MULTI-SCALE EROSION ASSESSMENT (A CASE STUDY OF THE MERAWU SUB-WATERSHED)

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march, 2012

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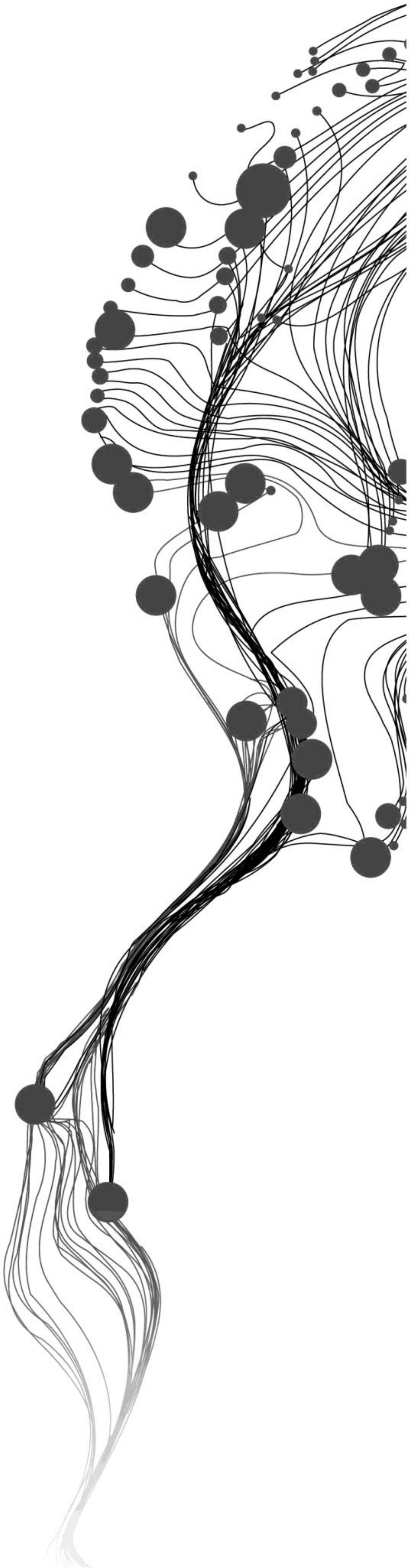

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Enschede, The Netherlands, March, 2012

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

Specialization: Applied Earth Sciences

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DISCLAIMER

ABSTRACT

Soil erosion is one of the most important environmental problems in Indonesia. To control soil erosion, assessing soil erosion at different scale is important. Satellite imagery data and Digital Elevation Models are being used increasingly to assess erosion at different scales, but the main restrictions for these assessments are availability and quality of data. Therefore, it is necessary to analyse a most reliable way of assessing soil erosion and different scales. This study aim was to assess various methods of land cover classification and DEM by aggregation to produce a reliable erosion assessment method.

Land cover classification for this assessment was done by Pan sharpening 30m Landsat 7 EMT of 2010 .The bands 4,2,1 were pan sharpened using the panchromatic band 8 to give a representation of the 15m image for land cover classification . Two methods were adopted for creating land cover maps in different resolution, 1. The pan sharpened image was first aggregated to course resolutions of 30m and 90m using the nearest neighbour for aggregation and then the land cover classification of the aggregated images are obtained using the spectral angular mapper for supervised classification. The second method is by first carrying out land cover classification of the pan sharpened image by spectral angular mapper and the aggregating the 15m land cover map to courser resolutions of 30m and 90m. The comparism of the two methods show that the most of the land cover types are aggregated to the predominate cover which is dry cultivation.

The DEM was aggregated from the 15m DEM obtained for 10m contour lines of the area, to 30m and 90m using two methods, aggregation by median and average .The two methods of aggregation showed that the slope variation reduces as the DEM becomes courser.

The Soil erosion and sediment delivery ratio was assessed by using the Revised Morgan Morgan Finney. The result from the second method of land cover aggregation was used as land cover in the model and both methods of DEM aggregation were used and the soil loss results were compared to see the best aggregation method for soil erosion assessment. The result show that the soil loss in both methods show increase as resolution becomes courser and also discharge increases as resolution becomes courser .After comparism of result with field result it show that the median aggregation gives a better erosion and sediment transport result than the average aggregation.

Keywords: Land cover aggregation, DEM aggregation, SAM classification, RMMF model.

ACKNOWLEDGEMENTS

First, I will like to give all praise and glory to God for his mercy that endures forever and for his guidance and protect through my MSc studies.

I would like to express gratitude to Dr. Shrestha, Prof. Jetten and Bert Krol for their invaluable support and advice during the preparation of this thesis. Without their abundant insights and willingness to share knowledge, I would not have gained so much through my MSc thesis.

My sincere thanks go to Nugroho Christanto, Otgo and Beatrix for their invaluable guidance and support during my MSc thesis.

