SOIL LOSS ESTIMATION FOR SOIL AND WATER CONSERVATION PLANNING IN DIKO WATERSHED, NORTHEASTERN ETHIOPIA.

Msc THESIS

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SCHOOL OF GRADUATE STUDIES

I hereby certify that I have read and evaluated this Thesis entitled " Estimating Soil Loss for Soil Conservation Planning in Diko Watershed, Northeastern Ethiopia" prepared under my guidance by Hamid Makonnen. I recommend that it can be submitted as it fulfills the thesis requirement

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BIOGRAPHICAL SKETCH

The author was born in South Wollo Amhara Region, Ethiopia on September 29, 1996. He attended his primary education Faji primary school from 2005 to 2012 and Dogollo secondary School from 2013 to 2016, after the completion of preparatory school, he joined Arbaminch University and graduated in June 2019 with BSc degree in Natural Resource Management. The author was employed in Woldia University College of Agriculture in 2020 and was working as a Senior Technical Assistances in the Department of Soil Resources and Watershed Management until now. In 2022, he joined Woldia University to pursue his MSc study in soil sciences.

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ACRONYMS AND ABBREVATION

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ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
DEM	Digital Elevation Model
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Position System
IFSP	Individualized Family Service Plan
IDW	Inverse Distances Weight
LULC	Land Use Land Cover
MOA	Ministry of Agriculture
NMSA	National Meteorological Services Agency
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
USLE	Universal Soil Loss Equation

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ABSTRACT

Soil erosion is a worldwide problem in Ethiopia and other African country, Diko Watershed has been affected by soil erosion for long years due to several factors. This study aimed to prioritize sub-watersheds for planning soil conservation and quantify soil loss in the watershed using a RUSLE model based on geographic information systems. The study's primary and secondary data were gathered from various sources and utilized to estimate the parameters of the RUSLE model. The model was trained with inputs related to land use, land cover, rainfall erosive effect, soil erodibility, topography effect, and supportive conservation practice components to estimate the quantity of soil lost from the watershed. The results of the soil loss estimating process, which combined the usage of GIS application, remote sensing technique, and RUSLE model, indicated that the watershed's annual soil loss was between 0- and 154-t ha^{-1} yr^{-1}, with a mean loss of 3.06 tons ha^{-1} yr^{-1}. The average soil loss, 3.06 tons ha^{-1} yr^{-1}, was lower than the 11 tons ha^{-1} yr^{-1} soil loss tolerance. Based on mean annual soil loss erosion 'hot spot' areas were identified and prioritized for conservation planning. As a result, the priority levels for SW2, SW7, SW1, SW5, SW3, SW4, and SW6 were 1 through 7, respectively. This study suggested that plans for soil and water conservation should be made for implementation, starting from SW2 to SW6 based on the capacity of logistics, time, budget and skill availability.

Key words: Diko watershed, GIS, Prioritization, Soil loss, RUSLE

1. INTRODUCTION

Soil is an essential part of the Earth that provides human wealth of resources, products, and services. But East Africa has a high rate of soil erosion, with Ethiopia seeing the greatest loss (Frank Berendse, 2015) Land degradation manifests itself in various ways, including soil erosion, nutrient depletion, loss of organic matter, loss of biodiversity, water loss, acidification, and salinization of the soil (Bewket, 2014).

The physical and chemical characteristics of the soil are impacted by soil erosion, which lowers crop production and fertility. Ethiopian farmers have been compelled to search for more fertile land, putting forest ecosystems at risk as a result of the increased cultivated area (Jothimani et al., 2022). The livelihood of 85% of the country's inhabitants is derived from agriculture. Food insecurity is caused by nutrient losses and soil. Since the 1970s, soil erosion caused by water has been Ethiopia's most significant environmental issue (Hurni et al., 2010).

Due to deforestation and the spread of marginal lands, which are frequently fragile and vulnerable to soil erosion, the growing human population has placed pressure on the country's land resources, severely reducing their productivity and hamper the country's ability to develop further, leaving many people vulnerable and food insecure (Berry, 2003; Hurni et al., 2015). The highlands of Ethiopia see 200–300 tons of soil loss per hectare each year, which contributes to the loss of productive (Ayele, 2018).

In order to meet the growing demands for food by a population that is constantly growing, all suitable agricultural areas in the Ethiopian highlands as well as less suitable, marginal lands on erodible slopes are intensively cultivated (Woldeamlak, 2003).

Seventy percent of the country's total soil loss is projected to occur in the Amhara region each year as a result of water erosion; this rate of loss is around 119 million t ha^{-1} yr^{-1}. (IFSP, 2004). As a result, 31% of the region's entire area has moderate erosion rates (16 t h^{-1} yr^{-1}), 10% has extremely high erosion rates, and 29% of its whole area has high erosion rates (51 t h^{-1} yr^{-1}).

(Over 200 t h^{-1} yr^{-1}); the remaining 30% exhibit low erosion rates (below 16 th^{-1} yr^{-1}) (Desalew, 2016).

North and South Wollo zones are among the most severely affected areas by soil-erosion induced degradation and droughts. The Wollo zones, especially those with elevations above 2000 m a.s.l., have a high erosion risk. Using the RUSLE model, GIS, and RS, various research are conducted in various areas (Abdelsamie et al., 2022).

Over the past 40 years, a large number of soil erosion models have been created to evaluate the risk of soil erosion at various single slope, catchment, regional, and global scales
One of the most widely used empirical models to forecast the average annual rate of soil loss over an extended period of time is the revised universal soil loss equation, or RUSLE. In these conditions, Remote Sensing (RS) and Geographic Information System (GIS) combined with RUSLE prove to be useful instruments to attain more favorable outcomes when evaluating soil erosion within the watershed (Melkamu, 2019).

Areas that have been eroded ware located and mapped using remote sensing (De Asis et al., 2007). GIS have a significant impact on many application domains because it makes data management, data update, and data presentation easy and customizable to user needs. In addition, GIS makes it possible to integrate enormous amounts of data from various sources and on various themes (Shi et al., 2004).

High rates of soil erosion and loss of soil fertility are present in the study area Diko watershed in the North Wollo zone due to a number of serious issues, such as the removal of residues, poor conservation practices, multiple plowings of the land, a lack of vegetative cover, and lack of conservation practices. Formal practices for soil and water conservation have been in place since the 1980s.Prior assessment of the spatial distribution of soil erosion, determination of soil loss rates, and identification and prioritization of prone areas at the sub-watershed level are thus critical for planning and long-term management programs (Kebede, 2023).

Therefore, this study's primary goal is to estimate the current state of soil erosion, create a spatial soil distribution map using the RUSLE model, and identify the watershed's prone erosion areas for conservation planning purposes as of now, no research has been conducted in the study area on the estimation of soil loss for the purpose of soil conservation planning (Habru woreda agricultural office report, 2023).

1.1. Statement of the Problem

Ethiopia's Highland region is well-known for its rapidly expanding population, uneven rainfall, steep slope, poor fertility rate, and diminishing topsoil due to water erosion. The loss of topsoil and subsequent degradation brought about by these occurrences make the ecological less sustainable for future generations. In the study area of the Diko watershed in particular, soil is a vital natural resource for agricultural development, as it is for livestock husbandry worldwide. It is apparent that a significant amount of soil has been lost as a result of the growth of crop farms using unsuitable practices, but no scientific study has been done to determine the precise amount of soil lost annually, the areas of the watershed that contribute most to erosion.

The Community who lives in the watershed have no clear information to decide where to start soil and water conservation activities since area is not classified on the basis of severity of erosion. So, this study was concentrated on estimation of soil loss and identification of the part of watershed that severely affected by soil erosion since soil erosion is so much great with the agent of water in the study area.

1.2. General Objective

- The general objective of this study is to estimate soil loss using GIS based RUSLE model for soil and water conservation planning in the study area.

Specific Objectives

- To estimate annual soil loss using GIS based RUSLE model in the watershed,
- To classify the watershed area on the basis of severity and vulnerability to soil erosion
- To prioritize watershed for soil and water conservation practices

1.3. Significance of the Study

The significant of this study was to recognize the most critically degraded area for rehabilitation planning. Moreover, the identification of watershed area that was vulnerable to soil erosion can contribute to make decision for developing the affected areas and control whenever possible and to promote the role of soil erosion vulnerability map, which helps to identify areas that are at potential risk of extensive soil loss and such study is provide a base line data for natural resource managers to formulate and implement effective soil conservation strategies. Furthermore, this work also be used as source of information for those researchers who intend to do similar or related research.

1.4. Scope of the Study

This study focuses on soil loss estimation and classification of the watershed on the basis of soil erosion severity and vulnerability and give Priotization sub-watershed for conservation practices planning in Diko watershed Melentena Kebele, Habru District, North Wollo.

2. LITERATURE REVIEW

2.1. General Overview of Soil Loss Estimation

Jothimani et al. (2022) calculated the amount of soil loss using remote sensing, GIS, and RUSLE in the kulfo river catchment, Rift valley, Southern Ethiopia. The revised universal soil loss equation model integrated with satellite remote sensing and geographic information system was used for erosion modeling. Soil type, annual average rainfall, slope length and slop steepness, cover management, and support practices were the model's input parameters. According to his research, the study area's mean soil erosion value was 68.47 t h^{-1} yr^{-1}.

According to Saha et al. (2018) by multiplying its five factors in raster format, the Revised Universal Soil Loss Equation (RUSLE), an empirically based model, has been used to create a potential soil erosion map. Olika (2019) conducted research that combined the Revised Universal Soil Loss Equation (RUSLE) with Geographic Information System (GIS). The digital elevation model (DEM), soil, rainfall, and satellite image data sets were utilized as inputs to produce RUSLE factor values.

Ganasri and Ramesh (2016) evaluated soil erosion in order to plan projects for soil and water conservation within a watershed. In the study, soil loss in the southwest Indian region of the Nethravathi Basin was estimated using the soil loss model Revised Universal Soil Loss Equation (RUSLE) integrated with GIS. GIS was used to identify the erosion probability zones, and remote sensing data was used to estimate the RUSLE model's parameters. The results indicated that the estimated total annual soil loss of 473.339 t h^{-1} yr^{-1} was comparable with the measured sediment of 441, 870 t h^{-1} yr^{-1} during the water year of 2002 and 2003. The weighted overlay index method indicate that the major portion of the study area comes under low probability zone and only a small portion comes under high and very high probability zone. The results can certainly aid in implementation of soil management and conservation practices to reduce the soil erosion in the Nethravathi Basin.

Amsalu and Mengaw (2014) planned and implemented a sustainable soil conservation and management system in the Jabi Taninan worada by measuring and mapping soil loss and looking at various topographic and anthropogenic factors. In order to map and quantify soil loss, the study employed multi-criteria evaluation, remote sensing, and integrated geographic information systems. The study used slope steepness and length, soil erodibility, rainfall erosivity, land management practices, and cover management as input parameters to estimate the amount of soil loss.

From the entire Enfraz watershed, the RUSLE estimated total and average soil loss as 30,836.41 t h^{-1} yr^{-1} and 4.81 t h^{-1} yr^{-1}, respectively. In light of the findings regarding the high soil loss estimated in previous studies, it is implied that the implemented soil water conservation measures have a positive impact on slowing the rate of soil erosion. The present value, however, still shows that a financially sensible conservation strategy is required to reduce the amount of soil loss in the watershed (Tiruneh, 2015).

Abdul et al. (2015) investigated soil loss from India's Kalar mini watershed to estimate soil loss, the revised universal soil loss equation (RUSLE) was employed. A household survey was done to find the main factors influencing the management of soil loss. Six main factors rainfall factor, soil erodibility factor, slope length and slop steepness factor, crop management factor, and support practice factor were used in the study to determine the annual amount of soil loss. The spatial variation in soil loss was found to vary from 4.5 mg/ha year in forest areas to 65.9 $mgha^{-1}$ yr^{-1} in crop land.

According to Molla and Sisheber (2017) on average, the rate of annual soil loss in the Koga watershed was predicted to be 42 t ha^{-1} with a specific spot at the upper part of the watershed exhibiting maximum losses of 716 t h^{-1}. The highest erosion rates are found at the upper hill parts of the study site and near channels of rivers. This situation was severe in mountainous lands where farming is common and the soil loss rates from these areas were above 50 t $h^{-1}yr^{-1}$. The estimated soil loss was relatively much lower on plain sites compared to the hill slope lands.

2.2. Prioritization of Erosion Prone Area

A key component of developing and managing programs for the development of sustainable agriculture is the prioritization of different micro-watersheds. Scientific understanding of resource data, anticipated erosion maps, and the priority classification of micro-watersheds for conservation planning are necessary for watershed management. The land use, the soil, the slope, the climate, and the land management techniques are the main causes of soil erosion. Because of the heterogeneity of watersheds, these factors display spatial variability (Kushwaha, 2017). Separated the study watershed into several micro-watersheds, and real-time information and trustworthy data on land usage and soil was obtained using remote sensing and GIS.

The risk of soil erosion and the sub watershed's prioritization according to the degree of soil loss within the watershed were examined by Bewket and Teferi (2009). When making decisions about conservation planning, the universal soil loss equation (USLE) combined with satellite remote sensing and geographic information systems is a helpful tool. Land use, slope steepness, slope length factor, monthly precipitation, soil map, and 30m resolution digital elevation model were all used. Results indicate that a greater portion of the watershed (above58%) is at risk for severe to very severe conditions (above 80 th^{-1} yr^{-1}). The watershed was divided into six priority categories for conservation intervention based on the expected rate of soil erosion, and 18 micro watersheds that could be used as units for conservation planning were identified.

Studied by Wondrade (2019), First and second order conservation priorities are needed because 555.93 ha (5.6%) of the watershed area is experiencing moderate to high erosion severity classes. This amount is estimated from steep slope watershed classes (above 30%) and represents 18.82% of the total soil loss (more than 0.5 mm of topsoil removal per year). In these watershed areas, soil loss rate exceeded SLT by more than 6.25 tons ha^{-1} yr^{-1}, indicating a high degree of erosion. The report clearly shows that erosion severity rises with slope steepness. High soil erosion on the watershed area's steeper banks may be primarily caused by improper land management techniques, such as deforestation, cultivation of marginal land, intensive cultivation, and inadequate vegetation during critical rainfall period.

According to Tiruneh (2015), the entire Enfraz watershed experienced an average annual soil loss of 4.81 tons ha^{-1} and a total estimated soil loss of 30,836.41 tons yr^{-1} calculated by RUSLE. In light of the findings regarding the high soil loss estimated in previous studies, it is implied that the implemented soil water conservation measures have a positive impact on slowing the rate of soil erosion. The present value, however, still shows that practical conservation planning is required to reduce the amount of soil loss in the watershed at a reasonable cost.

The main causes of the highest soil loss rate may be heavy rainfall-induced high erosivity (R-factor), erodibility (K factor), high LS value particularly for steep slopes and soils devoid of supportive practice factors. The major issues that have been identified and resulted in a high soil loss potential in this area are the steeper parts of the land slope lacking vegetative cover, intensive tillage operations, inadequate soil and water conservation measures, and land users' ignorance of the need to periodically maintain structures like clearing silt from the channel and repairing the embankment (Bekele, 2021).

Using remote sensing and a geographic information system assessed the revised universal soil loss equation parameters in order to prioritize the mini watershed in the Subarnarekha sub watershed of India. They made an effort to contrast the rank that came from the two parameters. Mini watershed prioritization was found to be better based on the rank of the universal soil loss equation parameters. Geographic Information System (GIS) and remote sensing-based evaluation of morphologic and revised universal loss equation parameter for ranking has an immerse help in the prioritization of small hydrologic unit (Londhe et al., 2010).

Shinde et al. (2010) studied soil loss and identified critical area for implementation of better management practice for decision making in soil and water conservation planning. In the study universal soil loss equation (USLE) integrated with raster-based geographic information system (GIS) has been applied to estimate potential soil loss at sub watershed level in the Konar basin of upper Damodar Valley Catchment, India.

The GIS methodology's primary benefit was its ability to quickly provide information on the estimated value of soil loss for any area under investigation. The soil erodibility K-factor ranges from 0.325 to 0.476, while the rainfall erosivity R-factor of USLE was determined to be 293.96. The catchment's slopes ranged from 0% to 83%, with LS factor values between 0 and 6.7. The catchment's current cropping patterns were used to calculate the C factor values, and land slope was used to assign support practices (P factors).

In the Konar basin, which covers 961.4 km^2, the average annual soil erosion at the micro watershed level was calculated to be 1.68 t h^{-1} yr^{-1}. In order to implement management practices, additional micro watershed priorities have been determined based on the risk of soil erosion.

Sub-catchments in West Bengal, India's Upper Kangsabati catchment were prioritized by Sujata Biswas in (2012), Georeferencing of IRS P6 LISS III satellite images have been done using SOI top sheets (1:50.000 scales). The catchment and drainage network have been determined using the mosaic top sheets, which has been updated with satellite imagery. Soil and slope maps were created using NBSS & LUP and Survey of India maps, and they have been integrated into a GIS database.

Estimates of soil erosion were derived from the integrated map for every sub-catchment. The estimation of erosion was used to rank the sub-catchments. According to the study, catchment prioritization can be achieved through the effective use of remote sensing and GIS techniques for soil erosion estimation. This facilitates the treatment of catchments for conservation measures.

Amare et al. (2014) mapped the erosion risk in the Wondo Genet watershed and studded soil erosion modeling, Ethiopia. They employed land cover management, rainfall erosivity, slope length and steepness, soil erodibility, and support practice factor as input parameters. To determine the degree of soil loss in a given spatial pattern, their study used the revised universal soil loss equation in conjunction with a geographic information system.
They determined various priority categories for conservation intervention based on the severity of soil erosion. According to the study, there is an erosion risk ranging from extremely severe to very severe for almost 39% of the watershed area. Primarily in regions with sparse vegetation and on the drainage areas' steeper slope banks, where improper farming practices are used.

2.3. Soil Erosion and its Extent

Given that it endangers both the natural environment and agriculture, soil erosion is one of the biggest environmental issues facing the globe today (Balabathina, 2020). Ethiopian soil erosion varies from 16 to 300 t h^{-1} yr^{-1} annually, primarily due to slope, land cover, and intensity of rainfall (Hurni, 1988). Gebreyesus and Kirubel (2009) study conducted at Medego watershed, Northern parts of the country has showed that the soil loss is highest on steep slopes (30–50%), or 35.43 t ha^{-1} yr^{-1}, and lowest on flat plains (<2% slope), or 1.59 t h^{-1} yr^{-1}.

Additionally, water erosion is thought to remove roughly 1.9 billion tons of fertile soil from highlands each year, according to a 1986 FAO study on highland reclamation in Ethiopia. Average was predicted by Hurni (1988) and Hurni et al. (2008) predicted average soil loss from cultivated fields of highlands of Ethiopia and its amount to about 42 metric t ha^{-1} yr^{-1}.

According to Yemkuph and Dagnew (2019) computed annual values of soil loss within the Gedalas watershed ranged from 0 in plain areas to well over 150 t h^{-1} yr^{-1}. The soil loss rate in the watershed's lower reach degraded sloping areas, along the banks of streams, and at certain locations on its steep slopes, exceeds 935 t h^{-1} yr^{-1}. The watershed's annual mean soil loss value was approximately 37 t h^{-1} yr^{-1}, with the majority of the watershed's annual mean soil loss occurring on croplands, where 51 t h^{-1} yr^{-1} was observed. Soil erosion is a primary cause of Ethiopia's severe land degradation issue, endangering both the agricultural output and the survival of the vast majority of the country's rural population. Nutrients, soil organic matter, and soil loss are occurring at a rate that is higher and much faster than their replenishment.

2.4. Revised Universal Soil Loss Equation for Soil loss Estimation

Soil erosion is identified as a serious problem all over the world, thus soil erosion risk mapping and quantitative estimation of erosion processes for its impact assessment is required. Models were developed for fine study scale along with assistance of Remote Sensing and GIS techniques, like USLE, Modified Universal Soil Loss Equation (MUSLE) and RUSLE. These models relate erosion to catchment properties, including drainage area, topography, climate, soil and vegetation characteristics (Jain et al., 2000).

Kienzle (1996) used the RUSLE for evaluation of the effect of grid cell size on the estimation of soil loss potential. It was determined that the soil loss was very sensitive to slope. Mean annual erosion values increased up to 67% when computed with the 400 m and 50 m resolution grids while this increment was 43% when the maximum erosion rates were compared. Molnar and Julien (1998) carried out study for relating cell size and erosion prediction using the USLE in two basins each of 2100 ha and 30400 ha area.

