” N, and Longitudes 13º 20′E 0” - 13º 27′ 0”E of the Greenwich Meridian. The study catchment area 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 show on Figure 3.

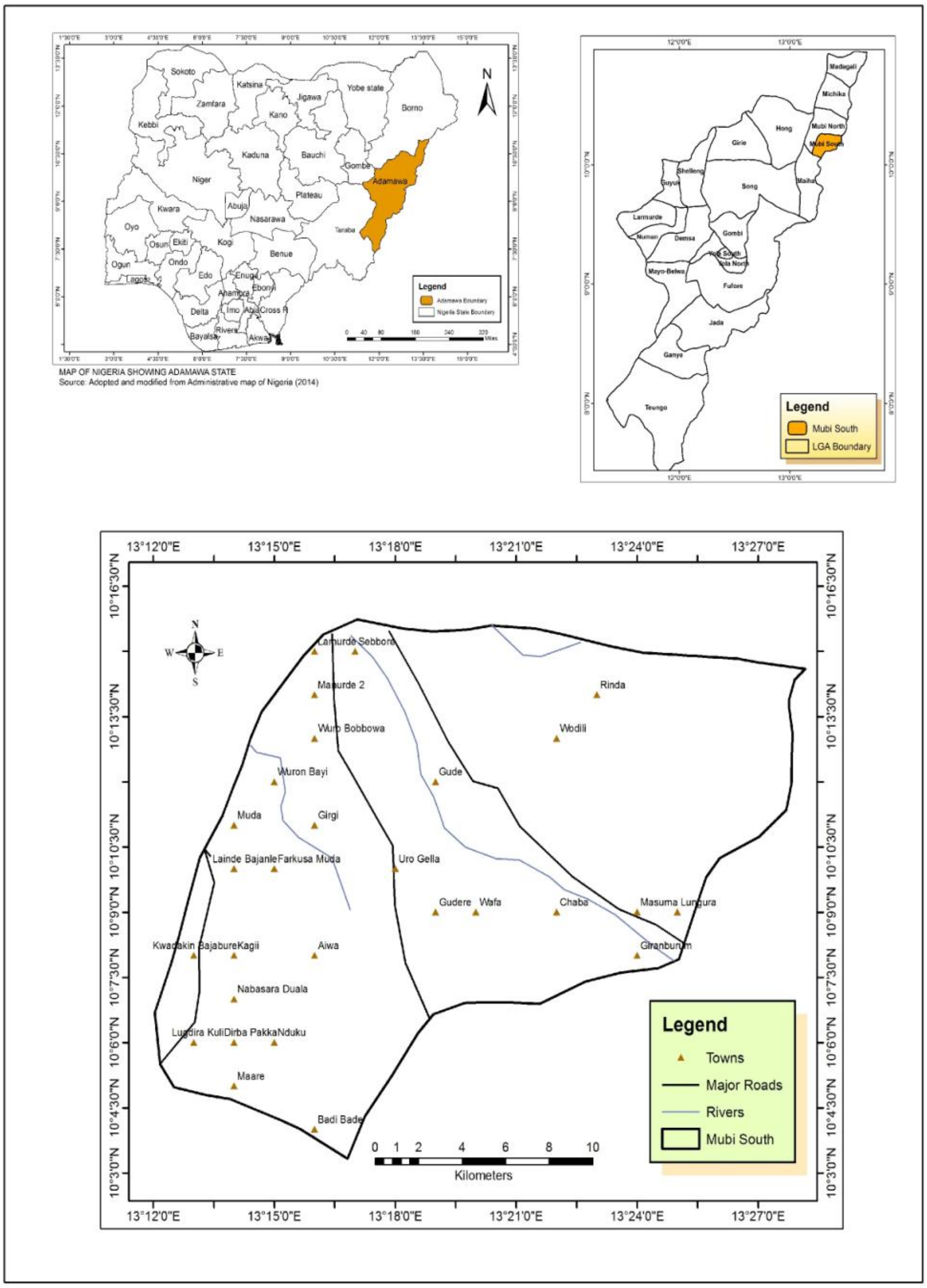

Figure 3: Map of the Study Area
Source: Modified from the Administrative Map of Adamawa State and field Survey (2015)

The climate of the study area is typical of the West African Savanna climate. 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^{o}C particularly in April and while minimum temperature can be as low as 18^{o}C in the south to 27.8^{o}C 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 4.5 m to 4.6 m rate of potential evapotranspiration.

The area is characterized by a typical tropical wet (April-October) and dry (November-March) climate with a mean annual rainfall ranging from 700 mm to 1,050 mm (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 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 State are the Southern Guinea Savannah, Northern Guinea Savannah, and 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.

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. 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 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 mm of soil porosity and 11.46 gkg^{-1} organic matter.

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). 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.

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.

1.6 METHODOLOGY

1.6.1 Reconnaissance Survey

Reconnaissance survey was carried out by the researcher to get acquainted with the study area in terms of selections of coordinate location points, choice for major land use classes, ground thruthing and major crop types selected for the study.

1.6.2 Type 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 GLCF web	Input Parameter for the Model as land use type
2	ASTER Image (DEM) (Advanced Spaceborne Thermal Emission and Reflection Radiometer)	Download from GLCF web	Input Parameter for the RMMF Model
3	Coordinates for the 80 soil sampling points	Field survey	Input Parameter for the RMMF Model
4	rainfall data	Geography department ADSU Mubi	Input Parameter for the RMMF Model
5	Organic matter Content	Laboratory determination	Input Parameter for the RMMF Model
6	Soil texture (Particle size distribution)	Laboratory determination	Input Parameter for the RMMF Model
7	Soil moisture (gravimetric)	Laboratory determination	Input Parameter for the RMMF Model
8	Soil detachability index	empirical relations	Input Parameter for the RMMF Model
9	Bulk density	Laboratory determination	Input Parameter for the RMMF Model
10	Cohesion of soil surface (aggregate stability)	Laboratory determination	Input Parameter for the RMMF Model
11	Soil moisture storage capacity	Field and laboratory determination	Input Parameter for the RMMF Model
12	Effective hydrological top soil depth. (porosity/particle density) Milting points at 0, 0.3 and 15 bars.	Laboratory determination	Input Parameter for the RMMF Model
13	Ratio of actual to potential evapotranspiration	empirical relations	Input Parameter for the RMMF

			Model
14	Crop types cover	Field survey	Input Parameter for the RMMF Model
15	Vegetation cover	Landsat imagery of 2015 in ArcGIS 10.3	Vegetation cover conditions for RMMF
16	Slope steepness	From ASTER image	Input Parameter for the RMMF Model

Source: Adopted from Iguisi, (2003)

1.6.3 Materials Used for the Research

The software used in conducting this research is ArcGIS 10.3 version used in generating some of the input data for models, analysis and presentation of result. The hardware used in conducting this research includes the followings: computer, mouse and printer.

1.6.3.1 Field Instruments Used

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

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

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

iv. Mettler Electronic Scale was used for measurements of soil moisture content at field capacity.

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

vi. Soil Thermometer was used to take soil temperature at field capacity.