I would like to acknowledge prof. Loran for his invaluable guidance and support during my MSc study and thesis.

I would like to thank my dear friend for their friendship.

My special thanks to my lovely father and mother, my brothers and sisters for their permanent support and love.

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1 INTRODUCTION

1.1 Background

Land degradation is a process that decreases the capacity of land (FAO, 1994). It has been one of the major global issues during the last century and will continue to be important in the international agenda in the 21th century (Eswaran, et al., 2001). The importance of land degradation among other global issues is related to its impact on world food security and the quality of the environment (Allan, et al., 2007). Soil erosion by water is one of the most important land degradation problems in the world (Eswaran, et al., 2001), which has a negative impact on agricultural production, water quality and in general quality of life (Lal, 1998). Human activities such as unsustainable agriculture practices, deforestation, and over grazing accelerated the rate of soil erosion (Lal, 2001). Therefore, it is of vital importance to protect the land from further degradation.

Mountainous areas are very susceptible to soil erosion due to their rough topography and erosive climate (Dadson et al., 2003). This observation is not new as already at the beginning of the 19th century the high sediment load of the rivers in Java, Indonesia was considered a serious problem and was attributed to deforestation (Coster, 1937), slash-and-burn practices (De Voogd, 1937), landslides (De Voogd, 1937), but also to poor land management practices (clean weeding) in coffee gardens (De Haan, 1942). Some studies shows that the increasing rate of population is causing degradation of the natural resources which leads to erosion and runoff (Shrestha et al, 2004). Human activities such as unsustainable agriculture practices, deforestation, and over grazing accelerated the rate of soil erosion (Lal, 2001).

Erosion processes consisted mainly of widespread sheet-interrill and rill erosion (Vigiak, 2006), this makes the effect of soil erosion not to be limited to just surface materials being removed but also the deposition of the materials off-site causing sedimentation which may reduce the river capacity and cause blockage of the river for navigation (Morgan, 1995) and also reduction in the river velocity.

Erosion assessment in Indonesia is mostly carried out at plot scale, mainly to quantify soil erosion rates according to different land cover, soil types and slope. The results of these assessments have led to a national level of commitment to soil conservation (Verbist et al, 2010). In the central Java area of Indonesia, most upland agricultural land has now being terraced, but the sediment yield problem persists and the effectiveness of these conservation programs has been challenged at a catchment scale (Rijsdijk, 2005). An important characteristic of the satellite images is spatial resolution. In general, coarse spatial resolution data have less information as compared to that from the fine resolutions. Many studies are limited to relatively small areas, because high-resolution data for getting information on erosion factors such as land use/cover, topography, and soil are not available, while the spatial variation of these factors affects the assessment of soil losses (Rojas, et al., 2008).

Multi-scale assessment allows assessing the sediment yield from various erosive and filter processes (van Noordwijk et al., 2004). In Indonesia a systematic monitoring rainfall and runoff discharge at catchment scale was undertaken in the early seventies, when for many large basins the potential for irrigation or hydropower was assessed (Verbist et al, 2010). The frequency of sediment load assessments is however much lower. The use of average daily runoff discharge values and the non-linearity between sediment concentration measurements and runoff discharge often leads to an underestimation of Sediment yield (Verbist et al, 2010).Information about the spatial distribution of sediment delivery is useful in identifying relative importance between sediment sources and how effective sediments are delivered (Newham et al., 2004).

A comparison of sediment delivery ratio at large scale with small scale erosion data allows exploring the homogeneity of the area and the effects of spatial scale on sediment yield. (Verbist et al, 2010).

One of the ways that spatial resolution of the satellite data can also affect soil erosion assessment is data in deriving a land cover map. Land cover classification at coarser resolutions gives a lot of errors (Moody and Woodcock, 1994) that can rise by increasing the fragmentation and decreasing the patch size of land cover classes (Turner, et al., 1989).

1.2 Problem Statement

The reservoir in the serayu watershed was constructed in central Java, Indonesia in 1988 and was built for the purpose of generating hydroelectric power for Java and Bali island .It was also to serve as a water source for farmlands around it. The reservoir has recorded a high sediment level after twenty years of its completion (Rustanto, 2010). Sediments eroded from the upper part of the watershed is being transported and deposited into the reservoir causing reducing in its productivity. Assessing of the soil loss in the watershed will give an idea of what quantity of soil is actually removed by soil erosion and assessment of the soil delivery ratio will help know what fraction of the removed soil is actually transported out of the watershed into the reservoir.

Assessment of erosion at a small grid size will give more detail about erosion factor but the sediment transportation may not be accounted for which will give an inaccurate assessment. On the other hand if the erosion assessment is done just on a large grid size, small but important factors that contributes to the erosion activities will be incorrectly estimated.