The study concluded by Jain et al. (2000) as grid cell sizes exceeded 100 m, a correction factor must be included in the calculation with the use of that correction factor, the USLE can be applied directly at macro-scales used the Morgan model and USLE model. Parameters required for both models were generated using remote sensing and ancillary data in GIS. The soil erosion estimated by Morgan model was of 22 tons ha^{-1} yr^{-1} and was within the limits reported for this region. The soil erosion estimated by USLE gave a higher rate. Although the USLE has been developed in the USA, it was used throughout the world (Bartsch et al., 2002).

The Revised Universal Soil Loss Equation (RUSLE) is an empirical soil erosion model designed to estimate the long term annual average soil loss carried by runoff from specific field slopes in specified cropping and management systems (Renard et al., 1997). RUSLE has been modified from the Universal Soil Loss Equation (USLE) by adapting the input factors to the local conditions (Renard et al., 1996). The RUSLE has been widely adapted and used to estimate soil loss from watersheds having different or similar land uses elsewhere (Prasannakumar et al., 2012 in India; Alexakis et al., 2013 in Cyprus; Alkharabsheh et al., 2013 in Jordan; Gelagay and Minale, 2016).

The model has been popularly used because of its clear and relatively simple computational inputs requirement compared to other conceptual and process-based models. RUSLE estimates soil loss from sheet and rill erosion as a function of five independent factors (Wischmeier and Smith 1978) as indicated in Eq. 1 below: A=R*K*LS*C*P where A is amount of soil loss in t ha^{-1} $year^{-1}$, R is rainfall erosivity factor, K is Soil erodibility factor, LS slope length and steepness factor, C is cropping and land-cover factor, and P is the conservation practice factor. The input factors for the RUSLE model in this study were adapted to Ethiopian conditions by (Hurni, 1985).

2.4.1. Soil Erosion Factors

Topography, vegetation, soil properties, and climate are the main variables influencing soil erosion. Since topography is influenced by geology, which in turn affects climate and other factors, these factors are not entirely independent. Erosion is significantly increased by both natural and human disturbances, such as fires and harsh weather. Human disturbances include tillage and construction. Among these, erosion can be controlled by adjusting the vegetation, a few disturbances, and, to a lesser extent, the soil and topography (Fangmeier et al., 2006).

2.4.1.1. Climate factor

Temperature, wind, humidity, precipitation, and solar radiation are the climatic factors that influence erosion. Raindrops acting on soil particles causes soil erosion. Rainfall and soil loss are strongly correlated, in part because of the way raindrops separate from the soil when they hit the surface and in part because of how rain affects runoff. The erosivity (R) factor refers to the potential for rain to cause erosion (Renard et al., 1997). Raindrops pick up kinetic energy as they descend and when they strike. The soil particles separate, expelling the kinetic energy. In order for the soil aggregates to break, splash, and then be carried by runoff, energy is needed (Saavedra, 2005).

2.4.1.2. Soil factor

The capacity for infiltration and the degree to which particles can be separated and moved are influenced by the physical characteristics of the soil. Generally speaking, soil transportability increases with a decrease in particle or aggregate size, while soil detachability increases as soil particle or aggregate size increases. In other words, whereas sand is easier to transport, clay particles are harder to separate. Soil structure, texture, organic matter, water content, clay mineralogy, density, and chemical composition are among the characteristics that affect erosion (Fangmeier et al., 2006).

Soils that have better soil structure, higher organic matter content, and faster infiltration rates are generally more resistant to erosion. Clay-rich soils have low K values because they are difficult to separate from one another. Despite being readily detachable, coarse-textured soils, like sandy soils, also have low k values due to their poor transportability. Due to their moderate susceptibility to detachment and moderate runoff, medium-textured soils, like silty loam soils, have a moderate k value. Because they reduce infiltration, high silt content soils are the most erodible of all soil types (Saavedra, 2005).

2.4.1.3. Topographic factor

The length and steepness of the slope, its shape (concave, uniform, or convex), and the size and composition of the watershed are topographic features that affect erosion. Topographic and/or relief factors are referred to as slope factors (LS). Because of the corresponding increases in surface runoff volume and velocity, erosion would typically be expected to increase with slope length and steepness (Doere, 2005). Slopes with steeper terrain result in faster flow, more splashes downhill, and higher runoff velocities, all of which increase soil erosion.

According to Remotel et al. (2001) erosion only doubled for a steepness change from 2-20% and then started to level off. As the raindrops strike at a greater angle, there is likely a slight increase in the detachment rate; however, this effect shouldn't cause a major change in total splash detachment.

2.4.1.4. Ground cover factor

One of the most important things you can do to stop soil erosion is to have vegetation cover. By shielding the soil from the effects of raindrops, increasing the amount of water that penetrates the soil, slowing surface runoff, mechanically binding the soil, preserving the roughness of the soil surface, and enhancing the physical, chemical, and biological qualities of the soil, vegetation helps to reduce soil erosion (DeAsis and Omasa, 2007).

In regions where soil, climate, and topography are similar, variations in erosion rates are frequently linked to land use. As per Lal's (1990) findings, there was a rise in soil erosion in

Malaysia from 0.24 t h^{-1} yr^{-1} under natural forest to 4.9 t h^{-1} yr^{-1} in mature coffee areas and 7.32 t h^{-1} yr^{-1} in vegetable crop areas. In Puerto Rico, adjacent coffee plantations with natural ground cover experienced ten times less soil erosion than the former. A cover and management factor (C-factor) has frequently been used in erosion assessments to account for the impact of vegetation. The ratio of soil loss from land that is cropped under certain conditions to the corresponding clean-tilled continuous fallow is known as the C-factor (Wischmeier and Smith, 1978).

The impact of vegetation, management, and erosion control techniques on soil loss is reflected in the cover management factor. The C value, like other RUSLE factors, is a ratio that compares the site's current surface conditions to the unit plot's standard conditions. Using the land use/cover map as an input, the land cover factor was computed for each mapping unit of a project area.

2.4.1.5. Conservation practice factor

Conservation techniques like terracing, strip cropping, and contouring minimize soil loss in agricultural areas. For example, in terracing areas, increased infiltration may slow down runoff speed, which will ultimately reduce soil loss and sediment delivery. A support practice factor (P-factor), which is the ratio of soil loss with the practice applied and up- and down-slope cultivation, is frequently used to assess the efficacy of such practices (Wischmeier and Smith, 1978; Renard et al., 1997). P-values, which vary from 0 to 1, have been allocated to land use classes based on literature values (Kaltenrieder, 2007).

2.5. Application of RUSLE through RS and GIS for Erosion Assessment.

When modeling soil erosion, remote sensing and GIS technology offer a useful analytical tool. Since soil erosion is a spatial phenomenon, geoformation modeling relies heavily on geoformation techniques (Yazidhi, 2003). In mapping and evaluating landscape attributes that control soil erosion, such as physiographic soils, land use/cover, relief, and soil erosion pattern, the potential utility of remotely sensed data, such as aerial photographs and satellite sensor data, has been widely acknowledged (Pande et al., 1992). Data from remote sensing can be linked to their spatial location in a GIS environment (Beck, 1987).

The following benefits can generally be obtained from using geo-information techniques in erosion modeling: quick and affordable estimates; increased opportunities to explore larger areas; increased potential for ongoing monitoring of these areas; and the ability to fine-tune the soil erosion model based on the desired output scale, i.e., from a rough global to a more precise local scale. Yazidhi (2003) states that topographical parameters useful for soil erosion modeling can be estimated through the use of GIS and digital elevation models.

2.5.1. Remote Sensing for Soil Erosion Assessment

The characteristics of electromagnetic radiation and how it interacts with matter form the foundation of remote sensing. Because satellite imagery offers a quick and affordable method of analyzing large watersheds due to its synoptic and repetitive coverage, remote sensing has ushered in a new era in the planning and development of watershed management (Jain and Goel, 2002). Thus, distinct ground features can be distinguished from one another and a thematic map illustrating land use/cover can be created by appropriately utilizing multispectral data. In various studies, satellite imagery has been effectively employed to measure both qualitative and quantitative changes in the terrestrial land-cover within a watershed (Lu et al., 2004) and to characterize and manage the watershed (Saxena et al., 2000).

Remote Sensing can facilitate studying the factors enhancing the process, such as soil type, slope gradient, drainage, geology and land cover. Multi-temporal satellite images provide valuable information related to seasonal land use dynamics. DEM (Digital Elevation Model) one of the vital is soil erosion modeling can be created by analysis of stereoscopic optical and microwave (SAR) remote sensing data (Pande et al., 1992).

2.5.2. Geographic Information System for Soil Erosion Assessment.

GIS is characterized by its capability to integrate layers of spatially oriented information. The number and type of applications and analysis that can be performed by GIS in a watershed are as large and diverse as the available geographic datasets (Deore, 2005). A watershed-based approach is necessary for the characterization and assessment of soil erosion, and GIS has been widely used in these studies (Khan et al., 2001). Furthermore, the modeling and visualization powers of contemporary GIS provide radically new instruments for comprehending the dynamics and processes that sculpt the chemical, biological, and physical environments of watersheds (Jain and Goel, 2002).

Using geographic information systems (GIS) to map soil erosion makes it simple to pinpoint areas that may be subject to significant soil erosion as well as to obtain data on the estimated cost of soil loss at different points within the watershed (Shi et al., 2003). In the current study, priority areas for conservation measures were identified using remote sensing and GIS techniques based on an erosion risk map.

3. MATERIALS AND METHODS

3.1. Site Description

Location and climate

The study was conducted at Diko watershed, which is located in Habru District of Northeastern, Ethiopia (figure 1). The center of the district is Mersa, which is located at 491 km north of Addis Ababa on the main road to Woldia. Currently this district has 36 kebele with 33 rural and 3 town administrations. Geographically, the study area lies between 11°42'23.006"N to 11°44'33.023"N latitude and 39°36'50.449"E to 39°40'43.669"E longitude and at an altitude ranging from 1619 to 2298 meters above sea level (m.a.sl). The area coverage of the watershed is about 1906 ha and is characterized by flat and hilly topography.

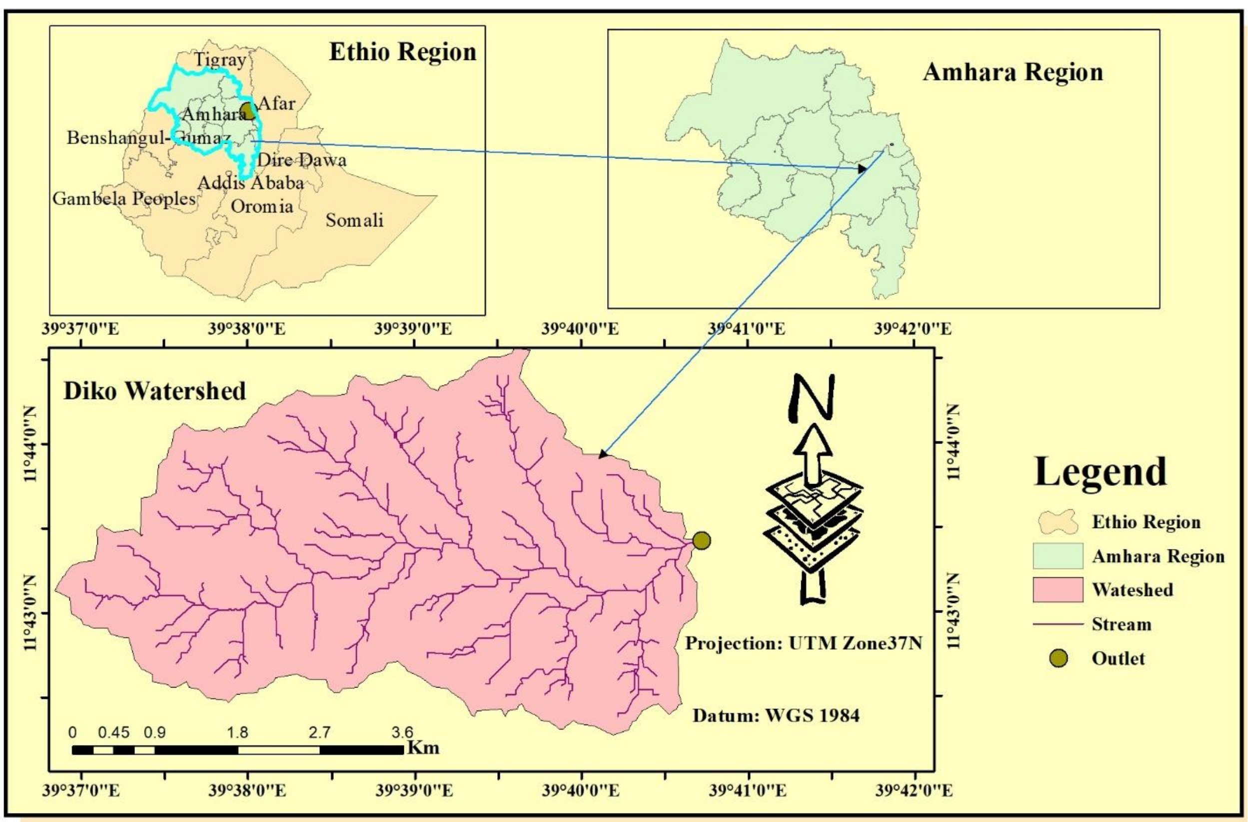

Figure 1: Location map of the study area (Diko watershed)

The area is characterized by bimodal rainfall pattern (Belg and Meher). The short (Belg) rain starts in February and ends in April while the main rainy season starts in June and ends in September. However, the distribution is erratic. According to the Ministry of Agriculture (MoA) (1998), there are three agro-ecological zones including: *Dega* (highlands, 2,300-3,200 m a s l), *Weyna Dega* (midlands, 1,500-2,300 m a s l) and *Kolla* (lowlands, 500-1,500 m a s l). The dominant agro ecological zone of the watershed is '*Woyna Dega'* with an average elevation of 1958.5 m.a.s.l. The meteorological data of the nearby representative stations, Sirinka Agricultural Research Center (2023) showed that the mean annual minimum and maximum temperature of the district are 15 and 28 C, respectively, and the mean annual rainfall is ranging from 700-1000mm.

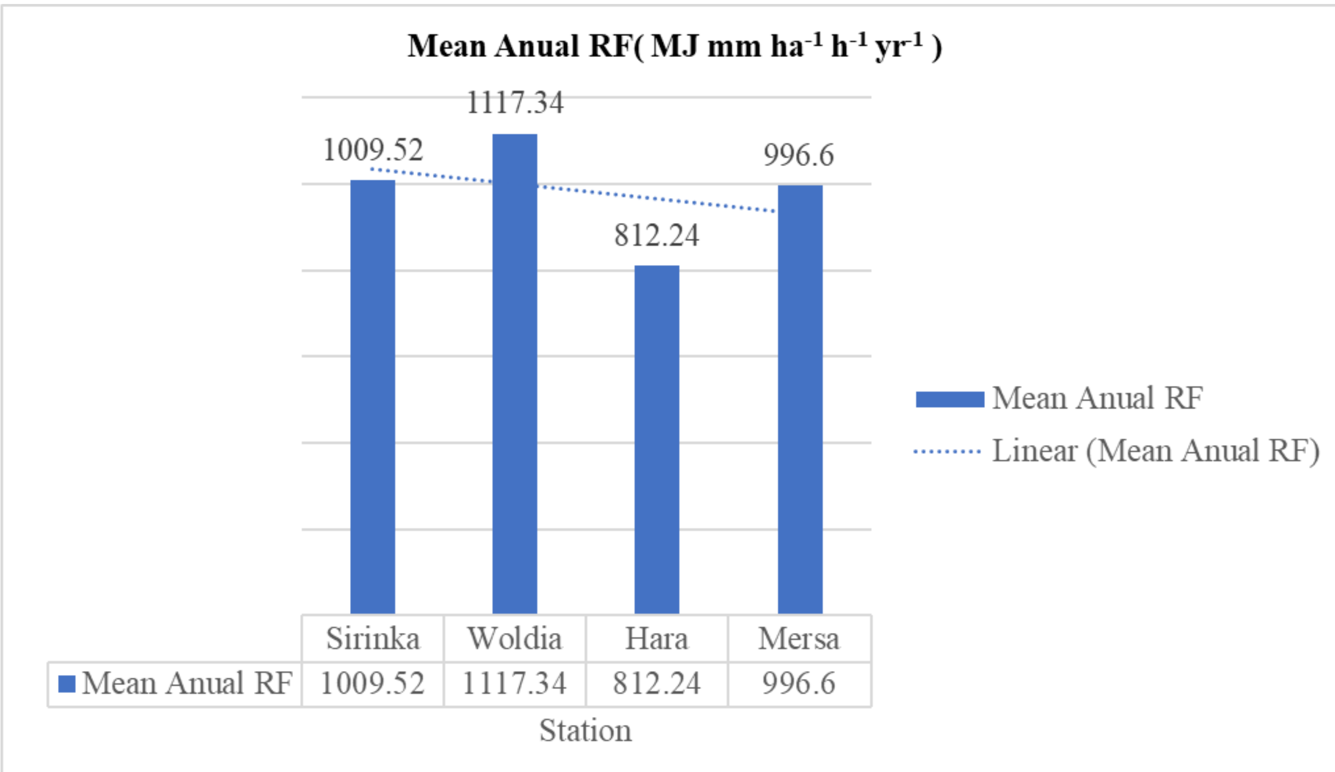

Figure 2: Mean Annual Rainfall

Land use land cover and Farming

According to the information obtained from the Kebele's agricultural office, the existing land use system consists of 60.8% Crop land 10.3% Tree,22.9% grazing land and 6% Built up area The smallholder farmers practice mixed farming system that integrates both crops and livestock. In rain-fed cultivation, teff (*Eragrostis teff*) and sorghum (*Sorghum bicolor*) are the dominant crops Farmers use oxen to pull the local plough 'Maresha'. Most of the time farmers cultivate their land 2-3 times before planting cereals. The most important tree species occurring in the study area includes eucalyptus (*Eucalyptus globules) and Olea Africana*

Geology and Soils

In this study major soil types of the study area used from Amhara soil map shape file and Agriculture and Natural Resources Management Offices. According to agricultural and Natural Resources Management office of Habru district the area is covered by Eutric Cambisols, Vertic Cambisol, Eutric Regosols and Lithosols. Cambisol is the dominant soil type which covers 51.19% and Regosol 40.78%, Lithosols 8.023% in the study area of watershed**.**

3.2. Data Sources and Methods of Data Collection

Both primary and secondary data was used for data sources. Primary data were collected by field observation through transect walk, major LuLc and land management practices including improved and local soil and water conservation measures GPS (garmin72) used to collect ground truth information of land use/land cover for Accuracy Assessments and soil sample in the study watershed was collected. Secondary data to be used like Sentinel2A image with spatial resolution of 10m × m10 downloaded from Copernicus Data Spaces Ecosystem (https://dataspace.copernicus.eu).

For Calculate NDVI and 10 m Resolution image from ESRI 2022 For land use land land cover classification, 30m by 30m resolution DEM from USGS Earth explorer (https://earthexplorer.usgs.gov), time series climatic data, particularly rainfall (2002-2023) obtained from Ethiopian National Meteorological Service Agency (ENMSA) and general Information about the study area was collected from Habru Woreda Agriculture and Natural Resource Management Office. Meanwhile, Software like ERDAS Imagine2014 software for satellite image processing and Image classification while Arc GIS 10.8.2 software was used for DEM processing, watershed delineation and soil loss analysis. Arc SWAT software was used to delineate sub watershed and ranking their severity.

3.2.1. Satellite Data

DEM was download from United States Geological Survey (USGS) webpage (http://glovis.usgs.gov) with 30m resolution for the purpose of this study in Geo-TIFF format with Geographic coordinate system projection. Sentinel2A data from Copernicus Data Space Ecosystem with 10m resolution for NDVI and 10 m Resolution Land Use Land Cover image from ESRI 2022((https://livingatlas.arcgis.com/landcover/),) for image classification and Accuracy assessment.

3.2.2. Field Data

Field data were collected randomly using Global Positioning System to verify the classified image and generate information regarding the ground truth for image classification and soil loss vulnerability verification. Then, the GPS waypoint easting and northing readings was recorded and also Soil sample was collected.

3.2.3. Climate Data

The meteorological data was collected from Ethiopian National Meteorological Service Agency (ENMSA). four meteorological stations located in and around the watershed Monthly rainfall of four stations (Woldia, Hara, Sirinka, Mersa) from 2002-2023 was gathered and mean annual rainfall data ware generate from the monthly rainfall data of 22 years and well adopted for the analysis.

