STUDY OF THE EFFECT OF SEASONAL VARIATION OF VEGETATION COVER ON SOIL EROSION IN THE RATAMBA WATERSHED, BANJANEGARA DISTRICT - CENTRAL JAVA, INDONESIA

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By

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Abstract

Soil erosion is a serious global environmental problem. With an increasing human population pressure, there is an increasing expansion in agricultural practices to meet the increase on food demand. This has in turn led to increase in the risk posed by soil erosion. Therefore, it is very essential to assess soil erosion under various land use practices, so that conservation measures can be implemented in time. Firstly, it is a common practice to estimate annual soil loss using average input parameters such as the rainfall amount, rainfall interception, cover factor, ground surface, canopy cover and plant height for a year or at times series of years. This study investigates if the results obtained by this approach give the same as the sum of the monthly soil loss estimates which takes into account seasonal variation. To analyze this, the RMMF erosion model was used to predict annual soil loss using average parameters and the model was also adapted to run for monthly soil losses estimations and the results were summed up to derived the value for the total annual soil loss. The results show that the annual predicted soil loss rates using average factors were relatively higher than those using the sum of the monthly predicted soil losses. The average soil loss prediction for the study area using the annual average input factors was 23.43 t ha^{-1} $yr^{-1}$and that of the sum of the monthly predicted soil loss was 12.01 t ha^{-1} yr^{-1}. With regards to the different land uses, the prediction with the average values predicted the highest soil loss in the tobacco fields with an average soil loss of 43.56 t ha^{-1} yr^{-1} and for the sum of the monthly soil loss, the highest soil loss was in the dry land agricultural field with an average soil loss of 21.35 t ha^{-1} yr^{-1}. The results also revealed that 18, 9122 tons in an annual basis of soil is lost from the study area annually using the average parameters. When soil loss was computed on a monthly basis, the results showed that 12, 0278 tons of soil is lost per year. From these results, there was a significant difference in the results derived from the two methods. This conclusion was drawn based on a statistical comparison to establish whether the differences in the different predictions are statistically significant. The quantile – quantile and box plots showed that the both had about 25% of the total predictions to be very low but the prediction from the averaged annual parameters gave extremely high values wish are probably not realistic. The predictions from the sum of monthly soil losses proved to give a realistic result.

Secondly, soil loss assessment requires quantitative data. There are several approaches to acquire the data necessary for assessing soil erosion. And improved and enhanced modelling of this situation requires remotely sensed data which gives information of the surface and at times subsurface conditions of the area. And these are usually derived from satellite images and digital elevation models. The level of information derived this approach however depends on the availability, quality, resolution and also the cost of the image required. The cost implication though less frequently discussed, is also an essential important factor coupled with the resolution could limit the use of satellite images for recurrent monitoring of soil erosion especially in small areas like the study area of this work. To assess use coarse and readily available in small area, this study used the Moderate Resolution Imaging Spectroradiometer at a resolution of 500m for obtaining quantitative information erosion modelling parameters such as the cover management parameter based on NDVI for the 17km^2 size study area. This apparently a small area and with such a resolution, it is believed that the obtained erosion parameter would be a generalized one without any true or detailed representation of the area. To evaluate the accuracy and reliability of the erosion parameter derived at this resolution, erosion modelling parameters such as cover factor was derived from NDVI values gotten from a LANDSAT image at a resolution of 30m. Aggregation functions were applied to the NDIV values from the LANDSAT to a coarser resolution as the MODIS image from which the cover factors were derived. Due to the unavailability of the LANDSAT images, this analysis carried only for one month (June, 2009), for which images were available for both the LANDSAT and MODIS images. A correlation was performed between the aggregated NDVI values of the LANDSAT image and that of the MODIS NDVI to establish a relationship. An r^2 of 0.66 was obtained and that shows a good relationship and as such showed that the MODIS (500m) image which is free and cost effective can also be used for erosion modelling study in small watershed in the absence of high resolution images.

But on applying it to soil loss assessment, it revealed that soil loss derived using the MODIS c-factor results overestimated the presence of vegetation cover since some fields in the area were just at the planting and vegetative stages. And when the soil loss result derived for the month of September was correlated with the soil loss prediction for the same month using the c- factor derived from the canopy cover, it gave a low value (r^2=0.11) which showed that it's extremely low prediction is not realistic.

As a conclusion from this, the MODIS (500m) image which is free and cost effective can be used for C-factor mapping but the results obtained when applied to soil loss assessments could be unrealistic and as such limits it's usefulness for erosion assesses in small watershed.

Finally, the management practice sensitivity analysis revealed that the management factor in the study area has little or no effect on the soil loss coverage but if the reverse slope terrace practice is implemented, there would be a reduction in the soil loss rate in the area.

Keywords: Soil loss, C-factor, NDVI, RMMF erosion model.

Dedication

This work is dedicated to God. For without Him, I am nothing and can do nothing. “In Him we live, we move and have our very being…Acts 17: 28”.

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"Veni, Vidi, Vici! I came, I saw, I conquered!"… Julius Caesar 47 BC.

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ABBREVIATIONS

USLE	Universal Soil Loss Equation
ANSWER	Areal Non-point Source Watershed Environmental Response Simulation
AUSLE	Adapted Universal Soil Loss Equation
AGNPS	Agricultural Non-point Source Pollution
RMMF	Revised Morgan-Morgan-Finney model
DEM	Digital Elevation Model
NDVI	Normalised Difference Vegetation Index
ISODATA	Iterative Self-Organizing Data Analysis
LAI	Leaf Area Index
SMAX	Canopy Storage Capacity

1. INTRODUCTION

1.1. BACKGROUND

Soil erosion is a major global environmental problem. It is the removal of the soil by denudational agents such as water and wind. The natural processes of soil removal either within or out of its in situ environment could be slow. It however becomes a serious problem when human activity causes it to occur much faster than under natural conditions.

Soil erosion can be termed as a form of land degradation which lowers the capacity of the soil to support fertility and productivity. Lal (2001) describes it as a stimulant of land degradation where it lowers soil quality thereby triggering soil degradation or vice versa where it could also be caused by the weakening of soil structure and is said to be a materialization of soil degradation. It could be a natural or human induced process which maybe slow or may occur at an alarming rate leading to the loss of topsoil. By removing the most fertile topsoil, erosion reduces soil productivity and where soils are shallow; it may lead to an irreversible loss of natural farmland. Even where soil depth is good, loss of the topsoil is often not conspicuous but nevertheless potentially very damaging. Soil erosion has adverse effects not only to agriculture but the natural environment as a whole.

But with an increase in human population growth there is also an increase on the demand of food production thus there is an increase in agricultural practices in order to satisfy this demand (Stein and Goudriaan 2000). This also implies that the land surface used for agricultural practices is also increasing. However, in as much as an increase in agricultural practices seems to meet the demand on food to a reasonably extent, it also, on the other hand, exposes the land to hazards such as degradation and soil erosion in particular if measures of conservation and management are not properly implemented.

Furthermore, soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from wind and raindrop impact and tends to slow down the movement of surface runoff and allows surplus surface water to penetrate the ground (Abegunde et al. 2006). However, several factors control the rate and amount of soil loss. These are: rainfall amount and intensity, vegetation, the slope of the terrain, organic matter content, soil storage, structural stability of the soil and the particle size of the topsoil actually indirectly through soil strength and hydrological parameters (Morgan 2005). Due to the damaging nature of soil erosion, an assessment of the process is essential.

There are several methods for assessing soil loss. These could either be by quantifying erosion from experimental erosion plot measurement or by integrating spatial data on erosion factors by using erosion models. Several studies show that erosion models require a lot of input data which may not be readily available in most areas and remote sensing has proven to be a very good tool in proving the input data required in erosion. Shrestha (2000)Therefore, integrating various quantitative data in a GIS environment have shown to be an effective tool in erosion modelling.

1.2. PROBLEM STATEMENT

Soil erosion in the Central Java district of Indonesia is one of the nation's most serious environmental degradation problems (Ambar and Mitchell 1997). The Serayu watershed and the study area of this thesis, the Ratamba catchment is a part of is located in Central Java. Moreover, erosion may increase as the population increases because most of the land will undergo several land use/cover changes due to the encroachment of marginal lands for agricultural purposes. In the agricultural areas, soil loss is being accelerated by inappropriate implementation of conservation measures in the agricultural practices in the area and also, these different vegetation/plant coverage have different rate of soil loss (Lal et al. 1990). Vegetation canopy protects the soil from the impact of falling raindrops and also helps in decreasing soil detachment by runoff. But canopy cover is dynamic especially in agricultural fields where the soil surface may be bare at the beginning of crop growth and as the vegetations grows, the canopy cover increases. Then when the crops are harvested, soil is again bare. Erosion is at highest rate when intensity of rain is high and when soil is bare (Shrestha et al. 2005). Thus, the cover factor shows continuous changes which needs to be optimally estimated in order to assess soil loss in the area.

Assessing the extent and seriousness of soil loss in the Serayu watershed remains a difficult task as a management challenge arises not only because of lack of understanding of soil erosion process and lack of data but also due to difficulties in the application of erosion models (Ambar and Mitchell 1997). Therefore, looking for an appropriate methodology that can be applied for predicting the rate of erosion in the study area is one of the major challenges of this work. This research is aimed at assessing the role of changing canopy covers at different agricultural seasons and to assess its role together with the managerial practices on the soil loss in the area. With a proper evaluation on the aforementioned, a better and improved soil conservation and management practice can be implemented for sustainable crop harvest in the area. But there is still a question of which erosion model will be most suitable for this study. Several models have been used for erosion assessment in Indonesia. Among these are the USLE (Universal Soil Loss Equation), ANSWER (Areal Non-point Source Watershed Environmental Response Simulation) and AUSLE (Adapted Universal Soil Loss Equation) which were studied and compared to suggest which of the model gives a better prediction (Moehansyah et al. 2004) and the AGNPS (Agricultural Non-point Source Pollution) was used by (Ambar and Mitchell 1997). The USLE model (Wischmeier and Smith 1978) is a field based model and is a commonly used model to predict soil loss but this limited to only average soil loss prediction by sheet and rills. It however, disregards transport capacity and flow accumulation and therefore, it cannot simulate deposition. Transport capacity is an essential parameter in erosion assessment which enables one to know the available transport available for the detached soil particles. The ANSWER model (Beasley et al. 1985) is an hydrological model which incorporates sediment detachment, transport and also routing capacity and was developed and validated on watersheds containing soil and eighty percent crop cover but on the other hand is data intensive and is mostly used for watershed not less than 1800 hectares. AGNPS model also assesses soil erosion in within a watershed taking into in consideration the sediments and transport but its limitation is the large data requirements. The Revised Morgan-Morgan-Finney (RMMF) model (Morgan 2005) simulates soil detachments both from raindrops and runoff, it also takes into account transport capacity of runoff and considers components such as the plant height, canopy cover and leaf drainage and yet still considered a simple model. The RMMF was selected for this study because the research focuses on understanding annual soil loss response in relation to seasonal variation of the erosion parameters. And the RMMF model could be easily adapted to meet the objectives of this work.

1.3. RESEARCH OBJECTIVES

The main objective of the research is to study the effect of seasonal variation of vegetation of vegetation cover on soil erosion in the Ratamba watershed of Banjanegara District, Centarl Java.

The specific objectives are:

1. To estimate if the annual computation of soil loss using average parameters is the same as the sum of the monthly estimates.
2. To assess the role of the management practice on soil loss in the area.
3. To assess the effectiveness and applicability of using coarser resolution remote sensing data such as the MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI images for C-factor mapping in small catchments.

1.4. RESEARCH HYPOTHESIS

1. The RMMF estimated annual soil loss from averaged input parameters is different from that of the summation of monthly soil loss prediction.
2. The management factor decreases the effect of soil loss in the area.
3. The MODIS images are applicable in c-factor mapping in very small areas as the Ratamba watershed.

1.5. RESEARCH QUESTIONS

1. Is the annual soil loss using average parameters the same as sum of the monthly soil loss including seasonal variations? If no, what causes the difference?
2. Which crop has a seasonal calendar that generates the highest soil loss and why?
3. Is the highest soil loss of the area in months with the highest rainfall?
4. Do the management practices in the area reduce soil loss in the area?
5. Can the estimated cover factor derived from MODIS imageries be useful soil loss assessment in small areas where detailed information is lost? If yes, how well can this it be done?

1.6. THESIS OUTLINE

The thesis consists of six chapters and the report is as follows:

Chapter 1: Gives a general introduction of the thesis, an overview of the problem statement, research objectives, hypothesis and the research questions.

Chapter 2: Contains literature review giving background information on the focus of the thesis; soil loss, causative factors and modelling processes.

Chapter 3: focuses on the introduction of study area; the climate, soils, land uses and geology.

Chapter 4: Presents the methodology used for the research. This chapter extensively and systematically describes each procedure taken to achieve the objectives and also to answer the research questions.

Chapter 5: Analyses and discusses the results of produced by the chapter 4.

Chapter 6: This is the final chapter and it presents the major conclusions drawn from the study and recommendations of the report.

2. LITERATURE REVIEW

2.1. SOIL EROSION

As a way of definition, soil erosion is removal of soil by the action of water or wind. This process could take place naturally or mechanically which is mostly induced by human activities. The action of soil loss is not only detrimental to agricultural practices but to the natural environment as a whole. Soil erosion could be a complex problem; it detaches top soil which serves as a platform for agriculture, transports and deposits it elsewhere especially in places where it could become a problem like sedimentation in reservoirs (Jain et al. 2001).Either way, soil erosion has both onsite and offsite problems. As earlier mentioned, soil erosion could be engineered by either water or wind but soil erosion by water is a serious universal problem and these enhances the removal of productive topsoil and most often deposits the detached particles in the lakes and oceans (Angima et al. 2003).

Soil erosion by water results from the process of detaching and transporting of soil particles from its in-situ environs to elsewhere. The detachment and transportation could be in the form of sheet, rill or Gully erosion. Sheet erosion entails the removal of an even thin layer of soil either by splash or water run-off. The process is gradual which depletes soil the nutrients in the top soil and could have adverse effects in terms of agriculture. It however, could look negligible until it approaches the rill phase. The rill phase develops as runoff begins to concentrate through small channels. Rills often occurs on exposed soil in sloping areas (Suriyaprasit 2008). When rills are deeper than 30 cm depth, they are termed gullies. Gullies are the extremely observable form of erosion. They are large, deep incised and vertical walled - channels on the land surface caused by concentrated overland flow. Here, a vast amount of soil is been detached and transported by running water.

Despite an increasing and alarming rate of erosion by water, if the right prevention and control measures are implemented, it could be curbed since the rate of soil loss is governed by certain factors. These factors include: rainfall, soil type, topography, crops and management practices.
By definition, (Wischmeier and Smith 1978) defines soil loss as a product of rain erosivity, Soil erodibility, the length of the slope, cover factor and the management factor (annual soil loss is in t/ha/yr).

2.2. SOIL LOSS FACTORS

2.2.1. RAINFALL

Rainfall can be described in terms of the amount of rainfall, the intensity of the rainfall, duration, distribution and the kinetic force when it reaches the ground. Rainfall, thus, plays an important role in soil erosion. However, soil detachment by rainfall could be done either by the falling drops in terms of the size and the velocity of fall or could be by runoff water (Shrestha 2008). When the intensity of rainfall is high and the amount exceeds that of infiltration, it tends to cause runoff. And an increased runoff on exposed or less vegetated soils, soils with little or no organic matter, loosely aggregated soils leads to the detached of soil materials in the area. More also, with all these factors in play, the kinetic impact of rainfall contributes to soil detachment. The size and the velocity of the raindrop play an important role in soil detachment. A high velocity and large drop size of rainfall could disaggregate a less resistant soil particle thus having a high erosive power. According to (Wischmeier and Smith 1978) rain erosivity is a product of the total kinetic energy and the maximum 30-minute storm depth (I_{30}) which is summed for the whole year. However, Morgan (2005) suggests that the best expression of the erosivity of rainfall is as an index which is based on the kinetic energy of the rain. This means that erosivity of rainstorm is a function of its intensity and duration and also the mass, diameter and velocity of the raindrops. And thus, to determine erosivity, rain-drop size distribution must be analyzed. Svorin (2003) suggests that data are often too sparse for the approach implement by Morgan and as such looked at other ways of estimating rainfall erosivity which included estimation from an Iso-erosivity map and also from a relationship from Tuscany between annual rainfall and R-factor.

2.2.2. SOIL TYPE

Soil erodibility refers to the susceptibility of a soil to detachment and transportation (Morgan 2005). It is based particle size distribution, organic matter content, soil moisture holding capacity, soil structure, infiltration capacity, bulk density, etc. These attributes serve as indicator for soil erodibility. This process is greatly enhanced by the texture of the soil, organic matter content and also the structure. According to (Wischmeier and Smith 1978), soil erodibility, K depends on particle sizes distribution, organic matter, soil structure and permeability. According to Morgan (2005), despite the fact that soil resistance to erosion depends to a large extent on the topographic extent, slope steepness and the amount of disturbance, the most important, he indicates are the soil properties. Soils like Sands and Loam are less likely to erode when compared to silt and very fine sand. The larger the particles are more resistance to transportation because high rainfall energy is required to move them and so also, the finer particles to detachment because of cohesion between the particles. Figure 2-1.shows a monograph for computing the k value to derive soil erodibilty for use in the Universal Soil Loss Equation.

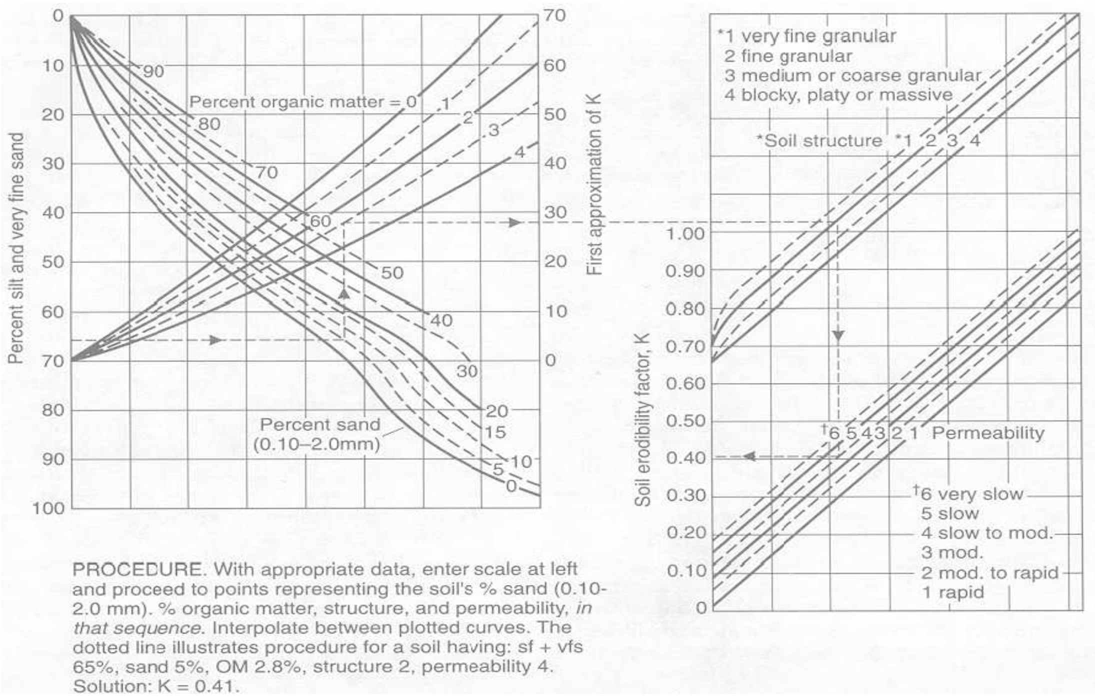


Figure 2-1: Monograph for Computing Soil Erodibility (K)

2.2.3. TOPOGRAPHY

This takes in account the slope gradient and slope length. These factors have a strong correlation with soil erosion (Shrestha 2008). A steeper slope tends to have more erosion due to the eroding power of runoff but if the slope length is short, it could have a much lesser erosion effect. However, high erosion could also be experienced with a gentler slope and a longer slope length. The topographic surface of the earth could also be spatially represented using a digital elevation model (DEM). Thomas et al (2001) noted that topographic factors such as slope gradient, slope aspect and slope length could be easily derived from a DEM.

2.2.4. CROPS / VEGETATION

This depends on cover percentage and also on the stage of the plant growth. Vegetation plays a key role in not only directly protecting the soil surface from rainfall but acts a buffer against soil erosion (Cyr et al. 1995). It is said to be a buffering layer because it separates the soil from the atmosphere and protects the soil surface from the initial rainfall impact and leads to an increase infiltration thus reducing soil runoff and also a decrease in soil loss (Yazidhi 2003).Soil erosion tends to increase on soils with little or no vegetation cover. (De Asis and Omasa 2007) adds that it also it binds the soil mechanically and maintains the roughness of the soil. However, the efficiency of this factor to prevent soil loss does not only depend on the percentage of cover but on the ground biomass, surface litter, surface roughness and cover during erosive rainfall period. Canopy cover only intercepts rainfall but does little or nothing about the rain that reaches the ground. That is where other factors such as ground cover such as plant litter, stones, mulch, plant roots and ground biomass such as buried residues comes into play. The plants roots help in holding the soil together and as such decrease soil particle detachment that could be transported by runoff. In densely vegetated areas, the volume of the runoff velocity is reduced and mass movement of soil particles trapped.

2.2.5. MANAGEMENT PRACTICES

This factor has a varying effect on soil loss. If good and proper management activities are implemented, soil loss is reduced. With the everyday increase in population, there tends to be an increase in agricultural land to satisfy the present demand. For instance, there been a lot of land reclamation for agricultural purposes where farm activities are even done on steep terrain(Yazidhi 2003). Certain measures such as terracing, etc are implemented to aid in sustainability of the farming project but these changes if not properly managed could have adverse effect on the structure and soil aggregates and in turn causing soil loss. Despite having these changes, if conservation measures are implemented, a decrease in soil loss could be witnessed.

2.3. SOIL EROSION MODELLING

According to (Oldeman and Van Lyden 1994) in a report to the Global Assessment of human-induced Soil Degradation, GLASOD project, soil erosion affects a vast land area of the earth’s surface and this trend is highest in the Asian continent. Generally, soil erosion particularly by water is a severe global problem which has increased during the 20^{th} century (Angima et al. 2003). As a result several efforts worldwide have been put into understanding the process of soil erosion, modelling and also in predicting it (Fu et al. 2005).Different approaches which include empirical, physical and a combination of physical and empirical approaches have been developed to model soil (lecture notes on erosion modelling - 2009, Geo-Hazards Empirical Modelling 2007 of D. Shrestha, ITC). However, despite the availability of several erosion models, a problem on the application of the right model to use in a given area arises, since the applicability of most of the models are restricted to certain locations or may require certain data input may not be obtainable in the research areas (Yazidhi 2003). It is, therefore, necessary to understand the model and the environment in which the model is to be applied. In the 1970s, the United States Department of Agriculture developed the Universal Soil Loss Equation (USLE) which has been applied not only in the United States but in other regions of the world. Erdogan et al.(2007) used the USLE to predict the soil loss in Kazan watershed located in Central Anatolia of Turkey and it yielded satisfactory soil loss estimation. In a researched carried out by Angima et al (2003), the RUSLE proved to be an efficient tool for estimating erosion and it also was able to delineated clearly areas highly prone to erosion for different cropping patterns and management practices. This is because the effect of vegetation is accounted for in the cover factor by RUSLE (Renard et al. 1997). In relating canopy cover to soil loss, Nearing et al. (2005) studied the response of seven models of soil erosion and runoff to changes in precipitation and cover. The Revised Morgan-Morgan-Finney (RMMF) model has also proven to be useful since it actually incorporates the rainfall leaf drainage from and direct through fall (Morgan 2001). The RMMF is a revised version of the Morgan-Morgan-Finney which developed to predict soil loss from field sized areas on hill slopes (Morgan et al. 1984). However, Morgan and Duzant (2008) modified the RMMF to incorporate soil particle size distribution to assess the effect of vegetation cover to soil loss. The revised version of the Morgan-Morgan-Finney model will be applied in this study.

2.4. SATELLITE IMAGERY, SPATIAL RESOLUTION AND SOIL EROSION ASSESSMENT

Spatial resolution as defined by Floyd Sabins (2007) is the minimum distance at which two objects can be distinguished. It could be said to relate to the smallest area that can be seen and identified as a unit. Spatial resolution of images could be said to be high, medium or low resolution. And depending on its application, different image resolution could be used. In assessing soil loss in small catchments, adequate ground information needs to be remotely sensed. And as such an image with a high resolution will give optimal interpretations. However, several studies have been done to assess the effects of image spatial resolution on soil mapping. Wang, George et al. (2008) showed that in monitoring the dynamics of soil erosion, it is important to determine the optimal spatial resolution in terms of the extent of sample plots used for the collection of ground data and the size of pixels for mapping. Vrieling and Rodrigues (2005) analysed the effect of spatial on directly detecting erosion features and reported that data availability and quality of the spatial resolution of the satellite image are important factors. Quite a number of studies have outlined the advantages of using high spatial resolution images for erosion. However, Vrieling et al (2008), noted that the price and volume may be a limitation to its applicability and as such a multi-temporal approach to assessing erosion may be constrained owing to this factor. It further applied the use of NDVI time series derived from a frequent and cost free coarse spatial resolution image (MODIS – Moderate Resolution Imaging Spectroradiometer) and concluded that these images could be also useful in the study of erosion controlling factors. However, it is most likely applicable in large areas were a homogeneous spatial and spectral variation could be detected. Vrieling (2006), also notes that due to the inability of detecting individual erosion features as a result of the spatial extent of the such features, assessing erode area from satellite images have been effectively applied.

2.5. NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

Normalized Difference Vegetation Index has been commonly used to assess vegetation density. NDVI however, has a wide applicability from investigation about vegetation health, crop yields, and cover percentage. The possible values of NDVI lie between the range of -1 and 1 where 0 indicates no vegetation where 1 or values approaching 1 represents dense vegetation. This means that vegetated areas have high reflectance in the near-infrared and low reflectance in the visible red (Zihni 2000) . NDVI is usually derived from bands that are susceptible to vegetation information such as the Near Infra-red (NIR) and the Red bands

3. STUDY AREA

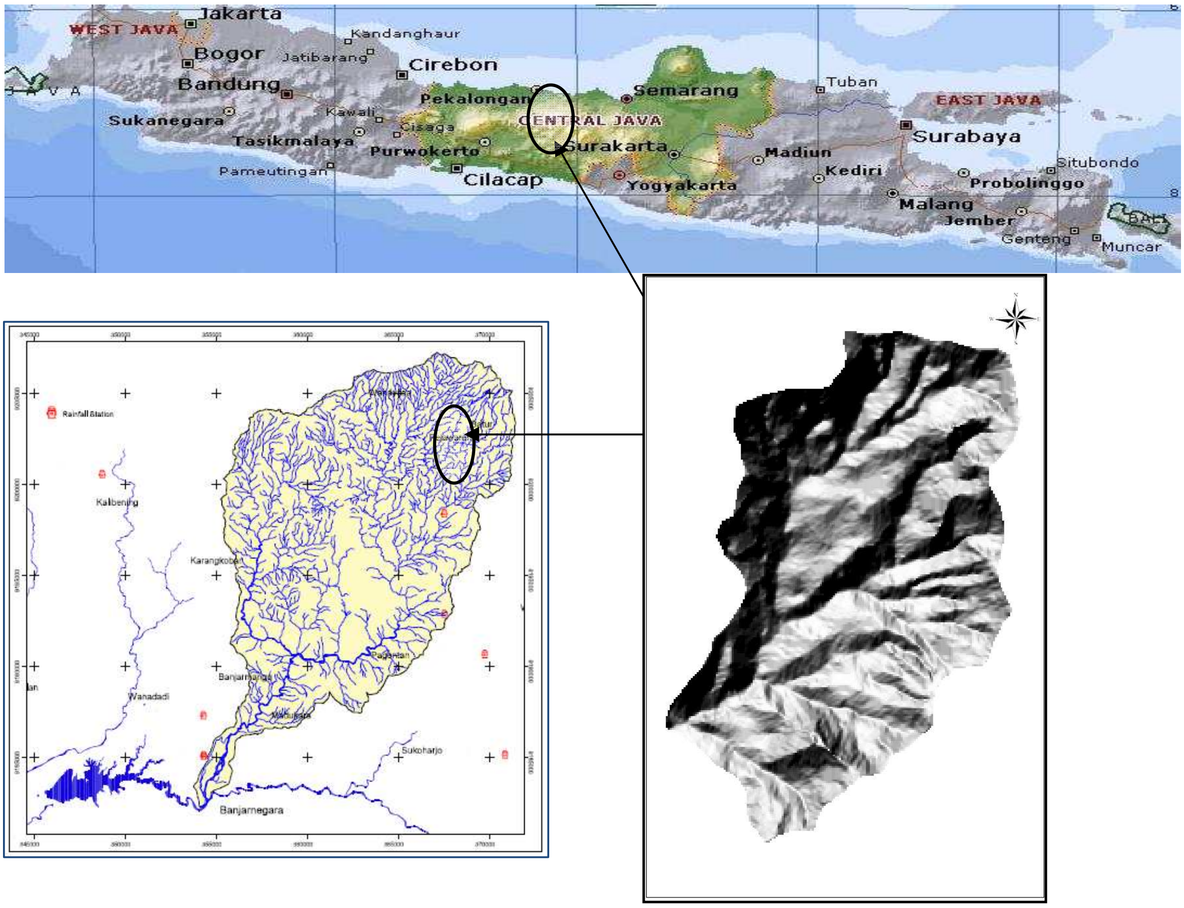


Figure 3-1: Study Area – Ratamba Watershed, Indonesia.