Several studies have been carried out to predict soil erosion in the previous years but, there is a lack of erosion assessment at large scale (Khatereh, 2010), this is due to the in availability of data and data quality. Available low-resolution data instead of high-resolution data, can affect the outcome of soil erosion models (Renschler and Harbor 2002).

Therefore, to know the quality of erosion assessment at different spatial resolutions; it is necessary to analyze the effect of using data at various spatial resolutions on deriving land cover and topographic factors, and also in the prediction of soil erosion.

1.3 Research Objectives

1.3.1 General objective

The general objective of this research is to assess soil erosion of the sub-water shed at multi-spatial resolutions.

1.3.2 Specific objectives

- To study the effect of aggregation on land cover map and on satellite image.
- To study the effect of aggregation of digital elevation model and on slope map.
- To Study of the effect of assessing erosion at different grid size on soil loss assessment.
- To Study of the effect of assessing erosion at different grid size on the Sediment delivery ratio.

1.4 Research Questions and Hypothesis

- What is the effect of aggregation on land cover and on satellite image?
- What is the effect of DEM grid size on the assessment of topographic parameters for assessing soil erosion?
- What is the effect of assessment in different grid sizes on erosion assessment?
- What is the effect of assessment in different grid sizes on the sediment delivery ratio?
- What scales of erosion assessment of the watersheds gives close results to the actual field condition?

1.5 Assumptions

The study was carried out without any fieldwork. Therefore, all required data and maps were provided by PhD study carried out in the same watershed (Christanto Nuhgoro). In addition, the accuracy assessment of land cover classification was accomplished based on the collected ground truth points from field by PhD student.

1.6 Thesis Outline

The thesis is organized as follows in six chapters:

Chapter 1 introduces the research problem and the research context; describing the research objectives and questions.

Chapter 2 describes and summarizes the literature with respect to the soil erosion process, erosion controlling factors, soil erosion modeling and finally gives an introduction to the scale problem.

Chapter 3 briefly describes the study area.

Chapter 4 is devoted to explain the used materials and applied methods in analyzing the data to achieve the research objectives.

In chapter 5 the results obtained from chapter 4 were discussed regarding the research objectives and research questions.

Finally, chapter 6 presents the conclusions of the research, developed in the thesis and some recommendation and possibility for future studies.

2 LITERATURE REVIEW

2.1 Soil Erosion

Soil erosion is the process of detachment and movement of soil particles, caused by either wind or water or both of them (Morgan, 1995). Various factors cause soil erosion; these can be grouped into natural factors such as climate and anthropogenic factors such as improper land management and deforestation activities.

2.1.1 Controlling factors of soil erosion by water

CLIMATE

Rainfall intensity is very important when considering the climatic factor, which affects soil erosion, but the rainfall amount, frequency as well as raindrop size are other factors that can significantly influence the soil erosion (Lal, 1994). The kinetic energy of rain drops and runoff can detach soil particles, which is moved down the slope by runoff. The effect of rainfall has on erosion varies according to different parameter which includes soil type, slope steepness and vegetation type. When Rainfall water which is not absorbed into the soil accumulate to creates the surface runoff .The runoff is also increased with the level of soil compaction which reduces infiltration

SOIL

Soil erodibility is a function of various soil properties which include the soil particle size distribution, organic matter content, aggregate stability, soil structure, bulk density, top soil shear strength, crust thickness, penetration resistance, and infiltration capacity (Lal, 1994). The particle size is an important factor; clay sized particles can't be detached as easily as sand but they can be easily transported, while sand particles are vice versa. Very fine sand and silt sized particles are most susceptible to erosion, whereas clay or sand-sized particles are more resistance to erosion. (Lal, 1994; Morgan, 1995).

TOPOGRAPHY

Another important factor in soil erosion is slope. Slope steepness and length have an effect on amount of soil loss by water. By increasing the slope steepness, the velocity of runoff increases which in turn increases the kinetic energy of the flow. In the same way by increasing the slope length, the volume of overland flow increases. Steep slopes having short slope length might cause less erosion than a slope with long slope length which has more length to gather run off velocity (Morgan, 1995; Wischmeier and Smith 1978).

VEGETATION COVER

Vegetation cover is an important protective factor against soil erosion. It reduces the runoff velocity by reducing soil detachment and transport capacity of run off significantly. It can be divided into two categories; above ground cover (Canopy Cover) and ground cover. The above ground cover minimizes the impact of raindrop on the soil surface, and the ground cover reduces the energy of the runoff. In addition, the roots of the plants add to the mechanical strength of the soil and also infiltration rate (Morgan, 2005).

2.1.2 Erosion Assessment Models

Different erosion models try to represent the underlying principles and process of soil erosion but no model can describe the complexity of the erosion process like reality. These models try to take into account the essential factors relating to the soil erosion according to obtained field observation, measurement, experiment, and finally the statistical analysis (Morgan, 1995). With increasing computation power of computers, many erosion models have been developed, and still new developments are in progress, as it is not possible to apply a model, which is developed under a certain condition and specific scale, for other locations and scales, without modifications or changes (Jetten, et al. 1999, 2003).

