UNIVERSITY OF NAIROBI

RISK ASSESSMENT ANALYSIS OF SOIL EROSION USING GEOGRAPHIC INFORMATION SYSTEM

A Case Study of Taita Hills

By

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ABSTRACT

This project study applied Geographical Information System (GIS) and the Revised Universal Soil Loss Equation (RUSLE) to predict the annual average soil loss rate from Taita Hills. To achieve the goals of the project, the RUSLE factors were calculated using the local data that was collected from Survey of Kenya (S.o.K), Kenya Metrological Department (K.M.D), and Kenya Agriculture Research Institute (KARI). The soil survey data were used to develop the soil erodibility factor (K), and a digital elevation model of the catchment was used to generate the topographic factor (LS). The values of cover management (C) factor and support practice (P) factor were collected from satellite image Landsat TM 2011 which was acquired from Regional Center for Mapping Resources and Development (RCMRD). Usually C and P factors are determined from land cover and land use classes respectively. The rainfall–runoff erosivity (R) was derived from annual rainfall data.

The results indicate that the average annual soil loss (A) within the catchment is about 600tons/ha/yr. This highly depends on R value which ranges between 300 MJ/ha.mm/year and 645MJ/ha.mm/year with the highest values being in Werugha location in Taita. It is also important to note that the steepest slopes show high risk of soil erosion. It is therefore recommended that further study be undertaken to establish the suitable soil and water conservation measures that should be implemented in these areas as well as the whole catchment.

Keywords: Soil Erosion, RUSLE, GIS, Taita Hills

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DEDICATION

I dedicate this report to my Savior Jesus Christ for being with me every moment of my life.

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LIST OF ACRONYMS AND SYMBOLS

ARUSLEs Equation Average Annual Soil Loss

C RUSLEs Equation Cover Management Factor

DEM Digital Elevation Model

E Storm Energy

EI Storm Erosivity

EI_{30}30 min Storm Erosivity

GIS Geographical Information System

I Precipitation Intensity (mm/h)

I_{30} Maximum 30 min Intensity

K RUSLEs Equation soil Erodibility Factor

KINEROS Kinematic Runoff and Erosion Model

LRUSLEs Equation slope length factor

ME Ministry of Environment

Mm millimeter

MUSLE Modified Universal Soil Loss Equation

KARI Kenya Agricultural Research Institute

NRCS Natural Resources Conservation Service

OM Organic Matter

P RUSLEs Equation Support Practice Factor

R RUSLEs Equation Rainfall runoff

RUSLE Revised Universal Soil Loss Equation

SRUSLEs Slope Steepness Factor

SERM Soil Erosion Risk Map

UON University of Nairobi

USLE Universal Soil Loss Equation

TIN Triangular Irregular Network

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CHAPTER ONE

1. INTRODUCTION

1.1 Overview

Soil erosion is a natural process, occurring over geological time and may be caused by water or wind. It leads to loss in soil productivity due to physical loss of topsoil, reduction in rooting depth, removal of plant nutrient and loss of soil. It's a discreet geomorphologic process but it has a widespread spatial distribution. Erosion is triggered by a combination of factors such as steep slopes, climate like long dry periods followed by heavy rainfall, inappropriate land use, land cover patterns like sparse vegetation, and ecological factors like forest fires (Ioannis Z. Gitas et al., 2001).

Soil erosion increased throughout the 20th century. About 85% of land degradation in the world is connected with soil erosion, most of which occurred since the end of World War II, causing a 17% reduction in crop productivity (Shi et al., 2004).

In assessing the economics of soil conservation in Kenya, soil erosion control under natural and agricultural conditions will be important for maintaining current agricultural production levels. There is also a stated need to identify critical areas for targeting limited erosion control funding. Erosion prediction models can help address long-range land management planning under natural and agricultural conditions. Even though it is hard to find a model that considers all forms of erosion, some models were developed specifically to aid conservation planners in identifying areas where introducing soil conservation measures will have the most impact on reducing soil loss.

The Revised Universal Soil Loss Equation (RUSLE) model, though developed to predict water erosion in temperate climates, is easier to adapt to tropical climates than other existing models. RUSLE is an empirically based model, founded on the Universal Soil Loss Equation (Wischmeier et al., 1978), but is more diverse and includes databases unavailable when the USLE was developed (Renard et al., 1997). RUSLE is designed for use at the runoff plot or single hillslope scales. The RUSLE model enables prediction of an average annual rate of soil erosion for a site of importance for any number of scenarios involving cropping systems, management techniques, and erosion control practices.

Sediment production is the main product of soil erosion due to surface water runoff. This is normally deposited in areas along water courses where the river flow rates are low and the physical conditions are favorable for deposition. Thus sediments are product whenever soil is exposed to rainfall energy and flowing water regardless of whether the location is urban or rural.

1.2 Statement of the problem

Nowadays one of the major problems on global scale is the rapidly increasing demand for food. This demand is of course totally parallel to the population growth. More land is thus used for agricultural purposes day by day. Cultivation without using specific control techniques, unplanned land use, and also destroying forests are fundamental factors of soil erosion (Biard et al., 1997). Soil erosion over Earth is a quite-frequent and well-distributed.

Soil erosion affects soil productivity by changing soil properties and particularly by destroying topsoil structure, reducing soil volume and water holding capacity, reducing infiltration, increasing run-off, and washing away plant nutrients, such as nitrogen, phosphorous, and organic matter (Oyedele,1996). The area at risk can be estimated using an appropriate model of soil erosion.

The impact of soil erosion can be worst in the highland areas where farmers are highly dependent on intrinsic land proprieties and unable to improve soil fertility through application of purchased inputs. In Taita highlands only, an annual soil loss reaches to more than 550 ton per hectare, per year. Hence there is an urgent need for policy interventions and soil conservation practices to alleviate soil degradation in these areas.

Agricultural field plots and catchments dominated by agriculture produce higher erosion rates than forested rate. The loamy soil of Taita Hills is more susceptible to erosion than clayey soils. Therefore the aim of the project is to use GIS technique to determine RUSLE’s parameters to estimate the annual average soil by erosion from entire Taita Hills.

1.3 Study area

The Taita hills study area is found in the Coast part of Kenya. It forms a northern part of Africa’s Eastern Arc Mountains, which have been identified by Conservation International as one of the top ten biodiversity hotspots in the world. Taita Hills is pressured environmentally, sensitive and ecologically important, there is continuing need for up to date and accurate land cover information that can be utilized in the production of sustainable land use policies.

The Taita hills have net water Surplus. Several rivers drain from the Taita hills (Bura, Kishushe, Mbololo, Mwatate, Paranga and Voi rivers). The rivers are perennial. The study area looked at seven locations namely Shaghasa, Rong'e, Mwanda, Werugha, Wundanyi, Mwanda and Chawia.

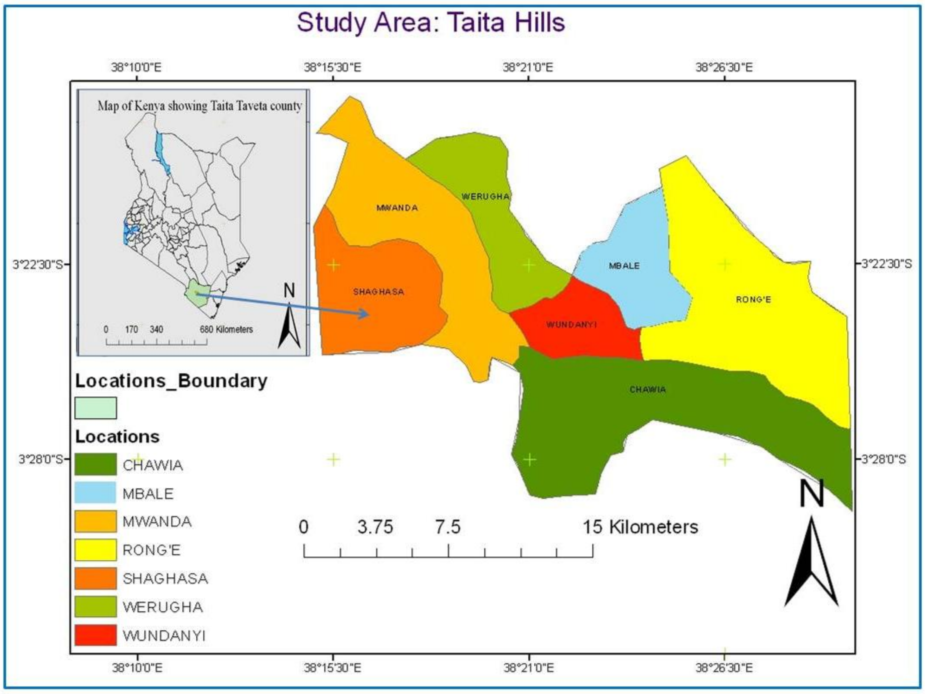


Fig 1.1: Map showing study area

1.4 Objectives

The objectives of this Project are:

- To evaluate the application of GIS and RUSLE to determine soil loss.
- To predict the amount of soil loss from Taita Hills using ArcGIS and RUSLE.

Its specific objectives are:

- To identify and describe the six components of RUSLE soil loss equation
- To support the RUSLE soil loss using the Sub rating Method
- To familiarize with the DEM, to generate slope length and steepness of Taita Hills.

1.5 Scope and limitation of the study

The study of soil erosion modeling using GIS is carried out using already collected data from national mapping agencies and Agricultural laboratories especially Kenya Agricultural Research Institute. The projects dataset is the topographic map which will act as the base map.

1.6 Organization of report

The report is composed of five major topics. In chapter one is the introduction of the study area covering its background information, problem statement, research objectives, and brief outline of project organization. The second chapter covers relevant literature on the study as well as looking at the contributory factors of soil erosion. It also outlines the role of remote sensing and GIS approach integrated with soil erosion models.

Chapter 3 is mainly the methodology used: the data required is of topography, soil and land use characteristics, precipitation and runoff. Precipitation and runoff data are needed to estimate the rainfall runoff erosive factor (R). DEM is created with 30m grid cell size and is needed to analyze the slope length (L) and slope steepness (S). A soil map based on vectorized feature data is used to estimate the soil erodibility (K) and transformed into the raster data file with 30m grid cell size. A land cover map, extracted from LANDSAT images, is used to predict the cover management factor (C), which is one of the most sensitive factors in analyzing the soil loss rates of the RUSLE model. Land use classification strategies in the context of their application to multi-source analysis are reviewed in this Chapter also. The process of image classification is described and applied to the study area.

Chapter four gives the project results and analysis. This is the results of the classification of each image using supervised and unsupervised classification techniques. The role of the DEM and textural data in improving spectral classification is considered.

Finally conclusions and recommendations are covered in chapter five.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Previous work done.

The title was Effects of Geographic Information Quality on Soil Erosion Prediction by Dr. Sc. ETH Karika May 2009, Zurich.

Soil erosion is one of the most serious problems in the mountainous areas. Geographic Information Systems (GIS) are widely applied to predict soil erosion, as all factors on soil erosion can be extracted by spatial analysis. Therefore, the quality of spatial data plays a great role on the prediction and the most appropriated data should be used for input data to the model. The purpose of this study was to evaluate the sensitivity of GIS data quality for the Revised Universal Soil Loss Equation (RUSLE) model. Different quality of GIS data input for two catchments in Switzerland and a catchment in Thailand are applied to the calculation. A programmed Visual Basic Application (VBA) extension on ArcGIS 9.2 and the geostatistics analysis are used for the calculation.
Moreover, the study aims to improve the soil erosion prediction, experienced from the study, using GIS technology. In order to achieve the aim, the study recommends different methods: the use of GIS database of different soil-scales, the soil GIS data sharing, the Web-based GIS soil data and the soil erosion metadata model.

From the study, the developed algorithm (VBA application) is implemented on ArcGIS 9.2 Interface and has shown to be a good tool for the RUSLE model in the study areas. The results of the study present that in the heterogeneous slope area, the finer Digital Elevation Model (DEM) yields more accurate the soil erosion values. In contrast, in the flatter area, coarse DEM derives similar results to the finer ones. The finer DEMs are expensive; therefore it should be used as necessary.

2.2 Soil Erosion

Soil erosion is a three phase phenomena consisting of the detachments of individual soil particles from the soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available to transport the particles, then the third phase “deposition”, takes place. The potential of soil erosion from watershed to watershed depending on the configuration of watershed (topography and shape) the soil characteristics and local climatic conditions and the land use and management practices implemented on the watershed (Arorak 2003 and Suresh R. 2000). The removal of topsoil by water takes place in the following way:-

- Sheet erosion
- Rill erosion
- Gully erosion
- Stream bank erosion
- River erosion

Sheet Erosion

This erosion is more or less the removal of a uniform thin layer of "sheet" of soil by flowing water from a given width of sloping land. The amount of soil removed by this type of erosion is small but as it flows down the slope, it increases in size and develops into rill erosion (Arorak 2003 and Suresh R. 2000).

Rill and gully Erosion

With rill erosion the erosive effect of flowing water suddenly increases at a location where a confluence of surface water occurs. Due to low infiltration rates and the occurrence of rainfall, the excess water collects very slowly over land surface and into the rill. As this gathering of water continues, the depth of water together with the velocity, kinetic energy and soil particle increases. The rill develops into gulley erosion (Arorak 2003 and Suresh R. 2000).

Stream Bank Erosion

The removal of soil from the stream of the stream bank occurs due to either water flowing over the sides of the stream from overland runoff or the water flowing in the stream and scouring banks. This type of erosion is a continuous process in perennial streams and is caused by the scouring and undercutting of the soil below the water surface caused by wave action during normal stream flow events (Arorak 2003 and Suresh R. 2000).

River Erosion

This type of erosion occurs particularly in rivers in which permanent water flow takes place usually with varying rate. River erosion is likely to be more effective in water courses of smaller catchment area and those having less favorable conditions for drainage discharge (Arorak 2003 and Suresh R. 2000).

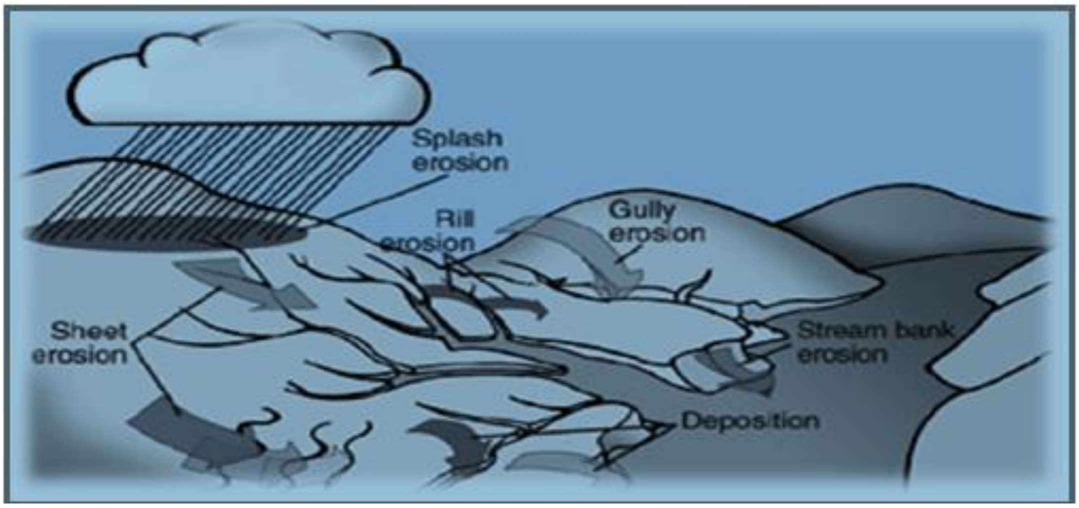


Fig 2.1: shows the development or stages of soil erosion by water (Sharma, Partha Das 2009).

2.2.1 Principal soil erosion factors

As introduced in the last section about different soil erosion types and the formation of these erosions, there are several factors principally concerned which are

- **climate**,
- **soil characteristic** or **soil type**,
- **topography** and
- **Ground cover**, including the crop management (Goldman et al., 1986).

All factors are related together directly and indirectly. These four factors are mainly composed in models of Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE) and as well as in other soil loss models.

Soil characteristics or **soil type** is associated to permeability, structure, organic matter content and texture of soil. These properties represent how soil reacts to raindrops, runoffs and sediment transport. When soil is high in silt or fine sand and low in clay or organic matter, it is generally the most erodible (Mills et al., 1976). On the other hand, the more organic content in soil, the less soil erosion occurs.

Related to the rainfall which is a **climate** factor, the rain intensity and raindrop size play main roles effecting to soil loss. Rain is the driving force of erosion. Highly intense rainfall and large rain drops are significantly more erosive than short duration and small rain drops significantly. Not only is the direct effect on soil erosion caused by the rain, but also climate effects soil erosion indirectly. The season effects vegetation growth covering which is one of the most important factors on soil erosion (Mills et al., 1976).

As specified earlier, **ground cover** is greatly significant in soil erosion. Vegetation acts as a protective layer or buffer between the atmosphere and soil, and is associated with other factors especially farming, land use and climate (Mills et al., 1976).

In Morgan, 2005, it is explained that there are several effects on soil erosion which almost all could be scaled down by vegetation cover. The vegetation absorbs the energy of rainfall, reduces the velocity of runoff, and helps to protect the land against mass movement. When the natural covering is disturbed, re-establishing vegetation can be a difficult and expensive process.

The last principal factor of soil erosion is **topography**. Erosion would normally be expected to increase with slope steepness and slope length increments as a result of respective increases in velocity and volume of surface runoff (Morgan, 2005). Long and steep slopes contributes large momentum, thus, the energy of flow (erosion potential) is increased. High velocity runoff is prone to concentrate in narrow channels and produce **rills** and **gullies** (Goldman et al., 1986).

2.3 Soil Erosion Models

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Wischmeier and Smith, 1978; Julien, 1998). The major forces originate from raindrop impact and flowing water.

.Soil erosion models can be divided into two main groups: empirical models and physically-based models. A large number of erosion models are based on the famous empirical model Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) (e.g., Agricultural) Nonpoint Source Pollution (AGNPS); Areal Nonpoint Source Water sheets Environment Response Simulation (ANSWERS), the Erosion Productivity Impact Calculator (EPIC) and Soil and Water Assessment Tool (SWAT). Although the USLE has been developed in the USA, it was used throughout the world because it seemed to meet the needs of researchers better than the other model. It was later modified to Revised Universal Soil Loss Equation.

2.3.1 RUSLE

The soil erosion prediction methods were first developed in the U.S.; consequently many soil loss estimation equations were developed by a number of researchers. Over the years, these equations improved as new variables and factors were added to the soil erosion equation. Smith and Whitt presented one of the first rational soil erosion equation and it is a method of estimating soil losses from fields of claypan soils (Smith & Whitt, 1947). This equation (equation 1) is shown below (Smith & Whitt, 1947):

$A= R\times K\times LS\times C\times P$……………………………………………………………Equation [1]

Where:

A – Annual soil loss, in tons per ha per year

R – Is a measure of the erosive forces of rainfall and runoff.MJ.mm/ (ha.hr. year)

K – Soil erodibility factor a number which reflects the susceptibility of a soil type to erosion i.e. it is the reciprocal of soil resistance to erosion. Mg h/MJ/mm

LS – Topographic factor which represent the slope length and slope steepness respectively. It is the ratio of soil loss from a specific site to that from a unit site having the same soil and slope of 9% but with a slope length of 22.1m

C – Cover management factor, which represents the protective coverage of canopy and organic material in direct contact with the ground. It is measured as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled land under clean-tilled continuous fallow conditions (Renard et al., 1997).

P – Support practice factor which represents the soil conservation operations or other measures that control the erosion. It is measured as the ratio of soil loss with a specific support practice to the corresponding loss with plowing up and down slope (Renard et al., 1997).

L, S, C and P factors are dimensionless parameters and they are ratios relative to standard plot conditions. The USLE and the RUSLE is currently a globally accepted method for soil erosion prediction in the U.S. and in other countries all over the world. These models have been accepted to be useful, accurate and reliable (Renard et al., 1997).

Then, the Universal Soil Loss Equation model (USLE) was adopted by the Soil Conservation Service in U.S. in 1958 and became the most widely used and accepted model to make long term assessments of soil erosion. The USLE model was developed by Wischmeier & Smith based on data from more than 10,000 test plots throughout the East of the U.S. in 20 years (Wischmeier & Smith, 1965).