3.1. LOCATION

The Ratamba watershed lies within the Merawu watershed which belongs to Serayu basin in Central Java in Indonesia. The Merawu water basin has an area of 219km^2 (Suwartha et al. 2006). The Ratamba watershed constitutes about 17km^2 of the Merawu watershed and is bounded by latitudes 7.24 ^{o} to 7.21 ^{o} S and longitudes 109. 83 ^{o} to 109. 81 ^{o} E and has an alternating altitude between 1300-1600m.

3.2. CLIMATE

The study area has a tropical climate with wet and dry seasons. The rainy season begins in October and spans through to March while the dry seasons begins in April and ends in September. About 85% of the total rainfall in the area is experienced during the rainy season. The area has mean annual temperature of 19^{o}C with February, March and April as the hottest months. The area receives mean annual rainfall of

3,500mm (Suwartha et al. 2006). Figure 3-2 shows a typical rainfall pattern in the area for one year and was obtained from the Badan meteorological station at Banjanegara, Indonesia.

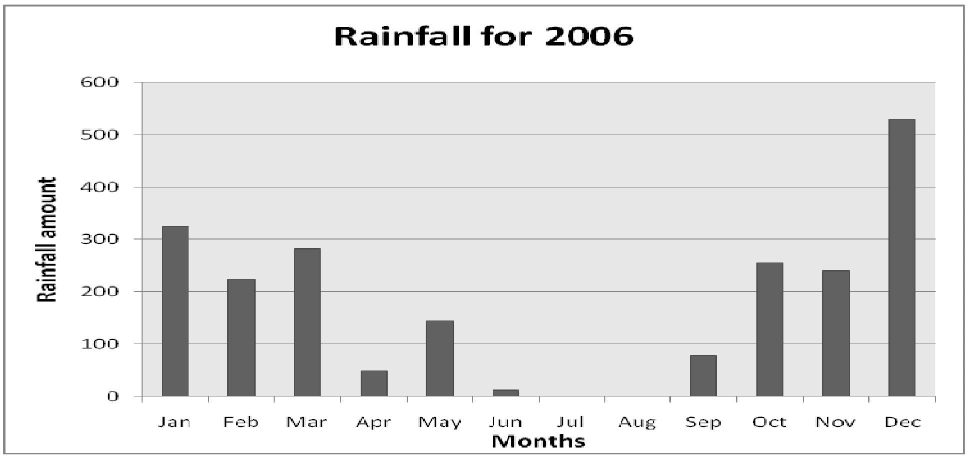


Figure 3-2: Monthly Rainfall Amount for 2006.

3.3. GEOLOGY/GEOMOPHOLOGY

The area is predominantly made-up of clay stones and marls of the marine facies of the Merawu formation which belongs to the Miocene periond. Geomorphologically, the area is characterized by the presence of denuded hills and slopes with severe mass movements (Linden 1983) and also volcanic materials.

3.4. SOILS

There are several soil types in the area such as Regosol, Litosol, Andosol, Latosol, Grumosol and Podizolik. The Regosol and Latosol are however the principal soil types in the area (Suwartha et al. 2006). The regosol soil at the watershed was derived from sedimentary rocks. The Latosol soil is reddish brown in colour and they result from volcanic rock through percolation water transporting soft material from soil surface to sub-surface soil and they are good for agricultural purposes (Indrajaya 2006). The soil texture of the area is predominantly loamy as shown below:

3.5. LAND USE

The land use is mainly carrots, potatoes, green peas, maize and cabbage which are mostly cultivated fields in the upper reach, bushes/forest in the middle area and rice fields in the lower reach. These crops area grown both for commercial and house hold consumption. Most crops are grown together and they are mostly planted along the slope. This is done mostly to cover any bare soil between the ridges and as such as a preventive measure against erosion. The outward sloping bench terrace is also implemented in the agricultural areas to trap any moving sediments. Figure 3-3 shows some practices in the area. (see appendix 2 for more pictures).

Figure 3-3: Agricultural Land Use (Cabbage with Carrots and Tobacco Planting).

Figure 3-4: Management Practice: Outward Sloping Terraces

4. METHODOLOGY

This research began with collection or relevant information and data concerning the Banjanegara district of Central Java in which the Ratamba watershed is located. Such data included information from past literatures concerning the area, satellite images, topographic maps, geological maps, geomorphologic, road maps, river maps and contour maps of the area (See appendix 3 for details of available materials and softwares used).

Following the scope of the work, the methods were group in a systematic approach to achieve the objectives. It is as follows;

- ***The main objective of the research is to study the effect of seasonal variation of vegetation of vegetation cover on soil erosion in the Ratamba watershed of Banjanegara District, Centarl Java.***

  To achieve this objective, the following specific objective was combined in this phase.

  - ***To estimate if the annual computation of soil loss using average parameters is the same as the sum of the monthly estimates.***

To study the role of seasonal variation of vegetation cover, a variety of approaches exists. This could be done by using remote sensing approach to derive certain input parameters. This approach entails image classification, deriving NDVI, cover factor, LAI and other input parameters which are combined with other field and laboratory parameters for soil loss assessment. The necessary input parameter will be discussed extensively in this chapter. The research will predict the annual soil loss using the Revised Morgan-Morgan-Finney model (RMMF) and will compare and analyze the results derived from a one step simulation of erosion for the whole year with the results derived from the sum of the monthly predicted erosions in the area

Having established the objective, the soil loss estimation took the following steps were;

a) Developing a detailed crop calendar, land use of the area
b) Deriving soil, climatic, land cover and erosion input parameters
c) Sensitivity analysis of the management factor.
d) Prediction and comparison of annual soil loss from the catchment

4.1. CROP CALENDAR AND LANDUSE

4.1.1. CROP CALENDAR

The objective of the research is to evaluate if the computation of annual soil loss using average input parameters is the same as the sum of the monthly soil loss. To do this requires monthly satellite images to derive the cover factor for each month. This was not feasible due to cloud coverage in the images in most months. As a result of this, the crop calendar is an option this study used in deriving the monthly cover factor (this will be later discussed in this chapter). The crop calendar was developed from informal interviews using a well defined questionnaire (see appendix 4) with eleven (11) farmers and also from the office of the Ratamba farmers during a meeting with the head of the farmers in the village. At the head of the farmers' office, map delineation was done to show where long term crops like tobacco were grown (see figure 4-1). However, due to language constraints, an interpreter was used to translate the questions to the farmers and also to translate the answers to English.

Figure 4-1: Crop Calendar Acquisition Methods

4.1.2. LANDUSE/ COVER CLASSIFICATION

Land use classification could be done in two ways: unsupervised and supervised classification. However, before embarking on the field work, a pre-image classification was earlier derived using the unsupervised classification in the ERDAS IMAGINE 9.3.2. Software. Here, a pre-knowledge of the area is not required. The classification is done using the data preparation tool in ERDAS and was based on the 2001 LANDSAT image of the area due to availability of the 2009 LANDSAT image before embarking on the field work.

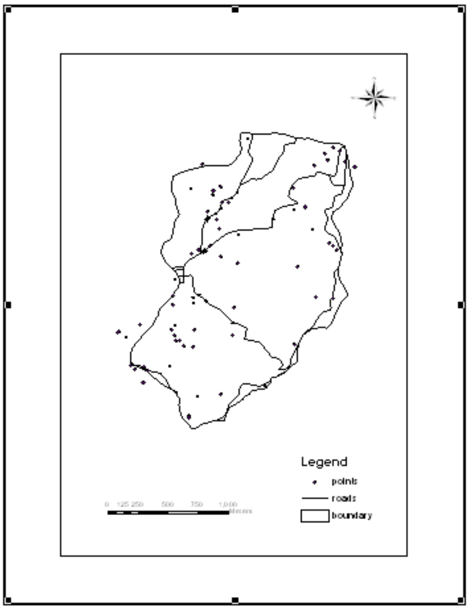


Figure 4-2: Sample Points in the Ratamba Watershed.

This uses the ISODATA algorithm for its execution. ISODATA stands for Iterative Self-Organizing Data Analysis Technique which uses the minimum spectral distance to create clusters and automatically generates the signature file. However, the user defines the number of classes, maximum iterations and other parameters. This classification gives a broad knowledge on the different land covers and also the area. In the field, training samples were collected for different land use types; the agricultural fields, tobacco fields, forest area, shrubs and plantation fields. This serves as ground truth information used for the supervised classification. This was used in the supervised classified land use which requires the users' expertise and prior knowledge of the area of study. Figure 4-2 shows the sample point location in the area.

The supervised land use/cover classification used for this work is for 2009 and was derived using the signature editor using the ERDAS IMAGINE software. A total of 83 samples were collected for this analysis. 60 of the samples were used as training samples for the classified land use and 23 samples were used for validation. The landuse/cover classes included shrubs/plantation, cabbage with carrot, potatoes with maize, green peas, tobacco, bare land and also settlements and roads. In the signature editor, different land cover types were digitized and merged and assigned different colours to differentiate them. These classes were merged together mostly because they were grown together and as such a clear distinction could not be made. For classification, the maximum likelihood classification option was used to produce a classified land use map of the area.

The classified land use was done using a quick bird image with a resolution of 2.4m. The high resolution image made it easy to identify the different land cover types in the study area. However, due to the small sizes of the individual field, proper delineation of certain land uses was difficult. And following the objective of this study, map aggregation from LANDSAT to MODIS resolution is required which will be further used in the erosion modelling, a land use will also be necessary at the scale of 30m from the LANDSAT image. Following this, the study area land use for 2009 previously derived by a colleague in the institution will be use which has the following classes; build up, dryland agriculture, forest, tobacco, shrubs and plantation. The bare lands in the area were combined with the dry land agriculture since there were bare as a result of a previous harvest. The satellite images however, were not only used for landuse classification, they use to derive NDVI values which were further used to obtain cover factor which is an input for the erosion model.

LAND USE ACCURACY ASSESMENT

A contingency matrix was performed on the land use generated from the quick bird image using 60 field samples points and also on the 23 samples used as a validation set. This was done using the maximum likelihood parametric rule and considering only pixel percentages in calculation. Also an accuracy assessment on the land use derived from the LANDSAT image done by Andry Rusanto, 2009 for the area was done using the GRASS GIS 6.4 RCS. This is further described in chapter 5.

4.2. SOIL, CLIMATIC, LAND COVER AND EROSION PARAMETERS

4.2.1. SOIL PARAMETERS

These includes soil texture, soil erodibility, moisture content at field capacity, effective hydrological depth of the soil, bulk density, cohesion of the surface soil, organic matter and soil locations.

SOIL TEXTURE ANALYSIS

Soil texture describes the proportion of different grain size of mineral particles in a soil are grouped into three classes a namely clay, silt and sand. And in most cases, a fourth class is added which is the loam. And the proportion of these classes in a soil determines the type of soil. These were analyzed both in the field and in the laboratory. In the field, soil texture was analyzed through the feel method. Here, the soil is felt and the texture class is given in response to the stickiness and flexibility of the soil which is determined by the amount of sand, silt and clay. Figure 4-3 shows the different soil rings and the corresponding texture classes. Here, a handful of soil is held in the hand, broken up with the fingers and water dropped into it and the mixture made into a ball and tried to make the shapes shown in figure 4-3 and figure 4-4 shows a systematic flow approach to feel method.

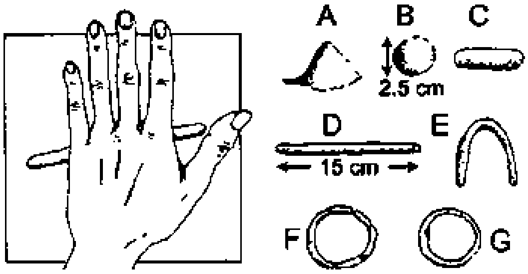


Figure 4-3: Field Texture Classification Methods

Source: FAO Document Repository (www.fao.org/docrep/006/x8234e/x8234e06.htm)

When the soil remains loose and cannot form anything then it is sand (A), if it easily forms a ball but cannot be rolled and has a gritty feel, then it is sandy loam (B), if it could be rolled into a short thick cylinder with a smooth feel, then it is C which silt loam. It is D which is loam if it can form a 15cm roll without breaking but cannot form a horse shoe without breaking. It is E which is clay loam and can easily form a horse shoe without breaking but breaks when trying to make a circle out of it. And F, G is clay which easily forms a circle ring without breaking.

Soil Texture Analysis Flow Chart

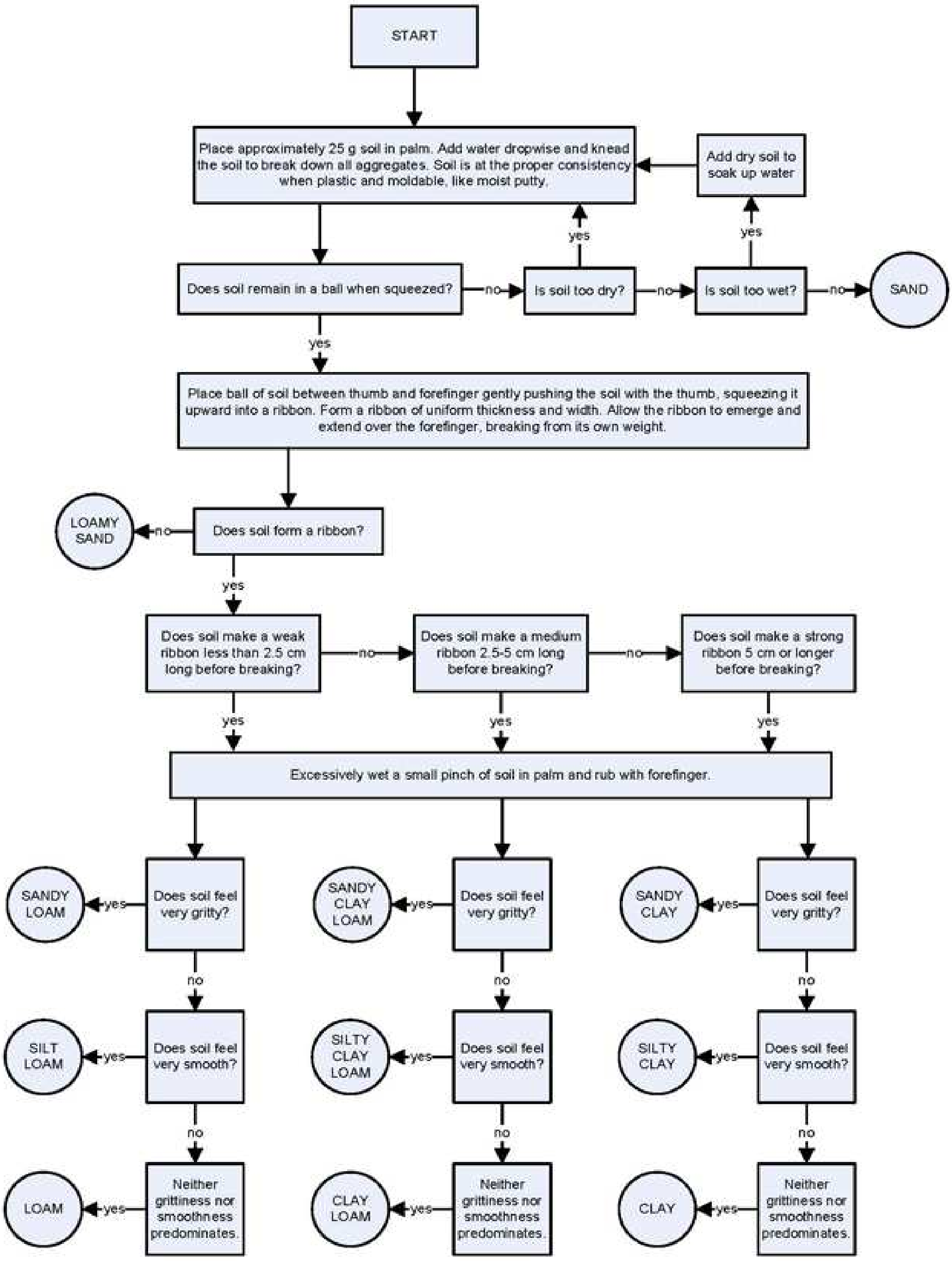


Figure 4-4: USDA Soil Texture Field Guide

[SOURCE: http://soils.usda.gov/education/resources/lessons/texture/]

However, the field test may be fast but less accurate has little or no practice with it. Based on this, a total of eight (8) representative sample of the texture derived in the field were analyzes at the ITC soil and water laboratory for validation of the assigned soil texture classes. The procedure was as follows:

Step 1: **Oxidation of Organic matter**

This was done to remove carbonate contents. 20g of the sample was put into beakers. And 15ml of water with 15 ml of $H_2O_2$30% added, then let to stand overnight. The next day, the beaker was placed on a water bath of 80 ^{0}c and 5-10ml of $H_2O_2$30% was added regularly until decomposition of organic matter was complete. Then, 300ml of water was added and place on a hot plate for about one hour to completely remove any remaining H_2O_2. This was allowed to cool and samples were centrifuged and decanted.

Step 11: **Dispersion**

After centrifuge and decanting, the remaining samples were transferred to polythene bottles and 20.ml of dispersing agent and water to make the volume about 400ml. Each bottled capped and was left in the shaking machine for 16 hours at a speed of 30 rpm.

Step 111: **Separation of Fractions**

The suspension was passed through a 50 µm sieve and water added to the 1 litre mark. Then sands fraction remaining in the sieve was washed into a porcelain dish and dried for at least one hour.

Step 1V: **Determination of Sand Fractions**

The dried sand was the top sieve of a stack of the following sets: 1000µm, 500 µm, 250 µm, 100 µm and 50 µm. After about 10 minutes, the different sand size materials were emptied and weighed.

Step V: **Blank Determination**

The blank cylinder was pipette with the same procedure as that of the silt and clay fractions.

Step V1: **Silt and Clay Fractions Separations**

After removing the sand fraction, the cylinder was shaken and 20ml was immediately pipette from the centre and the aliquot transferred and treated as previous with a slight change of drying overnight. This was done to separate fractions <50 µm. Subsequently, the cylinder was shook and a five minutes interval was observed and 20 ml was pipette and treated as previous sample. This was to separate the fractions <20 µm. And finally, the cylinder was shook again and allowed an interval of 5 ½ hour before another 20ml was pipette to separate the fractions <2 µm. All collected samples of clay and silt were treated alike.

The fractions were obtained using the following:

Clay (<2 µm) = (H x 50) – (Z x 50) (wt.K)

Silt (2-20 µm) = (G x 50) – (Z x 50) – K (wt.L)

Silt (20-50 µm) = (F x 50) – (Z x 50) – K – L (wt.M)

Sand (>50 µm) = A +B +C + D + E

Sample weight = K + L + M + N (all weights in gram)

Where

A through E = weight individual sand fractions

F = weight 20ml pipette aliquot of fraction <50 µm

G = weight 20ml pipette aliquot of fraction <20 µm

H = weight 20ml pipette aliquot fraction <2 µm

Z = weight 20ml pipette of blank.

And the proportion amounts of the fractions were calculated using the equations in table 4.1

% Clay (2 µm) = $\frac{K}{sample\_wt.} \times 100$

% Silt (2-20 µm) = $\frac{L}{sample\_wt} \times 100$

% Silt (20-50 µm) = $\frac{M}{sample\_wt} \times 100$

% Sand (>50 µm) = $\frac{A}{sample\_wt} \times 100$

Table 4-1: Particle Size Calculation (Van Reeuwijk 2002)

Thereafter, the results were analyzed using the SPAW (Soil Plant Atmospheric Water) model and the USDA triangle (figure 4-5).

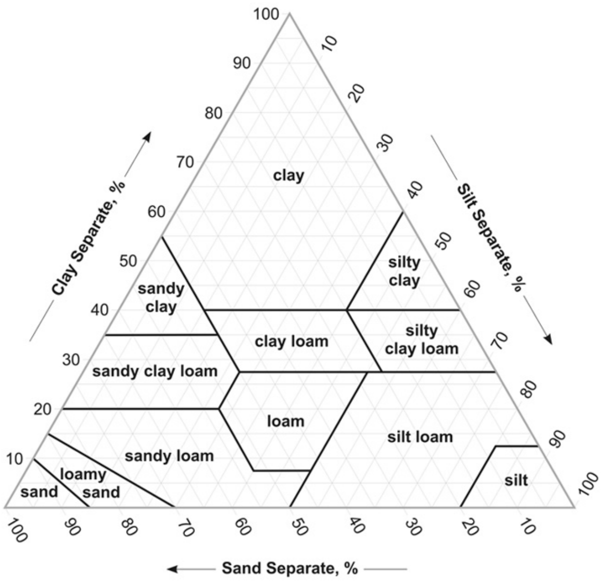


Figure 4-5: USDA Soil Texture Triangle

[SOURCE: http://soils.usda.gov/education/resources/lessons/texture/]

SOIL ERODIBILITY

Erodibility of a soil refers to its susceptibility to detachment and transportation. This parameter has been extensively discussed in chapter two (2.2.2). To estimate this parameter using the monograph, organic matter is essential. However, due to time restraints, organic matter could not be analyzed in the laboratory and as such typical values for the different soil textures where derived from a literature. The erodibility values were assigned to the different soil types and were created as a soil attribute map using the ILWIS software which was an input map for running the erosion model .

SOIL COHESION

This was carried out in the field using the shear vane test. The shear vane tester is calibrated instrumented (see figure 4-6) and has which has four blades. This is gently pushed in the soil surface to a depth of 2cm and rotated gently until there is a shear break. A reading is taken at the shear failure and is immediately calibrated again to zero for more readings. A total of five readings were taken for each location and an average value used to represent the cohesion value and it is quantified in Kpa. This was used to represent the soil cohesion of the area. The obtained values for each soil type were averaged and used to as a representative value for that soil type. The final cohesion map was created as an attribute map in the ILWIS software and was used as a parameter in running the erosion model.

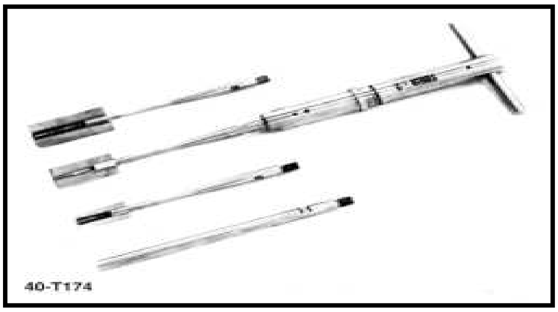


Figure 4-6: (a) Shear Vane Tester **(b) Shear Vane Calibration**

[Source: www.groundtest.co.nz/shearvane/shearvanepage1.php]

Furthermore, due to insufficient field work tool, parameters such as effective hydrological depth, bulk density and moisture content at field capacity were derived from literatures.

4.2.2. CLIMATIC DATA

This was made available through the Badan meteorological station in the Banjanegara. The information derived here included the rainfall amount and the number of rainy days. And the rainfall data spanned from 1995 – 2009. However, due to non-availability of data, the climatic data from one rain station in Pejawaran where the study area is located is used and uniform rainfall is assumed from for this research.

4.2.3 LAND COVER PARAMETERS

This includes canopy cover, ground cover, plant height, crop cover factor, rainfall intercepted by crop cover, ratio of actual to potential evapotranspiration and effective hydrological depth.

CANOPY COVER

Canopy cover which is usually represented as CC acts as a protective layer which buffers the soil from the kinetic energy impact of the rain. This could have been measured using a densitometer but it was realized in the field that it was more applicable to forest areas and not to the agricultural area. So, to get a uniform approach to measuring this factor, it calculated in two forms: visual estimation and also using reference measurement. A known square measurement was taken of a representative area for various land cover types in the field and the percentage coverage by the canopy was adopted to represent the entire field. This method was backed up by visual estimation of the canopy cover of the area. For the entire year, the canopy cover was estimated from the crop calendar which assumes different CC for different crop growing period and a constant value for forest and shrubs throughout the year. The crop calendar gives the cycle for the crop growth in the area. During the acquisition of the crop calendar, rough estimates of what the canopy coverage at each growth would be. From this information, canopy cover estimates were made for each month and stored as a table format which would to create attribute map for the canopy cover used in running the erosion model and also serve information for the derivation of other parameters such as leaf area index and cover factor. This will be discussed further in this chapter.

GROUND COVER (GC)

This was basically estimated visually. Also, during the crop calendar acquisition, information was derived on the practices that were done after planting had begun. This was necessary to estimate if how much changes take place in the agricultural areas but for the forest, shrubs and plantation. A uniform ground cover is assumed for the whole year and the value derived in the field was used.

PLANT HEIGHT (PH)

The plant height required by the RMMF model. This was done using two approaches: measuring the plants with a measuring tape and also from height and visual estimation. The second approach was used for plants that could not be directly measured due to their heights.

LAND COVER FACTOR (C-FACTOR)

Several factors affect soil erosion but vegetation does play an important role in soil erosion. Areas with no or little vegetation are assumed to be more prone to erosion than areas with high vegetation. As such, cover factor maps are necessary for erosion assessments. C-factor generation could be done in different ways (Zihni 2000). It could be derived from satellite images, from field work assessment (Suriyaprasit and Shrestha 2008). But deriving C-factor directly from satellite images may not use accurate results however, (Suriyaprasit 2008) established a correlation of an adjusted R^2 of 0.78 between the C-factor derived from satellite images and the C-factor values from training samples. Based on this result, the study focuses on C-factor generation derived from satellite data due to non availability of data. These were calculated from the NDVI maps generated from MODIS images of June through September, 2009. The NDVI maps were calculated using the algorithm:

Equation 1 $\quad$ ***NDVI = (NIR – RED) / (NIR + RED)***

Where NDVI = Normalized Difference Vegetation Index

NIR = Near-infrared band

RED = Visible band

Table 4-2 shows the respective bands used in the NDVI calculation.

	MODIS BANDS	LANDSAT BANDS
Red	Band 1	Band 3
Near-Infrared	Band 2	Band 4

Table 4-2: NDVI Bands for MODIS and LANDSAT Images.

There are different C-factor generation techniques from satellite data which includes:

i) Using the Van der Knijff's (1999) equation:

Equation 2 $$C = e^{-\alpha \frac{(NDVI)}{(\beta - NDVI)}}$$

Where C = C-factor

NDVI = Normalized Difference Vegetation Index

β and α = Parameters that determine the shape of the NDVI-C curve (the values 1 and 2 are given respectively) (Van der knijff et al. 2000)

ii) De Jong's (1994) equation:

Equation 3 $$C = 0.431 - (0.805 * NDVI)$$

Where C = C-factor

NDVI = Normalized Difference Vegetation Index

iii) Using the regression equation based on field assessment of C factor (Suriyaprasit and Shrestha 2008)

Equation 4 $$C = 0.227 * e^{(-7.337 * NDVI)}$$

Where C = C-factor

NDVI = Normalized Difference Vegetation Index

These three methods were used to generate C-factor maps in the ILWIS interface and the best optimal result was used in this work. Firstly, in the operation list, NDVI operation was used where the different corresponding bands were made as input and corresponding NDVI maps were created. Thereafter, a map calculation (see appendix 5) was used to generate the C-factor maps using the previously mentioned equations and the generated C-factor maps were masked using the boundary for the study area.

And due to unavailability of images for all the months in the year, monthly C-factor was generated from the canopy cover with inference to the crop calendar generated from the area.

Equation 5 ***C - factor = 1 – CC***

Where cc =canopy cover. This is based in the assumption that when canopy cover is 100%, c-factor is 0 and when canopy cover is 0, c-factor is 1.

Based on this, estimated valued for the monthly cover factor was derived.

RAINFALL INTERCEPTION (A)

Precipitation plays an important role in soil erosion studies. As earlier stated in chapter two, rainfall, its effect could be indicated in the detachment of soil particles on reaching the ground surface. However, De Jong and Jetten (2007) noted that not all precipitation reaches the soil surfaces: a fraction of it is intercepted by the vegetation and ground litter (see figure 4-7). And the fraction of the total rainfall intercepted by the vegetation and litter is referred to as interception.

