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Potential Soil Erosion Mapping Using RUSLE, Remote Sensing and GIS: The Case Study of Wolaita Sodo Town and Surrounding Area, SNNPR, Ethiopia

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Abstract

Soil erosion is the process of detachment, transportation and deposition of soil particles from land surface and events that cause economical, social and environmental damage. It is still one of the most important land problem and most pronounced form of soil degradation in Ethiopia. This study exploits the integrated approach of the Revised Universal Soil Loss Equation (RUSLE) with GIS and remote sensing techniques to assess soil erosion harshness in the Wolaita Sodo Town and surrounding areas. Digital elevation model (DEM), land use/land cover (LU/LC) maps, and rainfall and soil data were used as an input to identify the most erosion prone areas. Accordingly, the area was classified into five erosion intensity classes: very low (13.574%), low (9.873%), moderate (29.117%), high (18.792%) and very high (28.644%) risk classes. The soil erosion modeling showed an extremely high erosion risk in the bare land and a high erosion risk in the agriculture areas. The results of the study revealed that the total amount of potential soil loss in the study area is 500.9tons/ha/yr. The RUSLE model integrated with RS and GIS can easily identify areas that are at potential risk of extensive soil erosion and provide information on the estimated value of soil loss at various locations in the watershed area.

Keywords: Soil erosion, RUSLE, RS, GIS, Wolaita Sodo.

1. Introduction

1.1. Back Ground of the study

Soil erosion occurs naturally as a result of the dispersive action of rain and the power of water and wind to initiate soil detachment and transport soil particles across the surface (Golden Horseshoe Area Conservation Authorities 2006). As cited in Solomon (2004), the erosive action includes two processes: detachment and transport of soil particles (Morgan, 1995; Sharma, 1996). Blum (1998) and Morgan (1995) define soil degradation that includes, primarily, soil erosion as the loss of soil's capability to give sustained productivity or utility, which can be induced naturally or caused/accelerated by anthropogenic activities. The extent of erosion losses will depend on climate, topography, and the ability of soils to resist detachment and infiltrate water, but a good vegetative cover can largely offset the effect of these factors. As cited in Kebede (2014) Soil erosion is the most serious form of land degradation, in which it's on-site and off-site effects threaten the

Most studies in Ethiopia indicated that sheet and rill erosion by water and burning of cow dung and crop residue are the major components of land degradation that affect on-site land productivity (Hurni, 1993; Zeleke and Hurni, 2001). According to the Ethiopian Highland Reclamation Study (FAO, 1984), in mid1980's 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million hectares beyond reclamation. In general, Soil erosion is one of the major factors causing severe land degradation risk in Ethiopia, which in turn is threatening the agricultural productivity and the very survival of the overwhelming majority of the rural population. The rate of soil loss, depletion of soil organic matter and nutrients as a result is so high and much faster than they can be replaced. The Ethiopian Highland Reclamation Study (FAO, 1986) estimated that water erosion removes nearly 1.9 billion tons of fertile soil from highlands annually.

Erosion models are used to predict soil erosion. Soil erosion modeling is able to consider many of the

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complex interactions that influence rates of erosion by simulating erosion processes in the watershed. The Universal Soil Loss Equation (USLE) model is one of the real advancements in soil and water protection in the 20th century. This exact model has been connected far and wide to gauge soil disintegration by raindrop effect and surface spillover. It was at first proposed by Wischmeier and Smith (1965) taking into account the idea of separation and transportation of particles from precipitation to gauge soil disintegration rates in farming regions.

As cited in Jiang (2013) the Revised Universal Soil Loss Equation (RUSLE) is a widely used soil erosion intensity evaluation model, modified and improved from the Universal Soil Loss Equation (USLE), developed by Wischmeier (1976). There are several factors included in this model, such as rainfall erosivity, soil erodability, slope length and steepness factor, cover management factor, and conservation practice factor. RUSLE can be treated as a kind of multi-criteria analysis, since the results are calculated according to the influencing factors.

Geographical Information System (GIS) becomes a valuable tool. A GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced data (ESRI, 1994**).** Soil Erosion models are now being integrated in various Geographical Information Systems (GIS) software. The capability of GIS to integrate and analyze different layers of spatial data complements the setting of soil erosion models, which combine the influence of various factors that affect the erosion process (Tattao, 2010).

1.2. Statement of the Problem

Soil erosion has become a global concern for sustainable livelihood and recognized as a serious problem throughout the world. The erosion process is accelerated rapidly due to direct and indirect participation of human activities. Human activity such as construction of roads, highways, and dams, control works on streams and rivers, mining, and urbanization usually accelerate the process of erosion, transport, and sedimentation (Julien, 2010). Soil erosion has negative effects on land resource, soil productivity and available agricultural land and water resources due to sedimentation. There have been dangerous erosion and flood cases that have happened in the study area in 2006 and April 19, 2018.In rainy season high erosion and flood, which is normally due to the intensive rainfall in the up lands of the Damote Mountain, steep slopes and low infiltration capacity of the ground surface, is a major threat to the people living down town. Every summer month's excessive rain has cause erosion and flooded rivers and stranded families in low-lying areas. The incidents have caused damage to life, property and infrastructures due to overtopping. It appears that the impacts of these erosion and flood incidents are increasing, for instance even houses were destroyed during the last flood in 2018.

1.3. Objective

The aim of this study is to mapping potential soil erosion using RUSLE model and GIS and remote sensing background information for decision-making in Wolaita Sodo Town and surrounding areas.

1.3.1. Specific objective of these studies are

- to produce maps showing the distribution of the soil erosion factors.
- to combine the soil erosion factors based on the RUSLE equation and estimate the annual soil loss rates.
- to identify areas those are frequently affected by erosion in the study area.

- to recommend some mitigation measures for the recurrent erosion risks in the study area.

2. Review Of Related Literature

Soil erosion is a complex process, it is necessary to develop indicators that identify the causes. Physical factors that influence erosion rates include topography, soils, climate and land cover. Land cover is in turn influenced by the socio-economic environment and as such by anthropogenic activities, notably land use and management. Timely and accurate estimation of soil loss or evaluation of soil erosion risk is now regarded as an issue of high priority.

Research on erosion and soil erosion topics has a long scientific history and the underlying fundamentals of erosion processes have been investigated for many decades. But research is still ongoing and increasingly focuses on very detailed topics of erosion and soil erosion processes as well as its modeling. The long-term indicator approach for soil erosion is based on data used in the Universal

Soil Loss Equation (USLE), such as climate, soil, relief, vegetation and protection measures. Problems of such a methodology are the high variability in space and time of data such as ground cover, type of land use, and protection measures.

2.1. Theoretical Framework

2.1.1. Soil Erosion

Soil erosion is one of the major problems confronting agriculture worldwide. It is a major threat to the soil resource, soil fertility, productivity, and, lastly to food and fiber production, mainly on farm and range lands. Although the problem is as old as settled agriculture, its extent and impact on human welfare and global environment are more now than ever before. A continuation of high soil erosion will eventually lead to a loss in crop production even though fertilizers and other inputs often result in increased yield in the short term.

These problems are referred to as on-site effects of erosion. Soil erosion also leads to environmental pollution. Further downstream, erosion leads to flooding, sedimentation of water reservoirs and poor water quality. A decrease in soil quality invariably leads to a decrease in water quality, and often in air quality. These are off-site effects of erosion (Lakew & Belayneh, 2012).

2.1.2. Soil degradation and Land use/ land cover change

Changes in land use and land cover are central to the study of global environmental change including soil degradation and reflect the rapid population growth in tropics. As a result of increasing demand for firewood, timber, pasture, shelter, and food crops, natural land covers, particularly tropical rain forests, are being degraded or converted to cropland at alarming rate (Islam and Weil, 2000). Land degradation is largely a human problem, in both origin and effect. The impacts are felt by the community both rural and urban. These include a range of biological and ecological consequences, varying from the loss of genetic diversity and hydrological disruption, economic consequences, such as; a decrease in agricultural production and eventually loss of the underlying resource base, and all accompanying social problems and disruptions.

2.1.3. Soil erosion and models

Three reasons can be distinguished for erosion modelling (Lal, 1994): first of all erosion models can be used as predictive tools for assessing soil loss for conservation planning, soil erosion inventories or regulation. Secondly, models can predict where and when erosion is occurring, thus helping the conservation planner target efforts to reduce erosion. Finally, models can be used as tools for getting a sharpened understanding of the erosion process and for setting research priorities.