There are many different erosion models with different grade of simplification, from very simple to very complex, but they can be categorized into three main groups: empirical, conceptual and physically based models (Lal, 1994). Among all three model types, empirical models are the simplest one and their computational and data requirements are usually less than the other two model types. Empirical models are mainly based on the statistical analysis of experiments and observations, and trying to characterize a response from these data (Wheater, et al., 1993). Conceptual models lie between physically based and empirical models; they include a general description of catchment processes, without considering process interaction details, which need detailed information about catchment (Bowles and O'Connell 1991). Physically based models are based on the solution of fundamental physical equations that describe the erosion process, tending to represent the essential mechanisms of erosion such as the equations of conservation of mass and momentum for flow and the equations of conservation of mass for sediment (Bennett, 1974). The most important character of the physically based models is their ability to represent a synthesis of the individual erosion components, including the complex interactions, which occur between various components and their spatial and temporal variations (Lal, 1994).

The differences of these models are relating to complexity, considered processes, and the required data. There is no best model that can be used everywhere, however with regard to; data requirements of the model, the accuracy and validity of the model, model capabilities, the objectives of the user(s), and hardware requirements for the model, the most appropriate model could be selected (Merritt, et al., 2003). Input data is one of the most important factors among them; the main reason that the more complex physically based erosion models cannot predict better than lumped regression-based models is probably the input data (Jetten, et al., 2003).

2.2 Spatial resolution and Aggregation.

Spatial resolution is an important characteristic of the satellite imagery data is the smallest object that can be identified on the ground.

Satellite imagery data can be used in erosion assessment through visual interpretation of the erosion features that can be seen by the sensor. Several studies have used direct erosion detection techniques (e.g. Langran, 1983; Bocco, et al., 1991). Meanwhile, the erosion modeling can be affected by satellite images indirectly through derived attribute maps as controlling factors. One of the ways that spatial resolution of the satellite data can affect soil erosion assessment is the data used to derive a land use/cover map.

Atkinson and Curran (1995) obtained a relationship between the spatial resolution of satellite data and the precision of mean percentage of vegetation cover. It was proven by Mayaux and Lambin (1995) that the land cover maps gotten from satellite data in coarse resolutions like MODIS and AVHRR gives an underestimation of areas covered by forest where forest is more fragmented, and overestimation in the areas with less fragmentation.

Different works shows that the proportion of the classes after aggregation is affected by the spatial resolution, initial covered area by each land cover class, and the spatial variation within an area (Turner, et al., 1989; Moody and Woodcock 1994). The classes that are smaller with more inter-patch distances, are reduced while the classes with larger classes and more clustered, are increased.

Digital elevation models (DEMs) are common representation of the topography in a geographic information system. From DEM various topographical and hydrological features can be derived. Studies by (Chang and Tsai 1991; Florinsky, 1998) shows that the quality and resolution of the DEM has a considerable effect on the accuracy of generated topographic and hydrological features. Generally, coarser DEMs generalize the terrain and show only main relief features, it means in the coarser resolutions local slope and aspect results can be changed (Fahsi, 1989), which also results in low accurate slope maps (Chang and Tsai 1991). Reduction in the DEM resolution reduces slope gradient, especially in steep slope areas (Chang and Tsai 1991; Wolock and Price 1994; Thieken, et al., 1999). The slope distribution of the derived slope maps from coarser DEM resolutions is different from those in finer resolutions (Molnar and Julien 2000). By increasing the cell size, average slope, maximum slope, and standard deviation decrease (Molnar and Julien 2000). In fact, the maximum error occurs on steepest slopes while the minimum error takes place in the smoother areas (Bolstad and Stowe 1994).

Wilson and Gallant (2000) showed that due to spatial resolution micro topographic features, and steep slopes decrease, while the length of flow paths and in turn the size of catchment areas may increase. In the other word, as DEM became coarser, total flow lengths and drainage density (total channels length per area of watershed) decrease (Thieken, et al., 1999). By decreasing the spatial resolution, the peak discharge predicted in hydrological models increases (Zhang and Montgomery 1994; Thieken, et al., 1999), as a result runoff volume increases and time to reach at peak flow decreases (Thieken, et al., 1999). Wolock and Price (1994) reported that in a topographically based hydrologic model, by increasing the cell size the predicted ratio of overland flow to total flow and the maximum daily flow increases. In spite of the aforementioned works, Rojas, et al., (2008) observed that in greater cell sizes the portion of the infiltrated water increased, therefore the runoff volume and as a result discharge volume decreased. These changes substantially change the soil loss estimation.