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

1.6.3.2 Field Work

i. Soil Sampling

Grid Soil Sampling was used as bases to divide a field into soil units (zone sampling) in order to determine soil variability in the sampling zone and provide more information about soil hydro-physical parameter for the sample collected from entire 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).

ii. Soil Sample Collection

Each sampled soil was collected at 1.4km (l,240m) intervals along transects which were also 1.4km (l,240m) at a map scale of 1:100,000 apart and using spiral auguring (see Plate 4.10 to Plate 5.11). This helped in taking unbiased soil samples at equal intervals and in taking the soil coordinates. Since soils are heterogeneous in nature, there is a need to take the coordinates at equal interval (Birrell, Sudduth and Kitchen, 1996; Franzen, *et al.,* 1998). All the composite soil samples was collected 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. A total of 80 soil samples was collected based on grid sampling points generated in ArcGIS 10.3. Figure 4.1 shows the samples locations collected for this study.

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 4.08 for the equipment used), disturbing the sample soil structure as little as possible (Dirksen, 1999). Also core sampler of 5 cm 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 4.09. Open Data Kit form server platform (ODK) was used for soil sapling location description as show in Appendix I Form. Soil samples were air dried and sieved through 2 mm 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.

Soil sample coordinates 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, Plate 4.1 to Plate 4.2 shows the pictures of field assistance.

Plate 4.1: Equipment used for data collection during Field Work
Source: Author's Field Work (2016)

Plate 4.2: Core sampler used to take reading for Soil Moisture Content at field Capacity
Source: Author's Field Work (2016)

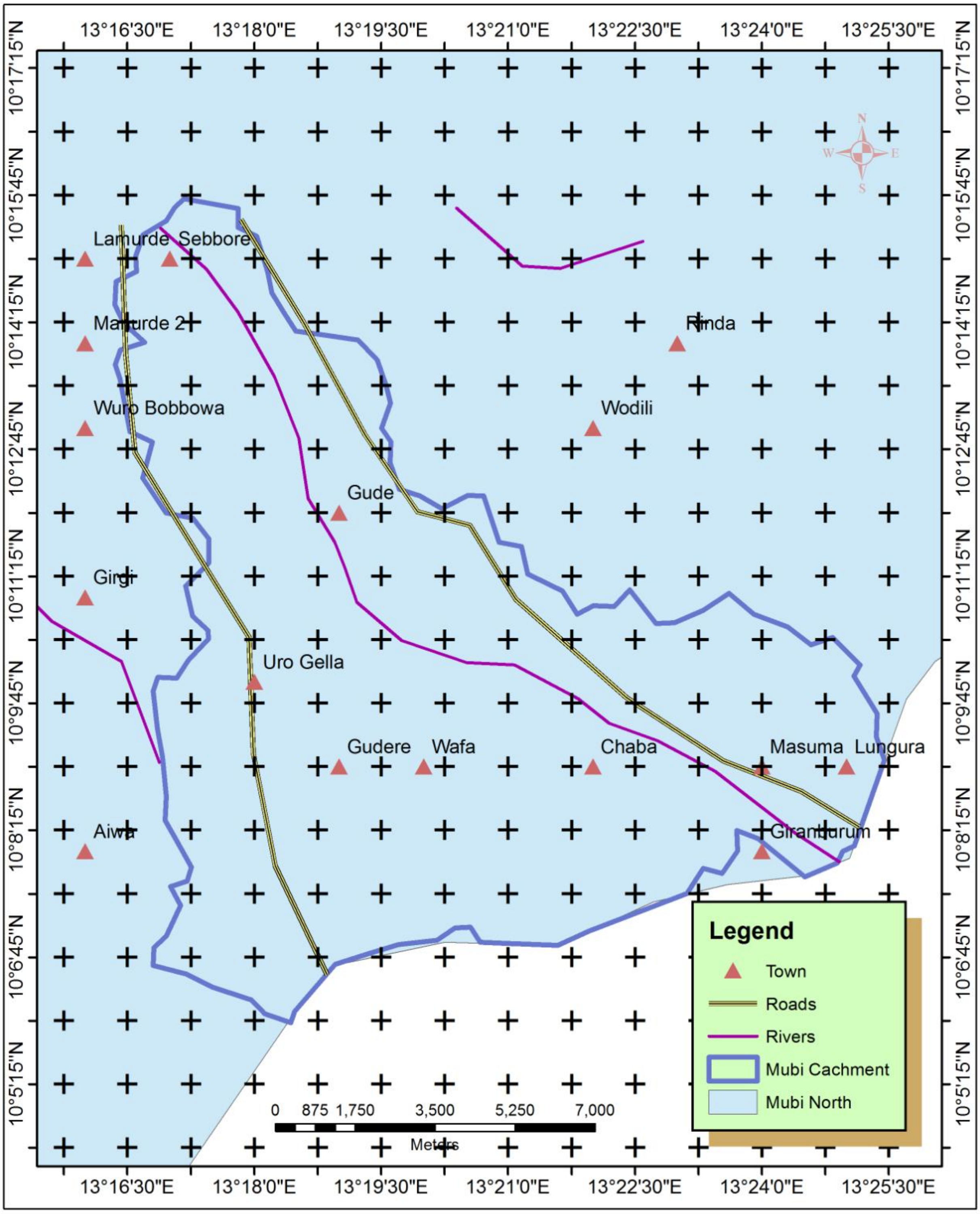

Figure 4.1: Mubi South showing 80 Grid Sample Points within the Catchment Area
Source: Generated from Advanced Spaceborne Thermal Emmission and Reflection (ASTER) Imagery of (2015)

Plate 4.3: Soil data collection along Transects during Field Work
Source: Author's Field Work (2016)

Plate 4.4: using spiral auguring for Soil data collection during Field Work
Source: Author's Field Work (2016)

Plate 4.14b: Field Assistance during research field work
Source: Author's Field Work (2016)

1.6.3.3 Laboratory Instruments Used

i. Sieve of 2mm was used to sieve 10g air dry soil for laboratory analysis.
ii. Bouyoucos hydrometer was used as measurement cylinder to determine soil texture.
iii. Capillary action in KR box was used to determine soil moisture content in the laboratory in 1500F1 20 Bar Pressure Plate Extraction.
iv. Pipette and sieving was used to determine soil particle size.
v. Erlenmeyer flask was used to weigh soil organic matter.
vi. 1500F1 20 Bar Pressure Plate Extraction was used to determine soil moisture retentions.
vii. Soil sampling Retaining Ring was used inside Pressure Plate hold sample during the extraction process.
viii. Soil psychrometer was used to estimation of effective soil hydraulic properties by top soil moisture.
ix. Pocket penetrometer was used to measure Cohesion of soil amongst others.

1.6.4 Input Parameters for the RMMF Model

The Input Parameters used for the RMMF Model were presented on Tabble 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 (^{o})
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)

i. Empirical Relations in Deriving Inputs of RMMF Model.

Some intermediate input parameters were used estimated from observed data in the catchment using the empirical relations described in (Morgan, Morgan and Finney, 1984) as:

$$E = R\,(11.9 + 8.7\log_{10}{}^{(I)}),$$
$$R_c = 1000 * \mathrm{MS} * \mathrm{BD} * \mathrm{EHD} * (Et/E_o)^{0.5},$$
$$\mathrm{SR} = R\exp(-RC/R_o), \quad \text{(Equation 1)}$$
$$R_o = R/R_n,$$

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 rain 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 ($E\ o$) 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).
The Cf combines C and P factors of the Universal Soil Loss Equation to give ratio of soil loss under a given management to that of bare ground with down-slope tillage, other conditions being equal. Where E is annual kinetic energy of rainfall (Jm^{-2}), I is intensity of rainfall which is assumed to be 25 mmh^{-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), $R\ o$ is annual rain per rain 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 ($E\ o$) evapotranspiration. EHD is the top soil depth within which the storage of water affects the generation of runoff.

