



***Assessment of Soil Erosion Risk Area Using Object Based Image Analysis
and RUSLE3D Model: A Case Study of Wenberta Watershed, Atsbi-Wenberta
Woreda, Tigray, Ethiopia***

BY

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This is to certify that the thesis prepared by **Tewodros Getachew Zenebe**, entitled: "*Assessment of Soil Erosion Risk Area Using Object Based Image Analysis and RUSLE3D Model: A Case Study of Wenberta Watershed, Atsbi-Wenberta Woreda, Tigray, Ethiopia*" and submitted in partial fulfillment of the requirements for the Degree of Master of Science (Remote Sensing and Geoinformatics) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Soil erosion is a global issue that threatens human livelihoods and civilization. The impact of soil erosion can be worst in the developing countries like Ethiopia, including Tigray Highlands, which is highly affected by the risk of desertification that is also aggravated by a combination of natural and human factors. In most areas of the country farmers are highly dependent on natural land proprieties and unable to improve soil fertility through application of purchased inputs. Therefore, the community try to protect the soil loss of the area to tackle such kind of problems. In this study, Revised Universal Soil Loss Equation (RUSLE) 3D model was used to quantify the erosion in a GIS environment in order to calculates actual average soil loss in Wenberta watershed, Tigray region, Ethiopia. RUSLE 3D model applied to produce the soil erosion risk map using ArcGIS10.3, SAGA GIS, and eCognition Essential software's. The model incorporates Rainfall , Soil, Topographic (a three dimensional modification), Land cover, and Practice Management factors. Land Cover map of the area was produced using Object Based Image Analysis (OBIA) from a very high resolution (0.25 cm spatial resolution) of aerial photographs for the entire watershed. The overall accuracy of land cover from OBIA was 85.2%. Slope and Upslope area were generated from a 10 m resolution Digital Elevation Model (DEM). The model final result shows that the actual soil loss quantity ranges from 0 to very high soil loss rates (127.92 t/ha/y). According to the final result the central parts of watershed have very high severity of soil erosion and most of the mountainous areas also high soil erosion risks. The study showed that stone bunds and bench terrace in Practice Management are successful management practice to conquer the soil erosion risks of the area. This study demonstrates that the RUSLE 3D model is a robust model for estimation of soil erosion studies and risk assessment mapping integrating with remote sensing products and Geographic Information Systems and can be applied in other parts of Ethiopia. As a result, the areas that have high erosion risk should be conserved in priority by the most known methods of conservation practices of the area.

Key words: RUSLE3D, Soil Erosion, OBIA, GIS, Remote Sensing, Wenberta watershed, SAGA GIS

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List of Acronyms

DEM	-	Digital Elevation Model
DTM	-	Digital Terrain Model
EMA	-	Ethiopian Mapping Agency
FAO	-	Food and Agriculture Organization
IDW	-	Inverse Distance Weight
INSA	-	Information Network Security Agency
GIS	-	Geographical Information System
GSD	-	Ground Sampling Distance
LULC	-	Land Use Land Cover
MoWIE	-	Ministry of Water, Irrigation and Energy
NN	-	Nearest Neighbor
OBIA	-	Object Base Image Analysis
OM	-	Organic Matter
RGB	-	Red Green Blue
RS	-	Remote Sensing
RUSLE	-	Revised Universal Soil Loss Equation
RUSLE 3D	-	Revised Universal Soil Loss Equation 3Dimensional
SAGA	-	System for Automated Geoscientific Analyses GIS
USLE	-	Universal Soil Loss Equation

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Chapter One

1. Introduction

1.1. Background

Soil erosion is a global issue that threatens human livelihoods and civilization. In many areas, farmers experienced a decline in real income due to demographic, economic, social, and environmental changes. Erosion is one of the biggest global environmental problems resulting in both on-site and off-site effects, which have economic implications and an essential actor in assessing ecosystem health and function (Demirci and Karaburun 2012). The economic implication of soil erosion is more serious in developing countries because of lack of capacity to cope with it and also to replace lost nutrients. Erosion is one of the major and most widespread forms of land degradation that creates difficulty to sustainably use agricultural lands and also that affects the physical and chemical properties of soils. (Gobin *et al.*, 2002).

A number of factors contribute to the high rates of soil loss at global, regional, and local levels. Climate, slope, soils, ground cover, and land management are the most important. Land misuse, deforestation, and overgrazing lead to severe erosion and excessive sediment yield. Soil erosion reduces soil fertility and it affects the agricultural productivity of the area. Eroded sediment is transported to other locations.

In the dry lands of Ethiopia, a combination of natural and human factors aggravates soil erosion. The rate of soil erosion is severe in the highlands of Ethiopia. Soil conservation is critically required in these areas to tackle soil erosion. Additionally, the physical makeup of the highlands with gorges and other topographic barriers restricts the implementation of management and conservation practices. With increasing numbers of people, cultivation has expanded into ecologically fragile and marginal mountainous lands. Soil erosion therefore increases, and is a symptom of misuse and mismanagement. To deal with erosion, site-specific management measures are necessary (Ademola and Paul , 2007).

Erosion is an inclusive term for the detachment and transport of soil by the action of erosive agents: water and wind, and influenced by factors such as climate, soil, vegetation, and topography (Demirci and Karaburun 2012). Soil erosion especially water erosion on cropland is one of the most severe problems affecting the agricultural sector in Ethiopia (Shiferaw and Holden, 1999; Sonneveld 2002).

Several studies in Ethiopia have revealed that soil erosion has become an alarming problem (Haile and Fetene (2012), Kebede *et.al*, 2015)). It is the major factor affecting the sustainability of agricultural production. Soil characteristics like soil particles size (texture), organic matter content and permeability determine the vulnerability of a soil to erosion. Most concerns about erosion are related to accelerated erosion, where the soil loss rate has been significantly increased by human activities such as changes in land cover and management (Gobin *et al.*, 2002).

Assessment of soil erosion factors through the use of spatial data integration is the most common method. By using spatial technologies and different methods of erosion models for the last 40 years operating at different scales and different levels of complexity, there has been a huge variations in the quantity and type of input data required (Morgan, 2011). When we say modeling soil erosion is the process of mathematically describing soil particle detachment, transport, and deposition on land surfaces. Modeling this process is important to predict soil loss.

Generally, Revised Universal Soil Loss Equation (RUSLE) erosion model is preferred method for soil erosion prediction model that can be easily applied at the local or regional level (B.P.Ganasri, Ramesh, 2015). According to (Renard *et al.* 1997) RUSLE are the best known and widely used soil erosion modeling tools in the world. RUSLE uses the same empirical principles as Universal Soil Loss Equation (USLE), but includes numerous improvements in computation of various factors. RUSLE predicts longtime average annual soil loss as a product of rainfall erosivity (R), soil erodibility (K), slope length (L), terrain steepness (S), vegetation cover (C) and conservation practices (P) factors. Therefore, for these research a three dimensional modification of RUSLE3D model applied to estimate the soil loss in Wenberta Watershed.

New opportunities for the application of satellite remote sensing and aerial photos for the detection of conservation practices have arisen due to the increased spatial resolution of satellite imagery and aerial photos with the help of object-based image analysis rather than pixel based image analysis. As a result, using high resolution imagery for mapping the P-factor value enables refinement of soil erosion modeling and allows for field level soil erosion risk mapping.

Object Based Image Analysis (OBIA) can be done on many connected levels that create a relational object structure. The main advantage of this method is the classification uses neighborhood functions that can be applied to image segments. These functions define spatial relations (such as ‘distance to’ or ‘relative border to’) that must be met to classify the object. Using the OBIA method, we can

distinguish LULC classes impossible to separate using traditional pixel-based classification (Y. Gao 2007) .

The a high resolution image and the OBIA approach give valuable support to this study, not only because reliable LULC mapping but also improving the C-factor estimation. This is because the actual erosion assessment as C-factor values could be assigned to particular fields or land parcels.

Topographic factor is the most sensitive factor, that used for the prediction of soil loss (Risse *et al.* 1993). The product of slope length (L) and slope steepness (S) factor represents the topographic factor (LS). The slope length in the USLE model is defined as the distance from the point of origin of overland flow to either where the slope decreases to the point that deposition begins, or to the point where runoff entered a well defined channel (Wischmeier and Smith 1978). However, slope length is defined as overland-flow path-length in RUSLE for its wider application (Renard *et al.* 1991). An overland flow path length is defined as distance from the origin of overland flow to where it enters a major concentrated flow area like an ephemeral gully, waterway, diversion, or stream (Renard *et al.* 1997). This overland flow path length helps in spatial prediction of topographic factor (LS) from a digital elevation model (DEM). Many authors, for example, (Moore and Burch 1986; Desmet and Govers 1996; Mitasova *et al.* 1999) have proved that the influence of terrain form on the overland water flow is accounted better when the slope length factor (L) is replaced by a unit upslope contributing area in RUSLE-3D. Upslope contributing area can be approximated easily using flow accumulation that can be generated from DEM. The merit of replacing the slope length by upslope area lies in the fact that the upslope area better reflects the impact of concentrated flow on increased erosion as normally witnessed in the hilly landscape. Due to this reason, the RUSLE/RUSLE-3D model has been widely used for spatial prediction of soil loss and erosion risk potential (Park *et al.* 2011).

In recent years, the availability of high resolution satellite data and aerial photos has facilitated in large-scale inventory of land use/land cover and soil resources up to micro-watershed level. Several GIS software provide in-built tools for computation of terrain attributes from DEM to estimate the slope length, Upslope contributing area and slope steepness factors (Panos 2015).

1.2.Objectives

1.2.1. General Objective

The general objective of this research is to identify the spatial distribution of soil erosion risk area in Wenberta watershed by using RULSE 3D Model.

1.2.2. Specific Objectives

- To Predict and map the annual average soil loss rate of Wenberta watershed using RULSE 3D Model.
- To obtain a high-resolution LULC map for the entire Wenberta watershed based on Object based Image Analysis.

1.3.Research Questions

Based on the above objectives, the following research questions are drawn.

- What is the annual rate of soil loss in Wenberta watershed?
- Which areas are the most susceptible to soil erosion in Wenberta watershed?
- What are the advantage of OBIA method using in soil Erosion ?

1.4.Significance of the Study

The main purpose of this research is predicting spatial distribution of soil erosion for Wenberta watershed by using RUSLE 3D (Revised Universal Soil Loss Equation–3D) models, the effects of topography on soil loss represented by the combined factor LS, where L is the slope length factor and S the slope gradient factor. The problems with measuring slope gradient and length over large areas were a problem not always estimated correctly, and different ways are used for their calculation.

Therefore, by using GIS (Geographical Information Systems) software has several algorithms for estimating topographic parameters included in the equations of LS. In the RUSLE3D slope length is replaced by upslope area, which takes convergent flow into account. Upslope contributing area is defined as flow accumulation per unit contour width (Mitasova *et al.* 1996) i.e., the length of the uphill paths of converging flow (Desmet & Govers 1997). In this research the RUSLE3D model with GIS used in identifying spatial distribution of soil erosion risk area in the watershed for soil conservation planning. In addition to changing the model LS to upslope contributing area the cover (C factor) and practice management (P factor) of the area were generated from OBIA method that is used to distinguish LULC classes that is impossible to separate using traditional pixel-based classification.

Moreover, such study will provides a base line data for policy makers, land use planner and natural resource managers to formulate and implement effective soil conservation strategies to the specific area of Wenberta watershed. Furthermore, this work could also be used as source of information for those researchers who intend to do similar or related research.

Besides, the soil erosion risk map of the area, the detailed LU/LC map is used for the community and local experts for proper management of their watershed area.

1.5.Statement of the problem

Ethiopia is currently faced a number of environmental concerns resulting directly or indirectly from agriculture and exploitation of natural resource. For a country like Ethiopia, soil is essential input to agricultural production, because agriculture is a back bone of the economy and majority of population depend on agriculture. Most areas found in Ethiopia often face a land degradation due to soil erosion and loss of natural soil fertility content and this affects the productivity of the farmer. Soil erosion occurs when soil particles are carried off by water or wind and deposited somewhere else. As stated in (Lulseged,T. and Vlek, G.L.P. 2008) annual soil loss reaches to 200 - 300 ton per hectare in Ethiopian highlands, while the soil loss movement can reach 23,400 million ton per year (Hurni, 1993). Therefore, soil are lost every year and the land is become unproductive or is being destroyed by erosion channels. Particularly, this is due to the pressure on the fragile natural resources and inappropriate farming methods and lack of soil conservation mechanism.

In most area of Tigray region, soil erosion by water is a fundamental problem and the farmers lack the capacity to cope with it and also to replace lost nutrients. In such areas like Tigray farmers experienced a decline in real income due to demographic, economic, social, and environmental changes. A study by Hurni and Perich (1992) indicated that the region has lost about 30 –50% of its productive capacities by soil erosion. The high soil-loss rates combined with the prominent gullies in the region comprise one of the most severe in land degradation and soil erosion problems in the Ethiopia (Eweg and Van Lammeren, 1996).

Therefore, several studies in Ethiopia revealed that soil erosion has become an alarming problem (Haile and Fetene (2012)) and it is the major factor affecting in the sustainability of agricultural production. Thus, soil erosion is a severe problem in the mountainous northern highlands of Ethiopia.

There are wide variety of technologies available in sciences of remote sensing and GIS. By using this technologies can estimate and map the spatial distribution of erosion risk using erosion models. From

this soil erosion models the most used and known model is RUSLE. The RUSLE model have problems over large areas and not always estimated correctly. Regarding in cover factor OBIA method is potential to produce land cover thematic maps with higher accuracies than those produced by traditional pixel-based method. Pixel-based image analysis is limited because image pixels are not true geographical objects and the pixel topology is limited. Therefore, three-dimensional modification of the Revisited Universal Soil Loss Equation (RUSLE 3D) together with OBIA method is used for this study, in conjunction with GIS and RS techniques to identifying high risk of erosion areas and to quantify the actual amount of soil loss of the watershed, anyone can use this study for remediation measures in the highly risky areas of the wenberta watershed.

1.6.Rationale

Most research paper estimating the soil loss by using coarse spatial resolution data's, that leads to generate inaccurate estimation of soil loss of the areas.

There are a number of soil erosion model available in GIS environment to estimate the amount of soil loss. Most of the time the selection of model is not based on considering the area. Depending on the area characteristics we should have to tune our model selection in addition with the data availability. In such county like Ethiopia, data availability is a huge concern. Each models have their own pros and cons regarding estimation of soil loss of the area. As stated in most research papers RUSLE is the most known model in the world. It's a revised version of USLE from Wischmeier and Smith 1978 and there are lots of advancement in changing a model data inputs and processing mechanism. Regarding this some literature stated that also the RUSLE have some limitation in estimation of the Soil loss in mountainous area and if the area is huge. Therefore by this study, want to show that the advantage of using RUSLE 3D, a three-dimensional modification of the Revised Universal Soil Loss Equation (RUSLE).

Therefore, Atsbi Wenberta watershed is selected due to the availability of high resolution aerial images and Digital Elevation Model (DEM) of the area. By using the high resolution aerial image can generate the land cover of the watershed easily and accurately by using an OBIA method. DEM that is generated from the aerial photos its edited DTM used for this study and have a 10m spatial resolution, that means it will accurately represent the topography of the area. Therefore, the accurate data availability and using the RUSLE 3D model can estimate good result in soil loss of the area.

1.7.Scope

The main part of this research is used estimate the amount of soil loss in Wenberta watershed using GIS and remote sensing technique. Verification/evaluation of the result is out of the scope of this research. It's because of that, soil erosion modeling it needs extensive field data with sample plots for actual estimation of soil loss in entire watershed for a minimum one year daily/monthly records that will convert to in annual base. This is not possible to do it with specified time to finish this research and available resources.

Therefore, by using GIS and remote sensing technique and briefly describe that the amount of soil loss with compared to previous research outputs, that will give us a base for our final result is with the acceptable range or not. Thus, for verifying the soil loss, sample data collection by using plot from the field is out of the scope of research.

1.8.Thesis Organization

The overall organization of the thesis can be divided into five major parts chapter by chapter. Accordingly, **chapter one** is an **introduction**, **chapter two literature review**, **chapter three materials and methods**, **chapter four result and discussion** and **chapter five conclusion, recommendation and further work**. A brief of all this chapters is presented bellow.

Chapter 1 briefly discusses the background, motivation for the work, defines the problems, state the research objectives, questions, significance and the scope of the study.

Chapter 2 analyses the related techniques and summarizes the knowledge and practical experiences gained to provide theoretical and methodological preparation for the method development.

Chapter 3 is the method design part. By adopting techniques on chapter 2, it design a method that works for the available input dataset. It also gives an indication and brief about the study area and summary of materials used are presented. Finally, it shows the implementation of the designed method.

Chapter 4 presents the result of every outputs of the analysis and discusses the results based on reports extracted from the research and by comparing with other research results.

Chapter 5 is a conclusion and recommendation part of the thesis. Based on the result achieved, conclusion has been given. Future works have also been pointed out for the next studies targeting on similar idea, which could not be finished in this research due to different constraints.

Chapter Two

2. Literature Review

2.1. Soil Erosion

As Stated in (Sukho, 2014) Erosion is the process whereby earth or rock material is loosened or dissolved and removed from any part of the earth's surface. Currently, soil erosion is one of the most serious environmental problems in the world today, as it threatens agricultural and natural environment (Vrieling, 2006). Soil erosion occurs by erosive agents such as water and wind from the earth's surface. Soil erosion by water is the main type of soil degradation that occupying 56 percent of the world wide area affected by human-induced soil degradation whereas the area affected by wind erosion occupies 28 percent of the degraded terrain mainly occurring in Asia and Africa. (Anamika, *et al* 2013).

Soil erosion by water classified according to the erosive agent (splash, sheet, Rill, Gully erosions)

- **Rain drop or splash erosion:** Erosion preceded by the destruction of the crumb structure due to the impact of falling raindrop on the surface of soil is termed as splash erosion.
- **Sheet erosion:** It is the fairly uniform removal of soil in thin layers from the land surface, often scarcely perceptible, especially when caused by wind. Areas where loose, shallow topsoil overlies compact soil are most susceptible to sheet erosion.
- **Rill erosion:** A form of water erosion in which numerous very small and more or less straight channels are produced; the channels get obliterated by ordinary use. It can be removed by normal tillage operations.
- **Gully erosion:** A form of water erosion in which gullies are produced by combination of unattended rills. (<http://www.forestrynepal.org/wiki/354>)

As cited in (Fabian, 2015) Erosion is a function of various parameters and controlled by the energy force of rainfall (erosivity) and the relief, the resistibility of soil particles to detachment and transport (erodibility) and the protective function of vegetation cover and soil conservation measures (Morgan 2009).

Topography and rainfall erosivity are mainly natural forces. The erodibility of a soil is first and foremost a natural characteristic but is also influenced by human impact such due to the use of

fertilization or overuse the soil for different purpose. (Ground) cover is either natural or, as it is often the case, influenced by human land use.

2.2.Factors affecting soil erosion

Moreover, Baver (1965) (cited in Sukho, 2014) summarize that the major factors affecting soil erosion are climate, soil properties, vegetation characteristics, and topography. described the factor in detail

- Climate factors play an important role in soil erosion. They include rainfall and temperature changes. Rain is considered the most important factor because rain drops are both initial energy causing soil particles to disintegrate and an agent of surface runoff as well as soil particle movements. Temperature changes between day and night or during seasonal transitions affecting soil structure, lessening soil particle gravitation.
- Topography factors include slope and slope length, affecting the velocity of soil erosion. The higher the slope, the more ferocious erosion becomes. Slope length is directly related to soil quantity being eroded.
- Vegetation cover reduces raindrop impact. The tree canopy shores up the rain and slowly releases the water to the ground by means of through fall and stem flow. Moreover, the canopy facilitates micro-organism activities providing food and energy as well as reducing surface flow.
- Soil properties affecting erosion are divided into two types: properties toward infiltration rate and permeability, and properties against detachment, abrasion and transportation forces of underground water and soil surface.
- Human activities play a crucial part in soil erosion. Some of the activities include deforestation, forest clearing for agriculture, forest fires for hunting, livestock over-farming, incorrect agriculture, and road and residence building. These activities are extremely difficult to solve or modify because they depend on people's education and individual conscience.