Station Name	Easting	Northing	Mean Annual RF
Mersa	571712	1293409	996.60
Sirinka	565648	1297142	1009.52
Woldia	564758	1305468	1117.34
Hara	577179	1304785	812.24

Table 1: Meteorology stations and mean annual rainfall

3.2.4. Soil Sampling

First the field information including land use type,, surface land features, altitude, slope gradient, soil management practices and sampling depth were recorded. After that Using grid cell sampling techniques 1000m x 1000m (1Km by1Km) and sample for analysis was collected from the center of each grid. minimum of 10 to 15 sub samples were collected and composited. Totally 18 composite soil samples were collected from 0 to 20cm soil depth using soil auger to determine the physical and chemical properties of the soil. The properties of analyzed are organic matter content, texture, structural, and permeability.

3.3. Method of Data Analysis

3.3.1. GIS database construction

ArcGIS 10.8.2 was used for the generation of R, K, LS, C and P parameter, integration of layers, reclassification of derived datasets and weighted overlay analysis. Watershed, and sub watersheds delineation were performed using Arc map and within ArcGIS 10.8.2. For digital image processing including preprocessing of satellite image data, masking the image with the watershed boundary enhancement, visual interpretation, and ERDAS Imagine 2014 software was used. All derived maps were projected into WGS1984 Zone 37N.

3.3.2. Laboratory Analysis

Soil texture was determined by Bouyoucos's hydrometer method (Bouyoucos's, 1962) that is calibrated to read the density of the soil water suspension in gram per liter after dispersing the soil particles with sodium hexameta phosphate ($NaPO_3$).

The soil OC was determined by the wet oxidation method (Walkley and Black, 1934) in which the sample is first digested with potassium dichromate in sulfuric acid solution and titrated with 0.5 N ferrous sulfate solution. Percent organic matter was computed by multiplying the percent soil OC by a conversion factor of 1.724. Soil structure was identified under field observation to determine soil structural class code. Soil structural class code was determined based on the observed shape and size of soil structure as adopted from the USLE Nomograph (Wischmeier and Smith, 1978); whereas, the permeability class code is obtained from soil textural classes (Boorman, *et al.,* 1995) which are encoded from the textural triangle based on the observed soil texture.

3.3.3. Remote sensing Data Analysis

3.3.3.1. Image processing

For digital image processing operations such as image restoration, georeferencing, image enhancement and image classification were done using ERDAS Imagine 2014 image processing software.

3.3.3.2. Image pre-processing

According to Lille sand and Kieffer (2000), remote sensing is the science and art of learning about an object, area, or phenomenon by evaluating data gathered by a device that is not in contact with the object, area, or phenomenon being studied. Information extraction from remote sensing data is driving the need for data input. There is a high need for information extraction from remote sensing data. Prior to identifying satellite pictures, pre-processing is a crucial step. Pre-processing jobs are those that are typically necessary before the primary data analysis and information extraction. The ERDAS Imagine software uses a variety of image processing techniques, such as layer stacking, picture extraction, restoration, and classification, to assess the satellite imaginaries.

3.3.3.3. Image classification

The method of supervised image classification used for this study. Supervised classification offers the software unique training classes, but requires prior knowledge of the scene area. After that, ERDAS Imagine software is used to classify land cover and land use under supervision using images from sentinel2A image Land use and land cover types were classified using image classification techniques, and the classified images were used as inputs to generate the crop management (C) factor of the Revised Universal Soil Loss Equation.

With the aid of the satellite image's features' various reflection properties and visual interpretation elements.

3.3.3.4. Accuracy assessment

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true, in order to determine the accuracy of the classification process. . field data has been compared with the classified images in order to evaluate the accuracy of the LULC maps. The crucial metric of accuracy is the number of ground truth pixels that are accurately classified.

A total 106 ground control points were collected using global positioning system (GPS) to validate the LULC classification and calculate the accuracy of classified image. For this purpose, 46 points from Crop land, 19 Rangeland 23 Tree, and 18 from Built up area were collected. Ground control sampling points are based on accessibility to road infrastructure and the ratio of land cover to other land uses in the study area.

The difference between LULC classification and the reference map were determined by performing accuracy assessment (Disperati & Virdis, 2015). To check the errors and validation of the classified LULC, the producer accuracy (Aronoff, 1985), user's and overall accuracy (Fung & LeDrew, 1988), and the Kappa coefficient (Congleton et al., 1983) were used to understand the level of accuracy of the classified LULC over the study period. According to Watson and Petrie (2010), the Kappa coefficient has a range of values from zero to one, where values equal to one indicate perfect agreement, values between 0.41 and 0.60 indicate moderate agreement, values between 0.61 and 0.80 indicate moderate agreement, and values greater than 0.80 indicate perfect agreement.

The accuracy of the land use and land cover classification is categorized using ERDAS software. The discrepancy between the LULC categorization and the reference map was assessed using accuracy evaluation (Disperati & Virdis, 2015). The errors were evaluated and the categorized LULC was validated using the producer accuracy (Aronoff, 1985), user's and overall correctness (Fung & LeDrew, 1988), and the Kappa coefficient (Congleton et al., 1983).

3.3.4. Identification and Estimation of Missing data

The years with insufficient annual recorded rainfall data for the chosen stations were recognized and treated as missing data in this study. To make the missing data at least somewhat full, they were recreated using estimation. It is crucial to take into account the target station's percentage of missing data before estimating the missing rainfall data. The usual yearly precipitation in the surrounding gauges is more than 10% of the gauge under consideration. Consequently, the Normal Ratio approach was used to compute the missing rainfall data for this study. This evaluates the impact of every nearby station (Singh, 1994).

$$PX = \frac{Ax}{n(\frac{P1}{A1}+\frac{P2}{A2}+\frac{P3}{A3}+\frac{Pn}{An})} \quad \text{..............} \quad \text{(Equation 1)}$$

3.3.5. Generation of Input Parameters for RUSLE Model

The amount of soil loss that happens each year as a result of runoff from different land forms and land uses within the watershed is estimated using the Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1978). It has been altered and tailored to the needs of Ethiopia by (Hurni, 1985). This method serves as an example of the possible soil loss brought on by splash, rill, and sheet erosion.

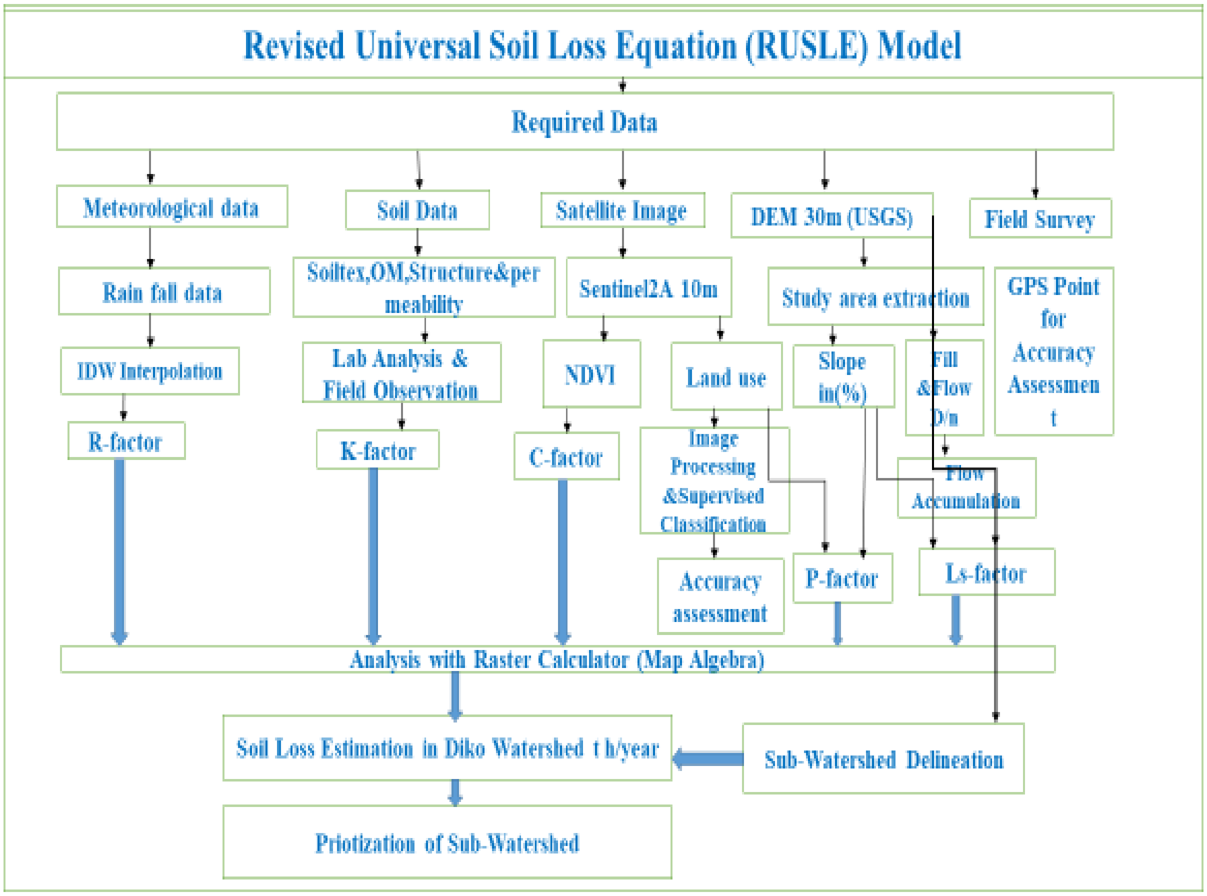

Figure 3: Methodological flowchart for soil loss estimation and Priotization.

A= R x K x LS x C x P, (Equation 2)

Where, A= average annual soil loss in tons/ha/yr.

R=rainfall erosivity factor,

K= soil erodibility factor,

LS=slope length and slope steepness factor,

C= cover management factor,

P= support practice factor

3.3.5.1. Rainfall erosivity factor (R)

Rainfall erosivity (r) is the potential of the erosive force of rainfall and runoff to cause erosion. The rainfall erosivity factor (R), the only climatic parameter in RUSLE, determines the effect of rainfall on sheet and rill erosion and provides a result in MJ mm ha^{-1} h^{-1} yr^{-1}. The erosive force produced by a rainfall event is indicated by the R-factor (Alexakis et al., 2013; Wischmeier

& Smith, 1978). Asmamaw & Mohammed, 2019; Bekele, 2021; Belayneh et al., (2019) for the Ethiopian highlands the most popular geostatistical spatial interpolation approaches for obtaining reasonably accurate rainfall erosivity information from sample points to the points with unknown values are the inverse distance weighted (IDW) interpolation techniques.

3.3.5.2. Soil erodibility factor (K)

Soil erodibility refers to the vulnerability of soil to erosion agents. as stated by Balabathina et al. (2020). It describes the extent or quantity of soil particles exposed to water erosion, as per Nut et al. (2021). It is impacted by soil depth, soil drainage and texture, structural integrity, and organic content. the estimation of erodibility value involves various physical parameters such as soil texture, soil organic matter content, percent of sand, silt, and clay in the soil, soil structure code, and profile permeability. and thus it requires substantial time, cost, resource, long-lasting field surveys, and laboratory analyses (andrew et al., 2022; Yesuph & Dagnew, 2019). however

Morgan (1995) states that the OM and chemical content of the soil, as well as its shear strength, infiltration capacity, aggregate stability, and texture, all affect erodibility. The K factor, under standard experimental settings, indicates the soil's or surface material's inherent erodibility at a given place. Foster et al. (1981) reported that K values typically range from 0.10 to 0.45 in US customary units and from 0.013 to 0.059 in SI units.

According to Kayet et al. (2018), it is the soil's susceptibility to erosion, the silt's ease of removal, and the quantity of runoff that is anticipated from each rainfall event. Soil erodibility factor was obtained from physicochemical properties of soils in the watershed.
The soil samples were analyzed for soil texture (% sand, % silt and % clay) and organic matter content of soil in laboratory, soil structure at the field and permeability from soil texture was analyzed.

The textural analysis made by the hydrometer method in laboratory. Subsequently, permeability is computed based on soil texture relation between soil textural classes and permeability rate developed by Wischmeir et al. (1971). Soil structure was determined by soil visual descriptors methods suggested by Shepherd (2000) and the OC was determine by Walkley and Black method (Bernard et al., 1993). In order to evaluate the effect of soil erodibility on the annual soil loss, the K-factor for each plot was estimated by the USLE equation as following

$$\mathbf{K = 2.8 \times 10^{-7} \times M^{1.14} (12\text{-}\%OM) + 4.3 \times 10^{-3} (S\text{-}2) + 3.3 \times 10^{-3} (P\text{-}3),} \quad \text{(Equation 4)}$$

Where: -K = the erodibility factor

M = is the product of the primary particle size fractions:

M = (% silt + % very fine sand) (100 – % clay)

OM= percent organic matter and

S = classes for structure code (very fine granular =1, fine granular = 2, medium r coarse granular = 3, blocky, platy or massive = 4), and P = permeability (rapid = 1, moderate rapid = 2, moderate = 3, slow to moderate = 4, slow= 5, very slow= 6) (Vaezi et al., 2010).

Finally, spatial soil erodibility map was generated as a raster data through interpolation in Arc toolbox (Interpolation) of ArcGIS10.8.2

3.3.5.3. Topographic factors (L and S)

The length (L) of the slope is the distance from the beginning of runoff to the deposition location. The LS factor in RUSLE takes topography into consideration while calculating erosion. Erosion is taken into consideration via the slope length factor (L), which increases with slope length. According to Wishlmeier and Smith (1978), slope length is the horizontal distance between the starting point of overland flow and the point at which runoff concentrates in a specific channel or the slope gradient lowers sufficiently for deposition to start.

The slope steepness factor (S) reflects the influence of slope gradient on erosion. Both slope length and steepness substantially affect sheet and rill erosion estimated by RUSLE.

In erosion prediction, the factors L and S are usually evaluated together. The slope gradient is determined from digital elevation model (DEM) of 30-meter resolution using ArcGIS10.8.2 and compute using the equation evolved from Smith and Wischmeier (1978).

Using spatial analysis tool in ArcGIS10.8.2 value of LS was calculated in the following steps: (1) using DEM of the watershed in spatial analysis tool, slope (in percent) of the watershed was analyzed, (2) then generated flow direction, (3) from flow direction flow accumulation was generated, (4) finally, in raster calculator the LS-factor was calculate using equation below. (Simms, 2003).

LS= (*flow accumulation* × *cell resolution* /22.13)$^{0.6}$ × (*sin* (*slope*×0.01745) ×0.0896)$^{1.3}$

3.3.5.4. Cropping and land-cover factor (C)

The ratio of soil loss from land with a particular vegetation to the equivalent soil loss from continuous fallow is known as the C-factor (Wischmeier and Smith, 1978). Land cover change has strongest effect on the C-factor, significant increase on the C- factor leading to increase in soil loss. The C-factor's value varies from 1 in completely bare land 0 in a water body or completely covered land surface (Mengistu et al., 2015).

The C-factor is used by the RUSLE to take cropping and management practices into consideration when estimating erosion rates. It is the statistic most frequently used to compare the relative effects of management practices on conservation plans, according to USDA (2001), The NDVI data, which was produced from a 10 m resolution Satellite Sentinel2A image, was used to calculate the C parameter and illustrate the link between changes in plant cover and water-soil erosion. For open land, the C value is approximately 1, while for dense vegetation, it is 0. Larger values of the C parameter denote the absence of vegetation cover and the presence of soil erosion, whereas lower values of the C parameter denote the presence of extremely strong vegetation cover (Erencin, 2000).

Normalize Difference Vegetation Index was calculated from the Landsat 8 satellite image by applying the equation given below using ERDAS IMAGINE 2014 software.

$$\textbf{NDVI} = \frac{NIR - Red}{NIR + Red}, \text{(Equation 5)}$$

Where NDVI is for Normalized Difference Vegetation Index, RED represents for surface spectral reflectance in the red band, and NIR for surface spectral reflectance in the near-infrared band. The following formula, which was suggested by Durigon et al. (2014) for tropical climates, was used to estimate the watershed's C-factor value once the NDVI was calculated. De Carvalho et al. made use of it (2014). According to Phinzi and Ngetar (2019) and Almagro et al. (2019), this method is more realistic for determining C-factor values in tropical regions.

The C-factor map was computed and produced using ArcGIS 10.8.2 Spatial Analyst Extension Raster Calculator.

$$\mathbf{C} = \frac{0.1(-\mathrm{NDVI}+1)}{2}, \text{(Equation 6)}$$

3.3.5.5. The support practice factor (P)

The impact of conservation practices on soil loss in comparison to soil loss under uphill and downhill cultivation is known as the support practice factor (P) (Ojo Atere et al., 2009). Soil erosion can be minimized by implementing techniques such as contouring, terracing, cross slope cultivation, and strip cropping that mitigate the effects of runoff. When land has sufficient conservation interventions, the management practice factor P shows how conservation practices affect soil erosion. Certain agricultural techniques have an impact on erosion by changing the direction and flow pattern of runoff as well as by lowering runoff levels (Renard and Foster, 1983).

According to its ability to stop soil erosion, reduce the amount and speed of water flowing through it, and promote infiltration, the P parameter indicates the percentage of soil erosion associated with each farming strategy (Rabia 2012). In any case, by lowering the likelihood that soil erosion would occur, the P parameter is one of the important factors that helps to decrease it (Mahala 2018; Das et al. 2018). To generate a P parameter map and classify land use/ land cover (LULC) in the study area, Sentinel2A image was used. The supervised classification method was employed in the directed classification process, and bands of the satellite image in the study area were combined using Arc GIS 10.8.2 software (Barrett et al. 2014).

To generate a P parameter map and classify land use/ land cover (LULC) in the study area, Sentinel2A image was used. The supervised classification method was employed in the directed classification process, and bands of the satellite image in the study area were combined using Arc GIS 10.8.2 software (Barrett et al. 2014). The slope map in GIS produced by combining LULC and DEM (Wischmeier and Smith 1978). The values of the P parameter range from 0 to 1. Best conservation methods are indicated by values that are close to 0, which correspond to areas that are resistant to water erosion. When a rating becomes close to 1, it indicates poor conservation techniques, is accountable for areas with high slopes, and indicates a deficiency in human support measures (Mahala 2018; Das et al. 2018).

Table 2: P value of different land uses with respect to different slope (%) classes (Wischmeier and Smith, 1978).

Land use land cover	Slope (%)	P-factor values
Agricultural lands	0–5	0.1
	5–10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	>50	0.33
Other lands	All	1

3.4. Calibration and Validation the RUSLE Model

An attempt to more accurately parameterize a model to a specific set of local conditions is known as model calibration, which lowers prediction uncertainty. By carefully choosing values for the model's input parameters (within each of their individual uncertainty ranges) and comparing the model's predictions (output) with the observed data under the same conditions, one can calibrate the model (Arnold et al., 2012).

This watershed has never had any case studies before. Consequently, the output of the current model was compared to the baseline results of soil erosion under fallow conditions as well as previous studies of a similar nature conducted in other regions of Ethiopia following the implementation of participatory watershed management. Additionally, a selective field observation was carried out to assess the coherence and consistency of the model's output. They assist in classifying forms of erosion and assessing conservation strategies. GPS was utilized to pick and collect ground truth data over a range of land covers, which is used to validate and confirm results. Qualitative approach such as rating the severity of soil erosion rate as very slight, slight, moderate, severe and very severe, based on the classification of for effective watershed management planning and, in addition, field observations was carried out to identify most erosion-prone areas (WBISPP, 2001).

The aim of validation is to ensure that the input components of the model work together to produce the intended result for which the model was developed. A validation process ensures that the input components of the model function to give the expected result. The model needs to undergo the validation process after calibration of uncertain parameters. The parameter values fixed by calibration phase were evaluated if they represent the real values or not. Erosion models have often been compared and validated using sediment discharge from small plots (Tiwari et al., 2000).

3.5. Prioritization of Sub watersheds

From the entire watershed, a few areas might be responsible and more critical for a huge amount of soil loss. Due to the limitations of labor and other resources to conduct watershed management practices, consideration to critical sub-watershed is suggested. Hence, identification and prioritization of more erosion-prone sub-watershed is essential to select a prior-focus area for planning and implementing SWC measures (Gashaw et al., 2018). For the purpose of identifying priority areas for conservation planning, soil loss potential of the study area was first categorized into different severity classes from the result of analysis. The assignment of a range depended on the judgment of how much erosion would be harmful to the soil. Area coverage in hectare and percent proportion are also tabulated for each of the soil erosion potential categories.