Intermediate maps were derived on the basis of land use/cover map include ratio of actual to potential evapotranspiration ($E\ t/Eo$), permanent rainfall contributing to permanent interception, and stream flow (A) and crop cover management factor (Cf). These were determined in the field.

Intermediate layers were generated from hydrophysical soil map (soil texture) including; soil detachability index (K) and cohesion of topsoil (COH) using ArcGIS 10.3 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.

1.6.4 Soil Laboratory Analysis

Table: 4.3: 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.

Table 4.3: 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 (2001)
6	Cohesion 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)

1.6.5 Image Processing

The Satellite image of the study area was corrected geometrically to remove distortions and subsequently enhanced to improve visual interpretation. This followed by classification into different landuse types. Supervised classification was employed because of its high accuracy and the researcher's knowledge of the training areas. Ten coordinates location for each landuse class were 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 was 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.

1.6.6 Techniques of Data Analysis

The stated objectives were achieved through the following:

i. **Assess patterns distribution of hydrophysical parameters:**

This was carried out using Geostatistical Interpolation in ArcGIS 10.3 software environment**.** The point data and their corresponding coordinates were downloaded from ODK Form entered into ArcGIS 10.3 software;

maps of hydrophysical model, input parameters were developed using kriging interpolation 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 location. Also, map of the characterized hydrophysical parameters based on soil erosion were produced. Ordinary kriging was selected as the preferred interpolation method for RMMF model spatial inputs derivation because it was more reliable than the other interpolation methods based on the mean squared error which compares measured values with the predicted ones.
Moreover, since the spacing to be measured or observed 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 determines the 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.

ii. Predict soil erosion risk in the study area. The soil erosion amount was predicted using the RMMF models as shown below:

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 are 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 as follows:
F (rate of soil detachment by rain drop impact) = $10^{-3} * K * (E * e^{-0.05A})$,
H (rate of soil detachment by runoff) = $10^{-3} * (0.5\text{COH})^{-1}(\text{SR})^{1.5} \sin(S)(1-\text{GC})$, (Eq.6)
TC (transport capacity of overland flow (runoff)) =$10^{-3} * Cf * \text{SR}^2 * \sin(S)$,
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/catchment area. Predicted soil erosion rate was classified into soil erosion risk classes (Singh, *et al.*, 1992): i.e.; very low, low, moderate, moderately high, high and very high.

1.7 RESULTS AND DISCUSSION

1.7.1 Soil Laboratory Analysis for RMMF Model Parameter

Table 5.1 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 5.1 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

Source: Author's Analysis (2016)

1.7.2 Landuse, Landcover in the Watershed

Table 5.2 presents result of land use land 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.
As shown on Table 5.2, 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. However, most to be area was also covered by bare land where no agricultural activities is taking place neither covered by forest.

Table 5.2: 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)

1.7.3 Assessment of the Spatial Distribution of Hydrophysical Parameters

Before assessment of spatial distribution of hydrophysical parameters of soil in Mubi South watershed, there is a need to assess the physical land morphology which plays a vital role in determining of 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 determinant factors that lead to soil erosion in the study area. Also, the Soil Laboratory Analysis for RMMF Parameters were used in assessing the spatial distribution of hydrophysical parameters which were later used as an input in predicting soil erosion risk in Mubi South watershed.

iii. Assess patterns distribution of hydrophysical parameters:

This was carried out using Geostatistical Interpolation in ArcGIS 10.3 software environment**.** The point data and their corresponding coordinates were downloaded from ODK Form entered into ArcGIS 10.3 software; maps of hydrophysical model, input parameters were developed using kriging interpolation 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 location. Also, map of the characterized hydrophysical parameters based on soil erosion were produced. Ordinary kriging was selected as the preferred interpolation method for RMMF model spatial inputs derivation because it was more reliable than the other interpolation methods based on the mean squared error which compares measured values with the predicted ones.

Moreover, since the spacing to be measured or observed 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) 43. The semivariogram analyses were conducted before application of ordinary kriging interpolation of the input parameters. This is because semivariogram model determines the 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.

1.7.4 Predicted Soil Erosion Risk

Soil erosion risk of the study area was predicted using hydrophysical parameters analyzed in Department of Soil Science Laboratory Ahmadu Bello University, Zaria. 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 5.1 to Figure 5.4.

1.7.4.1 Surface Runoff/Overland Flow (SR)

Result of spatial distribution of surface runoff/overland flow (SR) is presented in Figure 5.1.