2.1.4. Types of erosion models & model choice

Researchers have developed many predictive models that estimate soil loss and identify areas where conservation measures will have the greatest impact on reducing soil loss for soil erosion assessments (Angima *et al*., 2003).In general, erosion models fall into three main categories depending on the physical processes simulated by the model, the model algorithms describing these processes and the data dependence of the model (Merritt *et al.,* 2003).

a. Empirical models

Empirical models are a simplified representation of natural processes based on empirical observations. This model consists of empirical or statistical/metric models that use an extended database to identify significant relationships between input variables and soil loss. Empirical models are based primarily on observation and inductive logic. The applicability is generally limited to those conditions for which the parameters have been calibrated (Lal, 1994). Some common empirical models are: Musgrave Equation Equation (MUSLE) Sediment, Delivery Ratio Method, Universal Soil Loss Equation (USLE), Soil Loss Estimation Model for South Africa (SLEMSA), Dendy-Boltan Method Flaxman Method, Pacific Southwest Interagency Committee (PSIAC) Method.

b. Conceptual models

The conceptual models, lie somewhere between physically-based models and empirical models, and are based on spatially lumped forms of water and sediment continuity equations. Conceptual models tend to include a general description of catchment processes, without including the specific details of process interactions, which would require detailed catchment information (Merritt *et al*., 2003). Parameter values for conceptual models have typically been obtained through calibration against observed data, such as stream discharge and concentration measurements (Sorooshian, 1991). Some common conceptual models are: Sediment Concentration Graph, Renard Laursen Model, Unit Sediment Graph, Instantaneous Unit Sediment Graph, Sediment Routing Model Discrete Dynamic Models, Agricultural Catchment Research Unit (ACRU), Hydrologic Simulation Programme, FORTRAN.

c. Physically based model

Physically based models represent natural processes by describing each individual physical process of the system and combining them into a complex model. Physical equations hereby describe natural processes, such as stream flow or sediment transport. Physically based models, are intended to represent the essential mechanisms controlling erosion. Physically-based models are built on the solution of fundamental physical equations enveloping the laws of conservation of mass and energy (Morgan, 2005). The power of physically-based models is that they represent a synthesis of the individual components which affect erosion, including the complex interactions between various factors and their spatial and temporal variability (Lal, 1994). Physically based models also have drawbacks: in theory, the parameters used are measurable and known. In practice, the large number of parameters involved and the heterogeneity of important characteristics, particularly in catchments, means that often these parameters must be calibrated against observed data (Merritt *et al.*, 2003). Equations governing the processes in physics-based models are derived at a small scale and under very specific physical conditions.

In practice, these equations are regularly used at much greater scales and under different physical conditions, which may lead to fundamental problems in the application (Beven, 1989). Some common physical models are: Erosion Kinematic Wave Models, Quasi-Steady State, Areal Non-point Source Watershed Environment Response Simulation (ANSWERS), Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS), Water Erosion Prediction Project (WEPP), European Soil Erosion Model (EUROSEM). The distinction between model types is not sharp and can be somewhat subjective. Models are likely to contain a mix of modules from each of these categories (Merritt *et al.*, 2003).

2.1.5. Revised universal soil loss equation (RUSLE)

Numerous erosion and soil erosion models have been developed in the past decades, utilizing different scientific methods and modelling approaches. The Universal Soil Loss Equation (USLE) determines soil loss at any given point as a function of rainfall energy and intensity, soil erodibility, slope length, slope gradient, soil cover, and conservation practices (Wischmeier and Smith 1978). The Revised Universal Soil Loss Equation (RUSLE) has the same form as the USLE, but includes revisions for slope length and slope gradient calculations, more elaborate calculations for soil cover and conservation practices (Renard *et al.* 1997). However, RUSLE can estimate only annual average soil loss from rill and interill erosion caused by rainfall splash and overland flow, but not from gully and channel erosion (Renard et al., 1997). Therefore GIS methods are used to partition the areas into overland and channel types to estimate the soil loss in individual grid cells of overland areas. The RUSLE is expressed as:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

a. Rainfall erosivity factor (R)

Soil erosion by rainstorm is seen as one of the main problem especially in areas receiving variation in rainfall spatially and temporally (Arshad and Martin, 2002). Soil erosivity is a term used to describe the potential for soil to be washed off by rainfall. This factor is the most important parameter especially for risk assessment of for soil erosion. More readily available types of data on precipitation, such as mean monthly or annual rainfall also have been utilized.

a. Soil erodibility factor (K)

Soil erodibility relates to the sensitivity of soil types to erosion. The erodibility factor (K) is represented by the relationship between the soil loss and the rainfall erosivity, when such data are derived individually for each rainfall event (Mannigel et al. *2002*. The Soil property affects infiltration capacity and the extent to which the soil particles can be detached and transported. Texture is the dominant property determining erodibility, but soil structure, organic matter, water content and density or compactness, as well as chemical and biophysical characteristics of the soil also influence erodibility (El-Swaify and Dangler, 1976). Soil type has an influence on k value.

b. Topographical factor (LS)

Soil erosion increases with an increase in slope steepness, due to higher runoff velocity and the area where runoff the concentrates, whilst an increase in slope length allows a greater accumulation of runoff, which results in higher soil erosion. Water flow is expected to be faster on steeper slopes and consequently, the result is a higher erosion risk and an increase in sedimentation (Morgan, 2005).

c. Crop management (C) and Conservation Practice (P) Factors

The C factor describes the relationship between erosion on bare soil and erosion on cropped conditions. Values of C can vary from near zero for well-protected soils to 1.5 for finely tilled, ridged surfaces that are highly susceptible to rill erosion. RUSLE software provides extensive crop database values, including some tropical crops, which are used to evaluate the C-factor, especially when plant growth characteristics are known, or the user may develop a more appropriate database from experimental data (Renard *et al.,* 1997). The P-factor is the ratio of soil loss with specific support practice to the corresponding loss with up and down-slope tillage. These practices proportionally affect erosion by modifying the flow pattern, gradient, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster, 1983). Values for P-factor range from about 0.2 for reverse-slope bench terraces, to 1.0 where there are no erosion control practices (Wischmeier and Smith, 1978). On croplands, support practices include contouring, tillage and planting on or near the contour, strip cropping, terracing, and subsurface drainage and their values can be calculated in conjunction with the R, K, and LS-factors to reflect their effect on reducing runoff (Renard *et al.*, 1997).

2.1.6 Soil Erosion Modeling and GIS

Geographic Information System (GIS) became a very important factor in soil erosion studies and consequently in the development of appropriate soil conservation strategies.

GIS is a technology designed to store, manipulate, and display spatial and non-spatial data, has become an important tool in the spatial analysis of factors such as topography, soil, land use/land cover etc. A soil erosion analysis system based on GIS is capable of analyzing erosion rate as well as proposing the optimum location of sediment traps. Therefore, it has been the best way of scientific soil erosion assessment system to accurate data capture and access real-time data. GIS provides a digital representation of the catchment, which can be used in hydrologic modeling (Kumar, 2016).

2.2. Empirical Literature

There are many different studies that have been conducted by various researchers on the erosion risk assessment at global, continental, national and regional levels. Among the studies conducted (Mati *et al.*, 2000) estimated rainfall erosive using a regression analysis of annual rainfall spread in and around the Upper Ewaso Ngiro basin. The data was separated into two groups as per the agro-climatic zone location of each station, in order to get better correlation coefficients.

Oliveira *et al.* (2014) applied the RUSLE in order to assess the soil erosion vulnerability in the Verde River Basin, South of Minas Gerais state. The authors concluded that the soils of the Verde River Basin present a very high vulnerability to water erosion, with 58.68% of soil losses classified as High and Extremely High, considering classes that ranged from Slight to Extremely High soil loss vulnerability. Also, the authors related that the integration of RUSLE/GIS showed an efficient tool for spatial characterization of soil erosion vulnerability in the basin.

Marker *et al.* (2007) did a study in the Albegna river basin in southern Tuscany, in which they utilized the RUSLE approach to evaluate the different scenarios of land uses for current and future climatic change on a monthly basis. During the study, they kept the K-factor, LS-factor and P-factor value constant and only rainfall erosivities (R-factor) and C-factor values were changed according to the scenario settings. The analysis demonstrates the potential of this approach to assess landscape soil erosion susceptibility with scenario analysis (Marker et al., 2007). The authors state that the analyses might help to develop adaptation strategies for future climate change scenarios such as modification in land management techniques.

3. Description of The Study Area

3.1 Location

Sodo Town is located in the center of southern Ethiopia in Wolaita zone of southern nation nationalities and people's regional state. It is the capital town of Wolaita zone administration. The total area of the watershed delineated boundary is 5000.91hectares. The town is 390km (via Shashemene) and 328km (via Hosanna) away from the national capital Addis Ababa and 170km far from the regional capital Hawasa. Its geographical extent is between 352000 and 372000 N and between 748000m and 764000m E with altitude ranging from 1800 to 2500mamsl (EDHOI, 2005). Soddo Town is located from Northwest of Boloss sore, from Northeast of Damote Gale, from southwest in Goffa and from South of Humbo in Wolaita zone administration of SNNPR of Ethiopia. The boundary is delineated by using watershed of the study area.