The test plots were managed with a standard of 22 m flow lengths allowing this method to be more accurate and reliable (Wischmeier & Smith, 1965). The USLE has six factors and is applicable to calculate **sheet** and **rill** erosion only. However, the USLE is known to have a few shortcomings. If just one of the input data is not accurately specified, the multiplication of the six factors will lead to a large error of results (Sonneveld & Nearing, 2003). There are also questions about the reliability of the parameter values assigned to the model (Sonneveld & Nearing, 2003).

The Demerits of this model however are it’s that only sheet, rill and inter-rill soil erosion by water flow is taken into account and deposition is not included. Thus, the maps from this model should not be used to predict the occurrence of mass movements like landslides. The effect of management practice is nearly impossible to assess at the small scale used here.

Rainfall erosivity factor (R)

Is a measure of erosivity of rainfall which is a product of storm kinetic energy and maximum 30 minute intensity EI_{30}. When other factors are constant, storm losses from rainfall are directly proportional to total kinetic energy of the storm (E) times 30 minute Intensity I_{30} (Arnoldus 1978). The equation 2 is given below

$R=\frac{1}{n}\sum_{i=1}^{n}(\sum_{k=1}^{m}E(I_{30})$ ....Equation [2]

Where:

R – Rainfall erosivity factor

E – The total storm kinetic energy (MJ/ha)

I_{30} – The maximum 30 minutes rainfall intensity

i – The index for the number of years used to compute the average

k – The index of the number of storms in each year

n – The number of years to obtain average

m – The number of storms in each year

The total storm kinetic energy for each storm, E is obtained by summation of the product of unit kinetic energy and the respective rainfall volume of all the increments in a rainfall event, as given below in equation 3

$E=\sum_{r=1}^{K} e_r v_r$ ....Equation [3]

Where:

E – Total storm kinetic energy (MJ/ha)

K – Number of storm intervals

r– Index number of storm intervals

Er – Unit kinetic energy for rth interval

v_r– Total rainfall depth for rth interval

The kinetic energy is assessed in the RUSLE model following the approach of Brown and Foster, 1987:

$Er=0.29\ 1-0.72\ \exp(-0.05ir)]$ ....Equation [4]

$$i_r = \frac{\Delta v_r}{\Delta t_r} \text{...Equation [5]}$$

Where e*r:* kinetic energy of a storm for the *r* period (MJ /ha/mm)

i_r*:* The rainfall intensity for the *r* period (mm/h)

Δt_r The duration of the *r* period (min)

Most of the time rainfall intensity and storm kinetic energy are not at national meteorological station. This is because the rainfall intensity requires continuous rainfall records. To obtain an accurate R factor, EI_{30} needs to be calculated with continuous records, over multiple years for multiple stations located at the area of the study site. By the absence of rainfall intensity and storm kinetic energy data for this study area, mean annual and monthly rainfall data have been used to estimate the 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 most suitable expression of the erosivity of rainfall is an index based on kinetic energy of the rain. There are different ways of analyzing the R factor. For instance,

(i) R = 9.28 * P – 8838. Mean annual erosivity (KE > 25) [Morgan (1974) cited in Morgan (1994)]

(ii) R = 0.276 * P * I_{30}. Mean annual EI_{30}. [Fosteret.al (1981) cited in Morgan (1994)]

(iii) R = 0.5 * P. [Roose (1975) cited in Morgan (1994)]

Where P is mean annual precipitation

These formulas have been applied in different parts of the world. The first equation appears to work well for countries with annual rainfall below 900mm; the equation yields estimates of erosivity, which are obviously meaningless (Morgan, 1994). In line with this, the second equation needs the value of I_{30} for calculating of erosivity factor, which is difficult to get in context of the study area. Therefore, in this study, the third equation was used for the determination of R-value. Hence each grid cells of mean annual rainfall were calculated based on third equation to get the R-value using GIS software, ArcGIS.

Soil erodibility factor (K)

The soil erodibility factor (K factor) measures the susceptibility of soil particles or surface materials to transportation and detachment by the amount of rainfall and runoff input (Renard et al., 1997). It is known that the most easily eroded soil particles are silt and very fine sand and the less erodible soil particles are aggregated soils because they are accrued together making it more resistible (Kim, 2006).

$$K=\frac{1.0\times10^{-4}(12-OM)^{1.14}+4.5\ s-3\ +3.0(P-2)}{100}$$ ....Equation [6]

Where

K – Soil Erodibility Factor Mg h/ MJ/mm

OM –organic matter

OM – (% silt +% very fine sand) x (100 – % clay) S – Soil structure code

P – Permeability code/drainage class

Soil Types	K Factor
Clay	0.01
Clay with gravel or sediment clay	0.024
Sandy loam,silty clay loam	0.027
Clay mixed with sand	0.033
Clay loam, sandy clay	0.035
Silty loam	0.042

Table2.1: Showing K Factors assigned to different Soil Types

Slope Length and Slope Steepness factor (LS)

The effect of topography on soil erosion is accounted for by the LS factor in RUSLE, which combines the effects of a slope length factor (L) and a slope steepness factor (S).

Wischmeier and Smith (1978) defined slope length as the distance from the point of origin of overland flow to the point where the slope decreases enough that deposition begins or the point where runoff becomes concentrated in a defined channel. Slope steepness reflects the influence of slope gradient on soil erosion (Wischmeier & Smith, 1965). It is known that the amount of runoff increases due to the continuous accumulation down the slope as the slope length (L factor) increases; the velocity of runoff increases as the slope steepness (S factor) increases (Kim, 2006).The equation defined by Wischmeier (1975) for LS is as shown

$$LS=(\frac{\lambda}{\psi})^{m}0.065+0.045s+0.0065s^{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [7]$$

Where:

λ – Sheet flow path length (m)

Ψ – Constant 22.13

s – Average slope gradient (%)

m - is the variable slope length exponent

For ArcGIS, (Bizuwerk et al., 2008) presented that the slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by (Wischmeier and Smith, 1978).

$$LS=(\frac{\mathrm{X}}{22.13})^{\mathrm{m}}0.065+0.045\mathrm{s}+0.0065\mathrm{s}^{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [8]$$

Where:

X – Slope length (m)

S – Slope gradient (%)

The values of X and S can be derived from Digital Elevation Model (DEM). To calculate the X value, Flow Accumulation was derived from the DEM after conducting Fill and Flow Direction processes in ArcGIS.

X=**Flow accumulation *cell value**

By substituting X value, LS equation will be:

$$LS=(\frac{\textbf{Flow accumulation} * \textbf{cell value}}{22.13m})^{m}0.065+0.045s+0.0065s^{2} \ldots\ldots\ldots\ldots [9]$$

(i) Slope length factor (L)

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or to where the flow connects to a river system (Wischmeier and Smith, 1978). The USLE was formulated from empirical data collected from uniform field plots with fixed parameters, referred to as the unit field plot length (i.e. 72.6 ft. or 22.13 meters). The slope length factor (*L* factor) is dimensionless because it is simply a ratio of the horizontal length of the actual field plot divided by the unit field plot length, raised to the exponent *m*.

The *L* factor is defined as: $$\left(\frac{\lambda}{22.13}\right)^{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [10]$$

Where λ = horizontal projection of slope length; 22.13meters is the standard USLE unit plot; exponent *m* is the variable slope length exponent. (Renard et al., 1997)

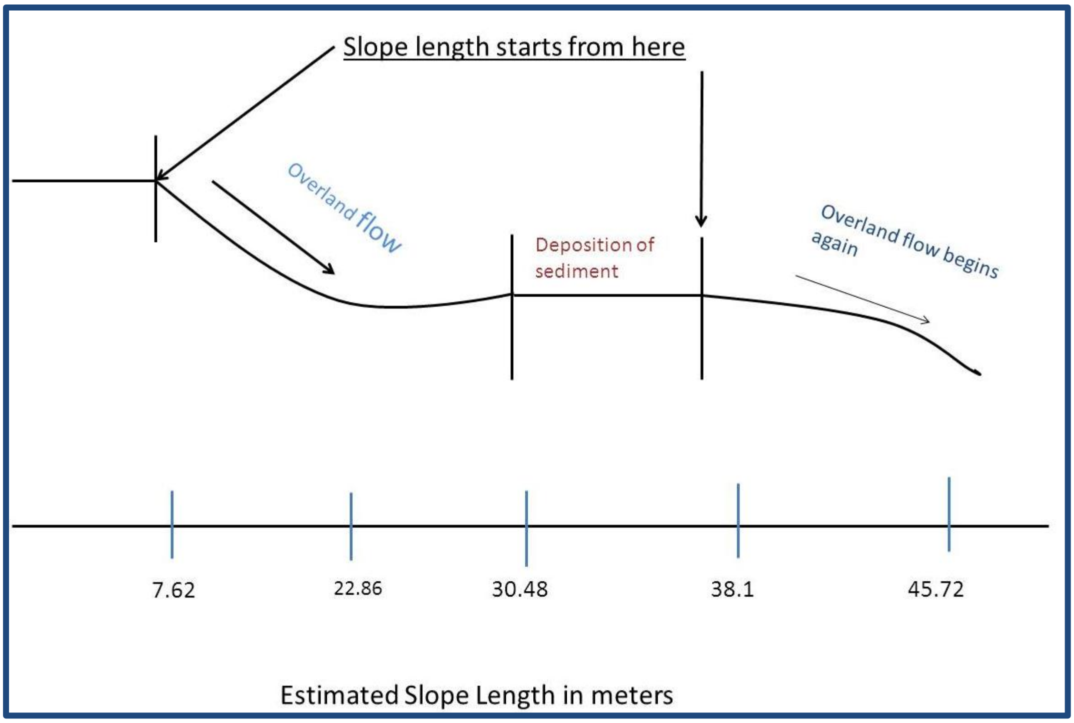


Fig2.2: Field Estimation of the Slope Length (LS) on a side profile of a hill

(ii) Slope Steepness Factor

The S factor is fundamentally related to the L factor and is generally grouped together in USLE calculations. When the LS factors are calculated, the corresponding equations normalize the values to the unit field plot parameters which are 72.6 ft. (or 22.13 meters) in length and have a 9 % slope, or about 5.14 degree slope angle. The common practice is to express the slope angle θ in degrees. The relationship between common angle names of degrees and percent rise are illustrated on Figure 2.3. Also of note is the radian measure, which is equal to approximately 57.296 degrees. There are 6.28 radians, or 360 degrees, in a full circle. An important relationship of triangles to note is that for a 45 degree right triangle, the hypotenuse, h, has a length of √2 or 1.414 when both the rise and run have equal lengths

$$\boldsymbol{Degrees = \Theta = \tan^{-1}\left(\frac{Rise}{Run}\right)}$$ ....Equation 11

Percentage rise= $\left(\frac{\boldsymbol{Rise}}{\boldsymbol{Run}}\right) \times 100$.................. Equation12

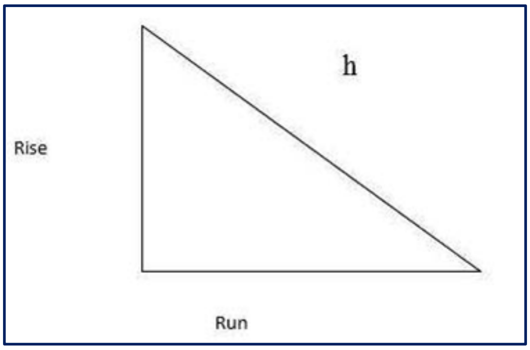


Fig2.3: Slope degrees and percent rise, fundamental relationship of right triangle.

Cover management factor (C) and Support practice factor (P)

Cover Management Factor (C) and Support Practice Factor (P) are two management factors that can be used to control soil loss at a specific site. The Cover Management Factor (C) represents the effect of vegetation and management on the soil erosion rates (Renard et al., 1997). The Support Practice factor (P) represents the impact of support practices on the soil erosion rates (Renard et al., 1997). Cover Management Factor (C) is the ratio of soil loss of a specific crop to the soil loss under the condition of continuous bare fallow (Renard et al. 1997). The amount of protective coverage of a crop for the surface of the soil influences the soil erosion rate. C value is equal to 0.48 when the land has continuous bare fallow and have no coverage. C value is lower when there is more coverage of a crop for the soil surface resulting in less soil erosion.

Land Use Erosion control treatment	C Factor
Forest/tree	
25% cover	0.42
50% cover	0.39
75% cover	0.36
100%	0.03
Bushes/Scrub	
25% cover	0.40
50% cover	0.35
75 % cover	0.30
100% cover	0.03
Agriculture crop	0.38
Bare soil	0.48

Table 2.2: Showing various cover management (C) Factor assigned to different land use

P is the support practice factor and reflects the impact of support practices and the average annual erosion rate. It is the ratio of soil loss with a specific support practice on croplands to the corresponding loss with upslope and downslope tillage. This factor considers any practice applied by humans to reduce erosion degree and soil loss amount deriving from water erosion process. It includes a variety of agriculture management activities such as tillage and planting along contour lines (contouring), fields alternated to sod strips along the contours (strip cropping), tree lines planted along agricultural fields and terracing. This last practice "terracing" consists of breaking the slope by moving part of the soil to build successive steps. P value is 1 when land is plowed up and down. This is known as the worst practice. The P value is lower than 1 when the adopted practice reduces soil erosion.

Land Use	P Factor
Forest	0.10
scrub	0.20
Bare land	0.70
Agriculture	0.40

Table 2.3: Shows various support factor (P) for different Land use.

2.4 Remote Sensing and Soil Erosion Modeling

Remote Sensing (RS) is a useful tool in hydrological analysis and natural resource management. The application of RS technique lends to evaluation soil loss based on different parameters. The software used to carry out the remote sensing was Idrisi Kilimanjaro. RUSLE (Revised Universal Soil Loss Equation) model is used for soil loss estimation.

Different parameters, namely the rainfall and runoff factor (R), soil erodibility factor (K), slope length and steepness factor (LS), crop management factor (C) and conservation practice factor (P), that are the mandatory inputs to RUSLE, have been either derived from remote sensing data or through conventional data collection systems. These parameters are obtained from monthly and annual rainfall data, soil map of the region, Digital Elevation Model (DEM), RS techniques (with use of Normalized Difference Vegetation Index) and land use/land cover map, respectively.

Soil loss is very high in the Taita Hill area, calculated as approximately 600 tons/year using RUSLE model. Thus, the RUSLE model integrated with RS has a great potential for producing accurate and inexpensive erosion assessment map in Taita Hills.

2.5 Geographic Information System (GIS) and Soil Erosion Modeling

A Geographic Information System (GIS) is a system that captures, stores, integrates, analyzes, manages, and visualizes data that are linked to coordinates or locations. GIS is a combination of statistical analysis, database and cartography that allows the user to identify geographic information, relationships, patterns, and trends (Omar, 2010). For this study, ArcGIS version 10.1 was utilized.

The ArcGIS version 10.1 has two essential sub-programs which are ArcCatalog and ArcMap. ArcCatalog is used for creating, deleting, and editing the spatial data files. ArcMap is the primary application where the data is analyzed and processed. The two spatial data types used in this project are vector and raster files. Vector data contain features defined by a point, line, or polygon. Vector data models are useful for storing and representing discrete features such as buildings and roads. ArcGIS implements vector data as a shapefiles. Raster data are composed of a rectangular matrix of cells. Each cell has a width and height and is a portion of the entire area represented by the raster. Each cell has a value which represents the phenomenon portrayed by the raster dataset, such as a category, magnitude, distance, or spectral value. The category could refer to a land use class, such as agriculture or urban. The cell size dimensions can be as large or as small as necessary to accurately represent the area. All raster layers used in this project had a grid resolution of 10 meters^2. The location of each cell is defined by either its reference system or projection. This project uses the WGS 1984 for all data types. The use of the same projection allows raster layers to overlap with each other.

The Digital Elevation Model (DEM) is a breakthrough in the field of geomorphological analysis because of its ability to portray elevation and topography (Kim, 2006). The DEM is able to demonstrate changes in landscape with time because of the relocation of soil leading to sediment deposition. This process naturally affects the hydrological processes that occur within and over hill slopes (Kim, 2006).

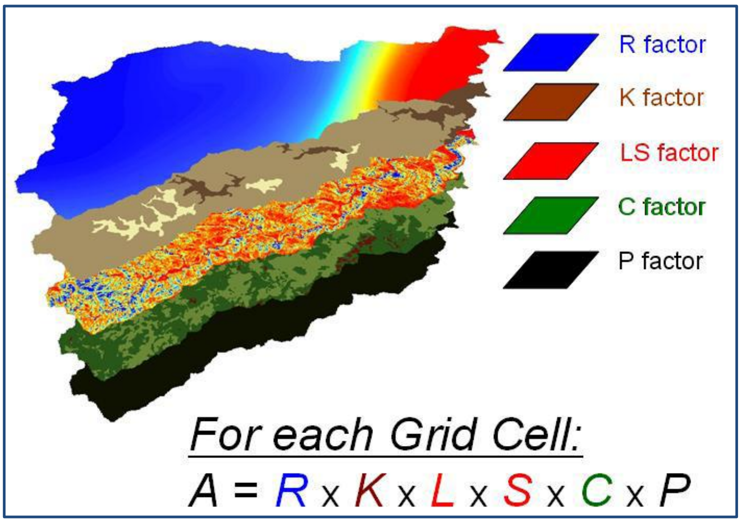


Fig 2.4: Illustration of USLE layers and how they overlap in ArcGIS 10.1

CHAPTER THREE

3. METHODOLOGY AND STUDY AREA

Executive summary

In this chapter the study area is first defined. The data collected is also indicated together with the base map. Data preparation is done. The methods used to combine and analyze the RUSLE with the ArcGIS software are described in a specific format:
Each RUSLE factor is briefly discussed and the methods of developing each factor are presented. The slope length and slope steepness factors are interrelated and described together in the next sections. The orders of presentation are the *LS* factors first, followed by the *K* factor, *C* factor, *P* factor, and the *R* factor. A description of creating each RUSLE factor in ArcGIS is given. A table summary of each RUSLE factor and the data source it is derived from is given in a table. The next method involved the sub rating method where the factors that cause soil erosion are weighted and summed together to give the final soil erosion risk map.

3.1 Study Area

The Taita Hills are a Precambrian mountain range in the south-east of Kenya in Taita-Taveta District. The Hills lie at (latitude 3^0 25’ S, Longitude $38^0$20’E). Taita hills lowest elevation is approximately 500 meters and the highest elevation is about 2200 meters above sea level.

In Taita Hills, numerous instances of soil erosion have been documented, mainly in association with timber extraction, mining activities and agricultural. Taita Hills has suffered a lot of degradation mostly due to expansion of populations and associated demand for land.

In the recent years there has been a general awareness of soil erosion as an environmental problem in Taita Hills. Soil erosion models that have been used in this area can play a critical role in addressing problems associated with land management and conservation, particularly in selecting appropriate conservation measures for a given field or catchment. They can also assist governmental agencies in developing suitable policies and regulations for agricultural and forestry practices. Despite many efforts made to quantify the extent of soil loss in Taita Hills, the available information at this stage is inadequate as it was mainly based on results obtained from selected regions. Therefore more detailed and extensive work is required to assess the spatial variability and extent of soil erosion within given region.

The Taita Hill has a bimodal rainfall pattern with two rain seasons. The long rains occur between March and May with a maximum in April. The short rains take place between October and December with a peak in November. The rainfall distribution varies depending on elevation and aspect. In Taita hills soil losses exceed more than 550tons/ha/year. Assessing the effect of soil erosion by water onsite and offsite is important. This assessment can be helpful for a better environmental policy making.

The Study Area is made up of seven locations Werugha, Chawia, Mbale, Rong’e, Shaghasa, Mwanda, and Wundayi. The highest population as seen from the map is Wundanyi with the leading population of 14,439. This is because it is a town. It is a promising site for job opportunities. The town has promoted rural to urban migration.

The total area of the seven locations is 31,678.446 hectares. The population in the study area has greatly increased. The Catchment of this area is given by the River Mwatate. The river flows towards the south from the northern hilly parts.

The area is mostly covered with clayey soils and loamy soils. The study area has well drained soils. The land use in this study area is basically Agriculture, scrubland, forest, and bare ground. It experiences a long period of dry spell followed by heavy rainfall in the rainfall season hence a lot of soil erosion occurs.