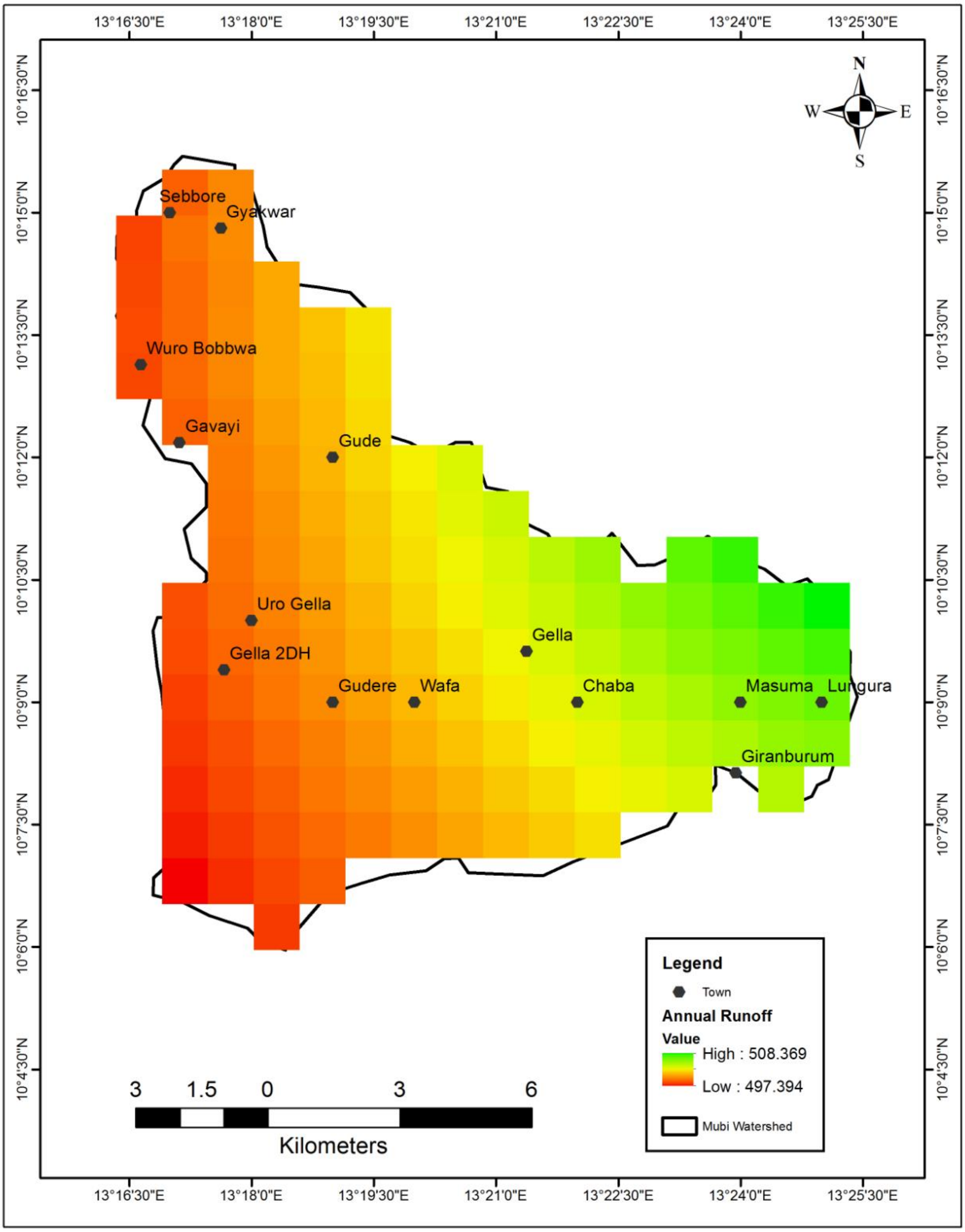

Figure 5.1: Estimated Runoff
Source: Author's Analysis (2016)

From Figure 5.1, 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 5.1. This is attributed to nature of landuse/landcover management practices in the study area.

1.7.4.2 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 5.2.

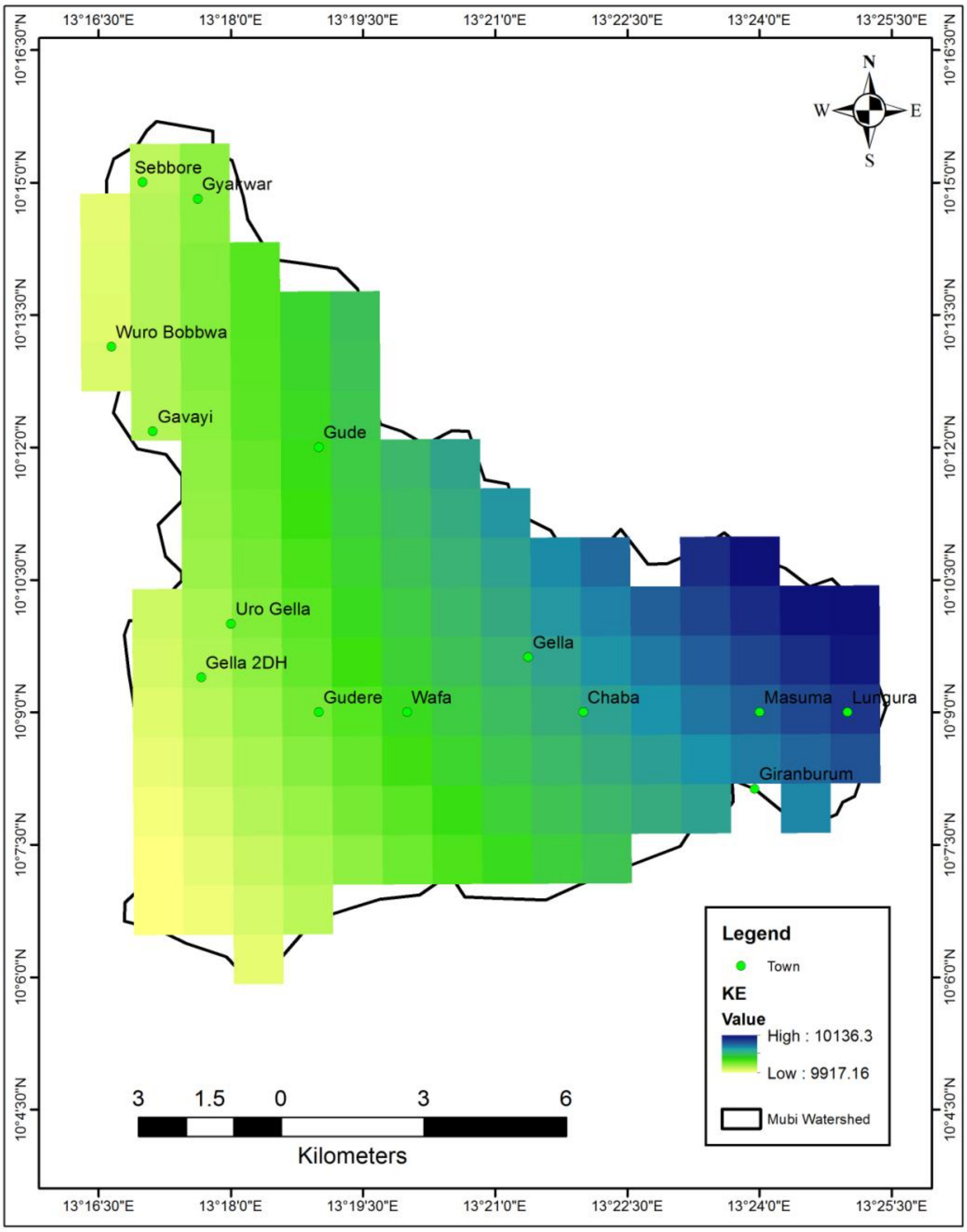

Figure 5.2: Total Energy of Effective Rainfall (KE)

Source: Author's Analysis (2016)

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 control runoff and soil loss.

1.7.4.3 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. 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).