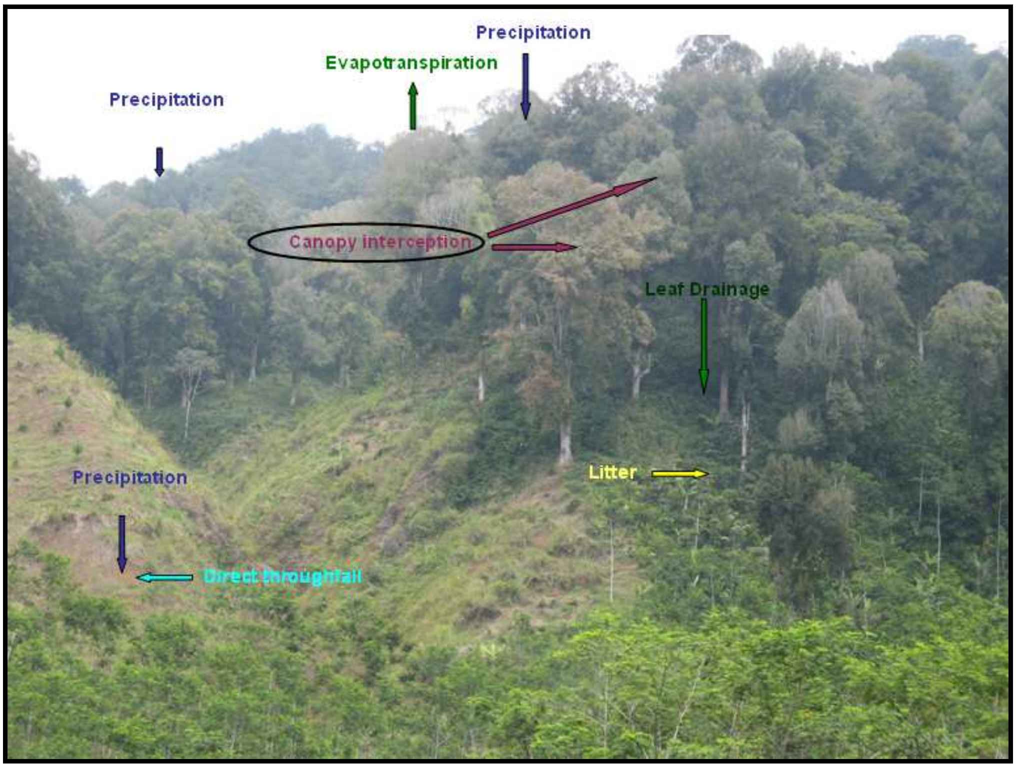


Figure 4-7: Rainfall Parameters

Interception also plays an important role in the soil erosion modeling as it reduces the impact of the kinetic energy that reaches the ground. However, Morgan (2005), also explains that stem flow and large rainfall drops formed from as a result of interception could largely contribute to detachment by splash and runoff on reaching the ground. To derive the interception parameter, an equation by Aston(1979) was used (De Jong and Jetten 2007).

Equation 6 $$I = C_p S_{max} (1-e^{-k\,p / S_{max}})$$

Where I = interception

C_p = Canopy cover fraction

S_{max} = Canopy storage fraction

K= the fraction of rainfall that falls on the canopy

P = cumulative rainfall (mm)

The final interception value was derived following a series of calculation steps and procedures;

1. Deriving the leaf area index (LAI) of the plants in the area
2. Estimating the storage capacity of the leaves
3. Calculation of the fraction of rainfall that falls on the canopy
4. Compilation of cumulative rainfall
5. Calculation of rainfall intercepts using the above outlined parameters

- **Leaf area index (LAI)**

According to Chen et al (1997), LAI is one half of the total green leaf area per unit ground surface area while Boyd et al (2002), defines it as just a measure of leaf area per unit of ground area. LAI could be derived directly in the field and could also be derived indirectly from canopy cover. Gower et al (1999), investigated and compared results derived directly and indirectly. This study derives LAI indirectly from canopy cover using the Lambert – beers equation ((Boyd et al. 2002):

Equation 7 $\boldsymbol{Lint = 1\text{-}e^{-k\,(LAI)}}$

Where k = 0.46 (an attenuation coefficient)

Lint is the percentage PAR intercepted and is considered to be the same as ground cover. However, according to Boyd et al (2002), Firman and Allen (1989) concluded that ground cover hardly takes into consideration, canopy density and as such should not be used to calculate LAI and however, suggested that canopy cover be used instead. Based on this, the research, replaces the Lint with canopy cover in the equation 7

Thus; Equation 8 $\boldsymbol{Cover = 1\text{-}e^{-k\,(LAI)}}$

From equation 8, the leaf area index was derived.

Equation 9 $\boldsymbol{LAI = \ln(1\text{-}cover)/\text{-}0.46}$

Where cover = canopy cover (see 4.2.2.1)

- **Canopy Storage Capacity (S_{max})**

S_{max} refers to the intercepted rainfall storage in the canopy cover. De Jong and Jetten (2007), reviewed different statistical methods on deriving S_{max} and showed that there exist a relationship between canopy storage capacity and LAI. This research uses one of the statistical equations which incorporates grass and low shrubs and also gave a good relationship between S_{max} and LAI ($r^2 = 0.82$): (De Jong and Jetten 2007)

Equation 10 $\boldsymbol{S_{max} = 0.3063LAI + 0.5753}$

.

- **The fraction of rainfall that falls on the canopy (K)**

This parameter was measured using an equation:

Equation 11 $K = 0.065LAI$

According to (De Jong and Jetten 2007), k values are obtained from a series of rainfall experiments on trees but Aston (1979) derived k by matching stimulated and measured interception using this parameter to obtain the best fit. However, this was derived with reference to eucalypt species; the study will evaluate its applicability to vegetation crops too.

- **Cumulative rainfall (P)**

This parameter was obtained from the meteorological station (refer to 4.2.2)

Other parameters such as ratio of actual to potential evapotranspiration and effective hydrological depth were derived from literature review (Morgan 2005).

4.2.3. EROSION PARAMETERS

4.2.4. THE REVISED MORGAN- MORGAN-FINNEY (RMMF)

The RMMF model is a revised version of the Morgan-Morgan-Finney (MMF) model which takes into account soil particle detachment by raindrop as used in the original MMF model but also the plant canopy height, leaf drainage and the soil particle detachment by flow. And also, some input parameters which were difficult to determine in the original MMF model such as the top soil rooting depth (RD) is replaced by the effective hydrological depth of the soil (EHD). The effective rainfall is also split into two: the kinetic energy of direct through fall (KE_{DT}) and the kinetic energy of the leaf drainage (KE_{LD}) and the total kinetic energy (KE) is the sum of both (KE_{DT}) and (KE_{LD}) Morgan (2001). The RMMF was selected for this study because the research focuses on understanding annual soil loss response in relation to seasonal variation of the erosion parameters. And the RMMF model could be easily adapted to meet the objectives of this work. It is adapted to also run on a monthly basis for the one year in the Ratamba by using monthly derived factors. The model is divided into two phases: the water phase and the sediment phase. They are described as follows:

The Water Phase:

This phase entails the following:

- **Estimation of rainfall energy**

Firstly, this uses the mean annual rainfall to calculate the effective rainfall after permanent interception. The effective rainfall is then split into two parts: the leaf drainage which takes considers the proportion of the rainfall that reaches the ground surface after interception by the canopy cover and also the direct through fall which reaches the ground surface without interception. And each individual kinetic energy is then derived in order to estimate the total kinetic energy of the effective rainfall. The kinetic energy of the direct through fall is a function of rainfall intensity and that of the leaf drainage is a function of the plant height. And the total kinetic energy is the sum of the two.

Equation 12 $ER = R*A$

Where ER = Effective Rainfall

R = total annual rainfall (monthly rainfall amount was derived from the meteorological data)

A = the rainfall interception by vegetation cover

The rainfall interception was a value range computed using Smax and canopy fraction.

The ER is then split into that which reaches the ground surface as direct through fall (DT) and that which is intercepted by the plant canopy and reaches the ground as leaf drainage (LD). The split is a direct function of percentage Canopy Cover (CC) **-** between 0 and 1

Equation 13 $LD = ER \times CC$

Average monthly Canopy cover for each over class (0**-**1) was estimated based on the field work data and the LD was then used to calculate the part that reaches the ground surface without interception known as the direct through fall of the effective rainfall, DT.

Equation 14 $DT = ER - LD$

The kinetic energy of the direct through fall (KEDT; J/m2) is determined as a function of the rainfall intensity (I: mm/h) and the value of 30 (Morgan and Duzant 2008) for strongly seasonal climates was applied which characterizes the area of study. And to estimate the total kinetic energy of the area, the kinetic energy of leaf drainage, KE (LD) and that of the direct through fall, KE (DT) were first estimated as

Equation 15 $KE\ (DT) = DT \times (11.9 + 8.7 \times \log I)$

The kinetic energy of the leaf drainage (KELD; J/m^2) is dependent upon the plant height (PH; m).

Equation 16 $KE(LD) = LD \times (15.8 \times PH^{0.5}) - 5.87$

The total energy of the effective rainfall (KE; J/m^2) is given as follows:

Equation 17 $KE = KE(DT) + KE(LD)$

- **Estimation of runoff**

Annual runoff is dependent on the mean annual rainfall, soil moisture capacity and also the mean rainy days. According to Morgan (2005), a study shown by Kirby (1976) shows that runoff occurs when daily rainfall exceeds storage capacity and the storage capacity if depends on a number of factors which include soil moisture at field capacity, bulk density, effective hydrological depth and evapotranspiration while the mean rainy days is a function of total annual rainfall and the number rainy days in a year.

The soil moisture storage capacity is estimated from:

Equation 18 $RC = 1000 \times MS \times BD \times EHD \times (Et/Eo)$

Where RC = soil moisture storage capacity

MS = soil moisture content at field capacity (%ww.)

BD = bulk density (g/cm3)

EHD = effective hydrological depth (m)

Et/Eo = ratio of actual to potential evapotranspiration

The mean rainy days is calculated from:

Equation 19 $Ro = R/Rn$

Ro = mean rainy days

R= annual rainfall

Rn = number of rainy days in a year

The total runoff is:

Equation 20 $Q = R \times \exp(-RC/Ro)$

Where Q = annual runoff (mm)

R = annual rainfall

Ro = mean rainy days

The Sediment Phase

This considers the detachment of soil particles by raindrop and also by runoff. Soil detachment by rainfall is a function of the kinetic energy of the effective rainfall and soil erodibility. And the detachment by runoff takes into account the ground cover, soil resistance, and runoff and slope steepness. And the total particle detached is a summation of both the particles detached by raindrops and runoff.

- **Soil particle detachment by raindrop**

The detachment of soil particles by raindrop impact (F; kg /m^2) is a function of the kinetic energy of the effective rainfall, the detachability of the soil (K; g/j)

Equation 21 $F = K \times KE \times 10^{-3}$

Where F = soil particle detachment by raindrop impact (kg/m^2)

K = soil erodibility (g/j)

KE = total kinetic rainfall

This model assumes that soil detachment by runoff only applies to areas where the soil is not protected by ground cover.

- **Soil resistance**

Equation 22 $Z=1/ (0.5*COH)$

Where Z = soil resistance

COH = soil cohesion (kpa)

- **Soil particle detachment by runoff**

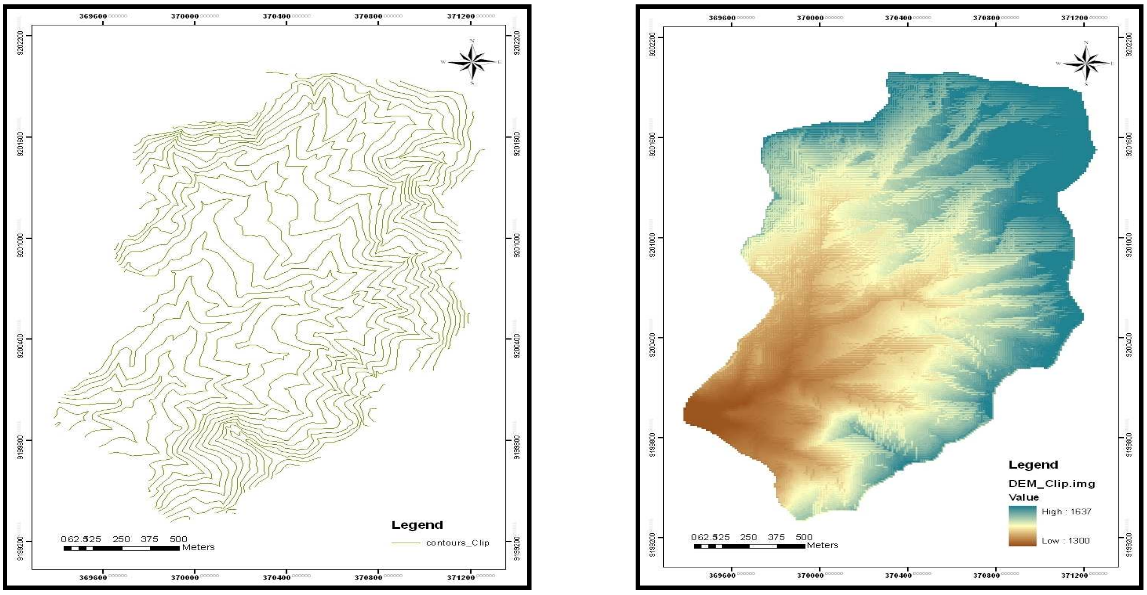
The soil particle detachment by runoff is a function of the runoff (Q), slope angle(S), soil resistance (Z) and the percentage of the ground covered by vegetation (GC: %)

Equation 23 $H = Z \times Q^{1.5} \times SIN(S) \times (1- GC) \times 10^{-3}$

Where H = soil particle detachment by runoff (kg/km^2)

And S= slope which was derived from the DEM map of the area.

The DEM map (figure 4-8) was created in the ILWIS software using the contour map of the area



(a) (b)

Figure 4-8: Contour Map (A) Converted to Digital Elevation Model (B) of Ratamba Watershed

Then linear filters in the X and Y directions were applied to the DEM to give height differences in the X and Y directions. These filters were used to generate the slope map in percentage and this was converted to slope in degrees. However, to have a good representation of the slope, it was converted to radiances for the erosion analysis. This could be seen in the script used to run the model in the Appendices.

- **Total particle detachment**

Where D = total soil particle detachment (kg/m^2)

Equation 24 $D = F + H$

The total detached soil particles from splash and runoff was accumulated know the total concentrated in the flow. Without accumulation, the detachment values just the sum of the materials detached per cell unit but with accumulating this material, it gives the influx of detached materials from the upslope element and the detached materials from the upslope are directed down slope in the same way. (See 4.2.5 for further explanation). The accumulation process was done using the PCRaster software. The total detachment map was first exported from the ILWIS and converted in an ASCII file which is a PCRaster readable file. And the accumulation was carried out in the nutshell interface of the PCRaster (see appendix 6 for script)

TRANSPORT CAPACITY OF RUNOFF

It is estimated from the cover factor (which is a function of C-factor and the management practice), annual runoff and the slope. According to Van der knijff et al. (1999), the C-management factor here refers to the ratio of soil loss from land and is dependent on vegetation cover and management practices. And Renard et al (1997) noted that for proper estimation of the C-factor, canopy cover, surface roughness, surface cover, soil moisture and prior use of the land should be taken in consideration. However, Van der knijff et al (1999) not disputing the fact that these parameters are necessary for proper evaluation of C-factor, mentioned that it is hardly possible to use the RUSLE approach for estimating C-factor especially at a national scale due to lack of sufficient data. And as such, used NDVI derived C-factor values though noted that relying solely on the NDVI could give incorrect results but despite its errors and no availability of adequate data, this technique was applied.

De Asis and Omasa (2007), suggested that linear spectral mixture analysis is better technique to estimation C-factor where a correlation factor of 0.94 with the values measured in the papers study area was obtained. Transport capacity of runoff is calculation is as shown below:

Equation 25 $TC = C \times Q \times SinS \times 10^{-3}$

Where TC = transport capacity (kg/m2)

C = surface cover factor (c-factor) which is a function of c-factor multiplied by the management factor. C-factor map was derived from NDVI values generated from satellite images. And the management factor used here is 0.05 indicating that the reverse bench terrace is implemented in the area. The value was derived from Morgan, R.C.P (2005) .

Q = total annual rainfall

S = slope (appendix 9 for slope map)

The transport capacity was also exported to the PCRaster software for accumulation like the total detachment. This enabled one to know how much transport is available to transport the soil out of the water watershed. Where the transport capacity was lower than the detachment, the soil transported is the same value as the transport capacity and the remaining materials deposited. As such, the deposited material is excluded from the total soil loss from the catchment.

Estimation of soil erosion

This is estimated by comparing the amount of material delivered to the flow, which is the soil particle (D) with the transport capacity (TC). The minimum between the two parameters equals soil loss. This was done in two ways: 1) summation of the monthly predicted soil loss 2) one year prediction using average values for the whole year.

Equation 26 *Soil loss = min (D, TC)*

Soil loss rate is in kg/ m^2 [This result was converted to both ton/year and tons/hectare/year]
Figure 4-9 shows a flow chart of the whole RMMF method.

4.2.5. FLOW ACCUMULATION

To estimate the flow accumulation of the area, it is suggested in Morgan (2001)that the entire watershed be divided into elements of homogenous character in terms of soil, slope and land cover. Here, the total runoff of (Q_i) in element (i) is the sum of the runoff generated on that element and the runoff received from the element upslope. The accumulation is used to calculate the flow detachment and transport capacity of that element (i). And the total material detached in that element is the sum of the materials detached in that cell and the influx of detached materials from the upslope element and the detached materials from the upslope are directed down slope in the same way. The total runoff accumulated at the outlet will give the runoff generated from the catchment which should correspond to the discharge at the stream outlet of the watershed.

4.2.6. RMMF MODEL FLOW CHART

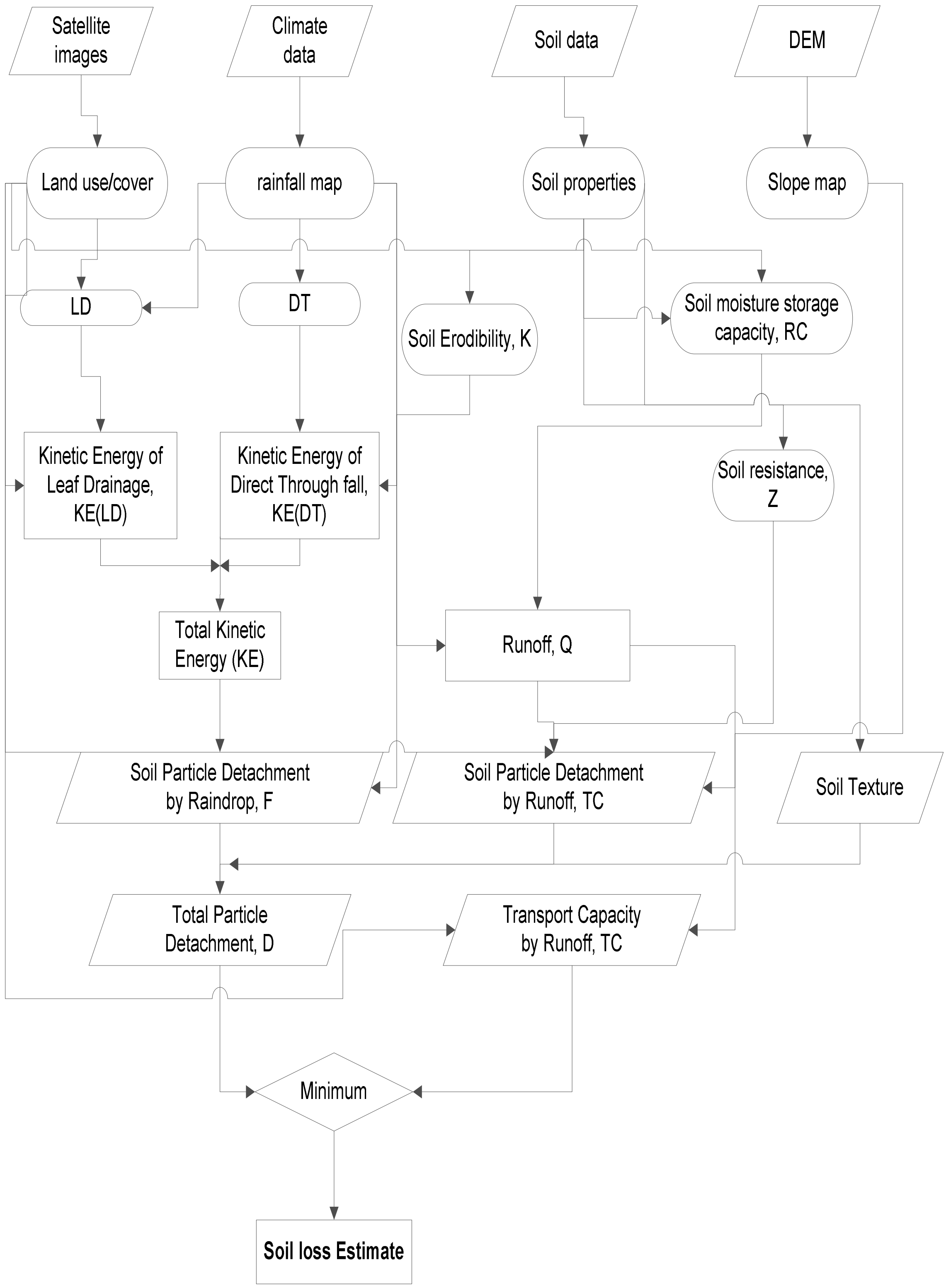


Figure 4-9: RMMF Model Methodology with Modification Adapted from the Modified MMF

4.3. SENSITIVITY ANALYSIS

The third objective of the research is:

- ***To study the influence of the of the management practice on soil loss in the area.***

  This effect will be analysed through a sensitivity analysis.

A sensitivity analysis was done for the management practice in the whole catchment to understand how these practice influencing soil loss in the area. From the field work, it was noticed that only one management practice is implemented in the area and that is the outward sloping slope bench terrace. Agricultural terraces are levelled part of hills which serves soil conservation measures implemented to protect the soil from erosion by reducing the speed at which water flows down. Terraces could be natural or man-made. For conservation and creating more room for crop cultivation, man-made terraces are created. There are different types of agricultural terraces and each terracing has different effects on soil erosion in the areas where it is implemented. The RMMF model allows effect of this management practice to be taken into account. This is structured in the transport capacity of the model (refer to 4.2.4.1). Four soil erosion management factors are taken into consideration in the sensitivity analysis and these are:

- The reverse slope bench terrace with a value of 0.05
- The level bench terrace with a value of 0.14
- The outward sloping bench terrace with a value of 0.35
- Level retention bench terrace with a value of 0.01

The values for this management practices are taken from Morgan (2005). For the sensitivity analysis, all the input variables for the RMMF model was kept constant with only changes in the management factor to assess which how effective the outward sloping terrace is in soil conservation of the area and also to proposed an alternative if otherwise.

And the final objective for this research study is:

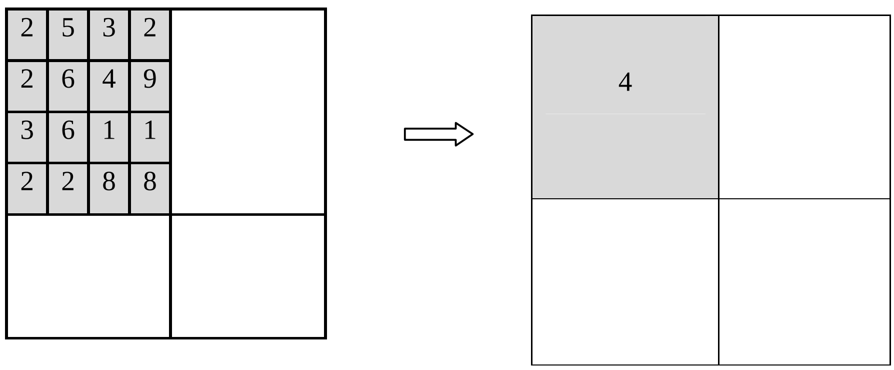
- ***Assessing the effectiveness and applicability of using coarser resolution remote sensing data such as the MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI images for C-factor mapping in small catchments.***

To assess the effectiveness and applicability of using the MODIS (Moderate Resolution Imaging Spectroradiometer), NDVI images for C-factor mapping on very small watersheds, a LANDSAT image for June, 2009 was also acquired to weigh the reliability of the cover factor derived from the MODIS images. These maps were first downloaded and imported into the ILWIS software analysis. NDVI maps were derived from the LANDSAT and MODIS images and to establish a correlation between the

MODIS and the LANDSAT C-factor maps, the LANDSAT 7 image was re-sampled from a 30×30 grid cell to that of the MODIS .Several methods exist for aggregating a fine resolution image to a coarse resolution. Bian and Butler (1999), discussed three techniques for aggregation which includes averaging, central-pixel aggregation and the median aggregation function. However, there are many other aggregation techniques which include the maximum count function, sum aggregation, majority rule-based aggregation, standard deviation aggregation and the minimum aggregation.

AVERAGE AGGREGATION

The average aggregation function computes the value of the output map by the value of the nearest pixel in the input map. In this study, it takes into account the 16 specified input pixels (see illustration in figure 4-10) by simply calculating their mean and gives the output value.



Original Image (30m) **Aggregated Image (480m)**

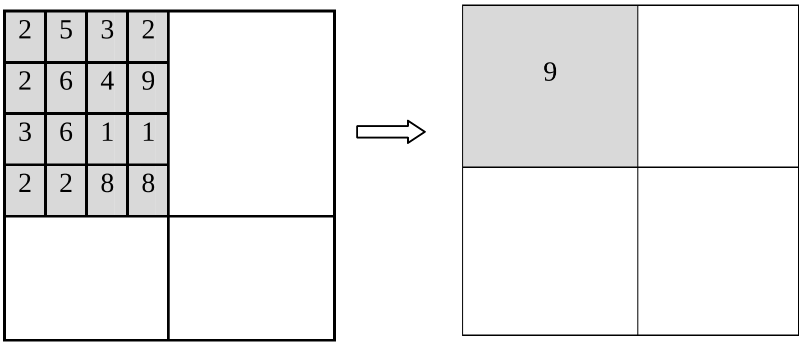
Figure 4-10: Illustration on Average Function

CENTRAL – PIXEL AGGREGATION

The central-pixel aggregation takes the central pixel value of the specified window and assigns that to the output column while the median aggregation assigns the median value of the input window to the output cell.

MAXIMUM AGGREGATION

The maximum function simply takes into account the maximum reflectance pixel values in the sixteen input pixels involved to give a single output value.



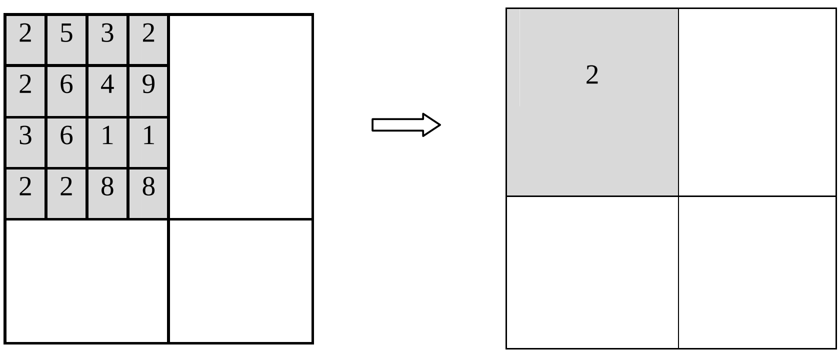
Original Image (30m) **Aggregated Image (480m)**

Figure 4-11: Illustration on Maximum Aggregation

The maximum aggregation of the LANDSAT (30m) to 480m when applied resulted in very high output pixel values in the coarse resolution grid which assumed that the area was covered mostly by forest. From the resultant values, it could be said to overestimate the percentage coverage of the forest class in the area and as such also underestimated the presence of other land use classes in the area.

MAJORITY-BASED AGGREGATION

The maximum aggregation is different from the majority based aggregation which only takes in account the most frequently pixel values in the specified computing input window. This function is also known as the predominant aggregation. This also resulted in very high values and it tends to overestimate the presence of vegetation and also underestimated the other representative pixel values.