2.3.Soil Erosion Models

Several erosion models are available to predict the soil loss and to assess the soil erosion risk. Soil erosion models are simplified depicted realities of a specific part of the landscape (Bork & Schroder 1996). As Soo Huey, 2011 mention that the soil erosion prediction methods were first developed in the U.S.; consequently many soil loss estimation equations were developed by a number of researchers. There are many different soil erosion models with different degrees of simplification, from the simple

to complex. According to Terranova *et al.* (2009), soil erosion models can be divided into three categories:

- **Qualitative models** – based on the direct observation of soil degradation phenomena, remote sensing or aerial photo interpretation, and the construction of geomorphological maps. These models use satellite imagery or aerial photos, applying them to direct detection of the active soil erosion and the erosive consequences (Vrieling, 2006). Although the qualitative model based on remote sensing methods can be rather time-consuming or costly due to long-term field measurements and detailed field surveys, it beneficially provides the new potentialities of data particularly for:
 - i. the automatic detection of gullies;
 - ii. the accurate assessment of aging in vegetation cover in different environments;
 - iii. the spatiotemporal evaluation of rainfall characteristics; and,
 - iv. the accurate mapping of soil properties and soil moisture in a wide range of environments (Vrieling, 2006).
- **Semi-quantitative models** – the simple models, based on scoring factors or expert judgments, which can be applied in complex climatic conditions and can cover a wide variability of the explanatory variables in a relatively short time span (Sonneveld *et al.*, 2011).
 - Examples of the semi-quantitative models are
 - CSSM – the Coleman and Scatena Scoring Model (Coleman and Scatena, 1986),
 - PSIAC – Pacific Southwest Inter-agency Committee (De Vente and Poesen, 2005; Tangestani, 2006),
 - FSM – Factorial Scoring Model (Verstraeten *et al.*, 2003),
 - EHU – Erosion Hazard Unit (Chakela and Stocking, 1988),
 - GLASOD – Global Assessment of Soil Degradation (Sonneveld and Dent, 2009),
 - EPM – Erosion Potential Method (Tangestani, 2006),
 - ERU – Erosion Response Units (Bou Kheir *et al.*, 2006) and
 - SPADS – Spatially Distributed Scoring Model (De Vente *et al.*, 2008).
- **Quantitative models** – based on the parameterization of several factors. The complexity of these models depends on the greater amount of factors considered and on the complexity of each single factor. Typically, they can be divided into three groups:

- **Empirically based models.** Most of these models have been developed based on field observations in specific environmental contexts to which the model was applied (Terranova *et al.*, 2009). Moreover, the parameter values in empirically based models possibly derived by calibration, but are more often transferred from calibration at experimental sites (Merritt *et al.*, 2003). The RUSLE – Revised Universal Soil Loss Equation (Renard *et al.*, 2011), and the SEDD – Sediment Delivery Distributed (Ferro and Porto, 2000) are such models that are more often used rather than the complex models, in particular for identifying soil erosion source and nutrient generation as a first step, especially operated in situations with insufficient data and parameter inputs (Merritt *et al.*, 2003).
- **Physically based models.** These models are the most complex and strict mathematical relationships. They are commented on by Bhattarai and Dutta (2007, p. 1636) that ‘these models are the synthesis of individual components that affect the erosion process and it is argued that they are highly capable of assessing both the spatial and temporal variability of the natural erosion processes’.
 - The physically based models include
 - WEPP – Water Erosion Prediction Project (Baigorria and Romero, 2007),
 - PESERA – Pan European Soil Erosion Risk Assessment (Kirkby *et al.*, 2008),
 - KINEROS – Kinematic Erosion Simulation (Martínez-Carreras, 2007),
 - EUROSEM – European Soil Erosion Model (Quinton *et al.*, 2011) and
 - LISEM – Limburg Soil Erosion Model (Hessel *et al.*, 2011).
- **Conceptually based models.** These models lie between the empirically based and the physically based models, and display a partial representation of the hydrological sediment yield processes (Karnoven *et al.*, 1999). They take into account the physical processes governing erosion by water through empirical relationships among the involved variables (Terranova *et al.*, 2009).
 - The conceptually based models include
 - SWAT – Soil and Water Assessment Tool (Shen *et al.*, 2009),
 - AGNPS – Agricultural Non-Point Source (Walling *et al.*, 2003),

- SEMMED – Soil Erosion Model for Mediterranean Area (De Jong *et al.*, 1999), and
- MMF – Morgan, Morgan and Finney (Morgan and Duzant, 2008).

As Stated in Sukho, 2014 RUSLE uses the same empirical principles as USLE, but includes numerous improvements in computation of various factors. It predicts longtime average annual soil loss as a product of rainfall erosivity (R), soil erodibility (K), slope length (L), terrain steepness (S), vegetation cover (C) and conservation practices (P) factors. (Risse *et al.* 1993) mention that among these factors, topographic factor is the most sensitive in the prediction of soil loss. The product of slope length (L) and slope steepness (S) factor represents the topographic factor (LS). The slope length in the USLE model is defined as the distance from the point of origin of overland flow to either where the slope decreases to the point that deposition begins, or to the point where runoff entered a well defined channel (Wischmeier and Smith 1978). Slope length is defined as overland-flow path-length in RUSLE for its wider application (Renard *et al.* 1991). An overland flow path length is defined as distance from the origin of overland flow to where it enters a major concentrated flow area like an ephemeral gully, waterway, diversion, or stream (Renard *et al.* 1997). This definition helps in spatial prediction of topographic factor (LS) equation based on a digital elevation model (DEM) (Moore and Burch 1986; Desmet and Govers 1996). Mitasova *et al.* (1996) replaced the slope length factor (LS) by the upslope contributing area in RUSLE-3D. Upslope contributing area can be approximated easily using flow accumulation. The merit of replacing the slope length by upslope area lies in the fact that the upslope area better reflects the impact of concentrated flow on increased erosion as normally witnessed in the hilly landscape.

The RUSLE assumes that detachment and deposition are controlled by the sediment content of the flow (Pitt, 2007). Erosion is limited by the carrying capacity of the flow but is not source limited (Pitt, 2007). Detachment will no longer take place when the sediment load has reached the carrying capacity of the flow (Pitt, 2007).

The RUSLE equation is shown below (Renard, Foster, Weesies, McDool, & Yoder, 1997) :

$$A = R * K * LS * C * P \quad \text{Eq. 1}$$

...where:

A – (tons/ha/year) soil loss

R – rainfall erosivity factor

K – soil erodibility factor

LS – slope and slope length factor or topographical factor

C – vegetative cover factor

P – conservation practice factor

The RUSLE is currently a globally accepted method for soil erosion prediction all over the world. These models have been accepted to be useful, accurate and reliable. In the RUSLE3D model the slope length is replaced by upslope area, which takes convergent flow into account.

2.4. Soil Erosion Risk

Soil erosion risk assessment is done in various regions, on different scales and temporal frameworks, with different goals and methods.

Different approaches can be used to identify high erosion risk areas. Soil erosion models represent an efficient means of investigating the physical processes and mechanisms governing erosion rates and identifying high erosion risk areas (Lane *et al.*, 1997; Jetten *et al.*, 2003). A wide range of models are available that differ in their data requirement for model calibration, application, complexity, and processes considered. A good model is one that can satisfy the requirements of reliability, universal applicability, ease of use with minimum data, comprehensiveness in terms of the factors and erosion processes included and the ability to take into account changes in land-use and management practices (Morgan, 1995).

As cited in (Fabian, 2015) there are two methodological approaches can broadly be distinguished: Expert-based methods and erosion modeling (Van der Knijff *et al.* 2000; Vrieling *et al.* 2006; Karydas *et al.* 2009). Expert-based methods generally only give relative results (Vrieling *et al.* 2006). The results of an erosion risk assessment is consistently a relative risk map of “hotspots” or priory areas, which show the spatial distribution of the erosion risk (Volk *et al.* 2010). The goal of this risk mapping is risk management and erosion control i.e. planning and implementation of soil conservation measurements (Vrieling *et al.* 2006), the identification of priority areas (Nigel & Rughooputh 2010)

Nigel & Rughooputh (2010) define erosion risk as the interaction of erosion susceptibility (of the topography) and sensitivity (of the land cover) in combination with rainfall erosivity.

2.5. Revised Universal Soil Loss Equation (RUSLE 3D)

The RUSLE model has been widely used for spatial prediction of soil loss and erosion risk potential (Terranova *et al.* 2009; Park *et al.* 2011).

In recent years, the availability of high resolution data's has facilitated in large-scale inventory of land use/land cover and soil resources up to micro-watershed level. Several GIS software provide in-built tools for computation of terrain attributes from DEM to estimate the slope length and slope steepness factors.

The topographic factor (LS) is based on elevation data like Digital Elevation Model (DEM) or some other data formats. Therefore, many authors (Moore and Burch 1986,1992; Desmet and Govers 1996; Mitasova *et al.* 1996) have proved that the influence of terrain form on the overland water flow is accounted better when the slope length factor (L) is replaced by a unit upslope contributing area in RUSLE-3D. Upslope contributing area is defined as flow accumulation per unit contour width (Mitasova *et al.* 1996) that is the length of the uphill paths of converging flow (Desmet & Govers 1997). In a grid-based algorithm, a unit contour width equals the resolution of the DEM. The merit of replacing the slope length by upslope area lies in the fact that the upslope area better reflects the impact of concentrated flow on increased erosion as normally witnessed in the hilly landscape. Park *et al.* 2011 stated that the RUSLE/RUSLE-3D model has been widely used for spatial prediction of soil loss and erosion risk potential.

Topographic factor is the most sensitive another factor, that used in the prediction of soil loss (Risse *et al.* 1993). The product of slope length (L) and slope steepness (S) factor represents the topographic factor (LS). The slope length in the USLE model is defined as the distance from the point of origin of overland flow to either where the slope decreases to the point that deposition begins, or to the point where runoff entered a well defined channel (Wischmeier and Smith 1978). Slope length is defined as overland-flow path-length in RUSLE2 for its wider application (Renard *et al.* 1991). An overland flow path length is defined as distance from the origin of overland flow to where it enters a major concentrated flow area like an ephemeral gully, waterway, diversion, or stream (Renard *et al.* 1997). This definition helps in spatial prediction of topographic factor (LS) equation based on a digital elevation model (DEM).

In recent years, the availability of high resolution satellite data and aerial photos has facilitated in large-scale inventory of land use/land cover and soil resources up to micro-watershed level. Several GIS software provide in-built tools for computation of terrain attributes from DEM to estimate the slope length and slope steepness factors.

The present study aims to assess the spatial pattern of soil erosion risk in Wenberta watershed using RUSLE-3D model.

2.6. Object based Image Analysis

Object-Based Image Analysis (OBIA) is used in remote sensing imagery changed into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale. The two main processes in OBIA are

- segmentation and
- classification

In object based image analysis, segmentation is always the first step of any process in eCognition developer and it generates the image objects on which the classification process will be performed. The important part is for the segmentation process to identify objects which a representative of the features you wish to classify and are distinct in terms of the features available within by using spectral values, shape and texture of the object in the Image. OBIA groups pixels into homogeneous objects. The analyst defines statistics in the classification process to generate land cover.

Working with objects rather than pixels have numerous benefits over traditional pixel based analysis (Y. Gao, 2007)

2.6.1. Comparison of Object Based and Pixel based Image Analysis

There are a lots of technology advancement in the last two decades regarding in earth observation , GIS science and related to computer technology. These advancements led to the development of “Object-based Image Analysis (OBIA)” as an alternative to the traditional pixel-based image analysis method.

As cited in (Y. Gao and J.F. Mas, 2007) Some researchers found that pixel-based image analysis is limited because of the following reasons: image pixels are not true geographical objects and the pixel topology is limited; pixel based image analysis largely neglects the spatial photo-interpretive elements such as texture, context, and shape; the increased variability implicit within high spatial resolution

imagery confuses traditional pixel-based classifiers resulting in lower classification accuracies (Hay and Castilla 2006).

OBIA works on homogeneous objects produced by image segmentation and more elements can be used in the classification. As an object is a group of pixels, object characteristics such as mean value, standard deviation, ratio, etc can be calculated; besides there are shape and texture features of the objects available which can be used to differentiate land cover classes with similar spectral information. These extra types of information give OBIA the potential to produce land cover thematic maps with higher accuracies than those produced by traditional pixel-based method.

The object-based image analysis has advantage over the pixel-based one, and in accuracy rating, the advantage was better represented by higher spatial resolution satellite images. (Y. Gao, 2007).

As Stated (Y. Gao, 2007) Pixel based image classification utilizes spectral information-digital values (DNs) stored in the image and classifies images by considering the spectral similarities with the pre-defined land cover classes (Casals-Carrasco *et al.* 2000). Although the techniques are well developed and have sophisticated variations such as soft classifiers, sub-pixel classifiers and spectral un-mixing techniques, it is argued that it does not make use of the spatial concept (Blaschke *et al.* 2001).

2.7. Soil Erosion in Northern Ethiopia: Nature and Extent of the Problem

In most area of Ethiopia, soil erosion by water is a fundamental problem and it's a main type. Soil erosion is a severe problem in the mountainous northern highlands of Ethiopia. In Tigray which is placed in northern Ethiopia, the topsoil, and in some places the subsoil, have been removed from sloping lands, leaving stones or bare rock on the surface (Tilahun *et al.*, 2002). A study by Hurni and Perich (1992) indicated that the Tigray region has lost about 30 –50% of its productive capacities. The high soil-loss rates combined with the prominent gullies in the region comprise one of the most severe land degradation and soil erosion problems in the world (Eweg and Van Lammeren, 1996).

Despite the severity of erosion and its associated consequences in the region, there have been few studies to quantify erosion rates and understand the spatial dynamics of erosion processes at the catchment scale. Some of the studies related to erosion are based on erosion plots (Nyssen, 2001), which cannot be easily extrapolated to basin scale and which are also too few to represent the diverse environments of the region.

Chapter Three

3. Material and Methods

3.1. Study area description

The Wenberta watershed is located in eastern Tigray, Atsbi Wenberta, Kilite Awlalo and Enderta Woreda which is located in Tigray Regional state. Geographically between longitude $39^{\circ} 24' - 39^{\circ} 48'$ E and latitude $13^{\circ} 24'$ to $14^{\circ} 01'$ N and the total area of the watershed is 73700 ha.

The watershed falls down in most of the area of Atsbi Wenberta woreda and it's one of the big woreda's in the Tigray Region. Located in the Eastern Zone at the eastern edge of the Ethiopian highlands, Atsbi Wenberta is bordered on the south by the enderta woreda from Southeastern Zone, on the west by Kilte Awulaelo, on the north by Saesi Tsaedaemba, and on the east by the Afar Region. Atsbi woreda is one of 8 woreda found in Eastern zone (Misrakawi Zoba). The administrative center of this woreda is Atsbi other towns and its woreda capital. The woreda is administratively divided in to 18 Tabiyas (Kebelles). In Atsbi woreda there are sixteen tabia (kebele). The tabia are Tegahne, Quret, Zahararo, Barka, Harresaw, Agewo, Zarema, Gendet, Debreselam, Adi Kebero, Baatiero, Maimetanu, Awdesel, Hichen, Qalqalet and Endaselassie. A small town and market called Dera are located in Abiy Dera Kushet. The region has been under continuous cultivation for two thousand years or probably more (Assefa and Yared, 1996). The altitude of the area is between 2,700 and 3,100 meters. Annual rainfall ranges between 350 and 500 mm. The topography of the area is full of ups and downs and there is considerable land degradation. There is no annual river and rivers are seasonal and flow during rainy seasons in the study area.

The area in general is affected by recurrent drought and good harvests can only be obtained about once in a decade. The type of soil is, by and large, white and sandy. The extent of degradation of the soil is serious and there is no forest land except in a few areas around the Afar escarpment where scattered forest is visible (Assefa and Yared, 1996).

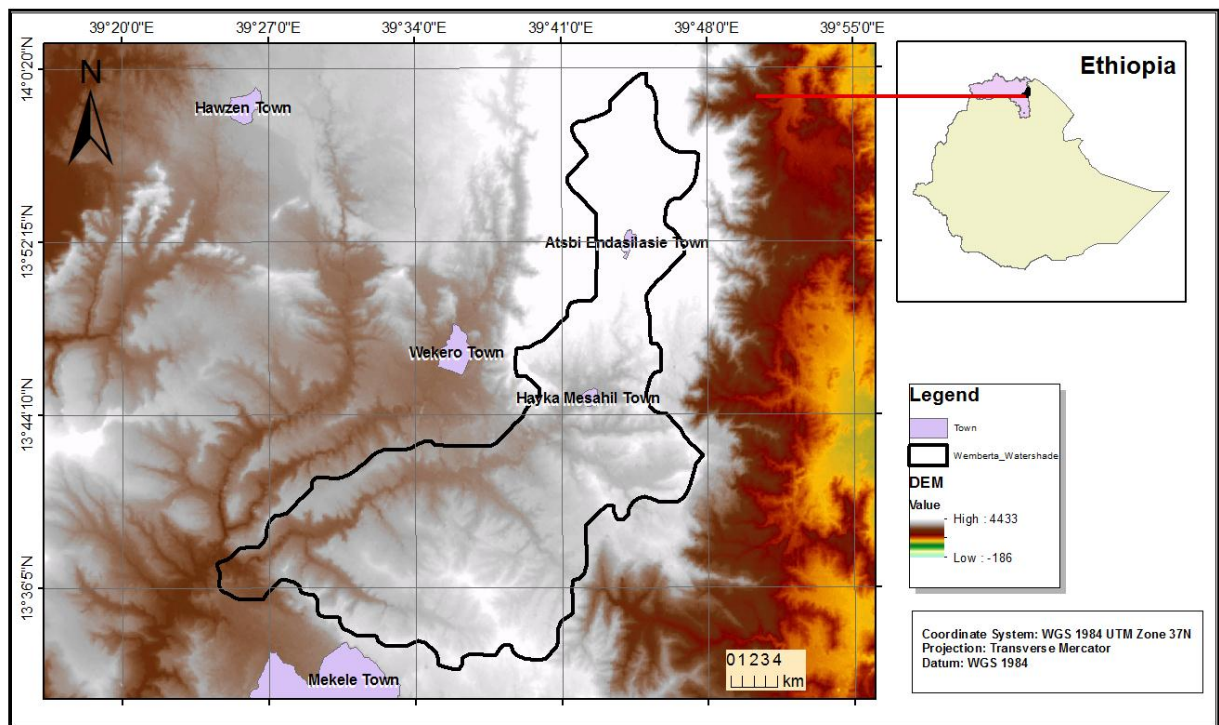


Figure 1. Wenberta Watershed Boundary

3.2. Data collection

To estimate the soil erosion using RUSLE model for Atsbi Wenberta Watershed, the following dataset are required:

- 1) Average annual precipitation (Data Source: Ethiopian Metrological Agency)
- 2) Soil type map (Data source: World Soil Data (FAO))
- 3) Digital elevation model (Data source: INSA)
- 4) Aerial Photo (Source: INSA)

3.2.1. Precipitation (Rainfall) Data

Monthly average precipitation data were provided from the Ethiopian National Meteorological Agency which is in charge of collecting the whole climate data including precipitation data for the entire country. For the Atsbi Wenberta watershed, monthly average precipitation data from gauging stations located around (7 gauging stations) and inside of (1 gauging stations) the watershed were obtained and processed to compute the rainfall runoff erosivity factor of the RUSLE method. There are additional stations available in the watershed but the station have a 4 - 5 years of record. Due to that reason we

don't use them for calculating the data. Therefore, by summing the annual average rainfall of 10 year rainfall data interpolated in ArcGIS by the spatial analyst tool to generate the raster value.

Table 1 shows summarized information about these 8 stations: name, location and average annual precipitation.

Table 1. Rainfall Station List and Location

Name of the Station	Average Annual Precipitation	Lat	Long	Elevation
Atsebi	503.1	580108.67	1534933.2	2711
Edagarebu (Edagaarb)	370.4	574865.90	1558239.2	2920
Aynalem	444.4	553128.97	1488106.8	2195
Senkata	478.5	561401.41	1554895.0	2437
Adigudom	429.7	555499.38	1464463.2	2100
Dengolet	642.2	534370.01	1472234.8	2371
Hawzen	410.4	546593.02	1544795.8	2242
Edaga Hamus	409.9	560644.01	1568208.5	2708

According to Wischmeier and Smith (1978), at least 20 years of rainfall records should be used to compute the rainfall runoff erosivity factor of the RUSLE model in order to accommodate the variation of the climate. Due to this there is a limitation in the study. Figure 2 shows that location of the stations around and inside of the of Atsbi Wenberta watershed.