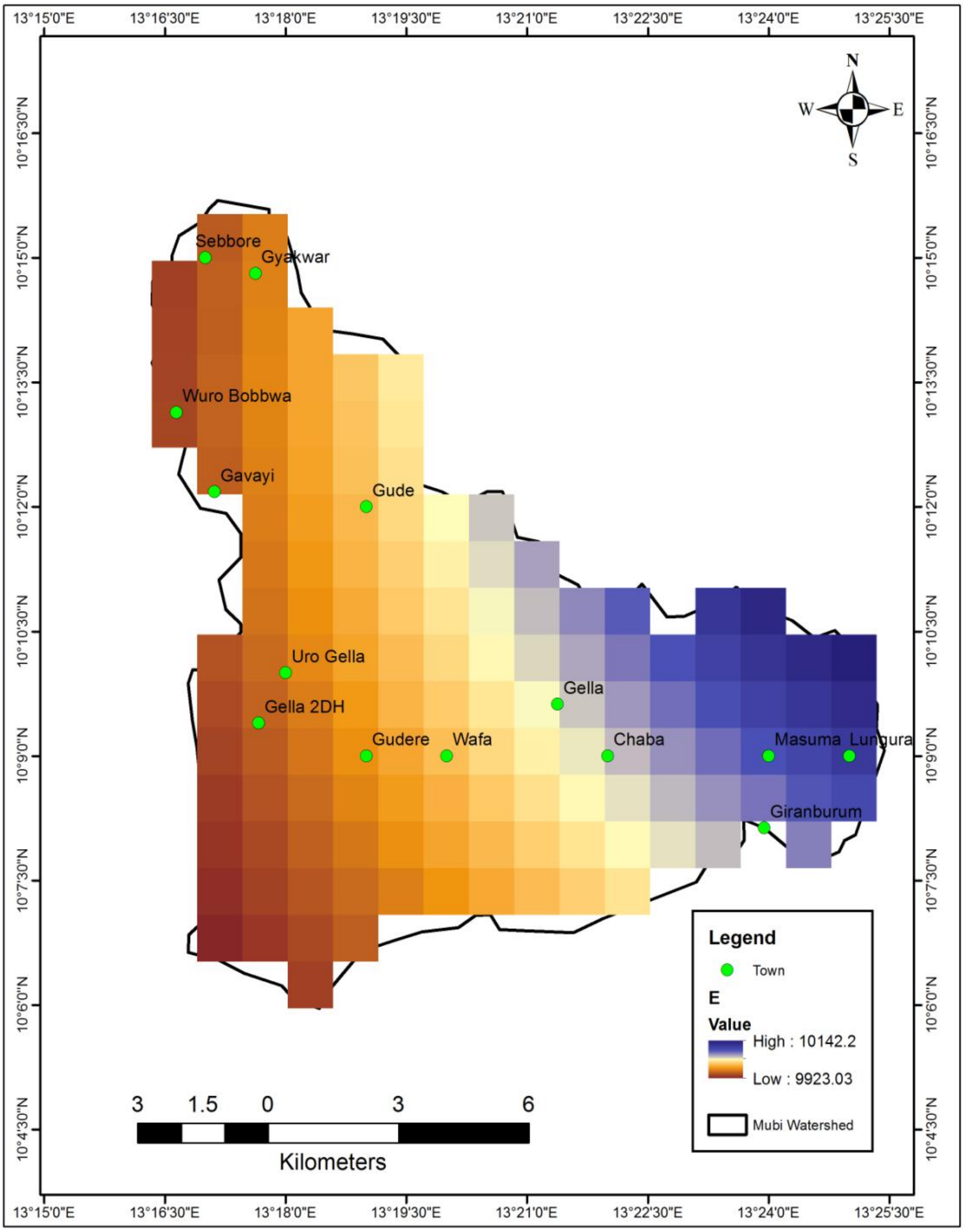

Figure 5.3: Annual Kinetic Energy of Rain Jm^{-2}(E)

Source: Author's Analysis (2016)

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 5.3.

From Figure 5.3, it was determined that kinetic energy of rainfall increased towards 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 resulted from 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 that owing 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).

1.7.4.4 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 5.4. The soil resistivity was used as input to determine runoff detachment as shown in Figure 5.5.

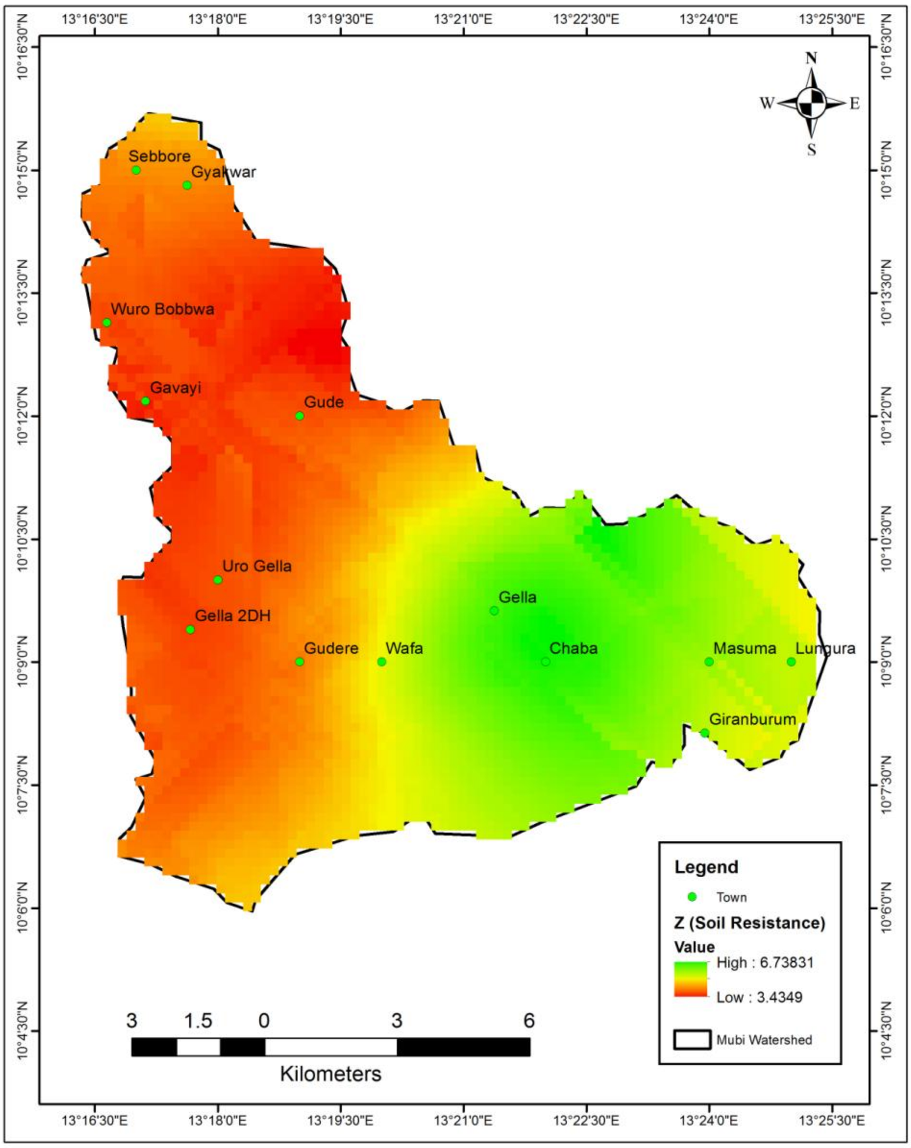

Figure 5.4: Soil Resistance (Z)

Source: Author's Analysis (2016)

Soil resistance as shown in Figure 5.4 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 inferred 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 were 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 reverse was the case for areas with low soil resistivity.

1.7.4.5 Soil Particle Detachable by Rain Drop

Spatial distribution of predicted soil particle detachability of raindrop in the study area is shown in Figure 5.35.