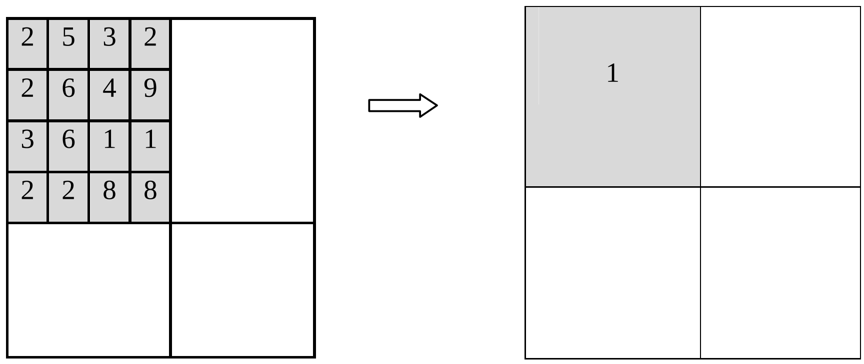


Original Image (30m) **Aggregated Image (480m)**

Figure 4-12: Illustrating the Majority-Based Aggregation

MINIMUM AGGREGATION

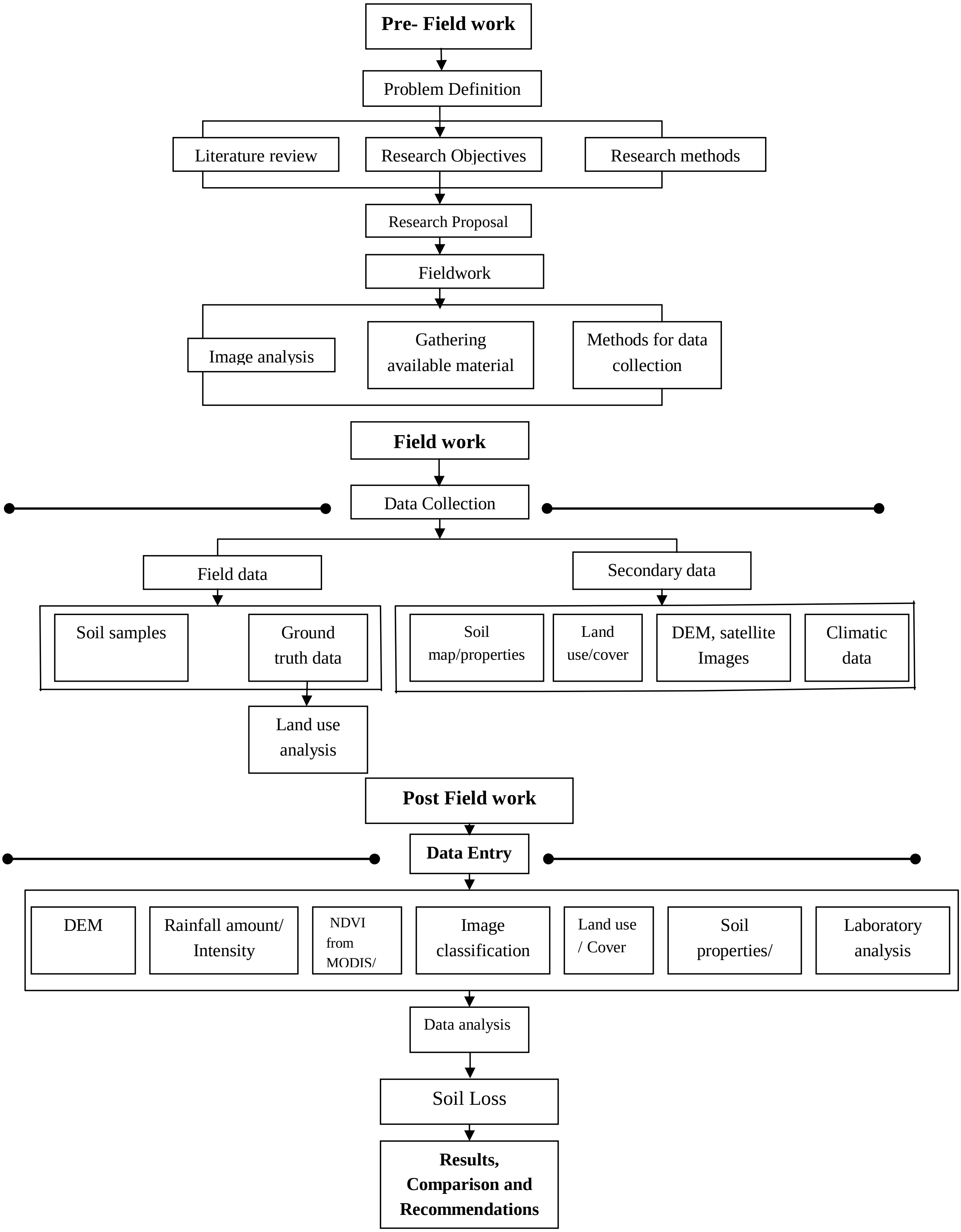
For the minimum aggregation, it took into account only the lowest value in the computing window and assigned that to the output image. This function tends to underestimate the presence of higher representative pixels.



Original Image (30m) **Aggregation Image (480m)**

Figure 4-13: Illustrating the Minimum Aggregation

4.4. METHOLOGICAL FLOW CHART



5. RESULTS AND DISCUSSIONS

The results will follow the same format as the methodology to achieve the research objectives.

The following research objectives results were discussed in the phase of this chapter;

- *The main objective of the research is the study of the effect of seasonal variation of vegetation cover on soil erosion*

The following specific objective was combined with the main objective:

- *To estimate if the annual computation of soil loss using average parameters is the same as the sum of the monthly estimates*

5.1. LANDUSE AND CROP CALENDAR

The main objective of the research is the study of the effect of seasonal variation of vegetation cover on soil erosion. For this it is necessary to generate a land use map and Crop calendar of the study area (Ratamba watershed). This will enable in the understanding of the cropping season and how they affect soil loss.

5.1.1. LANDUSE CLASSIFICATION

A land use classification of the study area was carried out in ERDAS imagine 9.3.2. Figure 5.1 shows the classification result. The maximum likelihood algorithm for the supervised classification was performed using sixty (60) field sample points out of the 83 points and the remaining 23 field points were used for accuracy assessment. The first supervised classification was done using the QUICKBIRD image at a resolution of 2.4m (figure 5-1). From this classification, it was realised that only the shrubs, bare land, tobacco and villages could be properly delineated. The agricultural fields such as cabbage with carrot, potatoes with maize and green peas had a lot of mixed pixels due to the small sizes of the field. As such for simplicity, the crops expect the tobacco fields will all be group as dry land agricultural field.

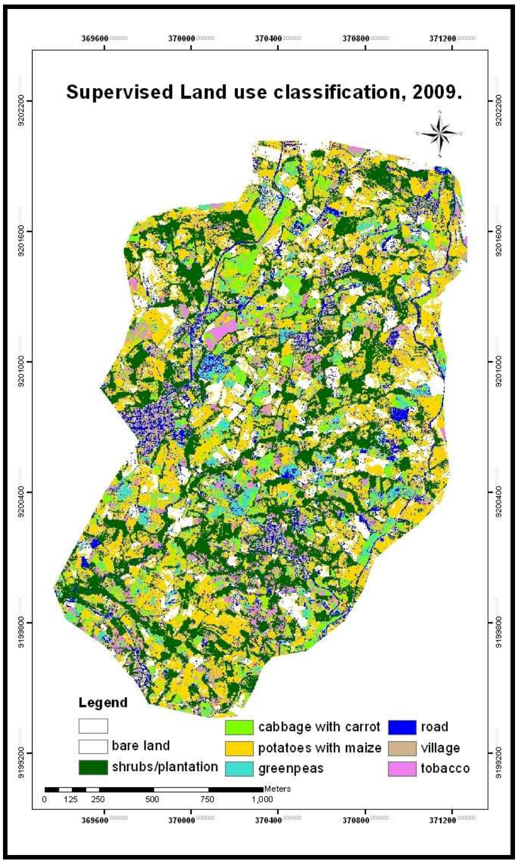


Figure 5-1: Supervised Land Use Classification 2009 Using Quick Bird Image

The error matrix of this classification is shown in table 5-1 below.

ERROR MATRIX: Reference Data

Classified Data	Bare Land	Shrubs/Plant	Cabbage	Potatoes
Bare Land	**86.42**	0.08	0.80	5.16
Shrubs/Plant.	0.25	**90.15**	3.07	4.38
Cabbage	0.00	0.93	**61.92**	21.24
Potatoes	7.78	4.42	13.12	**57.46**
Green Peas	1.85	0.27	7.16	6.38
Road	3.09	1.14	1.79	2.22
Village	0.62	0.54	0.04	0.33
Tobacco	0.00	2.47	12.10	2.83
Column Total	810	5178	2736	1803

Reference Data

Classified Data	Green Peas	Road	Village	Tobacco
Bare Land	5.79	10.72	2.03	0.00
Shrubs/plant.	3.38	6.90	0.68	9.43
Cabbage	33.11	6.95	0.34	19.71
Potatoes	11.74	12.73	5.07	2.73
Green Peas	**37.01**	8.58	0.68	3.56
Road	3.13	**46.11**	20.95	0.21
Village	0.21	5.64	**70.27**	0.21
Tobacco	5.64	2.38	0.00	**64.15**
Column Total	1951	2145	296	477

----- End of Error Matrix -----

Table 5-1: Error Matrix of the 2009 Supervised Classification from Quick Bird Image

As earlier discussed in chapter four, because there is a need to generate a land use map a 30m resolution for the research, the land use map used for the work is a 2009 land use generated from LANDSAT (30m) (figure 5-2) by Rustanto (2010)with a prior knowledge of the area was used. Figure 5-2 shows the different land use classes in the area and also the sample location points. Table 5-2 shows the percentage area of each land use

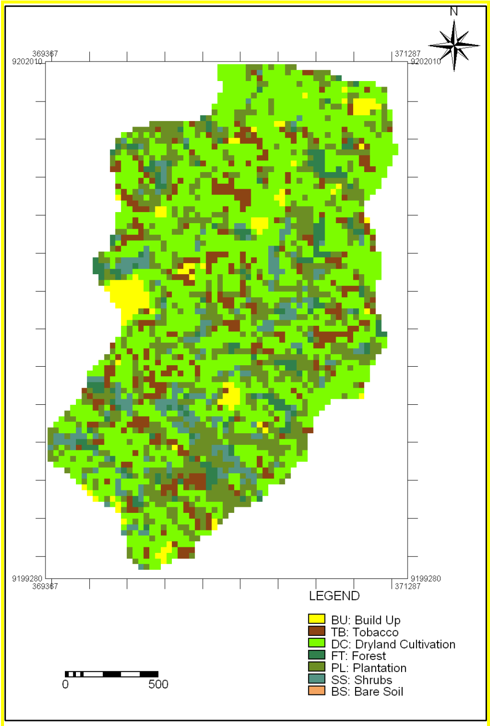


Figure 5-2: 2009 Land Use of the Ratamba Watershed, Banjanegara District, Central Java – Indonesia [source: (Rustanto 2010)]

Land Use	Area in Percent (%)	In hectares
Build Up	3	51
Tobacco	10	170
Dryland Agriculture	52	884
Forest	5	85
Shrubs	6	102
Plantation	24	408

Table 5-2: Land Use Percentage Cover in the Area

The table shows that the dry land agriculture covers 52 % percent of the study area predominantly agriculture, followed by the plantation class with 24 % area coverage, then the tobacco fields with 10 % area coverage while the shrubs, plantation , forest and build up area have the lest area coverage in the area.

VALIDATION /ACCURACY ASSESSMENT

The error matrix obtained for the classified land use generated using the LANDSAT image from Mr. Andry Rustanto, an accuracy assessment of 85.76 % was obtained (see table 5-3). A validation data set was also derived for the land use generated from the LANDSAT image using the same procedure as that of the land use classification.

ACCURACY ASSESSMENT

LOCATION: Upper_Serayu Watershed, Banjanegara District, Central Java – Indonesia

Date: Sat Jan 23 12:31:12 2010

MAPS: MAP1 = Accuracy Assessor Points

MAP2 = Classified Image

MAP Category Description

1: Built Up Area
2: Paddy Field
3: Water Body
4: Dryland Cultivation
5: Forest
6: Shrub
7: Plantation
8: Bare Soil

Kappa	Kappa Variance	
0.826475	0.000580	
Obs Correct	Total Obs	% Observed Correct
265	309	85.760518

Table 5-3: Accuracy Assessment [Source: Andry Rusanto, 2010]

5.1.2. CROP CALENDAR FOR RATAMBA WATERSHED, 2009

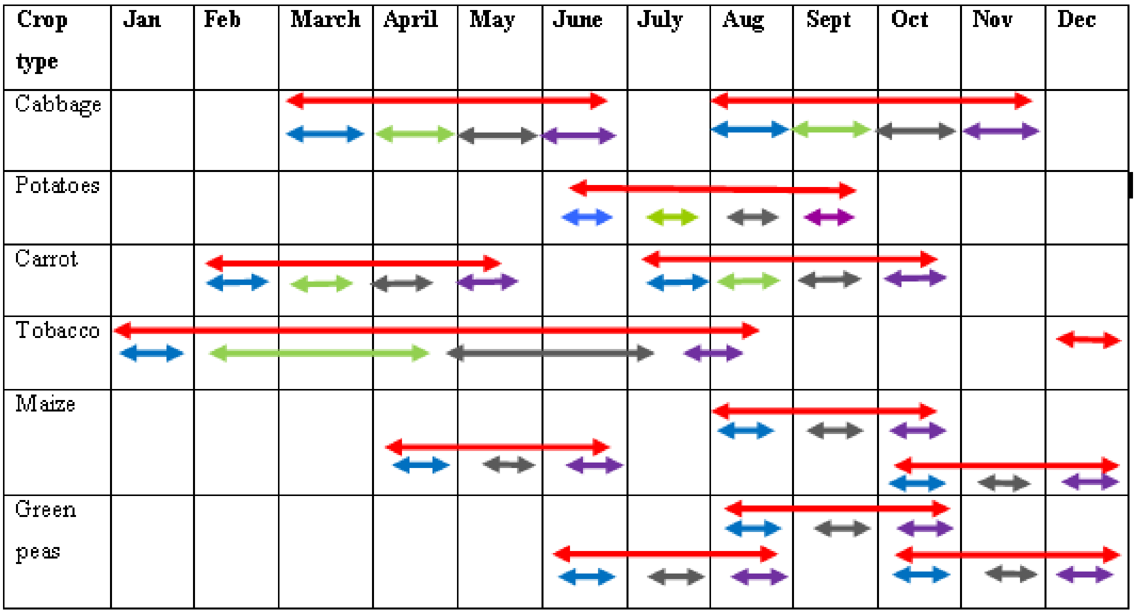


Table 5-4: Crop Calendar for Pejawaran, 2009 [Source: Fieldwork 2009]

Is the whole crop cycle

Is the planting/ starting period of the crop.

Is the young vegetative stage

Is the advanced vegetative stage

Is the harvesting stage

- The cropping pattern in the area entails clearing the land which is mostly done prior to planting and after harvest. Table 5-4 shows that fallow periods are mostly in between harvest and pre-planting season which can last for one or two months depending on the crop to be planted.
- Most fields except for the tobacco fields had intercropping which is mostly the case in the area. These, the farmers assume helps economically and also prevent soil loss as the ground surface in between the crops is covered. In most fields, it was observed that cabbage and carrots were grown alongside and also at different crop stage. The crops were grown in between each other to keep the soil covered and the carrots area usually harvested first. After harvest which is mainly in the dry season or at the beginning of the rainy season, the land can be left fallow or maize could be planted to serve as a cover to protect the soil from erosion. This was the same for potatoes and green peas. The farmers had maize or carrots grown alongside and in between them. However, the potatoes are only grown in the dry season and harvested just before the rainy season sets it since it doesn't require much water.

- The tobacco takes the longest crop cycle in the area and is mostly grown alone because space are needed in between to enable the farmers trim them when necessary.
- In an interview with the head of the farmers (personal communication), he noted that tobacco and tea were the only crops grown in the area twenty years ago and as at that time the experience so much soil loss. But a change to the cropping system was made. Tea and most of the tobacco fields were replace with inter cropping farming were a variety of crops are planted together. The various crops in the area can be seen in the crop calendar (table5-4). It was noted also that new farming system implemented which is the outward sloping terraces in combination with growing of crops in between each other was implement and this in his opinion , had tremendously decreased the rate of soil loss in the area

Relation between the crop calendar and rain fall

In relating crop calendar to soil loss, it necessary to compare the ground and canopy cover with respect to the rainfall variation. The rain fall is estimated at 3,500mm annually (Suwartha et al. 2006) . Table 5-5 and figure 5-3 shows the rainfall pattern of the area.

Month	Jan. 09	Feb. 09	Mar. 09	Apr. 09	May. 09	Jun. 09	Jul. 09	Aug. 09	Sep. 09	Oct. 09	Nov. 09	Dec. 09
Amt	579	601	282	192	104	44	55	35	73	430	535	350

Table 5-5: Derived from the Meteorological Station, Banjanegara - Central Java, Indonesia

And using the previous year rainfall together with the rainfall data of 2009, figure 5-3 shows that most of the crops in the area are dependent on rainfall for cultivation except the potatoes that grown in dry season and the reason being that it needs just little water for cultivation. It mostly makes use of soil moisture content of the soil from the just ended rainy season.

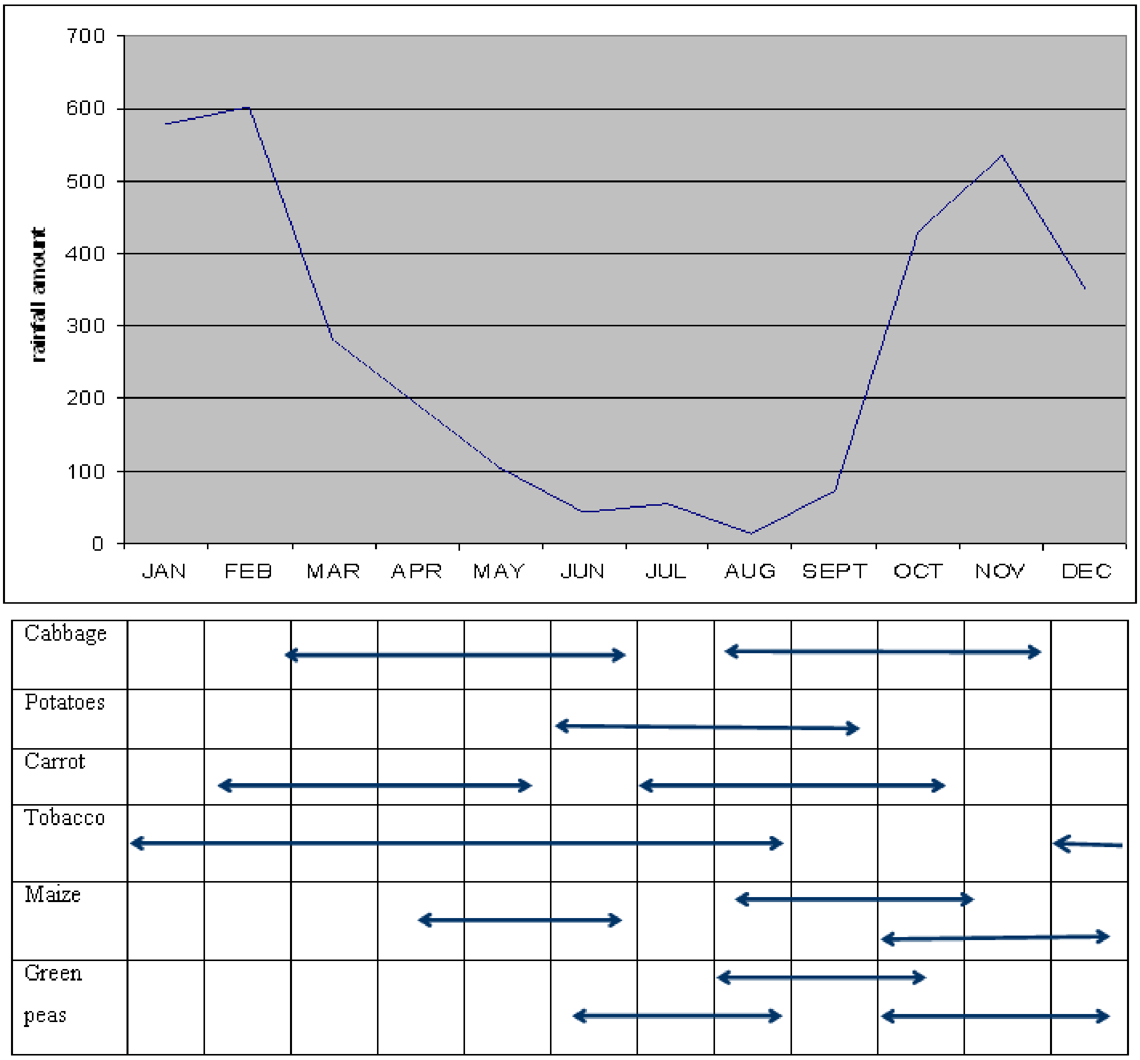


Figure 5-3 : Relationship between Rainfall Pattern and Crop Calendar

↔ represents the whole planting through harvesting season.

However, the irrigation system implemented in the area which is a recent development enables different crop cultivation (especially for those that are dependent on rain) throughout the year. As earlier discussed, most of the fallow periods are during the dry season and especially between June and July (see figure5-3). During this period, some farm areas are bare, unprotected, exposed to erosion agents and the infiltration rate high but with little or no rainfall, it can be said to experience very little or no soil loss. Immediately after the fallow periods crop planting begins again. But the specific choice of crop depends on the farmer and also differs from the previously harvested crop. The tobacco fields in the area don’t undergo any crop rotation system. When the tobacco plants are harvested, the fields are left with the residue of the harvest until the planting season begins again and that is after the rains have started.

For the potatoes field, since the crop does not require much water, it is only grown after the rains have stopped, in the dry season. Subsequent months before and after the potato crop cycle, other crops could be planted in the fields and that again is based on the farmers' decision but must be a crop that will be harvested at least one month before the dry season sets in. The one month interval will expose the ground to moisture which will be used by the potato crop when planting begins in the dry season. Also, during most parts of the rainy season, the vegetative covers are high expect in most like January, and February where some crops in the area are either at their planting or vegetative stage. Thus, the area in general could be said to have little soil loss during the rainy season because of high ground cover and also because of the management practice implemented. Except for months like January and February where there is high rainfall and little surface cover.

5.2. SOIL PROPERTIES ANALYSIS/DISTRIBUTION IN THE AREA

Based on the field work, the soils in the study area consist of having mainly silty clay, loam, sandy clay and loam but the textural. But the laboratory analysis results show that silty loam and loam are the main soil types in the area (table 5-6). Figure 5-4 shows the average distribution of the different soil particle size in the water shed.

Land use	%clay	%silt	%sands	Texture class
Dry land Cultivation	21	34	45	Loam
Tobacco	20	35	45	Loam
shrubs	15	67	18	Silty clay
plantation	21	34	45	Loam
Forest	16	66	18	Silty clay

Table 5-6 : Average Distribution of Soil Texture in the Ratamba Watershed

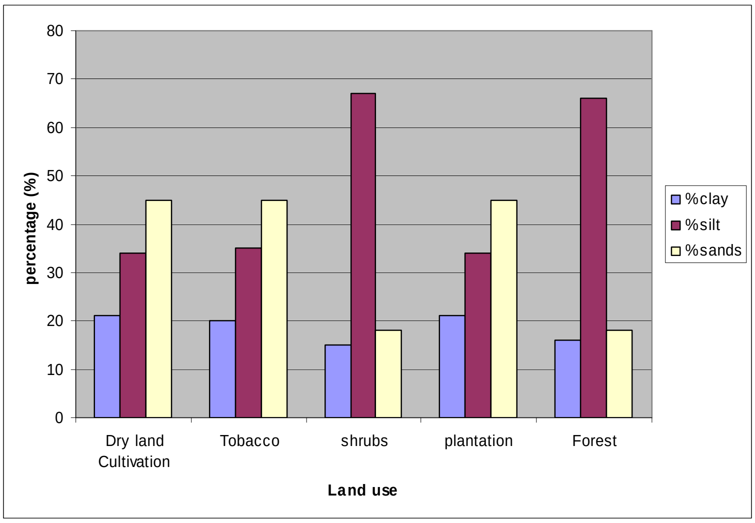


Figure 5-4: Average Distribution of Soil Texture in the Ratamba Watershed

As seen in Table 5-6 and figure 5-5, the shrubs and forest areas show the highest silt percentage content and the lowest percentage sand contents in the area. This was based on the laboratory results. The Dry land cultivation, Tobacco and plantation have low silt content, moderate clay and high sands. These proportions however, encourage cultivation.

The texture classes mentioned in Table 5-6 are derived using the SPAW (Soil Plant Atmospheric Water) model which requires individual texture class percentage for each soil sample values to determine the soil type. The USDA soil texture triangle was used also to verify the soil type gotten from the SPAW model. Each soil sample texture percentages were traced to know the soil type. The soil samples used for the laboratory analysis were representative samples of all the different soil types in the field. Figure 5-5 indicates that the loamy soil is the pre-dominant soil type in the study area.

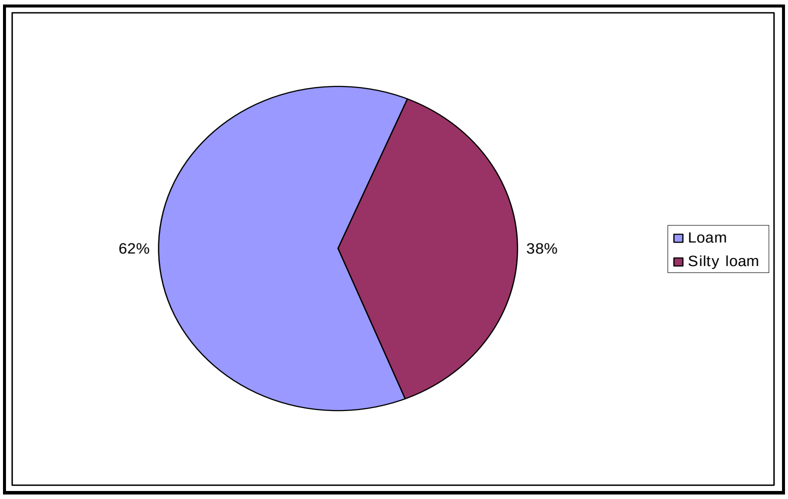


Figure 5-5: Percentage Area Dominated by Soil Type in the Study Area

5.3. DERIVATION OF LAND USE PROPERTIES AND ANALYSIS

5.3.1. C – FACTOR GENERATION

The research focuses on predicting annual soil loss using average input parameters derived for the year and also using the sum of the monthly predicted soil loss. For the latter option, this however, can only be achieved if there are available monthly parameters to run the model such as the cover factor and other erosion modelling inputs (see appendix 3 for a list of the erosion parameters). As such, the study tried to derive satellite images for each month and also estimated monthly cover factor from the assumed canopy cover which was derived from the crop calendar. For the satellite images, the MODIS images were used since they are cost effective and readily available. These images were acquired but could not be use for the whole duration of twelve months due to cloud coverage in most months. Nevertheless, the research was able to obtain average monthly cover factor values with reference to canopy cover derived from the crop calendar for a whole year. The steps to generating the c-values were (1) from NDVI maps were images were available and (2) as a derivative from canopy cover.

C - FACTOR GENERATION FROM NDVI GENERATION

As earlier stated, cloud coverage in most to the monthly satellites image limited the use of monthly remote sensing data to obtain monthly c – factor maps from NDVI. The most available data for this analysis were the MODIS images (500m resolution) from June to September 2009. These were downloaded for free from the National Aeronautics and Space Administration (NASA) website (ftp://e4ftl01u.ecs.nasa.gov/MOLT/). The downloaded images were geo-referenced to the UTM (WGS 84) co-ordinates using ERDAS IMAGINE. On geo-referencing, it was realized that the grid-cells of 500m × 500m decreased to 468.13 × 468.13m. The grid sizes were thus, re-sampled to a pixel size 480m × 480m which could also be attained when re- sampling the LANDSAT 7 image which will be used later in this work for comparison which will attempt to answer the last objective of this research. The images were then imported to the ILWIS software for generation of NDVI and c-factor maps. In the ILWIS software, the normalized difference vegetation index (NDVI) maps were derived from the red (which is the chlorophyll sensitivity) and near-infrared (which has less water vapour absorption) bands of images using the equation, (NIR-RED) / (NIR+RED) where NIR refers to the near-infrared band and RED is the visible band. A map calculation based on Van der Knifjj's equation (refer to equation 2) was used to obtain the c-factor maps (see figure5-7) since it gave a more realistic linear relationship with NDVI value.