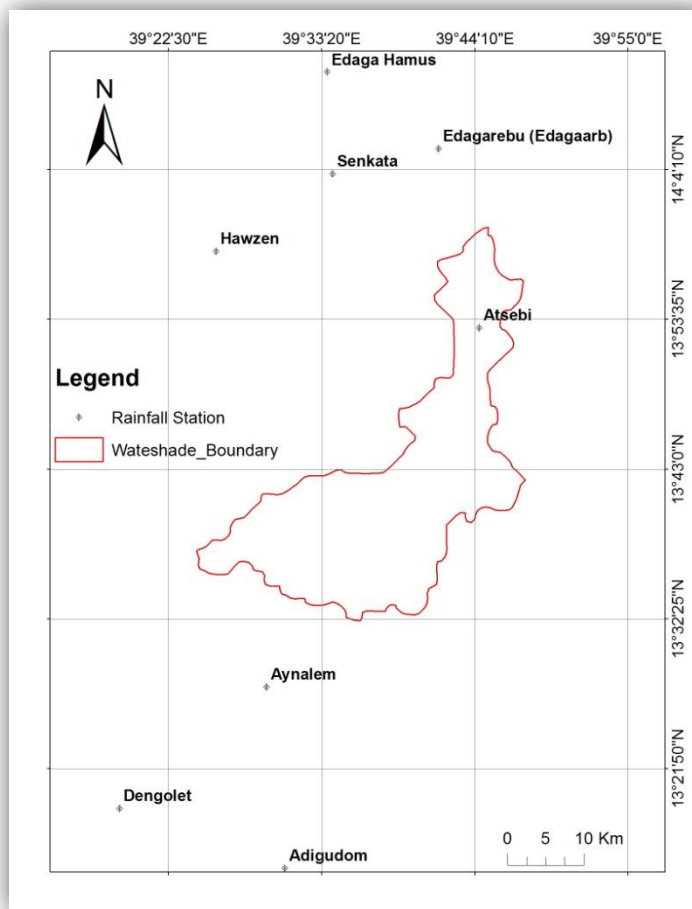


Figure 2. Rainfall Station Distribution

The monthly, amounts of precipitation of study area should be collected from Ethiopian Metrological Agency that are inside of the study area and nearby stations for minimum 10 years precipitation data . Therefore, by summing annual average rainfall of 10 year data interpolated in ArcGIS by spatial analyst tool. Finally, the layers were converted to raster with spatial resolution of 10 m x 10 m to meet the spatial resolution of other thematic maps used in the RUSLE 3D model.

3.2.2. Soil

The soil data used for Atsbi Wenberta watershed is obtained from digital soil map of world food and agriculture organization (FAO) of the united nations Version 3.6, completed January 2003 that is available to download in web; the digitized Soil Map of the World has been cleaned of errors both in the database and in the lines constituting the digitized map itself. The soil data is originally with the 30 arc second that means approximately 1 kilometer. By using Conversion tools in Arc Toolbox, layers were converted to raster with a spatial resolution of 10 m x 10 m to meet the spatial resolution of other thematic maps used in the RUSLE model.

Based on extracted soil map three soil regions are encounter in the Atsbi Wenberta watershed. The Table 2 gives information about soil classification and soil texture of the Atsbi Wenberta watershed. This data sources is available to download in the web and used as to develop the soil erodability factor (K factor).

Table 2. Soil Classification

Soil Classification	Sand % topsoil	Silt % topsoil	Clay % topsoil
Eutric Nitosols	68.4	10.5	21.2
Humic Cambisols	55.2	21	23.8
Cambic Arenosols	92	3.1	4.9

3.2.3. Digital Elevation Model (DEM)

The whole watershed DEM have a spatial resolution of 10 m x 10 m, this DEM is derived from aerial photos during the photogrammetric process. According to the DEM, the elevation of the area ranges from 1768-3052 meter this shows that the area is a huge topographical variation.

This DEM gives a better representation area for final result. By using DEM can determine the LS factor inputs elevation, Slope, Flow Direction, Flow Accumulation, Sink route that is used to generate LS factor using Upslope area. Slope length factor (L) is replaced by a unit upslope contributing area in RUSLE-3D.

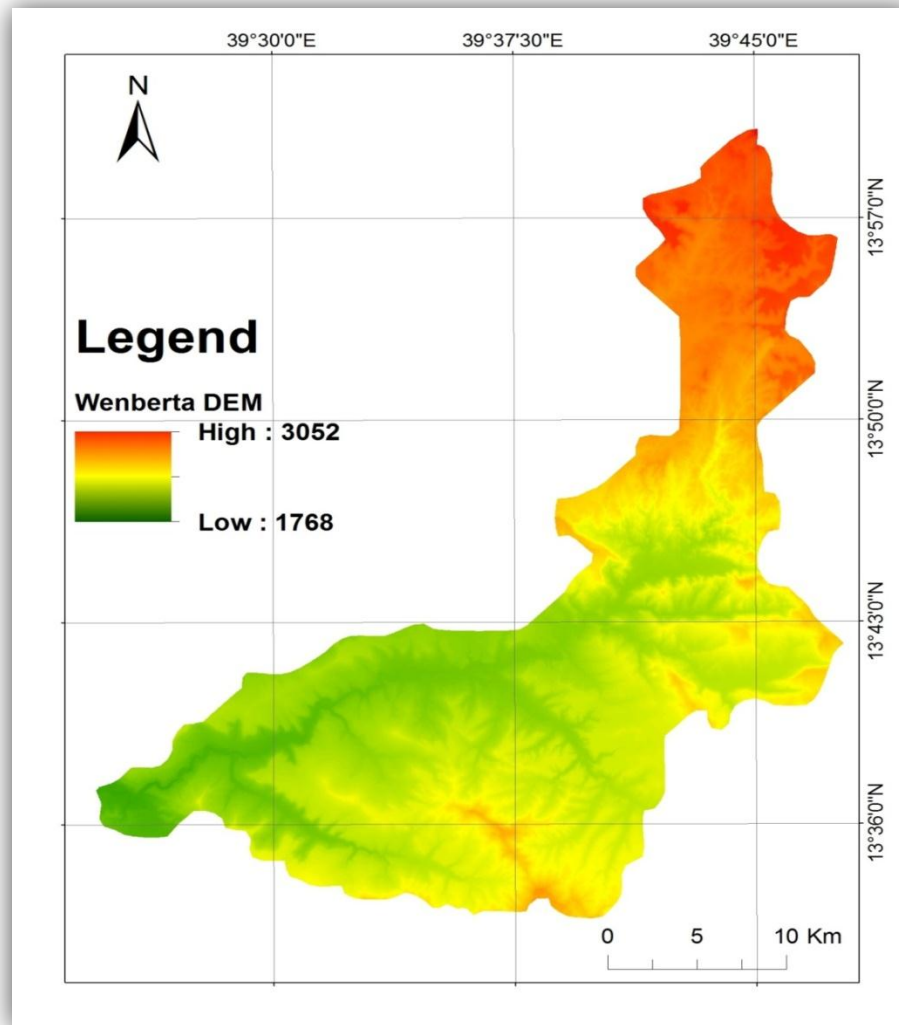


Figure 3. Digital Elevation Model

3.2.4. Aerial Photos

To generate land cover variation over the Atsbi Wenberta Watershed, Aerial Photos that is captured in 2013 by Information Network security Agency used as an input with a resolution of 0.25m for entire watershed. The aerial photos is with visible range that is RGB Band. The Photos is captured using the UltraCam Eagle Camera and Processed by the INSA photogrammetric department using INPHO software to generate a mosaic image. The entire project extracted using the boundary of the watershed with 25 cm GSD used for this research to classify the land use and land cover map of the watershed and is used to generate C and P factors.

Table 3. Camera Specification

Equipment	Specification	
UltraCam ultra large format camera system	Panchromatic image size	20,010 x 13,080 pixels
	Color image size	6670 x 4360 pixels
	Panchromatic physical pixel size	5.2 μm
	Color physical pixel size	15.6 μm
	Pan-sharpening ratio	1:3
	Input data quantity per image	1050 MB, 260 megapixels
	Lens system	1: 80 mm PAN and 27 mm RGBNIR
	Maximum frame rate	<1.8 seconds per frame
	CCD signal to noise ratio	72 dB
	CCD image dynamic	14 bit; workflow dynamic: 16 bit

3.2.5. Software used

The following software's was used for the assessment of soil erosion

- **eCognition Essential 1.3** - Used for OBIA method Land cover classification;
- **ArcGIS 10.3** - Spatial data Analysis for all factor and map preparation;
- **MS Office 2007** - Analyzing some simple calculation;
- **Global Mapper 13** - DEM Manipulation;
- **SAGA GIS** - Used for generating LS Factor .

3.3.Methods used for generation of spatial data layers

3.3.1. Model description

RUSLE-3D model calculates potential average soil loss (erosion hazard) expressed as tone per hectare per year. In this research, the amount of soil loss was determined using the RUSLE 3D model in a GIS environment with the following formula

$$A = R * K * LS * C * P \quad (\text{Eq.1})$$

Where, A (tons/ha/year) is the average annual soil loss per unit area

R is the rainfall intensity factor

K is the soil erodibility factor

L is the upslope contributing area factor

S is the slope steepness factor

C is the land cover factor

P is the soil conservation or prevention practices factor

3.3.1.1. R Factor

The rainfall-runoff erosivity factor R quantifies the effects of raindrop impact and reflects the amount and rate of runoff likely to be associated with rain (Renard *et al.* 1997). The annual erosivity was estimated by summing rainfall erosivity of individual erosive storms of the year or season (Wischmeier and Smith 1978). There are 8 stations available around the study area with 10 years station. The R -factor requires long term average rainfall data that records the energy available to erode soil. The R factor is one input to estimate average annual soil loss, must include the cumulative effects of the many moderate-sized storms as well as the effects of the occasional severe ones. The general approach has been used by several researches over the world to compute this factor annual precipitation data, easier to obtain in most parts of the world.

Many soil erosion studies in Ethiopia performed in Ethiopia with the equation of below. Thus, the R-factor was calculated based on the following equation (Bewket and Teferi (2009); Shiferaw (2011)),

$$R = -8.12 + (0.562 * P) \quad \text{Eq. 2}$$

Where R is rainfall erosivity and P is the mean annual rainfall (mm)

In order to compute R factor, the nearby eight metrological stations of 10 years annual rainfall data were used to estimate the point data in to surface using ArcGIS Kriging interpolation method. So, R-value was interpolated through annual rainfall data from surrounding metrological stations.

To use R-factor values derived for the Atsbi Wenberta watershed for the soil erosion prediction in the ArcGIS environment, an interpolated surface must be created from R-values at each station. Two sets of interpolation methods can be used for this purpose: deterministic interpolation methods and geostatistical interpolation methods. Deterministic interpolation refers to non-statistical methods that use the measured values at each point to determine values at the remaining locations across the surface. On the other hand, geostatistical interpolation methods use statistics based on measured points to statistically predict the remaining locations values across the surface. The main advantage of geostatistical methods is that they provide standard error values to indicate the accuracy of the predictions (Krivoruchko, 2011). Inverse distance weighting is a commonly used deterministic interpolation method. It predicts cell values at unknown locations based on the distance between the unknown cell and the known points.

Table 4 shows the Name, the location with elevation and mean annual precipitation value of each of the metrological stations used in this study.

Table 4. Average annual Precipitation value

Name of the Station	Average Annual Precipitation	Latitude	Longitude	Elevation
Atsebi	503.1	580108.67	1534933.2	2711
Edagarebu (Edagaarb)	370.4	574865.90	1558239.2	2920
Aynalem	444.4	553128.97	1488106.8	2195
Senkata	478.5	561401.41	1554895.0	2437
Adigudom	429.7	555499.38	1464463.2	2100
Dengolet	642.2	534370.01	1472234.8	2371
Hawzen	410.4	546593.02	1544795.8	2242
Edaga Hamus	409.9	560644.01	1568208.5	2708

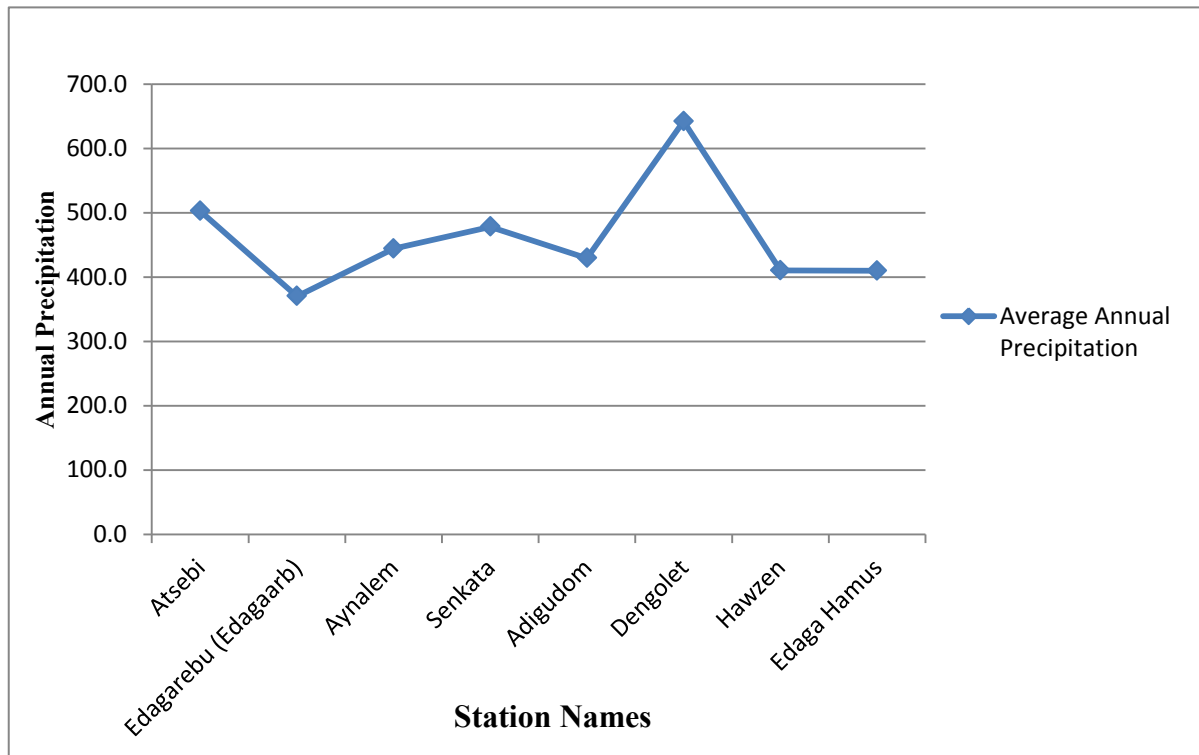


Figure 4. Average Annual Precipitation

3.3.1.2. Soil erodability (K) factor

Soil erodibility is a measure of a soil's resistance to the erosive powers of rainfall energy and runoff. Practically, in the RUSLE, soil erodibility is an integration of the impacts of rainfall and runoff on soil loss for a given soil (Haan *et al.* 1994).

Soil erodibility index (K) of surface soils of each soil type, associated with the mapping units was computed using following equation:

$$K = 2.1 * 10^{-4} (12 - OM) * M^{1.14} + 3.25 * (S - 2) + 2.5 * (P - 3) \quad \text{Eq. 3}$$

where K is the soil erodibility factor (t ha⁻¹ per unit R), M is particle size parameter (% silt + % very fine sand) * (100 - % clay), Organic Matter (OM) is the organic matter content (%), S is soil structure code and P the soil permeability class. The soil map was reclassified based on K value of each map unit to generate soil erodibility map using GIS.

In FAO digital soil map of world the value of OM is not available in attribute information therefore in order to meet the equation it's better to have OM. Organic matter (OM) is difficult for laboratories to measure directly, so they usually measure total organic carbon like available in digital soil map of the world. This is probably why organic matter and organic carbon are often confused and used

interchangeably. There is a conversion factor of 1.72 is commonly used to convert organic carbon to organic matter:

$$\text{Organic matter (\%)} = \text{Total organic carbon (\%)} * 1.72 \quad \text{Eq. 4}$$

This conversion factor assumes organic matter contains 58% organic carbon.
 (<http://www.soilquality.org.au/factsheets/organic-carbon>)

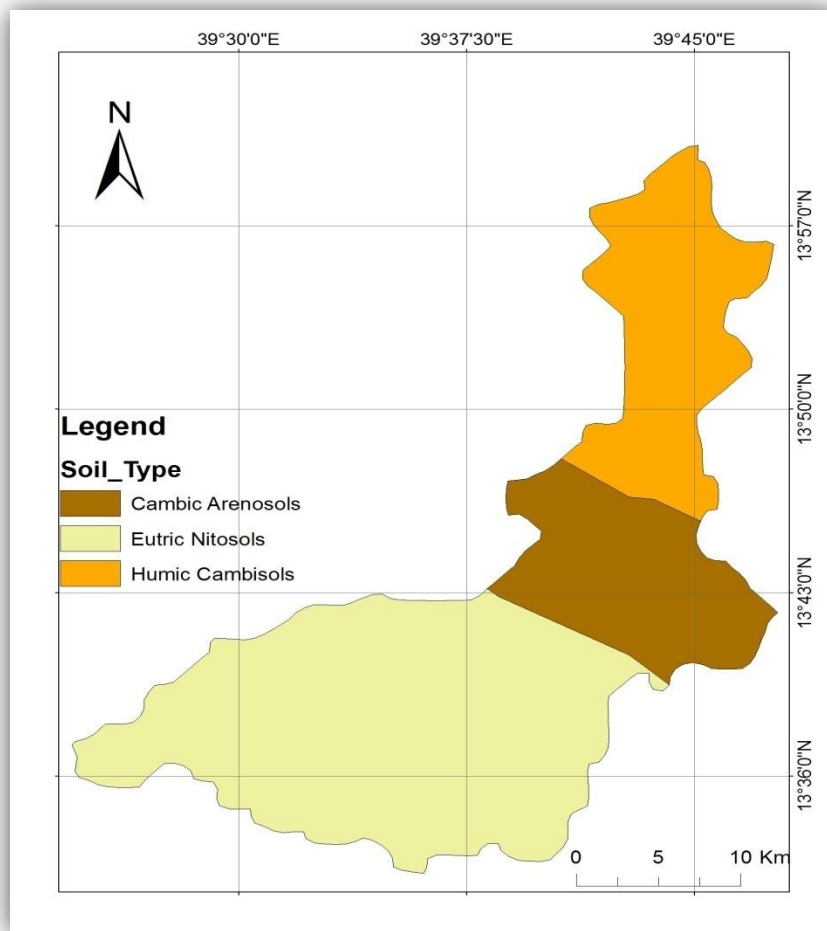


Figure 5. Soil Type

Table 5. Soil classification and Organic Carbon

Soil Classification	Sand % topsoil	Silt % topsoil	Clay % topsoil	OC % topsoil
Eutric Nitosols	68.4	10.5	21.2	0.6
Humic Cambisols	55.2	21	23.8	3.86
Cambic Arenosols	92	3.1	4.9	0.21

3.3.1.3. Topographic factor (LS)

The topographic factor (LS) of the RUSLE 3D is calculated using the approach of Mitasova *et al.* (1996). In contradiction to the original version of the USLE (Wischmeier & Smith 1978), this approach is based on upslope area instead of slope length.

Upslope contributing area is defined as flow accumulation per unit contour width that is the length of the uphill paths of converging flow (Desmet & Govers 1997). In a grid-based algorithm, a unit contour width equals the resolution of the DEM.

The original RUSLE's LS-factor is the ratio of soil loss from the area under investigation to the standard plot from a length of 22.13m and a slope of 9% (Wischmeier & Smith 1978).

The RUSLE LS factor is the product of slope length and slope steepness factors . It was calculated for each grid cell. The slope length was replaced by the upslope contributing area per unit width of cell spacing $A(r)$ ($m^2 m^{-1}$) in RUSLE-3D (Mitasova *et al.* 1996). The modified LS factor of a grid cell or at a point $r = (x, y)$ is calculated as:

$$LS_{(r)} = (m + 1) \left[\frac{A_{(cont)}}{\lambda_0} \right]^m \left[\frac{\sin \beta}{\beta_0} \right]^n \quad (\text{Eq.5})$$

where LS_r = computed LS factor, $\beta_0 = 9\% = 5.14^\circ$ is the slope of the standard plot, $\lambda_0 = 22.13m$ is the slope length of the standard plot, A_{cont} is the upslope contributing area in meter and $m = 0.1$ and $n = 1.3$ are dimensionless parameters, adapted to a high vegetation cover and the absence of a rill network (Hoffmann *et al.* 2013).