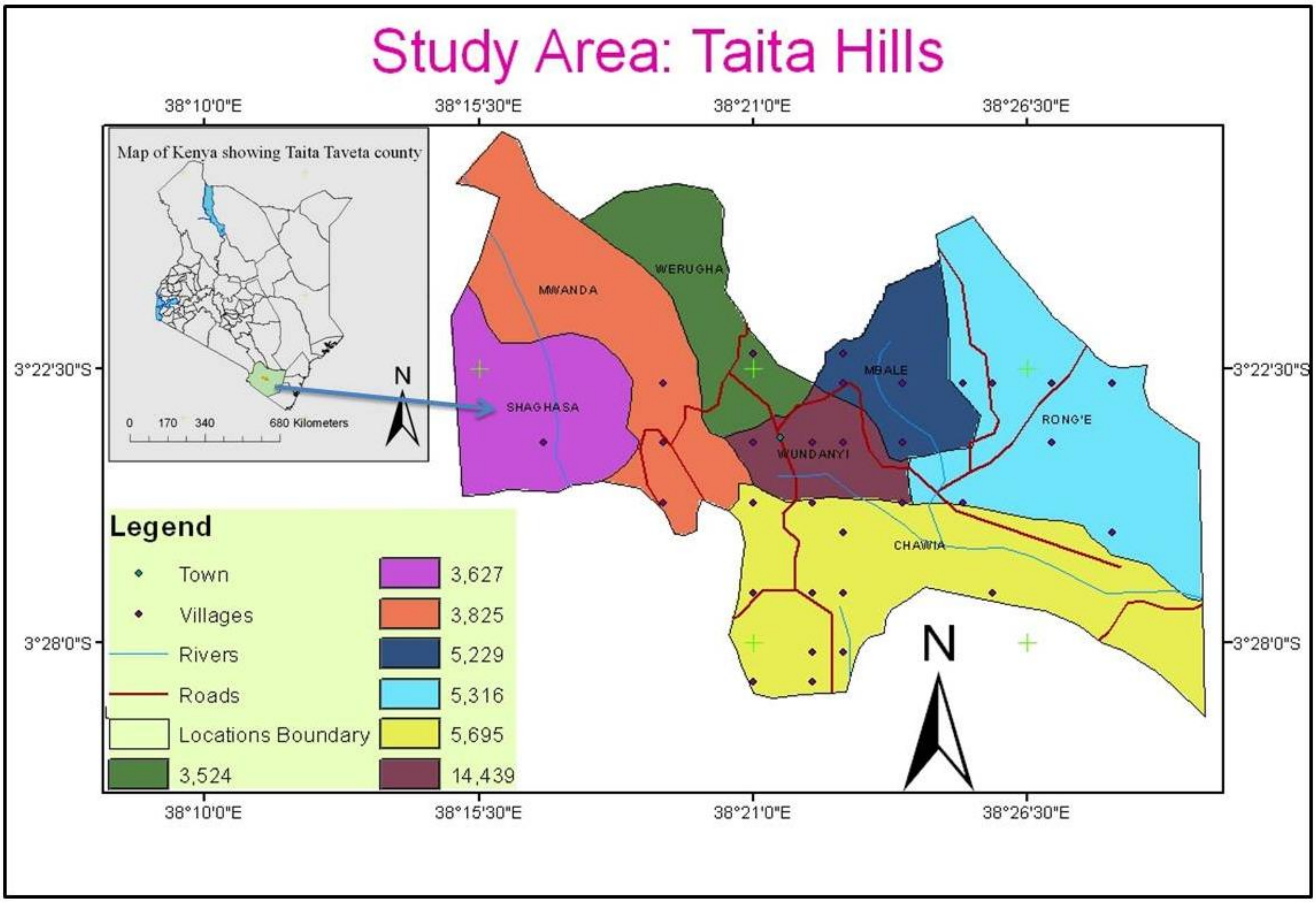


Fig 3.1: Study Area of Taita Hills showing locations and their population

Location	Area In ha	Population 1999 in ones	Population 2009 in ones	Percentage increase
Chawia	7873.124	1682	5695	238.59
Mbale	2441.313	3627	5229	44.17
Mwanda	5453.422	1965	3825	94.66
Rong'e	7409.964	1911	5316	175.35
Shaghasa	2441.313	2622	3627	38.33
Werugha	2989.921	1594	3524	121.08
Wundanyi	1858.768	4499	14439	220.94
Total	31678.466	17900	41655	132.71

Table 3.1: Locations in the study area showing area in hectares and population

3.2 Equipment and Data collected

Hardware

- A personal computer of the following specification Pentium (R) 4 with speed of 3.40 GHz, 1.99GB of RAM and hard Disk of 160GB
- Printer
- External Storage: 4 GB flash disk

Software

- Global Mapper 10
- ArcGIS 10.1
- Microsoft Excel
- Idrisi Kilimanjaro

Data Preparation

1. **Topographical Map**

This map was from the Geography Department. The digital topographic Map was Georeferenced using Global Mapper 10.1.Georeferencing was done using Coordinate System of WGS 1984. It was used as the base map. Contours were digitized in ARCGIS 10.1.

The topographic map was published for the Kenya government by the British Government Ministry of Overseas Development under the Special Commonwealth Assistance Plan. The scale of this map is 1: 50,000.

It has the following data:-

Grid: UTM zone 37

Projection: Transverse Mercator

Spheroid: Clarke1880 (modified)

Units of measurement: meters

Datum: New (1960) Arc

2. Population Data, 2009

The hardcopy was taken from Kenya National Bureau of Statistics (KNBS). The values were input in an excel sheet. The table was converted to comma Delimited version (CSV). These were then joined with the location's shapefile of Taita hills in ArcGIS 10.1.

3. Landsat TM July, 2011

This was from Regional Center for Mapping Resources for Development. This image was loaded in Idrisi Kilimanjaro. Using the supervised classification four classes of land use were identified using their reflectance value. This was later exported as a Geotiff for it to be used in ArcGIS 10.1.

4. Rainfall, 2011

This was from Kenya Meteorological Department. The data was in soft copy. The excel file was converted to comma delimited version and the table joined with the location boundary shapefile in ArcGIS 10.1.

Data Acquired	Source	Date Collected
Topographic Map Scale 1:50,000	Geography Department U.O.N	1975
Soil Data	Kenya Agriculture Research Institute(KARI)	2010
Landsat TM Image	Regional Center for Mapping Resources for development (RCMRD)	July 30th 2011
Population Data	Kenya National Bureau of Statistics Institute(KNBSI)	2009,1999
Rainfall	Kenya Meteorological Department	2011

Table 3.2: Showing table that summarizes the raw data collected their sources and date collected.

There are basically two methods of coming up with Soil Erosion Risk Map. One involves rating various contributive factors. This method involves weighting the factors. Each class in a contributive factor that mostly contributes to soil erosion is assigned the highest value i.e. 5 depending on how many classes they are. The class that least affects is given a low number i.e. 1. After the scaling process the factors were integrated to give the prediction of soil erosion spots.

This method however, does not show the quantitative amount of soil loss. The other method RUSLE fully predicts the soil loss and gives the amount of soil lost hence to fulfill the objective the RUSLE method was used in this Study and sub-rating was used to support the results from RUSLE. It is essential to prepare and analyze the different types of data with regard to soil erosion prediction and hazard assessment as there are many factors that affect soil erosion.

Different sources and types of data were used in this study. The basic data used in this study included: (i) A Digital Elevation Model (DEM), generated from a 30-m interval contour map of the Taita Hills study area. This was derived from the topographic Map; (ii) soil attribute data collected from Kenya Agriculture Research Institute; (iii) satellite image, Landsat Thematic Mapper (TM) taken in July 2011 (path 167 and row 62) from (RCMRD); (iv) Annual rainfall data from the Kenya Meteorological Department (v) soil and geology maps of the study area which were digitized in order to convert them to a digital format.

For further analysis, all data/layers were projected using the World Geodetic System 1984. Finally, a grid cell of rainfall, soil, combined slope length and steepness, land use and practice management was prepared. These layers were overlaid and the soil loss rate was calculated as per the USLE equation. Fig 3.2 shows how the layers overlay in ArcGIS 10.1

3.3 ArcGIS implementation of the RUSLE factors

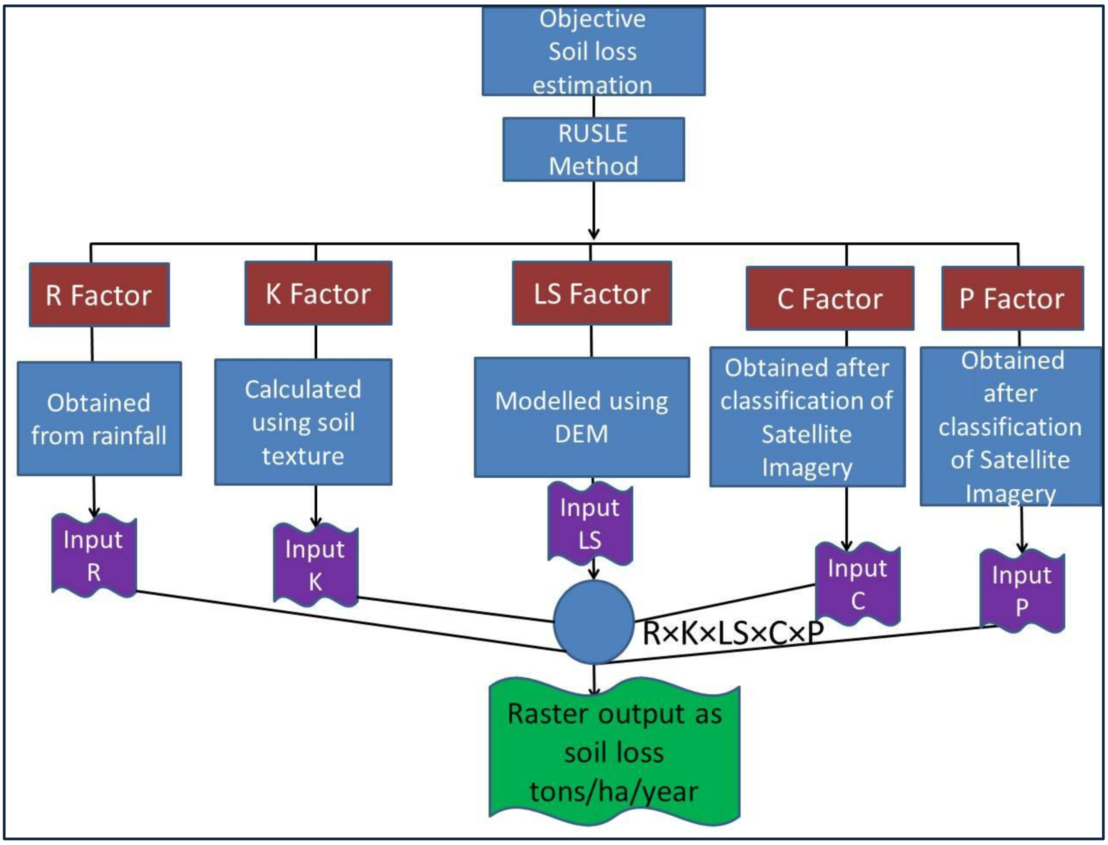


Fig 3.2: Methodological flow chart for the preparation of soil assessment map

3.3.1 DEM implementation in ArcGIS 10.1

A specific type of raster data called a digital elevation model (DEM) is used to model the complex terrain of the Taita Hills Watershed. The cell size resolution of the DEM is 30 meters by 30 meters. The DEM serves as the primary input for calculating the Slope Length and Slope Steepness factors (LS-factors).

DEM serves as the input for determining important hydrological parameters such as the slope angle and flow direction. The ArcGIS software uses a specific numerical method called the Deterministic-8 or D-8 method to calculate the slope angle for each grid cell. The DEM matrix is analyzed in a moving 3 x 3 window illustrated below. The four grid cells closest to the center cell are weighted twice as much as the four grid cells located diagonally to the center cell.

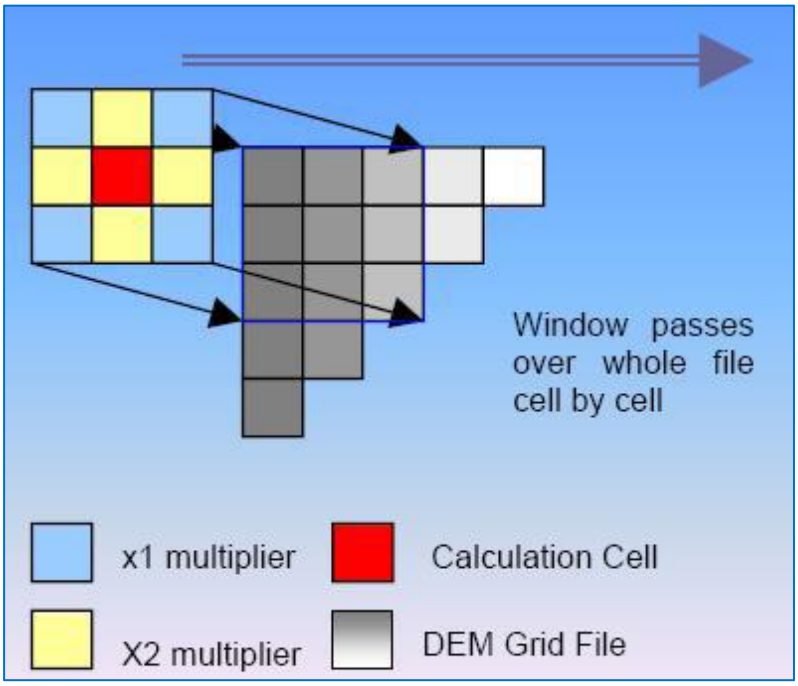


Fig 3.3: Illustration of the moving 3 x 3 window

The following algorithm is functional to each grid cell with respect to the center cell, labeled e in the illustration below (Figure 3.4)

a	b	c
d	e	f
g	h	i

Fig 3.4 Shows a 3×3 matrix

Value

$$\frac{dz}{dx} = \frac{c+2f+i \; - \; a+2d+g}{8\times \; cell\ size\ of\ 10\ meters}$$ ....Equation [13]

$$\frac{dz}{dx} = \frac{(c+2f+i)-(a+2d+g)}{8\times(cell\ size\ of\ 10\ meters)}$$ ....Equation [14]

Equations 13 and 14 are for D-8 slope determination in ArcGIS (Burrough, 1998).

The direction of steepest descent from each cell center to the next closest neighboring cell center is called the FLOWDIRECTION. Running the FLOWDIRECTION function in ArcGIS assigns a numeric value to each grid cell according to the direction of steepest descent (i.e. N, S, E, W, NE,). The FLOWDIRECTION function is found in the spatial analyst tool function in ArcGIS 10.1.

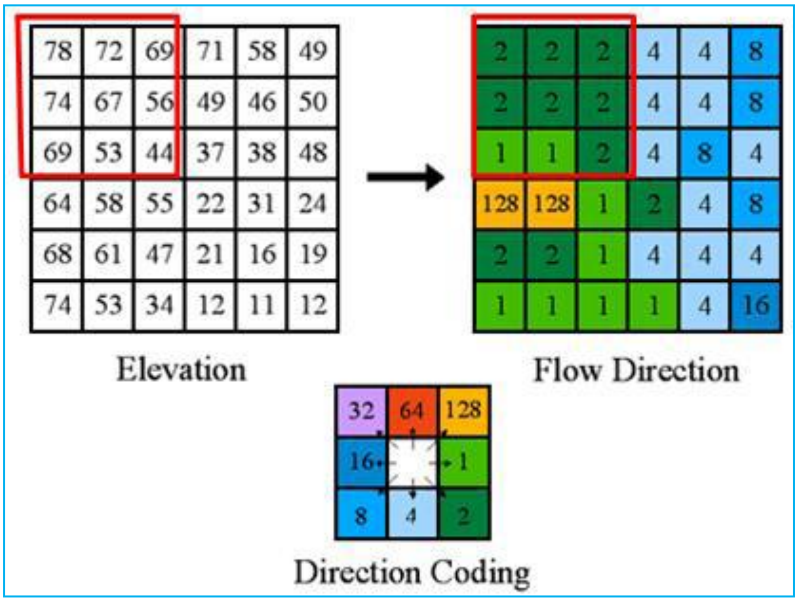


Fig 3.5: Illustration of FLOW DIRECTION in ArcGIS (ESRI Inc. 2005-2012)

The DEM was generated by digitizing the contours in the topographic sheet. Then in the arctoolbox window under the surface analysis select the contours, and then create Triangular Irregular Network (TIN) from features. The final step involves converting the TIN to Raster. Determination of the flow direction from the DEM is the first step in delineating the watershed boundary. A watershed is defined as any land area which contributes water to a common point. Traditional methods of delineation required examining contour maps of the area. The outlet point and all high points surrounding that outlet are identified and marked on the map. A watershed boundary line is drawn which connects all the high points. The boundary line runs perpendicular to each contour line along the path of steepest descent.

Watersheds can be also be delineated by ArcGIS by using a DEM of the area as input. The procedure requires that sinkholes or depression are filled in so that the boundaries are delineated properly. The FLOWDIRECTION function is executed. Conceptually, this function defines which direction water would flow from each grid cells assuming the surface is impermeable. The output from the FLOWDIRECTION function then serves as input for the next step. The FLOWACCUMULATION function describes the drainage network by calculating each cell's contribution to its neighboring cells. Conceptually, each cell will contribute a value of one to its closest neighbor cell along the direction of steepest descent. The values will additively increase along the direction of steepest descent. Cells with high flow accumulation values are typically located where streams or rivers are located. If a specific pour point is chosen along the flow accumulation network, all the cells upstream which contributes flow to that point are identified as being within the watershed. This specific point is called a pour point and is generally placed at intersections of two rivers or at the outlet.

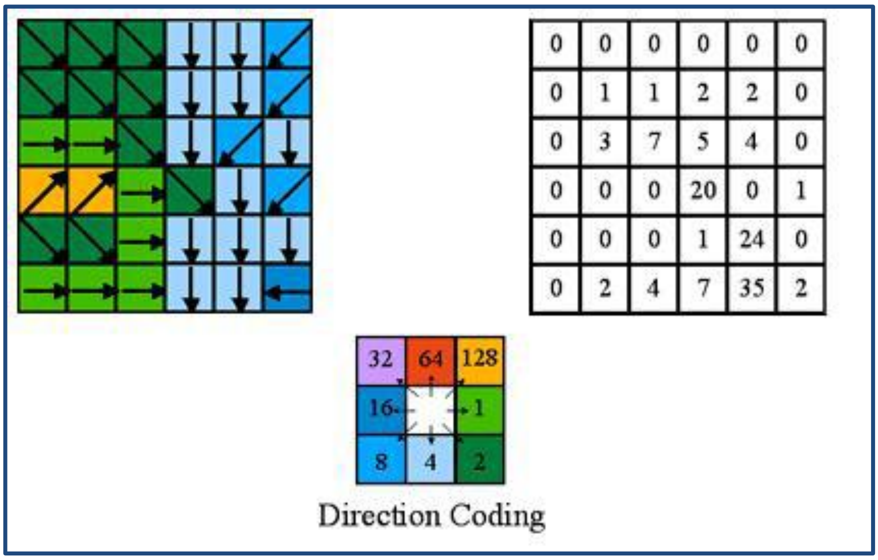


Fig 3.6: Illustration of FLOW ACCUMULATION in ArcGIS (ESRI Inc. 2005-2012)

The final step is to run the WATERSHED function in ArcGIS to automatically delineate the watershed boundary. Once the watershed boundary is delineated from the original DEM, the output data file can be used as a template to cut out, or extract, the exact area from other digital maps. The delineated Taita Hills DEM serves as the base template for the USLE calculations. All the USLE layers will overlap when the resolution of each raster grids are exactly the same (30 by 30 meters) and the geographic projection is assigned by the World

Geodetic System 84 (WGS84). The projection allows the data to be displayed accurately on the computer screen while still being aligned to the real world object that it represents.