The risk of soil erosion and the sub watershed's prioritization according to the degree of soil loss within the watershed were examined by Bewket and Teferi (2009). When making decisions about conservation planning, the universal soil loss equation (USLE) combined with satellite remote sensing and geographic information systems is a helpful tool. Land use, slope steepness, slope length factor, monthly precipitation, soil map, After the estimation of the soil loss, a priority ranking of all sub-watersheds have been done for identifying the highly erosion/soil loss-affected area then Sub watersheds were prioritized based on mean annual soil loss estimated and soil erosion risk area coverage. For implementation of land and water conservation measures.

4. RESULTS AND DISCUSSION

4.1. Watershed Delineation

To delineate the watershed, the geographical location of the outlet points (573965m Easting and 1296086 m Northing) and Digital Elevation Model with a range of 1619m.asl to 2298m.a s l was used. The delineation result showed that the total area of Diko watershed was 1906(ha) and show figure 4

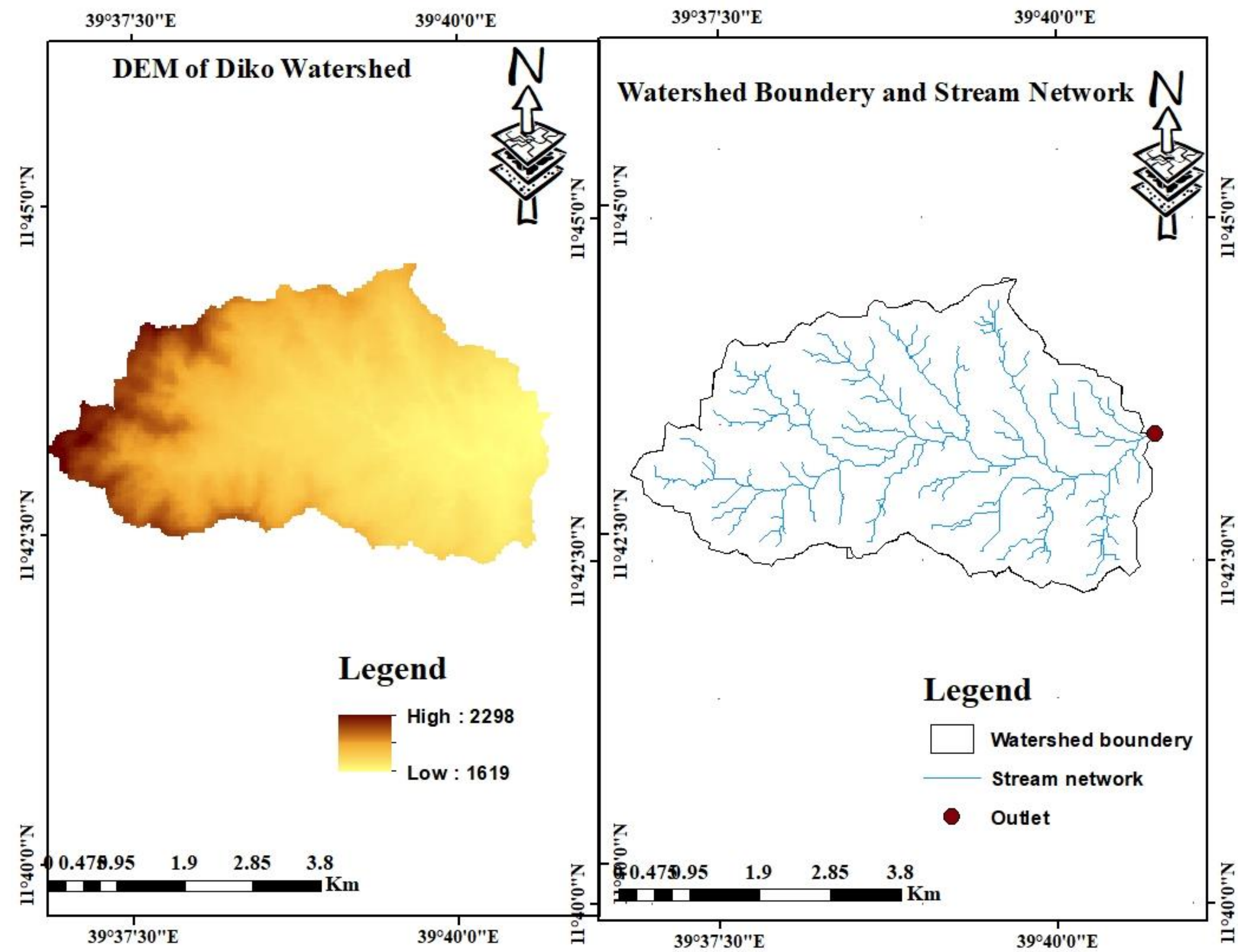

Figure 4: Diko Watershed DEM and watershed map

Based on minimum threshold area given to form the origin of the stream the watershed was divided into 7 (Seven) sub-watersheds and shown in Figure 5 below.

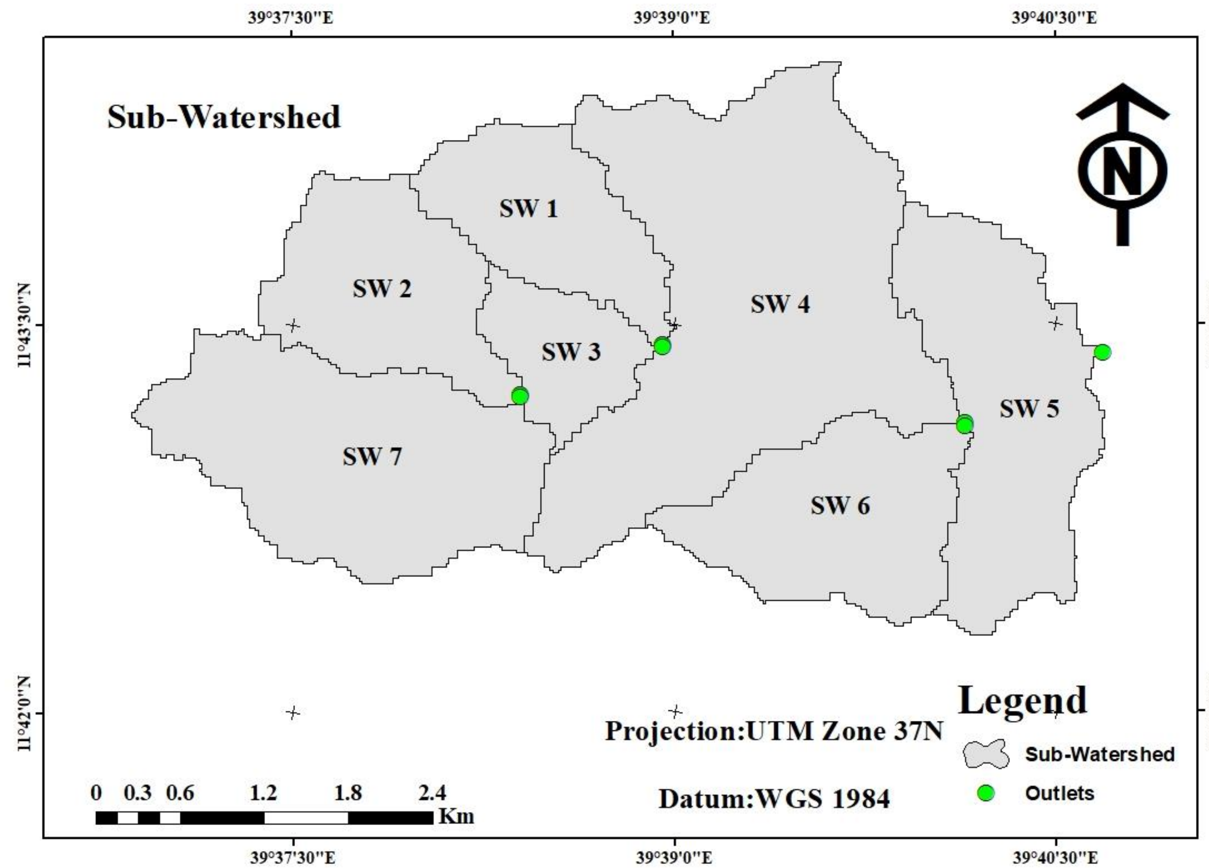

Figure 5: Sub-watersheds map of Diko watershed

The sub-watersheds under study were delineated using the automatic delineation option available in Arc SWAT Tools of ArcGIS10.8.2 Extension. Seven sub-watersheds were delineated using Arc SWAT automatic watershed delineation tool. Areas of 7 sub-watersheds were calculated and found in the range of 101.92 ha (SW3) to 581.59 ha (SW4) or from the smallest area coverage of 4.99 % to largest area coverage of 31.12 % and presented in Table 3. Below

Table 3:Sub-watershed and its area coverage

Sub watershed	Area(ha)	Area(km)	Percent
SW 1	165.88	1.6643	8.530
SW 2	198.52	1.9907	10.304
SW 3	101.920	1.014	4.998
SW 4	581.59	5.8199	31.125
SW 5	285.72	2.8627	15.046
SW 6	223.68	2.2223	11.564
SW 7	348.96	3.4851	18.430
Total	**1906**	**19.06**	**100**

4.2. Estimation of Missed Rainfall Data

Stations having inadequate annual records of rainfall were identified and considered missed. The stations with missed annual records were Mersa Station for the year of 2016,2021, Sirinka for the year 2021 Woldia for the year 2022 and Hara for the year of 2002,2003 and 2004 using equation 1 the complete annual rainfall data were presented.

4.3. Consistency Test of Annual Rainfall Data

Double mass curve was used to plot annual cumulative total rainfall of each individual station with the average annual cumulative rainfall of all group stations to test consistency of rainfall data. The graph of the double mass curve plot was founded linear for meteorological stations. This implies that the rainfall data was consistent over the considered period as shown in Figure 6 below.

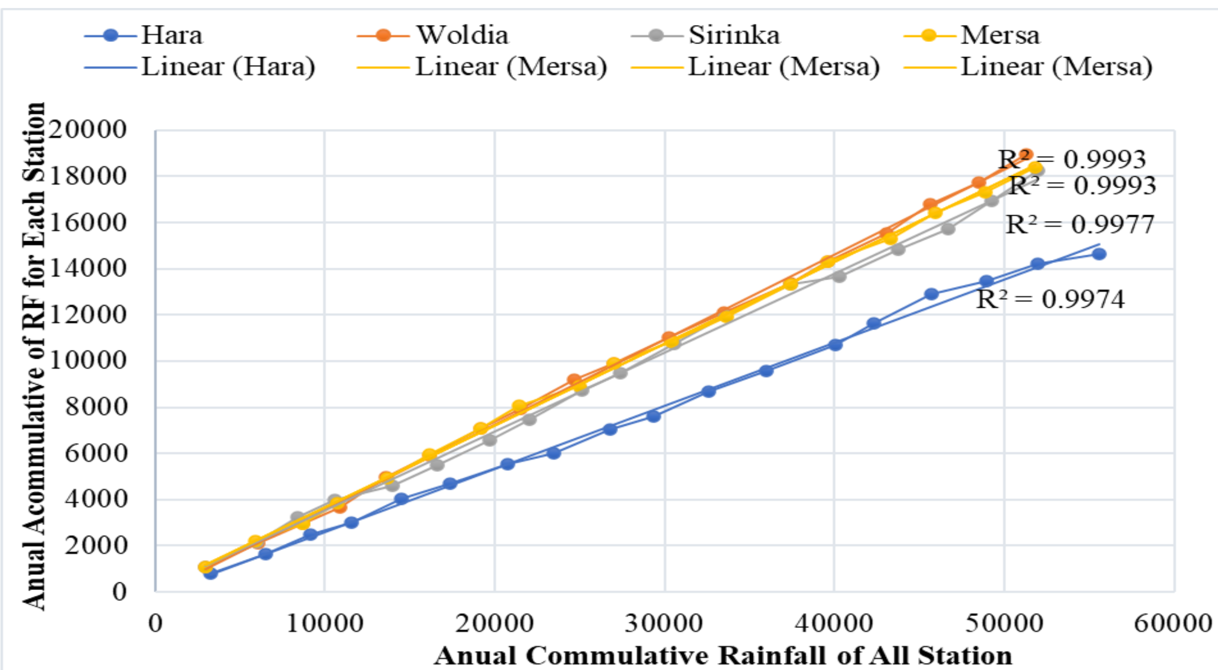

Figure 6: Double mass curve of meteorological stations

4.4. Homogeneity Test of Annual Rainfall data

The homogeneity of the annual rainfall data from 2002 to 2023 was tested for all stations using RAINBOW software (Raes et al., 2006). The result of the homogeneity test for the rainfall data showed that the collected data were homogeneous. When the deviation crosses one of the horizontal lines the homogeneity of the data set was rejected with respectively 90%, 95% and 99% probability but, for this study no cumulative deviation crossed horizontal lines and the restriction of homogeneity assured that the observation of all stations were from the same population (see Appendix Table 4 and Appendix Figure 5, 6, 7 and 6).

4.5. Estimated RUSLE Model Parameters

4.5.1. Rainfall erosivity (R) factor

The soil loss is closely related to rainfall partly through the detaching power of raindrop striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1994). The mean annual rainfall data of 22 years (2002-2023) derived from four rainfall stations (Mersa, Sirinka, Woldia and Hara) were considered to estimate R factor. The calculated R factor for each station was converted to raster surface with 30m grid cell using ArcGIS 10.8.2. Rainfall erosivity depends on amount, intensity and distributions of rainfall. Based on the analysis the minimum and the maximum (R) factor value slightly the same throughout in the watershed were 550.293 to 559.364 mm h^{-1} ha^{-1} yr^{-1}, respectively. in a complex topographic terrain an erosivity value greater than 500 MJ mm ha^{-1} h^{-1} yr^{-1} can causes extreme to very extreme erosion events (oliver's, 1980), and thus rainfall erosivity (ranging from 550.29 to 559.36MJ mm ha^{-1} h^{-1} yr^{-1}) is one of the most sensitive factors of soil erosion in the study area. Similar study conducted by Kebede & Fufa (2023) show that the R-factor value for Finca'aa sub catchment in the Western ethiopia ranges from 582 – 712 MJ mm ha^{-1} h^{-1} yr^{-1}. a Similar approach is used by Hagos (2020) to estimate the erosive force of rainfall in Zariema catchment in northern ethiopia which was found to be 635- 758 MJ mm ha^{-1} h^{-1} yr^{-1}.

The distribution of rainfall stations ware Mersa within the watershed and Sirinka, Woldia and Hara were around the watershed affecting the rainfall erosivity of Diko watershed with the developed Thiessen polygon were shown in Figure 7 below. Mersa station was occurred and cover more than the middle part of the watershed.

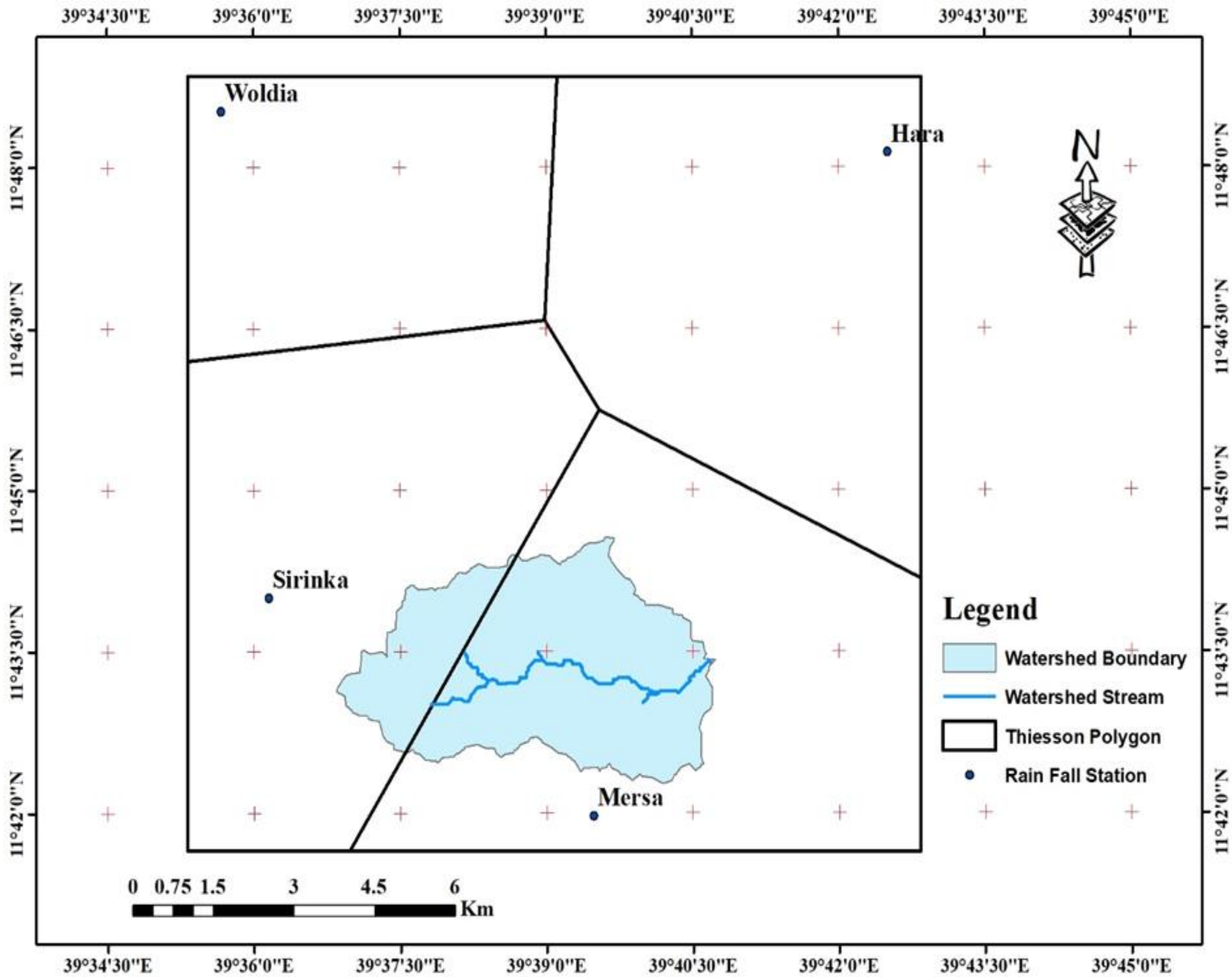

Figure 7: Distribution of rainfall stations and Thiessen polygon

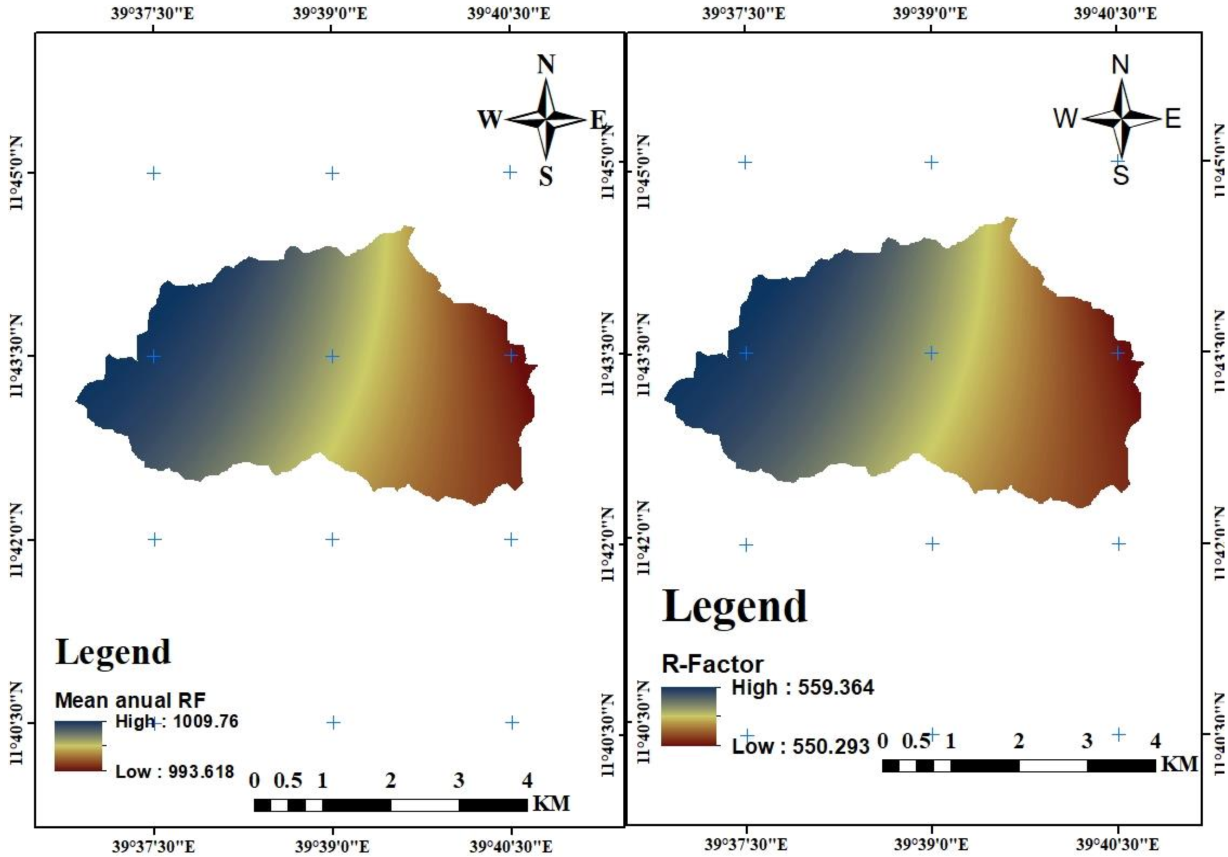

Figure 8: Spatial distribution of rainfall erosivity map

4.5.2. Soil erodibility (K) factor

Soil erodibility value was obtained from analysis of soil samples taken in the watershed. Distribution of soil sampling points were shown in Figure 9 below. Soil Erodibility factor (K) value of the Watershed was found on the bases of texture; % silt, % very fine sand, % sand, % organic matter, soil structure, and permeability rate of the soil in the watershed. Based result of soil physico-chemical properties in the watershed obtained from laboratory, the soil erodibility factor map of the Watershed was resulted ranging from 0.315-ton ha h ha^{-1} MJ^{-1} mm^{-1} to-0.101-ton ha h ha^{-1} MJ^{-1} mm^{-1}.