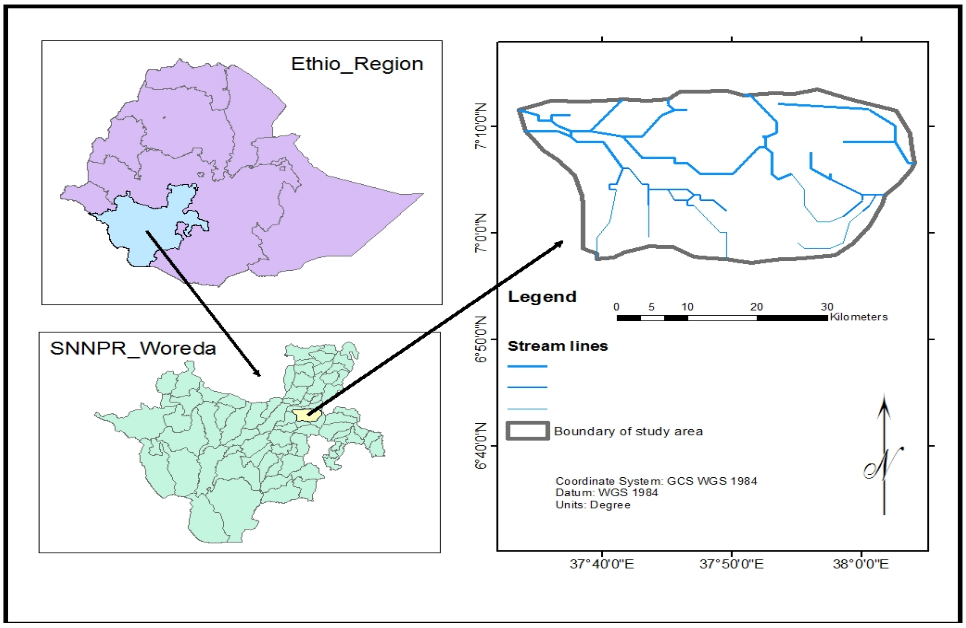


Figure 3.1: Location map of Sodo Town.

3.1. Topography and Climate

The topography is predominantly characterized by mountains steep or hilly, gorges and plain land especially toward southern part of the town. The average altitude of the town is 1880 meters above sea level. The town established at the foot of mountain Damota the highest mountain in Wolaita zone. The town cut by the two small rivers Calte and Beshir which are flowing from mountain Damota to south east and south west of the town respectively. These rivers also roughly divide soddo Town in three parts such as Arada Sub-City, Mehal Sub-City and Mercato Sub-City (WSM, 2001).

The climate of Wolaita Sodo Town is described by the type of rainfall and temperature. The mean annual rainfall is greater than 1550mm per year. Most part of the Wolaita Sodo Town experience woinadega (warm to cool) type of climate (BRMAR, 2012) except the mountain Damota of SodoTown top areas that experience colder climate some times. The south and southwest peripheries of the town experience transitional types of climate (warm to hot) (woinadega to kola) mainly due to the south east rift valley that cross the surrounding woreda (DellboWogen and HumboTaballa) and run into the lowlands of lake Abaya and Chamo which are rift valley lakes.

3.2. Soil and Geology of the Study Area

Soil is defined by Davidson (1980) as cited in Flax (2002) in natural body consisting of layers or horizons of mineral and / or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biological characteristics. According to the soil classification of FAO (1997), there are four soil types in the study area: chromic luvisols, chromic vertisols, pellic vertisols and dystric nitisols. Chromic luvisol is the dominant type of soil in the areas covering the northern parts of the study area including the north central part of the town. This part of the town has more elevated and rugged terrain. Chromic vertisols type of soil is dominant in the central area of the town. This kind of soil covered the whole areas of the central town which is highly urbanized and occupied by multi urban land uses. Dystricnitisols covers the southern parts of the study area including most parts of the current expansion areas (FAO, 1997).

Materials and Methods

The remote sensing technology has found its acceptance worldwide for rapid resource assessment and monitoring, particularly in the developing world. The synoptic view of the area allows better monitoring capability, especially when the coverage is repetitive, interval is short, and resolution of the image is high. Remote sensing provides data in several discrete bands, enabling creation of false colour composites (FCC) and the interpretation accuracy is thereby increased visually and digitally. It provides real time and unbiased base line information (Gupta, 2001).

The knowledge of land use and land cover is important for many planning and management activities as it is considered as an essential element for modeling and understanding the earth feature system. Land use is defined as to the human activity or economy related function associated with a specific piece of land, while the term land cover relates to the type of feature present on the surface of the earth (Lillesand and Kiefer, 2000).

4.1 Materials

Soil erosion is influenced by a variety of factors such as rainfall intensity and distribution, soil types, topography of watershed, land use types, etc. These factors are presented very well with the temporal and spatial type using GIS technique. GIS application is increasing more and more to predict soil erosion in the watershed. In order to predict the soil erosion in Wolaita Sodo Town and surrounding areas, the following spatial and temporal data are used:

1) Digital Elevation Model: (downloaded from earth explorer, cell size: 30 by 30m)

2) Soil types map (Source, FAO, vectorized map)

3) Satellite image ETM+ (downloaded from earth explorer, cell size: 30mby 30m, year, 2018)

4) Daily precipitation data (Source, National Meteorological Agency).

Land Use /Land Cover

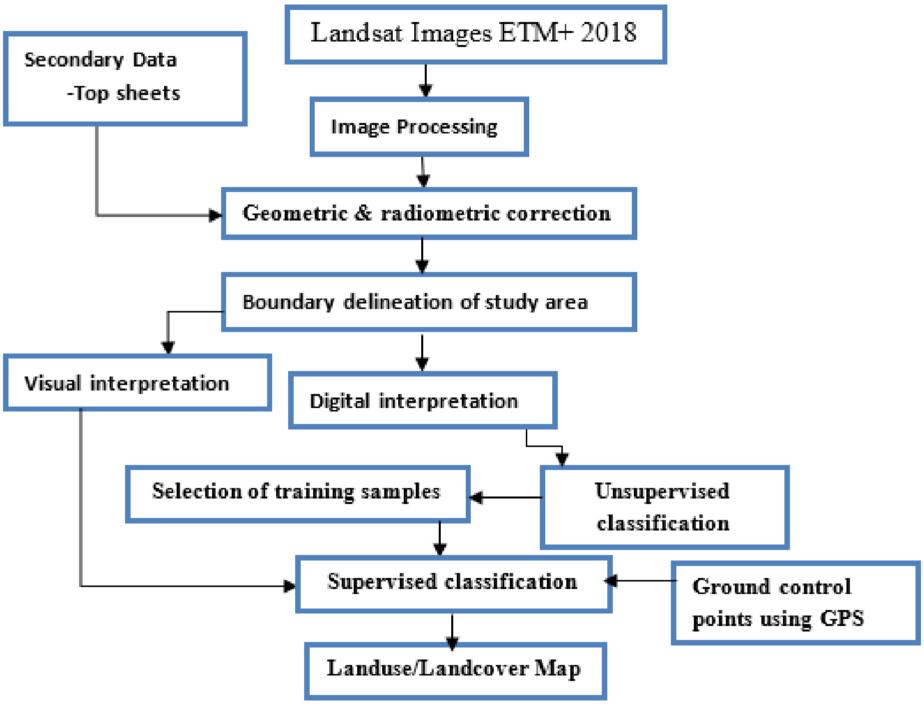


Chart 4.1: Methodology adopted for Land use/Land cover classification.

In classifying the images, both unsupervised and supervised image classifications techniques were applied, for the latter case training site was established based on the ground truth taken during field work. The unsupervised was done before field work. By having applied the techniques of image classification, land use / land cover types have been identified so as to use the classified images as inputs for generating crop management (C) factor and support practice (P) factor of Universal Soil Loss Equation. With the help of visual interpretation elements and the different reflection characteristics of the features in the satellite images, the study area has been classified in to five land use / land cover classes, namely, agricultural land, forest land, grazing land, bare land and built up.