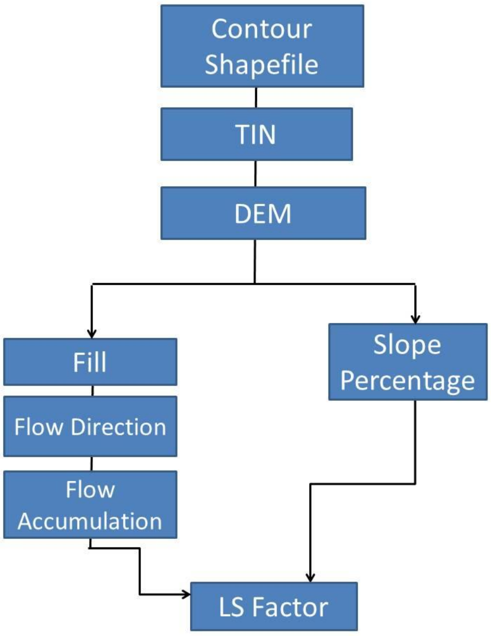


Fig 3.7: The Summary of the generation of LS factor from the DEM

3.3.2 ArcGIS implementation of the LS factor

The major steps taken in ArcGIS 10.1 involves: - TIN was generated using the 3D Analyst function using two themes which were the boundary and contour maps. TIN is a representation of the 3D vector point file. In the next step TIN file was converted to raster file with the grid cell size of 30m x 30m which then becomes DEM. DEM represents the surface terrain of the catchment and permits to retrieve geographical information. Slopes of DEM in percentage were also generated using Surface Analysis under the Spatial Analyst function.

As the first step, the elevation value was modified by filling the sinks in the grid. This is done to avoid the problem of discontinuous flow when water is trapped in a cell, which is surrounded by cells with higher elevation. This was done by using the Fill tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS.

Then, Flow direction was generated from the Fill grid. The Flow direction tool takes a terrain surface and identifies the down-slope direction for each cell. This grid shows the on surface water flow direction from one cell to one of the eight neighboring cells. This was done by using the Flow direction tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS.

Based on the Flow direction, Flow accumulation was calculated. Flow accumulation tool identifies how much surface flow accumulates in each cell; cells with high accumulation values are usually stream or river channels. It also identifies local topographic highs (areas of zero flow accumulation) such as mountain peaks and ridgelines. This was done by using the Flow accumulation tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS.

Finally, Raster calculator function under Spatial Analyst feature was used to input the modified equation to compute LS factor. Themes of slope of DEM in percentage and flow accumulation were activated to run the process.

Mainly the LS was calculated automatically by a C++ programmer. The program is available which automatically processes the DEM input to compute the LS-factor. The program was originally written in ArcMacro Language (AML) (Hickey et al. 2001) and has been updated in 2004 with the C++programming language to be more efficient in processing. These publications can be obtained from the website: http://www.yogibob.com/slope/slope.html. The C++ program can be downloaded from The C++ program can be downloaded from the website: http://www.iamg.org. A link to all published program code is located on the right hand side of the website under "Computers & Geosciences". The publication by van Remortel et al. 2004 as published on Volume 30 of Computers and Geosciences. Select volume 30, 2004 and scroll down the list until the publication description appears (Figure 3.8).

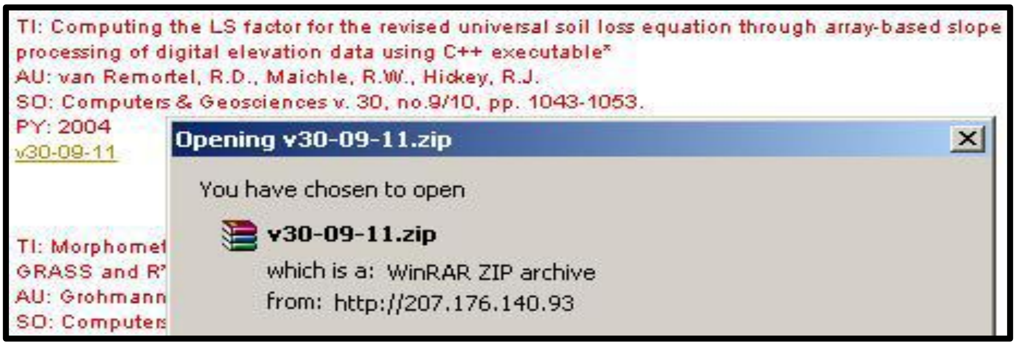


Fig 3.8: Click on v30-09-11 to bring up a download menu for the C++ program.

After downloading and uncompressing the package, the C++ executable program along with the source code files are accessible. To run the program, the DEM input needs to be in text format called ASCII. ArcMap has the function to do this located under the Conversion toolbox extension. Select the “From Raster” extension and select the “Raster to ASCII” tool. In the menu, navigate to the DEM to be converted and note the location of the output ASCII text file. Edit the output file into a short, easily recognizable name. After the conversion, double-click on the C++ executable program to run it. A series of command lines appears. The first line asks for the user to enter the path and filename for the DEM data, which must be in ASCII text format. Enter in the full path to the text file in the form of C:\Folder name\ name of file with .txt suffix. A second line then asks for the path where all the output files should be placed. Specify this path to lead to the appropriate folder. The third line asks the user to enter a short prefix for the output files. The prefix can be no longer than four letters. The fourth line asks if intermediate files should be produced during the computation process. Select “YES” to see each intermediate output file.

DESCRIPTION OF C++ PROGRAM’S OPERATION

A brief description of the C++ executable program’s operation is given. The program begins with a fill function on any depressions or sinks found on the DEM input.

The highest elevation points on the DEM are then identified by the program and the flow direction is determined. Conceptually, if rainfall lands on a high point, the direction of flow can be in either one of the cardinal directions (i.e. N, S, and E, W) or the diagonal directions (i.e. NE, SE, SW, NW). In situations of converging flow, the flow direction of steepest descent takes precedence. The distance between the centers of one grid cell to the next grid cell is then calculated by the C++ program as the non-cumulative slope length (NCSL).

The assumption is that deposition would begin in areas where the slope angle decreases sufficiently enough so that overland flow can no longer transport sediment. The program has a function called the cutoff slope angle and is defined as the ratio of change in slope angle from one grid cell to the next along the flow direction. These values are based on observations that deposition are easier to initiate on slopes with low gradients (Van Remortel et al. 2004). When the slope angle decreases sufficiently, the cumulative slope length calculation stops. If the land surface extends further downhill, the calculations begin again.

The C++ executable program applies the LS factor equations to each grid cell of the DEM input. The primary files used in the computation of the LS factors have the following file suffixes: slp_ang for the slope angle of each grid cell, slp_len for the cumulative slope lengths, and slp_exp which contain the slope dependant exponent m that each grid cell is raised to in the L factor equation. This is shown below in **Fig** 3.9

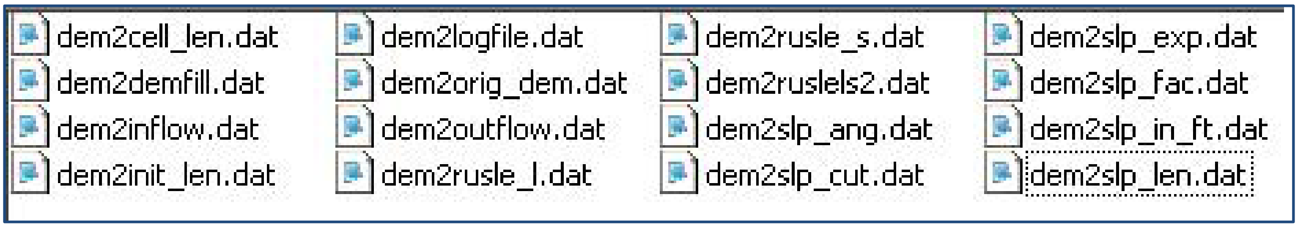


Fig3.9: Output files from the C++ program

To convert the output files back to a raster format, the file suffix must be .txt in order for ArcMap to recognize it. This can be done simply by right-clicking on each output file and selecting "Rename." By changing only the suffix from .dat to .txt accomplishes the conversion. Open ArcMap and select the "ASCII to Raster" tool under the Conversions toolbox. Individually convert the output files with the suffixes –rusle_l, –rusle_s, and –ruslels2 to import the *LS* factor as a raster layer

3.3.3 ArcGIS implementation of Soil Erodibility Factor K

For this study, K factor was not produced from the soil equation. The Taita Hills soil map shapefile was obtained from the Department of Agriculture. After the soil map shape file was added as a layer into ArcGIS, the soil map attribute table was edited with adding a new field of K values under the Edit menu at attribute view. Then under conversion in spatial analyst the feature (soil shapefile) using K as the field it was converted to Raster.

The K factor used for Clayey comprised of sandy clay, silty clay and clay texture classes was 0.01 and for Loamy comprising loam, sandy clay loam, clay loam, silt, silt loam and silty clay loam 0.042; these values were adopted from the K factor list from the Department of Agriculture, 2010. This is as shown below

Object Id	Soil drainage	Soil drainage description	Clay	Texture
1	E	Extremely slow	Kaolinitic	Clayey
2	R	Rapid	Montmorillonitic	Clayey
3	S	Slow	Montmorillonitic	Clayey
4	S	Slow	Montmorillonitic	Clayey
5	W	Slow	Kaolinitic	Loamy
6	W	Well	Kaolinitic	Loamy

Table3.3: The soil texture and soil drainage of Taita Hills

Where

(C) Clayey ---sandy clay, silty clay and clay texture classes

(L) Loamy---loam, sandy clay loam, clay loam, silt, silt loam and silty clay loam

The present drainage of the soil component described according to one of the classes mentioned below (after FAO, 2010)

(E)- Excessively drained- water is removed from the soil very rapidly

(S)-Somewhat excessively drained-water is removed from the soil rapidly

(W)-Well drained-water is removed from the soil readily but not rapidly

(R) Rapid:-excess water drains rapidly even during periods of prolonged rainfall

3.3.4 ArcGIS implementation of Cover management factor (C) and Support practice factor (P).

The land cover information was developed from the Landsat image of the study area taken in July 2011 using Idrisi Kilimanjaro software. The supervised classification was carried out as follows. First, the training sites were identified. Four training sites were identified

- Agriculture
- Forest
- Scrubland
- Bare ground

Collecting Training Areas for the classification Algorithm

The Signature Editor in Idrisi Kilimanjaro allows creation, management, evaluation and editing of the signatures. Parametric rule was used for the signatures (that is to say, assuming that statistically, the training data have normal distribution). The AOI tools were used to collect signatures from the image to be classified.

Selecting classifier>signature Editor from Idrisi Kilimanjaro open the signature editor tool under it select view in columns and in the view Signature Columns dialogue select all rows. The AOI tools was used for the selection of the areas in the image to be defined as training areas, and therefore used to collect spectral signatures. Before the actual classification, an evaluation of the separability between signatures was undertaken. This was done using Signature separability (Utility which computes the statistical distance between signatures that can be used to determine how distinct the signature is from one another. Hence the process was run twice, first considering all 6 bands at once and then considering 3 bands at a time). From this method it was found that different land cover has different reflectance value. The forest has a different reflectance from the Agriculture hence using these; the polygons were digitized for the four different training sites. From this, the training sites polygon was then drawn by the AOI polygon.

The actual classification was done as follows: in the signature Editor, a command Classify>Unsupervised was issued which opened Unsupervised classification dialogue. Then output image specified and parametric rule set to maximum likelihood. After the classification process a reduction of noise was done by filtering process which involved Raster>Filtering>statistical filtering using majority filtering function from the drop list and applied using 3×3 pixel window.

From the training sites identified in the Landsat TM 2011, they were used to generate the C and P factor. Hence to produce the C and P factor, the land use shape file was added to ArcGIS 10.1 from Idrisi Kilimanjaro. C and P factors were generated the same way as K factor by auditing the attribute table. The land use attribute table was edited with adding a new field of C and P values under the Edit menu at attribute view before the C and P factor was produced. The values of C were adopted from the Department of Agriculture. For this study, P values were chosen based on the land use instead of soil management.

3.3.5 ArcGIS implementation of Rainfall Erosivity Factor R

After data collection, R factor was determined for year 2011 for all selected rainfall gauge stations using the equations listed above. The data collected annually at different location within the study Area. The rainfall data was used to generate the R factor which is the measure of the total annual erosive rainfall for a specific location, as well as the distribution of erosive rainfall throughout the year. The R factor is affected by storm energy and intensity, the amount of rainfall, and runoff that occurs during different seasons of the year. Most of the time rainfall intensity and storm kinetic energy are not available at KMD. By the absence of rainfall intensity and storm kinetic energy for this study area, the annual rainfall data have been used to estimate R factor.

3.3.6 ArcGIS implementation of RUSLE.

The five factors, K factor, R factor, LS Factor, C factor and P factor are overlaid by multiplying it in the spatial Analyst in Map Algebra where we have Raster Calculator. This is as shown in Fig. 3.10 Basically the most contributing factors are R factor alongside LS factor

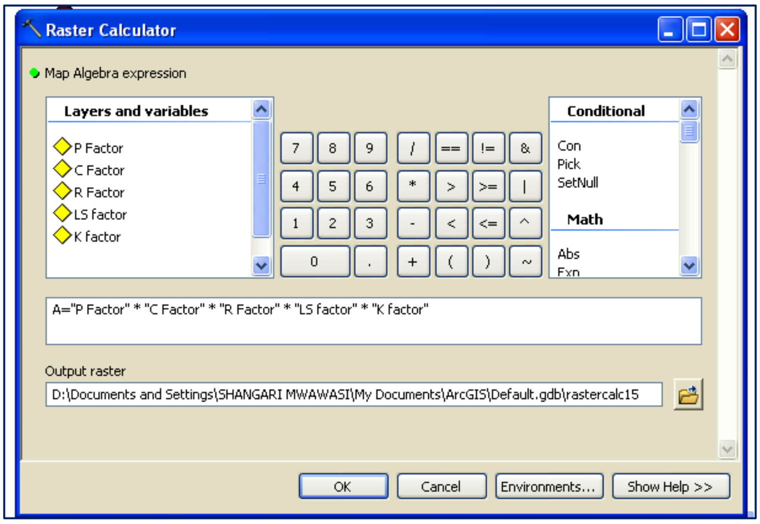


Fig 3.10: Showing RUSLE factors in the Raster Calculator in ArcGIS 10.1

Finally each location was assessed to show which was greatly affected by soil erosion. Each location‘s boundary was digitized. Since the final RUSLE map was a raster, extraction by mask was used. The tool required the raster to be put as the main input. The Raster in this case was the soil erosion risk map. The shapefile was what was used to extract the raster of a particular location. Here the shapefiles were Werugha, Wundanyi, Chawia, Rong'e Shaghasa, Mwanda, and Mbale boundaries' shapefiles. The process was repeated for all the seven shapefiles as the tool takes one shapefile at a time. The Final values from each class were put in an excel sheet and a graph was produced.

3.4Sub Rating Method

3.4.1Rainfall Ratings

Moore (1979) stated that the Rainfall Erosivity Factor in Kenya is strongly related to the Kinetic Energy of 15 minutes for rainfall intensities of over 25mm/hr. The area with the most rainfall erosivity value was assigned the highest weight of 4 while the lowest was assigned 1.

The Kinetic energy produced by the impact of raindrop was able to detach soil from the ground hence the higher the kinetic energy the more soil was detached from the ground.

From the rainfall shapefile another field of rainfall Erosivity was added and using the formulae of calculating Rainfall erosivity the values were calculated by the Field calculator.

Then in the Arctoolbox box the conversion tool was selected. The Rainfall feature class was converted to raster. Having the raster, weighting the classes was paramount. So in the Spatial Analyst the reclassify under classify was chosen. The various classes were then assigned weight according to the way they contributed to soil Erosion with the value that mostly contributed to soil erosion being given the highest value.

3.4.2 Slope Factor

The slope factor is also a major contributor to soil erosion. The Area with the most slope percentage rise was assigned the highest value. Having the DEM as the input, the slope percentage was generated. The class with the highest slope percentage rise was given the highest weight.

In the Spatial Analyst, the Reclassify tool under the classify tool was chosen. The Slope factor raster was chosen as the input raster. The various resulting classes were then assigned weight according to the way they contributed to soil erosion with the slope factor value that mostly contributed to soil erosion being given the highest value.

The highest slope factor value was assigned weight value of 5 while the lowest slope factor was assigned weight value of 1.

3.4.3 Land Use

Having the land use shapefile previously created, the shapefile was converted to raster by going to the arctoolbox and under conversion; feature to raster tool was chosen. The feature class was selected and converted to raster. The reclassify tool in the spatial analyst was used to assign weight. Then the bare ground was given the highest value of four as it was the main contributor to soil erosion, and forest being given the lowest value as soil erosion is low where there is land cover. The roots hold the soil together and also reduce the kinetic energy from rainfall drops using their leaves hence soil erosion in the forest was given a lower weight of 1.

3.4.4 Soil Texture

Taita Hills is made up of Loamy and Clayey type of soil. Soil texture also determined soil erosion. Clayey soil is more resistant to soil erosion than the loamy soil. The soil shapefile was to be converted to raster. Using texture as the field during conversion from feature, the shapefile was converted to raster. Then in the reclassify under the classify tool the loamy soil was assigned the highest weight of 2 as it was more susceptible to soil erosion than Clayey which was assigned the weight value of 1.

3.4.5 Sub rating overlay

This was done using the overlay weighted sum tool in the overlay function under the spatial analyst of ArcGIS 10.1.

Soil erosion Map= Land use sub rating map + Soil Texture sub rating map + Rainfall Erosivity Factor sub rating factor + Slope Sub- rating map.

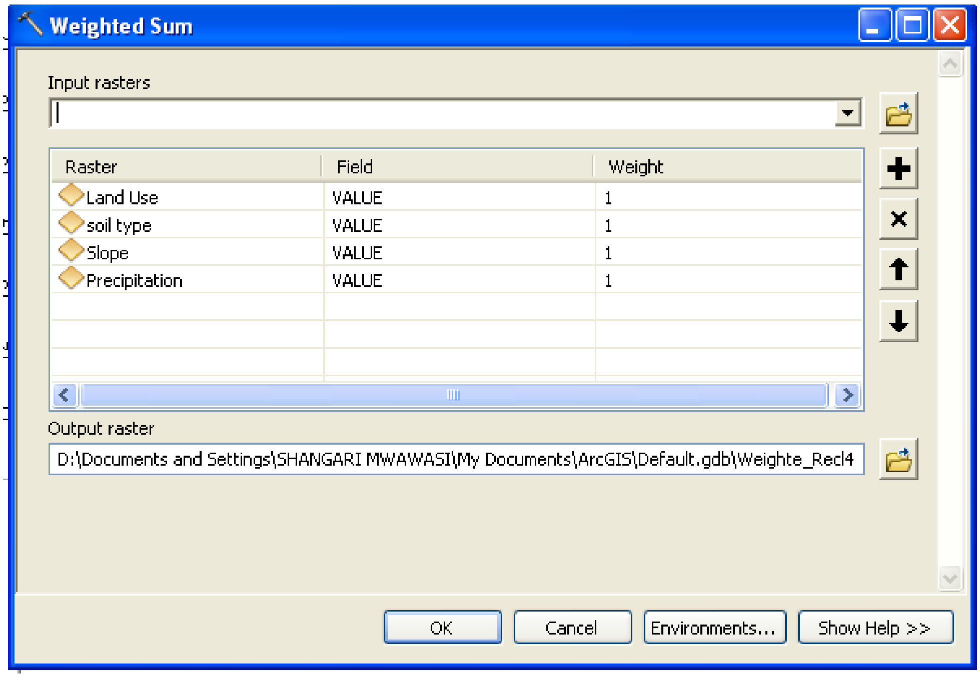


Fig 3.11: Showing weighted sum tool for sub-rating method in ArcGIS 10.1

CHAPTER 4

4. DATA ANALYSIS, RESULTS AND DISCUSSION

4.1Calculation of RUSLE factors

4.1.1 The LS Factor

The LS factor accounts for the effect of topography on erosion in RUSLE. The slope effect L represents the effect of Slope length on erosion and the slope steepness factor (s) reflects the influence of slope gradient on erosion. The maximum value of slope length is 62 while minimum is 1. The maximum slope percentage rise is 74.71% while minimum is 0%.Following the Methodology given in chapter three the results are as shown in Fig 4.1.