The increasing availability of DEMs has promoted the use of image-processing techniques and software for deriving terrain properties such as LS-factor. SAGA (System for Automated Geoscientific Analyses) software is a user-friendly platform that provides a comprehensive set of modules for data analysis and numerous applications such as those focusing on DEMs and Terrain Analysis. The estimated LS-factor by using one of the hydrology modules available in SAGA (Up slope area and LS) which incorporates the multiple flow algorithm. Moreover, SAGA carries out computations much more quickly than the classical ArcGIS toolbox, and calculates upslope area directly from the DEMs.

LS factor maps is generated by using the DEM. The average slope of each pixel was calculated from the greatest elevation difference between it and its eight neighboring pixels. The slope was classified into nine steepness classes (Wischmeier and Smith 1978) of erosion hazards of nearly level (0–2%), gently undulating (2–4%), strongly undulating (4–6%), gently rolling (6–10%), strongly rolling (10–

16%), hilly (16–25%), steep (25–40%), very steep (40–60%) and the extremely steep (>60%) slope classes.

The DEM is used to calculate the two input variables of LS-factor that is Slope and Upslope Area. By using DEM of the whole watershed a slope grid and upslope area is calculated using both calculated by using SAGA GIS Software.

Desmet & Govers Algorithm

As stated in (Anna Hoffmann et.al 2013) the great disadvantage observed in the USLE/RUSLE models is the two-dimensional evaluation used to determine the effects of the topography. In these models, the landscape has been generically treated as homogeneous, with plane characteristics. The first research that developed a procedure for soil loss calculation capable to consider the slope form divided the irregular slopes into a limited number of uniform segments. Continuing this study, weights were attributed for the slope stretches according to their convexity or concavity. The upstream contribution area concept was introduced for the calculation of the L factor that was applied to the RUSLE LS factor equations. For the calculation of the contribution area, a multiple flow direction algorithm was used. The L factor is expressed according to the equation:

$$L_{i,j} = \frac{[(A_{i,j-in} + D^2)^{m+1} (A_{i,j-in})^{m+1}]}{[D^{m+2} x_{i,j}^m (22.13^m)]} \quad \text{Eq. 6}$$

Where $L_{i,j}$ is the slope length factor of a cell with coordinates (i,j); $A_{i,j-in}$ is the upslope contribution area of a cell with coordinates (i, j); D = is the cell grid size (m); $x_{i,j}$ is the flow direction value.

By using the above Equation Desmet & Govers, an LS factor equation was generated that is used by the RUSLE 3D model. The model includes irregular hillsides integrating a wide spectrum of hillside convexities and concavities and it incorporates the contribution area A for the determination of the LS factor:

Typical m values are 0.4-0.6 and for n 1-1.3. The exponents for the runoff and slope terms in the soil detachment and sediment transport equations reflect the interaction among different flow, detachment and soil transport types

3.3.1.4. Cover Factor (C) and Conservation Practice (P) factors

Satellite images or aerial photos is used to determine the C-factor by land cover classification (Folly *et al.* 1996). In RUSLE satellite images or aerial photos in preparation of land cover maps has been widely applied. Those data's provide up to date information on land cover. High resolution Aerial

images of the watershed will help for this study to prepare detailed land use/land cover and to derive vegetation cover, to observe the conservation practices.

The C-factor is used within the RUSLE to reflect the effect of cropping and management practices on erosion rates, and is the factor used most often to compare the relative impacts of management options on conservation plans (USDA-ARS, 2001 as cited in Israel,2011).

Assessment of the type of land use/land cover was made separately for each land unit and corresponding value for land use/land cover was obtained from Hurni (1985 as cited in Israel, 2011) which was adapted to Ethiopian condition. In order to determine C-factor, Atsbi Wenberta watershed classified into eight land use classes generated from aerial photos by using object based image analysis (OBIA) using multiresolution segmentation and nearest neighbor classification technique. After getting the classified image, data format changed into vector format and the corresponding C-value which was obtained from Hurni ((1985) as cited in Israel 2011) was assigned and C - factor map was produced and changed to raster again to for the final calculation .

Based on this information, C and P values for each land use/cover class Table 10 was assigned based on the literature (Hurni 1988; Helden 1987; Singh *et al.* 1981; Patric 2015).

3.4.OBIA Nearest Neighbor Classification

Object based nearest neighbor classification (NN classification) is a super-powered supervised classification technique. The reason is because you have the advantage of using intelligent image objects with multiresolution segmentation in combination with supervised classification.

3.4.1. Image Segmentation

From the Image segmentation process Multiresolution segmentation is one of the most widely used algorithm in OBIA. It has been included in eCognition since the first versions , and despite its recent availability, it is rapidly becoming one of the most cited segmentation algorithms.

The key parameter for this segmentation method is the scale parameter, although there is no straight forward method available to obtain an optimum value of the same. The usual approach is to find a compromise value for the whole image by trying several values and evaluating the results.

The Multiresolution Segmentation algorithm locally minimizes the average heterogeneity of image objects for a given resolution of image objects. It can be executed on an existing image object level or the pixel level for creating new image objects on a new image object level.

The multiresolution segmentation algorithm consecutively merges pixels or existing image objects. Thus it is a bottom-up segmentation algorithm based on a pairwise region merging technique. Multiresolution segmentation is an optimization procedure which, for a given number of image objects, minimizes the average heterogeneity and maximizes their respective homogeneity.

The Cover Management Factor (C) represents the effect of vegetation, soil cover, cropping, soil-disturbing activities and management practices on soil erosion. Land cover maps with adequate spatial resolution are needed to derive C values over a river basin. For the Atsbi Wenberta Watershed there is no existing land cover maps with the appropriate resolution for the purpose of generating C factor, High Resolution Aerial photos used to derive land cover maps of the watershed.

There are numerous classification methods. From the perspective of the image classification methods, there are two basic categories Object based Image Classification and Pixel based Image Classification methods are available that is detailed explained in literature review part. For this study the OBIA method is used for generating the land cover map of watershed. A general methodology flow chart presented in (figure 6).

Assessment of Soil Erosion Risk Area Using Object Based Image Analysis and RUSLE3D Model
A Case Study of Wenberta Watershed

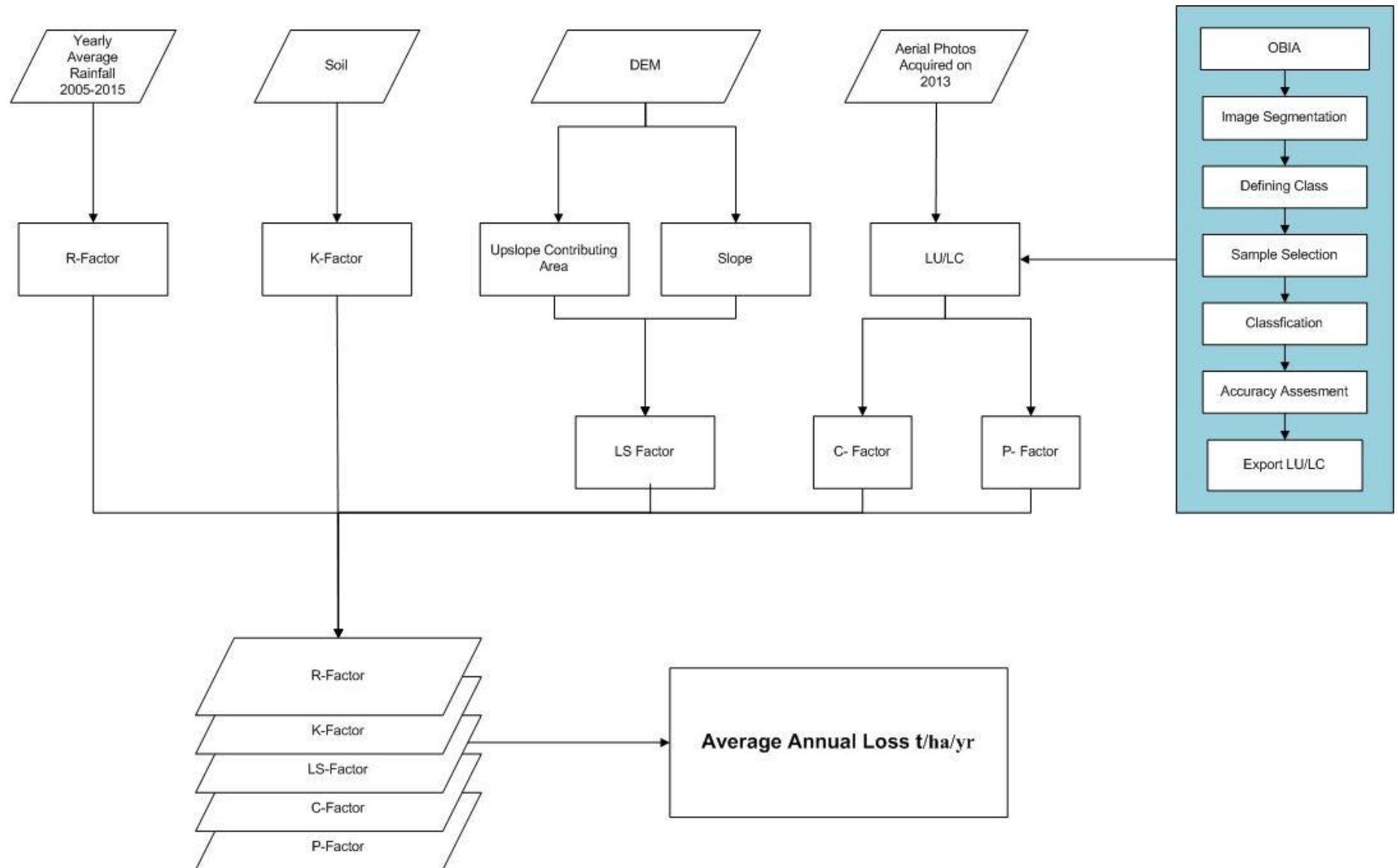


Figure 6. Soil Erosion Risk Map flow chart

Chapter Four

4. Results and Discussion

4.1. Results

This chapter present the results of annual average soil loss rate of wenberta watershed. As described in materials and methods chapter to quantify the amount of soil erosion the following dataset are required: Digital elevation model, Average annual precipitation, Soil, Aerial Photo's needed to estimate the annual soil erosion of the watershed. In materials and method chapters those data's are explained in detail their uses and description.

The R, K, LS, C and P factors should be generated by using the methods that described in methodology chapter for RUSLE 3D model. The final result is multiplied within the raster calculator. All the maps were produced in this chapter were produced with the **Coordinate system: GCS** , **Datum: WGS 1984** and **Units : Degree**.

4.1.1.R- Factor

Before going to further processing it's better to verify the rainfall data that is collected from Ethiopian Metrological Agency by using the world climate data if there is a huge difference in precipitation values from the year 1960-2000 the average precipitation will be used as the comparing the precipitation value of the year 2005-2015. The following graph shows the difference.

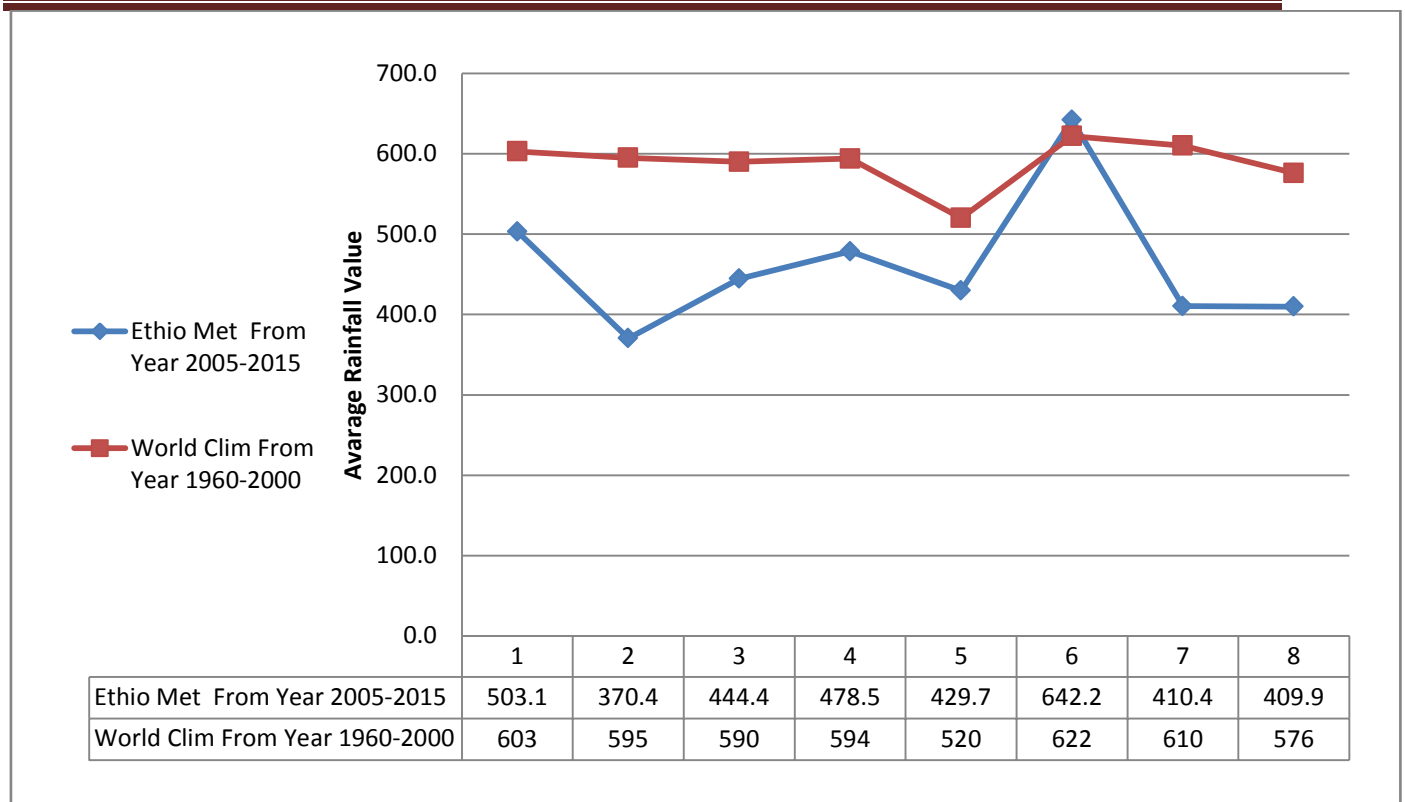


Figure 7. Average Rainfall Value Comparison

In order to compute R factor, the nearby eight metrological stations of 10 years annual rainfall data were used to estimate the point data in to surface using ArcGIS Kriging interpolation method. Therefore, R-value was interpolated through annual rainfall data from surrounding metrological stations.

To use R-factor values derived for soil erosion prediction ArcGIS environment, an interpolated surface must be created from the R-values at each station. Inverse distance weighting is a commonly used deterministic interpolation method. It predicts cell values at unknown locations based on distance between unknown cell and from the known points.

As stated in the methodology part many soil erosion studies in Ethiopia performed in Ethiopia with equation 1 . Thus, the R-factor was calculated based on Eq.2 and Erosivity value calculated as shown in (Table 6).

Table 6. Erosivity value

Name of the Station	Average Annual Precipitation	Erosivity	Easting	Northing	Elevation
Atsebi	503.1	274.622	580108.6795	1534933.239	2711
Edagarebu (Edagaarb)	370.4	200.044	574865.9044	1558239.257	2920
Aynalem	444.4	241.632	553128.9761	1488106.827	2195
Senkata	478.5	260.797	561401.4154	1554895.053	2437
Adigudom	429.7	233.371	555499.3804	1464463.292	2100
Dengolet	642.2	352.796	534370.0125	1472234.815	2371
Hawzen	410.4	222.524	546593.0232	1544795.871	2242
Edaga Hamus	409.9	222.243	560644.0148	1568208.555	2708

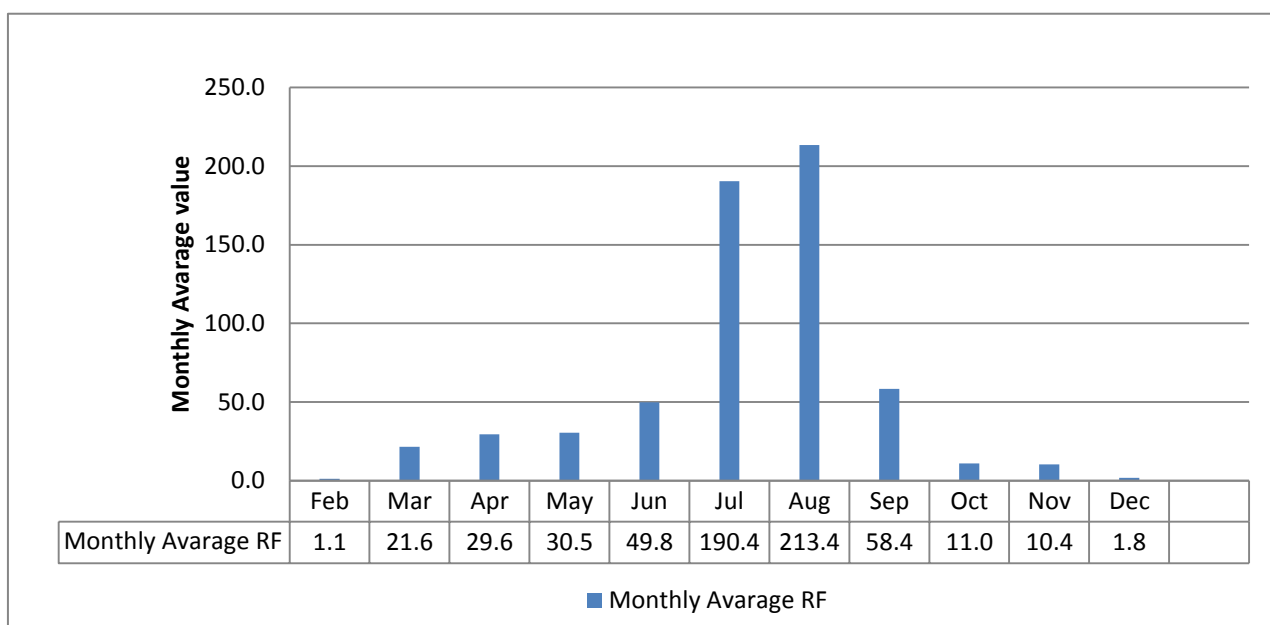


Figure 8. Monthly Average Rainfall

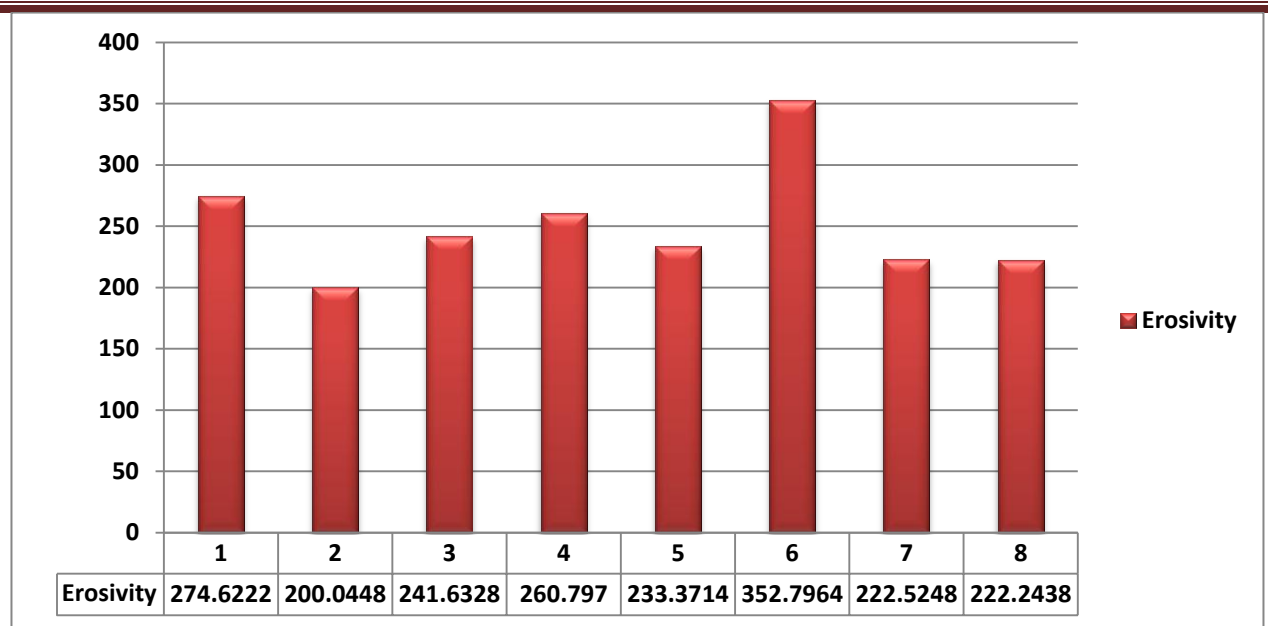


Figure 9. Erosivity value graph

According to Erosivity value and using ArcGIS 10.3 IDW statistical Interpolation technique the raster value R factor was generated with the cell size of 10 m * 10 m to meet the spatial resolution of other thematic maps used in the RUSLE model. Therefore the interpolated value is shown in below map Figure 10. The result shows that the northern tip of the watershed has the lowest value with a range of R(237.06) to R(247.52). On the other hand, the area that is close to the rainfall station Atsbi, has a higher values of R(267.27) to R(274.62) this is because the IDW interpolation working in a distance base. Therefore most of the areas of the watershed fall in the range of R(247.53 to 253.85) specifically in the southern parts of the watershed area (figure 10).