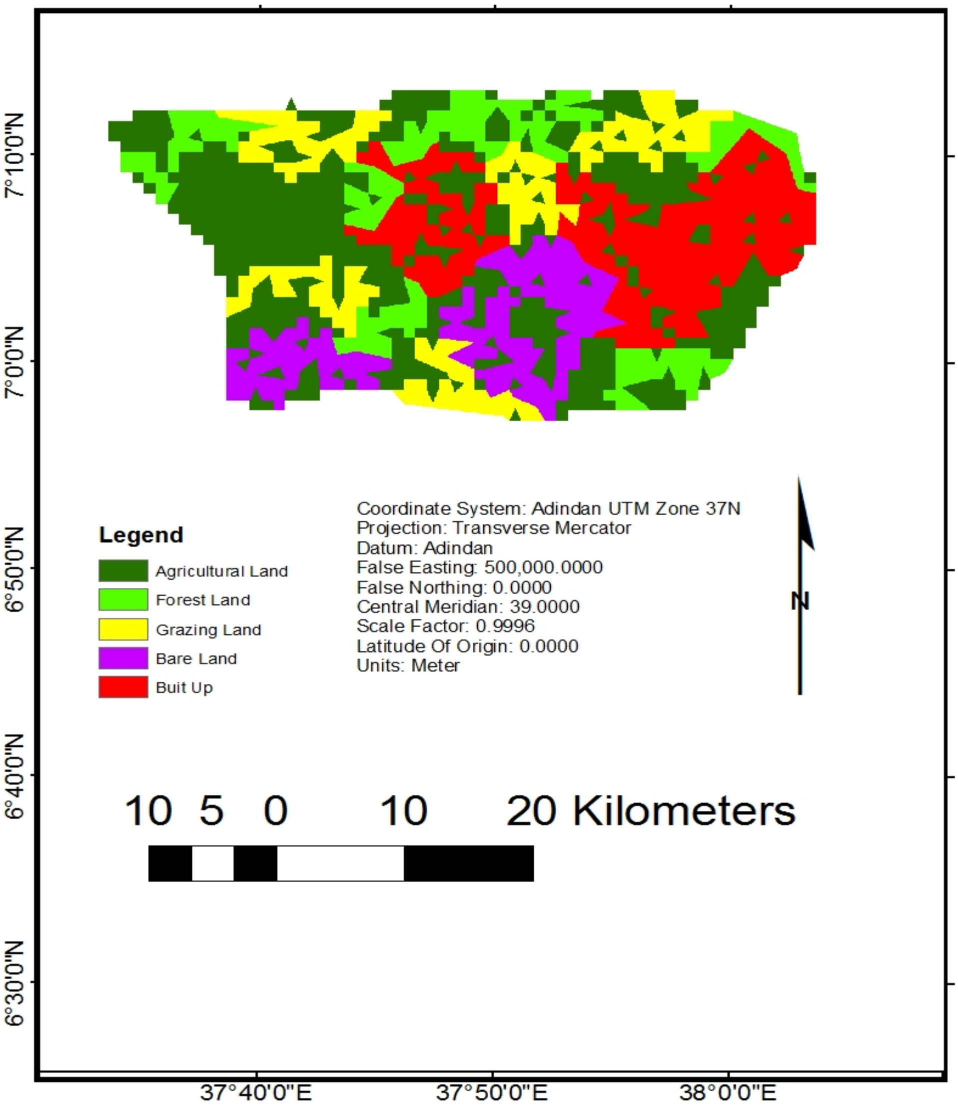


Fig. 4.2: Land use /cover map

4.2 Methods

In this study, soil erosion model RUSLE input parameters and Arc GIS system were used to estimate spatial soil erosion and sediment yield of the Wolaita Sodo Town and surrounding areas watershed. The RUSLE predicts soil loss for a given site as a product of six major erosion factors, whose values at a particular location can be expressed numerically. The soil erosion is calculated as follows.

$$A = Rx\ Kx\ LSx\ Cx\ P \qquad (2)$$

- A- represents soil loss in tons/ha/yr,
- K-erodibility factor which is the soil loss rate per erosion index for a specified asa measured on a unit

plot, which is defined as a 22.1m length under identical condition

- R-erosivity factor that is computed as total storm energy multiplied by the maximum 30min intensity,
- L-slope length is the ratio of soil loss from the field slope gradient to soil loss from a 22.1 m slope length under otherwise identical conditions,
- S-slope steepness is the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.
- C- crop management factor is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land.
- P- Support practice factor is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to soil loss with straight–row farming up and down the slope.

Fig 4.2: Flow chart of method

4. ANALYSIS, RESULTS AND DISCUSIONS

5.1. Rainfall Runoff Erosivity Factor (R)

Among the various parameters that affect erosion of soil, precipitation plays a vital role. Rainfall erosivity depends primarily on amount, intensity and distributions of rainfall. The soil loss is closely related to rainfall partly through the detaching power of raindrop striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1994). Though there are a number of ways of analyzing the rainfall erosivity depending on the local conditions of the place (country), the values of R-factor for this study was estimated according to the equation adopted by Hurni (1985) for Ethiopian conditions.

$$R = -8.12 + 0.562*P \qquad (3)$$

Where, R= Rainfall erosivity

P= mean annual rainfall (mm/yr)

In order to compute R factor using such formula eight stations with mean annual rainfall of 20 years were used.

Table 5.1: Rainfall Gauge Stations

Station Name	E	N	Average
Mi'irab Abaya	363328	757937.77	102
Hosaena	373406.58	834725.47	87.11
Wolaita Sodo	363676.18	757851.95	57.5
Bilate	396549.44	792188.55	61.3
Wulbareg	409810.87	859048.98	92.4
Mayokote	696234.77	985020.20	61.77
Shone	384564.81	789344.31	49.86
Gesuba	340413.25	743524.83	57.869

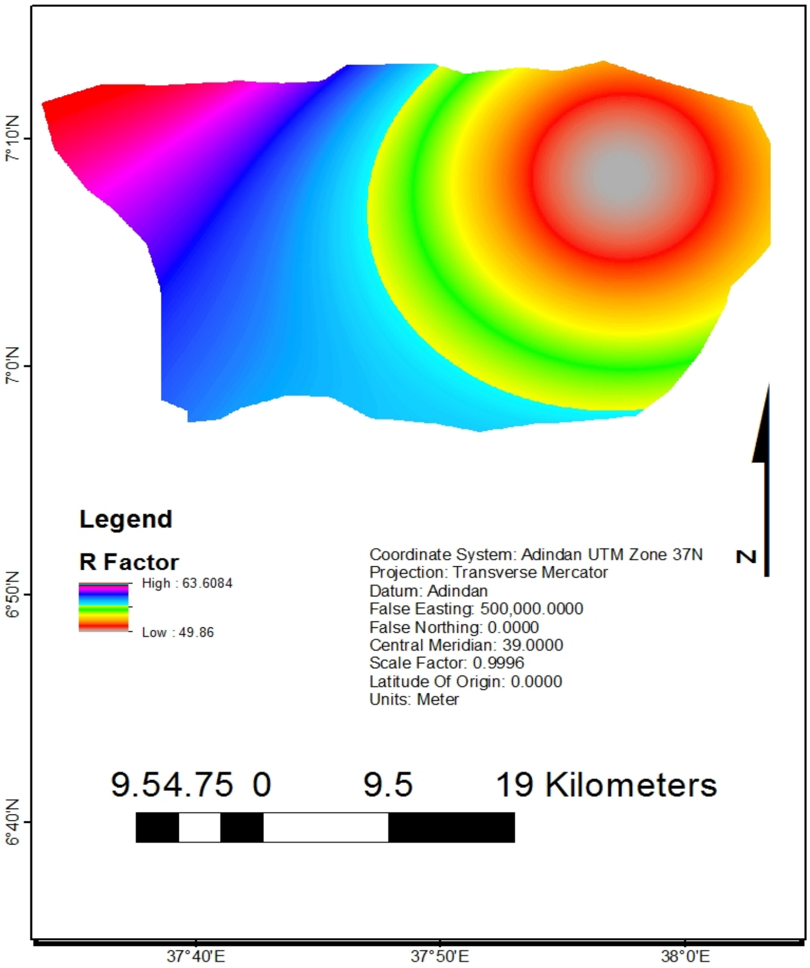
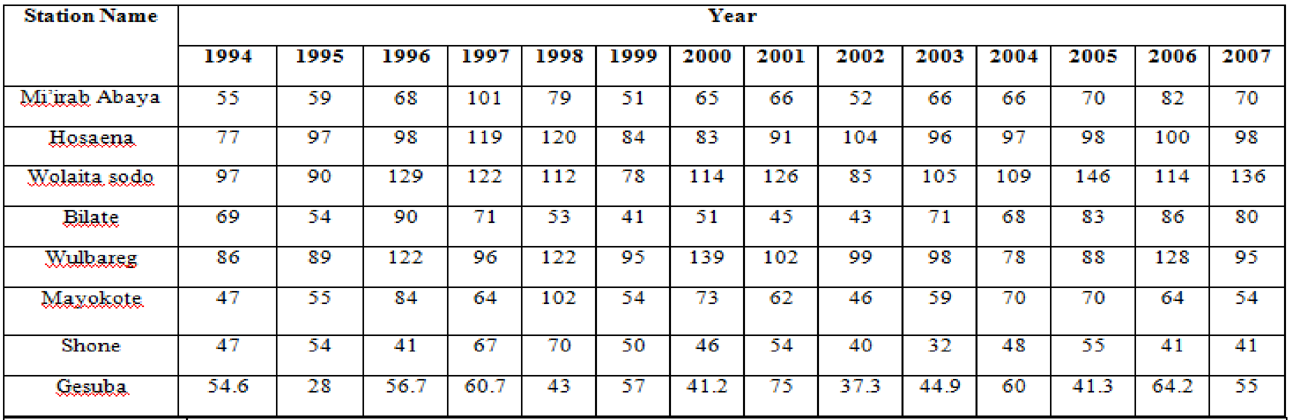
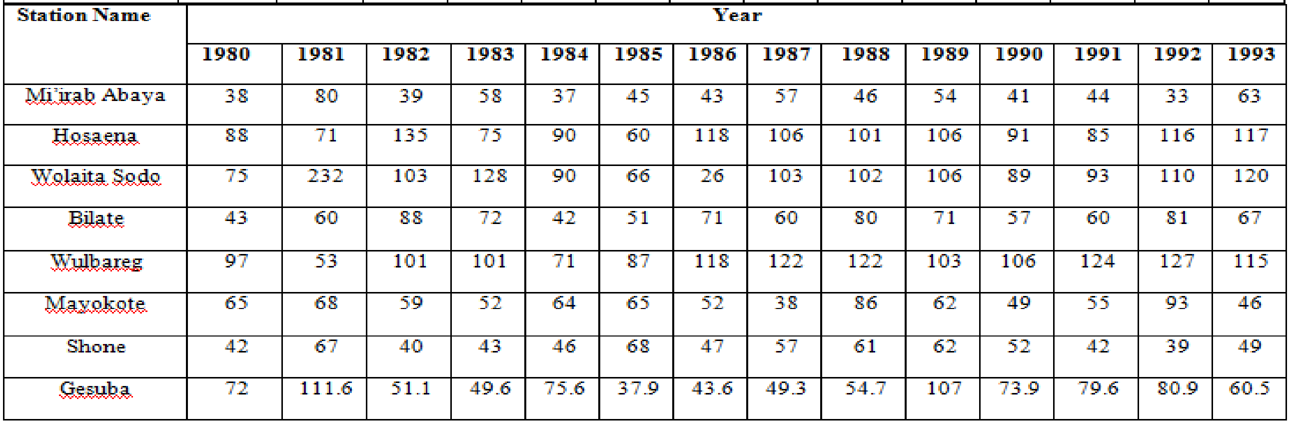