By applying similar approach (Jothimani et al., 2022) calculated K factor value ranging from 0.2 – 0.36 tons/ha for Kulfo river catchment in the Southern ethiopia. this value of K was somewhat larger than our estimated value of K. this was because the soils of Kulfo river catchment behave differently and are more vulnerable to erosion than that of Diko watershed. The lowest soil erodibility factor was obtained in vertic Cambisol and the highest soil erodibility factor was found Eutric Cambisol respectively (Figure 10 below). The upper part of the watershed had more erodible soil than the middle and lower part.

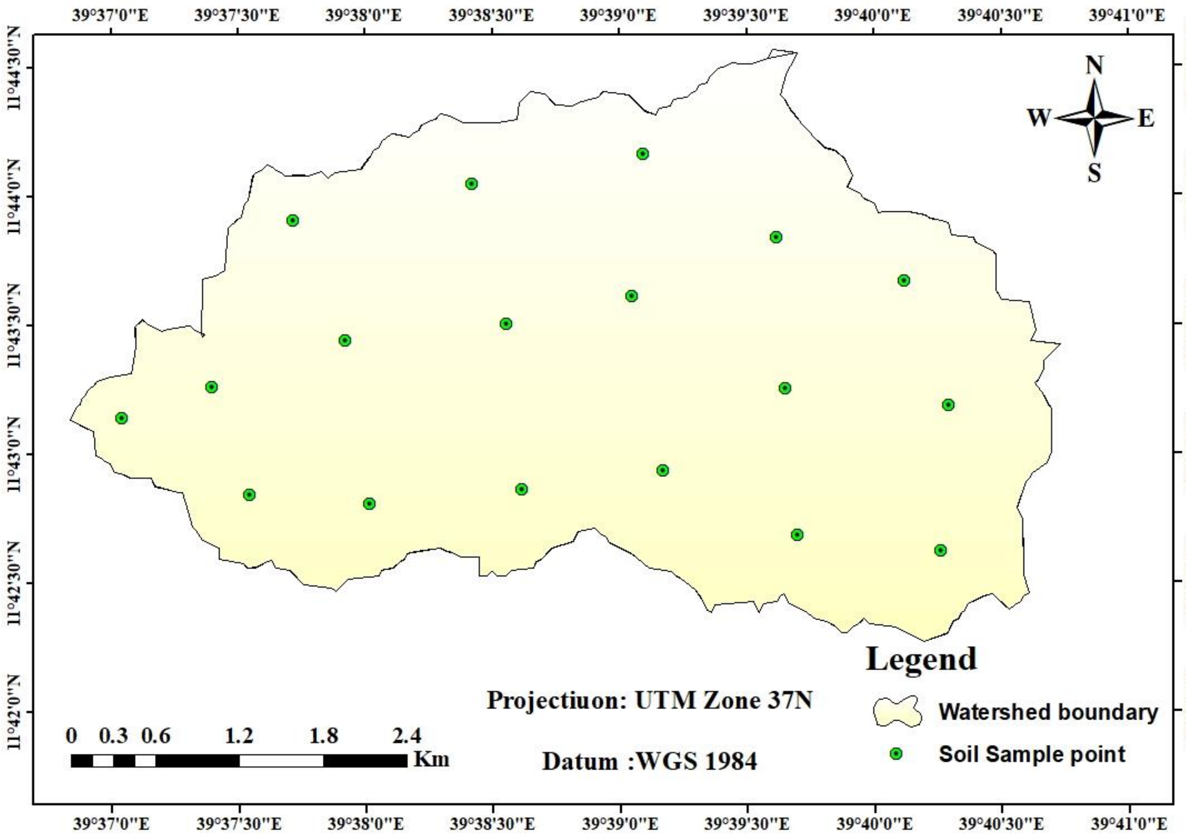

Figure 9: Distribution map of soil sampling points

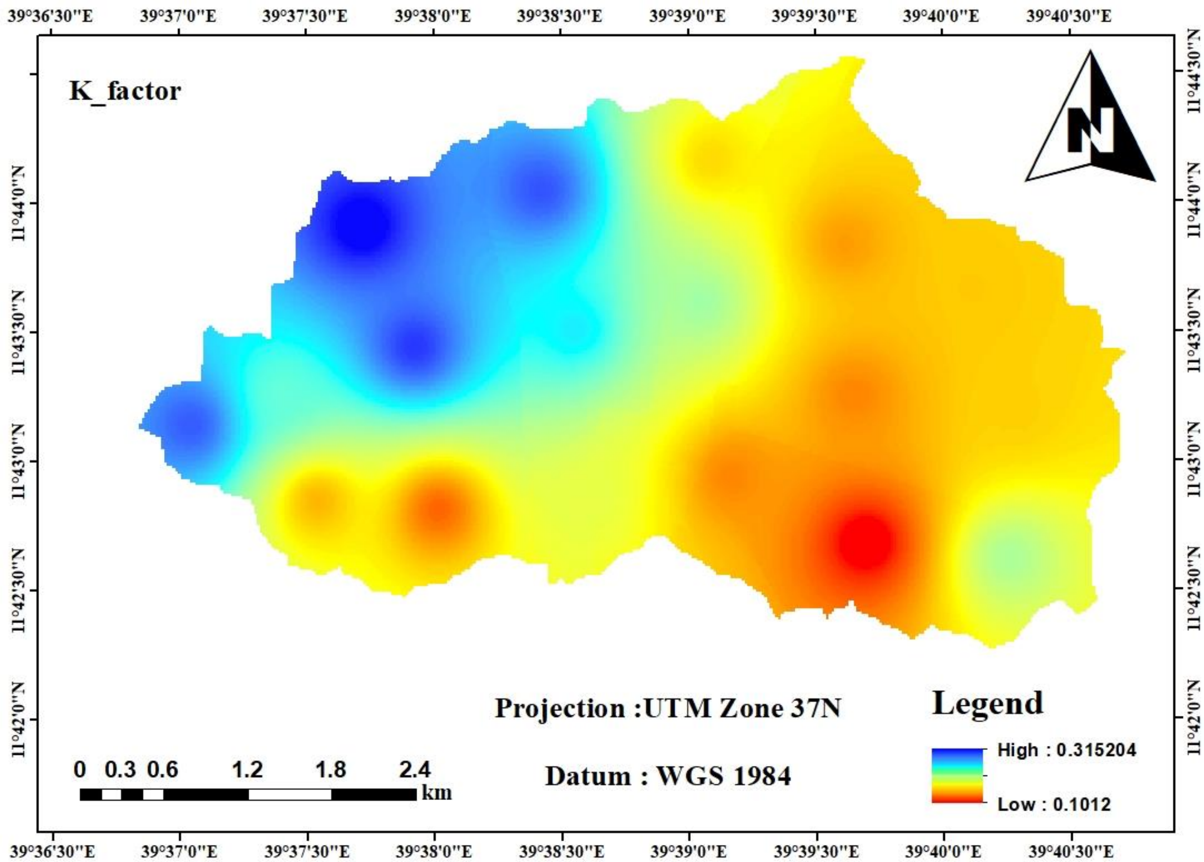

Figure 10: Spatial distribution of soil erodibility map

Table 4: Major Soil type in the Diko Watershed

Soil type	Mjor soil Type	Percent	Area_ha	Area_Km
Eutric Cambisols	Cambisols	31.80	606.42	6.06
Vertic Cambisols	Cambisols	19.38	369.61	3.69
Eutric Regosols	Regosols	40.78	777.64	7.77
Lithosols	Lithosols	8.023	152.98	1.52

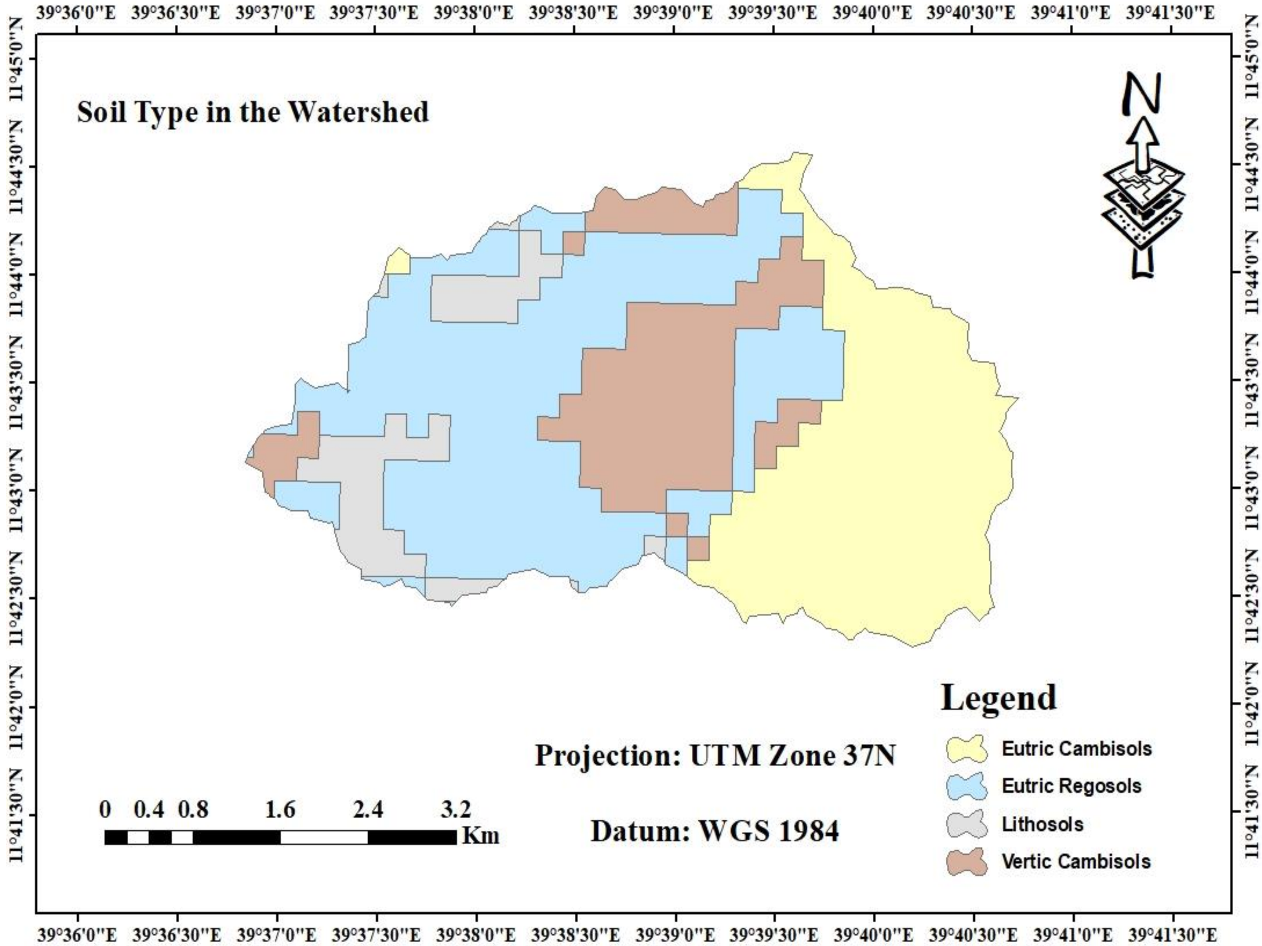

Figure 11: Soil Type in the Watershed

4.5.3. Topographic (LS) Factor

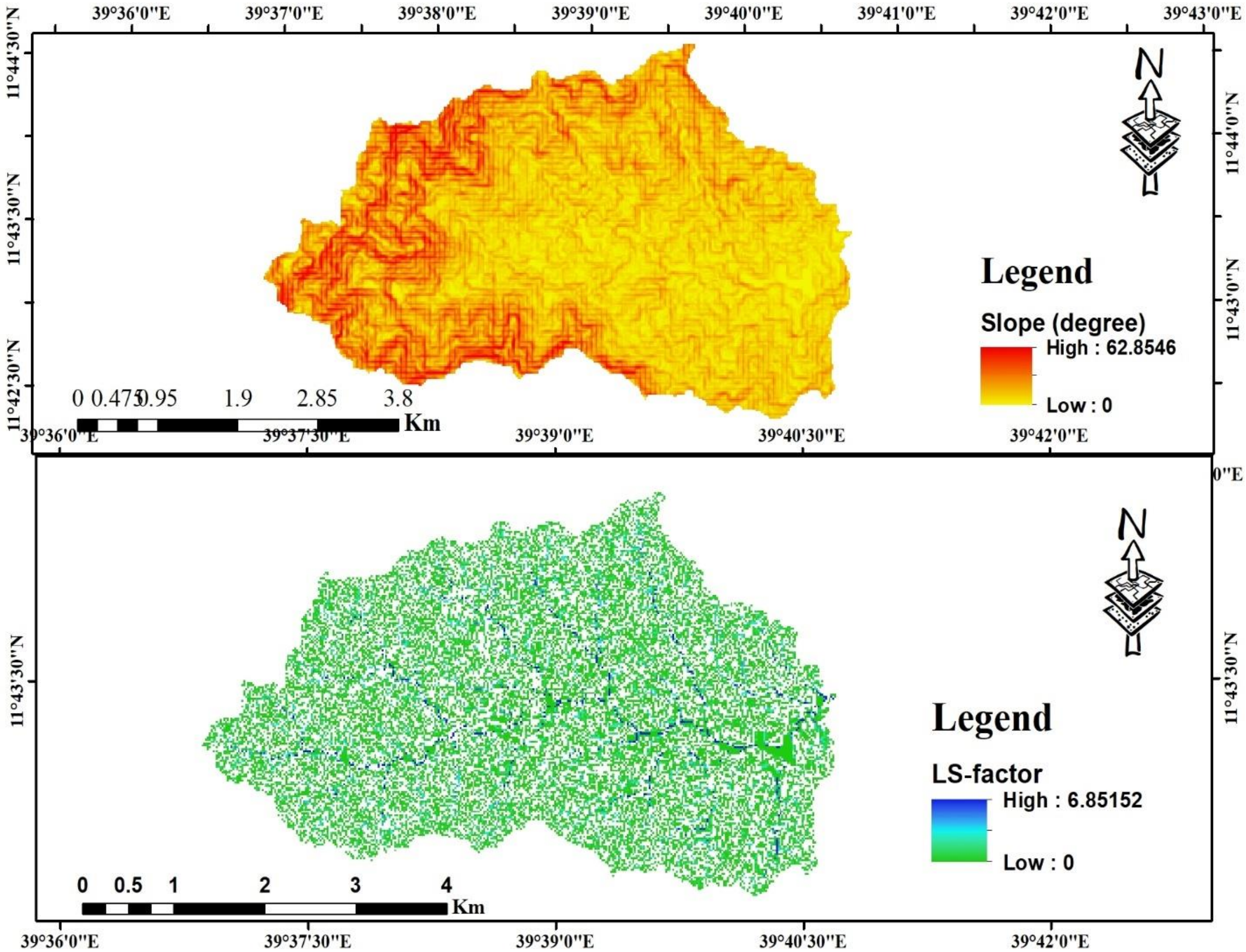

Figure 12. Slope class of Diko watershed

Topographical factor constitutes two factors which are slope length (L) and slope steepness (S). L-factor is the effect of slope length on erosion and S-factor represents the effect of slope steepness on soil erosion. The resulted combined topographic effect (LS-factor) was in the range of 0 to 6.85. The greater the LS-factor, the greater the area's sensitivity to water-induced soil erosion, that is nature of areas with steep slopes and high elevation. The areas with a gentle slope have low LS values, which indicate that these areas are less susceptible to erosion. This is in line with studies by Gelagay and Minale (2016), Yadeta et al. (2021) and Dawit et al. (2022), who found that the LS factor had a significant influence on soil loss in the watershed's steeper areas. The highest value was at the boundaries and near the upper end of the watershed which had high elevation and the lowest value was at the middle or bottom and outlet of the watershed (Figure 12).

The FAO (2006) guideline was used to evaluate the distribution of slope classes and to reclassify the slope of the watershed. Accordingly, from the total watershed area, about 95.37% landmass coverage lies between level and gentle slope (0 to 5%). The remaining 4.63% of the study area is categorized under sloping to very steep slope terrain (Table 5).