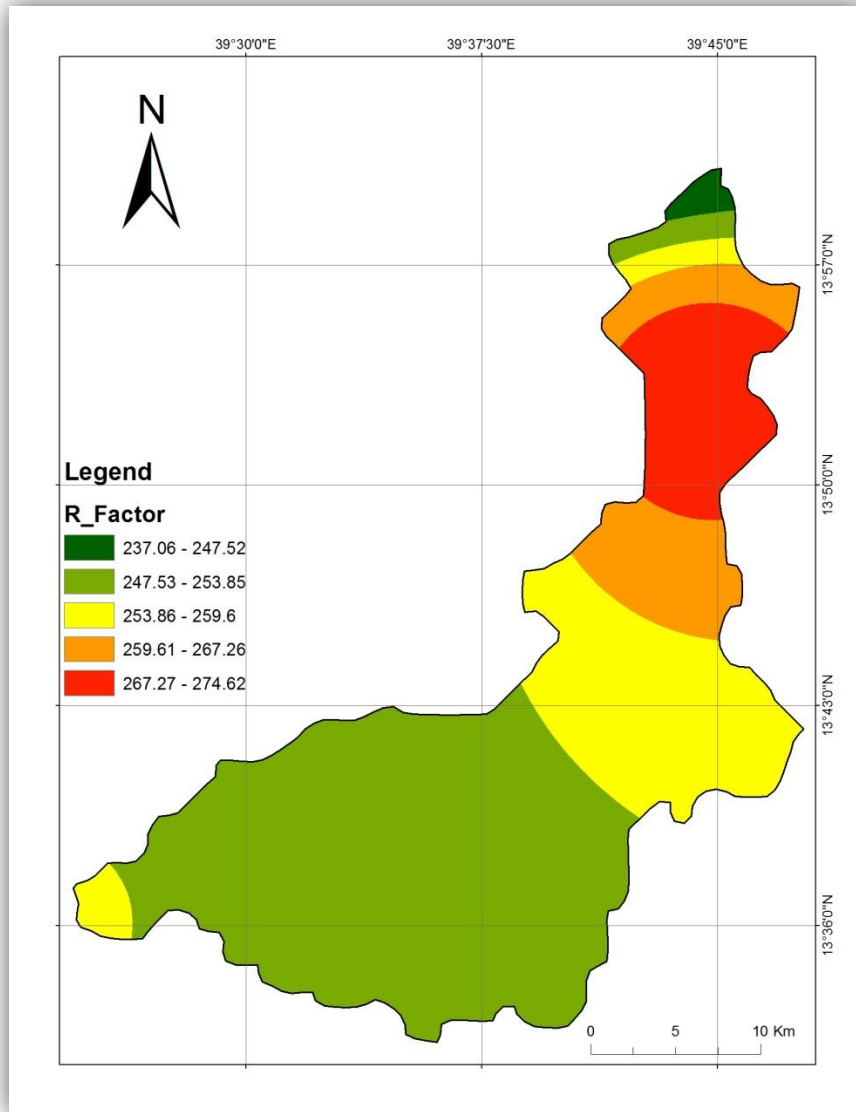


Figure 10. R-Factor Map

4.1.2. Soil erodibility Factor

Soil erodibility Factor (K) of surface soils of each soil type, associated with the mapping units was computed using equation 3. The soil map was reclassified based on K value of each map unit to generate soil erodibility map using GIS. The data that found from FAO don't have a OM values. Therefore to get the OM value the equation Eq.4 used. Most of the time, wrongly organic matter and organic carbon used interchangeably. There is a conversion factor of 1.72 is commonly used to

convert organic carbon to organic matter by using equation 4. Therefore, the OM content of the soil is calculated by using Ms-excel as shown in the Table 7.

The soil data used for Atsbi Wenberta watershed is from the digital soil map of world. The data is originally it's a shape file format therefore it needs to be converted to Raster. To do this we used ArcGIS 10.3 conversion tools from Arc Toolbox. The Conversion tools in Arc Toolbox, have a capability to convert vector layers to raster therefore the layers were converted to raster with a spatial resolution of 10 m x 10 m to meet the spatial resolution of other thematic maps used in RUSLE model.

To create the soil erodibility map of Atsbi Wenberta watershed, soil map shapefile derived from the world soil data of FAO database was used as an input ArcGIS using the excel file generate K values using ArcGIS. Then, the shapefile was converted to raster using the conversion tool “Feature to Raster” of the Arc Toolbox. Figure 11 shows the soil erodibility (K) map of the Atsbi Wenberta watershed.

Based on the extracted soil map three soil regions are encounter in the Atsbi Wenberta watershed. Table 7 gives information about classification, organic carbon, organic matter and soil texture of the Atsbi Wenberta watershed.

Table 7. Soil Classification and Organic matter

Soil Classification	Sand Topsoil %	Silt Topsoil %	Clay Topsoil %	OC Topsoil %	Organic Matter	Soil erodibility factor
Eutric Nitosols	68.4	10.5	21.2	0.6	1.032	0.2020
Humic Cambisols	55.2	21	23.8	3.86	6.6392	0.4539
Cambic Arenosols	92	3.1	4.9	0.21	0.3612	0.7829

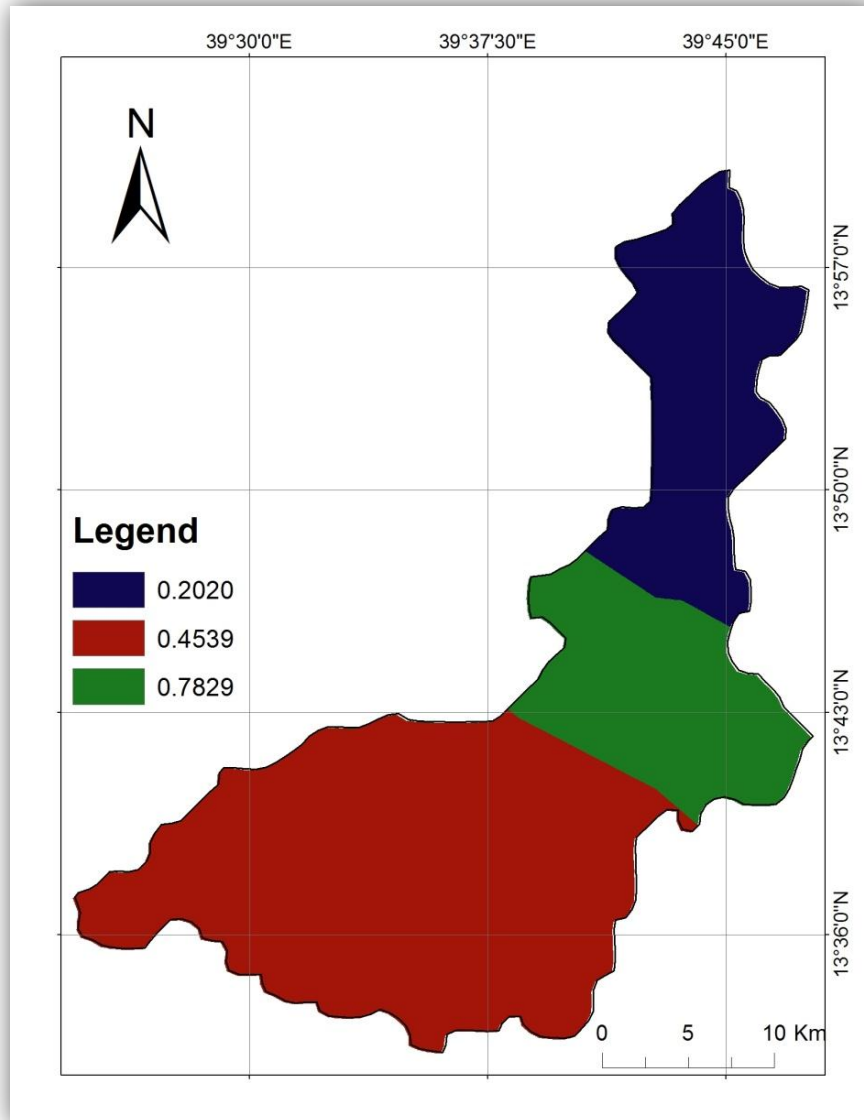


Figure 11. K-Factor Map

The result shows that the central parts of watershed high k factor value. This is because the soil type of the area is Cambic Aeronosols, this soil by itself chemically exhausted and highly sensitive to erosion. Therefore, the central parts of the area is also more sensitive to erosion and the lower parts (Humic Cambisols) in the watershed have also higher values for erosion. The northern parts of the watershed, the soil type Eutric Nitosols have lowest k factor value comparing to the rest of the study area.

4.1.3. LS Factor

DEM of the whole watershed have the a higher spatial resolution of 10 m x 10 m, this DEM is derived from aerial photos. The DEM showed that the elevation variation of the area ranges from 1768 m - 3052 m. This shows the area has a huge topographical variation. This DEM gives a better representation of entire watershed area for the final result. By using these DEM can determine the LS factor inputs that is elevation, slope, flow direction, sink and upslope area that is used for implement it RUSLE 3D model.

The DEM are used to calculate the two input variables of LS-factor that is the Slope and Upslope Area. By using the DEM of the whole watershed a slope grid and the upslope area is calculated using both calculated by using SAGA GIS Software.

The results calculated by using Equation 5 and Equation 6. Those Equations have already built-in algorithm in SAGA GIS software to calculate the upslope area value and the LS factor. The latest software developments such as SAGA have contributed significantly to LS factor improvement. As DEM resolution increases, the landscape is more accurately modeled contributing to better spatial soil loss estimates. Therefore, the upslope area to the i^{th} downhill grid cell is calculated as a proportion of flow between two down slope pixels. The proportion is the proximity of the flow direction angle to the direction angle of the grid cell center (Tarboton 1997).

The slope value of the area was calculated in ArcGIS using Spatial Analyst tool “slope”. The slope grid can be output either a value in degrees or percent rise. The slope varies from 0 to 63 % and most areas fall down in the (10 - 16 %) of slope.

According to slope value the slope was classified into eight steepness classes (Wischmeier and Smith 1978) of erosion hazards of nearly level (0–1%), gently undulating (2–4%), strongly undulating (4–6%), gently rolling (6–10%), strongly rolling (10–16%), hilly (16–25%), steep (25–40%), very steep (40–60%) and the extremely steep (>60%) slope classes.

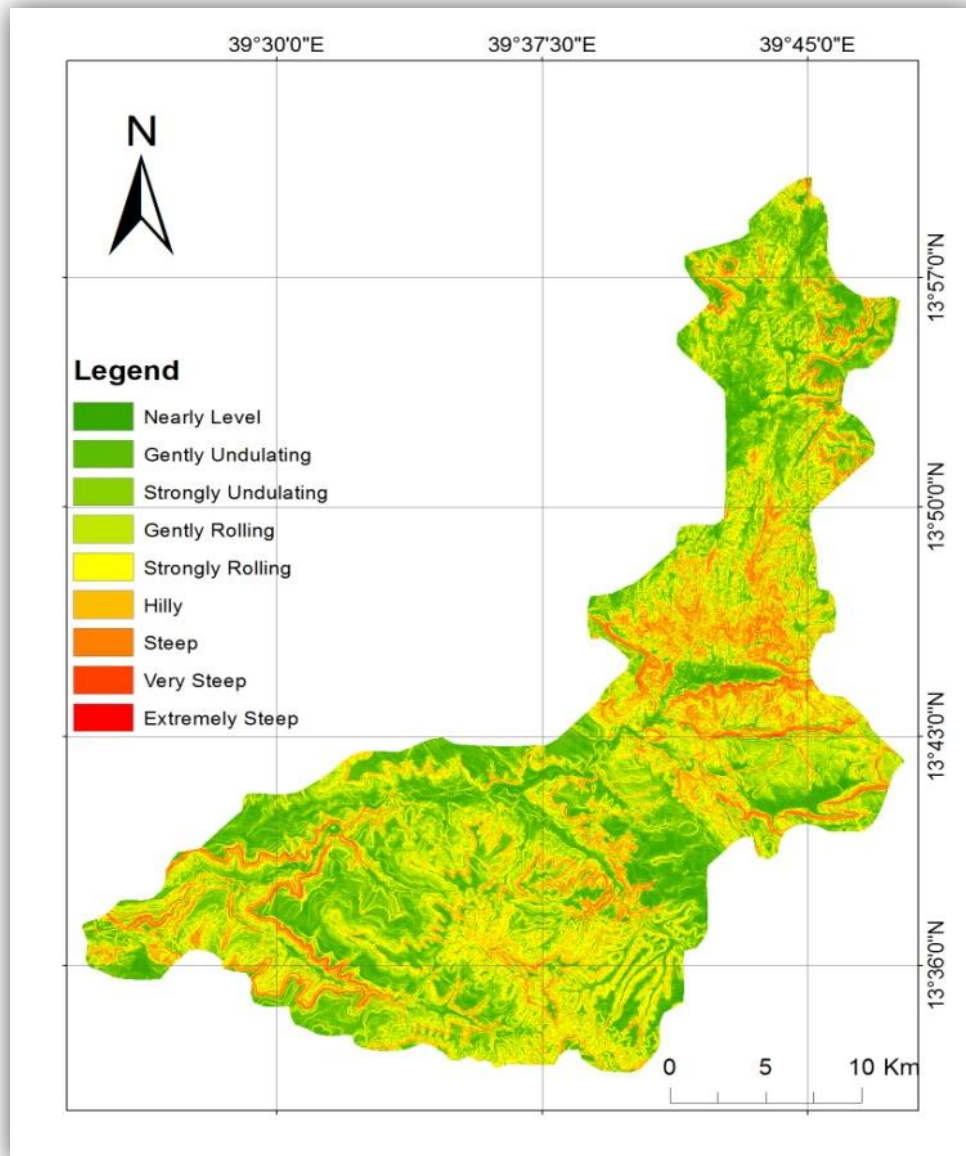


Figure 12. Classified Slope Map

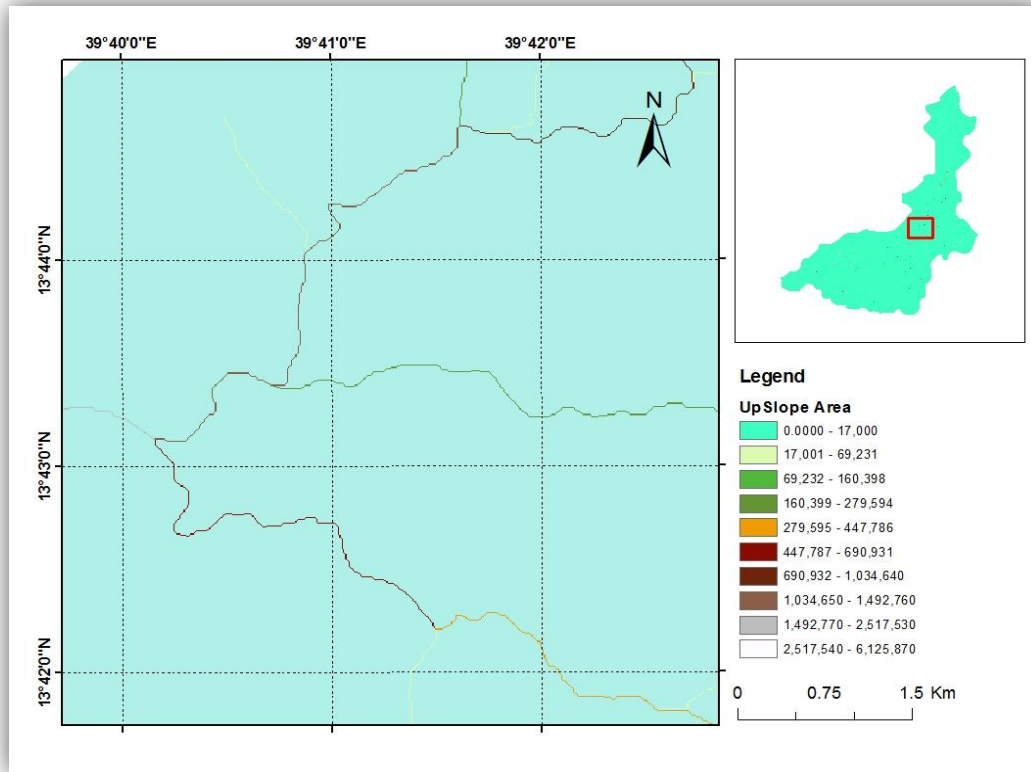


Figure 13. Upslope Area

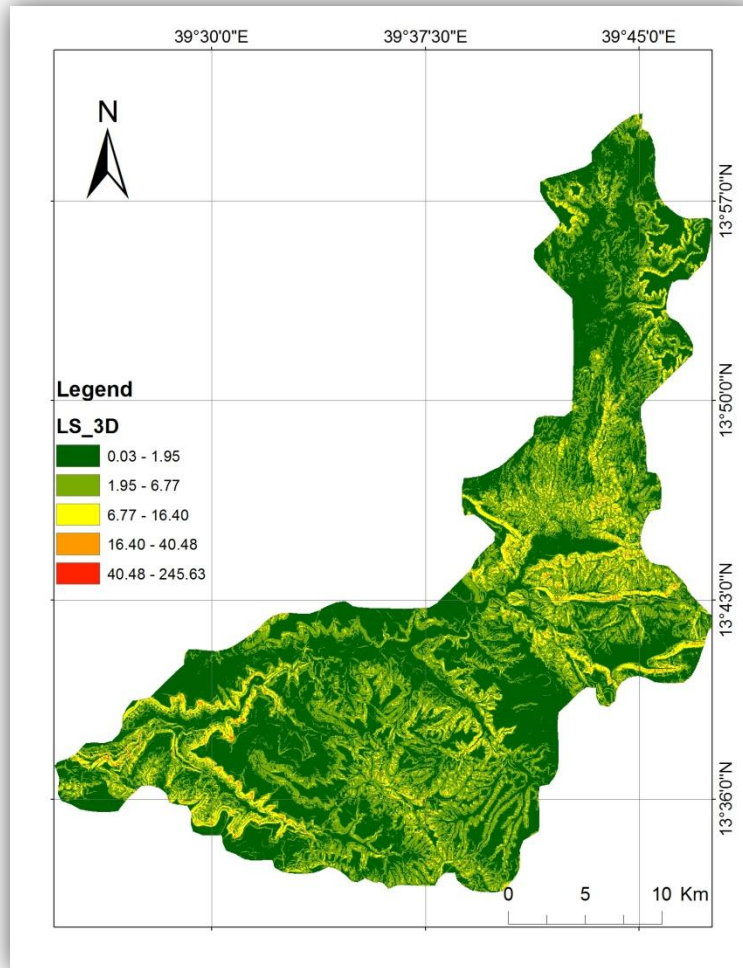


Figure 14. LS - Factor Generated by SAGA GIS

The result shows that, the combined LS-factor of slope length (Upslope area) and steepness factor describes the effect of topography soil erosion under given conditions. As DEM resolution and accuracy increase, the landscape will be more accurately described, soil erosion topographic factor will be calculated precisely and erosion estimates will approach actual values (Wu *et al.* 2005). Therefore, the result shows that steeper and longer the slope, the higher the risk for erosion. This is a very important factor in the overall erosion rate.

4.1.4.C - Factor and P - Factor

The cover factor is generated from aerial images for the entire watershed with the spatial resolution of 0.25 cm by using the OBIA method. Using an OBIA method have lots of advantages regarding in the classification of LU/LC. As detail described in the methodology part the Object Based Image Analysis (OBIA) was used to generate the cover factor. The OBIA analysis is done via eCognition essential 1.3. In order to determine C - factor, Atsbi Wenberta watershed classified into eight land use classes generated from aerial photos by using object based image analysis OBIA method.