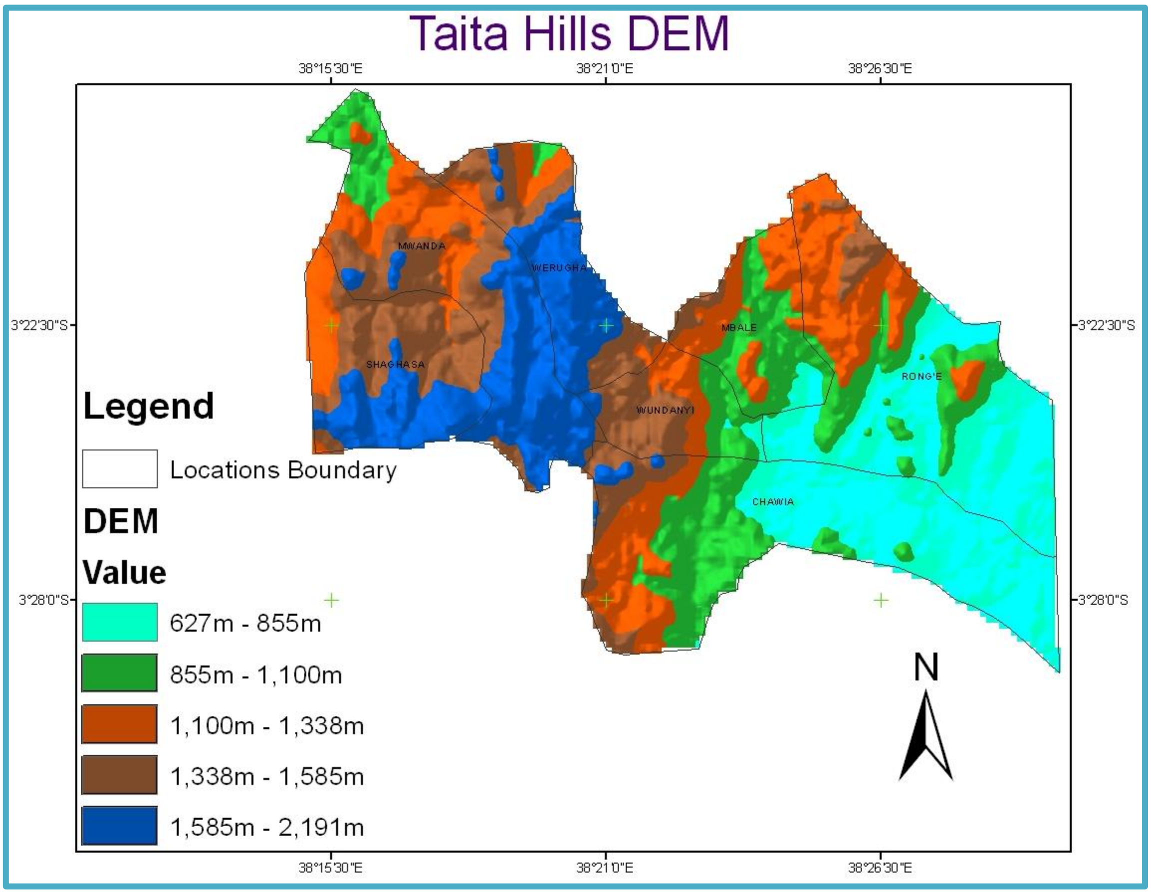


Fig4.1: Taita Hills DEM, main input for the generation of LS Factor

The Slope Length and Slope Steepness factor (LS) is dimensionless. The regions with the highest values of 35meters to 62 meters are more susceptible to soil erosion than those with the least values of 1 to 7. The minimum LS value is 1. The maximum is 62. The minimum is 12.9 and the standard deviation is 8.76.

It can be deduced that the northern part of the study area, from the slope percentage map, has the highest value 74.71% .The northern regions of the study area with high slope percentage rise are more susceptible to soil erosion than the southern regions. From this you can conclude that slope factor is one of the major factors that cause soil erosion.

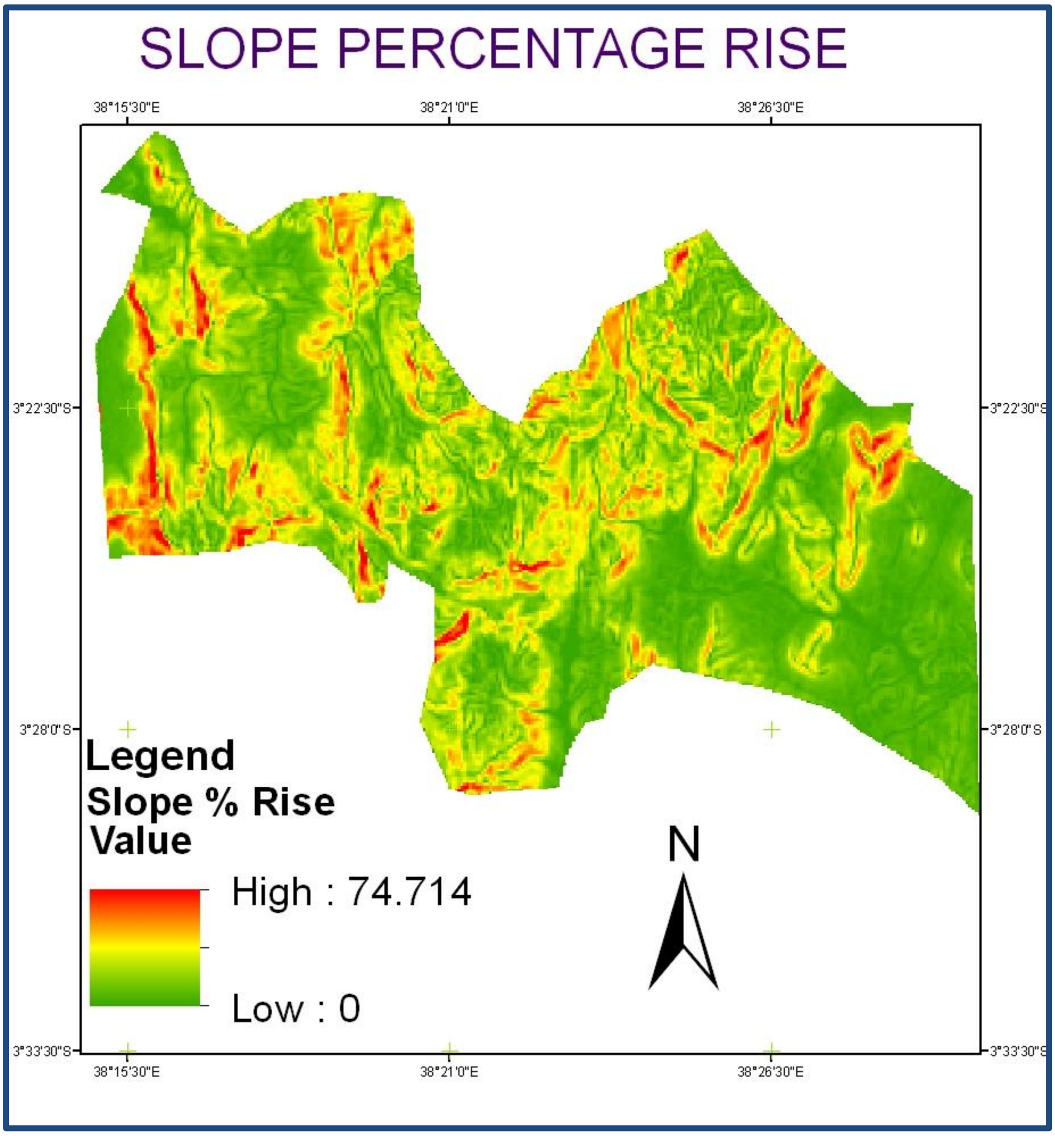


Fig 4.2: Map showing slope percentage rise in Taita Hills

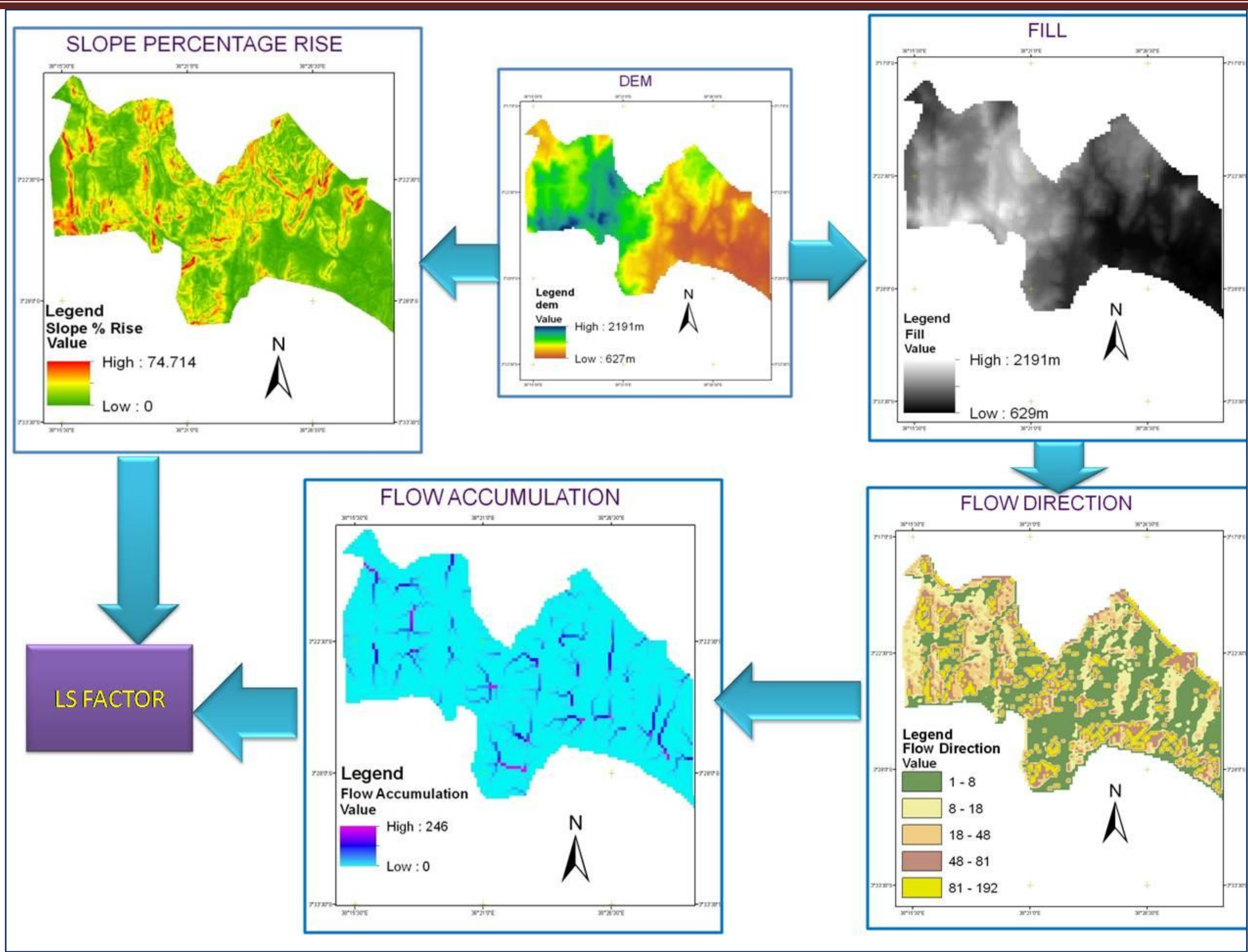


Fig 4.3: Maps showing how LS factor is Derived from DEM

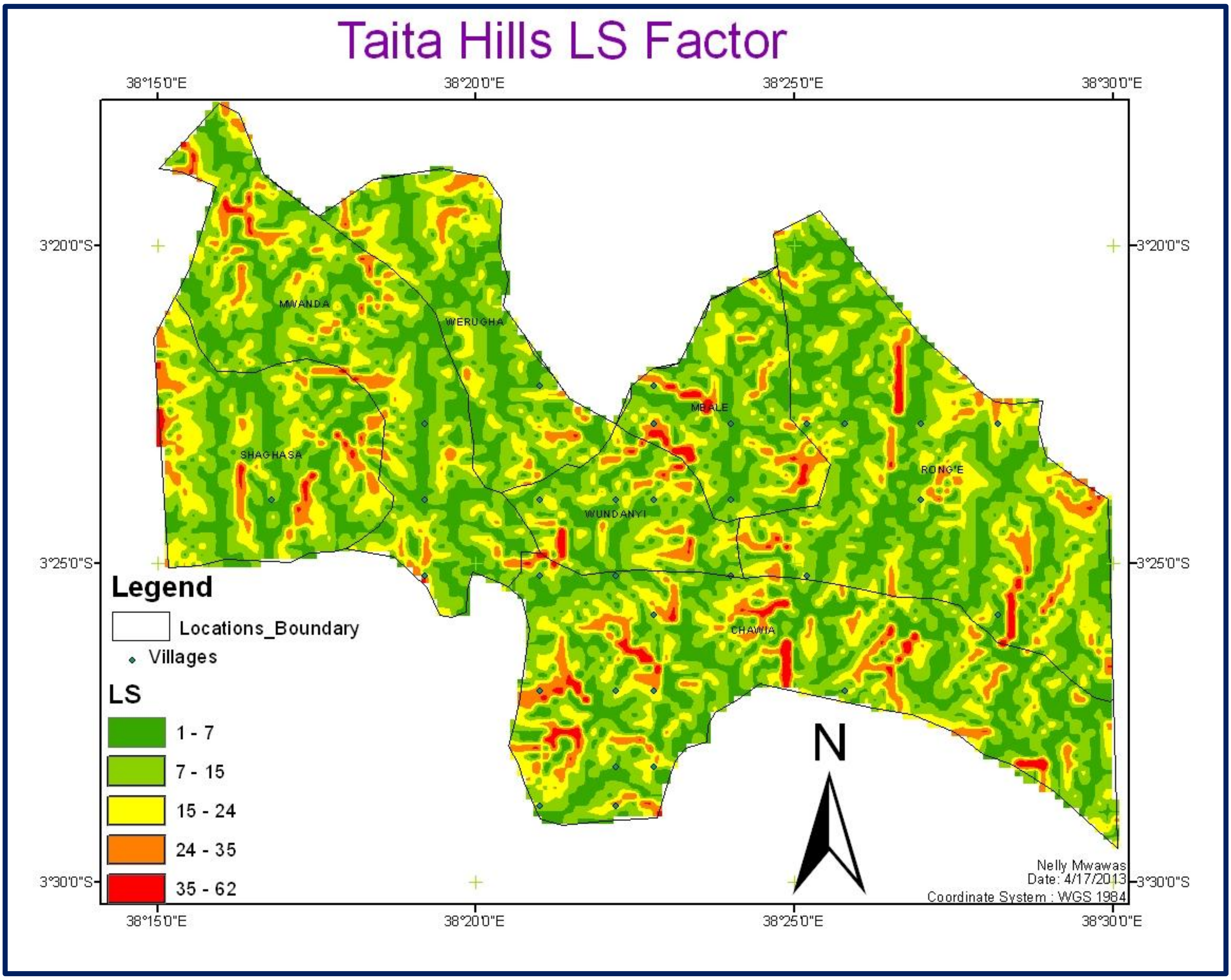


Fig 4.4: Map showing LS Factor

4.1.2The K Factor

The K factor is based on the soil texture. In Taita Hills the soil texture was mainly that of loamy and clayey. Clayey type of soil is more resistant to soil erosion than the loamy soil. Hence from the table in the literature review the loamy soil is assigned the highest value of 0.042 while the clayey soil is assigned 0.018. Following the methodology in chapter three the results are as shown in Fig 4.5

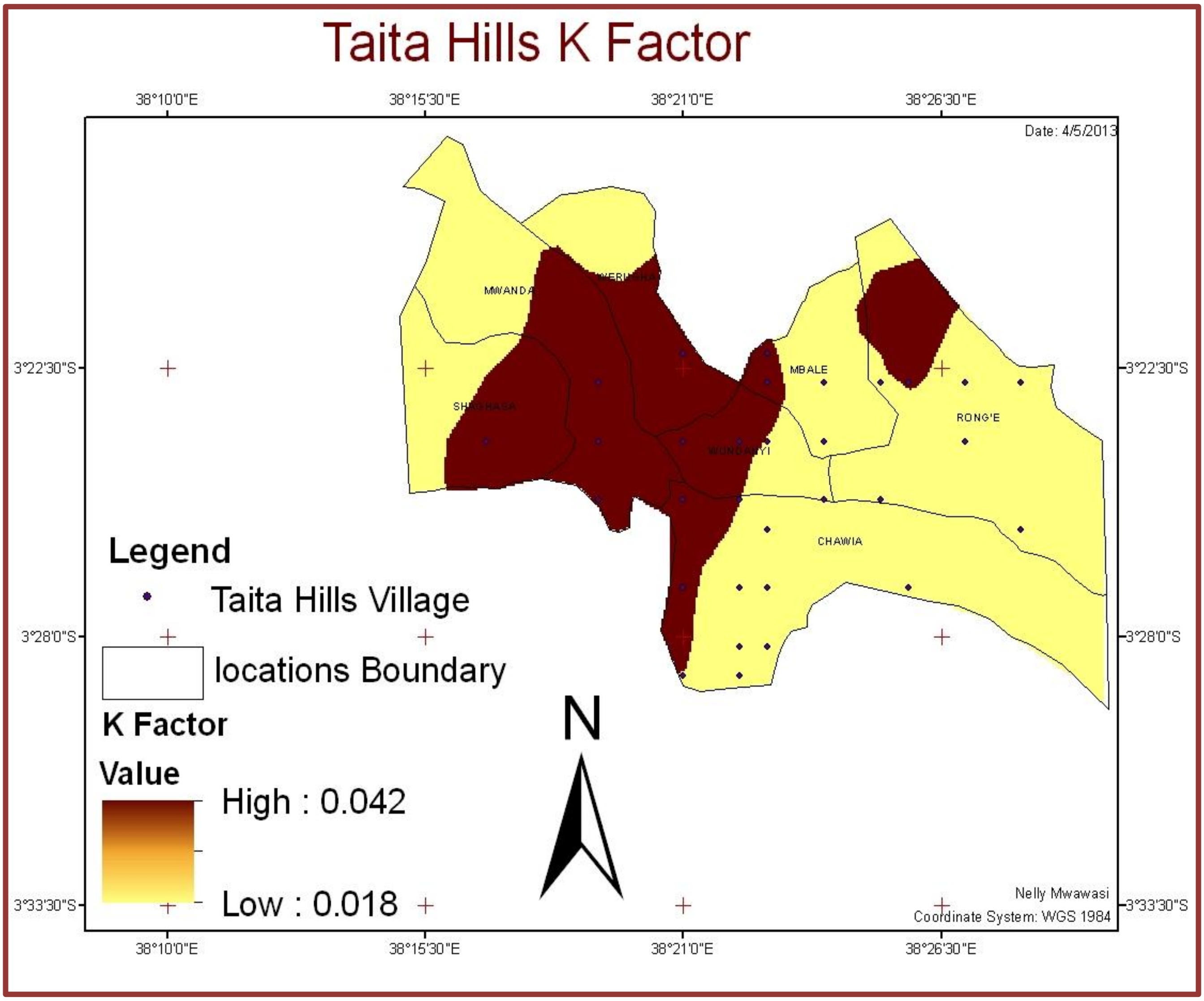


Fig 4.5: Map showing K factor of Taita Hills

4.1.3 The C factor

After supervised classification, of the Landsat TM 2011, it gave rise to four main classes which were: - agriculture, scrubland, forest and bare ground. Using the Agriculture handbook the values were added in the attributes table of land use shapefile. Using the C factor as the field during the conversion of feature class to raster the land use shapefile was converted to raster. The C factor was high for areas with less crop cover. This is seen below. The areas with high C factors are more susceptible to soil erosion than the ones with low C Factor.