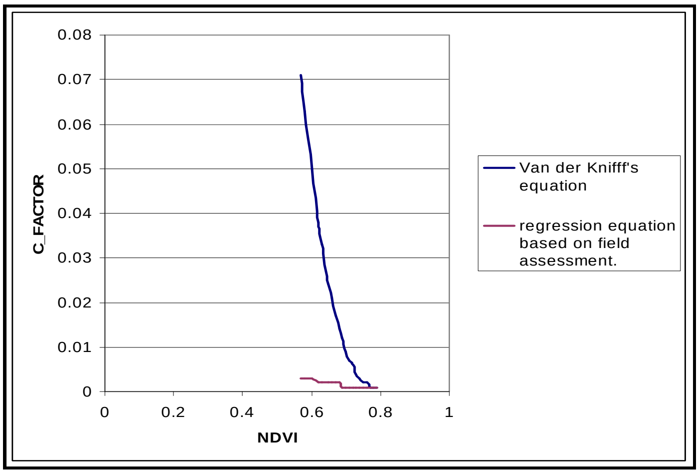


Figure 5-6: Linear Relationship between MODIS JUNE C-Factors Generated and NDVI

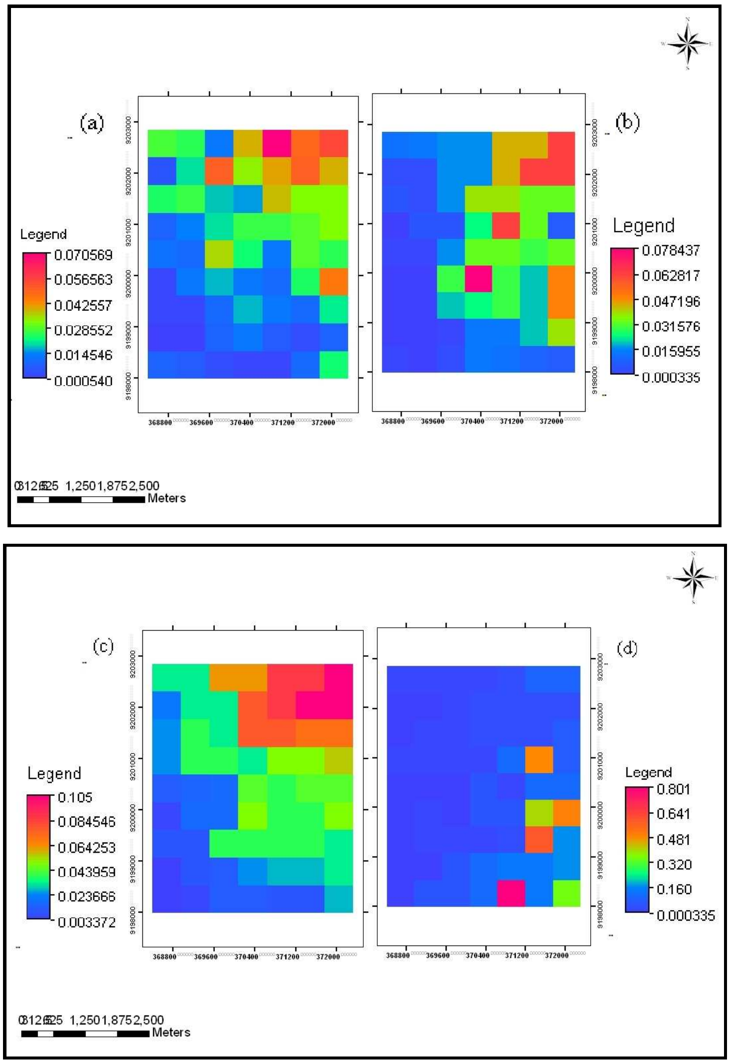


Figure 5-7: C-factor Maps (a) June, 2009 (b) July 2009 (c) August 2009 (d) September 2009 Generated from Respective NDVI maps

C- FACTOR GENERATION FROM CANOPY COVER

Firstly, an average monthly canopy cover was derived from the area. This was done based on the both the field observation and also on the crop calendar in the area. Canopy cover based on field observation was derived for both the months September and November. Other months were derived from the information derived in the field concerning the planting duration which includes start of planting season, vegetative duration and the harvesting periods. Based on this, a relative canopy cover representing the different crop calendar seasons were derived for the year. Table 5-7 shows the average canopy for the different land use types in the area

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.80	0.30	0.20	0.20	0.10
Dry Agric.	0.43	0.20	0.50	0.34	0.57	0.55	0.60	0.53	0.66	0.50	0.60	0.63
Forest	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Shrubs	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Plantation	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70

Table 5-7: Monthly Average Canopy Cover Estimate for the Study Area

And from the canopy cover estimations, an average monthly C-factor was derived for the study area (see table 5-8) using the equation:

Equation 27 ***C - factor = 1 – CC Where cc =canopy cover***

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up	0	0	0	0	0	0	0	0	0	0	0	0
Tobacco	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.20	0.70	0.80	0.80	0.90
Dry Agric.	0.57	0.8	0.50	0.66	0.43	0.45	0.40	0.47	0.34	0.50	0.4	0.37
Forest	0.05	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Shrubs	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Plantation	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table 5-8: Showing the Average C-factor Values per Month in the Study Area.

5.3.2. RAINFALL INTERCEPTION DERIVATIVES

This factor was generated from an equation by Aston(1979) was used (De Jong and Jetten 2007).

Equation 28 $$I = C_p S_{max} (1-e^{-k\,p / Smax})$$

Where I = interception (value between 0-1)

$\mathbf{C_p}$ = Canopy cover

$\mathbf{S_{max}}$ = Canopy storage fraction derived

K= the fraction of rainfall that falls on the canopy

P = cumulative rainfall (mm)

(See appendix 7 for table of values for each parameter stated above and chapter 4.2.2.5 to see how these parameters were derived).

However, the average interception values derived for the study area is seen in table 5-14 and the it showed that forest class had the highest rain fall interception (also see figure 5-13) ranging between 0.089 – 0.22 and the agricultural class with the lowest interception values ranging between 0.004 – 0.059. With reference to past literatures, these results could be said to be acceptable. Morgan (2005) gave the interception values for forest to range between 0.15 - 0.35 and Jetten (1996) in a study of throughfall rates for dry evergreen forest and mixed forest in Central Guyana (South America), gave interception values of 0.173 and 0.16 respectively. For the dry agricultural rainfall interception, the value obtained here is that of a mixed variety of crops, so the study will use the value as obtained.

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up	0	0	0	0	0	0	0	0	0	0	0	0
Tobacco	0.0045	0.0087	0.0222	0.0379	0.0660	0.0977	0.0733	0.1010	0.0118	0.0047	0.0047	0.0015
Dry Agric.	0.0173	0.0044	0.0352	0.0170	0.0584	0.0536	0.0369	0.0373	0.0594	0.0244	0.0348	0.0514
Forest	0.0950	0.0888	0.1673	0.1858	0.2243	0.2239	0.1087	0.1525	0.1483	0.1030	0.1018	0.1420
Shrubs	0.0644	0.0604	0.1101	0.1215	0.1445	0.1443	0.0733	0.1010	0.0984	0.0696	0.0688	0.0945
Plantation	0.0459	0.0431	0.0762	0.0834	0.0978	0.0977	0.0520	0.0703	0.0686	0.0495	0.0489	0.0660

Table 5-9: Average Monthly Rainfall Interception

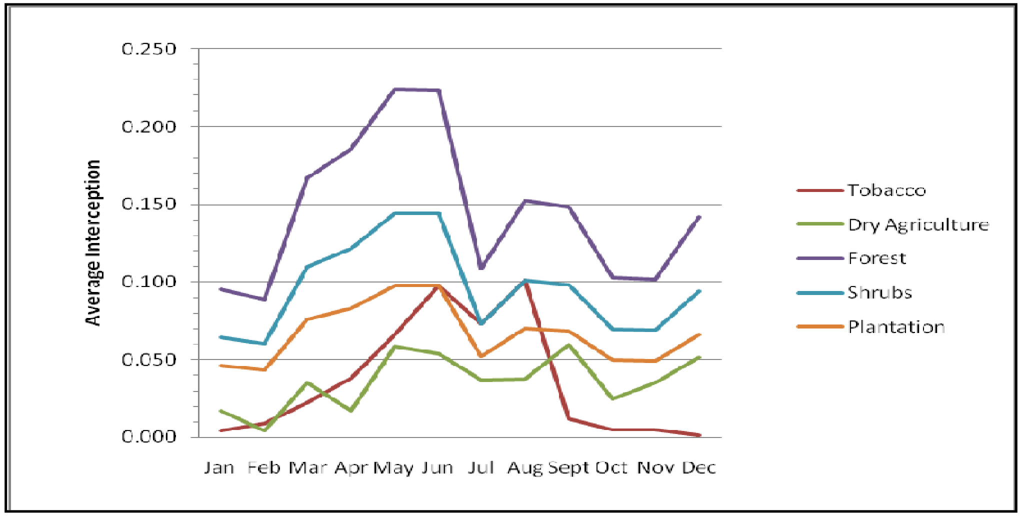


Figure 5-8: Derived Interception Trends for Different Land Use

5.4. SOIL EROSION ASSESSMENT

This phase deals with procedures to answer the question posed by the objective of this study:

- *Is the annual soil loss using averaged annual parameters the same as sum of the monthly soil loss including seasonal variations?*

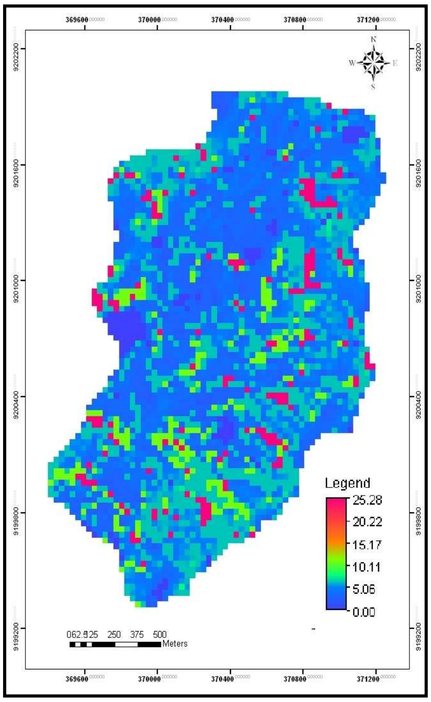
The RMMF model was used to estimate the annual soil loss in the study area (see appendix 8 for script used in running the model). The model was run two times. The first run was to obtain the annual soil loss for the area using averaged erosion parameters and the second run was to obtain the annual soil loss for the area using a sum of the monthly soil loss. For the RMMF model analysis, two values were obtained for each pixel, the total annual soil detachment and the total annual soil transport capacity and the lesser of the two values gave the predicted soil loss for that pixel.

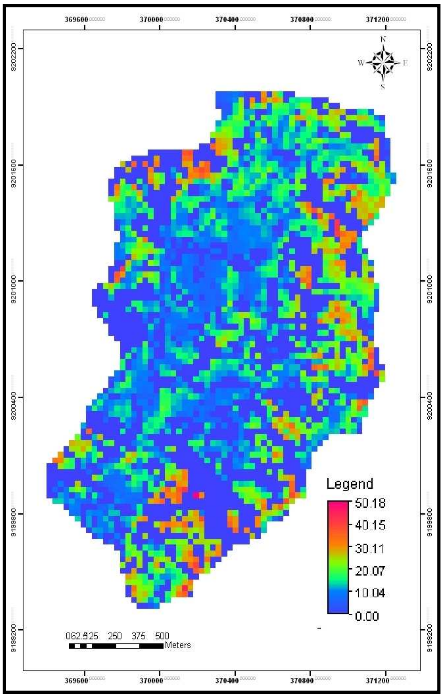
(1) The first analysis was to compute annual soil loss using averaged annual input parameters derived for year which is commonly used in soil assessment.

This was based on the average parameter values for one year derived from assumed canopy cover for the whole year (see appendix 7 for tables of monthly derived parameters). The canopy cover, cover factor, plant height and ground surface were averaged to give the values used for this analysis. The soil loss result is presented to ways in two ways: (a) soil loss without particle detachment and transport capacity accumulation. (b) Soil loss from accumulated soil particle detachment and transport capacity.

Soil Loss without Accumulation

Figure 5-9 shows the soil detachment and soil transport map which was further used to generate the total annual predicted soil loss for the year.





(A) (B)

Figure 5-9: (A) Soil Detachment Map (B) Soil Transport Capacity Map

The minimum between the two maps gives the value for the soil loss (figure 5-10).

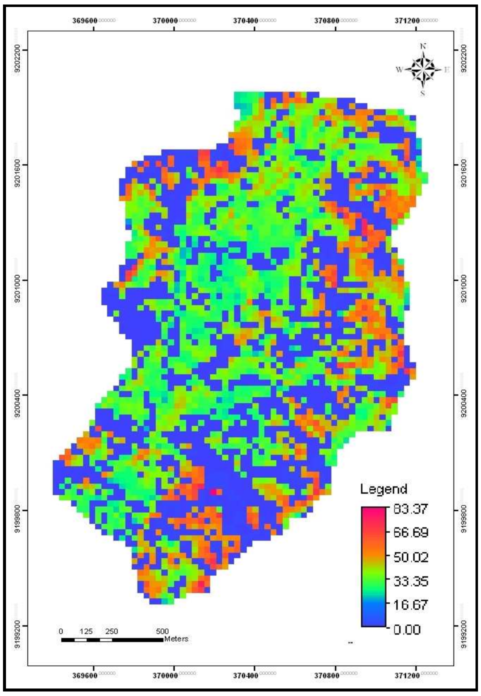


Figure 5-10: Predicted Soil Loss Using Average Parameters in Tons/Hectare/Year

The annual soil loss prediction per pixel in this computation ranges between 0 – 83.37 tons per/hectare/year. (Figure 5-10). And the average soil loss prediction for the whole year is 23.43 t/ha/yr.

From the results (table 5-10), the average soil loss was highest in the tobacco fields (43.56 t/ha/yr) and lowest in the forest area (0.01 t/ha/yr). The dry land agricultural fields had the second highest average soil loss of 39.85 t/ha/yr. The shrubs area and the plantation area also had very low average soil loss (see table 5-15). It is evident in the result; vegetation does play a major role in erosion process. It strongly affects the erosion in each class. Classes with lesser vegetation cover experienced more soil loss. For the forest, plantation and shrubs which had a high canopy cover and ground cover, the soil loss predictions were either very low or a zero prediction. And for the tobacco and agricultural fields, the predictions were high due to alternating moderate and low canopy cover and also low ground surface. This could also result from farming activities which involves clearing the land for planting, weeding during vegetative periods and on harvesting, the land may be left with little or no canopy cover.

Land Use Class	Area in Percent	Soil Loss Rate (t/ha/y)
Forest	5	0.01
Shrubs	6	0.05
Plantation	24	0.87
Tobacco	10	43.56
Dry land Agric.	52	39.85
Built-up	3	Masked out
Total	100	

Table 5-10: Average Annual Soil Loss Prediction in Different Land Use for 2009

The estimated annual soil loss maps were further classified into five (5) severity classes which are very slight (<2 t/ha/y), slight (2-5 t/ha/y), moderate (5-10 t/ha/yr), severe (10-50 ton/ha/yr), very severe (50-100 t/ha/yr) which was adapted from Morgan (2005).

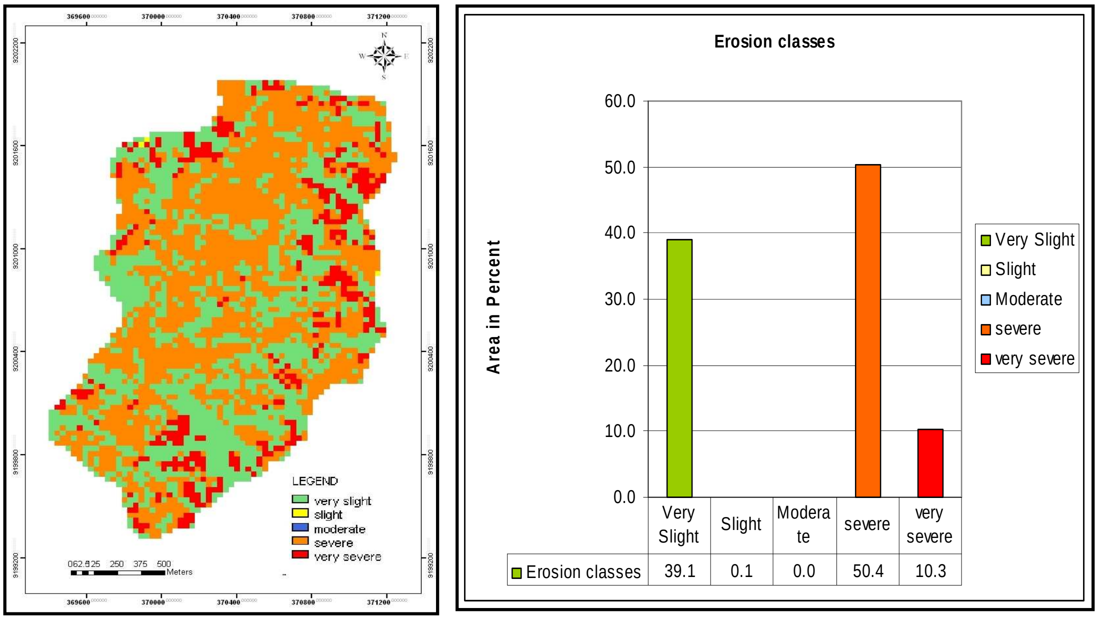


Figure 5-11: Predicted Soil Loss Classified from the Soil Loss Map

Figure 5-11 shows that 39.1% percent of the area falls into the very slight erosion class, only 0.1% in the slight erosion class, none in the moderate class, 50.4% of the study area falls into the severe class which ranges between 10-50 ton/ha/yr and according to Morgan (Morgan 1995), 10 ton/ha/yr is the tolerance soil loss rate for agricultural areas and 10% of the area falls into the very severe class. Table 5-11 shows the distribution of the land use classes with their severity rates.

Land use class	Area in percent	Soil loss(tons/year)	Soil loss rate (t/h/y)	Erosion class
Forest	5	0	0.01	Very slight
Shrubs	6	0	0.05	Very slight/slight
Plantation	24	0.08	0.87	slight
Tobacco	10	3.59	43.56	Severe and very severe
Dry land Agric.	52	3.92	39.85	Slight, severe and very severe
Built-up	3	Masked out	Masked out	
Total	100			

Table 5-11: Average Soil Loss Prediction in Different Land Use for 2009

According to table 5-11 the Tobacco fields have very high erosion rates as they all fall between the severe to very severe classes. This is followed by the dry land agricultural areas which fell into several classes ranging from slight to very severe classes. The table also shows that forest, shrubs and plantation fields experience the lowest soil loss rates in the area (very slight to slight classes).

Soil Loss Analysis from Accumulated Parameters

Without accumulation, the soil loss per cell is seen as an indication for the soil loss on a farmer's field but the accumulated soil loss gives the total soil loss of the whole catchment. The PCRaster software was used for this analysis. It is a dynamic slope model which allows different routing methods. The total detachment and transport capacity maps were first exported from the ILWIS software to ASCII file and then imported to the PCRaster software for accumulation. And on importing to PCRaster, the ASCII files were converted to map for analysis (see appendix for script). Firstly, for accumulation of detached particles, the drainage system was masked out. It is assumed that not particle detachment takes place in it except transportation. Then the 'accuflux' command was applied to it instructing it accumulate the material flowing into the downstream cell. And on accumulating the transport capacity, the assumption is that the anything deposited into the river, is transport depending also on the transport capacity else deposition takes place. The 'accucapacity' command was applied to the final soil loss whish allowed it accumulate material flowing downstream over a local drain direct network and the results was represented in t/ha/yr. The annual soil loss predicted from the Ratamba watershed using the average parameters is 18, 9122 t/ha/yr. This still follows the regular RMMF model which gives soil loss value as the minimum value of the total accumulated soil particle detachment and the total accumulated transport capacity. Though the transport capacity is much higher on accumulation than the detached soil particles (see figure 5-12, and B), that effect is negligible since the accumulated detached soil particle is much smaller. And the minimum value was assigned as the soil loss (figure 5-12 C).

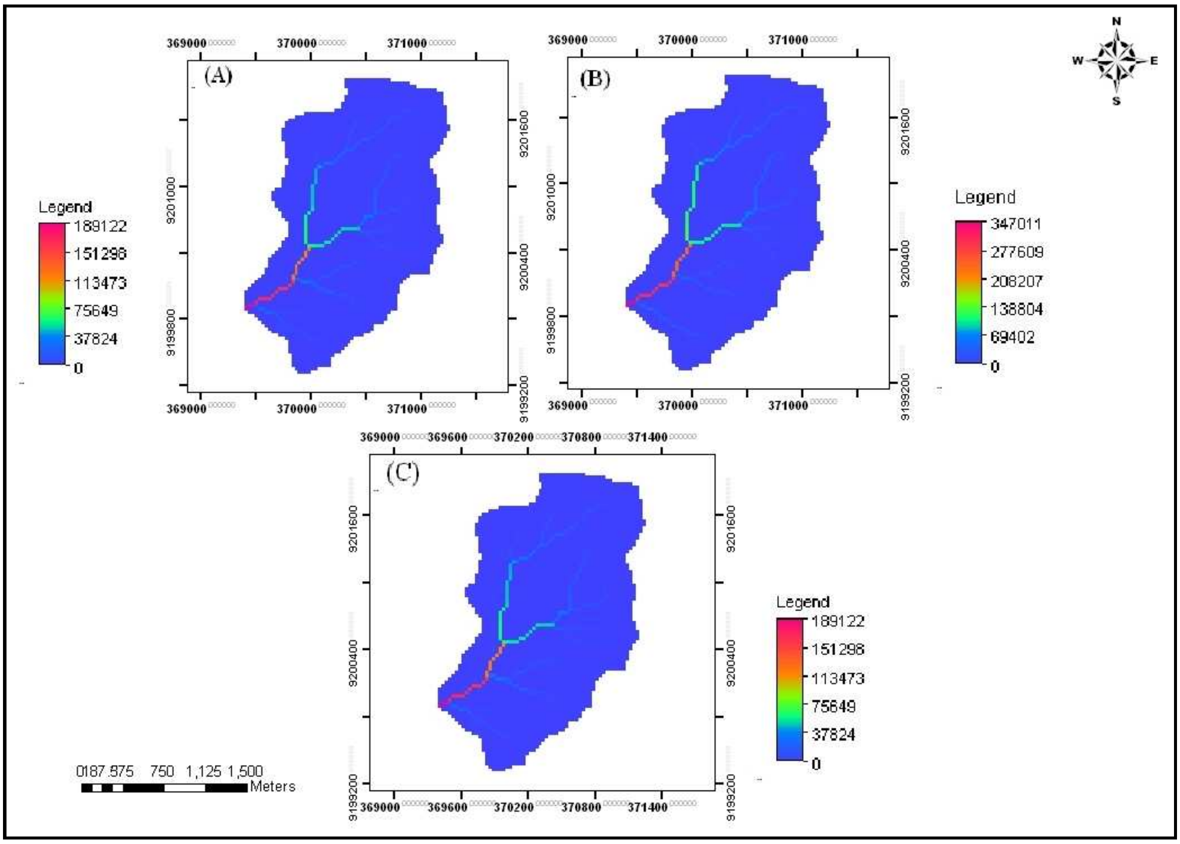


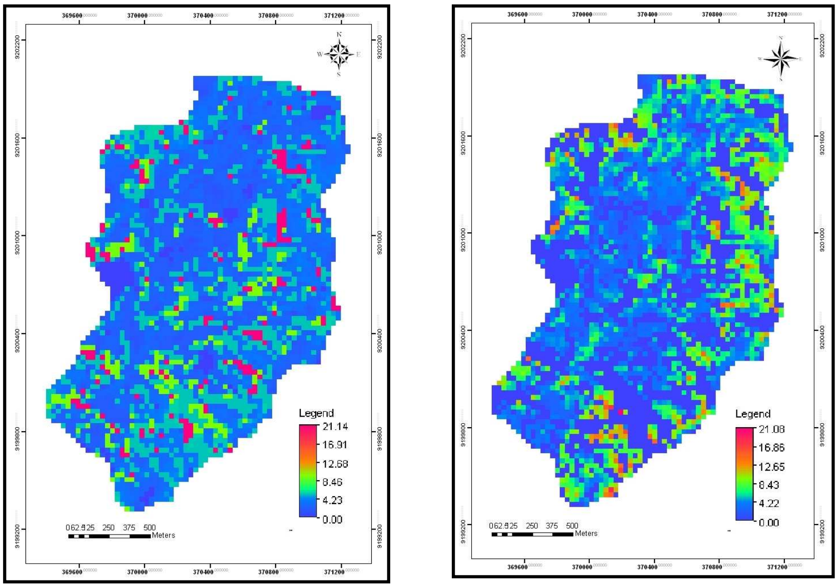
Figure 5-12: (A) Accumulated soil detached particles (B) accumulated transport capacity (C) Accumulated soil loss from the catchment.

(2) The second analysis was done using the sum of the monthly predicted soil loss.

This analysis made use of monthly obtained parameters like the monthly rainfall, number of rainy days in the month, monthly canopy cover, monthly surface cover and also monthly plant height (see appendix 7 for tables). The canopy cover, cover factor, plant height and ground surface for forest, shrubs and trees were kept constant through out the whole year because in reality the variation in this factors through the year is not significant.. The result was also presented to ways in two ways: (a) soil loss without particle detachment and transport capacity accumulation. (b) Soil loss from accumulated soil particle detachment and transport capacity.

Soil Loss without Accumulation

The result in figure 5-14, was derived from the sum of the monthly predicted soil loss from parameters derived from the assumed monthly crop cover for the year. It shows the predicted soil loss in a range of 0 – 46.89 t ha^{-1} yr^{-1}. Figure 5-13 shows the predicted total detachment and transport capacity available to compute the soil loss and the total detachment capacity is higher than the transport capacity.



(A) (B)

Figure 5-13: (A) Soil Detachment Map (B) Soil Transport Capacity Map

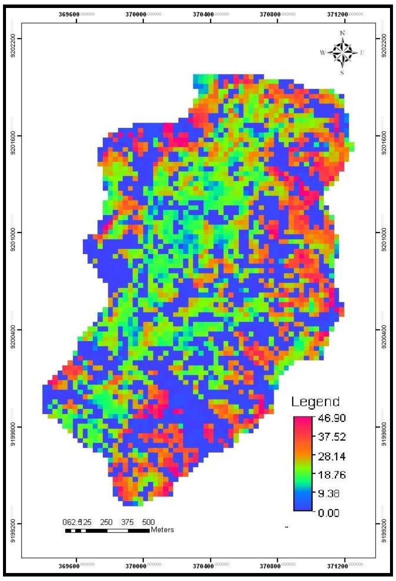


Figure 5-14: Predicted Soil Loss in Tons/Hectare/Year

The average soil loss for whole year is estimated to be 12.01 t ha^{-1} yr^{-1}. The results in table 5-12 show that the dry land agricultural fields have the highest predicted average soil loss (21.35 t ha^{-1} yr^{-1}) and the forest class with the lowest predicted average soil loss (0 t yr^{-1}). The tobacco fields also record high soil loss rates in the area while the shrubs and the plantation record very minimal soil loss rates. This zero or low predictions are as a result of the limited transport capacity in these areas (figure 5-13 b).

Land Use Class	Area in percent	Soil Loss Rate (t/h/y)
Forest	5	0
Shrubs	6	0.05
Plantation	24	0.85
Tobacco	10	18.33
Dry land Agric.	52	21.35
Built-up	3	Masked out
Total	100	

Table 5-12: Average Soil Loss Prediction in Different Land Use For 2009

The average soil loss for each month for the whole year is shown in table 5-13 The total soil losses for the twelve months were summed up to give the annual soil loss prediction for the study area (see appendix 10 for derived monthly soil loss maps).

Months	Average Soil loss
January	5.12
February	5.79
March	0.14
April	0.03
May	0.00
June	0.11
July	0.04
August	0.00
September	0.02
October	1.79
November	2.53
December	0.69

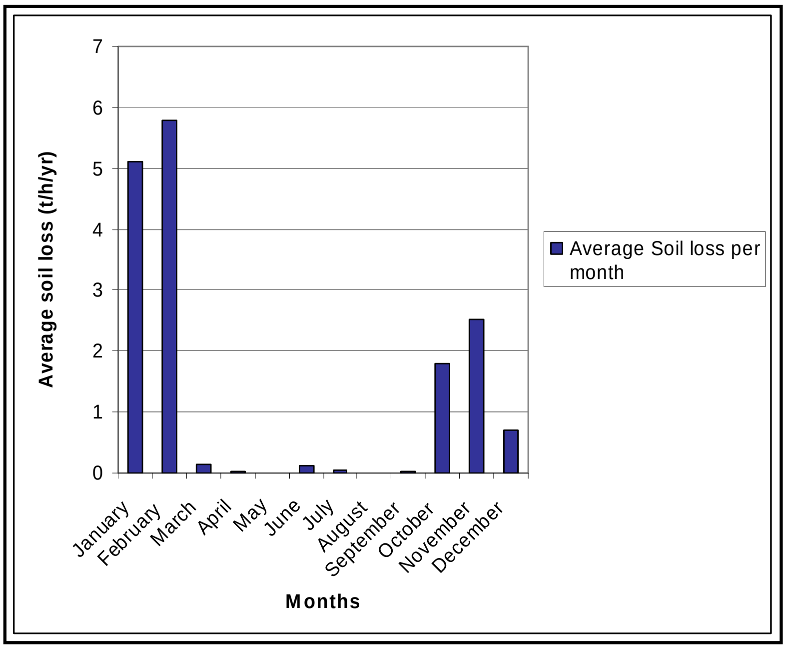


Table 5-13: Average Soil Loss per Month in the Study Area

The total estimate derived from a summation of the monthly soil loss was classified into five severity classes; very slight (<2 t/ha/y), slight (2-5 t/ha/y), moderate (5-10 t/ha/yr), severe (10-50 ton/ha/yr), very severe (50-100 t/ha/yr). Figure 5-16 shows the spatial distribution and histogram of the soil loss classes in the area.