In Object Based Image Analysis (OBIA) method image segmentation is the first process. From this process the most known method is a multiresolution segmentation. Therefore the multiresolution segmentation was applied and executed to segment aerial photo and convert it to a meaningful object. The segmentation output objects is used for the classification of land cover. Therefore, by using OBIA method the final segmentation result achieved a set of 3,161,322 objects was obtained.



(a)

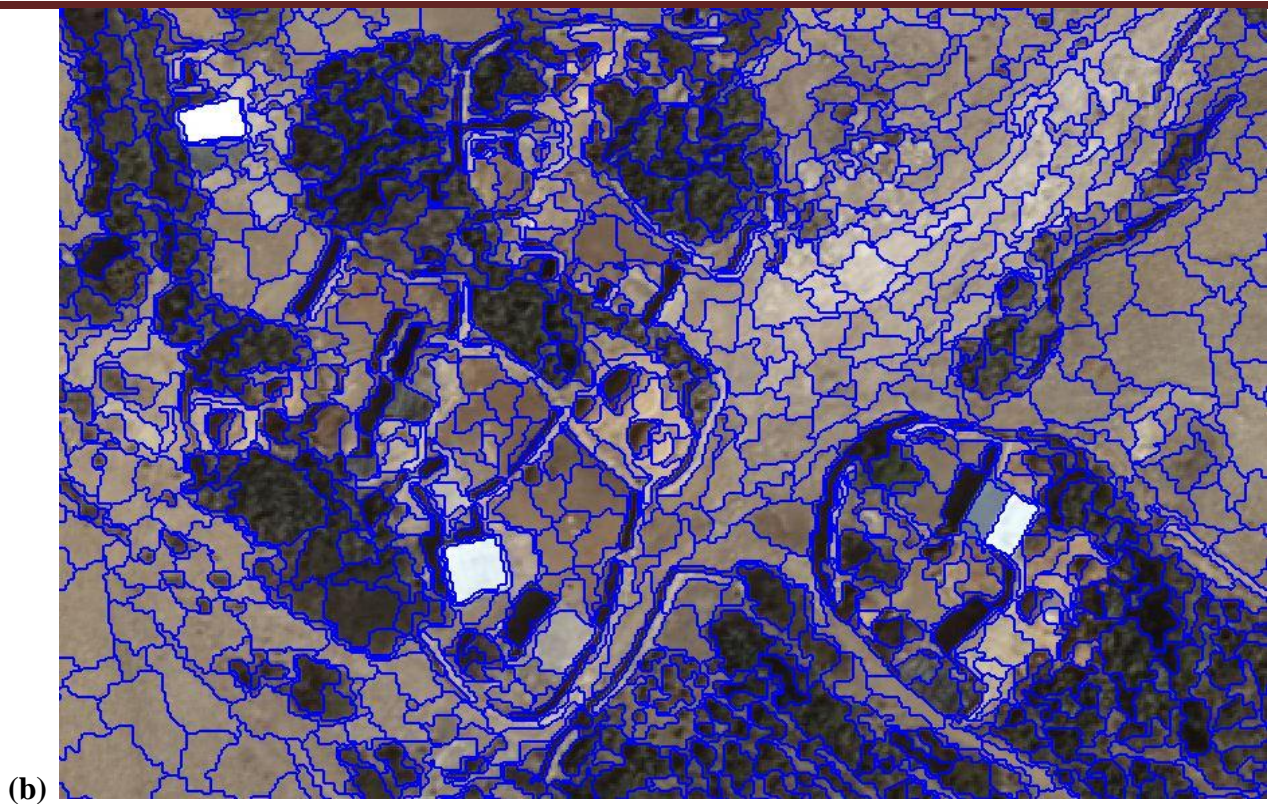


Figure 15. (a) Original Image (b) Segmented Image

(Figure 15) shows that aerial photos before segmentation (a) original aerial photos and after segmentation (b) segmented image.

The next step is after segmentation process defining the classes according Annex D and then select samples for each land cover class. For this study the area was defined in 8 land cover class's. Therefore, for all selected land cover class a number of samples taken from the aerial images as the number of samples is listed in Table 8.

Table 8. Number of samples taken for each class

Class	No. of Objects
Agriculture	3214
Built-Up	835
Forest	317
Bare Land	963
Open wood Land	1426
Grass Land	701
Shrub Land	1299
Water	24

After defining the class the next step is classify the objects according to the given sample objects using KNN classifier algorithm using eCognition Essential.

Table 9. OBIA Classification Result Report

Class	No. of Objects	Area (ha)	Relative Area (%)
Agriculture	59204	32995.99	44.89
Built-Up	21184	2074.17	2.82
Forest	21376	2420.72	3.29
Bare Land	23575	4407.31	6
Open wood Land	88431	12664.08	17.23
Grass Land	36986	3636.99	4.95
Shrub Land	70493	15253.01	20.75
Water	260	50.99	0.07

Therefore, checking the classification results is the next step. Accuracy assessment for the classification done by in eCognition Essential and the ground truth data was selected randomly using ArcGIS. After the accuracy assessment of classification Minimum Mapping unit will be set and it will be merged to neighboring land cover types. For this study the object that have a number of pixel below 100, it will eliminate and considered that and merged to neighboring region. After getting the classified image that shown in (Figure 16), the data format will be changed into vector format and the corresponding C-value which was obtained from (Israel (2011), Hurni (1988) and Hellden (1987), Patrick Ndolo Goy (2015), Nathawat (2013)) was assigned the C-Factor and P-Factor value as stated in Table 10 using ArcGIS. The vector format C-Factor and P-Factor changed to raster again for the final calculation Figure 17 and Figure 18 with 10 *10 m to meet the spatial resolution with other factors.

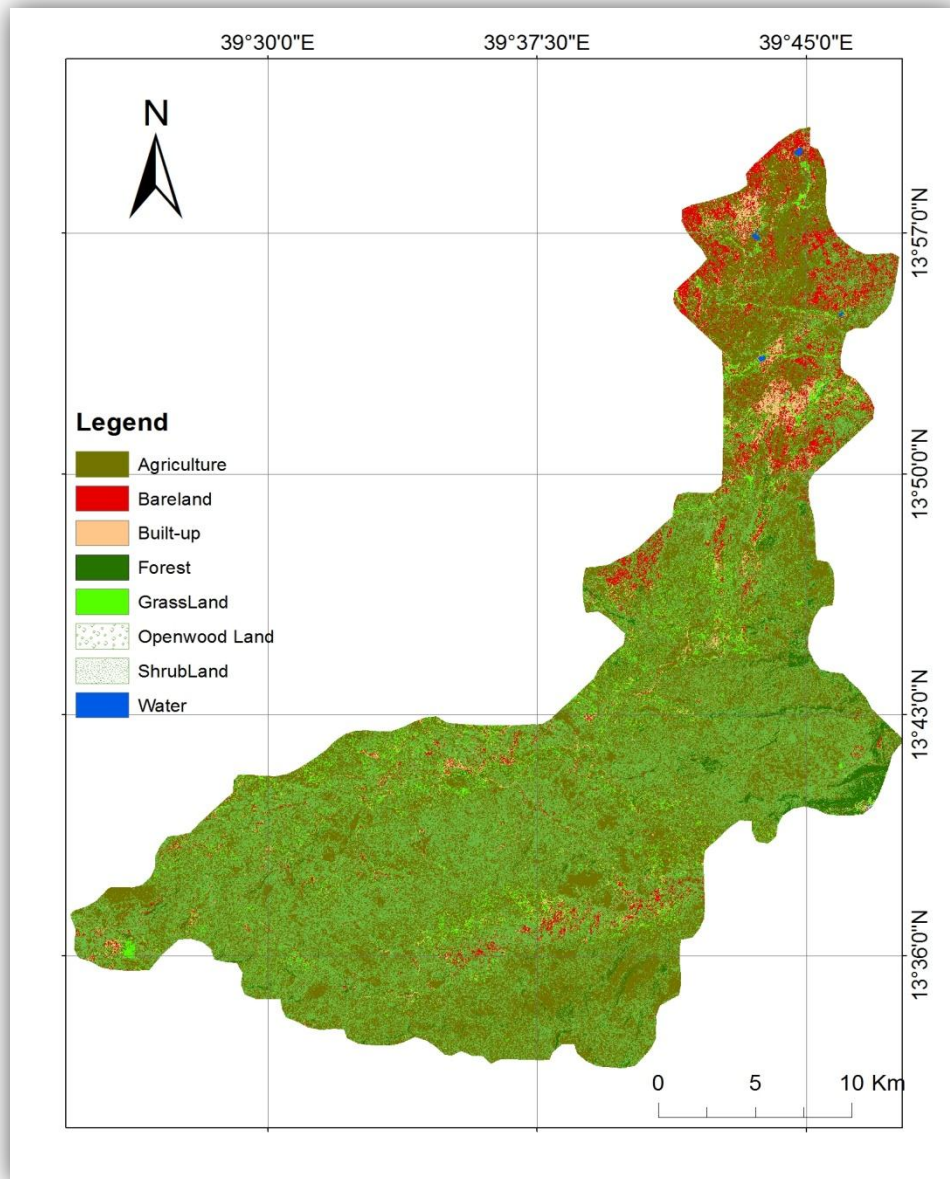


Figure 16. Land Cover Classification Using OBIA

Table 10. C _Factor Value and P Factor Value

Land Cover Class	C Factor Value	P Factor Value
Agriculture	0.39	0.6
Bare Land	0.6	0.9
Built-up Area	0.15	1
Grassland	0.04	0.63
Forest	0.02	0.8
Shrub land	0.3	0.53
Open Wood Land	0.53	0.6
Water	0	1

Source: Adapted from Hurni (1988) and Hellden (1987), Patrick Ndolo Goy (2015), Nathawat (2013)

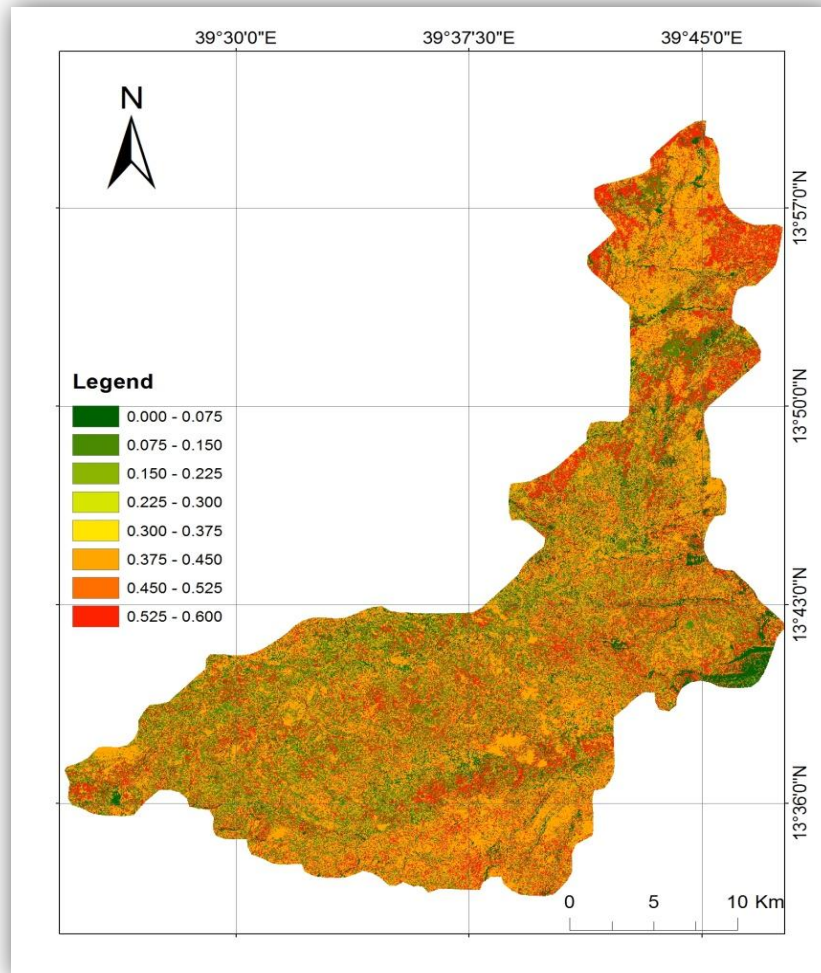


Figure 17. C-Factor Map

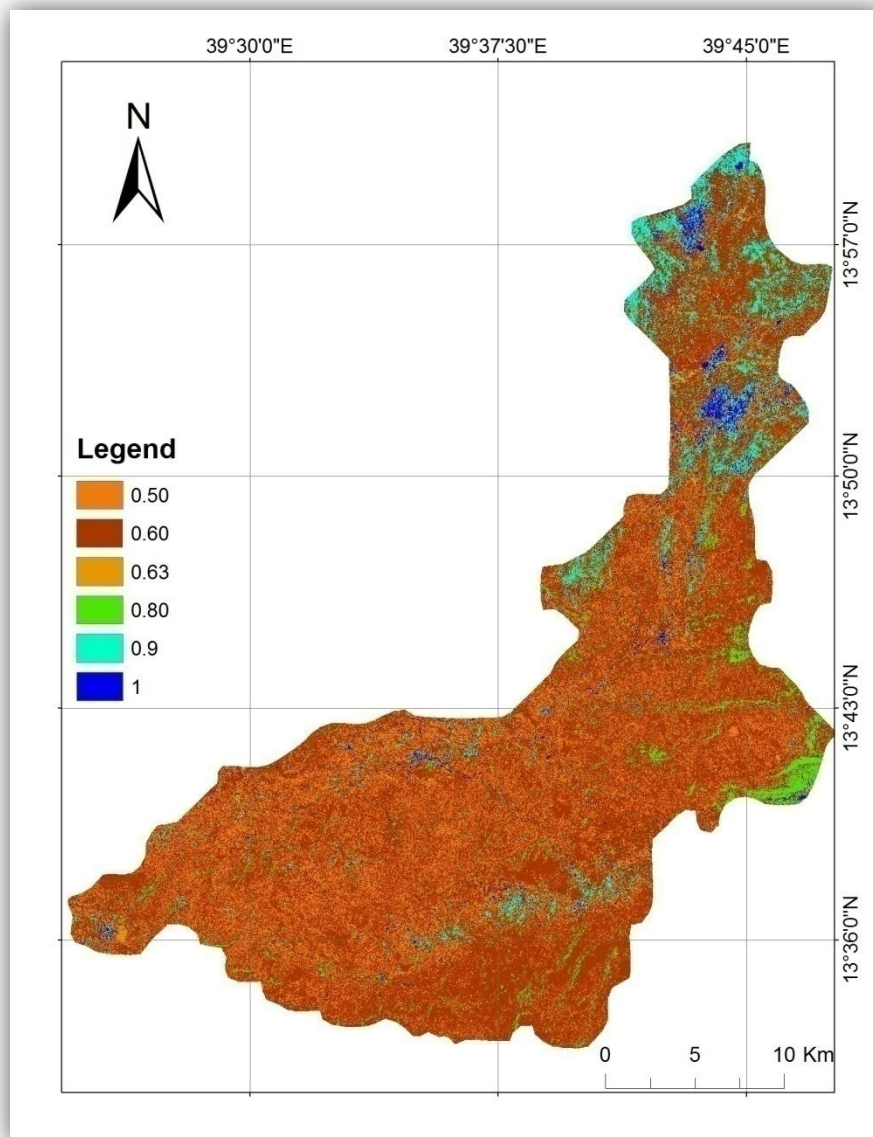


Figure 18. P-Factor Map

Using an OBIA method have a lots of advantages regarding in the classification of LU/LC. It's because of that the high resolution aerial image of the watershed gives a detail information about the area, each features are clearly displayed in the aerial image. Therefore, in defining the land cover features and defining a P factor which is the conservation practices applied on the area should be easily distinguished and can easily defining those factor values.

4.1.4.1. Accuracy assessment result

A classification is not complete until the accuracy is assessed (Leliland, 2001). This statement express the importance of accuracy assessment in classification result.

Accuracy assessment is a general term for comparing the classification result to the Ground truth. For this study we are using a 25 cm aerial photos, therefore it's not needed to collect the ground truth from the field. It can easily identify features from high resolution images.

The use of ArcGIS here is for the selection of random 1580 sample ground truth points as seen in figure 20 for the whole project area and define each points with specific land over class using an aerial photo. Finally by adding those sample shapefile in eCognition used as an accuracy assessment ground truth value and then the final accuracy assessment is calculated.

The classification accuracy assessment of OBIA result was done by eCognition Essential and ArcGIS software together. The accuracy assessment tool that is found in eCognition Essential, the error matrix only shows that the overall accuracy of classification, user accuracy and producers accuracy for each class.

As shown in Table 11 the final land cover classification overall accuracy result achieved 85.2 %. Considering that, using an OBIA classification method is a good method to achieve a good accuracy value. From the producer accuracy of the class water is quite good result (91.66%). This means 91.66% of water area has been correctly identified. But the users accuracy of this water class is truly of that category. From the table 11 it can be see that Grass land and built up area has both poor accuracy compared to other class.

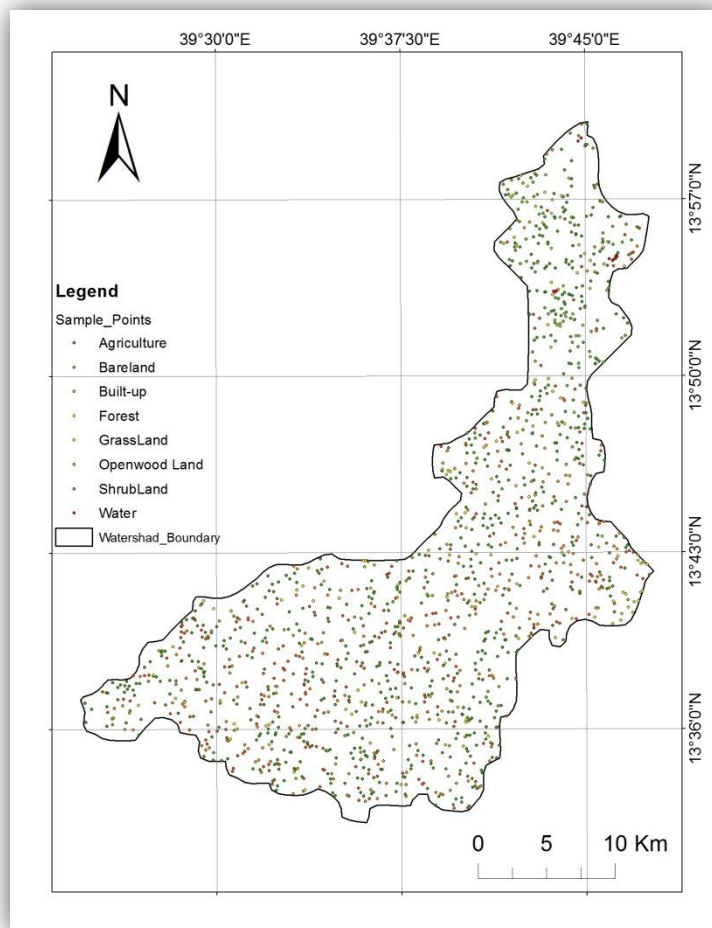


Figure 19. Selected Random Sample Point Distribution Map

Table 11. Classification Accuracy

Class	Users Accuracy %	Producers Accuracy%
Grass land	82.92	74.72
Open wood land	78.44	80.72
Agriculture	90.49	87.8
Built-up	75	76.59
Water	100	91.66
Forest	79.16	82.6
Bare Land	81.44	86.81
Shrub land	82.56	86.26