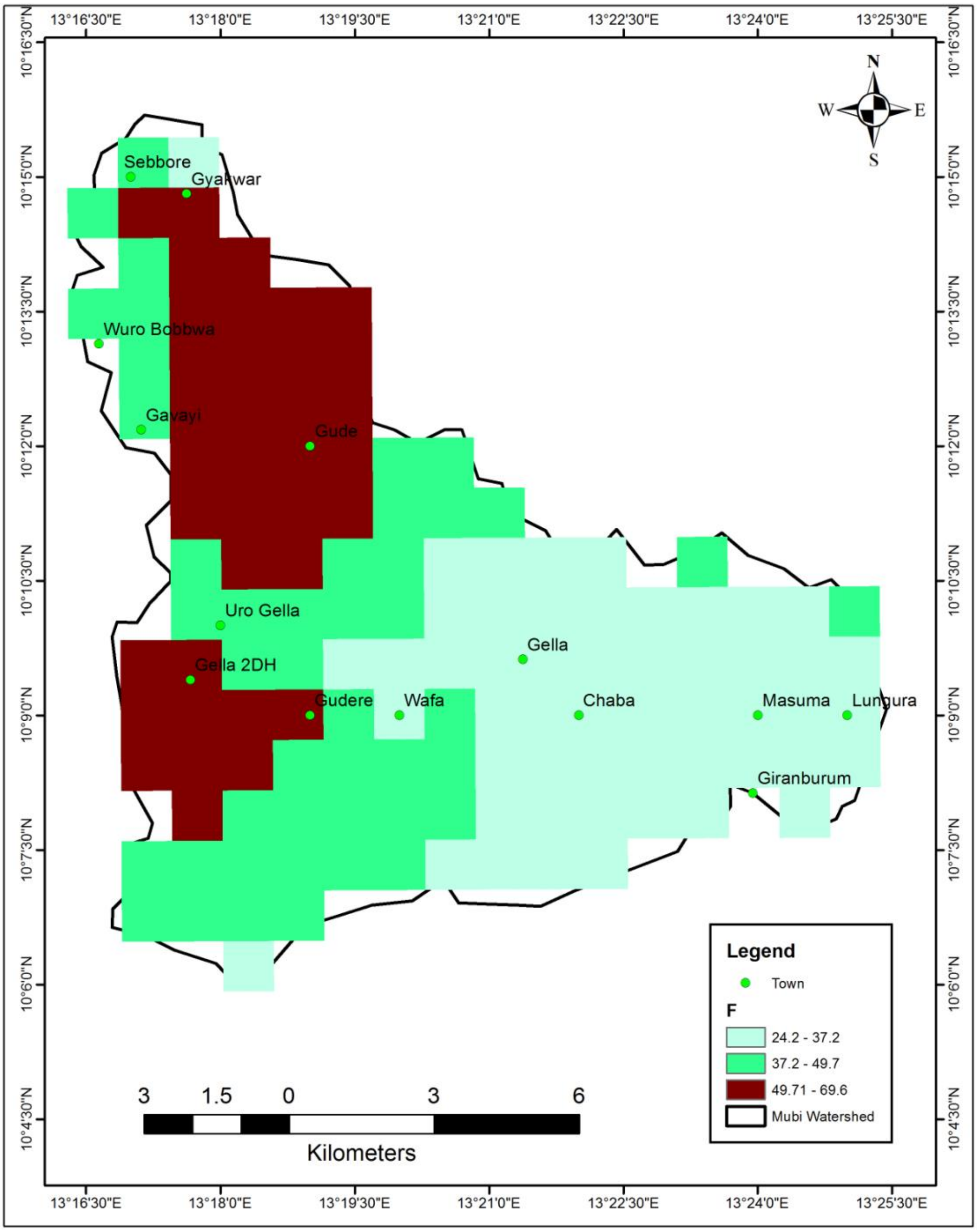

Figure 5.5: Soil Particle Detachable by Raindrop (F)

Source: Author's Analysis (2016)

From the predicted result of soil particle detachability in Figure 5.5, it was inferred that soil particles were categorized 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 4.9.7.1 – 6.9.6 tha^{-1} yr$^{-1($} high) respectively. 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 5.4). Also, observed in areas with high annual kinetic energy, high particle density with high sandy soil content (Figure 5.9). Roreover, 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 watershed as supported by FAO (1978) whereas reverse is the case with the areas having moderate to low soil particle.

1.7.4.6 Predicted Rate of Soil Detachment by Runoff

The result of spatial distribution of predicted rate of soil detachment in the study area is shown on Figure 5.6.

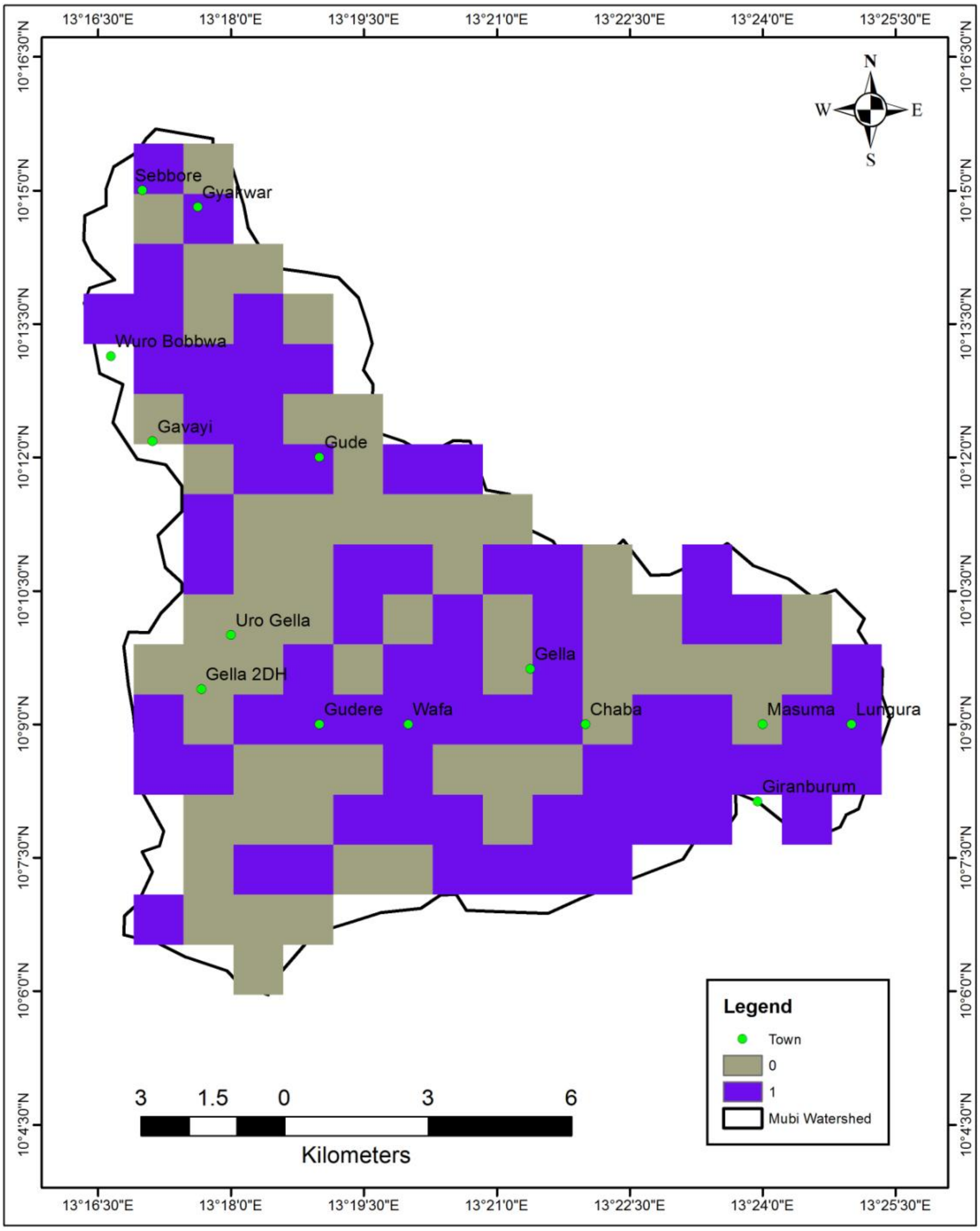

Figure 5.6: Rate of Soil Detachment by Runoff (H)

Source: Author's Analysis (2016)

As presented in Figure 5.6, watershed area had annual rate of 1 t ha^{-1} yr^{-1} soil detachment. It was found that rate of soil detachment by runoff occurred 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.