Table 5: Slope in Degree of Watershed

Slope in Degree	Area (Ha)	Slope Class
0-1	12.769	Level Slope
1-5	309.73	Gentle Slope
5-10	570.64	Sloping
10-15	361.73	Strongly Sloping
15-30	467.46	Moderatly steep
30-60	176.89	Steep
> 60	6.228	Very Steep
Total	**1906**	

4.5.4. Land use/land cover (C) factor

Land use land cover of the watershed was classified into four major land use classes; crop land, Range land, Tree and Buil up area. The percentage of areas include for Crop land (60.88 %), Range land (22.90%), Built up area (5.904%), Tree (10.30%) and grazing land (9.95%). Crop land was found to be the dominant type of land use classified which covers about 60.88 % of the total study area, followed by Range land while the least classified was built up area land which accounts for 5.90% (Table5 and Figure 12)

Table 6: Land use land cover and their area coverage of Diko watershed

LuLc_Type	**area_ha**	**area_km**	**Percent**
Built up area	112.57	1.125	5.904
Range land	436.74	4.367	22.90
Tree	196.51	1.965	10.30
Crop land	1160.77	11.60	60.88

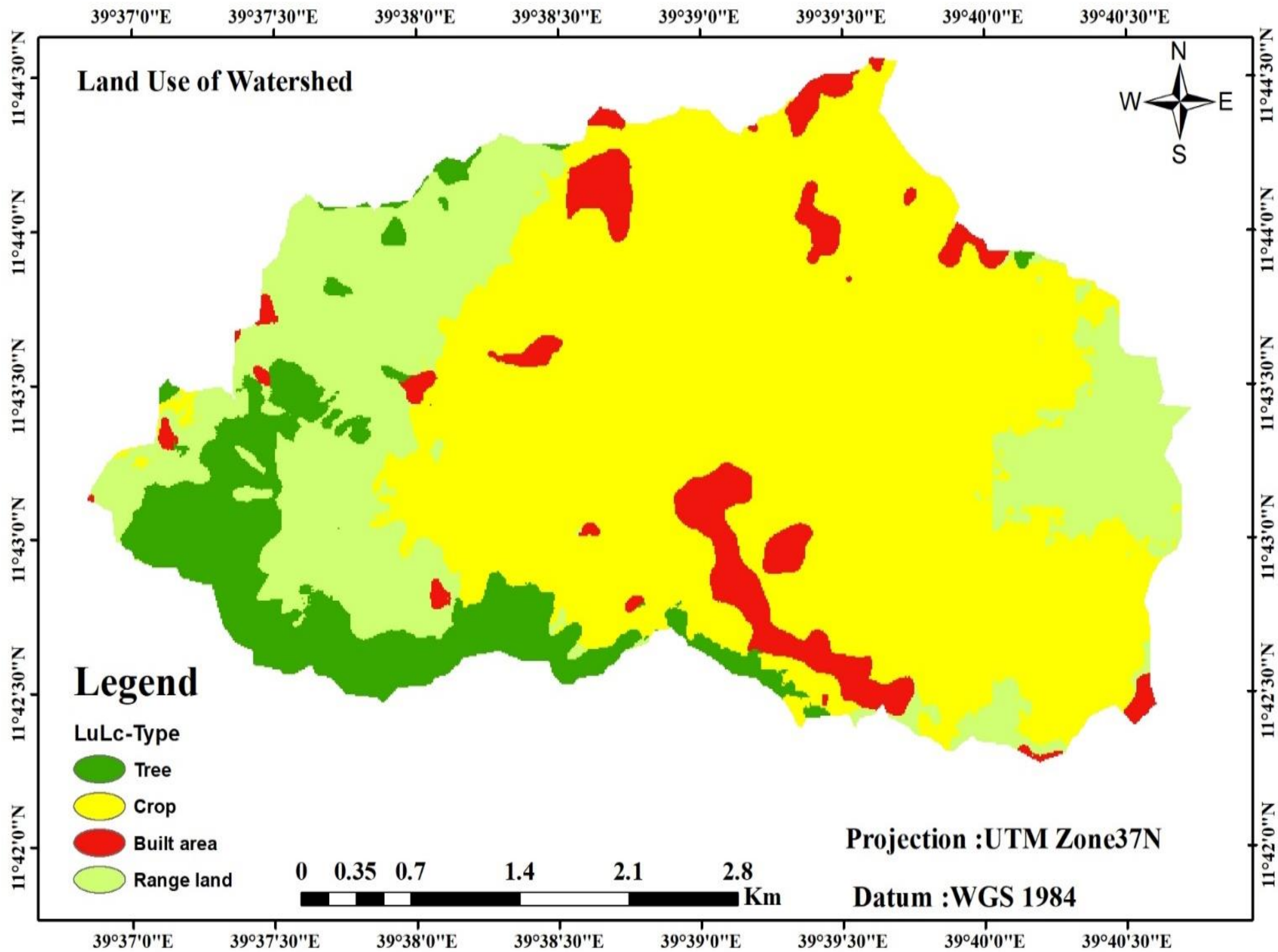

Figure 13: Spatial distribution of LULC of Diko watershed

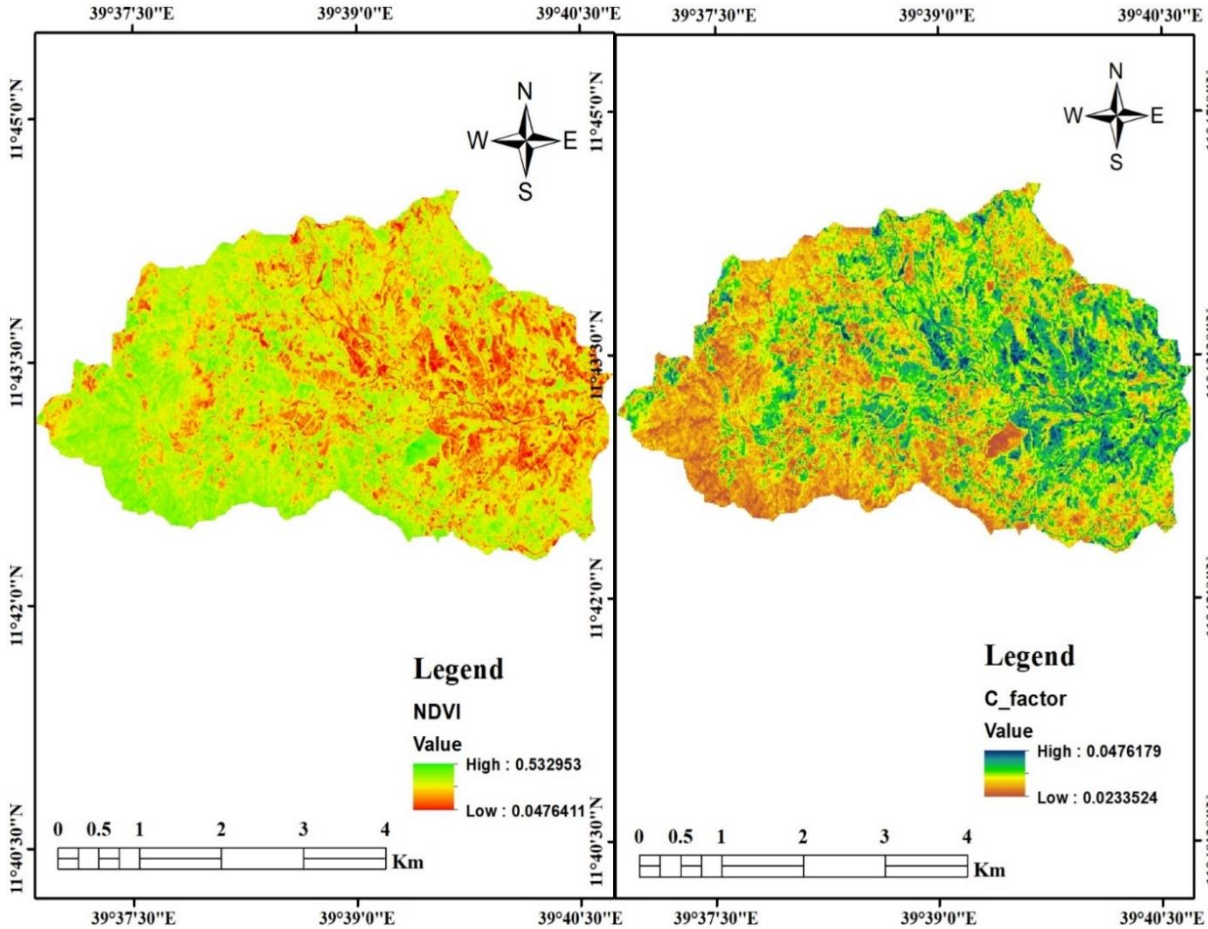

Figure 14: Spatial distribution of land cover (C) factor map

the C-factor value ranges from 0 to 1, with a value close to 0 indicates lower soil erosion vulnerability and more effective conservation efforts while a value approaching to1 infers no conservation efforts, and that area is extremely vulnerable to soil erosion (Jothimani et al., 2022).only 10.30% (196.51ha) of the watershed covered by tree the remaining 89.7% (1709.5 ha) of the watershed is covered by other LULC types including built up area , range land and Crop land. the C factor for the studied study area was calculated by using eq. (6). accordingly, the C-factor value for the watershed varied between 0.023 and 0.047 (Figure 14). the higher the C-factor value the more is the vulnerability of the soil to erosion. large C factor value corresponded to areas of bare soils and crop lands whereas small C value corresponded to areas covered by scattered shrub land, natural forest, and plantation forest. the same procedure was followed by the same procedure was followed by Degfie et al. (2024).

to estimate the C factor value for Upper Meki sub catchment, rift valley sub-basin, Ethiopia , ranging from 0.001 to 0.5 this value implies that compared to Diko watershed less conservation measures are made in Upper Meki sub catchment are highly susceptible to erosion.

4.5.4.1. Accuracy Assessment

Sentinel 2A image classification accuracy assessment resulted a total of 106 points (locations) were Collected 70 point using Garmin GPS72 from field and 36 points from Google Earth Pro in the classified image of the study area. Table 7 shows the relationship between ground truth data and the corresponding classified data obtained through error matrix report. The overall classification accuracy was resulted 96.22% and the overall Keppa coefficient was 0. 94.

These values were indicated image classification was better since, both 0.96 and 0.94 were approaching to 1(one) rather than to 0 (zero). The columns of the confusion matrix showed to which classes the pixels were in the validation set belong (ground truth) and the rows showed to which classes the image pixels have been assigned to in the image. The diagonal showed the pixels that are classified correctly. Pixels that are not assigned to the proper class do not occur in the diagonal and give an indication of the confusion between the different land-cover classes in the class assignment.

Table 7: Error matrix of LULC classification

	Tree	Range Land	Crop land	Built Up	Total (User)
Tree	22	0	1	0	23
Range Land	1	17	1	0	19
Crop Land	0	0	46	0	46
Built Up	0	0	1	17	18
Total (Producer)	23	17	49	17	106

$$\text{Overall Accuracy} = \frac{\text{Total Number of Correctly Classified Pixels (Diagonal)}}{\text{Total Number of Refferences Pixels}} \text{x100}$$

$$= \frac{102}{106} \text{x100}$$

$$= 96.22\%$$

$$\text{User Accuracy} = \frac{\text{Number of Correctly Classified Pixels in each Catagory}}{\text{Total Number of Classified Pixels in that Catogory (Row Total)}} \text{x100}$$

Tree = $\frac{22}{23} \times 100$ = 95.6%

Range Land = $\frac{17}{19} \times 100$ = 89.47%

Crop Land = $\frac{46}{46} \times 100$ = 100%

Built up =$\frac{17}{18} \times 100$ = 94.44%

Producer Accuracy

$$= \frac{\text{Number of Correctly Classified Pixels in each Catagory}}{\text{Total Number of Classified Pixels in that Catogory (ColumnTotal)}} \text{x100}$$

Tree = $\frac{22}{23} \times 100$ = 95.6%

Range Land = $\frac{17}{17} \times 100$ = 100%

Crop Land = $\frac{46}{49} \times 100$ = 93.87%

Built up =$\frac{17}{17} \times 100$ = 100%

Keppa Coefficient (T) =$\frac{(TS*TCS-\sum(\text{Column Total}*\text{Row Total})}{TS^2-\sum(\text{Column Total}*\text{Row Total}} \times 100$

Where: TS=Total Sample

TCS =Total Corrected Sample

Keppa Coefficient = $\frac{106*102-\sum(23*23)+(17*19)+(49*46)+(17*18)}{(106)^2-\sum(23*23)+(17*19)+(49*46)+(17*18)} \times 100$

$= \frac{10812-3412}{11236-3412} \times 100$

$= \frac{7400}{7824} \times 100$

= 94.58%

4.5.5. Supportive conservation practice (P) factor

The only conservation support practice in the study area was contour farming, ploughing along the contour. So that a corresponding P-value of contouring based on slopes given by Shin (1999) was assigned to cultivated lands and values given by Wischmer and Smith, (1978) for other land uses. Accordingly, the estimated values of P factor were in the range of 0.1 to 1.0 (Figure 15).

The P-factor was high in all types of land uses, except in low slopes of cultivated land that could reduce by the effect of contouring.

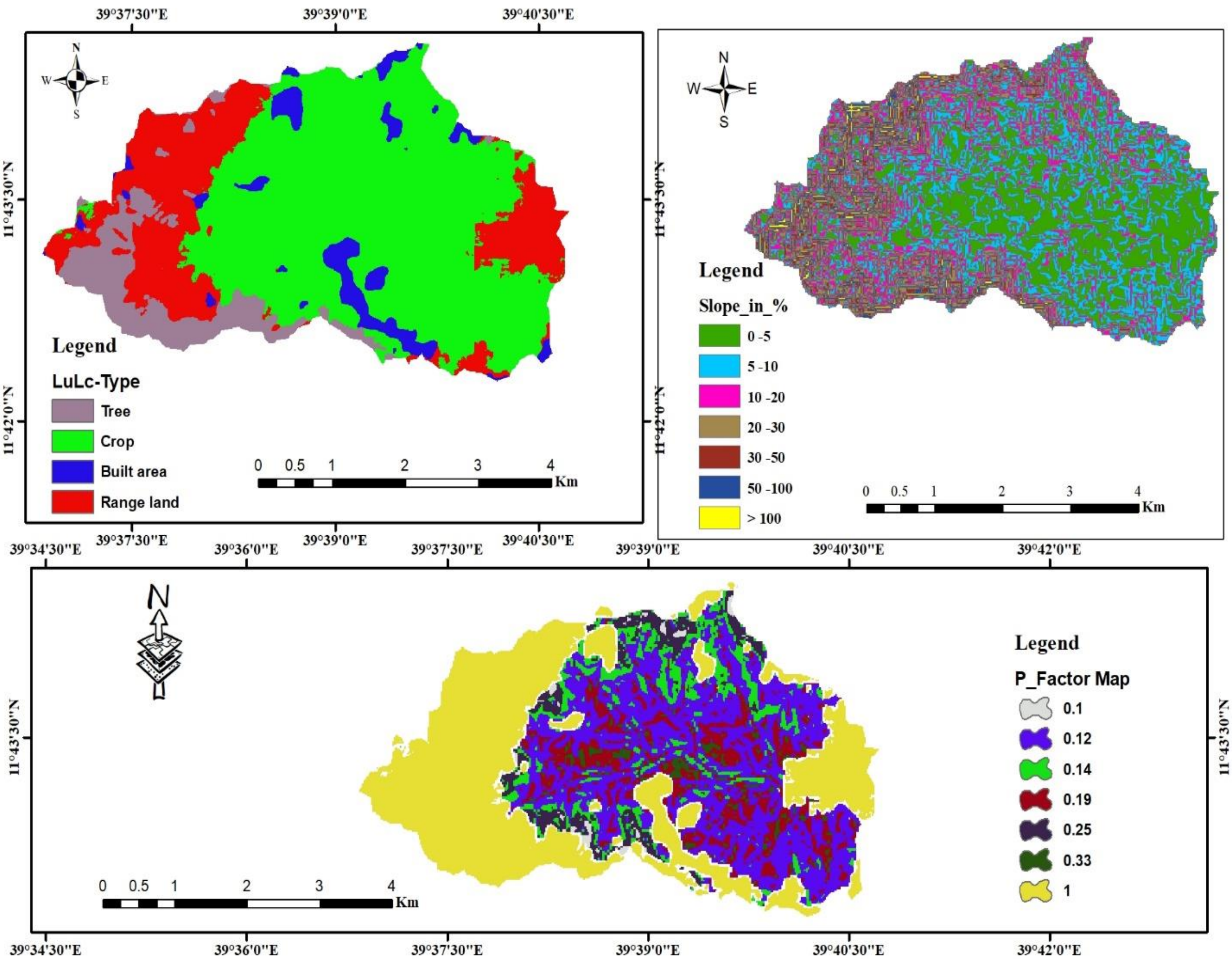

Figure 15: Spatial distribution of conservation practice factor map

4.6. Estimated soil loss by RUSLE Model

After completing data input procedure and preparation of the appropriate maps of RUSLE factors with 30 m x 30 m pixel size raster data layers, they were combined and analyzed in raster calculator of ArcGIS10.8.2, to provide estimate of the annual soil loss map. The computed annual soil loss of the watershed was found in a range of 0 to 154.409-ton ha^{-1} $year^{-1}$ (Figure 16). Thus, with mean soil loss of 3.06-ton ha^{-1} $year^{-1}$.

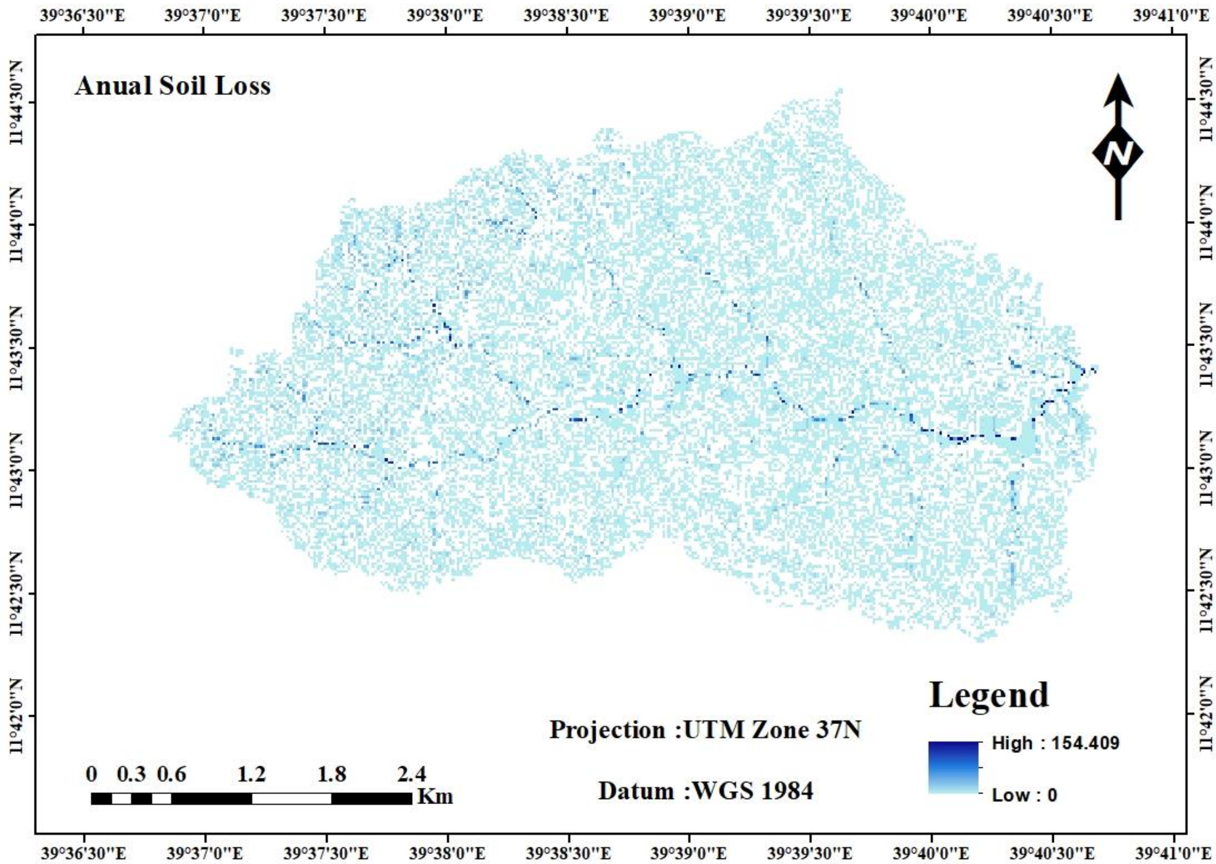

Figure 16: spatial distribution of soil loss map

The annual soil loss from Diko watershed ranged from 0 in plain areas to 154 t ha^{-1} yr^{-1} in very degraded sloping regions and at specific spots of steep slopes of the watershed (Figure 16). The total soil loss in the study area was estimated to be 54439.17 metric tons per year from the total area of 1906 ha. The result shows larger spatial variation of soil loss over the watershed, mainly caused by the difference in soil, rainfall, slope, land cover and land management.

The entire watershed loses a total of about Fifty-Four Thousand Four Hundred Thirty-nine tons, with a mean soil loss rate of 3.06 t ha^{-1} yr^{-1} annually. As observed from the mean value, the largest soil loss rate exceeding 3.06t ha^{-1} yr^{-1} accounts for only a small amount of the total soil loss, and this huge rate comes from a small proportion of watershed area. According to the assessments of several scholars, these results fall within the range of tolerable soil loss that can be replenished by natural soil formation (Morgan, 2005). Soil loss tolerance (SLT) denotes the maximum allowable soil loss that will sustain an economic and a high level of productivity (FAO and UNEP, 1984; Brhane and Kirubel, 2009).

Soil loss tolerance refers to the maximum soil loss that can occur from a given land without leading to degradation of the soil (Hurni, 1983). Inappropriate land use accelerates rate of soil erosion beyond the tolerable limit, which is a threshold value assumed to be equivalent to rate of natural soil formation (Kraushaar et al., 2014). This value of soil loss is varying for different soils found in different geographic locations.

Hurni (1985) reported the tolerable soil loss level for various ecological zones of Ethiopia from 2-16 t ha^{-1} yr^{-1} . According to Renard et al. (1997), the normal SLT values range from 5 to 11 t ha^{-1} yr^{-1}. Generally, an acceptable mean tolerable soil loss is 11 t $ha^{-1}yr^{-1}$ depending on the susceptibility of the soil to erosion (Wischmeier and Smith, 1978). From the current result (3.06 t ha^{-1} yr^{-1}) can be observed that rate of soil erosion in the study area was within the tolerable limit according to Hurni (1985), but lower than that of the lower limit given by Renard et al. (1997). For watershed sustainability, soil conservation measures should be implemented, even though the result of average annual soil loss is within the normal range of SLT values.