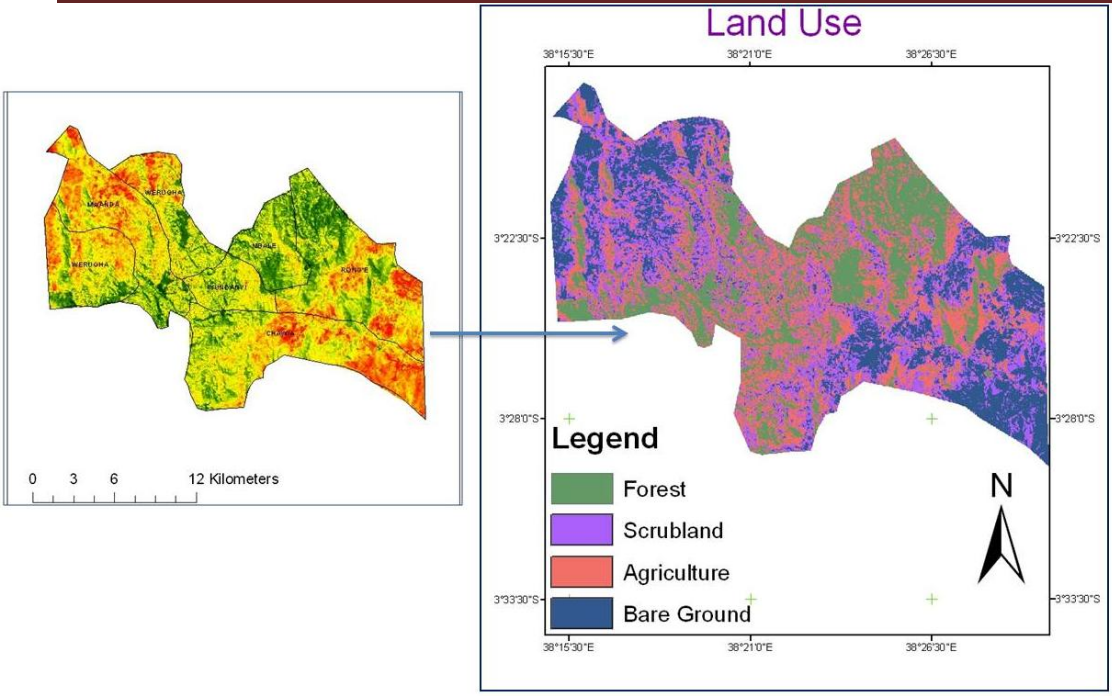


Fig 4.6: Map showing Landsat TM and Map after land use classification

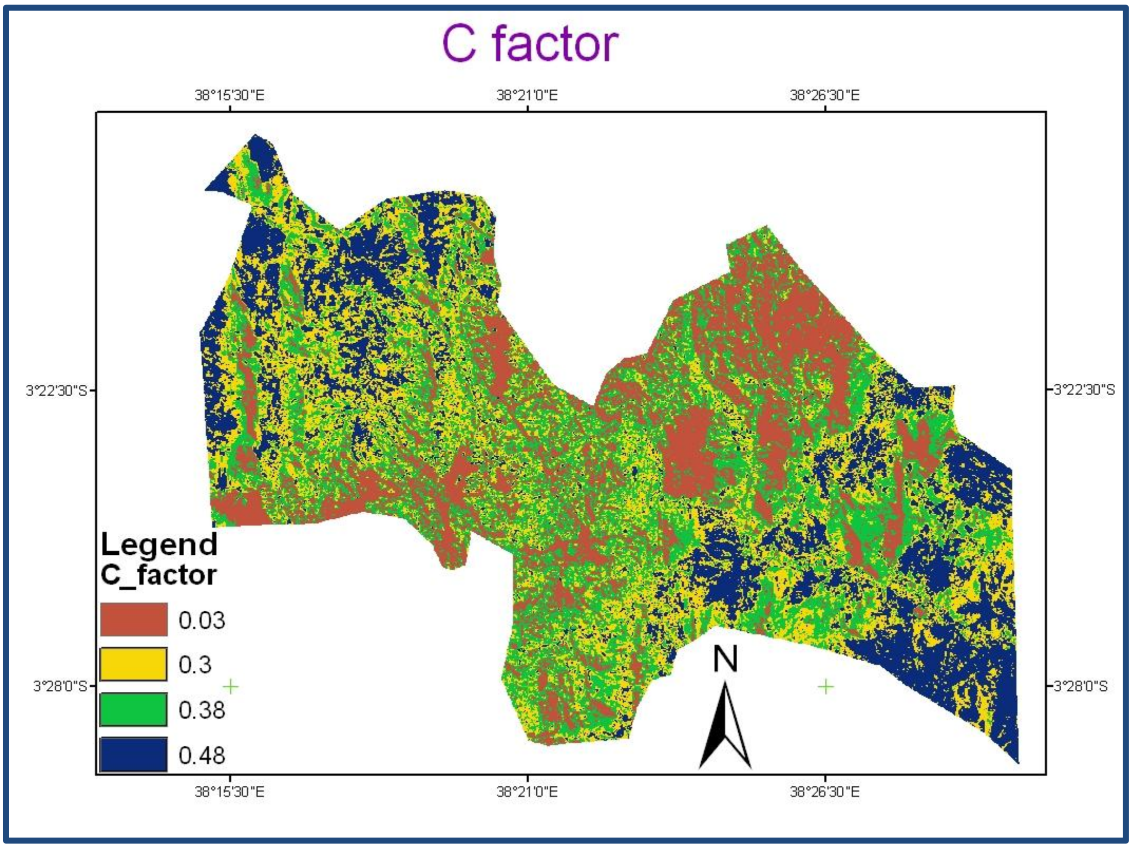


Fig4.7: Map showing C Factor based on land use classes

4.1.4 The R factor

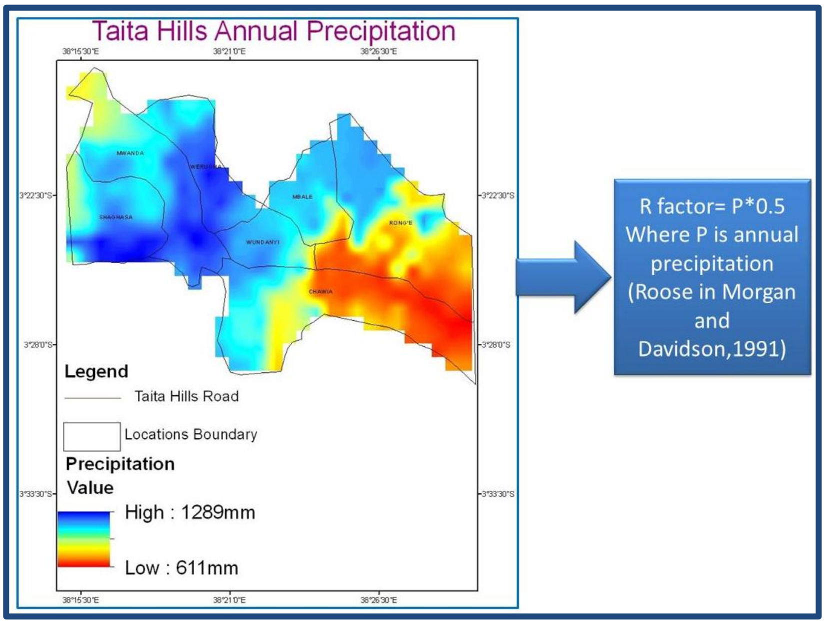


Fig 4.8: Map showing Taita Hills Annual precipitation

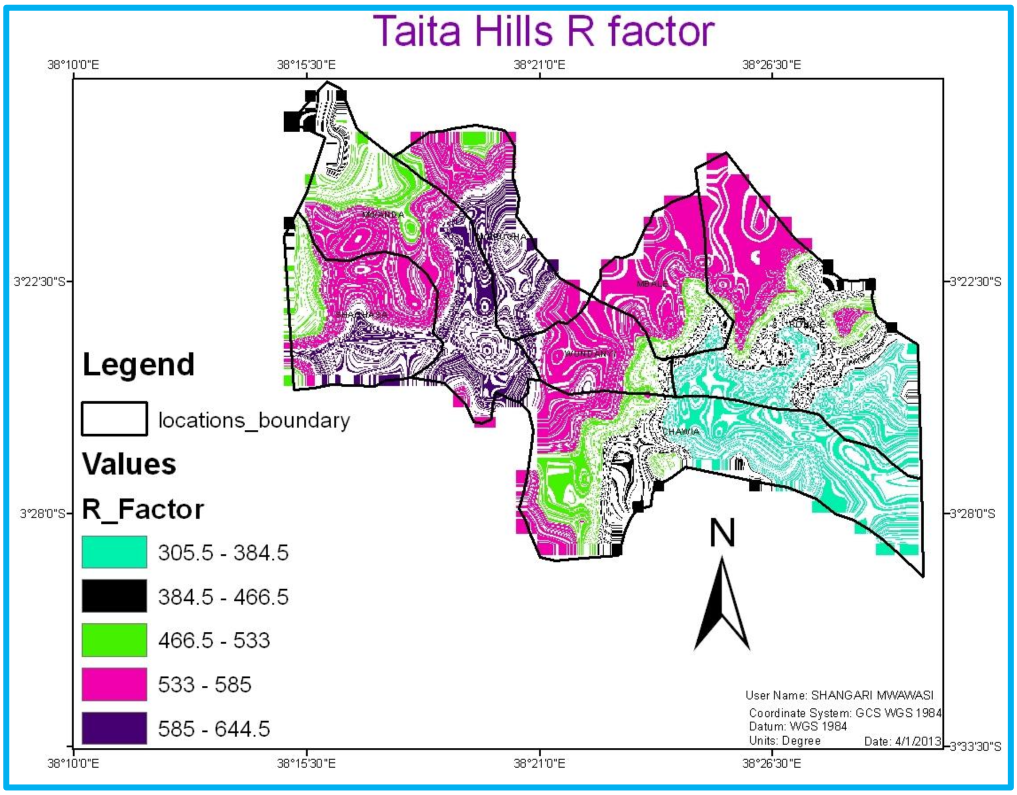


Fig 4.9: Map showing R Factor of Taita Hills

Following the formula by (Morgan and Davidson, 1991) the final R factor is as shown in **Fig**. 4.9

4.1.5 The P Factor

This crop practice management was based on land use since there was no detailed crop management practice available for the study area. Instead the land use class was used. Using the P factors given in the literature review, **Fig** 4.10 was derived.

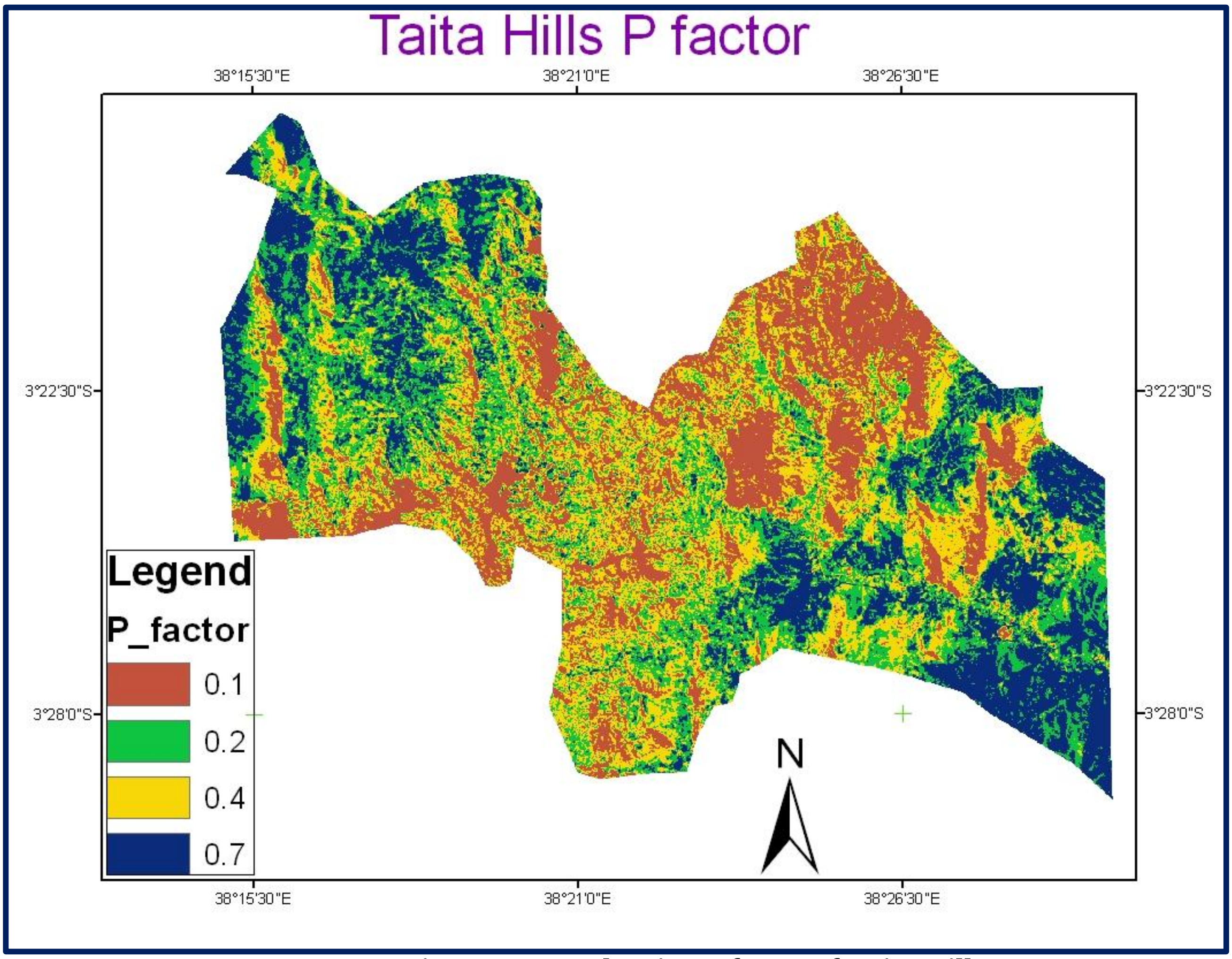


Fig 4.10: Map showing P factor of Taita Hills

4.1.6Soil Erosion Risk Map by RUSLE method

The final quantitative RUSLE values show the quantity loss of soil in tons/ha per year, ranging from less than 1to very high soil loss rates (563.9tons/ha/year). The mean annual soil loss in Taita Hills is 69.31tons/ha/year. The standard deviation is 90.86tons/ha/year. The minimum soil loss is 0.51tons/ha/year. The spatial locations of the high spot area for soil erosion in the study revealed that the potential soil loss is typically greater along the steeper slope of the Taita Hills.

The soil lost in tons/ha/year was then converted to depth of soil lost in mm/year. The conversion was by dividing the amount of tons/ha/year by specific gravity of 2.67tons/m^3, the specific gravity of clayey soil. This is because the study area is mostly covered by clayey type of soil. The resulting volume is then divided by the area that is 10,000m^2 to give the depth of soil in meters then converted to millimeter by multiplying by 1000.
The table below shows the quantity of soil lost in tons/ha/year and how it was classified to soil erosion risk classes. It also shows the depth of top soil lost in a year in mm. From the final Soil Erosion Risk Map it is shown that the areas with bare ground in the southern part of the study area were least affected as they were on an almost leveled ground this shows that slope is one of the major factors alongside rainfall erosivity factor R. Other high soil erosion areas are dispersed throughout the Mwatate river basin and are typically associated with high erosion potential.

Soil Erosion Risk Class	RUSLE values tons/ha/year	Depth of top soil eroded in mm/year
Very High	315.0 - 563.9	11.790- 21.120
High	175.70 - 314.9	6.580 – 11.785
Medium	91.72 -175.69	3.400- 6.575
Low	34.12 - 91.71	1.280- 3.350
Very Low	0.51 - 34.11	0.019- 1.275