1.7.4.7 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 Figure 5.7. To show that, about 98% of the study area had about 1.57 t ha^{-1} yr^{-1} soil transport capacity rate of overflow in the watershed. The areas with low 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.

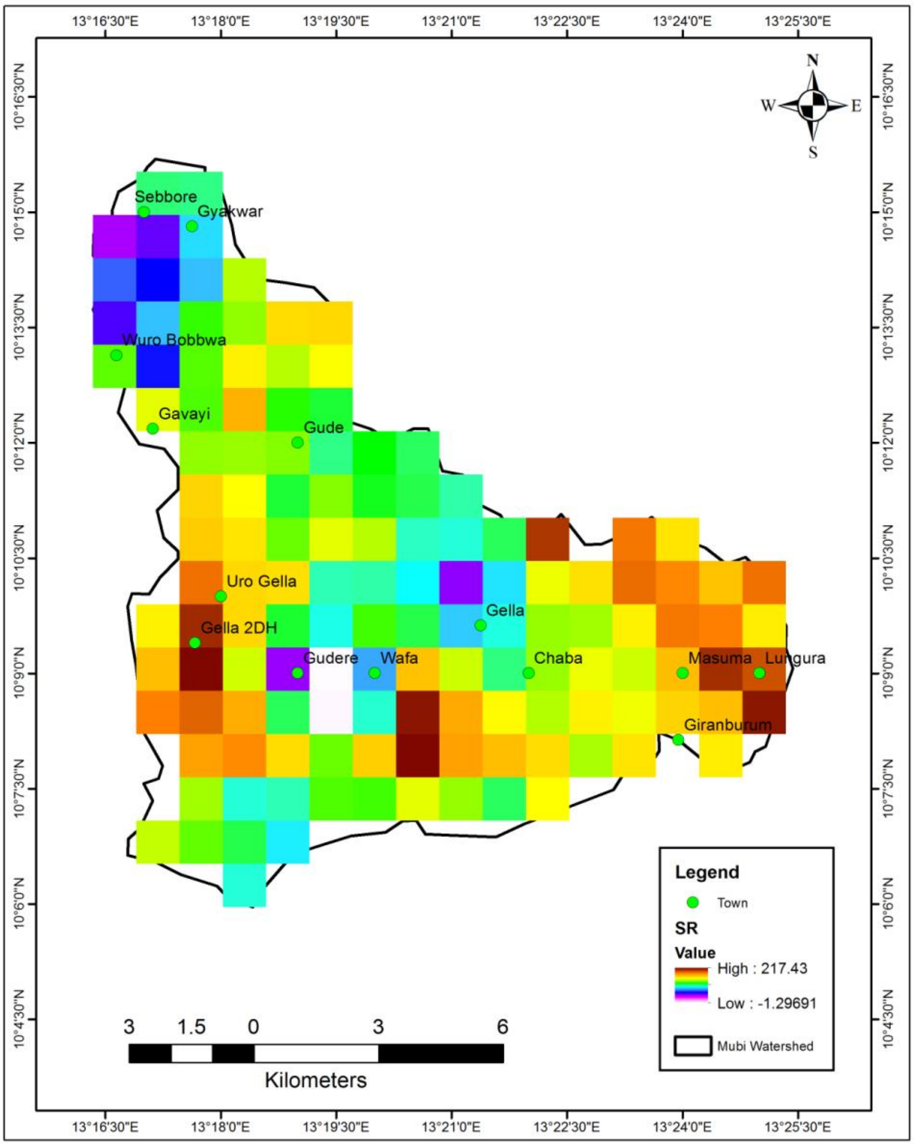

Figure 5.7: Surface Runoff/Overland Flow (SR)

Source: Author's Analysis (2016)

1.7.4.8 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 Figure 5.8.

Figure 5.8 shows that the study area has higher value of about 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 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.

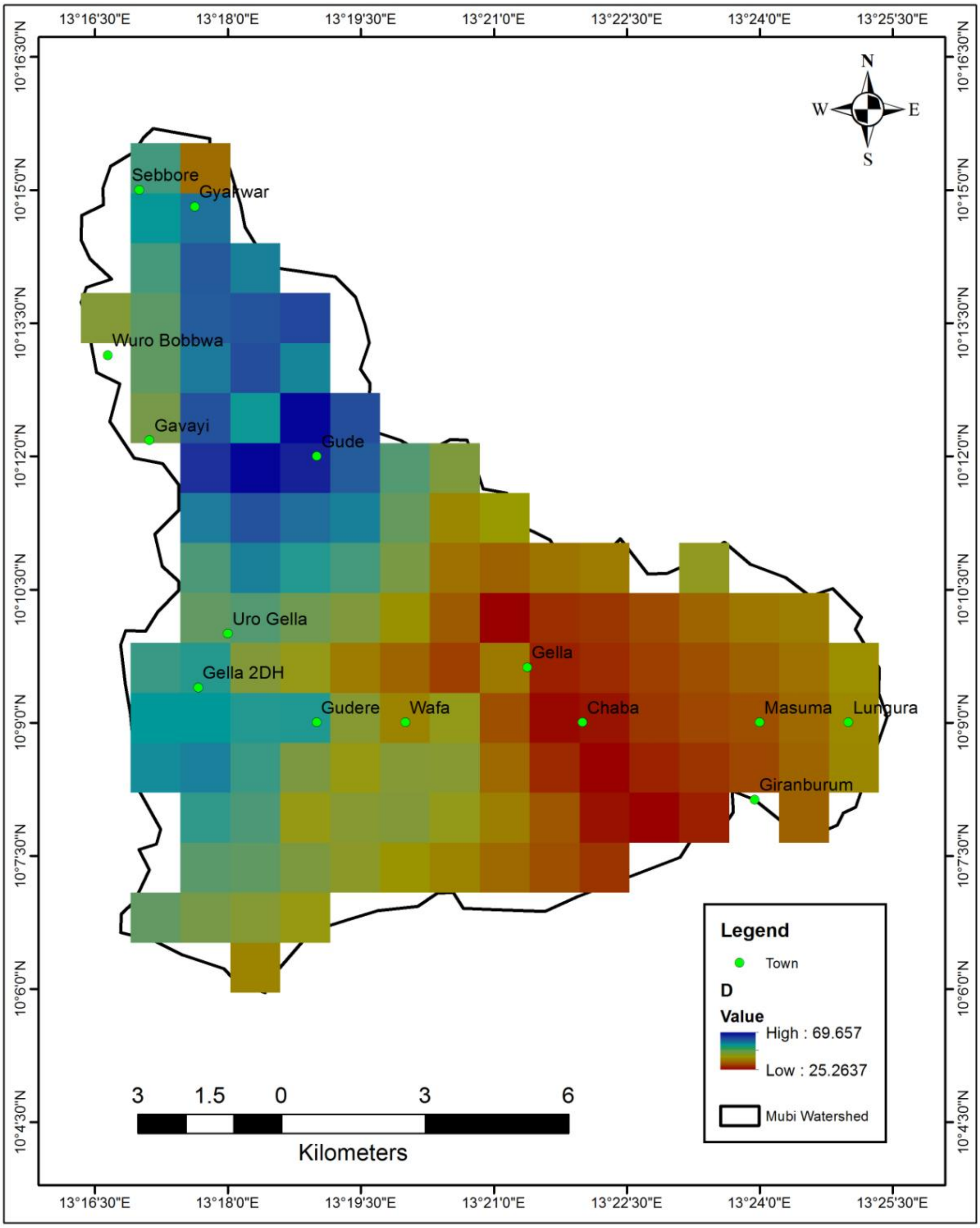

Figure 5.8: Total Particle Detachment (D)

Source: Author's Analysis (2016)

1.7.4.9 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 (watershed) is presented in Figure 5.9.