Fig.5.1. Spatial variability of rainfall erosivity in the study area from NMA (mm)

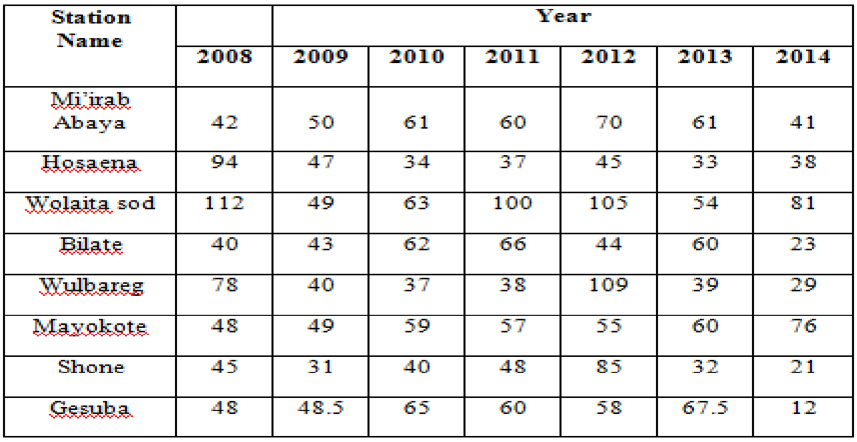
Table 5.2: Mean annual rainfall



Station Name	Year													
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Mi'irab Abaya	55	59	68	101	79	51	65	66	52	66	66	70	82	70
Hosaena	77	97	98	119	120	84	83	91	104	96	97	98	100	98
Wolaita sodo	97	90	129	122	112	78	114	126	85	105	109	146	114	136
Bilate	69	54	90	71	53	41	51	45	43	71	68	83	86	80
Wulbareg	86	89	122	96	122	95	139	102	99	98	78	88	128	95
Mayokote	47	55	84	64	102	54	73	62	46	59	70	70	64	54
Shone	47	54	41	67	70	50	46	54	40	32	48	55	41	41
Gesuba	54.6	28	56.7	60.7	43	57	41.2	75	37.3	44.9	60	41.3	64.2	55



Station Name	Year													
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Mi'irab Abaya	38	80	39	58	37	45	43	57	46	54	41	44	33	63
Hosaena	88	71	135	75	90	60	118	106	101	106	91	85	116	117
Wolaita Sodo	75	232	103	128	90	66	26	103	102	106	89	93	110	120
Bilate	43	60	88	72	42	51	71	60	80	71	57	60	81	67
Wulbareg	97	53	101	101	71	87	118	122	122	103	106	124	127	115
Mayokote	65	68	59	52	64	65	52	38	86	62	49	55	93	46
Shone	42	67	40	43	46	68	47	57	61	62	52	42	39	49
Gesuba	72	111.6	51.1	49.6	75.6	37.9	43.6	49.3	54.7	107	73.9	79.6	80.9	60.5



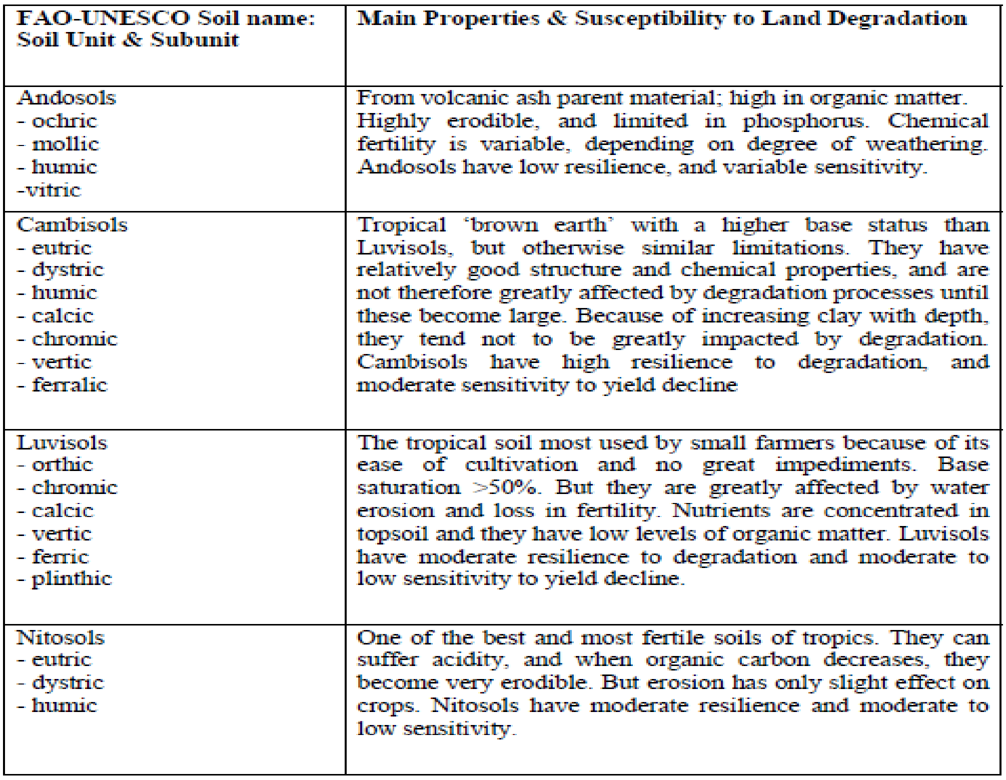
Station Name		Year					
	2008	2009	2010	2011	2012	2013	2014
Mi'irab Abaya	42	50	61	60	70	61	41
Hosaena	94	47	34	37	45	33	38
Wolaita sod	112	49	63	100	105	54	81
Bilate	40	43	62	66	44	60	23
Wulbareg	78	40	37	38	109	39	29
Mayokote	48	49	59	57	55	60	76
Shone	45	31	40	48	85	32	21
Gesuba	48	48.5	65	60	58	67.5	12

After having averaged 20 years (1994-2014) for each station, interpolation was made to make the points distribution into surface. Then kriging spatial interpolation was applied in ArcGIS to get a spatially distributed R factor map of the watershed area. Kringing is based on statistical models that include autocorrelation that is, the statistical relationships among the measured points. Because of this, not only do geostatistical techniques have the capability of producing a prediction surface, they also provide some measure of certainty or accuracy of predictions.

5.2. Soil Erodibility Factor (K)

Soil erodibility factor denoted by letter "K" in the USLE reflects the liability of a soil type to erosion, the unit depending upon the amount of soil occurring per unit of erosivity and under specified conditions. The inherent properties of the soil would have more influence for being liable to erosion than other factors (Tsegaye, 2007). However, some soils erode more readily than others even when all other factors are the same.