3 STUDY AREA

3.1 Location

The study area is located in central Java, Indonesia (Figure 1). The area lies between the latitude of 7° 10’ 13” S to 7° 23’ 29” S and longitude 109° 40’ 36” E to109° 50’ 06”E. Marewu catchment is one of the major catchment of the Serayu basin. It covers an area of 236Km^2.

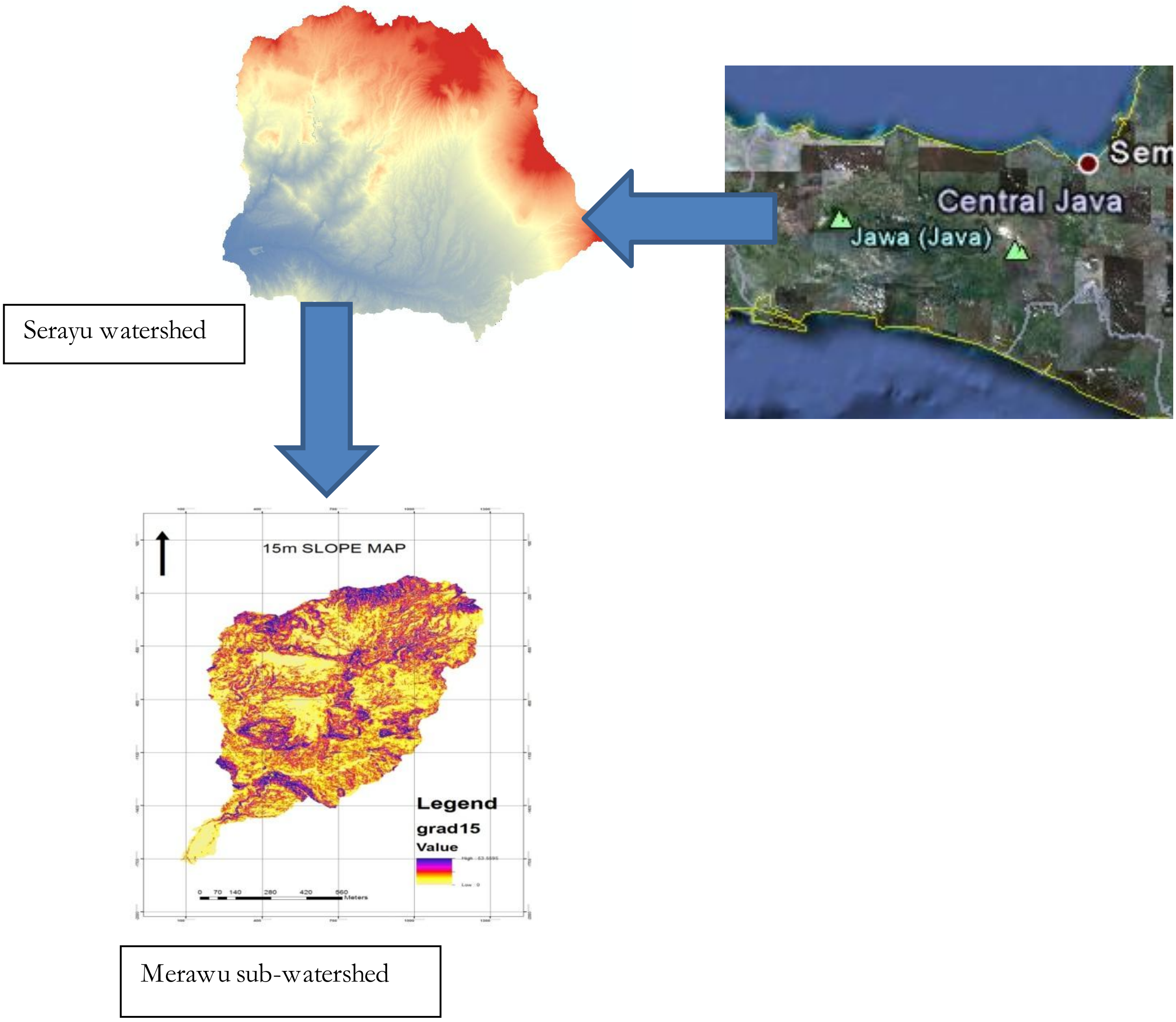

Figure 1. Location of study area serayu, Indonesia

3.2 Climate

The overall climate in Indonesia is of a tropical humid type. However the study area, Merawu catchment is located in a mountainous area. Therefore the rainfall and the temperature of the study area related to the elevation of the area. The area is a high rainfall area, however the annual average rainfall is about 2770mm and a maximum and minimum is 1332-4453 mm/year with about 142days/year. Rainy season occurs during November to April, while dry season falls during May to October (figure 2). About 73% of mean annual rainfall falls in the rainy season. Mean temperature in the area is around 14 up to 27° C According to Koppen's Climate Classification system the climate type of the area is tropically moist in which all months have an average temperature of above 18° Celsius.