4.6.1. Comparison of Soil Loss Estimates with Other Assessments

The result of this study seems to be realistic, as compared to previous research studies mentioned below. For instance, the current result agrees with similar findings reported by Bekele and Gemi (2020). the average annual soil loss rate in Dijo watershed was estimated to be 2.2 ton ha^{-1} yr,$^{-1}$ A total of 456,415.60 ton of soil has been lost annually and Wondrade (2019) reported that the mean annual soil loss of a study area about 4.27 t ha^{-1} yr^{-1} in the Karesa Watershed, South West Ethiopia. the mean annual soil loss in anka shashara watershed, southern Ethiopia was estimated 15.22t ha^{-1} yr^{-1} (Bekele, 2021).

In Welmel Catchments of Ganale-Dewa River Basin Bale Lowland South Eastern Ethiopia With an average soil erosion rate of 32 t ha^{-1} yr^{-1}, an estimated 546,769.92 tone of top fertile soil have been lost from the watershed annually (Defar et al., 2024). The annual soil loss (t ha^{-1} yr^{-1}) was estimated using pixel-by-pixel ArcGIS map overlays to ensure the accuracy of RULSE output. The model output revealed on average 12.52 (t ha^{-1} yr^{-1}) soils was lost from Gilgel Gibe-I Catchment, South West Ethiopia through sheet and rill erosion (Gemeda Wedajo et al., 2022).

Contrary to the findings of this study, other scholars reported a very high mean soil loss rates. For instance, the average annual soil loss of the Ayigebire watershed, North Shewa zone of Amhara region, Ethiopia was found to be 47 t ha^{-1} yr^{-1} (Getachew Abebe & Woldemariam, 2024) and The average annual soil loss in Finca'aa, catchment's oromiya, western Ethiopia was 33.3 t ha^{-1} yr^{-1} (Kebede & Fufa, 2023). at watershed level in the upper beles, Ethiopia the estimated mean annual gross soil loss from the entire watershed is about a 4.67million ton, with a mean soil loss rate of 13.2 t ha^{-1} yr^{-1} (Kebede et al., 2021).

In chereti watershed, northeastern Ethiopia the annual soil loss rate of the watershed ranged up to 187.47 t ha^{-1} yr^{-1} in steep slope areas with a mean annual soil loss of 38.7 t ha^{-1} yr^{-1}, and the entire watershed lost a total of about 487 057.7 tons of soil annually (Negese et al., 2021). the total annual potential soil loss from the upper Meki sub-catchment, rift valley sub-basin, Ethiopia was about 2,756,540 tons per year with a mean estimated soil loss rate of 28.12 t ha^{-1} yr^{-1} and the total actual annual soil loss is 492929 tons with an estimated erosion rate of 37.05 t ha^{-1} yr^{-1} (Teku et al., 2024). in the Sululta catchment, Abbay Basin, Ethiopia average annual soil loss rate was found to be 5.03 tons/ha/year (Tullu, 2024).According to research by several scholars, soil erosion affects many parts of Ethiopian; however quantitative estimations of soil loss were still uncertain and unreliable. The likely reasons could be the input data, variation in time and assessment scales, lack of correspondence in the methodologies used and heterogeneity of the study area. As a result, extrapolations and estimations of soil loss rates can only provide a general idea of an average order of magnitude. This is because erosion is a process with great variation both in time and space (Yadeta et al., 2021).

4.7. Prioritization of Sub watershed for Soil Conservation Planning

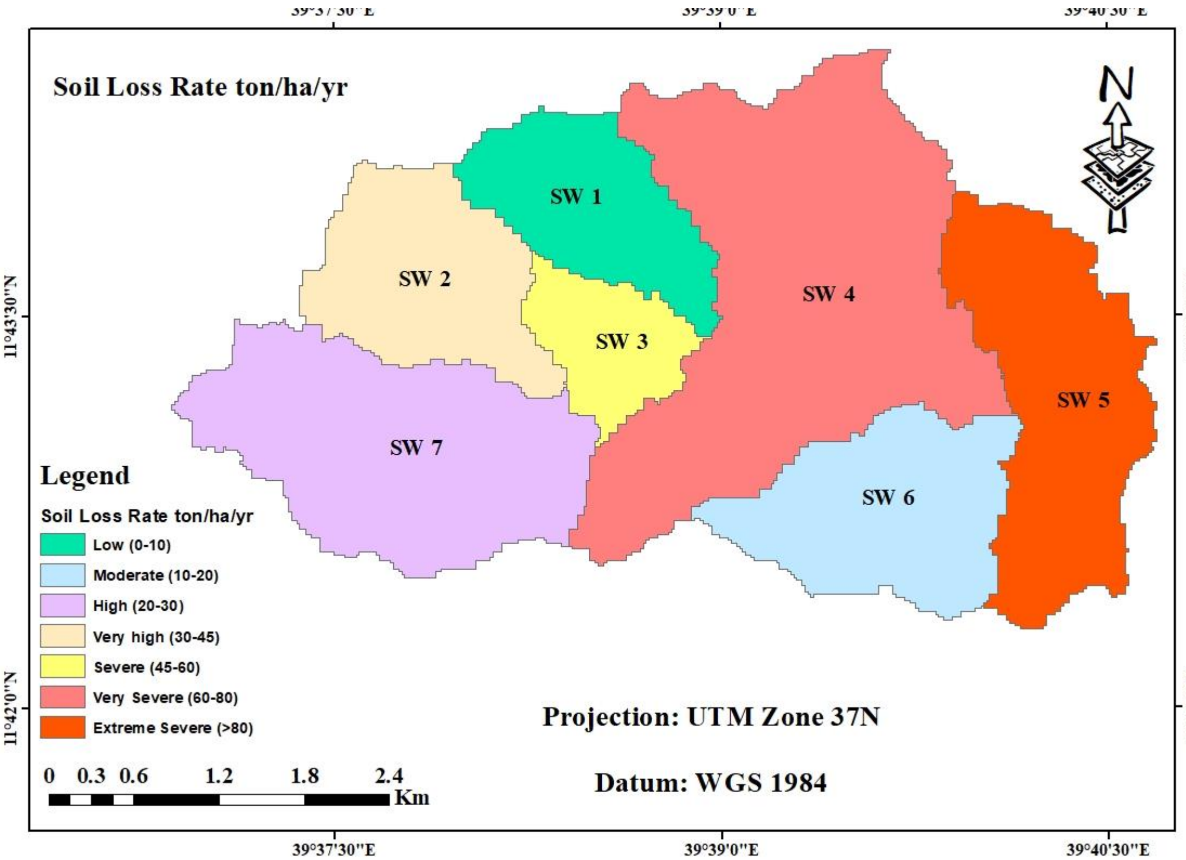

Figure 17: Soil loss rate of watershed

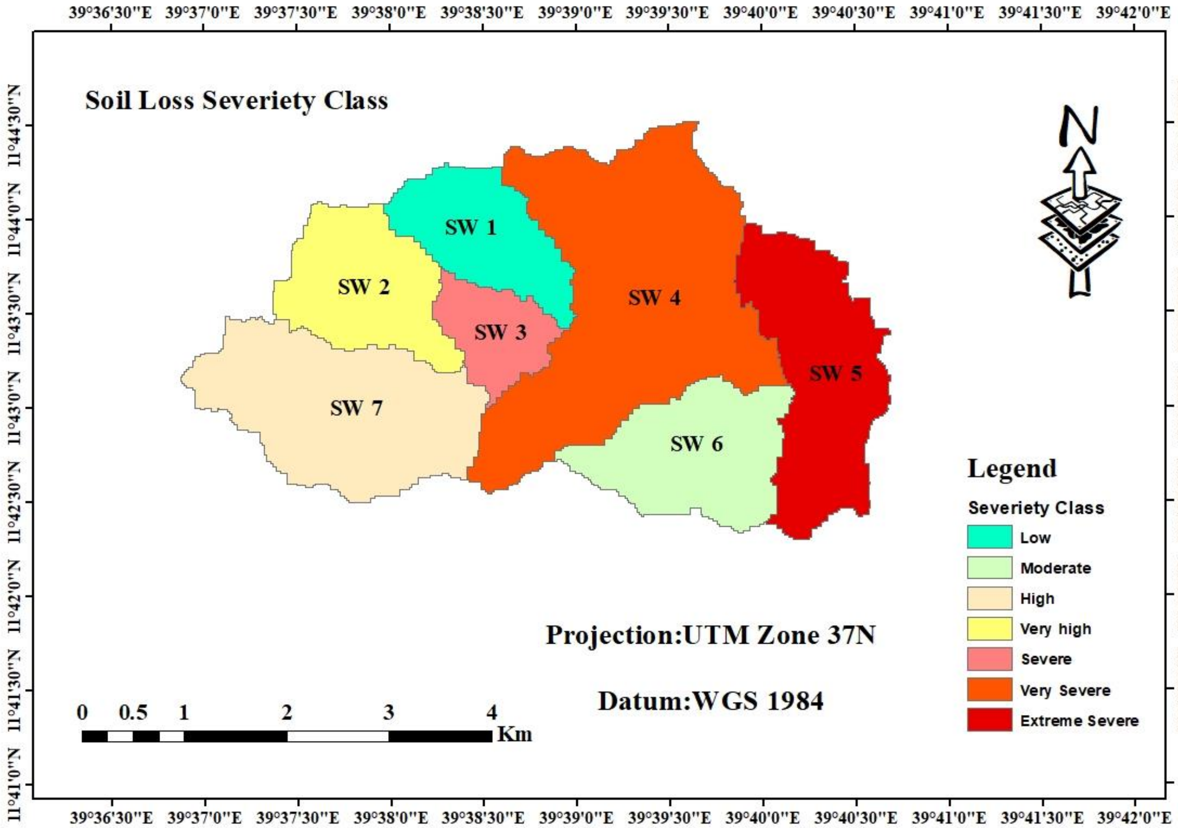

Figure 18: Spatial distribution of Soil loss severity class

The soil loss severity in the watershed were categorized as (0 to 10) ton ha^{-1} yr^{-1} as low, (10 to 20) ton ha^{-1} $year^{-1}$, as moderate (20 to 30) ton ha^{-1} yr^{-1} as high, (30 to 45) ton ha^{-1} yr^{-1} as very high, (45 to 60) ton ha^{-1} yr^{-1} as severe,(60 to 80) ton ha^{-1} yr^{-1} as very severe, and greater than 80 ton ha^{-1} yr^{-1} as extreme (FAO, 1986).

Accordingly, the watershed area was covered, 49.24 % low, 19.03% moderate, 8.147% high, 6.045 % very high, 6.081 % severe 5.89 % very severe and 5.55 % extremely severe (Table 4). It was obtained that about 938.74 ha area (49.24 %) of the watershed was under low soil loss class while 968 ha (50.76%) of the watershed was under moderate to extremely severe soil loss class. Generally, the 50.76% of the watershed area have soil loss greater than tolerable level, which is 11ton ha^{-1} yr^{-1} The soil loss severity classes map were presented as low, moderate, high, very high, severe very severe and extremely severe (Figure 18). Low soil loss was mostly found in the areas of minimum slope and also in areas of better land covers were located while moderate to extremely severe soil loss was found in areas of high slope and also poor land covers were located (i.e. cultivated land and degraded grazing land).

Table 8: Soil loss rate

Soil_loss rate(ton $ha^{-1}yr^{-1}$)	**Severiety class**	**Area (ha)**	**Area (%)**	**Conservation priority**
0-10	Low	938.74	49.24	7^{th}
10-20	Moderate	362.9	19.03	6^{th}
20-30	High	155.32	8.147	5^{th}
30-45	Very high	115.25	6.045	4^{th}
45-60	Severe	115.93	6.081	3^{rd}
60-80	Very severe	112.32	5.89	2^{nd}
80-154	Extremely severe	105.95	5.55	1^{st}

Table 9:Sub-watershed priority class based on soil loss rate

Soil_loss rate(ton $ha^{-1}yr^{-1}$)	**Severiety class**	**Priority Class**
0-10	Low	SW1
10-20	Moderate	SW6
20-30	High	SW7
30-45	Very high	SW2
45-60	Severe	SW3
60-80	Very severe	SW4
80-154	Extremely severe	SW5

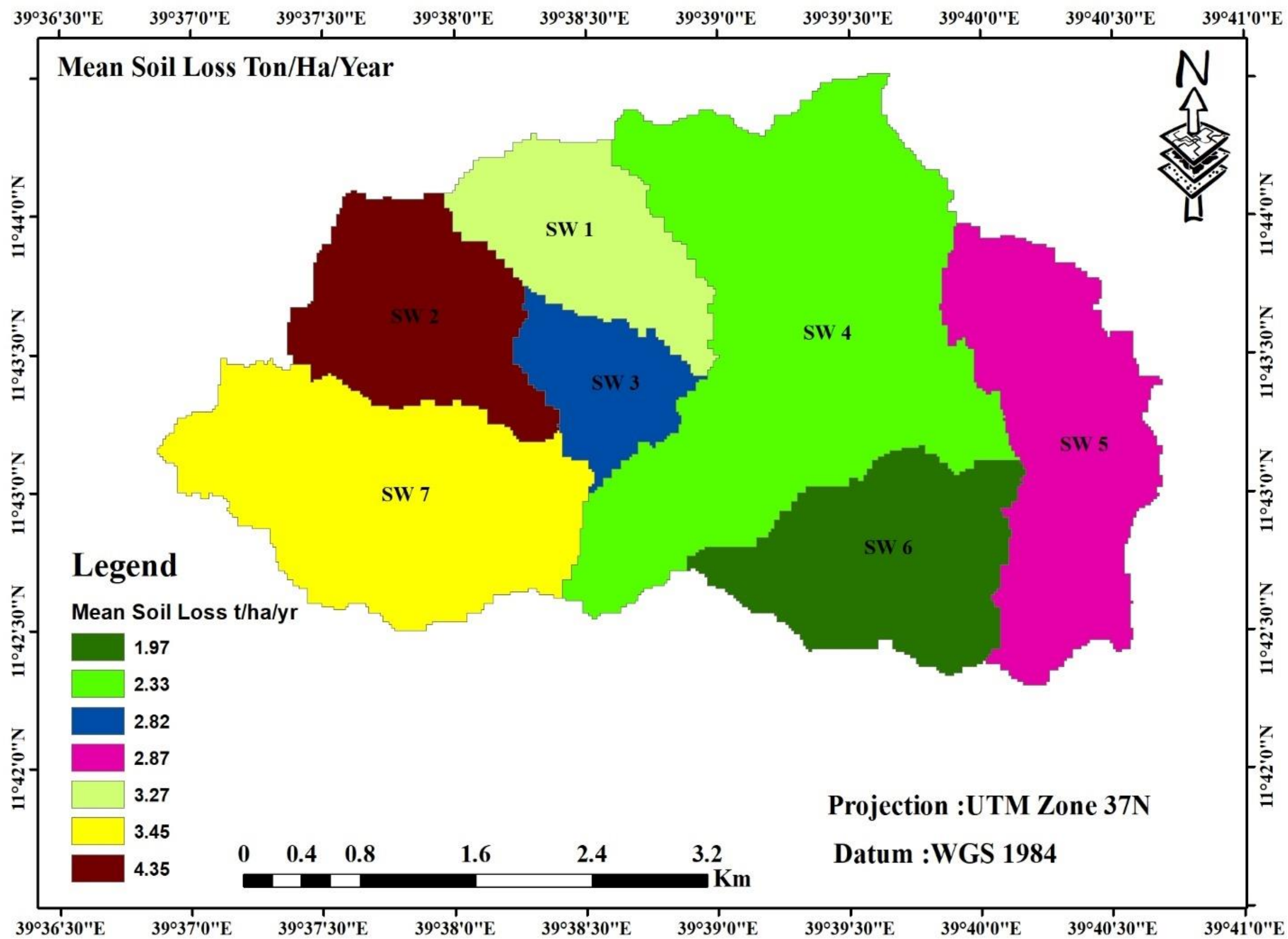

Figure 19: Annual Mean Soil Loss

Sub_watershed	Area (ha)	Percent	Mean Soil Loss t ha^{-1}yr^{-1}	Soil Loss ton ha^{-1}	Based on Mean soil loss
SW 1	165.88	8.53	3.27	4455.84	3rd
SW 2	198.59	10.30	4.35	7645.69	1st
SW 3	101.96	5.00	2.82	2423.33	5th
SW 4	581.47	31.13	2.33	10903.33	6th
SW 5	285.79	15.05	2.87	7956.24	4th
SW 6	223.68	11.56	1.97	2871.41	7th
SW 7	348.98	18.43	3.45	10227.09	2nd
Total	**1906**	**100**	**21.06**	**54439.17**	

Table 10: Prioritized sub watersheds for conservation planning purpose

Based on mean soil loss obtained in the sub watersheds were ranked for conservation planning (Table 10). Accordingly, SW2 has got rank 1 based on mean soil loss. Generally, the important sub watershed prioritization was when erosion risk area coverage (area affected and could out of production because of the soil erosion continuum) had been considered. So, the priority was; SW2 to SW6 had got the first and last rank respectively.

4.8. Sub-watershed that Needs Prior Soil Conservation Measure

Based on their mean soil loss, the sub-watershed that comes first was given the top priority for conservation measures to reduce the soil loss.

Table 11: Slope class and Mean soil loss

Slope (Degree)	**Slope Class**	**Arean (ha)**	**Max**	**Mean Soil Loss(t $ha^{-1}yr^{-1}$)**	**Soil loss (ton ha^{-1})**
0 -5	Level Slope	120.91	32.14	2.6	3092.3
5 -10	Gentele Slope	166.33	35.6	2.57	3166.7
10 -15	Strongle Sloping	242.56	49.7	2.28	4791.4
15 -20	Sloping	371.65	63.6	1.8	7455.7
20 -30	Moderately steep	507.17	135.9	1.89	13579.7
30 -40	Steep	440.87	154.4	3.01	13559.2
40 -62	Very steep	56.74	22.9	4.38	1069.6

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5. 1. Summary and Conclusion

Soil erosion is a major worldwide environmental issue. One of the biggest environmental issues facing Ethiopia has been soil erosion and nutrient loss. The reduction of land cover and steepness of the slope are the main causes of soil erosion, which can worsen land degradation in the watershed. The majority of processes are the outcome of interactions between manmade and natural elements. Population increase is the main element influencing changes in land usage in Ethiopia, as it usually is in developing nations.

In the Diko watershed and other micro watersheds of the A wash Basin, the issue of soil erosion has gotten worse. Erosion hotspot locations should be identified for improved planning of soil and water conservation in the watershed in order to address the issue. When combined with the Universal Soil Loss Equation, remote sensing and GIS become useful tools for estimating the rate of soil loss with in a watershed.

The parameters used in RUSLE were rainfall erosivity, soil erodibility, topographic factor, land use land cover factor and supportive conservation practice factor with the range 550.364 MJ mm ha^{-1} hr^{-1} yr^{-1} to 559.293 MJ mm ha^{-1} hr^{-1} yr^{-1}, 0.10ton ha h ha^{-1} MJ^{-1} $mm^{-1}$to 0.31ton ha h ha^{-1} MJ^{-1} mm^{-1}, 0 to 6.851, 0.023 to 0.0475 and 0.1 T1o 1.0 respectively. The RUSLE factors map was prepared to 30 m x 30 m pixel size raster data layer and combined raster calculator of ArcGIS10. 8.2 and annual soil loss obtained in the watershed was in the range of 0 ton ha^{-1} yr^{-1} to 154.409 ton ha^{-1} yr^{-1} with mean soil loss of 3.06 ton ha^{-1} yr^{-1}. The mean soil loss obtained in the watershed was less than the tolerable soil loss level of 11-ton ha^{-1} yr^{-1}. About 49.24 % of the watershed have a soil loss less than tolerable erosion level and about 50.76 % of the watershed had a soil loss greater than tolerable soil loss level. 19.03 %, 8.147%, 6.045%, 6.081%, 5.89%, and 5.55% of the watershed have soil loss severity class of moderate, high, very high, severe, very severe and extremely severe respectively. Based on mean annual soil loss were identified and prioritized for conservation planning. Accordingly, SW2, SW7, SW 1, SW 5, SW3, SW4, SW6, got 1 up to 7 priority level respectively.

5.2. Recommendations

- According to the identified erosion 'hotspot' areas (sub-watershed priorities) appropriate soil and water conservation structures should be implemented to minimize the amount of top soil removed from the watershed.
- The Sub watersheds which fall under high, very high, severe, very severe and extreme severe category need immediate attention in their order of soil erosion potential.
- Multi-disciplinary integrated watershed management approach should be conducted to develop sustainable natural resource management in the watershed for healthy ecosystem.
- Creating awareness among farmers about the impacts of land degradation and designing appropriate strategies that participate farmers in soil and water conservations strategies
- The local communities should take immediate soil conservation measures in their cultivated lands by applying different soil protective methods like mulching, Strip cropping, Terracing, contour plowing, multiple cropping and other indigenous means of soil conservation techniques.
- Because erosion through gullies was not considered in this study, further research is needed to predict actual soil loss in the watershed and recommend more intervention techniques.