Table 5.3: Soil Susceptibility to land degradation (Website)



FAO-UNESCO Soil name: Soil Unit & Subunit	**Main Properties & Susceptibility to Land Degradation**
Andosols - ochric - mollic - humic -vitric	From volcanic ash parent material; high in organic matter. Highly erodible, and limited in phosphorus. Chemical fertility is variable, depending on degree of weathering. Andosols have low resilience, and variable sensitivity.
Cambisols - eutric - dystric - humic - calcic - chromic - vertic - ferralic	Tropical 'brown earth' with a higher base status than Luvisols, but otherwise similar limitations. They have relatively good structure and chemical properties, and are not therefore greatly affected by degradation processes until these become large. Because of increasing clay with depth, they tend not to be greatly impacted by degradation. Cambisols have high resilience to degradation, and moderate sensitivity to yield decline
Luvisols - orthic - chromic - calcic - vertic - ferric - plinthic	The tropical soil most used by small farmers because of its ease of cultivation and no great impediments. Base saturation >50%. But they are greatly affected by water erosion and loss in fertility. Nutrients are concentrated in topsoil and they have low levels of organic matter. Luvisols have moderate resilience to degradation and moderate to low sensitivity to yield decline.
Nitosols - eutric - dystric - humic	One of the best and most fertile soils of tropics. They can suffer acidity, and when organic carbon decreases, they become very erodible. But erosion has only slight effect on crops. Nitosols have moderate resilience and moderate to low sensitivity.

The erodibility of soils as defined by Hurni (1985), in the adaptation of USLE to Ethiopia considers the soil colour to have relation with erodibility even though others consider soil texture and structure so as to determine the value of soil erodibility factor.

Table 5.4: Values of soil colour to estimate soil erodibility (Tsegaye, 2007)

Soil colour	**Black**	**Brown**	**Red**	**Yellow**
K value	0.15	0.2	0.25	0.3

According to UNESCO/FAO soil classification, seven types of soil are found in the study area, namely eutric cambisols, vitric andosols,dystric nitisols,chromic luvisols,eutric nitosols or pellic vertisols, eutric fluvisols,chromic luvisols and eutric nitisols. All these soils have different quality to stand with erosion.

Soil erodibility index is related to the integrated effect of rain fall, run off and infiltration. However, the establishment of K value is based on colour of each soil type and its value determined to it.

Table 5.5: estimated value of soil erodibility

Soil type	**Colour**	**K Value**
eutric cambisols	Brownish	0.2
vitric andosols	Black	0.15
dystric nitisols	Reddish	0.25
chromic luvisols	Brownish	0.2
pellic vertisols	Black	0.15
eutric fluvisols	Reddish	0.25
eutric nitisols	Reddish	0.25

After having established K value on the basis of previous research considering the colour of each soil, the K values were put in geodatabase and converted the feature class into grid raster format with 30m cell size.

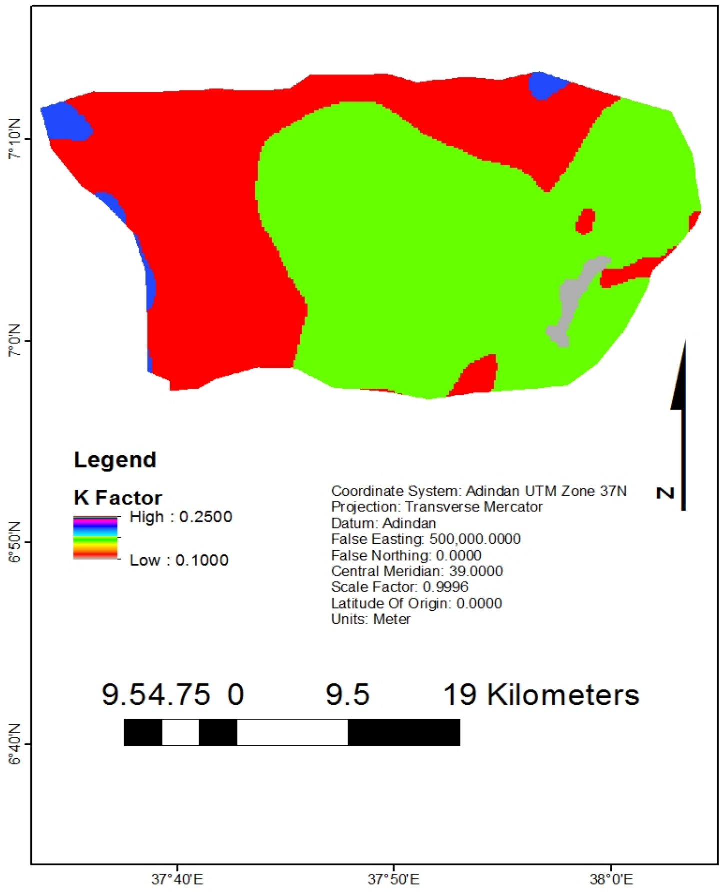


Fig.5.2: Raster format of soil erodibility factor.

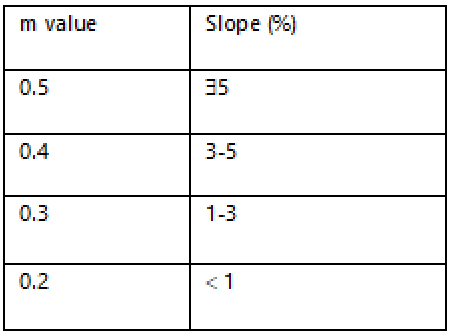
5.3 Topographic Erosivity Factor (LS)

Topographic Erosivity Factor (LS) has been considered as one of the most important model parameters in USLE analysis. When the slope length increases, the soil erosion by water also increases as due to the greater accumulation of surface runoff. Slope gradient and slope length factor is calculated from the flow accumulation and slope values. Finally the topographic erosivity factor (LS) map has been derived using the following formula in ArcGIS spatial analysis raster calculator function.

$$LS = (\text{Flow Accumulation} * \text{cell size}/22.1)^{m} (0.065+0.045s+0.0065s^{2}) \quad (4)$$

The value of m varies from 0.2 – 0.5 depending on the slope as shown in Table 5.6 (Wischmeier &Smith, 1978).

Table 5.6: Values of m (slope)



m value	Slope (%)
0.5	35
0.4	3-5
0.3	1-3
0.2	< 1

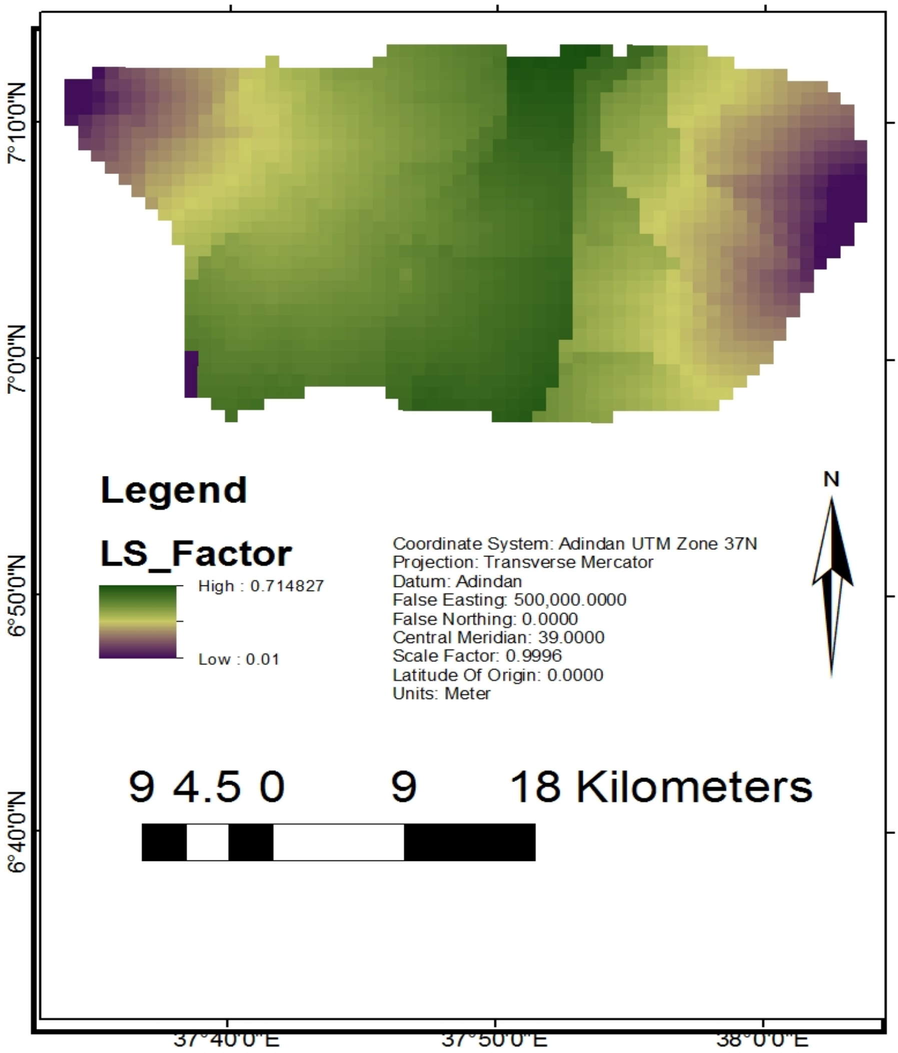


Fig.5.3: Raster format of topographic erosivity factor

5.4. Cover (C) factor

The *C*-factor represents the effect of cropping and management practices on erosion rate. It has a close linkage to land use types and is a reduction factor in soil erosion vulnerability. This expresses influence of vegetation upon soil erosion, ranging from 1 to 0, where higher values indicate no cover effect hence more erosion while lower C means a very strong cover effect resulting in no erosion. These values can be derived from satellite imagery.