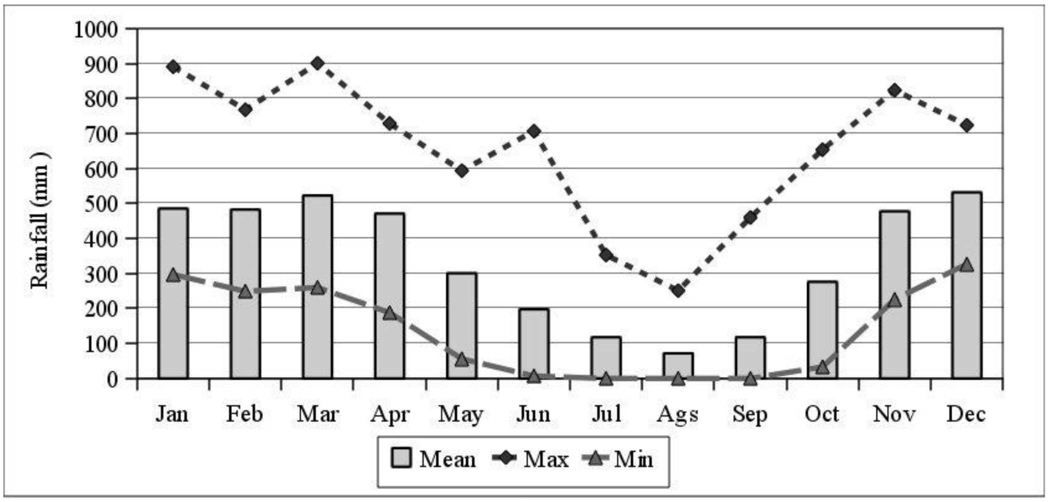

Figure 2. Monthly rainfall (source: Wonosobo rain gauge station)

3.3 Geology and Geomorphology

Merawu is one of the sub-watersheds within Mrica watershed, in the Serayu river. The study area is a mountainous area, ranging from 225 -2215 meter above sea level The geological map of the Serayu basin shows that the Merawu catchment is formed in breccia's which include mainly sand stones , conglomerates and fine to coarse grains of breccia's and also some tufts and lahar deposits. Volcanic materials are also well pronounced in the area. The major geomorphological units of the study area are low relief areas and stable slopes, moderate to high relief areas structural plateau, lava field, volcanic foot slopes. The low relief and stable slopes is located in the upper northeast part of the area and it extends to the west and to the south. It is mostly covered by cropland and mixed trees with agro-forestry with dense population. Likewise, the moderate to high relief area is located from the middle to the southwest part of the area and is mostly occupied cropland.

3.4 Soil

The prevailing soil types in the Mrica watershed are red-brown Latosols and Regosols (Suwartha et al., 2006). The major soil types in the area are Latosol, Andosol and Vertisol with coverage of 44.0%, 34.0% and 19.0% respectively. These major soils occupy almost 98% while the Alluvial, Litosol and Regosol altogether cover only 2%. The latosols are one of the major soil types in the area characterized by granular structure and physical properties of this soil is silty clay loam because of the high content of kaolin and iron oxide where kaoline groups make up >50% of the clay fraction together with iron oxide. The abundance of sesquioxides which consist of hydrated iron oxides leads to leaching of minerals in the soil and the rate of leaching is normally high and the soil nutrients are low. Another major soil type is the Andosols which are commonly found in volcanic areas. They are very porous, friable and crumb or granular structure. Aggregation stability of the soil is good and has high permeability, they relatively resistance to water erosion but where the area is deforested.

4.0 MATERIALS AND METHODOLOGY

4.1 Used data and Software

- Satellite imagery data: 8 bands of Landsat 7 ETM+ image obtained from USGS dated 15th April 2010 having band 1-5and 7 in 30m resolution and band 8 which is the panchromatic band in 15m.

- Daily rainfall volume records from meteorological station between 2009 and 2010 provided by my PhD supervisor.

- Soil Map generated by PhD supervisor from fieldwork and geomorphological map in 30m with scale with the scale of 1:150,000.

- 30m Contour map of the area with 10m interval gotten from PhD supervisor.