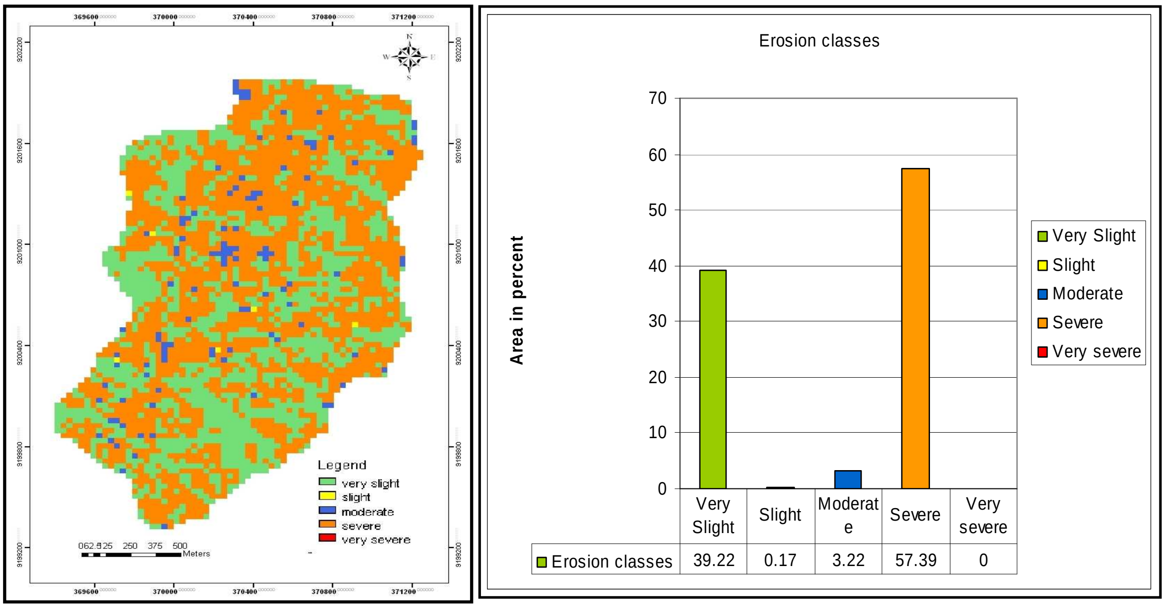


Figure 5-15: Soil Loss Classified Map and Histogram

The classified map and histogram show 39.22% of the area falls under the very slight class, 0.17% falls within the slight class, 3.22% in the moderate class, and 57.39% of the area falls under the severe class and none in the very severe class. Table 5-14 shows the different land use in the different severity class.

Land Use	Area in percent	Severity Class
Forest	5	Very slight
Shrubs	6	Very slight
Plantation	24	Very slight
Tobacco	10	Slight, moderate and severe
Dry land Agric.	52	Very slight, slight, moderate and severe
Total	100	

Table 5-14: Soil Loss Classes for Different Land Use

The forest, shrubs and plantation all fall in the very light class indicating that little or no erosion is taking place in those areas. The dry land agricultural area falls in to most of the classes in the area the tobacco field is shown to fall into slight, moderate and sever classes only.

Soil Loss Analysis from Accumulated Parameters

The same procedure was taken as discussed in the first analysis. The results (figure 5-16 A and B) show that the available accumulated transport was lower than the accumulated total detachment. This is just the same the results of the detachment and transport capacity without accumulation. The total soil loss from the study area is predicted as 12, 0278 t/ha/yr (figures 5-16, map C). This is the value recorded at the outlet cell as the total soil loss from the catchment.

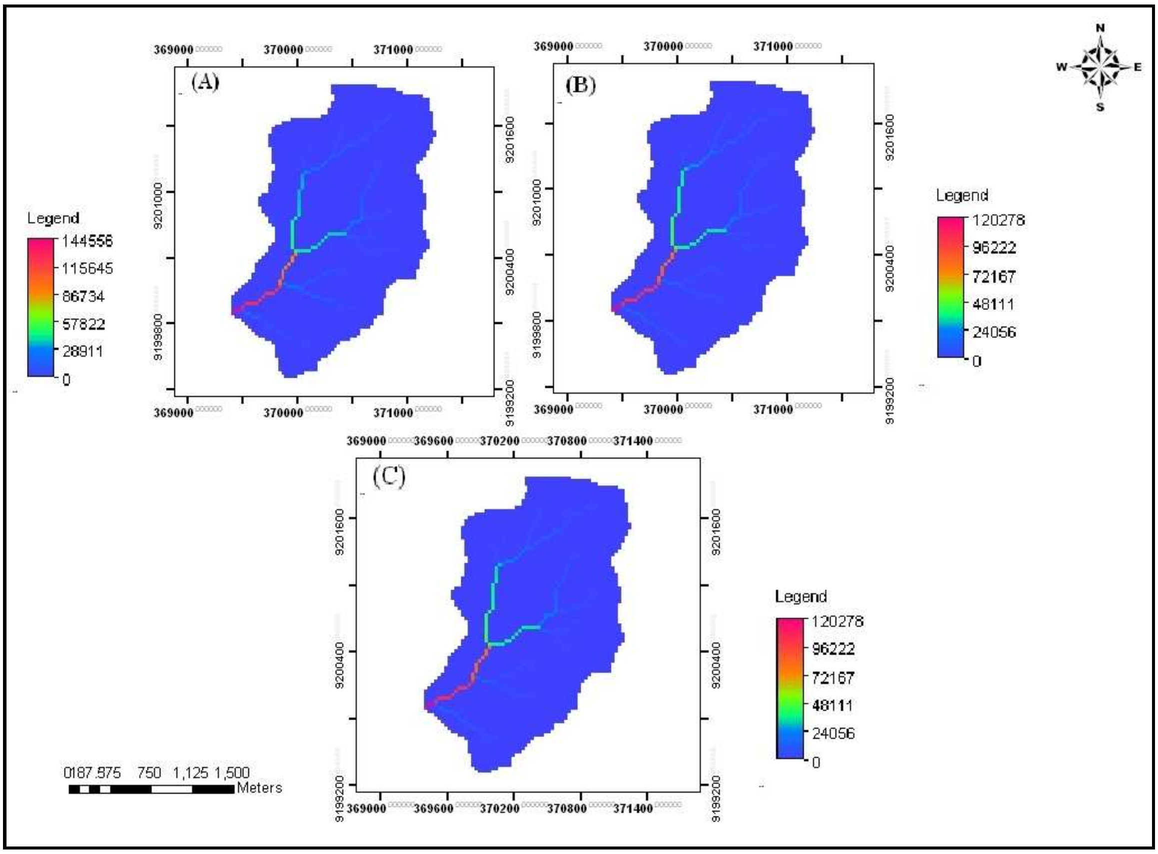


Figure 5-16: (A) Accumulated Soil Particle Detachment Map (B) Transport Capacity Map C) Soil Loss Map from Catchment

5.5. COMPARISON AND DISCUSION ON SOIL LOSS RESULTS

Table 5-15 shows a comparative statistics between the predicted annual soil loss derived from average parameters and that of the sum of monthly soil loss using with crop calendar derivatives.

	Soil loss prediction using the RMMF model (t/ha/yr)	
Summary	Averaged-annual parameters	Sum of monthly soil loss for one year
Minimum	0	0
Maximum	83.37	46.89
Average	23.43	12.01
Standard deviation	21.64	11.57
Accumulate soil loss	18, 9122	12,0278

Table 5-15: Comparative Soil Loss Summary

From the summary, the predictions made by using the average parameters gave higher average results than the other two methods. Also, statistical linear regression correlation was performed between the two obtained soil loss predictions and an r^2 value of 0.97 was derived.

```
Call:
lm(formula = Average ~ Sum, data = corr)

Residuals:
   Min      1Q Median      3Q     Max
-8.496 -2.104 -1.368  0.817 14.486

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.368369   0.114751   11.93   <2e-16 ***
Sum         1.837975   0.006884  267.00   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 4.033 on 2564 degrees of freedom
Multiple R-squared: 0.9653,     Adjusted R-squared: 0.9653
F-statistic: 7.129e+04 on 1 and 2564 DF,  p-value: < 2.2e-16
```

Table 5-16: Summary of Soil Loss Correlation

The correlation was made to establish a relationship between the soil loss prediction from average parameters and that from using the sum of the monthly derived soil loss. It shows that for every increase in the soil loss prediction made by the sum of the monthly soil loss, there is a 1.83 increase in the soil loss prediction by using averaged annual parameters. Another statistical analysis, Box plots and quantile - quantile plot, was computed in the Rgui programme to establish if there was any significant difference in the predictions.

The box plot with whiskers was used to compare the distribution of the predicted soil loss results to check for any abnormalities. The box plot is also known as a five number summary statistics which shows the smallest and largest observation, the first and third quartile and also show the median in one setting. This distribution pattern in figure 5-17 shows for that the soil loss based on averaged annual parameters (A) is strongly skewed to the right or could be said to be positively skewed indicating that there are many low values and the median of the soil loss prediction is mostly influenced by the higher values (B) shows that the median is nearer the centre of the box for the predictions using the sum of the monthly soil loss for the year.

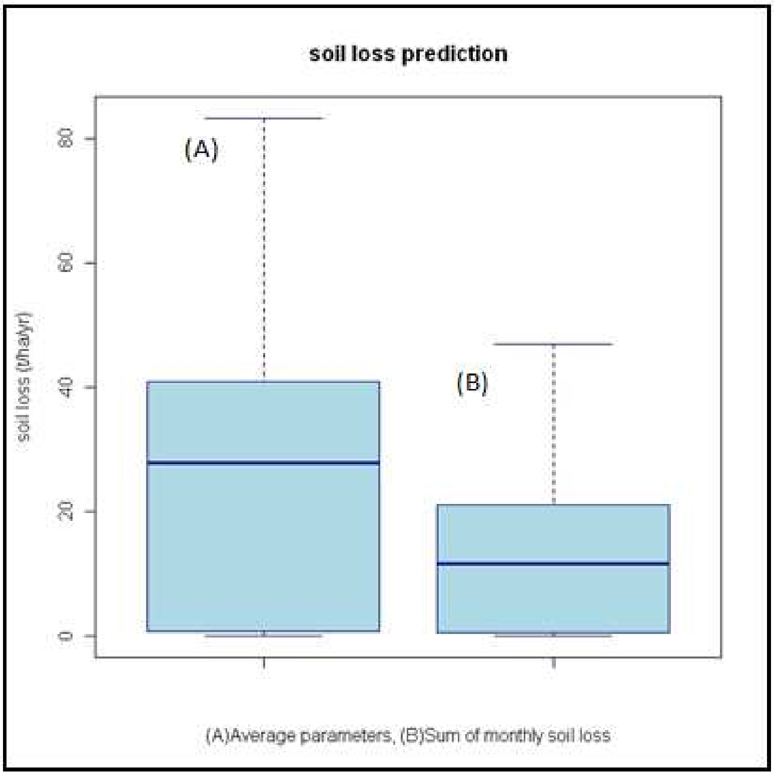
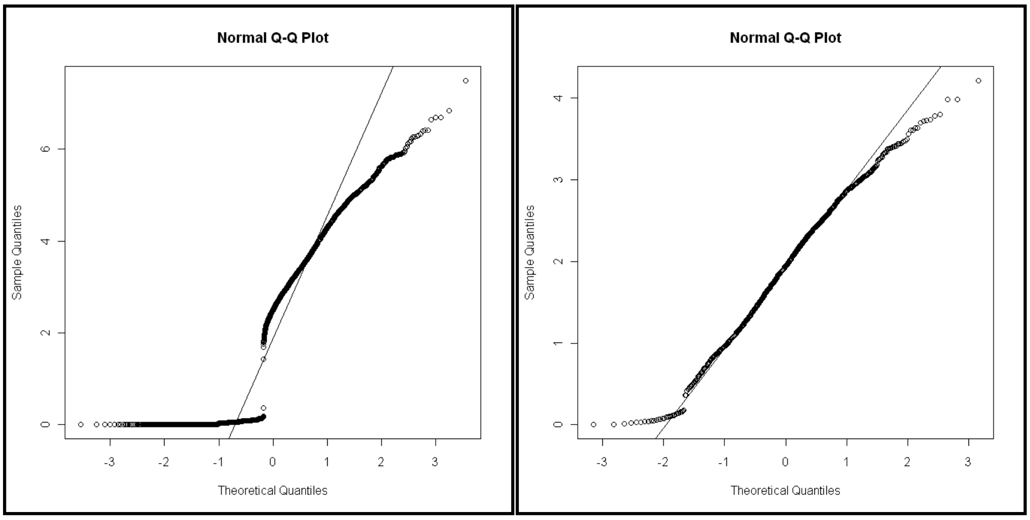


Figure 5-17: Box and Whisker Plots of the Soil Loss Predictions from the Annual Soil Loss Using (A) Averaged Input Parameters (B) Sum of the Monthly Soil Loss for a Year

The two box plots however show that in both cases about 25% percent of the pixel values exhibit extremely low erosion rates. Also, the box plot reveals that the annual soil predictions using the averaged values (A) gives a much higher and extreme estimates which can not be seen in the estimates from the sum of the monthly soil loss (B). The result from the sum of the monthly soil loss for the year gives a more realistic prediction because the extreme high erosion values area avoided which are probably unrealistic. This gives it an advantage over the estimates resulting from averaged annul input parameters. Another statistic parameter which is the quantile - quantile (qq plot) plot was also performed to on the results to compare the soil loss variables with a hypothetical normal distribution (figure 5-18).



(A) (B)

Figure 5-18: Quantile – Quantile Comparison Plot for (A) the Soil Loss Estimates Using Average Parameters and (B) the Soil Loss Prediction from the Sum of the Monthly Erosion

The quantile – quantile comparison plot shows that for the soil loss using average parameters (figure 5-18 a), the soil loss is not normally distributed. If it was normally distributed, the pixel values of the estimate should fall on the solid line. For the soil loss derived from the sum of the monthly estimates, there seem to be a normal distribution as revealed in the plots along the solid line. Based on this results, the soil loss predictions from the sum of the monthly erosion rates is normally distributed and as such it is believed to give a more reliable soil loss estimate for the study area.

5.6. SENSITIVY ANALYSIS

This section is analysed to meet the third objective of this study.

- *To study the influence of the of the management practice on soil loss in the area.*

A sensitivity analysis was performed on the management factor to know how much influence it has on the predicted soil loss in the study area. The RMMF model was run four times with different management factors while every other input parameter was kept constant. The first run was with the original management practice in place and subsequent runs were done with the different value representing the different management practice (refer to 4.4 for values). After running the model with the different values, the predicted soil losses were imported to excel spreadsheet for statistical analysis.

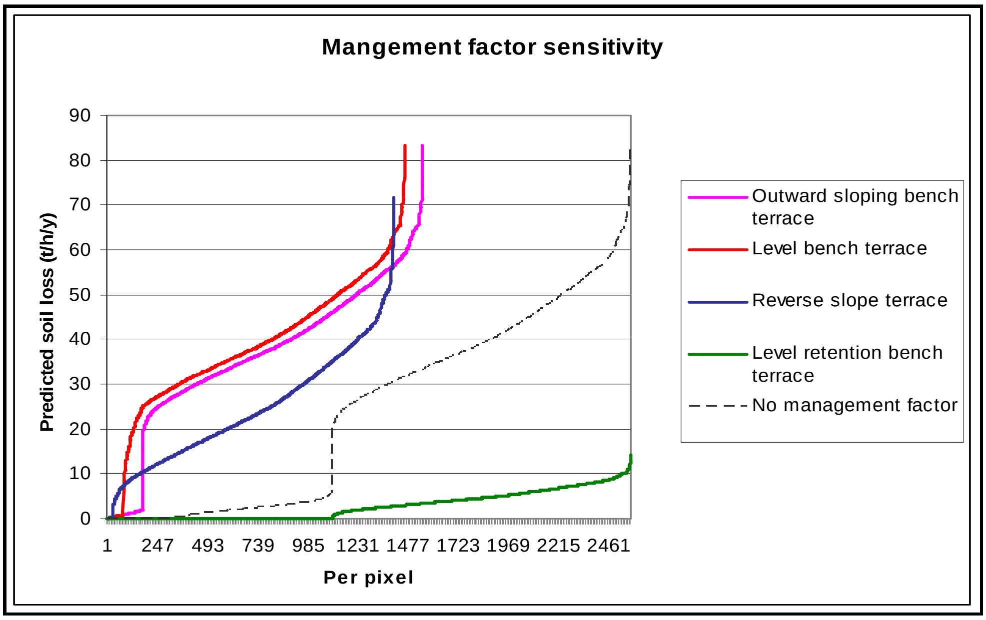


Figure 5-19: Sensitivity Analysis for Management Factor

The x-axis in figure 5-19 represents the soil loss per pixel values while the y-axis shows the soil loss in t/ha/yr. The figure revealed that the level bench terracing has the highest negative effect on erosion rates. This is followed by the outward sloping bench which is implemented in the area. This means that management factor used in the study area has little or no effect to the erosion rates when compared to the level retention bench and no management factor. The level retention revealed a drastic reduction in soil loss when implemented in the analysis. This would most probably be the best management factor to implement but the level retention bench terrace is mostly associated with paddy fields which are used to grow rice. This is because rice needs much water for cultivation. Since there are no paddy fields in the study area and one of the major crop types which is potatoes, doesn’t require much water for cultivation.

Figure 5-20 Shows that the predicted soil loss using the outward sloping terrace falls with the very slight, slight, severe and very severe classes. This probably most explains the predicted high soil loss from the watershed as derived in the soil loss estimation.

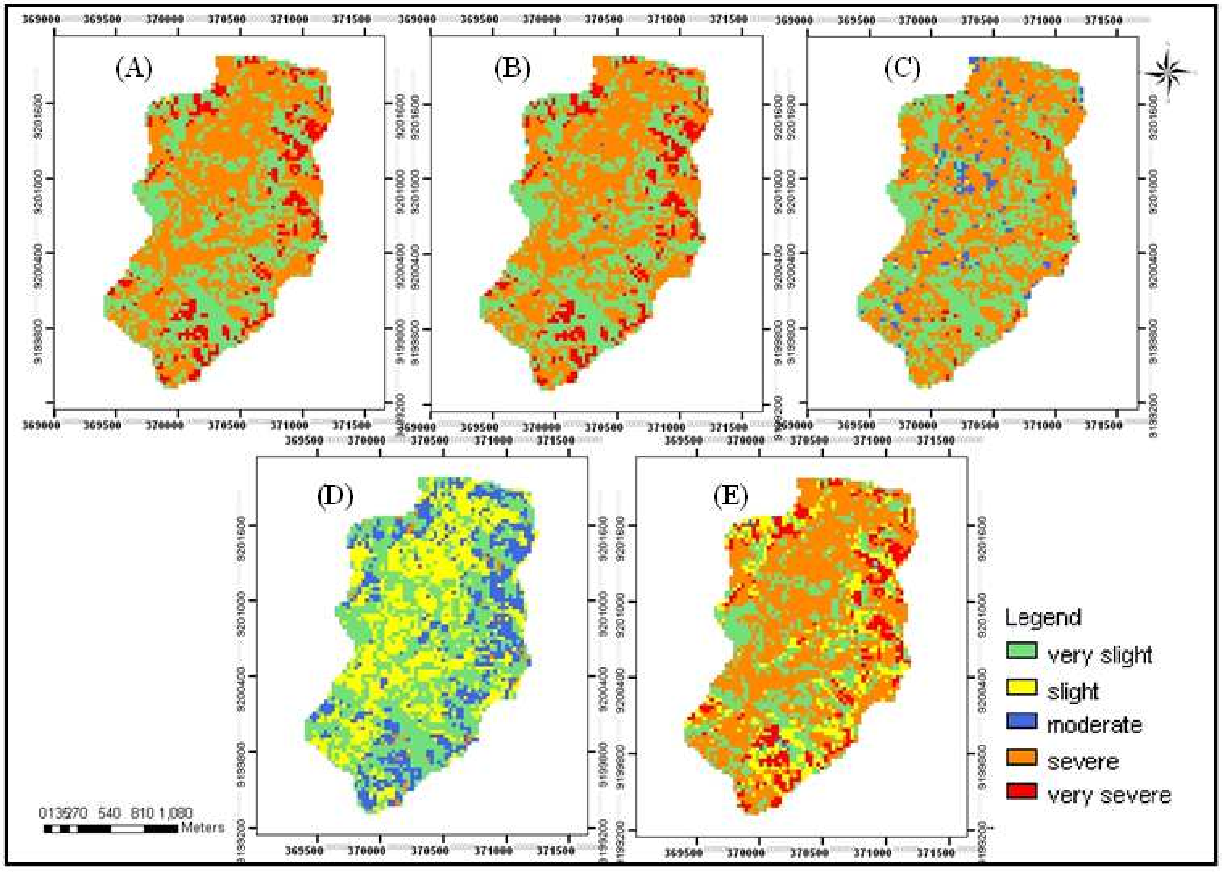


Figure 5-20: (A) Predicted Erosion Rate with the Outward-Sloping Bench Terrace (OSBT) (B) Predicted Erosion Rate with Level Bench Terrace (LBT). (C) Predicted Erosion Rate with Reverse Slope Bench Terrace (RSBT) (D) Predicted Erosion Rate with Level Retention Bench Terrace (LRBT) (E) Predicted Erosion Rate with No Management Factor

As a conclusion to this, the soil erosion management practice implemented in the study area in reality is one a good management practice which allows for rapid movement of water over the slope and entrapments of upslope sediments but despite this advantage, its effect is minimal due to the high rainfall intensity in the area and probably as a result of combination of bare surfaces in the agricultural and tobacco fields with specific rain fall that causes soil loss to be higher in some months than the other with higher canopy coverage. But if that if the reverse slope terrace practice is implemented in the area, there would be a reduction in the soil loss rate (figure 5-19).

5.7. C-FACTOR MAPPING USING COARSE RESOLUTION REMOTE SENSING DATA

This phase in this chapter addresses the last objective of this work.

- *To assess the effectiveness and applicability of using coarser resolution remote sensing data such as the MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI images for C-factor mapping in small catchments.*

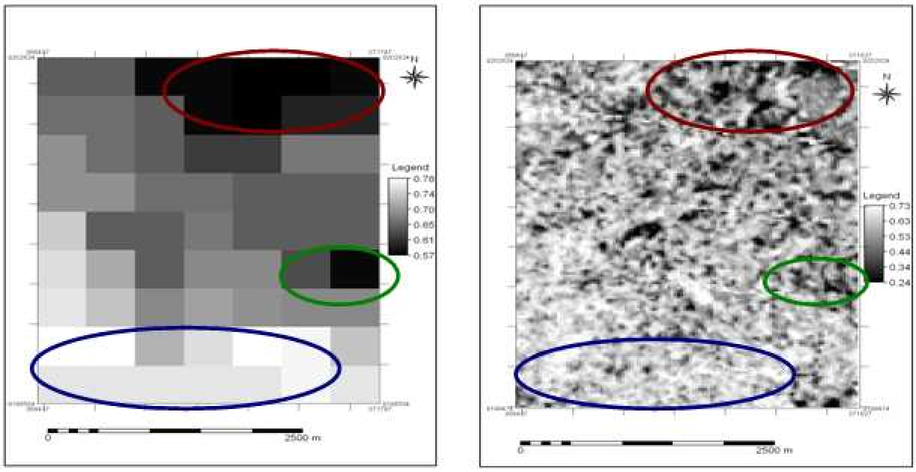
Deriving cover factor maps is not only the aim of this objective but to evaluate how useful it could also be for erosion assessments. Based on this, comparison will done between the soil losses results for the months of June through September when images were available with the soil loss of the same months derived from crop calendar parameters. Image resolution affects the parameters derived from it. An image with a 500m resolution especially in a small catchment will most likely generalise the features and as such no clear distinction of land cover parameters can be made. To validate the results generated by the MODIS image, a LANDSAT image with a 30m resolution for the month of June, 2009 was also downloaded. The image for June was the only available cloud free image. The cover factor maps were not derived directly from the satellite images but rather as a derivation from NDVI values which were derived from the satellite images of the area.

NDVI GENERATION

From previous studies, It is shown that the MODIS imagery which is free, is been used for a series of application especially on a large area. However, the coarseness in spatial resolution tends to limit its applicability in certain fields and also in small areas. In order to assess its usability for small areas such as the catchment of my research work, MODIS images (500m resolution) from June to September 2009 were downloaded for free from the National Aeronautics and Space Administration (NASA) website (ftp://e4ftl01u.ecs.nasa.gov/MOLT/). The downloaded images were geo-referenced to the UTM (WGS 84) co-ordinates using ERDAS IMAGINE. On geo-referencing, it was realized that the grid-cells of 500m × 500m decreased to 468.13 × 468.13m. The grid sizes were thus, re-sampled to a pixel size 480m × 480m which could also be attained when re- sampling the LANDSAT 7 image which will be used for comparison. To attain this, a LANDSAT 7 image (30m resolution) of June, 2009 was also downloaded from the USGS Global Visualization Viewer (http://glovis.usgs.gov/). This was used to establish a correlation with the MODIS of the same month. The LANDSAT 7 layers were first converted from radiance to reflectance data using LANDSAT 7 reflectance conversion in

ERDAS. The parameters needed for the conversion were available in the header file. This was done so as to give the LANDSAT 7 image the same parameters with the MODIS image which will aid in evaluation of comparison. Having done that, the converted LANDSAT 7 layers were stacked in ERDAS IMAGINE and changed from unsigned 8 bits to signed 16 bit which corresponds to that of MODIS, geo-referenced to the UTM, WGS 84 and cropped using AOI (area of interest). Both maps were exported to a geotiff format which makes it easy to import to the ILWIS software for further analysis.

In the ILWIS software, the normalized difference vegetation index (NDVI) maps were derived for both images (Fig 5-21) from the red (which is the chlorophyll sensitivity) and near-infrared (which has less water vapour absorption) bands of images using the equation, (NIR-RED) / (NIR+RED) where NIR refers to the near-infrared band and RED is the visible band.



(A) **(B)**

Figure 5-21: NDVI Map for MODIS (A) and NDVI Map for LANDSAT (30m) (B)

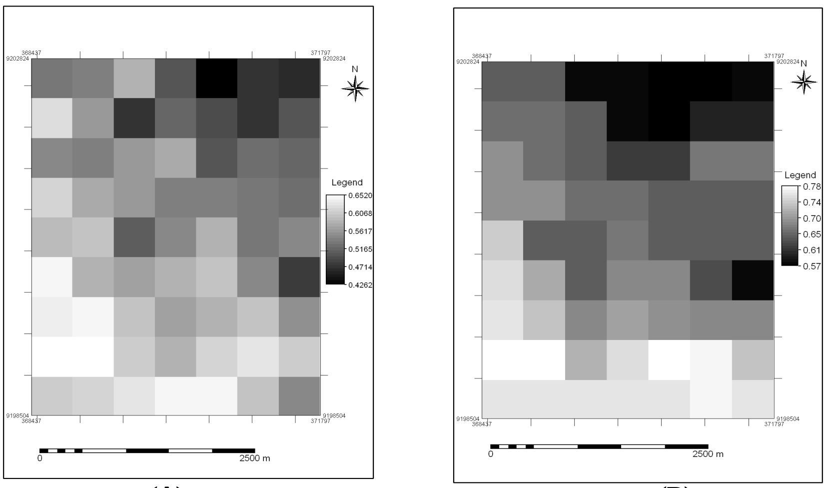
Figure 5-21 shows that the NDVI values derived from MODIS and LANDSAT at 30m resolution both show high vegetation cover though that of MODIS show less variations in the values when compared to that of LANDSAT. However, just mere visually looking at the area encircled, it can be show the similar NDVI reflectance. For the areas with the red circle, NDVI values are low in both cases though that of LANDSAT are much lower than MODIS. This is justifiable. LANDSAT is a 30m resolution and as such can detected cover to a 30 m area on ground MODIS only has a 500m resolution and as such it uses maximum or average values to reflectance values and everything in a 500m area is seen as an average of the mixed land cover in the area were the predominant cover plays a major role in the reflectance value. And also the areas with the green circle show low NDVI values and area encircled with blue show high NDVI values which suggest high vegetative cover.