Table 4.1: Table showing Soil Erosion Risk Classes based on RUSLE values

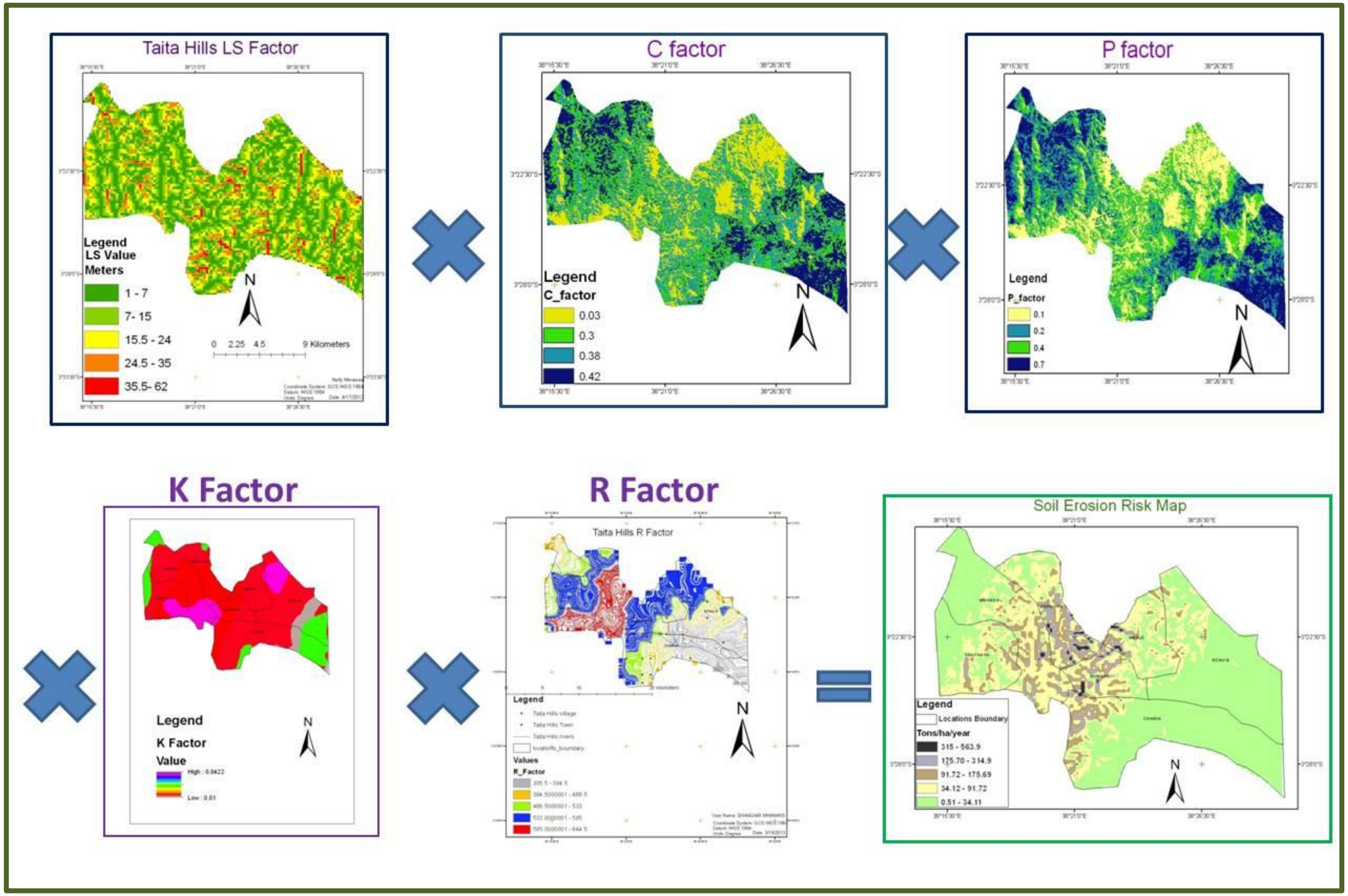


Fig 4.11: RUSLE Equation to produce the Annual Soil Loss Map

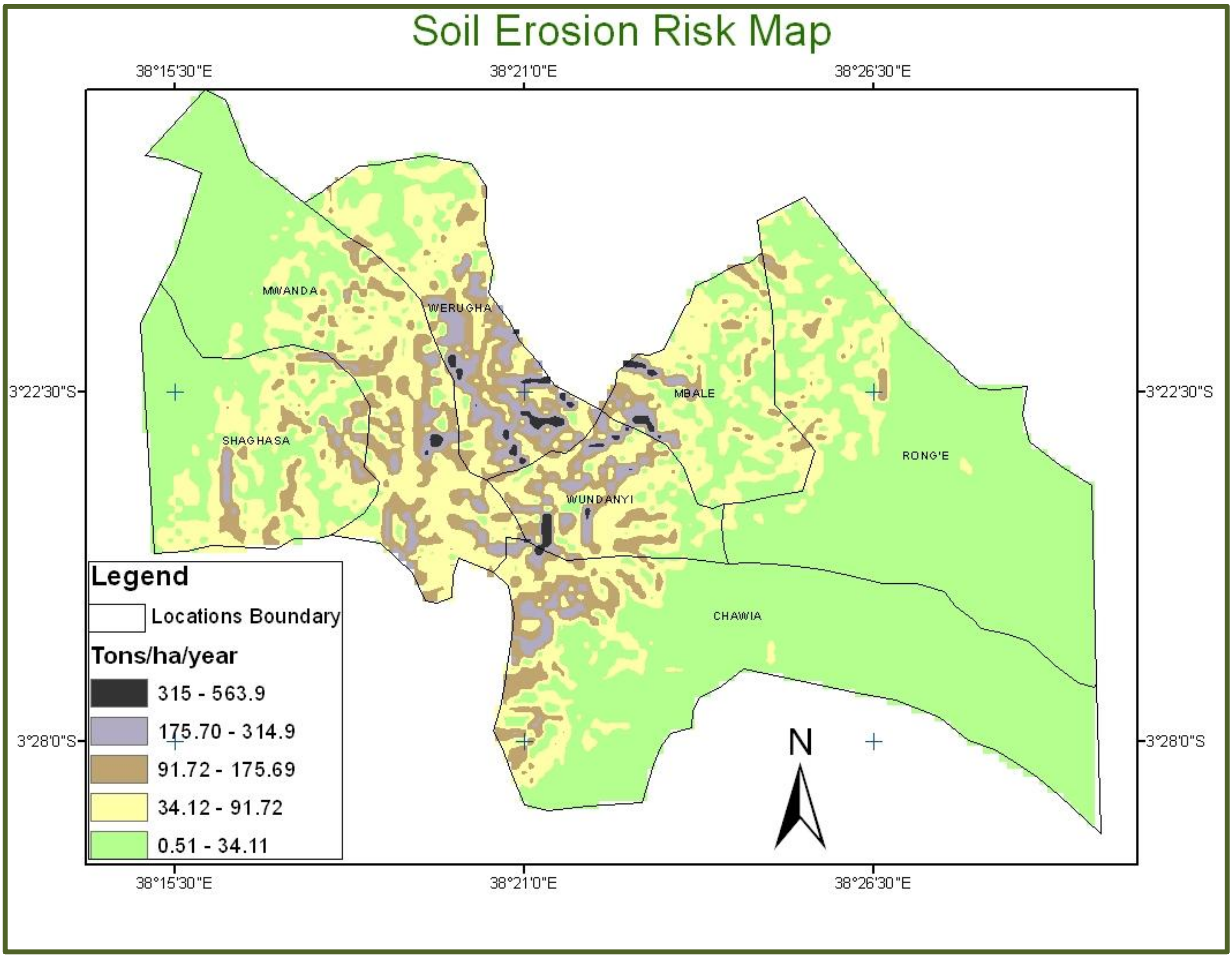


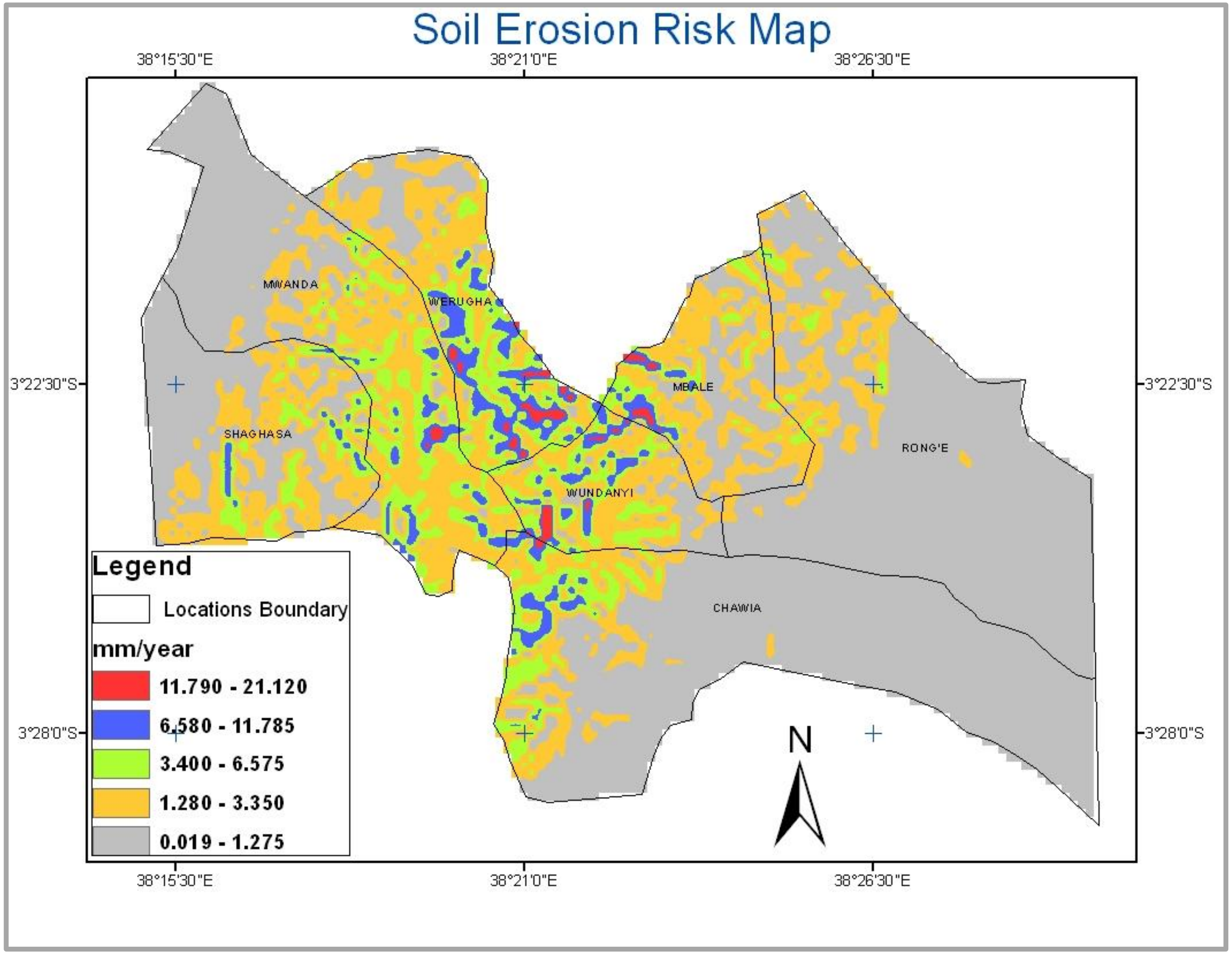
Fig 4.12: Map showing quantitative soil lost to erosion in Tons/ha/year

Fig. 4.12represents the quantity of soil lost in tons/ha/year. Fig 4.13 shows the depth of top soil carried off from the ground. From this map the highest depth of soil carried off in a year is 21.120mm while the least is 0.019mm of soil.

For ease of interpretation, the values of erosion potential were divided into 5 classes as shown in **Fig.** 4.12.

From the map the black color shows region losing more than 550 tons/ha/year.

Fig 4.13: Map showing soil lost in mm/year



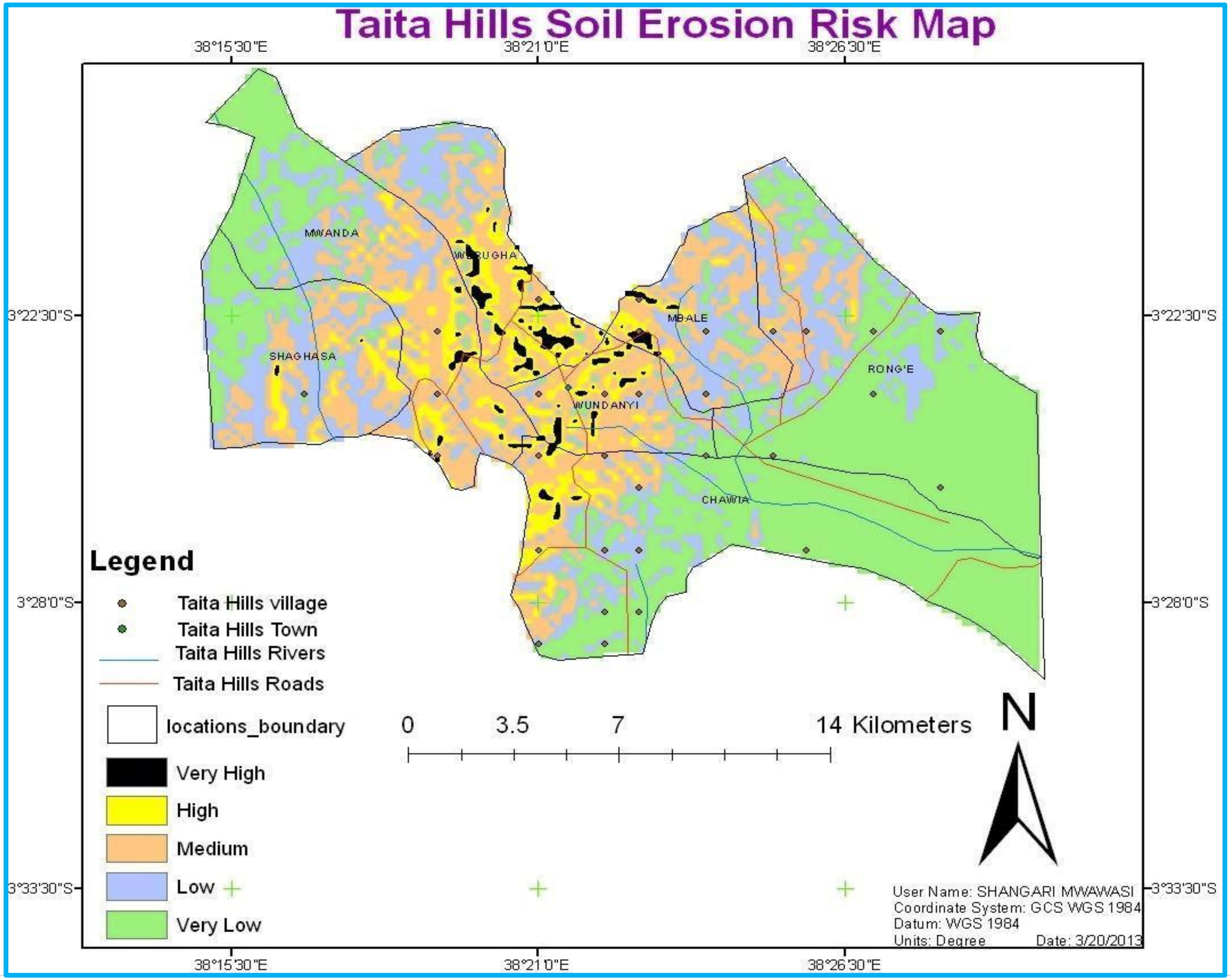


Fig 4.14: Soil Erosion Risk Map of Taita Hills using RUSLE method

From **Fig** 4.12 the soil erosion of each location was created by extracting the required location from the raster using the extraction by mask tool in the spatial analyst. Using the Fig 4.12as the input raster and using the locations shapefile as the feature the soil erosion of each location was generated. The Table below shows soil erosion per location. The series present the various classes of soil erosion per location. From this Werugha was found to be the location greatly affected by soil erosion. This was followed by Wundanyi, Mbale, Mwanda, Shaghasa, Chawia and finally Rong'e with the least. The amount of soil lost is high for this reason farmers are advised to use terraces or do contour stripping to reduce the slope inclination hence preventing soil erosion.

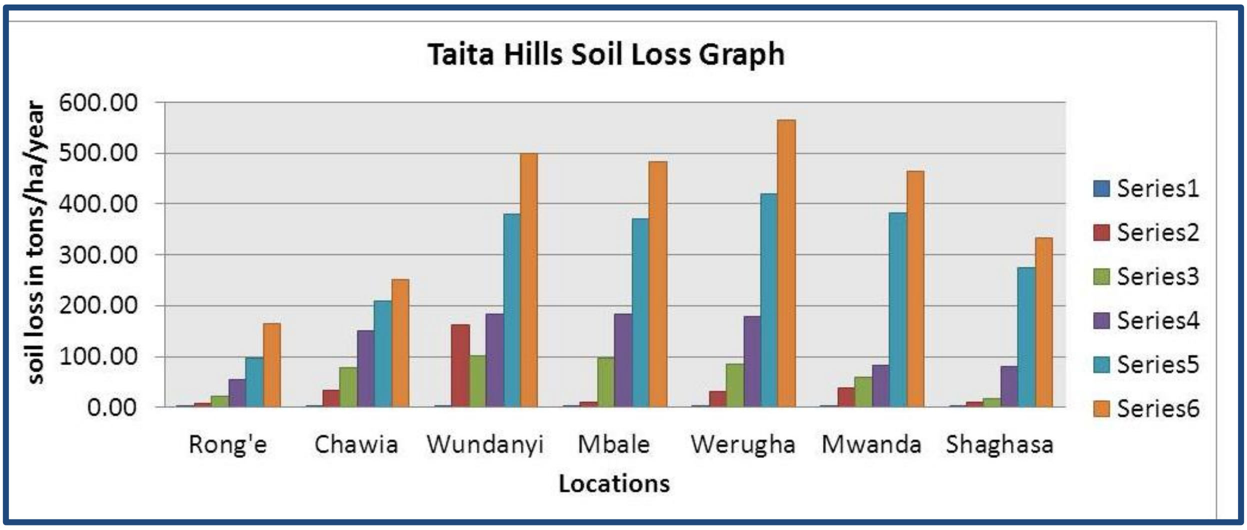


Fig 4.15: Graph showing soil loss in tons/ha/year per location

From the final soil erosion risk map (Fig.4.14), it is shown that the areas with bare ground in the southern part of the study area were least affected by soil erosion as they were on an almost leveled ground. This shows that slope is one of the major contributing factors alongside rainfall erosivity factor R.

Also from the soil erosion risk map it is seen that part of the roads are in regions that are mostly affected by soil erosion. This hinders farmers in the study area from selling their farm products.

From Fig 4.15 it can be said that slope is one of the greatest contributing factors since Rong'e location even though it comprises of a higher percentage of bare ground it still has the least amount of soil lost. This is basically because the location is on a place where the slope is not that steep.

4.2 Soil Erosion Risk Map by Sub rating Method

4.2.1 Rainfall Erosivity Factor (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). Rainfall erosivity factor is one of the main contributors to soil erosion. From the map the areas with the highest R factor are more susceptible to soil erosion hence given 4.

Rainfall erosivity Factor	Sub-rating	Rainfall Erosivity Factor Class
305.5 - 394	1	Very Low
394. 5 - 492	2	Low
492.5 – 577.5	3	High
577.5 – 644.5	4	Very High

Table 4.2: Shows rainfall erosivity class and how it contributes to soil erosion

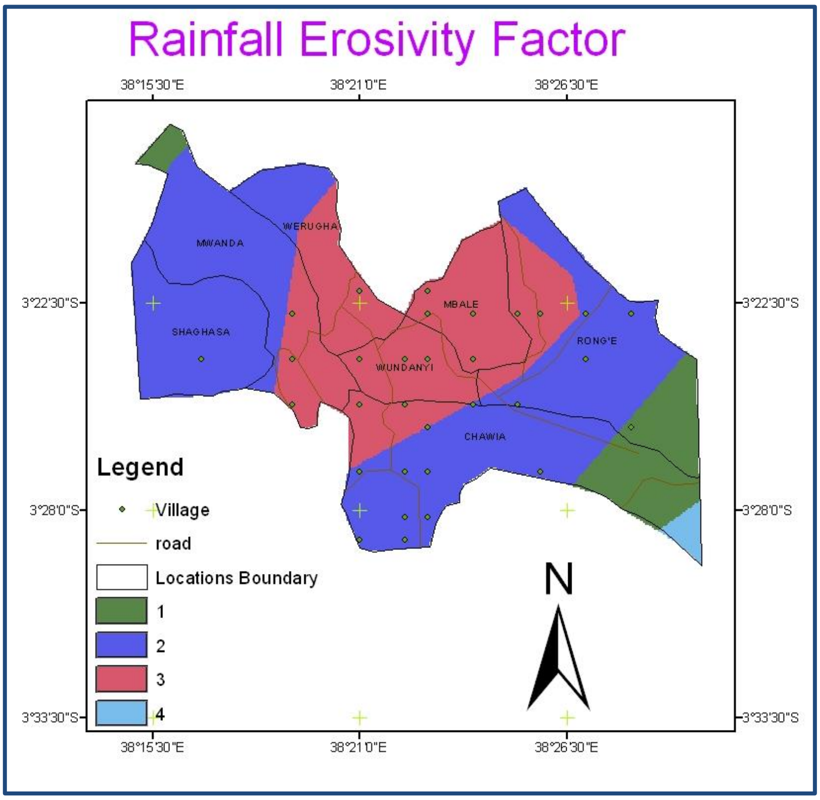


Fig 4.16: Map showing Rainfall Erosivity Factor classes and their weights

4.2.2 Slope Factor

The areas with the highest slope value were assigned the highest weight value as they were more susceptible to soil erosion.

Slope Factor in meters	Sub-rating	Slope Factor class
627 - 855	1	Very low
855.01 - 1100	2	Low
1100.01 - 1338	3	Medium
1338.01 - 1585	4	High
1585.01 - 2191	5	Very High

Table 4.3: Shows slope factor class and how it contributes to soil erosion

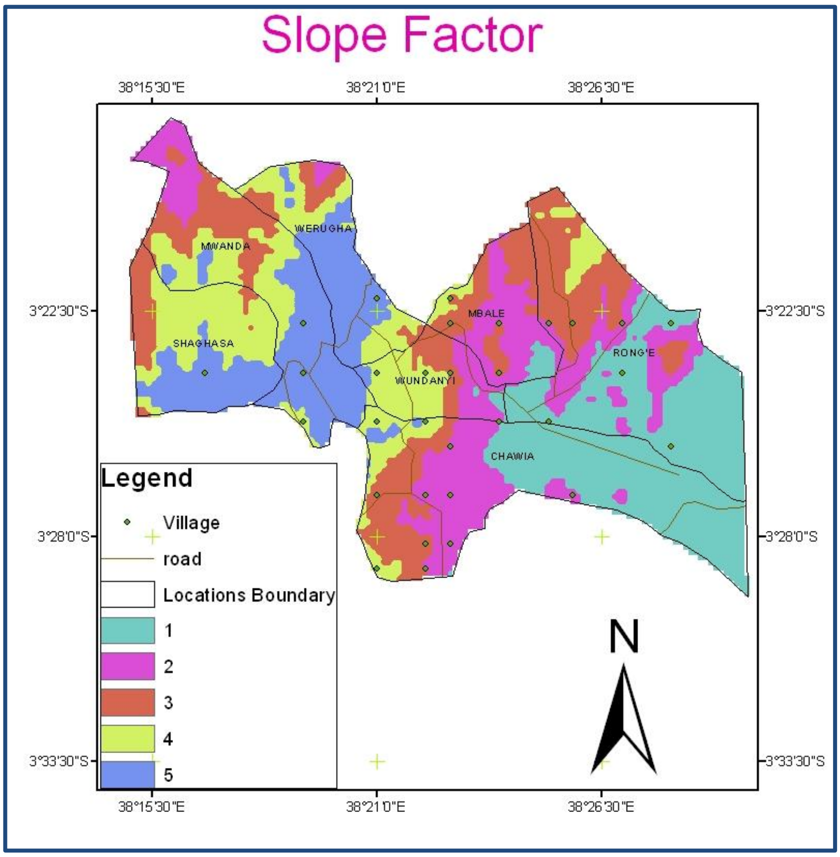


Fig 4.17: Map showing Slope Factor classes and their weights

4.2.3 Land Use

Land mostly covered by land cover is less susceptible to soil erosion than bare ground hence bare ground was given the most weight of 4 than the Forest which was given the weight of 1. The table below shows the various types of land use, their sub-rating weight values and the land use class and the magnitude they affect soil erosion.