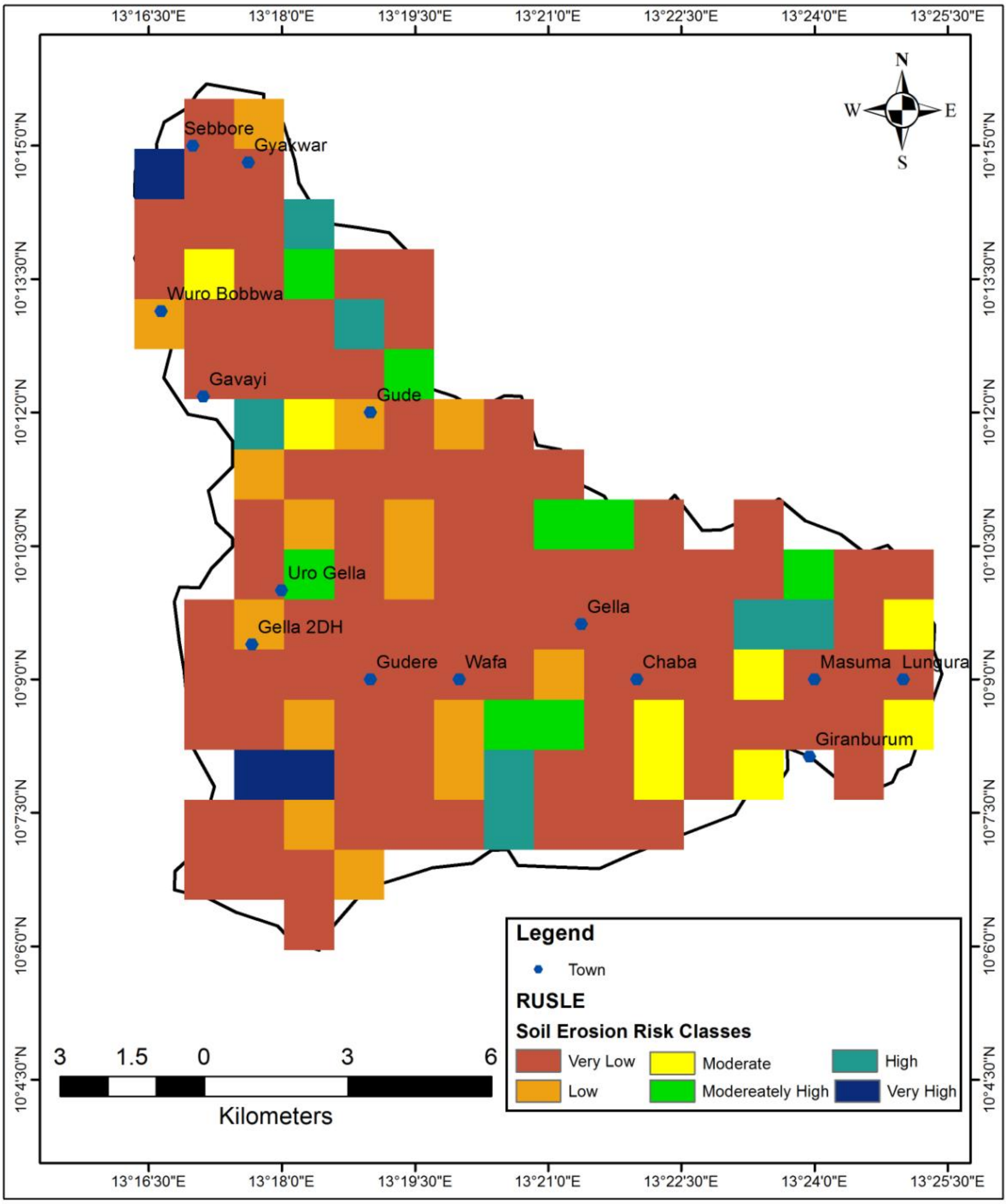

Figure 5.9: Soil Erosion Risk Map

Source: Author's Analysis (2016)

Figure 5.9 shows the class as well as spatial distribution of soil erosion risk in the study area. It was noted that about 50% of the watershed had 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 was covered by low soil erosion risk, 12 % moderate, 6 % moderately high, 11 % high and 4 % very high.

Based on this result, it could be said that the watershed areas have 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 moved large grains, even rock fragments up to 9 cm in diameter (Poesen, 1987).

Also, 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 5 mm. 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 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.

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).

CONTRIBUTIONS TO KNOWLEDGE

i. The watershed 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).
ii. This document provides document that shows the extents and nature of watershed catchment area in Mubi South Local Government Area, and zones of soil erosion risk of the study area which can be used as basis for further research works.
iii. 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.
iv. It also serves as document for sustainable Drainage System for soil erosion risk management with the aim of preventing soil erosion risk within a watershed catchment and urban surface flow (runoff).

II. 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. 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.

III. Recommendations

i. Also, others soil erosion model to be applied in the study area to further compares and analyse soil erosion risk.
ii. Agronomic measures, combined with good soil management, are 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).
iii. There is the need for soil conservation supports by individual or private organizations, Local Government, State and Federal Government so as to provide protective measures in order to retain their reputations for management of the environment as recommended by Morgan (2005).
iv. There is the need for constraints for adoption of conservation strategies innovative because conservation strategies have proved to be effective in controlling soil erosion risk as also supported by FAO (2002).
v. 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.

6.3.1 Recommendation for Further Research

i. The Mubi South Local Government Area has two Watershed catchment areas. This research concentrated in one catchment 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. 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.
iii. 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.
iv. It is also recommended for comparative research between physical and chemical parameters of soil erosion to be conducted in the study area.

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APPENDIX I

LOCATION OF THESIS SOIL SAMPLE SITES IN MUBI CATCHMENT AREA

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

APPENDIX 11
SOIL PROFILE DESCRIPTION

Soil Profile Number ……………………………

A) Information of Soil Profile Site

Date of examination	/ /
Authors	……………………………………………………………………………
Status	Mini-pit description………………………………………………
Location (UTM)	……………………………………………………………………………
Elevation (meters)	……………………………………………………………………………
Locality	……………………………………………………………………………
Landscape	……………………………………………………………………………
Geological unit	……………………………………………………………………………
Position	……………………………………………………………………………
Slope	……………………………………………………………………………
Local Relief	……………………………………………………………………………
Vegetation	……………………………………………………………………………
Land use	……………………………………………………………………………

B) Information on Soil Profile

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
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