Used soft wares to accomplish this research are:

ENVI 4.7

ILWIS 3.6

ERDAS 9.3

ArcGIS 9.3.1

PcRaster

4.2 Method applied

To achieve the objectives of the study, the methodology of this research includes three main parts; Data preparation, erosion modeling and results analysis. Data preparation consists of different steps such as converting formats, geo-referencing, geo-coding, and creating satellite imagery data and DEMs in different resolutions. For erosion modeling, the revised Morgan-Morgan-Finney (RMMF) model was used. The RMMF was used due to its simplicity. By using input data with different spatial resolutions it is possible to assess the effect of spatial resolution on soil loss estimation. The study evaluated the effect of spatial resolution in three different resolutions, namely 15m, 30m, and 90m. The choice of these resolutions was made to simulate the effect of spatial resolution of commonly used resolutions; ASTER (15m), Landsat (30m), satellite images and SRTM (90m) Digital Elevation Model (DEM). The effect of spatial resolution of satellite imagery data on estimation of soil loss was simulated by aggregation of Landsat image (15m) to coarser resolutions (30m, 90m). However, the aggregation from Landsat image (15m) to coarser spatial resolution likely creates an image with much better characteristics than the originally coarser spatial resolution image (Townshend and Justice 1988). An over view of the methodology I applied in this research is shown in figure 3.

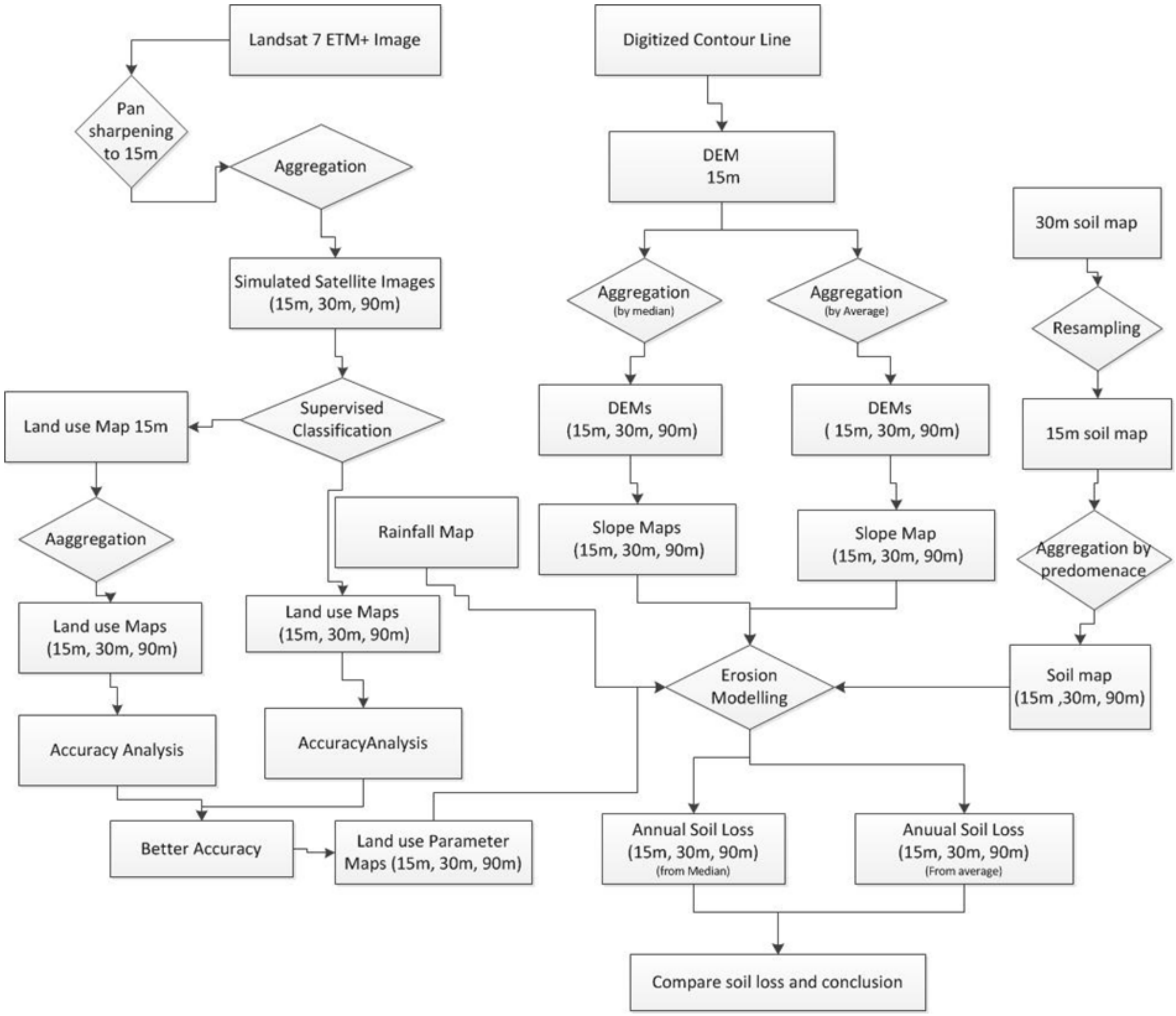

Figure 3. Flow chart of methodology

4.2.1 Data preparation

To obtain the land cover map and evaluate the effect of spatial resolution on land cover and consequently on erosion assessment, three land cover maps were produced in 15m, 30m and 90m. For classification, two methods were used and the one with the better accuracy of classification was used for this research.