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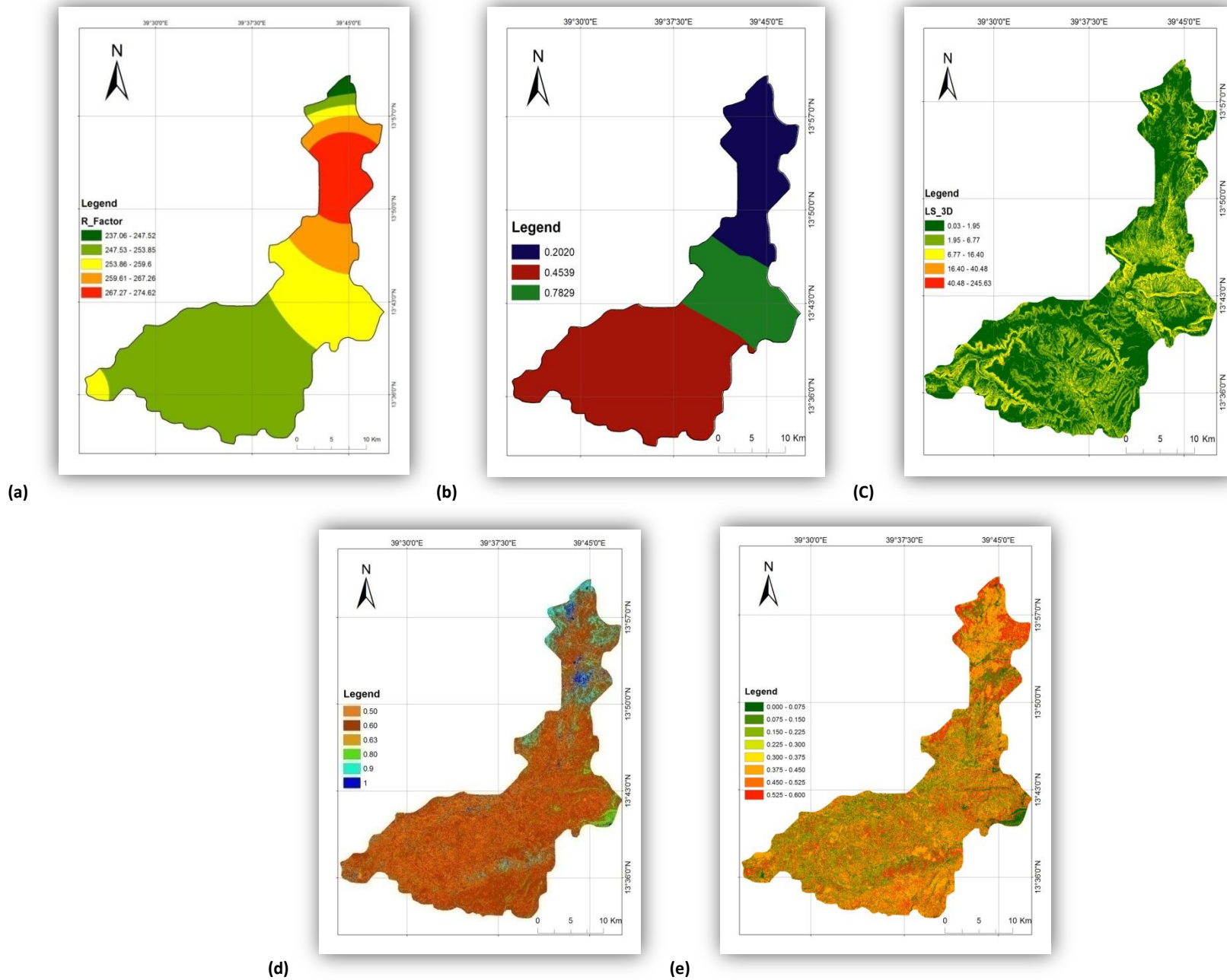


Figure 20. R K LS C P Factor Maps

To calculate the annual soil loss of RUSLE3D result from using ArcGIS Raster Calculator tool executes Map Algebra was used. The tool has an easy-to-use calculator interface. Therefore, by using the map algebra calculator all five raster layer which are R, K, LS, C and P factor that was generated and shown in figure 21 added together and multiplied each raster values to generate the annual soil loss t/h/y.

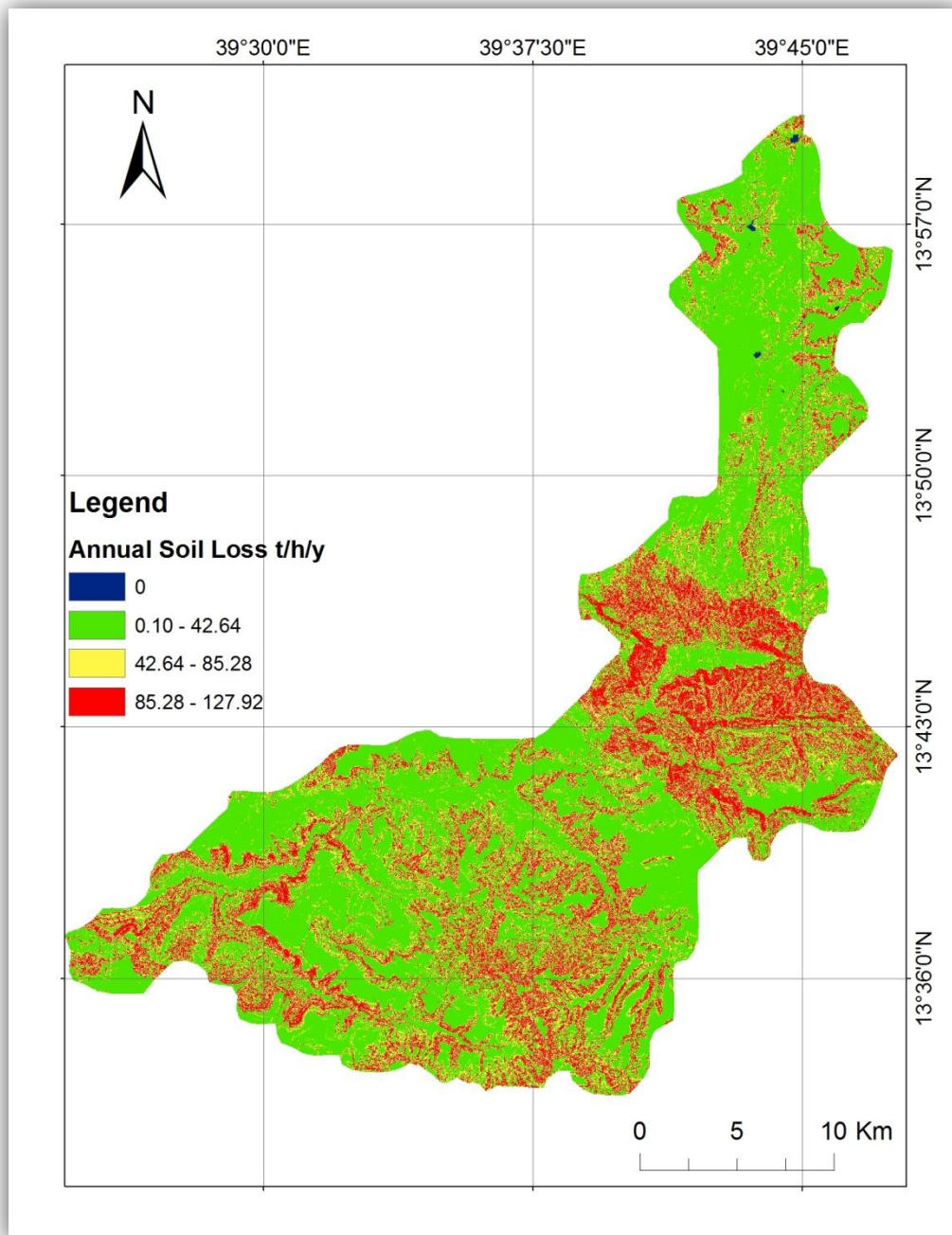


Figure 21. Annual Soil loss Map

Figure 22 shows that the annual soil loss of the area in t/h/y, the value ranges from 0 (no erosion in the water areas of the watershed) and the highest value of erosion 127.92 which is mostly found in central parts of watershed and in most mountainous areas of the watershed. Thus, by using the final soil loss output the soil loss severity class should be generated as shown in figure 22.

Table 12. Annual Soil loss Severity Class

ID	Average soil loss (t ha yr)	Erosion severity class
1	0	No Erosion
2	0.1 – 30	Low
3	30 - 60	Moderate
4	50 – 90	High
5	> 90	Very high

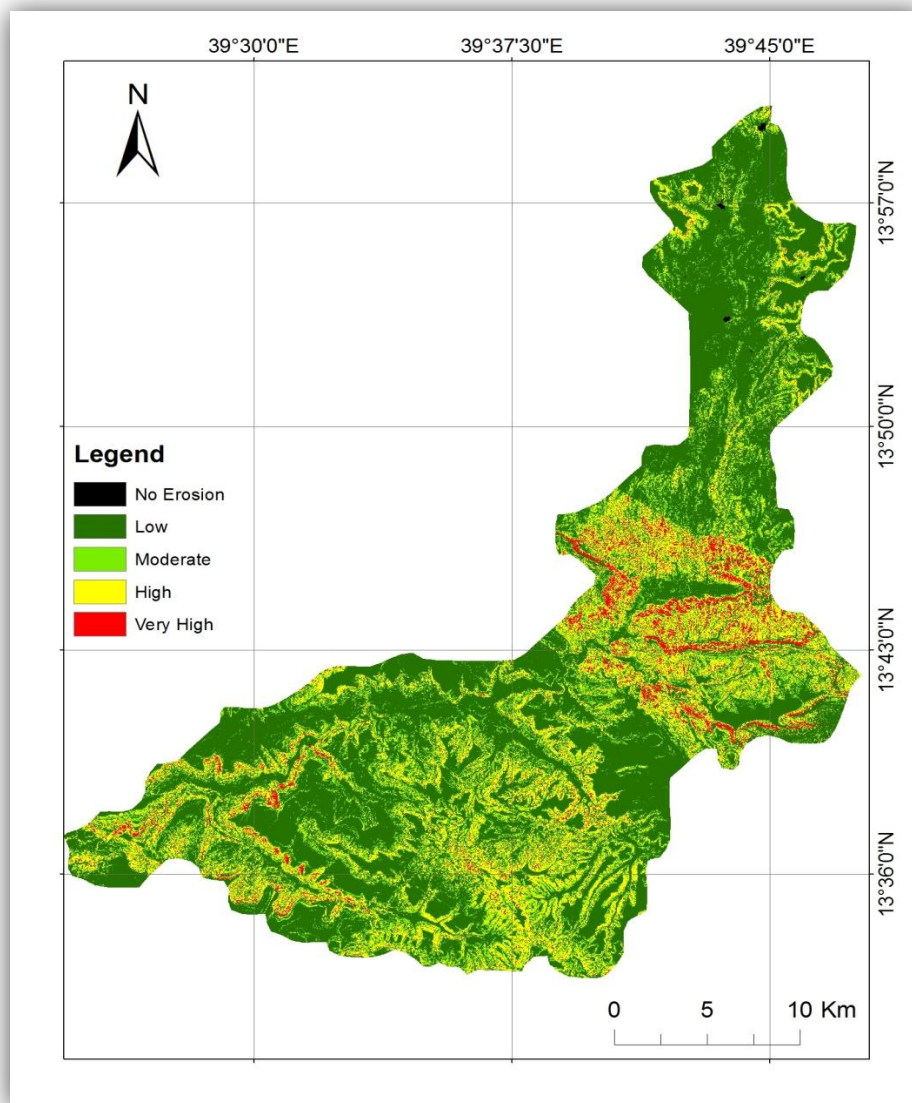


Figure 22. Annual Soil loss Severity Class

The results of soil loss assessment in wenberta watershed reveal a majority of the area characterized by low and moderate erosion risk levels. However, high resolution soil loss maps show its substantial spatial diversity in soil loss. But, in most central parts of watershed soil loss value varies between moderate, high and very high soil loss. Due to this case central part of the watershed should be conserved with higher priority. In addition to that, in most mountainous areas, the value of soil loss is very high. This shows that the amount of soil loss decreased by the conservation mechanism compared to previous studies but still soil loss is not eliminated.

4.2. Discussion

RUSLE was originally developed for USA, but also has been proven valuable for estimation of soil erosion loss in other regions of the world (Millward and Mersey, 1999; Reusing *et al.*, 2000; Angima *et al.*, 2003, Ma *et al.*, 2003). In general, RUSLE is used for estimating average annual soil erosion loss based on available geospatial data. The use of remote sensing and GIS allows to map the spatial distribution of soil erosion risk. Five parameters, derived from different data sources such as DEM, soil, rainfall, and remotely sensed data which is (Aerial Photos), was used.

The final quantitative soil loss using RUSLE3D expressed in ton/ha/year (Mitasova *et al.* (1996)). According to results of soil loss in wenberta watershed shows that the quantified value of erosion ranging from (0 to very high soil loss rates 127.92 t/ha/y).

The soil loss results shows that the central parts of wenberta watershed the value falls with medium to high severity class of soil erosion. This is because the soil type of the area cambic aeranosols have a high K factor value of 0.782 compared to other soil types. Thus, the area was also the most mountainous part and undulating terrain compared to other parts of watershed area. Therefore, the soil type together with the topography make the area high value of soil erosion zone. In addition to the central part, most of the mountainous area of the watershed also shows that a higher soil erosion rate. The results of soil loss assessment in wenberta watershed reveal the fact that a majority of the watershed area characterized by moderate or low erosion risk levels. However, high resolution erosion risk maps show its substantial spatial diversity.

Therefore, the result of RUSLE3D model showed that its more reliable result compared to previous research. (Hurni, 1988, and Hurni, Herweg, Portner, and Liniger, 2008) estimates that soil loss rates in the Ethiopian highlands measured on test plots amount to 130 to 170 metric tons/ha/yr. Therefore, compared to RUSLE3D result of wenberta watershed with (Hurni, Herweg, Portner, and Liniger, 2008) a bit different in value though the Hurni research value was generated long time ago in the end of 1980's. In addition to this, their research expresses the values for all over Ethiopian highlands not specifically for wenberta watershed. Therefore, during the field visit as showed in Annex 3 and using the aerial photographs observed, in most areas of wenberta watershed there are a lots of new conservation mechanisms applied. Therefore, the soil loss value is decreased due to applied conservation mechanism in the area and besides that previous researcher method used was the

original RUSLE method not a three dimensional modification of RUSLE and also it will be the effects of the data they used for their analysis is a coarse resolution imagery.

The LULC change analysis in the wenberta watershed area shows that most of the area is agricultural land (44.89%) and shrub land (20.75%) the smallest area that is found from the classification result was a water area (0.07%) from the total area. The spatial resolution of the images also provided the necessary level of accuracy in the results. Thanks to the application of the OBIA method, a high accuracy level of classification was obtained. The final accuracy achieved using an OBIA method for wenberta watershed is a good result compared to (Xiaoxiao Li., 2014), the overall classification accuracy result achieved by his research was 93.17 %. In addition to this, the classification done by (Binyam T., 2015) showed that an overall accuracy achieved 84.3%. Finally, be able to wind up that the overall accuracy achieved by this research 85.2 % was a good classification result. Therefore, by using an OBIA method gives a good result in land cover classification.



(a)



(b)

Figure 23. (a) and (b) Example of conservation mechanism in Hayk Mesahil stone bunds

Chapter Five

5. Conclusion and Recommendations

5.1. Conclusion

The objective of this study was to assess soil erosion risk area in wenberta watershed which is located in the eastern part of Tigray that is a part of Tekeze basin tributary. The study demonstrate that an empirically based erosion assessment model, the RUSLE3D, integrated with satellite remote sensing and geographical information systems. GIS and remote sensing technologies provides a great advantage to analyze multi-layer of spatial data. The use of GIS provides the tools to manage and analyze these data. However, the evaluation of these data is necessary before use them. Which is like comparing the rainfall values with available world data's. The estimation of soil loss in the wenberta watershed using GIS and remote sensing techniques, that gives a clear idea about the severity of soil loss of the watershed.

There are uncertainties regarding data sources may introduce larger uncertainties in soil erosion estimates. For example there was different kinds of soil data available with different level of detail and attribute information. Therefore, for this study from the available sources of soil data's that is found from FAO online soil database was used it's because of that the data have a good attribute accuracy.

The estimation of soil loss was done by using RUSLE 3D and the output provides several insights such as which area is first conserved that have high level severity of soil loss with the interactions among erosion factors in a highland environment like Ethiopia. The results of soil loss assessment in wenberta watershed reveal the fact that a majority of the area characterized by low and moderate erosion risk levels. However, high resolution soil loss maps show its substantial spatial diversity in soil loss. But, in most central parts of watershed the soil loss value varies between moderate, high and very high soil loss. Due to this case the central parts of the watershed should be conserved with higher priority. In addition to that, in most mountainous areas, the value of soil loss is very high. This shows that the amount of the soil loss decreased by the applied conservation mechanism compared to previous studies but still the soil loss is not eliminated.

The latest software developments such as SAGA GIS and available high resolution DEM was contributed significantly for LS factor values. As the resolution of DEM increases, the landscape is more accurately modeled contributing to better spatial soil loss estimates.

The final land cover classification overall accuracy reveals that using an OBIA method result 85.2 % was good one comparing to others achieved results. This shows that the land cover features are classified with good accuracy level. Therefore, to conclude that OBIA classification method is a good method to achieve a good accuracy value in land cover classification.

In summary, this study provides an approach for the assessing of soil loss areas of wenberta watershed based on a combination of RUSLE3D, OBIA, remote sensing and GIS. This is an effective way to map the spatial distribution of soil erosion risks in a large area. Therefore, the RUSLE3D together with an OBIA method can be applied in other parts of Ethiopia for assessment and delineation of erosion-prone area prioritization for conservation.

5.2. Recommendations

The main focus of this study was to estimate soil erosion risk of the study watershed using the RUSLE 3D model and OBIA method. However, during remotely sensed data capture surface characteristics reveals that features at the time of image acquisition, there are caution must be taken when applying conservation practice planning cause the data was captured in the year 2013. Always the current available data should be used to estimating the cover factor because land cover features varies throughout the year. Therefore, further analysis and calibration needed in RUSLE3D for estimation of an absolute soil erosion loss for conservation planning purpose specifically in R-factor, C- factor and K factor.

As a limitations of this study it lacks, soil erosion factor RUSLE3D should be calibrated or tested by the actual result from the field to validate the result. An estimation of soil erosion loss in a large area is difficult, as well as its validation from the field data. Therefore, anyone can interested to peruse his research can see the listed gap for further research.

Finally, RUSLE 3D results seem to be an acceptable result comparing from previous researches and from the current condition of the area. According to the final result output the application of the RUSLE3D model is possible to apply in huge watershed level to estimate soil loss of the area by considering the available gaps.

Therefore,

- Further studies will be recommended to determine the actual effects of RUSLE 3D in soil erosion estimation by using continuous field observation and sample collection in different places of the area.
- Further studies will be needed on what are the effects of using the 10 years rainfall average rather than 20 years that recommends by other researcher to use a 20 year rainfall data value that is used for the estimation of the R values.
- Further studies is recommend in what will be the cause of the C-factor generated from one time remote sensing imagery because cover factor varies throughout the year. Therefore further analysis and calibration should be needed in for more accurate result.
- The actual soil data of the area should be mapped cause the available resources lacks the detail thematic accuracy.

- Based on the result of this study, the watershed areas, which have a very high and high severity classes, need immediate attention for additional conservation. Therefore, the concerned organization and the regional government offices should taking care of the area from further soil erosion by using some conservation practices.

During the field visit there are lots of conservation practices done by the community and by the regional government. Such as stone bunds, bench terracing and area closure are the most known methods in the study area. Thus, from any of this conservation strategy that is applicable in Tigray region for soil conservation mechanism must be put into practice in the areas of high severity soil erosion risky areas.