Table 5.7:.Values suggested by USDA, Handbook no. 282, 1981 for C and P factors.

Land Cover Classes	C Value	P Value
Built-Up	0.011	1
Grazing land	0.01	0.9
Agricultural Land	0.50	0.5
Barren Land	0.351	1
Forest	0.001	0.8

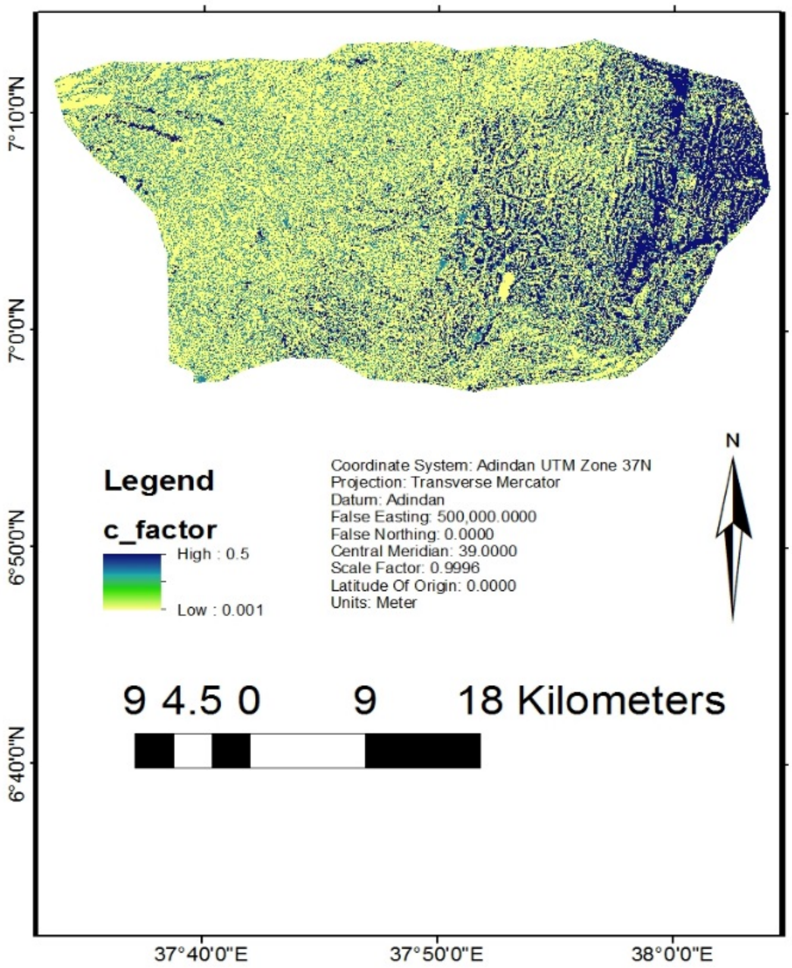


Fig.5.4: C-factor values map of the study area.

5.5 Support practice factor (P)

The support practice factor reflects the impact of support practice on the average annual erosion rate. It is defined as the ratio of soil loss with the specific support practice to that of straight row farming-up and down the slope. This factor account for control practices that reduce the potential soil loss with value ranges from 0 to 1 indicates from good to poor conservation practice, respectively. Conservation practice (P) factor was adopted from (Wischmeier and Smith, 1978).

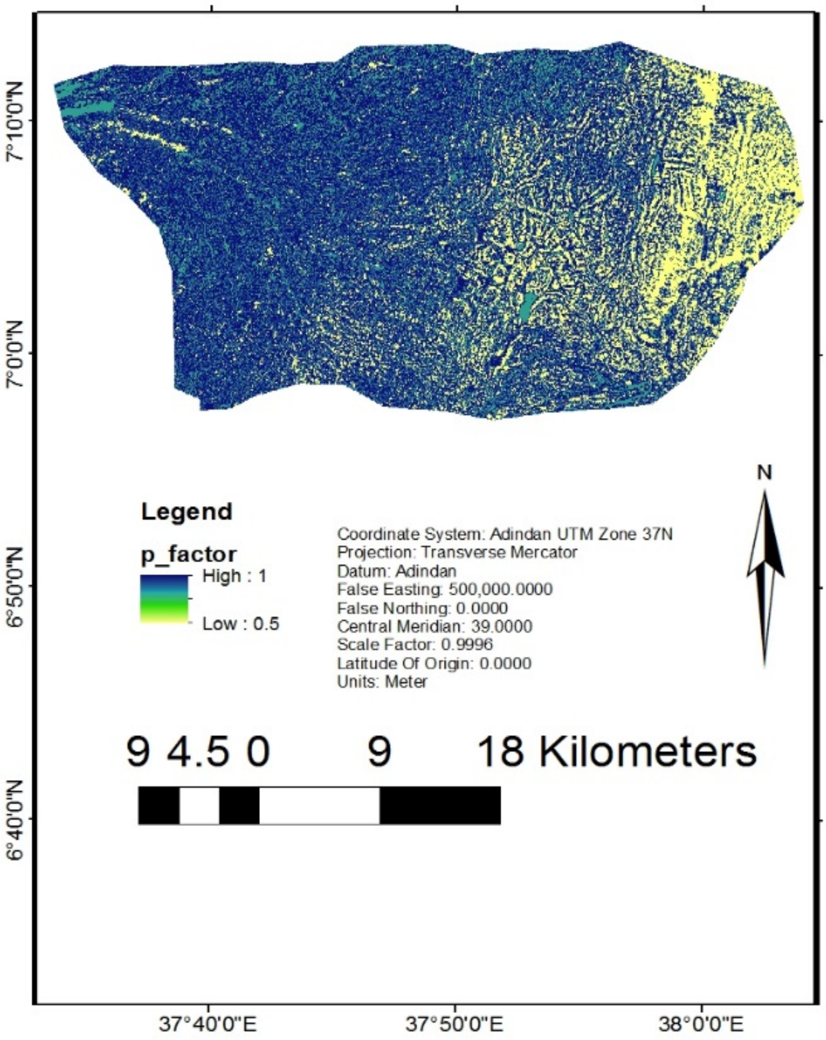


Fig.5.5: Variation of estimated P-factor values for the study area.

5.6. Average annual soil loss (A factor)

The RUSLE model estimates the amount of annual soil loss as a function of the parameters. After preparation of all the RUSLE factor maps, they were overlaid using raster calculator in GIS environment to obtain the average annual soil erosion (A) map. The average annual soil loss in the watershed was found to be 500.91t/ha/yr.

Predicted average annual soil loss of basin has been classified into five erosion intensity classes (Table 5.8) to assess erosion potential severity. Very low soil loss areas have been recorded under the forested areas and low soil loss was found underbuilt up area and grazing area. Soil erosion rate was predicted moderately high for agriculture, which needs proper soil conservation measures to reduce erosion. The high rate of soil erosion was found along the main stream and along the valley portion of the basin, because of moderate slope value and the high slope length and steepness factor.