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7. APPENDICES

Appendix Table1. Mean annual rainfall of twenty-two years (2002-2023)

YEAR	MERSA	SIRINKA	WOLDIA	HARA
2002	840.4	994	1388	
2003	974.1	977.2	1589.9	
2004	970.5	832.5	1634.5	
2005	724.9	1166.9	1017.1	
2006	1078.4	1100.8	1104.4	780.6
2007	1150.4	1068	992.7	881.2
2008	729.9	1066.7	864.3	821.3
2009	879.9	769.3	716.3	537.8
2010	1075.6	614.6	1299.9	1025.5
2011	1042.8	881.9	943.1	665.1
2012	1134.5	1078.8	1162.9	819.7
2013	967.1	870.8	839.5	496.3
2014	840.5	1260.7	1256.4	1022.1
2015	992.1	781	744.6	555.6
2016	965	1232.4	1112.1	1065.7
2017	1073.6	1248.5	1053.4	895.5
2018	1419.5	1342.5	1286.3	1155.3
2019	977.8	320.3	945.9	895.6
2020	965	1198.7	1231	1307.1
2021	1145.6	877.2	1240.7	536.5
2022	887.7	1219.7	940.8	756
2023	1089.9	1307	1217.8	403.5
MEAN	**996.6**	**1009.52**	**1117.34**	**812.24**

(Source: Ethiopian NMA, 2024)

Appendix Table 2. Soil permeability class for the textural classes

Texture class	Permeability Class	Permeability Rating
Clay, Silty clay	**6**	Very slow
Silty clay loam, Sandy clay	**5**	Slow
Sandy Clay loam, Clay loam	**4**	Slow to moderate
Loam, Silty loam, Silty	**3**	Moderate
Loamy sand, Sandy loam	**2**	Moderate to rapid
Sandy	**1**	Rapid

Source: (Wischmeier, et al., 1971, as quoted in Bobe (2004)

Appendix Table 3. Soil structures codes

STRUCTURE CODES	DESCRIPTIONS
1	Very fine granular
2	fine granular
3	Medium of course granular
4	Blocky, platy or massive

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ?		
	90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Appendix Table 4: Probability of rejecting Homogeneity of Annual Rainfall Stations\

No of CSAM	Depth(cm)	OC (%)	OM (%)	% Sand	% Clay	% Silt	Te. Class
1	0-20	1.6	2.76	22	46	32	Clay
2	0-20	1.5	2.59	25	44	31	Clay
3	0-20	1.35	2.33	28	42	30	Clay
4	0-20	1.65	2.84	20	40	40	Silt Clay
5	0-20	1.69	2.91	27	42	31	Clay
6	0-20	1.62	2.79	30	44	26	Clay
7	0-20	1.6	2.76	26	42	32	Clay
8	0-20	1.8	3.1	29	45	26	Clay
9	0-20	1.45	2.5	22	40	38	Clay
10	0-20	1.61	2.78	34	38	28	Clay Loam
11	0-20	1.4	2.41	32	40	28	Clay
12	0-20	3.18	5.48	35	35	30	Clay Loam
13	0-20	3.2	5.52	40	30	30	Clay Loam
14	0-20	3.2	5.52	35	41	24	Clay
15	0-20	1.55	2.67	27	32	41	Clay Loam
16	0-20	3.1	5.34	34	28	38	Clay Loam
17	0-20	3.16	5.45	19	41	40	Silt Clay
18	0-20	1.41	2.43	30	37	33	Clay Loam

Appendix Table 5: Soil laboratory Results

No	X Coordinate	Y Coordinate	LuLc type
1	571666	1296825	Crop Land
2	572021	1296545	Crop Land
3	571686	1296172	Crop Land
4	572015	1296039	Crop Land
5	572352	1295782	Crop Land
6	572430	1294965	Crop Land
7	572498	1294422	Crop Land
8	570186	1295516	Crop Land
9	570305	1295535	Crop Land
10	570507	1295440	Crop Land
11	570566	1295493	Crop Land
12	570552	1295605	Crop Land
13	570695	1295657	Crop Land
14	570859	1295733	Crop Land
15	571240	1295551	Crop Land
16	571127	1295450	Crop Land
17	571037	1295377	Crop Land
18	571155	1295383	Crop Land
19	571260	1295401	Crop Land

20	571303	1295499	Crop Land
21	571472	1295468	Crop Land
22	571281	1295711	Crop Land
23	571414	1295679	Crop Land
24	569415	1295338	Crop land
25	569454	1295476	Crop land
26	569209	1295513	Crop land
27	569833	126007	Crop land
28	569992	1296152	Crop land
29	571445	1295485	Crop land
30	571569	1295546	Crop land
31	571613	1295747	Crop land
32	571703	1295853	Crop land
33	571816	1295805	Crop land
34	571945	1295755	Crop land
35	572070	1295645	Crop land
36	572280	1295702	Crop land
37	572305	1295771	Crop land
38	572554	1295405	Crop land
39	572734	1295326	Crop land
40	572922	1295044	Crop land
41	573061	1294966	Crop land
42	573184	1294904	Crop land
43	573232	1294861	Crop land
44	573397	1294543	Crop land
45	573401	1294456	Crop land
46	573422	1294399	Crop Land
47	571406	1294408	Tree
48	571320	1294412	Tree
49	571212	1294506	Tree
50	571162	1294561	Tree
51	571002	1294606	Tree
52	570906	1294645	Tree
53	570831	1294714	Tree
54	570691	1294760	Tree
55	570716	1294878	Tree
56	570667	1294840	Tree
57	570300	1294662	Tree
58	570190	1294596	Tree
59	570135	1294635	Tree
60	570288	1294684	Tree
61	570118	1294617	Tree
62	570005	1294575	Tree
63	569960	1294723	Tree
64	570044	1294783	Tree

65	569837	1294672	Tree
66	569677	1294991	Tree
67	569718	1294834	Tree
68	569646	1294665	Tree
69	569562	1294868	Tree
70	568599	1296299	Range Land
71	568814	1296458	Range Land
72	569473	1296723	Range Land
73	568935	1295820	Range Land
74	568667	1295377	Range Land
75	573760	1295415	Range Land
76	568488	1296471	Range Land
77	568200	1296550	Range Land
78	568581	1296585	Range Land
79	568925	1296706	Range Land
80	569059	1296903	Range Land
81	569584	1297439	Range Land
82	570504	1295570	Range land
83	569565	1295343	Range land
84	568982	1295560	Range land
85	568935	1295561	Range land
86	568849	1295535	Range land
87	569108	1295680	Range land
88	570317	1296482	Range land
89	571666	1296825	Biult up
90	572021	1296545	Biult up
91	571686	1296172	Biult up
92	572015	1296039	Biult up
93	572352	1295782	Biult up
94	572430	1294965	Biult up
95	570186	1295516	Biult up
96	570507	1295440	Biult up
97	570695	1295657	Biult up
98	570859	1295733	Biult up
99	570726	1295346	Biult up
100	570072	1295422	Biult up
101	569657	1296176	Biult up
102	569601	1296196	Biult up
103	570781	1295265	Biult up
104	570599	1295109	Biult up
105	570677	1295265	Biult up
106	570682	1295308	Biult up

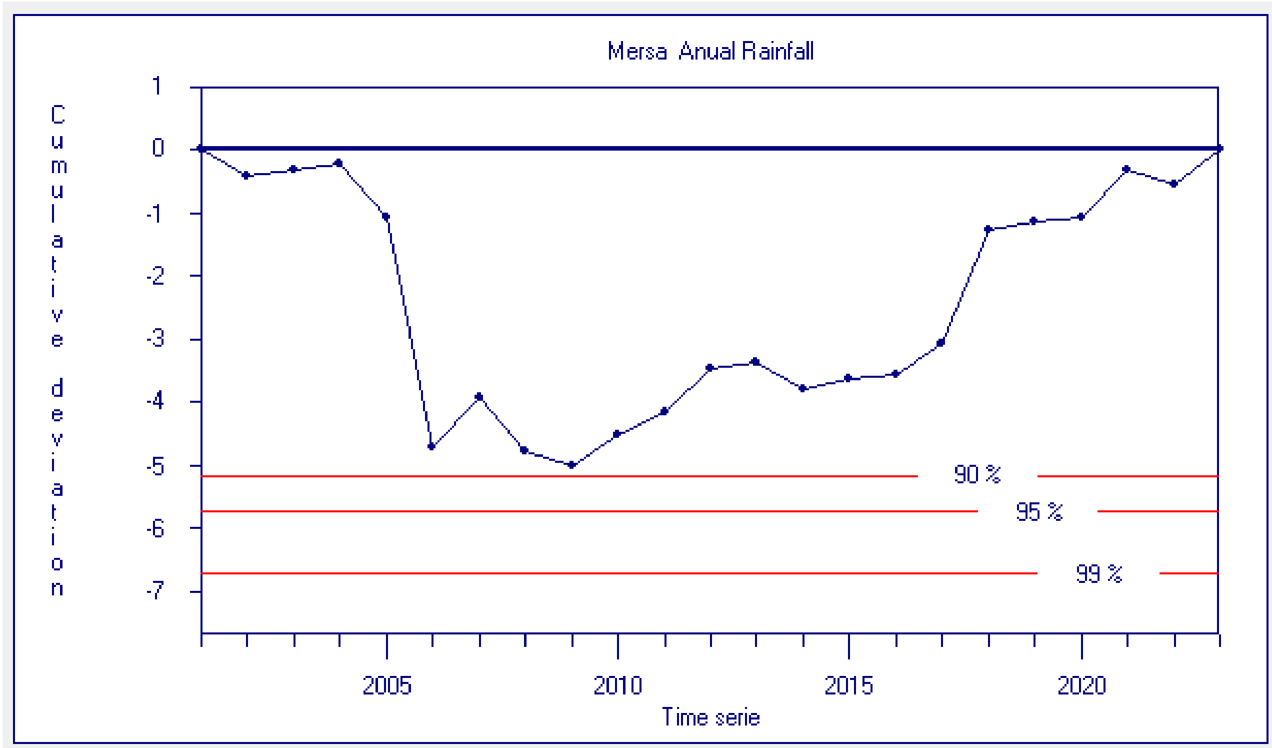
Appendix Table: 6 Ground truth data for Image Classification

Figure 1: Crop land

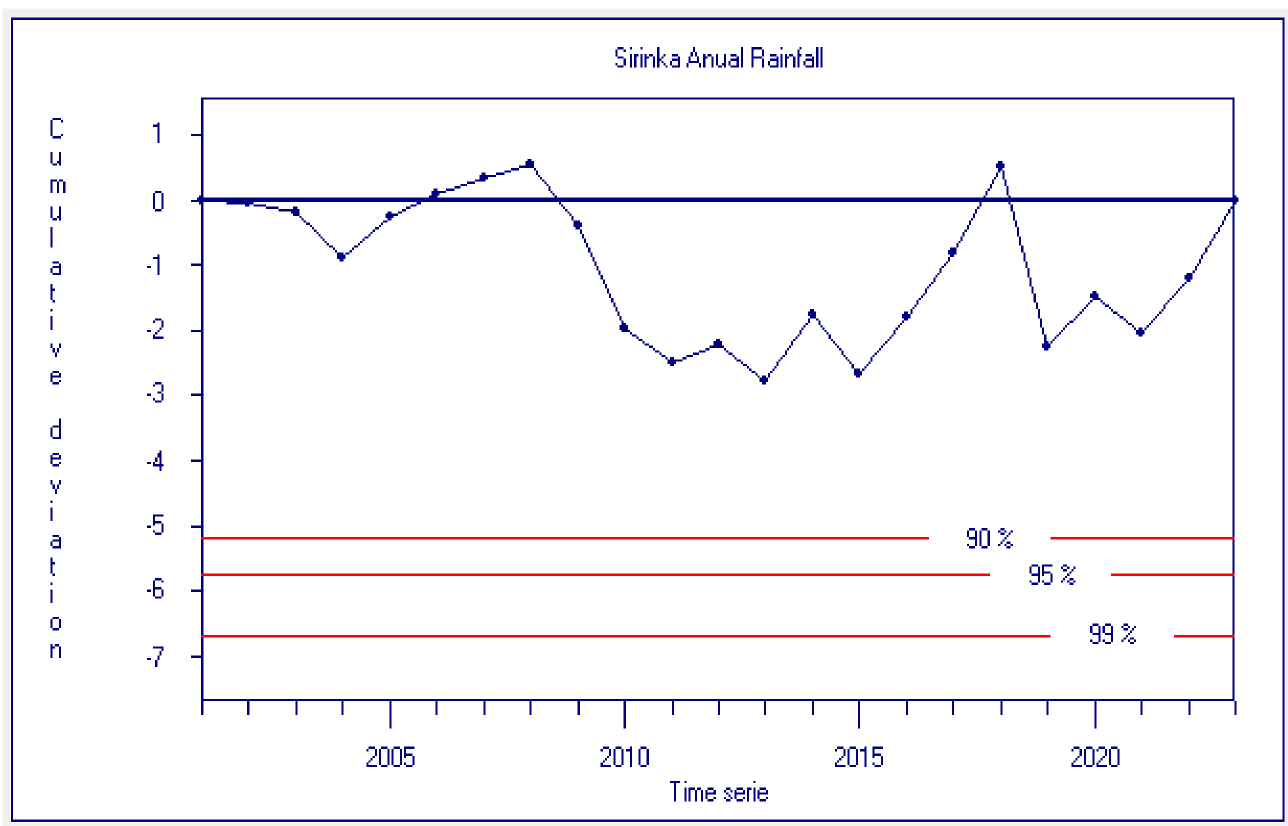

Figure 2: Range land Area

Figure 3: Tree

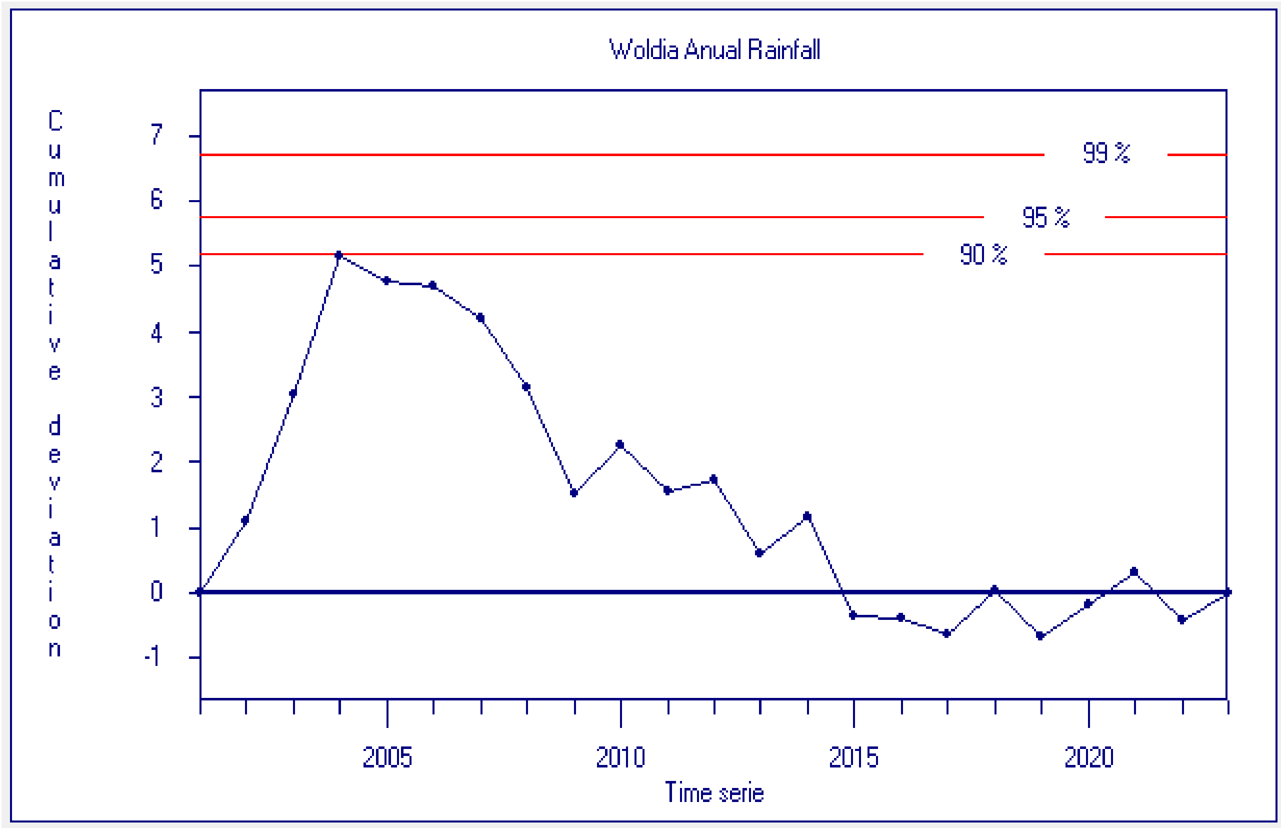
Figure 4: Biult up area



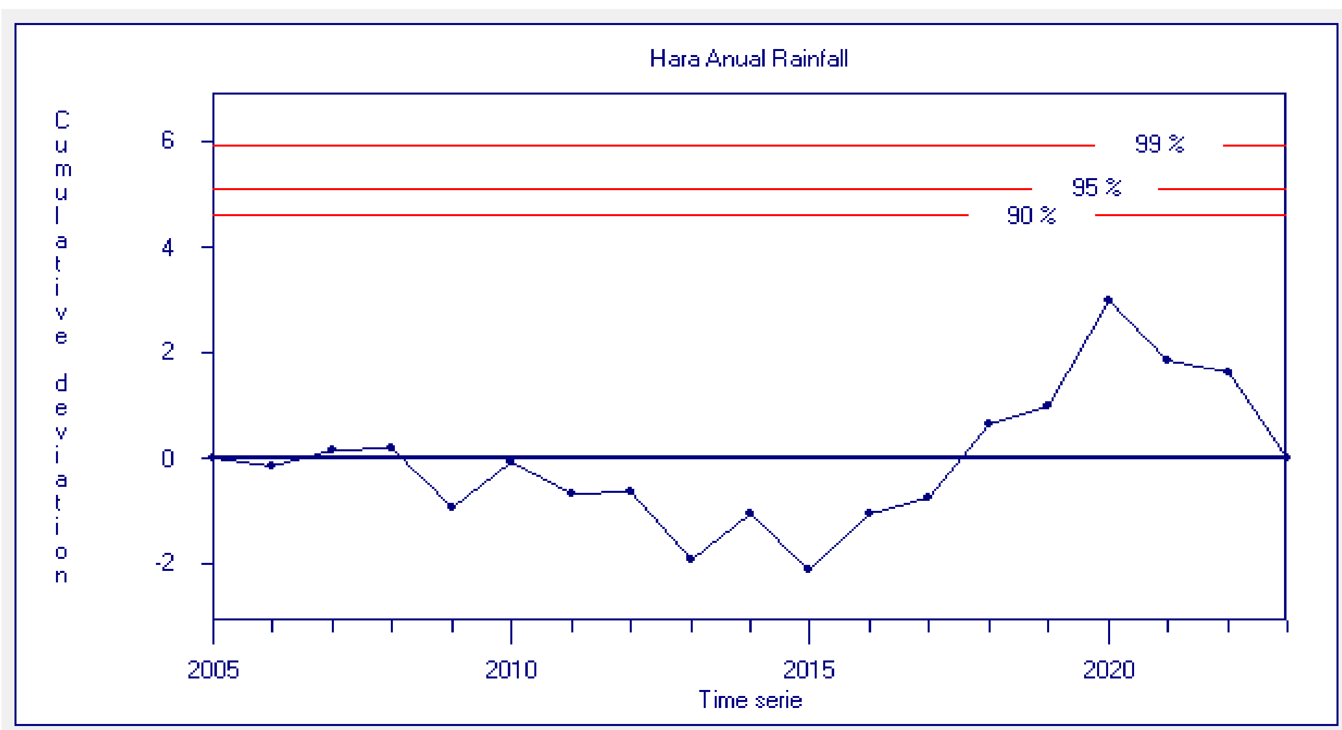
Appendix Figure 5: Homogeneity graph of Mersa Rainfall Station



Appendix Figure 6: Homogeneity graph of Sirinka Rainfall Station



Appendix Figure 7: Homogeneity graph of Woldia Rainfall Station



Appendix Figure 8: Homogeneity graph of Hara Rainfall Station.