In order to establish a correlation between the MODIS and the LANDSAT C-factor maps, the LANDSAT 7 image was re-sampled from a 30×30 grid cell to that of the MODIS. Firstly, the LANDSAT 7 NDVI was aggregated to 480m using the aggregation techniques in chapter four.
And to know the best optimal aggregation method to use, a linear regression correlation between the MODIS NDVI and all the aggregated LANDSAT NDVI maps was implemented to establish the highest correlation (see table5-17). Based on the results, the average aggregation method was chosen to aggregate of the LANDSAT image to fit the coarse resolution of MODIS image.

	LANDSAT NDVI AGGREGATION			
Aggregation Technique	Predominant	Maximum	Minimum	Average
MODIS NDVI	0.51	0.13	0.39	0.67

Table 5-17: Correlation of Aggregated LANDSAT NDVI with MODIS NDVI

The average aggregation had the highest correlation factor of 0.66. This technique takes into account all the computing input pixels and as such the output value is an integrated value representing the computing window (fig 5-22a).



(A) **(B)**

Figure 5-22: LANDSAT NDVI Aggregated Map (A) and MODIS NDVI Map (B)

CORRELATION OF MODIS NDVI AND LANDSAT NDVI

The Correlation was done using the R software. The correlation was based on the pixels values in the same grid cells for the two images and if the correlation between the NDVI values derived from the aggregated LANDSAT 7 and that of MODIS imagery comes back positive, then MODIS NDVI could be said to demonstrate a fairly, if not accurate vegetation reflectance even in very small image areas such as that of the study area. This would be an added value to any research work that needs to be done in very small areas due its availability and also charge-free. The scatter plot in fig 5-8 shows the correlation between the two images.

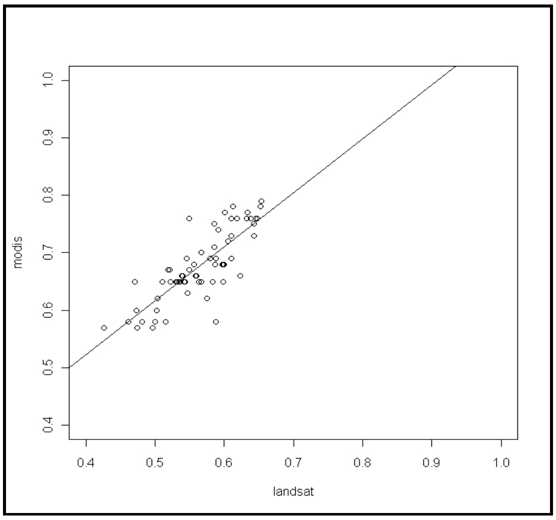


Figure 5-23: Scatter Plot Showing Relationship between the MODIS NDVI and LANDSAT

The correlation factor, r is 0.81 and r^2 0.67. The correlation value is high and shows that there is a good relationship between the two images. The table 5-18 shows the summary of the correlation, at zero (0) LANDSAT, MODIS is 0.13. This can be translated to mean that for each increase in the MODIS NDVI, there is also a .94 increase in LANDSAT. However, drawing from this statistical result, it can say that there is a good correlation between the two images despite conversion of the 30m resolution image to that of 480m. With a correlation in the NDVI maps, the MODIS derived the C-factor map for the area to be used to show the cover effect in relation to erosion in the area.

```
Call:lm(formula = modis ~ landsat, data = ndvi2)
Residuals:
     Min        1Q    Median       3Q       Max
-0.118532 -0.021016  0.003776  0.020902  0.098187
Coefficients:
            Estimate Std.  Error   t value    Pr(>|t|)
(Intercept)  0.14662    0.04813   3.046  0.00342 **
landsat      0.93910    0.08487  11.065 3.22e-16 ***
Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.03594 on 61 degrees of freedom
Multiple R-squared: 0.6675,     Adjusted R-squared: 0.662
F-statistic: 122.4 on 1 and 61 DF,  p-value: 3.219e-16
```

Table 5-18: Summary of Correlation

C-FACTOR MAPS BASED ON NDVI

Based on the methods mentioned in chapter four (4.2.2.4), C-factor maps were generated for the LANDSAT and MODIS images using both the Van der Knijff (1999) and the regression equation based on field assessment of C factor. The cover factor values range from 0-1 where 0 indicates the presence of very high vegetation which could translate to no erosion and 1 indicating no cover effect and also very high erosion effect.

- ✓ **C- factor maps for MODIS**

The maps in figure 5-24(a) and (b) shows the different C-factor maps generated from MODIS NDVI values.

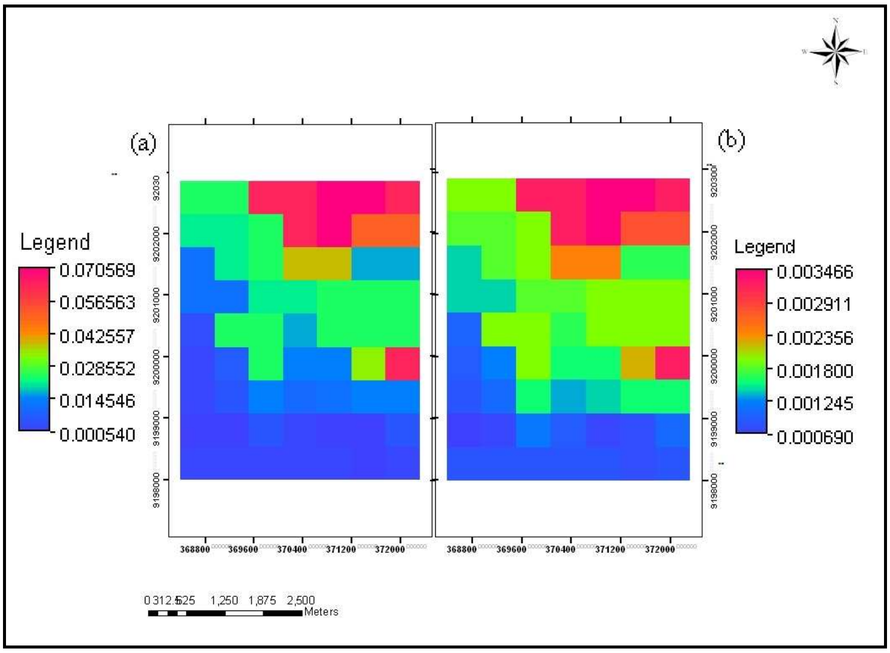


Figure 5-24: (a) MODIS C-Factor Derived Using Van der Knijff's Equation (b) C-factor Using the Regression Equation Based on Field Assessment

✓ **C-factor maps for LANDSAT**

C-factor maps for the aggregated LANDSAT map were also generated using the different methods. Figure 5-25 shows the different output maps. The C-factor map generated using the regression equation based on field values had a much lower value than that of the Van der Knijff's equation. Figure 5-25 (a) and (b) show the Cover maps generated from LANDSAT NDVI values.

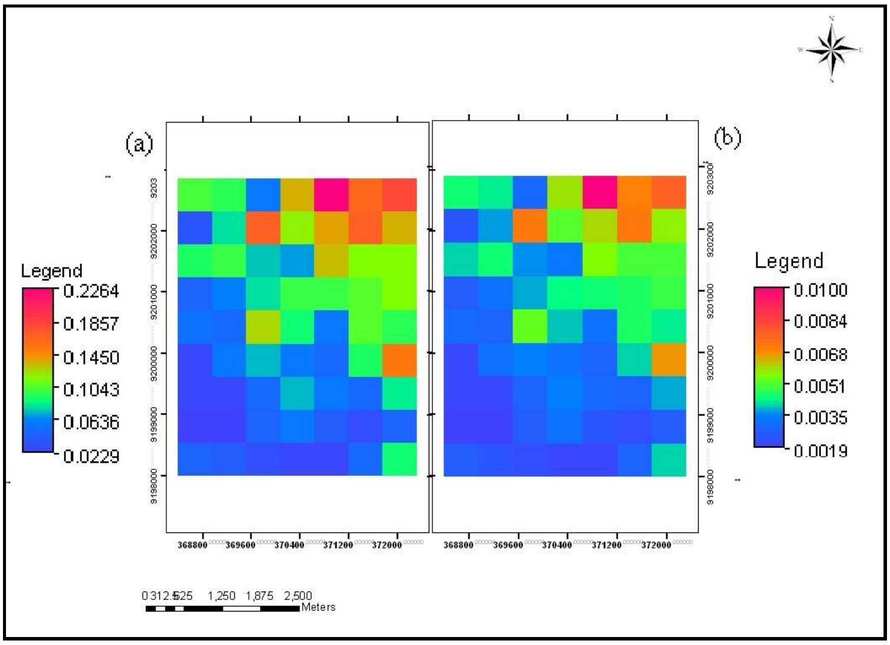


Figure 5-25 (A) C-factor Generated from Van der Knijff's Equation (B) C-factor Generated from the Regression Equation

Following the derivation of the respective maps from the different C-factor equations from MODIS and LANDSAT images, the Van der Knijff's equation which showed higher values than that of the c-factor maps generated from the regression equation which gave extremely small values was used.

Conclusion on C-factor Mapping Generated from NDVI

Based on the correlation between the aggregated LANDSAT NDVI and that of MODIS at a re-sampled 480m resolution, it can be conclude that The MODIS image despite its coarse resolution show a good correlation with the aggregated LANDSAT image. NDVI values may not detect variables such as ground cover density in forest, canopy structure, litter layer or management practices (Zihni 2000) which are important factors in the estimation of C-factor values but Suriyaprasit (2008) was able to established a correlation of an adjusted R^2 of 0.78 between the C-factor derived from satellite images and the C-factor values from training samples. This also as previous stated is the bases for using satellites images where available in the research work. However, comparing the C-factor derived from the original LANDSAT with that generate from the aggregated LANDSAT (figure 5-26) there seems to be a disparity in values obtained. The values obtained from the aggregated LANDSAT are much smaller than that of the original LANDSAT. This could be said to be as a result of the window aggregating function used the average function. This function simply added 16 input pixel values in a window and gave an output of one value which is the average of the sum of all the values of the pixels in that window. Hence, it will not exhibit or reflect the original reflectance value but it underestimated the C-factor values for the area since the land use/ cover can no longer be differentiated at this resolution.

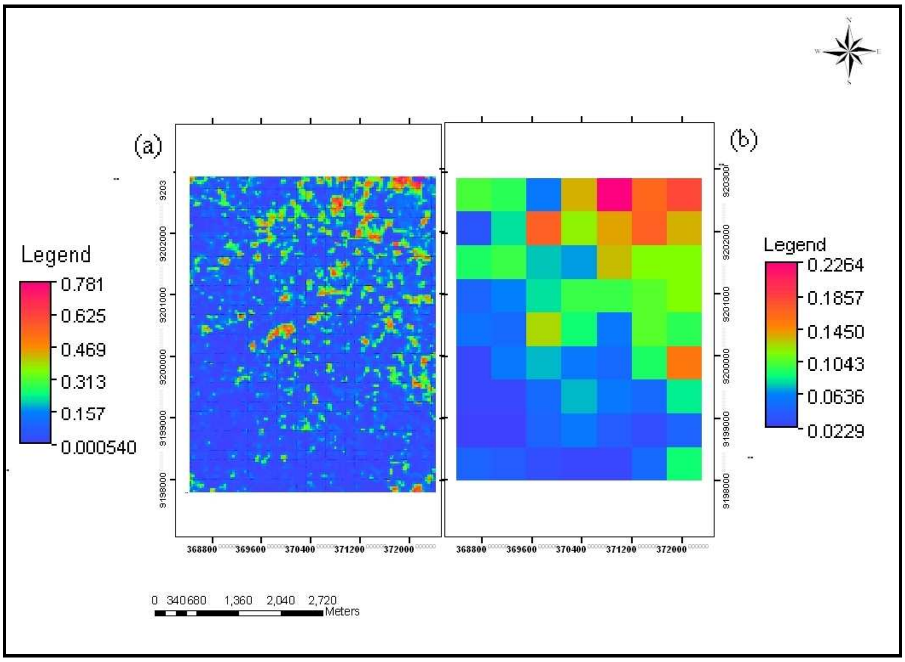


Figure 5-26: (A) C-Factor Map from LANDSAT (30m Resolution) and (b) C-Factor Generated from the Aggregated LANDSAT (480m Resolution)

- *The second part of this objective is to assess the usefulness of the derived c-factor MODIS images to soil loss studies.*

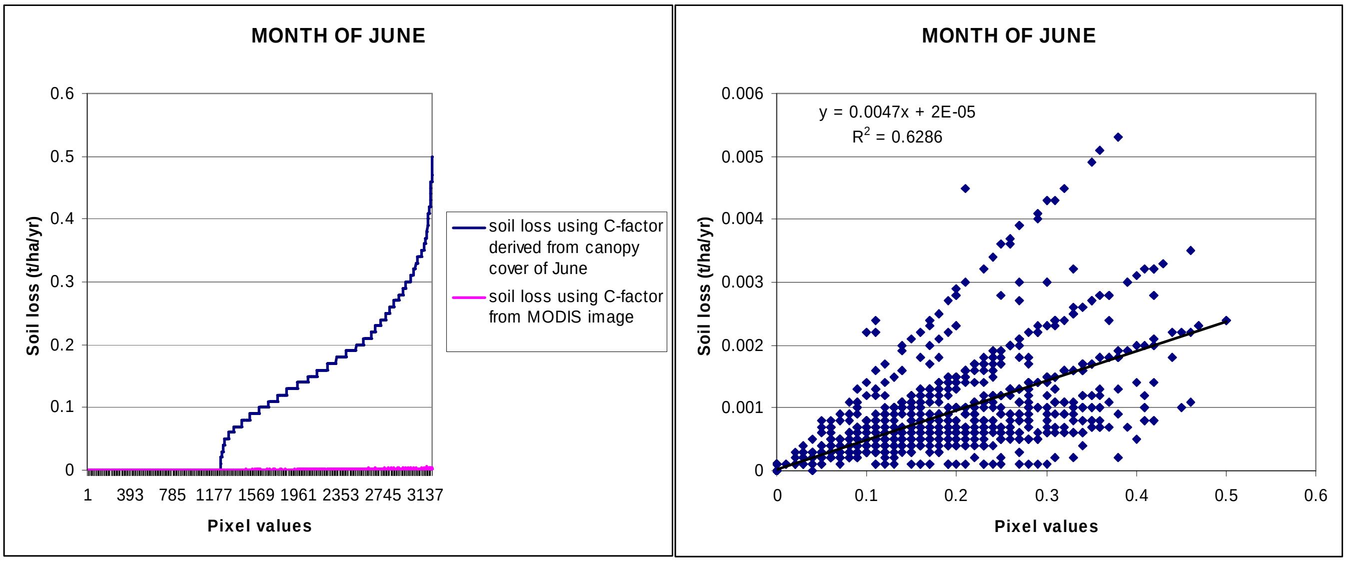
The study area is only 1700 hectares and that makes it difficult to identify or distinguish any features on ground. To justify the accuracy of the obtained parameter, a correlation factor of 0.66 was obtained from establishing a relationship between the MODIS NDVI and that of an aggregated LANDSAT (30m). There was, however a limitation in obtaining cloud free images for twelve months. Only four months had cloudless images which spanned from June through September, 2009. Based on this analysis done through a comparison between the soil losses results for the months of June through September when images were available with the soil loss s of the same months derived from crop calendar parameters. Since the months through June through August has roughly the same rainfall values, it will not be necessary to show all threes results. Only the results of June and September will we discussed here.

Soil Loss Prediction for the Month of June, 2009

The table below shows the summary of the soil loss derived using the c-factor map from MODIS imagery and the c-factor map derived from canopy cover using in previous analysis. Figure 5-27 (B) shows that a correlation factor, r^2 of 0.63 exist between the two results derived. Howbeit, the soil loss prediction using the MODIS c-factor tends to underestimated the erosion rates in the area (illustrated in figure 5-27 (A). It could be as a result of the over estimation of the presence of vegetation from the MODIS NDVI values through which the C-factor was derived. Though the soil loss rates using the c-factor derived from canopy cover was also low, the MODIS c-factor gave extremely low values and that in my opinion is not a true representation of the vegetation cover in the area.

	Soil Loss Predictions for June	
Summary	**MODIS C-Factor**	**Canopy Cover Derived C-Factor**
Minimum	0	0
Maximum	0.50	0.0053
Average	0.11	0.0005
Standard Deviation	0.11	0.0007

Table 5-19: Summary of Soil Loss Predictions Using C- Factor Derived from MODIS and the C-Factor Derived from the Canopy Cover of June



(A) (B)

Figure 5-27: (A) Line Chart Showing Distribution of Soil Loss Predictions (B) Correlation of Soil Loss Using C- Factor Derived from MODIS and the C-Factor Derived from the Canopy Cover of June

Soil Loss Prediction for the Month of September

The results from this analysis can be seen in table 5-20. There is a disparity between the values obtained. This can be seen in a linear regression analysis done to establish the relationship between the two predicted soil losses. The correlation factor obtained (r^2=0.11) was extremely low.

	Soil Loss Predictions for September	
Summary	**MODIS C-Factor**	**Canopy Cover Derived C-factor**
Minimum	0.00	0.00
Maximum	0.09	0.14
Average	0.00	0.02
Standard Deviation	0.02	0.02

Table 5-20 : Summary of Soil Loss Predictions Using C- Factor Derived from MODIS and the C-Factor Derived from the Canopy Cover of September

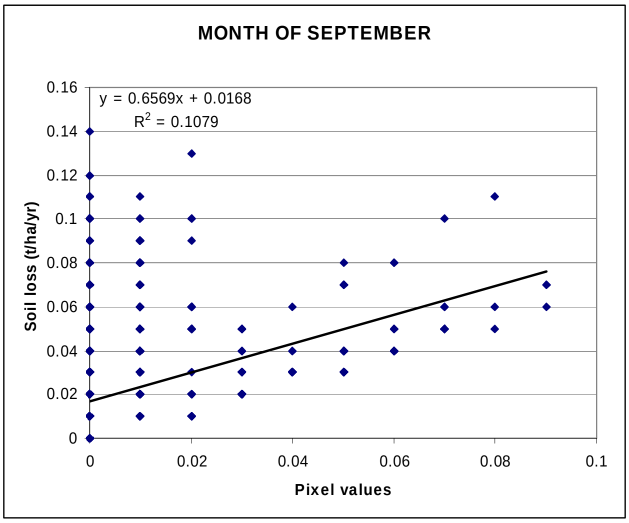


Figure 5-28: Correlation of Soil Loss Using C- Factor Derived from MODIS and the C-Factor Derived from the Canopy Cover of September

CONCLUSION

The conclusion from this soil loss comparison results show that the applicability of MODIS c-factor to Soil loss assessments in small catchment is limited. Due to the resolution of the MODIS image used in this study, the NDVI values showed very high vegetation cover and as such the c-factor derived from it shows little or no tendencies for erosion. The effect of other land cover parameters is underestimated. This is probably the reason why the soil loss predictions were extremely low and cannot give a true representation of the soil loss in the study area which is a small catchment.

6. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

Soil loss estimation and assessment especially in agricultural areas is essential. This will not only delineate areas most likely affected by erosion or give a predicted amount of soil loss but it will help implement good management practices and will at the long run, lead to an optimal and sustainable agricultural process and crop production yields. There, assessment of soil loss and the contributing factors are important not only on a large scale assessment but even on a small catchment level. As such, remotely sensed data do play a major role in this assessment. Availability, scale and cost-efficiency do determine the limit to which the remote sensing data could be used. Part of the study focus was integrating the use of available frequently obtained coarse resolution image to assess effectiveness and applicability for obtaining quantitative parameters, most specifically, the cover factor for soil erosion modelling in small catchment. Based on my objectives, my conclusions were as follows:

- The main objective of the study is to assess the effects of seasonal variation of vegetation cover on soil erosion in the Ratamba watershed, Banjanegara District, Central Java using averaged annual input parameters for one year and comparing the results with the sum of the monthly soil loss for the same year.
  - ✓ *Is the annual soil loss using average parameters the same as sum of the monthly soil loss including seasonal variations? If no, what causes the difference?*

The results show a disparity between the predicted soil loss results. The soil loss prediction with using average parameters are only estimates based on one set of input factor which is assumed to represent the whole year. As such, it does not take into consideration variations in rainfall amount, rainfall interception, canopy cover, plant height and ground surface. It gives a generalised result to which portrays the climatic, land use and soil parameter to be constant throughout the whole year. This is in fact not the case in the real world. There are months with high, moderate and little or no rainfall, also month with varying plant height; canopy and surface cover which the average inputs do not take into considerations. These variations were taken in account by the total sum of the monthly soil loss prediction and the results derived were lower. A conclusion is drawn here is that the average input parameters which does not incorporate rainfall and other input variation tends to overestimate the annual soil loss rates in the area and may give alarming erosion rates as the case may be. This conclusion is also based on the statistical result which was used to compare the distribution pattern of the different final soil loss results which revealed that the soil loss estimates using average values was negatively skewed and as such lacked a normal distribution in the area.

- To develop a crop calendar of the area.
  - ✓ *Which crop has a seasonal calendar that generates the highest soil loss and why?*
  - ✓ *Is the highest soil loss of the area in months with the highest rainfall?*

The crop calendar and rainfall pattern in the area showed that most crops are dependent on rainfall and the highest rainfall in the area occurs between January and February which coincides with the months of low land cover. This apparently, suggests that these months would have the highest soil loss in the year. A total rainfall of 579 mm and 601 mm was recorded for these months respectively and from the monthly erosion analysis, these months also had the highest average predicted soil loss of 5.12 t/ha/yr and 5.79 t/ha/yr (based on the monthly soil loss derived for the year).

- To estimate soil loss in the Ratamba watershed, Java District using the RMMF model.

The soil loss estimates were derived as follows; average soil loss prediction for the study area using the average input factors was 23.43 t /ha/yr and that of the sum of the monthly predicted soil loss for one year was 12.01 t/ha/yr. With regards to the different land uses, the prediction with the average values predicted the highest soil loss in the tobacco fields with an average soil loss of 43.56 t/ha/yr and for the sum of the monthly soil loss, the highest soil loss was in the dry land agricultural field with an average soil loss of 21.35 t/ha/yr. These results from the sum of the monthly soil loss for the year seems reasonable for the study area but this cannot be said to be tentative as no validation was done for the obtained results.

- To assess the role of the management factor in the area
  - ✓ *Do the management practices in the area reduce soil loss in the area?*

The results from the sensitivity analysis showed that the management factor has little or no effect on the erosion rates in the study area. This could result from a combination of bare surfaces in the agricultural and tobacco fields with specific rain fall that causes soil loss to be higher in some months than the other with higher canopy coverage but if the reverse slope terrace practice is implemented, there would be a reduction in the soil loss rate in the area.

- To assess the effectiveness and applicability of using the MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI images for C-factor mapping in small catchments.
  - ✓ *Can the estimated cover factor derived from MODIS imageries be useful soil loss assessment in small areas where detailed information is lost? If yes, how well can this it be done?*

In relating the NDVI derived from the aggregated LANDSAT image and that of the MODIS image, there results showed a 66% correlation. This difference in the correlation could be said to result from the range difference in the C-factor values generated from the NDVI which was an interpretation from the different image resolutions.

From this result, it revealed that the MODIS image could be used for assessing healthy vegetation and vegetation changes on a small catchment level. And the cover factor derived from the aggregated LANDSAT and MODIS images using the Van der Knijff's equation gave a higher correlation factor than results obtained using the by De Jong and the regression equation based on field assessment. However, it should be noted that there was a difference in the range of the C-factor values generated from the NDVI which could have been as a result of interpretation at different image resolutions which could not be accounted for in the correlation co-efficient. Nevertheless, the C-factors generated from the MODIS image showed an average crop cover in the area for the month of June. This however, could be feasible since it was seen to have similar values with the C-factor values derived from the relationship between the c-factor and canopy cover and also a was a correlation factor of 0.96 derived for the soil loss of the month of June using the c-factor values obtain from the NDVI and that of the soil loss derived using the c- factor derived as a derivative from the canopy cover of the same month. But on applying it to soil loss assessment, it revealed that soil loss derived using the MODIS c-factor results overestimated the presence of vegetation cover since some fields in the area were just at the planting and vegetative stages. And when the soil loss result derived for the month of September was correlated with the soil loss prediction for the same month using the c- factor derived from the canopy cover, it gave a low value (r^2=0.11) which showed that it's extremely low prediction is not realistic.

As a conclusion from this, the MODIS (500m) image which is free and cost effective can be used for C-factor mapping but the results obtained when applied to soil loss assessments could be unrealistic and as such limits its usefulness for erosion assesses in small watershed.

6.2. RECOMMENDATIONS

My recommendations are:

- That a further analysis and validation assessment be done to investigate the results derived for the soil loss to evaluate which result gave a more realistic prediction or improve on the results derived.
- More research be done on deriving monthly modelling parameters to estimate soil loss as against the use of average input parameters which is most done for convince and also due to un availability of data.
- Due to the more frequent availability and cost-efficiency of acquiring the MODIS images, I propose that a further research be carried out using the parameters derived from a MODIS (250m resolution) image in predicting soil loss in small catchment.

- For erosion assessment, more time and proper orientation for acquiring erosion modelling parameters such be seriously considered. Quite a number of the input parameters used for were derived from a literature which has been the case for most erosion studies. Therefore, results obtained cannot be said to be tentative.
- Field work should be done in an English speaking community and or in home country of residence to enable proper communication and cordial acceptance in the study area.

6.3. LIMITATIONS

Language barrier in the study area posed a great limitation. Interviews had to be done through interpreters and a great deal of information lost in transcribing and interpreting questionnaires and interviews.

Due to time constraints and unavailability of field work instruments, some modelling parameters were derived from literatures and this as earlier is not a pragmatic approach to soil loss predictions in the area.

Also due, to time constraints, acquisition of MODIS (250m resolution) was not possible. The study partly used derived soil erosion parameters from MODIS (500m resolution) which were compared to LANDSAT (30m resolution) which are far apart in resolution. And a also a validity assessment could not be done on the soil loss predictions in this study.

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8. APPENDICES

Appendix 1: Field Sample Points

Sample no.	X	Y	Land cover/ use	Crop type
1	369915	9200494	vegetation/Agricultural	Carrot
2	369915	9200494	vegetation/Agricultural	Cabbage
3	369915	9200494	vegetation/Agricultural	Leaf Onions
4	369917	9200444	vegetation/Agricultural	potatoes
5	369390	9199878	Bridge	
6	369424	9199841	vegetation/Agricultural	Tobacco
7	369502	9199858	vegetation/Agricultural	cabbage
8	369502	9199858	vegetation/Agricultural	carrot
9	369529	9199830	building/residential	
10	369492	9199717	Vegetation/agricultural	maize
11	369770	9199626	vegetation	grassland
12	369759	9200656	building	village ratamba
13	370074	9201429	Vegetation/agricultural	maize
14	370082	9201424	Vegetation/agricultural	Maize
15	370082	9201466	Vegetation/agricultural	maize
16	370146	9201496	Vegetation/agricultural	carrot
17	370140	9201506	vegetation/tree plantation	Acai tree
18	370372	9201940	Vegetation/agricultural	potatoes and maize
19	369991	9201705	Vegetation/agricultural	potatoes and maize
20	369466	9200245	Vegetation/agricultural	potatoes
21	369466	9200245	Vegetation/agricultural	cabbage
22	369349	9200131	Vegetation/agricultural	mixed crops
23	369290	9200180	vegetation	grassland
24	369280	9200174	vegetation	grassland
25	370012	9200911	building	bridge
26	370147	9200867	vegetation/agricultural	cabbage
27	370147	9200867	vegetation/agricultural	potatoes
28	370284	9200804	Vegetation/agricultural	potato
29	370057	9200964	Vegetation/agricultural	cabbage
30	370135	9201119	Vegetation/agricultural	green peas

31	369960	9200926	Vegetation/agricultural	kinikid
32	371268	9201681	Vegetation/agricultural	cabbage
33	371188	9201724	Vegetation	grassland
34	371143	9201828	Vegetation/agricultural	potatoes
35	371089	9201857	vegetation	cabbage
36	371017	9201802	vegetation	green peas
37	371042	9201746	village	
38	370927	9201694	vegetation	potatoes
39	370750	9201493	vegetation	potatoes
40	370853	9201317	vegetation	potatoes
41	370760	9201291	vegetation	shrubs
42	370583	9201209	vegetation	Carrot
43	370583	9201209	vegetation	Cabbage
44	370292	9201063	vegetation	Carrot
45	369900	9200888	vegetation	Shrubs
46	371085	9200964	vegetation	cabbage
47	371054	9200989	vegetation	potatoes
48	371116	9200924	vegetation	cabbage
49	371088	9200481	vegetation	maize
50	370763	9200069	vegetation	carrot
51	370513	9199690	vegetation	maize
52	369872	9199415	Road	
53	369875	9199400	vegetation	potatoes
54	369743	9200504	vegetation	carrot
55	369740	9200426	vegetation	potatoes
56	369760	9200240	vegetation	carrot
57	369732	9200200	vegetation	tobacco
58	369756	9200144	vegetation	potatoes
59	369768	9200099	River	
60	369800	9200100	vegetation	grassland
61	369836	9200051	vegetation	green peas
62	369913	9200045	vegetation	carrot
63	369924	9200198	Bare soil	
64	370034	9201274	vegetation	shrubs
65	370103	9201254	vegetation	cabbage
66	369716	9199865	vegetation	cabbage
67	370789	9200775	vegetation	potatoes
68	370789	9200775	vegetation	potatoes
69	370941	9200497	vegetation	cabbage
70	370255	9200404	vegetation	green peas

71	370244	9200148	vegetation	green peas
72	370146	9199614	vegetation	carrot
73	369950	9199593	vegetation	potatoes
74	370914	9201112	vegetation	carrot
75	369892	9201483	vegetation	cabbage
76	370153	9201360	vegetation	tobacco
77	370212	9201357	vegetation	potatoes
78	370212	9201357	vegetation	green peas
79	370240	9201402	vegetation	carrot
80	370280	9201448	vegetation	cabbage
81	370149	9201304	vegetation	carrot
82	370149	9201304	vegetation	onion leaf
83	370107	9201202	River/shrubs	shrubs

Appendix 2: Land Use/Management Pictures

Appendix 3: Field Data Collection/Software

This shows the collection of relevant data for the research, the data requirements and their sources.