Land Use	Sub-rating	Land Use Class
Forest	1	Very Low
Scrub	2	Low
Agriculture	3	High
Bare land	4	Very High

Table 4.4: Land use class and how it contributes to soil erosion

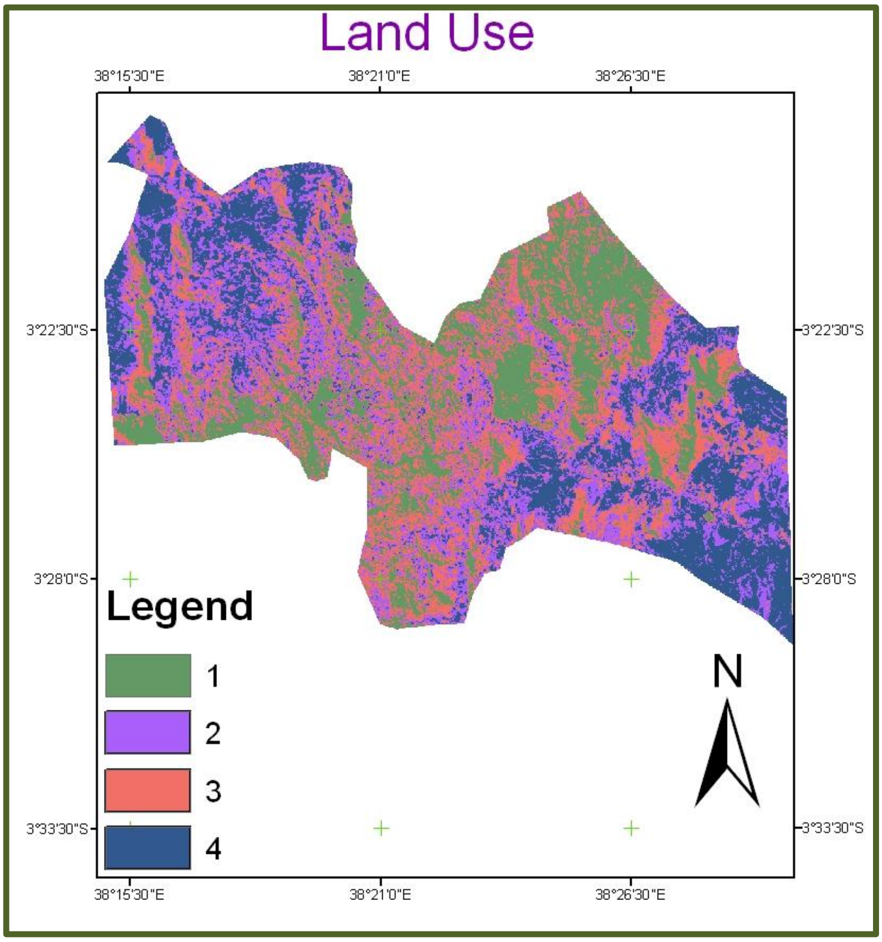


Fig 4.18: Map showing Land Use classes and their weights

4.2.4 Soil Texture

The clayey soil as seen in the literature is less susceptible to soil erosion than the loamy soil hence the loamy soil is assigned the highest weight value of 2 as compared to clayey soil with weight value of 1.

Soil texture	Sub-rating value	Soil Texture Class
Clayey	1	Low
Loamy	2	High

Table 4.5: Showing soil texture classes and how each class contributes to soil erosion.

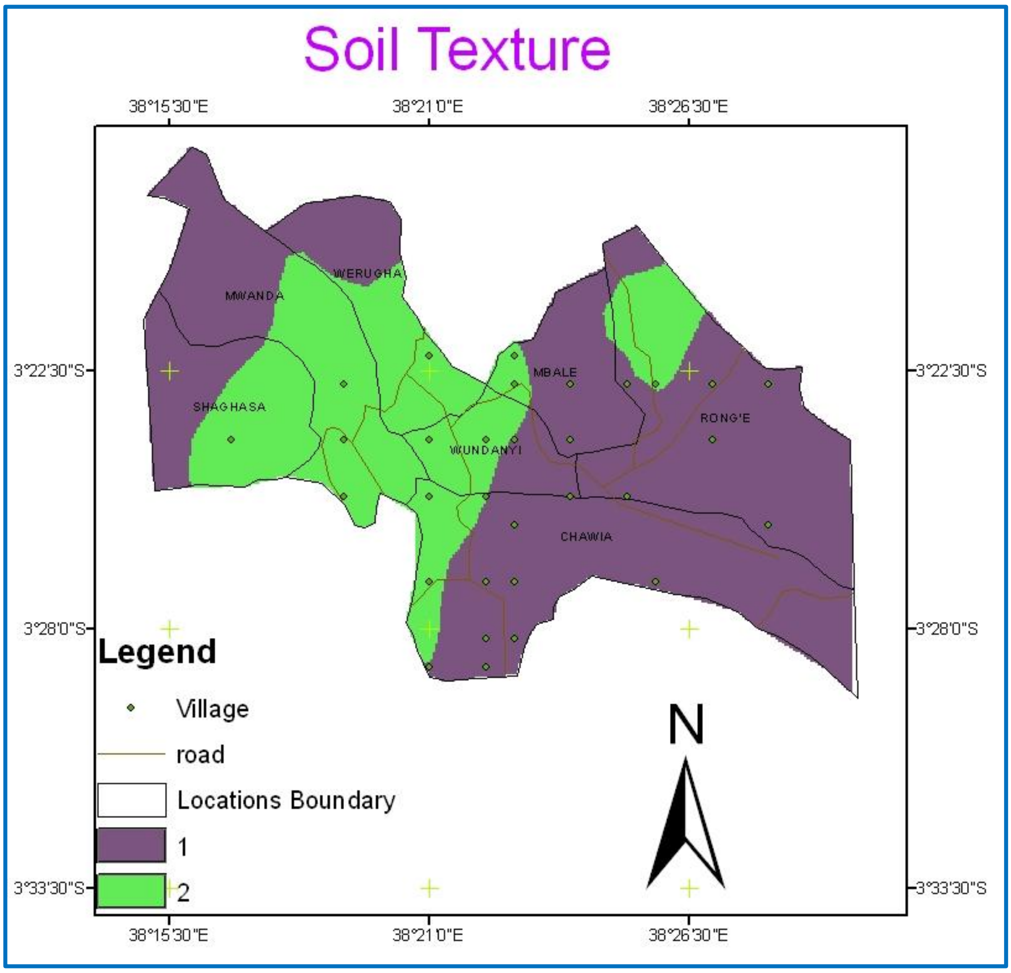


Fig 4.19: Map showing soil texture classes and their weights

4.2.5 Soil Erosion Model Using Sub rating method

In the project, all classes belonging to the factors that contribute to soil **erosion** were weighed. Then all the soil contributing factors were overlaid using the weighted sum overlay tool. The final values generated by this tool, were then classified using reclassify tool in the Spatial Analyst. The most value was assigned the highest weight value of 4, while the least was assigned the least amount of 1.

Soil Erosion	Sub rating Value	Soil loss erosion Class
10.021 - 13	4	Very High
8.011 – 10.020	3	High
6.041 -8.010	2	Low
5 - 6.04	1	Very low

Table 4.6: Table showing Soil Erosion Classes

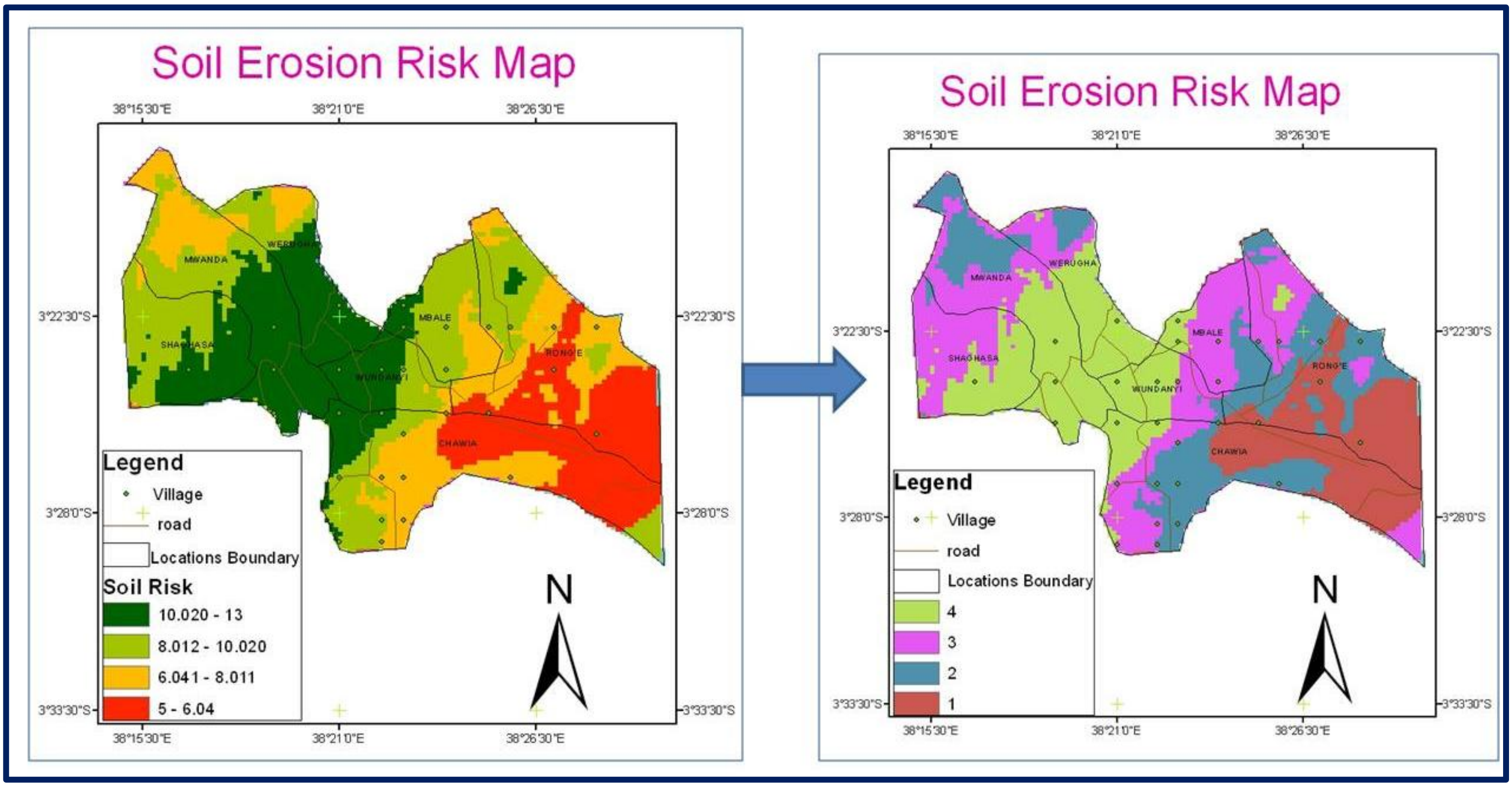


Fig 4.20: Maps showing soil erosion classes and their weights respectively

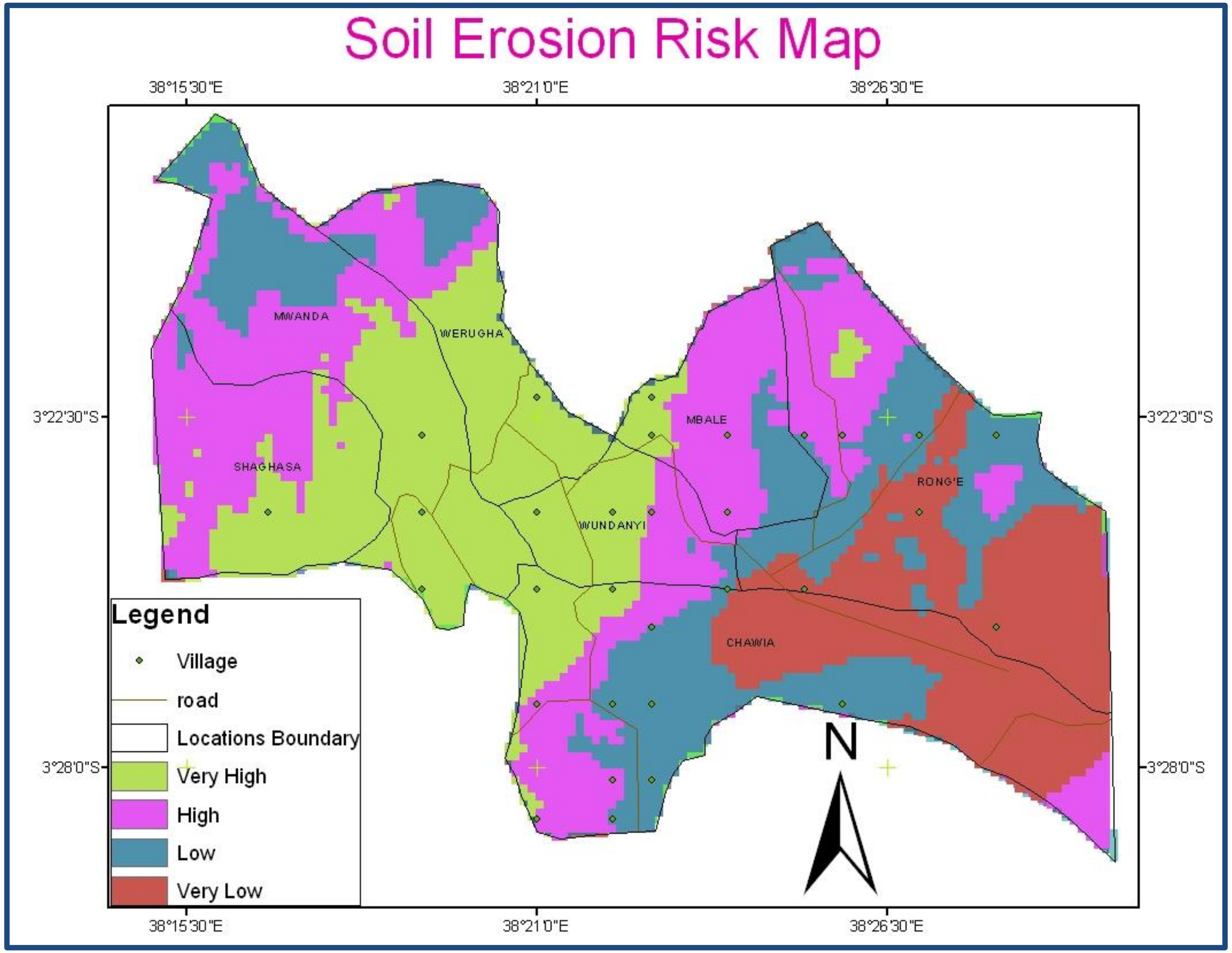


Fig 4.21: Soil Erosion Map of Taita Hills obtained from sub-rating Method

From **Fig** 4.21 the Soil Erosion Risk Map it is evident that the places that are mostly affected by soil erosion are the northern parts of the Study area. This is the same as the Soil Erosion Risk Map created using RUSLE. From this it is seen that indeed rainfall erosivity factor and slope are the major factors that affect soil erosion.

From this comparison it is true to say that both methods complement each other. The difference is that the RUSLE method estimates the amount of soil lost to soil erosion per year.

CHAPTER FIVE

5. RECOMMENDATION AND CONCLUSION

5.1 Conclusion

In this study, the importance of the use of RUSLE is well recognized in which the R factor plays the most important role. The R factor which is the mean annual sum of individual storm erosion Index values EI_{30} depends on the value of the total kinetic energy of the storm and the I_{30} value, the maximum 30 min rainfall intensity. Since energy of the storm and 30 minutes rainfall intensity of Taita Hills is not available from KMD an alternate procedure was applied to compute R factor.

From the soil erosion risk map it is seen that part of the roads are in the regions that are mostly affected by soil erosion. This hinders farmers in the study area from selling their farm products.

Generally this study provides an approach for the evaluation of soil erosion loss in Taita Hills based on combination of RUSLE and GIS. This is an effective way to map and predict the Soil Erosion loss of certain areas. However, an error in a factors value will produce an equivalent percentage error in the soil erosion estimation.

One of the main advantages of the Universal Soil Loss Equation (USLE) is that it is well-known and it has been applied widely at different scales. Compared with the methods described above, it probably gives the most detailed information about the Taita Hills distribution of soil erosion risk. Its value lies in the fact that the estimates of erosion are based on standardized, harmonized data sets for Taita Hills and the model produces quantitative output as actual loss, for example tons/ha/year.

Modeling soil erosion is complicated because soil loss varies spatially and temporally depending on many factors and their interactions. The study proves that soil erosion model in combination with GIS is an efficient tool for determining the high erosion risk places.

The RUSLE is a good method to estimate soil erosion risk for different scenarios because it is simple, fast and economic to use. This study demonstrates that geostatistic techniques are advantageous to estimate soil erosion and their factors at unsampled locations.

The evaluation of soil erosion risk vulnerability is essential for sustainable land-use planning and comprehensive local and regional development. Those maps can be important to plan the future land-use alternatives and to apply specific soil conservation practices at the identified high-risk areas.

The Soil erosion risk map produced can be used as a solid base to create a Decision Support System (DSS) so as to provide site specific methods and mitigation measures for decision-makers (Fig. 5.1). These methods and measures could decrease the risk of soil erosion, increase farmer's product and improve the transportation system.

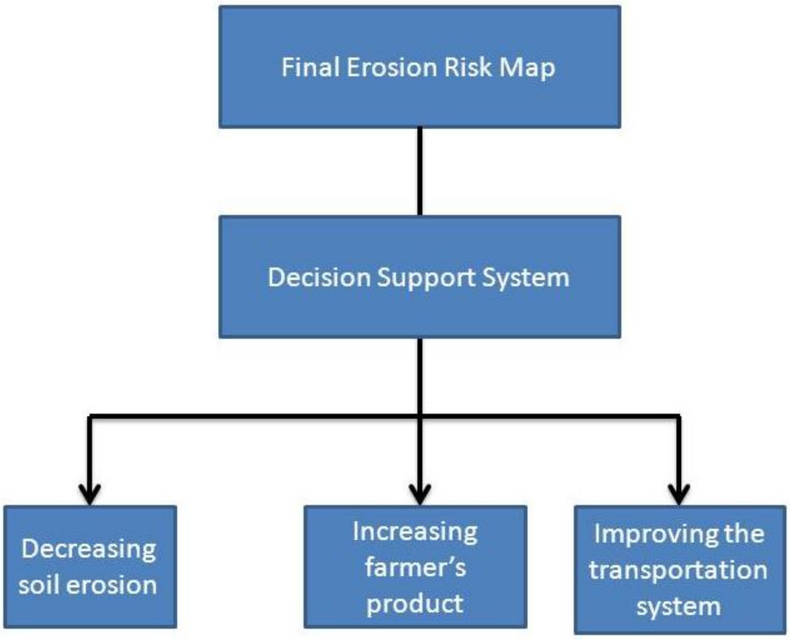


Fig 5.1: Chart illustrating the potential service of a new modelling approach based on the RUSLE model

In conclusion farmers should be advised to use terraces to reduce the instability of slopes as this reduces the steepness of the slope to zero.

In conclusion, the results of this study may be considered as a further step towards harmonized soil erosion risk map of Taita hills. Some major improvements could be achieved by using a more detailed digital elevation model, a better representation of rainfall erosivity, and satellite data that have better spectral and geometric characteristics than the Landsat TM data that are currently used to estimate the vegetation cover. Finally, more detailed soil data is needed (especially soil depth, stone volume and surface texture).

5.2 Recommendation

The accuracy of the predicted soil loss can be improved if each parameter is better estimated for example; an R value can be better produced by using direct storm energy and 30 minutes Intensity.

The LS can be improved by better generated DEM that has a high resolution, and infinite flow direction. The C factor can be improved by better estimation of the fractional vegetation cover. To access the accuracy of the produced maps, validation with independent data is recorded. This can be obtained from field measurements, surveys or high resolution image like an aerial image.

Also a better image of aerial photograph should be provided for the study area rather than the Landsat TM image for better mapping of land use of a case study. GIS provides a great advantage to analyze multi-layer of data spatially and quantitatively within the basin. The estimation of soil loss in the basin using GIS is also in the ranges of other studies. GIS not only provides accurate results but also provides cost and time effective ways of analysis. The soil erosion modeling using GIS should be carried in all environmentally pressured regions in the country due to the benefits accruable.

There is a need for research to determine appropriate P factors for local soil conservation practices such as trash lines, *fanya-juu* terraces and stone lines, which are not available from the USLE guide table.

A better model that incorporates soil erosion prediction and sedimentation should be used.

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