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Annex A: Picture that are taken during the field visit.



a)



b)



c)



d)



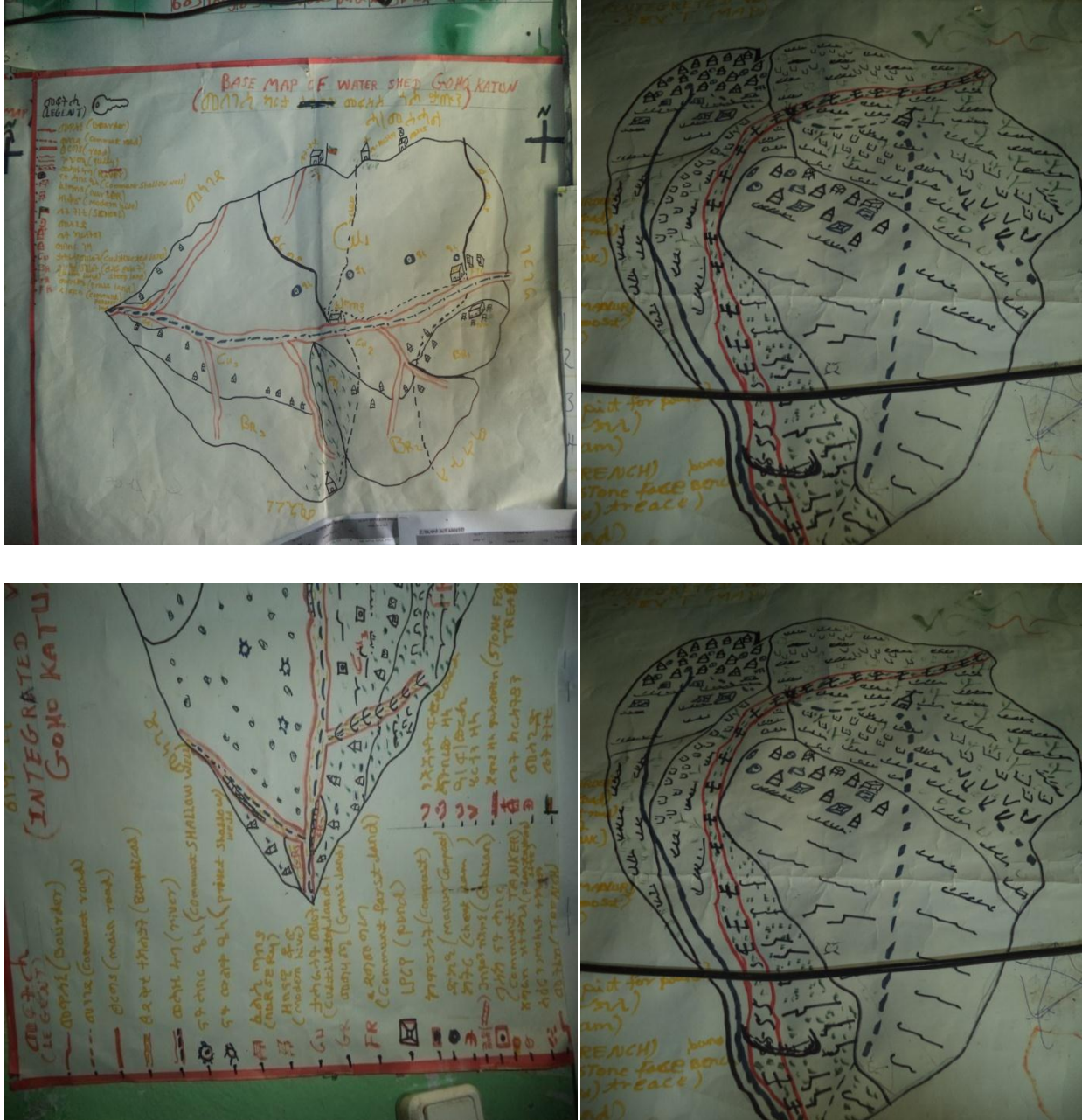
e)



f)

The Above image was taken from Hayek Mesahil its one of the central part of the watershed.

Annex B: Type of maps local expert used



Sample Maps Local experts used

Annex C: Monthly rainfall values

Name	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adigudom	2006	0.0	0.0	29.6	25.9	26.5	28.4	151.8	285.6	79.2	9.1	0.0	0.0
Adigudom	2007	4.2	0.0	0.0	9.3	2.5	23.3	275.4	212.9	57.0	0.0	0.0	0.0
Adigudom	2008	6.8	0.0	0.0	0.0	6.4	3.2	73.3	98.3	69.5	0.0	20.4	0.0
Adigudom	2009	0.0	0.0	6.4	8.2	0.0	7.3	180.0	159.7	6.2	6.4	3.1	2.4
Adigudom	2010	2.2	0.0	0.0	15.9	0.0	X	100.9	249.3	61.4	0.0	0.0	X
Adigudom	2011	0.0	0.0	8.3	4.2	27.8	27.8	132.5	171.4	41.1	3.1	11.7	0.0
Adigudom	2012	0.0	0.0	2.1	8.4	6.4	36.8	280.4	292.1	12.5	0.0	0.0	0.0
Adigudom	2013	X	0.0	0.0	9.5	0.0	34.7	151.2	301.3	260.4	6.3	4.2	0.0
Adigudom	2014	0.0	5.3	25.0	8.5	26.3	X	X	X	X	X	X	X
Adigudom	2015	0.0	X	X	X	35.0	54.6	X	X	X	X	X	X
Atsebi	2006	X	X	X	27.0	81.7	14.4	84.3	X	128.2	10.7	7.5	7.8
Atsebi	2007	2.3	6.5	0.0	72.7	9.9	109.5	333.9	324.7	73.7	0.0	0.8	0.0
Atsebi	2008	0.0	0.0	0.0	20.5	23.0	28.3	45.5	86.7	110.9	4.1	1.2	0.0
Atsebi	2009	0.0	0.4	17.2	3.8	6.7	0.0	181.9	235.6	10.0	15.4	6.0	1.3
Atsebi	2010	X	3.6	25.2	70.1	42.0	0.0	221.3		8.6	8.6	8.8	0.0
Atsebi	2011	1.3	0.0	41.7	31.5	37.2	14.1	197.0	175.4	95.2	6.8	60.4	0.0
Atsebi	2012	X	X	24.3	23.9	20.8	110.2	153.5	160.6	37.0	X	X	X
Atsebi	2013	0.0	0.0	10.4	46.9	3.1	99.8	X	234.3	16.3	35.0	15.5	0.2
Atsebi	2014	X	X	72.3	16.9	48.9	55.1	135.2	123.2	155.5	X	X	X
Aynalem	2006	0.0	0.0	30.7	151.6	35.8	16.3	175.6	206.0	21.0	4.6	0.0	0.0
Aynalem	2007	0.0	6.0	7.7	18.9	10.7	43.7	217.3	133.5	90.5	0.0	0.0	0.0
Aynalem	2008	11.6	0.0	0.0	24.2	6.9	14.5	129.9	111.1	52.5	1.3	4.3	0.0
Aynalem	2009	0.0	0.0	7.2	X	0.0	8.1	175.3	196.5	2.6	3.7	1.4	0.0
Aynalem	2010	0.0	0.0	12.4	52.4	30.2	X	141.9	305.5	X	0.0	0.0	0.0
Aynalem	2011	0.0	1.4	42.6	0.0	23.3	37.3	199.3	139.3	21.0	0.0	3.7	0.0
Aynalem	2012	0.0	0.0	2.3	29.9	43.1	52.1	172.7	203.9	37.5	14.5	4.0	0.0
Aynalem	2013	0.0	0.0	30.8	24.3	0.0	15.5	196.7	159.4	0.0	0.0	0.0	0.0

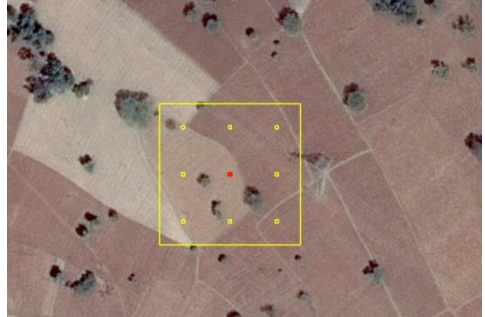
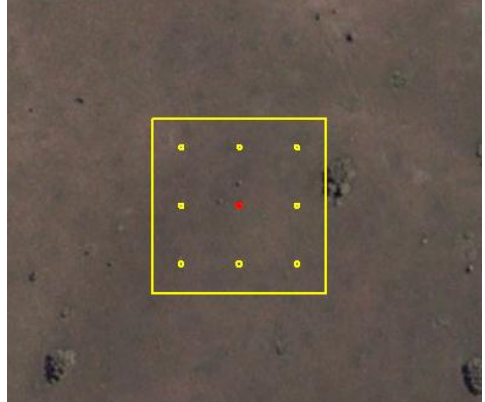

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Aynalem	2014	0.0	6.3	53.1	42.6	49.3	10.1	163.3	X	8.0	X	X	0.0
Aynalem	2015	0.0	0.0	34.0	0.0	36.1	31.0	92.1	X	X	X	X	X
Dengolet	2006	0.0	0.0	62.5	57.9	61.8	39.8	117.9	333.7	75.2	13.4	2.6	0.0
Dengolet	2007	0.0	5.0	19.0	34.6	14.3	35.6	314.2	247.5	99.1	0.0	0.0	0.0
Dengolet	2008	17.6	0.0	0.0	19.7	26.0	31.3	133.2	201.8	54.0	2.2	21.6	0.0
Dengolet	2009	0.0	0.0	19.9	9.6	0.0	14.8	297.7	238.4	64.4	17.5	0.0	16.4
Dengolet	2010	0.6	0.0	11.2	26.1	35.5	105.3	244.9	395.1	16.2	0.0	0.0	X
Dengolet	2011	0.0	0.0	28.0	13.2	26.0	48.7	218.0	297.2	X	X	X	X
Dengolet	2012	0.0	0.0	76.9	66.7	46.7	122.6	298.9	318.7	67.8	9.9	0.0	0.0
Dengolet	2013	0.0	0.0	3.8	40.6	0.0	38.4	0.0	272.4	81.9	32.3	3.4	0.0
Dengolet	2014	0.0	3.2	78.1	67.4	27.2	18.7	213.8	X	125.3	X	X	1.4
Dengolet	2015	0.0	0.0	X	0.0	25.8	38.6	154.9	X	X	X	X	X
Edaga Hamus	2006	0.0	0.0	90.8	X	34.1	6.4	124.6	197.2	15.4		25.6	21.5
Edaga Hamus	2007	2.4	20.4	11.7	23.3	33.0	67.5	120.7	99.4	9.3	53.7	36.2	0.0
Edaga Hamus	2008	11.1	0.0	0.0	23.3	33.0	67.5	120.7	99.4	9.3	53.7	36.2	0.0
Edaga Hamus	2009	0.0	0.0	11.3	30.6	6.9	5.7	190.5	155.2	0.0	24.1	3.3	0.0
Edaga Hamus	2010	2.0	0.0	21.0	51.3	8.6	0.0	146.9	159.4	37.4	0.0	0.0	X
Edaga Hamus	2011	11.0	0.0	27.7	27.7	31.5	45.3	200.8	205.6	56.1	0.8	55.5	X
Edaga Hamus	2012	0.0	0.0	10.0	80.5	3.1	54.0	228.5	108.6	12.5	16.3	15.0	0.0
Edaga Hamus	2013	0.0	0.0	5.9	63.2	91.7	68.1	133.7	15.5	0.0	0.0	6.0	0.0
Edaga Hamus	2014	0.0	4.5	X	15.0	28.9	8.9	133.7	X	0.0	X	X	X
Edaga Hamus	2015	X	X	X	X	X	7.4	24.3	X	X	X	X	X
Edagarebu	2006	0.0	0.0	61.4	92.2	43.4	12.5	106.5	201.5	60.2	2.0	X	X
Edagarebu	2007	X	2.6	0.6	82.0	17.4	91.8	220.5	147.7	37.7	0.5	0.0	0.0
Edagarebu	2008	8.5	0.0	0.0	21.7	X	8.7	0.0	102.4	22.5	7.1	24.2	0.0
Edagarebu	2009	0.0	0.0	23.3	7.8	2.7	0.0	76.3	233.5	2.7	17.7	14.2	6.1
Edagarebu	2010	1.3	0.0	21.6	74.7	43.2	2.8	172.5	239.6	7.3	0.0	0.0	4.5
Edagarebu	2012	0.0	0.0	60.1	54.0	14.5	45.7	161.8	X	6.4	0.0	77.3	0.0
Edagarebu	2014	X	X	44.3	30.6	56.1	X	X	X	X	X	X	X

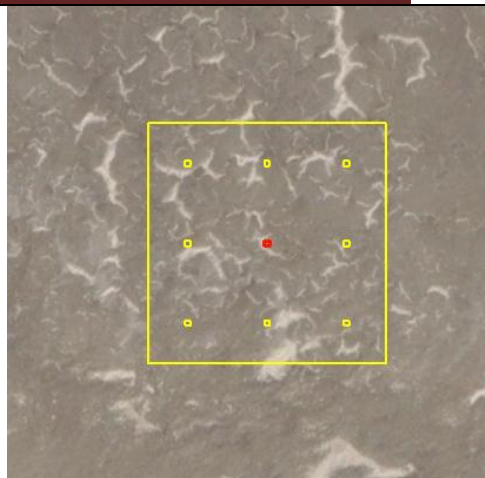


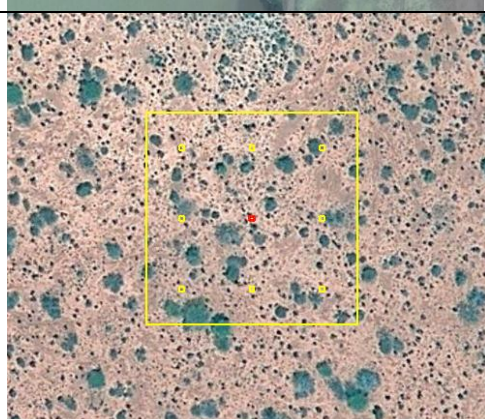
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Edagarebu	2013	0.0	0.0	0.0	30.7	4.0	15.0	238.3	184.0	0.0	24.1	3.2	0.0
Edagarebu	2014	X	7.3	44.3	30.6	56.1	13.7	X	X	25.3	X	X	X
Edagarebu	2015	0.0	0.0	0.0	13.7	58.1	77.3	X	X	X	X	X	X
Hawzen	2006	0.0	0.0	35.4	60.2	75.7	9.9	251.4	246.4	16.2	34.5	12.9	4.6
Hawzen	2007	0.0	8.2	9.2	19.4	8.6	75.0	150.5	149.0	101.0	0.0	2.2	X
Hawzen	2008	X	0.0	X	10.2	X	40.7	X	X	34.0	X	11.3	X
Hawzen	2009	0.0	0.0	2.7	52.5	2.5	6.6	208.3	185.6	0.0	15.4	1.6	0.0
Hawzen	2010	0.0	0.0	7.0	52.5	5.3	26.9	198.5	224.0	43.6	0.0	2.0	8.2
Hawzen	2013	X	2.6	9.6	21.4	14.5	50.0	209.6	148.0	0.0	16.8	0.0	0.0
Hawzen	2011	0.0	0.0	3.1	26.8	44.0	52.3	169.3	141.5	30.8	11.7	20.8	0.0
Hawzen	2012	0.0	0.0	22.8	21.0	17.3	29.1	240.0	X	30.0	6.1	4.0	0.0
Hawzen	2014	0.0	0.0	X	0.0	63.7	34.3	X	X	X	X	X	0.0
Hawzen	2015	0.0	0.0	0.0	0.0	84.0	20.8	X	148.0	X	X	X	X
Senkata	2006	0.0	X	3.1	30.6	X	5.2	207.4	283.8	11.2	X	6.8	19.1
Senkata	2007	0.0	1.6	5.3	42.0	4.3	143.0	203.6	133.2	31.0	0.0	0.0	0.0
Senkata	2008	0.0	0.0	0.0	17.7	23.5	23.7	308.6	90.7	20.4	18.0	47.5	0.0
Senkata	2009	0.0	1.2	19.9	8.8	26.7	2.3	105.4	106.9	1.5	11.9	0.4	0.0
Senkata	2010	0.0	0.0	46.6	82.2	97.7	7.6	222.6	121.4	52.6	5.1	10.6	5.2
Senkata	2011	1.4	0.0	26.2	3.8	12.3	59.9	214.8	175.4	82.2	2.1	37.0	0.0
Senkata	2012	0.0	0.0	67.2	20.5	19.5	109.5	188.5	99.2	11.0	5.4	28.4	X
Senkata	2013	0.0	0.0	44.8	44.5	1.4	97.8	139.6	98.7	0.0	18.0	0.0	0.0
Senkata	2014	0.0	1.0	38.5	19.6	58.3	10.9	139.6	131.3	21.8	X	X	X
Senkata	2015	0.0	1.0	28.8	0.0	45.0	61.9	X	X	X	X	X	X


Annex D: Land Use/ Land Cover Classification Description

LULC Code	LULC Name	Description	Example of the land cover category
1	Agriculture	Arable and fallow land that grow annual crops (wheat, maize, sorghum, 'teff', Cotton etc) or perennial crops (, sugar cane, 'enset', coffee and permanent fruit trees) on the small scale or commercial level by rain fed or irrigation schemes	
2	Grassland	Land covered with the natural growth of <i>graminea</i> and herbaceous vegetation or a land sown with <i>introduced grass and leguminous</i> for the grazing of livestock.	
3	Forest	A naturally generated vegetation area composed of either or mixed of evergreen, deciduous, semi deciduous and bamboo forests , with the area exceeds 0.5ha, height $\geq 2m$ and Canopy cover $\geq 20\%$	

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4	Bareland	<p>It is land of limited ability to support life and in which less than one-third of the area covered by vegetation or other cover. It may be constituted by bare exposed rock, Strip mines, quarries and gravel pits. In general, it is an area of thin soil, sand, or rocks. Vegetation, if present, is more widely spaced and scrubby than that in the Shrub and Brush category. Unusual conditions, such as a heavy rainfall, occasionally result in growth of a short- lived, more luxuriant plant cover. Wet, non-vegetated barren lands are included in the Nonforested Wetland category.</p>	
5	Builtup	<p>Urban or Built-up Land is comprised of areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, villages, strip developments along highways, transportation, power, and communications facilities, and areas such as those occupied by mills, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas.</p>	
6	Water body	<p>Area occupied by major rivers of perennial or intermittent (width $\geq 15m$), lakes, ponds and reservoirs.</p>	
7	OpenWood land	<p>Land covered by natural growth of graminea and herbaceous vegetation, with some scattered trees (tree canopy cover between 5-10. it is composed of a canopy of grass wooded ecosystem of Combretum-Terminalia and Accacia-Comiphora that can both tolerate burning and temporary flooding with the tall grass stratum, in case of the former one.</p>	

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8	Shrubland	<p>Land with shrubs/bushes canopy cover $\geq 10\%$ or combined cover of bush, shrubs and trees $\geq 10\%$. Shrubs and bushes are woody perennial plants, 2 m in height at maturity in situ. Tree canopy cover $< 5\%$ (tree are woody perennial plant > 5 m at maturity in situ).</p>	 An aerial photograph showing a dense, dark green shrubland. A yellow square is overlaid on the image, centered in the right half. Inside the yellow square, there is a small red dot, likely representing a specific point of interest or a sampling location.
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Annex E: Aerial Photo Metadata

Name	Tigray Rural cadastre Aerial Imagery 2013
Abstract	Tigray Rural cadastre Aerial photography Flown on March2013
Purpose of Data	For Rural Cadastral map preparation and Any Purpose
Date of capture	March,2013
Data type	Raster
Native Data format	TIFF
Update frequency	No update
Positional Accuracy	The positional accuracy of this image after Aerial Triangulation is X= 0.072,Y= 0.086 and Z= 0.094
Accuracy statement	The accuracy of Tigray Rural Cadastre Aerial Imagery has been approved by Ethiopian Mapping Agency for intended purpose.
Resolution/GSD	0.25 cm
Data History	Data Acquisition done by Information Networking Security Agency Camera: UltraCam Eagle large Format Camera Pixel size: Along track; 13800 Across track: 20010 Physical pixel size: 5.2 micron Focal length: 79.8 Overlap: End lap 70%;Side lap 40% Aircraft: Aero commander, Lever arms' X=-0.051m,Y=-0.149m,Z=-1.334m Boresight Angle: X = 6.77Arcmin, Y = 1.01Arcmin, Z = 3.5Arcmin.
Additional information	Imagery and Orthophoto of this zone has been delivered to Tigray Region Rural Land use and Administration Agency. Orthomosaic Map has been prepared using this data as an input.
Coordinate system	UTM, Datum WGS 84 and Adindan Clarke 1880, Zone 37
Point of contact	Information Networking security Agency, Geospatial Information Security Directorate E-mail: info@insa.gov.et Phone:+251113204005/+25111717114

DECLARATION

I hereby declare that the thesis entitled “*Assessment of Soil Erosion Risk Area Using Object Based Image Analysis and RUSLE3D Model: A Case Study of Wenberta Watershed, Atsbi-Wenberta Woreda, Tigray, Ethiopia* ” has been carried out under the supervision of **Dr. Binyam Tesfaw** in School of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2016 as a part of Master of Science program in Remote Sensing and Geoinformatics. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma

Tewodros Getachew Zenebe

Signature: _____

Addis Ababa University
Addis Ababa.

June 2016

C E R T I F I C A T E

This is certified that the dissertation entitled “*Assessment of Soil Erosion Risk Area Using Object Based Image Analysis and RUSLE3D Model: A Case Study of Wenberta Watershed, Atsbi-Wenberta Woreda, Tigray, Ethiopia* ” is carried out by Tewodros Getachew under my guidance and supervision. This is the actual work done by Tewodros Getachew Zenebe for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and Geoinformatics from Addis Ababa University, Addis Ababa, Ethiopia.

Dr. Binyam Tesfaw

Signature: _____

Date: _____

School of Earth Sciences
Addis Ababa University
Addis Ababa.