(a) MATERIALS

- GPS
- Field equipments for field test which includes PH kit, shear vane tester, an auger, soil field book, munsel colour chart, field knife, field bags, digital camera, densitometer spherical and measuring tapes.
- Satellite images, aerial photographs, DEM. The images used in this study are:
  - Topographic maps of the study area at a scale of 1:25,000 from Bakosurtnal Office.
  - Geomorphologic map from Bakosurtanal Office.
  - Geological map a scale of 1:100000 from Indonesian Geology.
  - Satellites images which include LANDSAT ETM for 1989, 1991, 1992, 1999, 2000, 2001, 2002, 2003 at a 30 meter resolution. And also, a LANDSAT 7 image for June, 2009. These were all downloaded from USGS website.
  - Aerial photographs: Available years and scale are shown below

Year	scale
1946	1:50,000
1970	1:35,000
1972	1:20,000
1973	1:20,000
Source: Serayu valley Project - Forest Ministry, Indonesia.	

  - Dem map of the area was created at a 10metre resolution from the contour map with 22.5metre interval.
  - Digital Soil maps at a scale of 250,000 from Puslintanah Office.

(b) SOFTWARES

- ILWIS 3.3
- ENVI 4.5
- ARC GIS 9.2
- ERDAS IMAGINE 9.1
- SPAW(Soil Plant Atmosphere Water)
- Microsoft package.

(c) DATA USED AND SOURCES

SOIL SAMPLES	**SOURCES**
• Soil texture • Soil detachability, K • Soil moisture content at field capacity, MS • Effective Hydrological Depth of the soil, EHD • Bulk density, BD • Cohesion of the surface soil, COH • Organic matter, OM • Particle size distribution • Soil locations	Field work, preceding field work results and past literature.
CLIMATIC/RAINFALL DATA	**SOURCES**
• Monthly rainfall amount (mm) • Number of rainy days per year • Intensity, *I*	Meteorological stations and preceding research results.
LAND USE/LAND COVER	**SOURCES**
• Rainfall intercepted by crop cover, A • Ratio of actual (Et) to potential evapotranspiration (Eo), Et/Eo • Crop cover factor, C-factor • Canopy cover, CC • Ground cover, GC • Plant height, PH • Surface roughness, n	Field work, previous research and from NDVI
LANDFORM	**SOURCE**
• Slope steepness(^{o}), S • Length slope, LS	DEM
CROP CALENDAR	**SOURCES**
	From local farmers through questionnaires and from previously done researches.

Appendix 4: Crop Calendar/ Erosion Perception Questionnaire

CROP CALENDAR

No: ……

Village: ……………………………………………………………………………………………………….

Location: …………………………………………………………………………………………………….

How long have you been farming? ……………………………………………………………………………….

Crop type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	REMARK

[Crop seasons: planting, vegetative and harvest]

QUESTIONS:

What types of crops do you grow?

What is the growth cycle for each?

How are they harvested?

………………………………………………………………………………………...

Fallow activities:

……

……

How are the fallow activities carried out?

…………………………………………………………………………

How much of the rain do the crops rely on and what are the alternative measures to watering the crops?

....

....

RELATING CROP CALENDAR TO RAINFALL / SOIL LOSS

1. Do you know what soil erosion is?

………

………

2. Perceptions of soil erosion

Circle the location of the field	**1**-Hilltop	**2**-Shoulder	**3**-Midhill	**4**-Foothill	**5**-Valley	**6**-Flat (No Hill)
Estimate the slope of the field	**1**-None to slight (0°-4°)	**2**-abit (5-9°)	**3**-Medium (10°-14°)	**4**-Steep (15° +)		
What type of agriculture practice is being carried out?						
How do you prepare this field for planting?	**1**-Ox-plough	**2**-Tractor	**3**-Hoe			
Is there erosion on this field?	**0**-No, no erosion	**1**-Yes, a little erosion	**2**-Yes, much erosion			
What causes erosion in your farm?						
How much is eroded?						

3. Relating crop calendar to soil loss

	Fallow period	**planting**	**vegetative**	**harvesting**
When crop seasons do you have soil erosion?				
Which season has the highest erosion?				
What do you suggest is the cause?				
What is the size of the crop cover/leaves?				
Which season has the lowest or no erosion?				

4. Relating soil loss to rainfall

<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>When does the rain start/end?</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Which months have the highest rainfall?</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Which period has the highest erosion because of the rain?</td><td colspan="3">Fallow period</td><td colspan="3">Planting</td><td colspan="3">Vegetative</td><td colspan="3">harvesting</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Which period has the lowest erosion because of rain?</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>In your own opinion, does the rain really affect soil loss and if it does, how?</td><td colspan="12"></td></tr>
</table>

Appendix 5: Script for Deriving Cover Factor

i) Using the Van der Knijff's (1999) equation:

$$C = e^{-\alpha \frac{(NDVI)}{(\beta - NDVI)}}$$

Command: C = (EXP(-2)*((NDVI)/(1-NDVI)))

ii) Using the regression equation based on field assessment of C factor (Suriyaprasit and Shrestha 2008)

$$C = 0.227 * e^{(-7.337 * NDVI)}$$

Command = 0.227*EXP(-7.337*NDVI)

Appendix 6: Accumulation Script

```
asc2map --clone clone.map -S -a tc_mask.asc tc_masked.map
asc2map --clone clone.map -S -a d_mask.asc d_masked.map
report nonriv.map=scalar(accuflux(ldd.map, 1) le 30);
# river assumed all area above 30 cells accumulation
report detaccu.map=accuflux(ldd.map,
nonriv.map*d_masked.map)*cellarea()/1000;
#tot detachment in ton/cell
report tcaccu.map=accuflux(ldd.map, tc_masked.map)*cellarea()/1000;
#tot transport cap in ton/cell
#report test.map=min(detaccu.map,tcaccu.map)
report soilloss.map=accucapacityflux(ldd.map, detaccu.map, tcaccu.map);
#soil loss at each cell including all sediment movement upstream, ton
report depo.map=accucapacitystate(ldd.map, detaccu.map, tcaccu.map);
#deposiiton, soil not transpoted, ton
report outletsl.map=maptotal(scalar(pit(ldd.map))*soilloss.map);
```

Appendix 7: Rainfall Interception Derivatives

CANOPY COVER

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.3	0.2	0.2	0.1
Dry Agric.	0.43	0.2	0.5	0.34	0.57	0.55	0.6	0.53	0.66	0.5	0.6	0.63
Forest	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Shrubs	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Plantation	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

LAI – LEAF AREA INDEX

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.558	0.892	1.277	1.733	2.291	3.010	4.024	4.024	0.892	0.558	0.558	0.263
Dry Agric.	1.405	0.558	1.733	1.039	2.110	1.996	2.291	1.888	2.697	1.733	2.291	2.486
Forest	5.756	5.756	5.756	5.756	5.756	5.756	5.756	5.756	5.756	5.756	5.756	5.756
Shrubs	4.024	4.024	4.024	4.024	4.024	4.024	4.024	4.024	4.024	4.024	4.024	4.024
Plantation	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010	3.010

SMAX – MAXIMUM STORAGE CAPACITY

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.746	0.848	0.966	1.106	1.277	1.497	1.808	1.808	0.848	0.746	0.746	0.656
Dry Agric.	1.006	0.746	1.106	0.893	1.222	1.187	1.277	1.153	1.401	1.106	1.277	1.337
Forest	2.339	2.339	2.339	2.339	2.339	2.339	2.339	2.339	2.339	2.339	2.339	2.339
Shrubs	1.808	1.808	1.808	1.808	1.808	1.808	1.808	1.808	1.808	1.808	1.808	1.808
Plantation	1.497	1.497	1.497	1.497	1.497	1.497	1.497	1.497	1.497	1.497	1.497	1.497

K

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.036	0.058	0.083	0.113	0.149	0.196	0.262	0.262	0.058	0.036	0.036	0.017
Dry Agric.	0.091	0.036	0.113	0.068	0.137	0.130	0.149	0.123	0.175	0.113	0.149	0.162
Forest	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374
Shrubs	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262
Plantation	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196

Interception (I) (mm) per month

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	2.608	5.253	6.267	7.284	6.868	4.298	4.033	3.536	0.862	2.013	2.491	0.508
Dry Agric.	10.011	2.618	9.933	3.269	6.074	2.360	2.027	1.304	4.338	10.504	18.634	17.991
Forest	54.987	53.366	47.168	35.677	23.332	9.854	5.978	5.338	10.825	44.273	54.440	49.685
Shrubs	37.292	36.274	31.062	23.321	15.031	6.349	4.033	3.536	7.185	29.934	36.826	33.061
Plantation	26.581	25.921	21.476	16.008	10.174	4.298	2.858	2.460	5.006	21.264	26.173	23.097

Interception fraction (0-1)

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.005	0.009	0.022	0.038	0.066	0.098	0.073	0.101	0.012	0.005	0.005	0.001
Dry Agric.	0.017	0.004	0.035	0.017	0.058	0.054	0.037	0.037	0.059	0.024	0.035	0.051
Forest	0.095	0.089	0.167	0.186	0.224	0.224	0.109	0.153	0.148	0.103	0.102	0.142
Shrubs	0.064	0.060	0.110	0.121	0.145	0.144	0.073	0.101	0.098	0.070	0.069	0.094
Plantation	0.046	0.043	0.076	0.083	0.098	0.098	0.052	0.070	0.069	0.049	0.049	0.066

Rainfall data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Total rainfall	579	601	282	192	104	44	55	35	73	430	535	350
No. of rainy days	27	26	28	23	19	8	3	3	6	22	27	27
Mean rainfall	21.44	23.12	10.07	8.35	5.47	5.50	18.33	11.67	12.17	19.55	19.81	12.96

Monthly C-factor estimates from canopy cover

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up	0	0	0	0	0	0	0	0	0	0	0	0
Tobacco	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.70	0.80	0.8	0.9
Dry Agric.	0.57	0.6	0.50	0.66	0.43	0.45	0.40	0.47	0.34	0.50	0.4	0.37
Forest	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Shrubs	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Plantation	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Monthly plant height

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.70	0.9	1.2	1.5	1.7	1.8	1.9	2.1	1.8	1.7	1.7	0.50
Dry Agric.	1.0	0.05	0.18	0.22	0.55	0.59	0.22	0.24	0.48	0.55	0.55	1.2
Forest	16	16	16	16	16	16	16	16	16	16	16	16
Shrubs	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Plantation	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0

Ground cover

Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	0.10	0.15	0.25	0.30	0.40	0.50	0.60	0.60	0.30	0.40	0.40	0.10
Dry Agric.	0.30	0.10	0.10	0.15	0.40	0.20	0.15	0.15	0.40	0.30	0.40	0.50
Forest	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Shrubs	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Plantation	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70

Cohesion

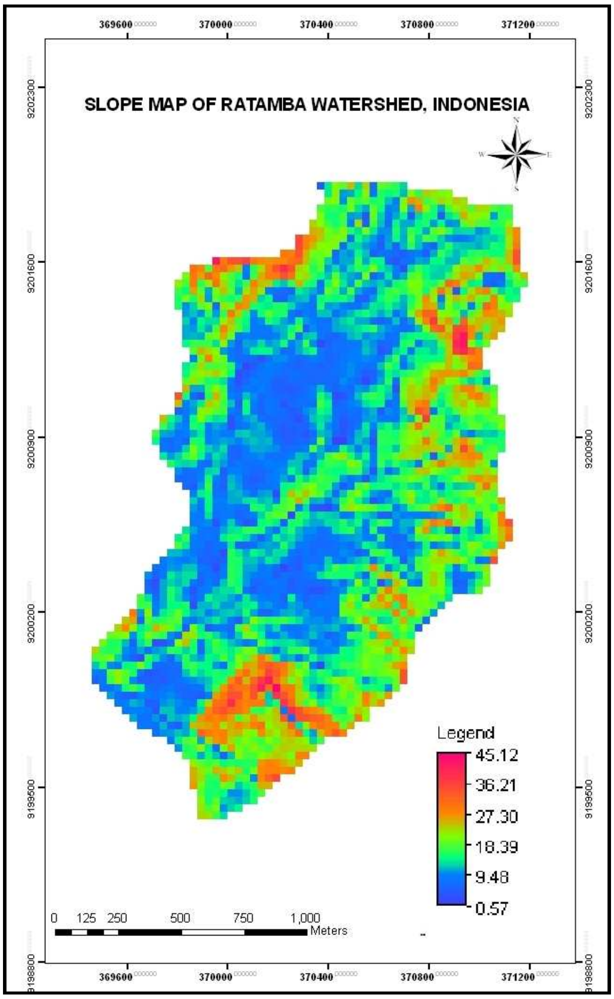
Crop type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Built up												
Tobacco	22	22	22	22	22	22	22	22	22	22	22	22
Dry Agric.	25	25	25	25	25	25	25	25	25	25	25	25
Forest	38	38	38	38	38	38	38	38	38	38	38	38
Shrubs	34	34	34	34	34	34	34	34	34	34	34	34
Plantation	30	30	30	30	30	30	30	30	30	30	30	30

Appendix 8: Script used for running the RMMF model in ILWIS

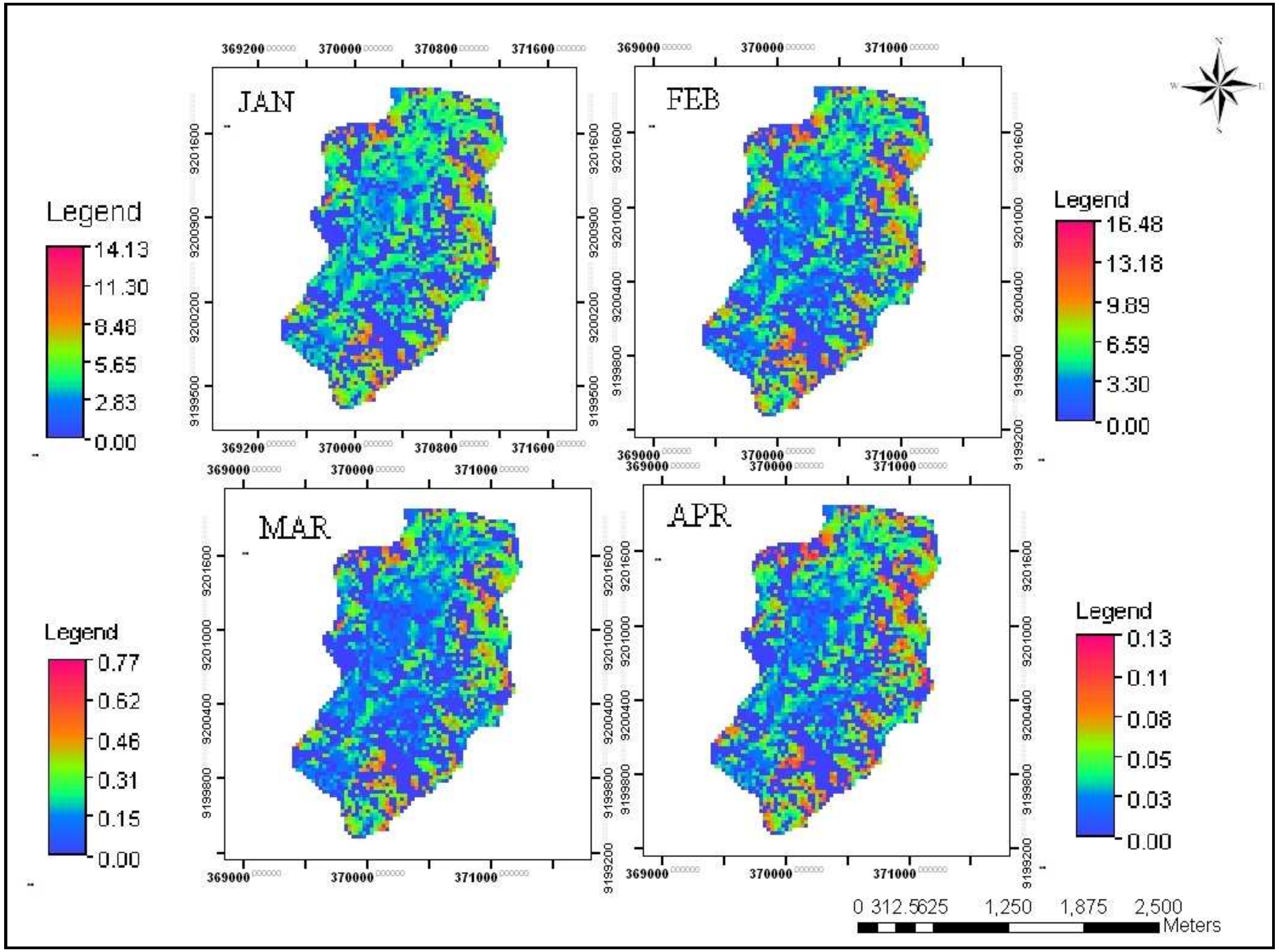
```
//created attribute maps of A, Et/Eo, CC, PH, EHD, MS, BD, K, COH
//Calculate Kinetic Energy
//(Water phase)
//Effective rainfall
ER=rainfall map*A
//Leaf Drainage
LD=ER*CC
//Direct Through fall
DT=ER-LD
//Kinetic Energy of Direct Through fall
KE_DT=DT*(11.9+(8.7*(log(30))))
//Kinetic Energy of Leaf Drainage
KE_LD=LD*(15.8*(PH_area^0.5))-5.87
//Total Kinetic Energy
KE=KE_DT+KE_LD
//Mean rainy days(Ro)
Ro=(Rainfall_map/91)
//Ro= R/Rn; annual rainfall/no. of rainy days in a year.
//Soil moisture storage capacity (mm)
RC=1000*MS*BD*EHD*Et_Eo
//Annual runoff (mm)
Q=rainfall map*(exp(-RC/Ro))
//Soil detachment by raindrop impact (k/m2)
F=K*KE*10^-3
//Soil resistance (kpa)
Z=1/(0.5*COH)
//Soil detachment by runoff (k/m2)
H=Z*Q^1.5*(SIN(DEGRAD(slope_degrees)))*(1-GC)*0.001
//Total Particle detachment (k/m2)
detachment=F+H
//Transport Capacity (kg/m2) where C=C-factor*management practice value
TC=(C*0.35(Q^2)*(SIN(DEGRAD(slope_degrees)))*0.001)
//Soil loss((kg/m2)) converted to tons/yr
SOILLOSS= min(((D/1000)*900),((TC/1000)*900))
```

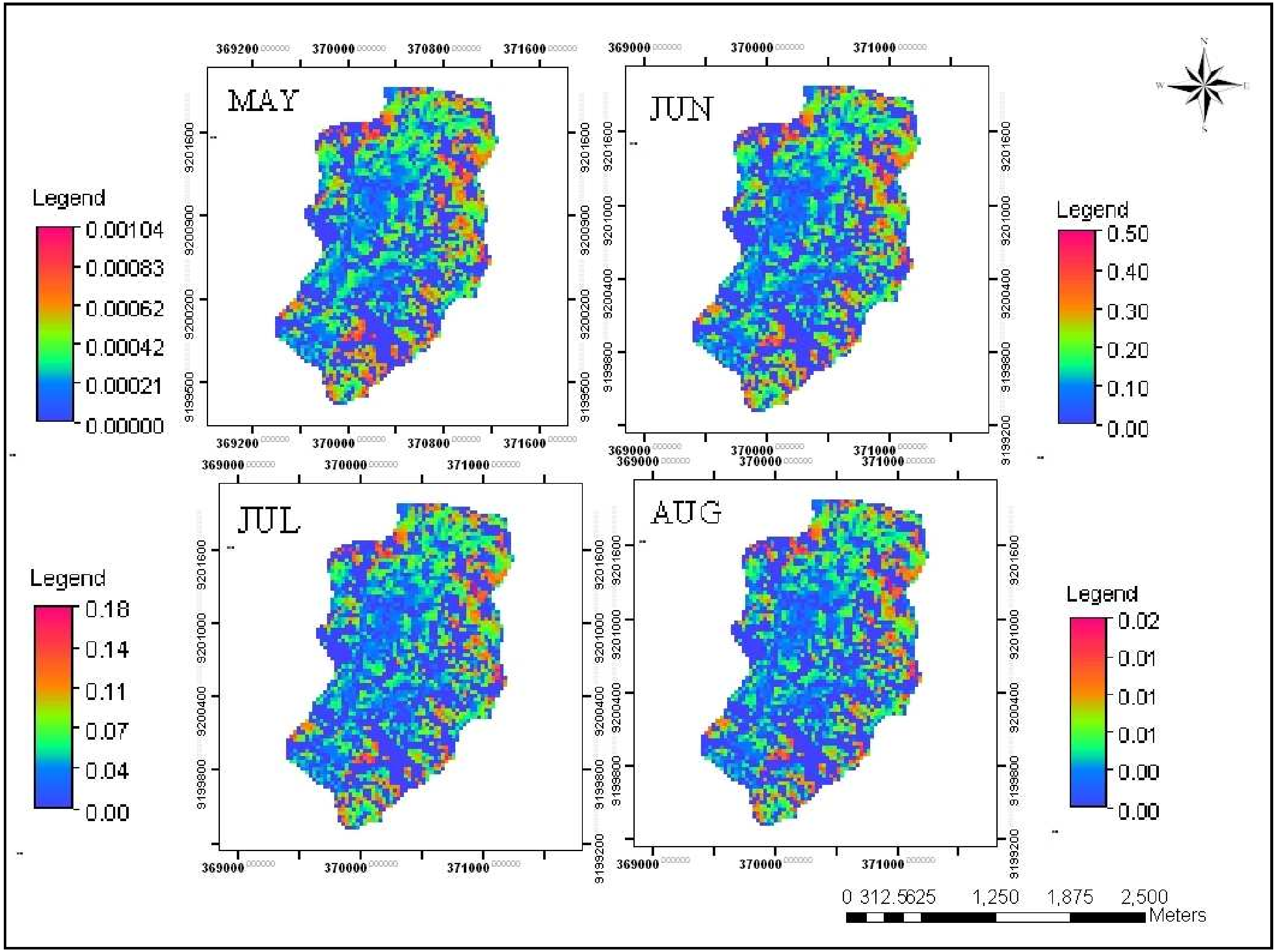
```
//Soil loss((kg/m2)) converted to tons/ha/yr
SOILLOSS= min(((D/1000)*10000),((TC/1000)*10000))
```

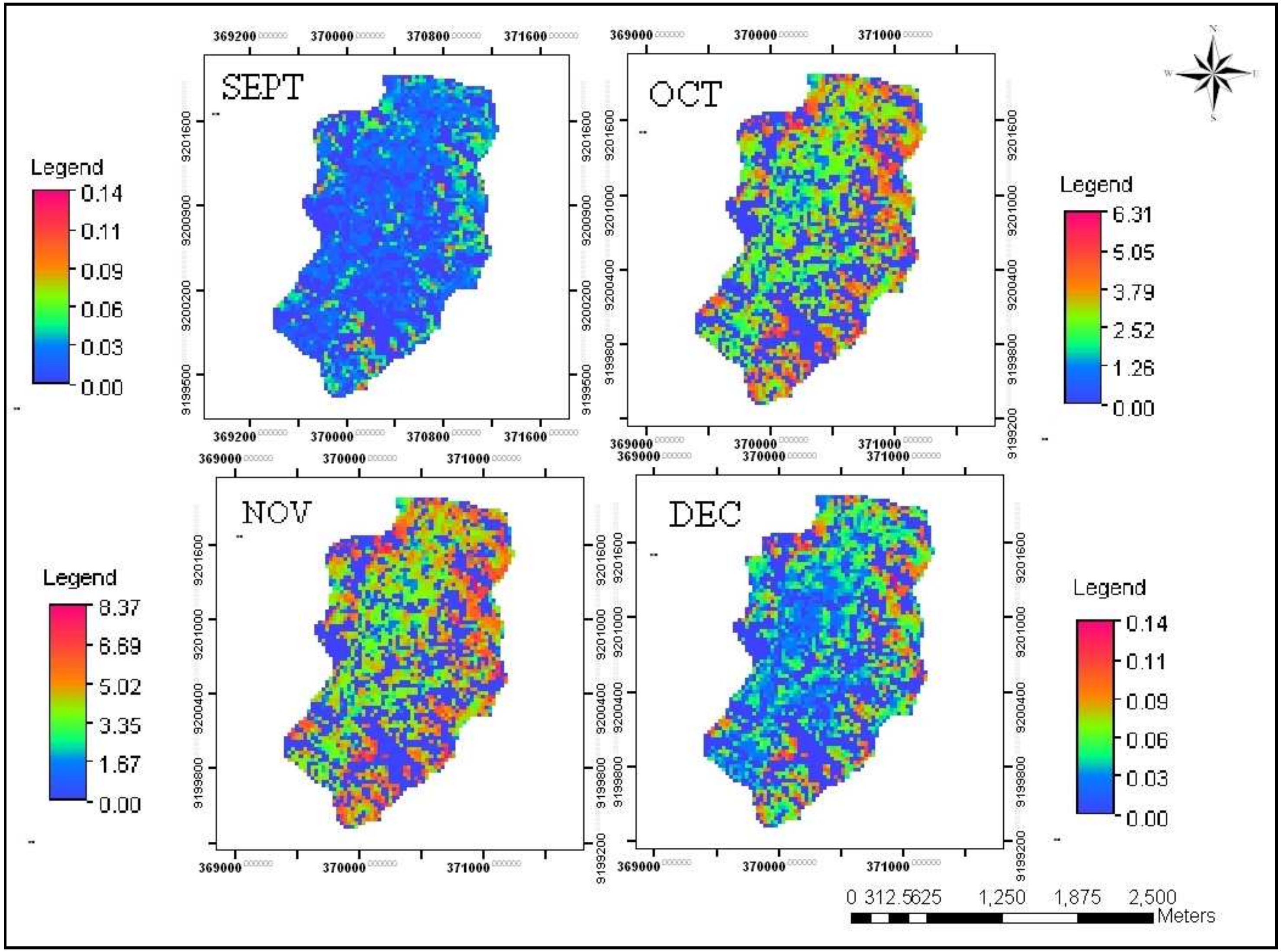
Appendix 9: Slope Map of the Ratamba Watershed



Appendix 10: Monthly Derived Soil Loss Maps, 2009 for the Study Area




MAY
JUN
JUL
AUG
Legend
0.00104
0.00083
0.00062
0.00042
0.00021
0.00000
Legend
0.50
0.40
0.30
0.20
0.10
0.00
Legend
0.18
0.14
0.11
0.07
0.04
0.00
Legend
0.02
0.01
0.01
0.01
0.00
0.00
0 312.5625 1,250 1,875 2,500
Meters


SEPT
Legend
0.14
0.11
0.09
0.06
0.03
0.00
OCT
Legend
6.31
5.05
3.79
2.52
1.26
0.00
NOV
Legend
8.37
6.69
5.02
3.35
1.67
0.00
DEC
Legend
0.14
0.11
0.09
0.06
0.03
0.00
0 312.5625 1,250 1,875 2,500
Meters