Table 5.8: Soil erosion potential

Erosion proneness area	Annual soil loss in (t/ha/yr)	Percentage (%)
<195	67.995	13.574
195-240	49.457	9.873
240-280	145.849	29.117
280-320	94.129	18.792
>320	143.480	28.644
Total	500.91	100

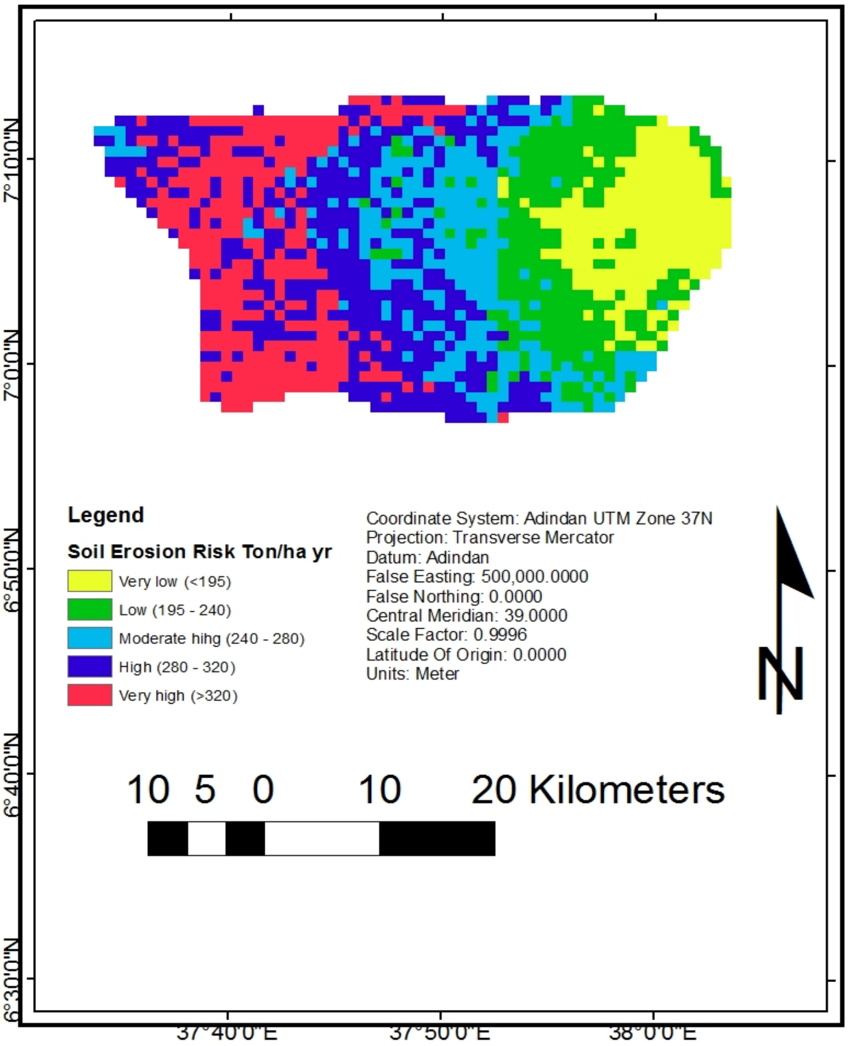


Fig.5.6: Predicted soil erosion risk map in study area.

6. Conclusion and Recommendation

6.1 Conclusion

Soils are recognized as a limited resource and asset. Soil loss can occur rapidly, due to intense rainfall, national level without accounting for land cover characteristics. These limitations may give rise to large uncertainties in estimates of soil loss amounts, and lead to inappropriate soil management.

Geographic Information Systems (GIS), coupled with the USLE model, can identify and assess soil erosion potential and estimate the value of soil loss. Results from the soil erosion risk mapping show that the soil erosion risk is higher in the northwest than in the southeast of the watershed. The regional soil erosion risk map showed that, the average soil loss found was 500.91 t ha-1 ya-1 in the watershed, and the spatial distribution of erosion risk classes was 13.574% very low, 9.873% low, 29.117% moderate, 18.792% severe, 28.644% very severe. Soils susceptible to erosion with a soil loss more than 49.457t ha-1 ya-1 are found primarily in the lower watershed.

Recommendation

✓ The study recommends that the local communities should adopt immediate soil conservation measures in their cultivated lands by applying different soil protective methods like mulching, strip cropping, terracing, contour plowing, cover crops and other indigenous means of soil conservation.

✓ Soil erosion hot spot areas that were identified in the soil erosion map should be given a serious attention and priorities for implementing soil conservation activities before the areas reached to irreversible soil degradations.

✓ The variety of empirical, conceptual and physically based soil erosion models other than the conventional soil erosion models (USLE, its revisions and modifications) are available. The researchers should try to use these models in their research works wherever these models are giving satisfactory results compared to the observations.

✓ The GIS has made it possible to manage rationally the different factors of soil degradation, it gives us relatively reliable results that can provide valuable help to forest managers in order to simulate evolution scenarios and, target priority areas that require conservation and erosion control actions.

References

Angima, S.D., Stott, D.E., O'Neill, M.K., Ong, C.K. and Weesies, G.A. (2003). Soil erosion prediction using RUSLE for central Kenyan highland conditions. Agriculture, Ecosystems and Environment 97, 295–308

Arshad, M.A. and Martin, S. (2002). Identifying critical limits for soil quality indicators in agro-ecosystems. Agriculture, Ecosystems and Environment 88, 153–160.

Beven, K. (1989). Changing ideas in hydrology - the case of physically-based models. Journal of Hydrology 105, 157-172.

El-Swaify, S., and Dangler, E., (1976). Erodibilities of selected tropical soils in relation to structural and hydrologic parameters. In: Foster, G.R. (Ed.), Soil Erosion Prediction and Control. Soil and Water Conservation Society, Ankeny, IA, USA, pp. 105–114.

Golden Horseshoe Area Conservation Authorities (2006). Erosion and Sediment Control Guideline for Urban Construction.

Gupta, H. S. (2001). Remote sensing techniques forevaluating landuse/land cover: a case study.*Indian Forester*, 127: 755-761.

Hurni, H. (1985). Erosion-productivity conservation systems inEthiopia. Paper presented at IV ISCO conference, venezuala.

Islam, K.R. and Weil, R.R (2000). Land use effects on soil quality in a tropical forestecosystem of Bagladesh. Agriculture, Ecosystems and Environment.

Jiang, B. (2013). GIS-based time series study of soil erosion risk using the Revised Universal Soil Loss Equation (RUSLE) model in a micro-catchment on Mount Elgon, Uganda.

Jong, D., Brouwer S.M. and Riezebos, H. (1998). Erosion hazard assessment in the Peyne catchment, France. Working paper DeMon-2 Project. Dept. Physical Geography, Utrecht University.

Kebede, A. (2014). Assessment and Mapping of Soil Erosion Risk Using Remote Sensing and GIS Techniques in Horro District, Oromia Region, Western Ethiopia

Kumar, H. (2016). Estimation of Soil Erosion in Mohgaon Watershed using Remote Sensing and GIS Techniques.

Lakew, D & Belayneh, A (2012). Nile Basin Initiative: A Field Guide on Gully Prevention and Control.

Lal, R. (1994). Soil erosion research methods. Soil and Water Conservation Society.

Lillesand, T. M. and Kiefer, R.W. (2000). Remote Sensing and Image Interpretation. IV Edition, John Wiley & Sons, Inc., USA.

Mati, B.M., Morgan, R.P.C., Gichuki, F.N., Quinton, J.N., Brewer, T.R. and Liniger, H.P. (2000). Assessment of erosion hazard with the USLE and GIS: A case study of the Upper Ewaso Ng'iro North basin of Kenya. JAGeol. 2 (1), 1–9.

Marker, M., Angeli, L., Bottai, L., Costantini, R., Ferrari, R., Innocenti, L. and Sililiano G. (2007). Assessment of land degradation susceptibility by scenario analysis: A case study in Southern Tuscany, Italy. *Geomorphology* 93 (2008): 120-129.

Merritt, W.S., Letcher, R.A., Jakeman, A.J., (2003). A review of erosion and sediment transport models. Environmental Modelling & Software 18, 761-799.

Morgan, R. (1994). Soil Erosion and Conservation. Silsoe College,Cranfield University.

Morgan, R.P.C. (2005). Soil Erosion and Conservation. Blackwell publishing, Oxford, UK.

Morgan, R.P.C. (2005). *Soilerosionandconservation,*ThirdEdition,Oxford:Blackwell Publishing.

Source:WWW.unu.edu/env/plec/1-degrade/index-toc

Oliveira, V. A., Mello, C. R., Durães, M. F.; Silva, A. M. (2014). Soil erosion vulnerability in the Verde River Basin, Southern Minas Gerais. Ciência & Agrotecnologia, v. 38, p. 262- 269.

Solomon G. (2004). Mapping potential soil erosion using RUSLE, remote sensing, and gis:the case study of weenen game reserve,kwazulunatal.

Sorooshian, S. (1991). Parameter Estimation, Model Identification, and Model Validation: Conceptual-Type Models, in: Bowles, D.S., O'Connell, P.E. (Eds.), Recent Advances in the Modeling of Hydrologic Systems, pp. 443-467.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C. (1997). Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE), Agriculture Handbook, No. 703, USDA-ARS.

Tattao, E. (2010). The Use GIS and Remote Sensing in the Assessment of MagatWatershed inthe Philippines.

Tsegaye, B. (2007). Assessment of land degradation using gis based model and remote sensing in Bishan Guracha-adilo subcatchments,Southern Ethiopia.

Wischmeier, WH., Smith DD. (1978). Predicting Rainfall Erosion Losses-A Guide to Conservation. Agricultural Handbook 537. US Department of Agriculture: Washington, DC.

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