Pan sharpening.

To be able to generate a 15m image for land cover classification , pan sharpening of the 6 bands (band 1-5,7) of the Landsat ETM was done in ENVI .The Landsat image was imported into ENVI as a GeoTiff file ,then the 6 bands were then image sharping operation was carries out using the color normalized option .Bands 4,2,1 were selected for the image display and for the high resolution input file the band 8 (panchromatic band) which has a resolution of 15m was selected . For the resampling method the nearest neighbor was used .After the pan sharping was carried out, the new pan sharpened RGB bands are gotten in 15m resolution giving a more detailed image to be used for the 15m land cover classification.

4.2.3 Supervised classification

Supervised classification with the Spectral Angle Mapper (SAM) algorithm was carried out using the pan sharpened bands for land use classification in ENVI 4.8 .The SAM algorithm was used first, it can be considered as a scale independent method, which avoids the problem of training points in the coarser resolutions. Second, Merawu sub-watershed is a mountainous area that is affected by illumination variation, while SAM algorithm is comparatively insensitive to this factor (Kruse, et al., 1993).

4.2.4 Spectral Angle Mapper (SAM) Algorithm

Spectral Angle Mapper (SAM) is a spectral classification that uses an n-D angle to specify the spectral similarity between two spectra; the unknown spectra and the reference spectra (end members or spectral libraries) (Kruse, et al., 1993; Boardman, 1992). Figure 4 illustrates the concept of the SAM algorithm in two-dimensional.

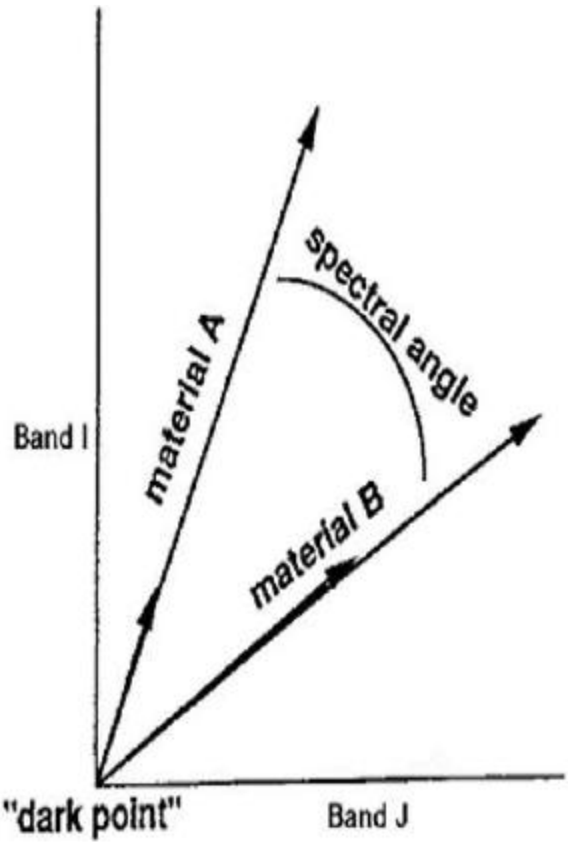

Figure 3. : Two-dimensional illustration on the concept of SAM algorithm (Margate and Shrestha, 2001)

The mathematical formulation of SAM calculates the angle between an unknown spectrum (t) from image and a reference spectrum (r) by treating them as vectors in a space with dimensionality equal to the number of bands (Kruse, et al., 1993; Boardman, 1992).

$$\Theta = \cos^{-1}\left[\frac{\sum_{i=1}^{n} t_i r_i}{\sqrt{\sum_{i=1}^{n} t_i^2 \sum_{i=1}^{n} r_i^2}}\right]$$

where:

Θ = Angle between a reference spectrum and an unknown spectrum in radiance.

t = Unknown spectrum

r = Reference spectrum

n = number of bands

A low angle represents more similarity between unknown spectra and reference spectra. Although, SAM algorithm assumes reflectance data as input, but by using radiance data that is the case in this study, the error is generally not significant (Kruse, et al., 1993).

In the study to classify the satellite imagery data two steps were implemented; collecting the end members from pan sharpened 6 band 30m Landsat image, and creating the spectral signatures for each land cover type to apply them as spectral library in the coarser resolution. The end members were selected through the regions of interest tool from existing land cover from the study area was used to train the Landsat data. These training points were categorized into seven land cover classes including forest, Plantation, dry cultivation, shrubs, paddy, settlement areas and water with a minimum of 30 pixels per each class.

The spectral values of the training points for each class in 6 bands were used to create their spectral signatures. The derived signatures from training points were saved as spectral library to classify the satellite images in coarser resolutions, thus the same training spectra were used for classifying satellite images in all resolutions. Figure 5 presents the derived signatures for different land cover classes.

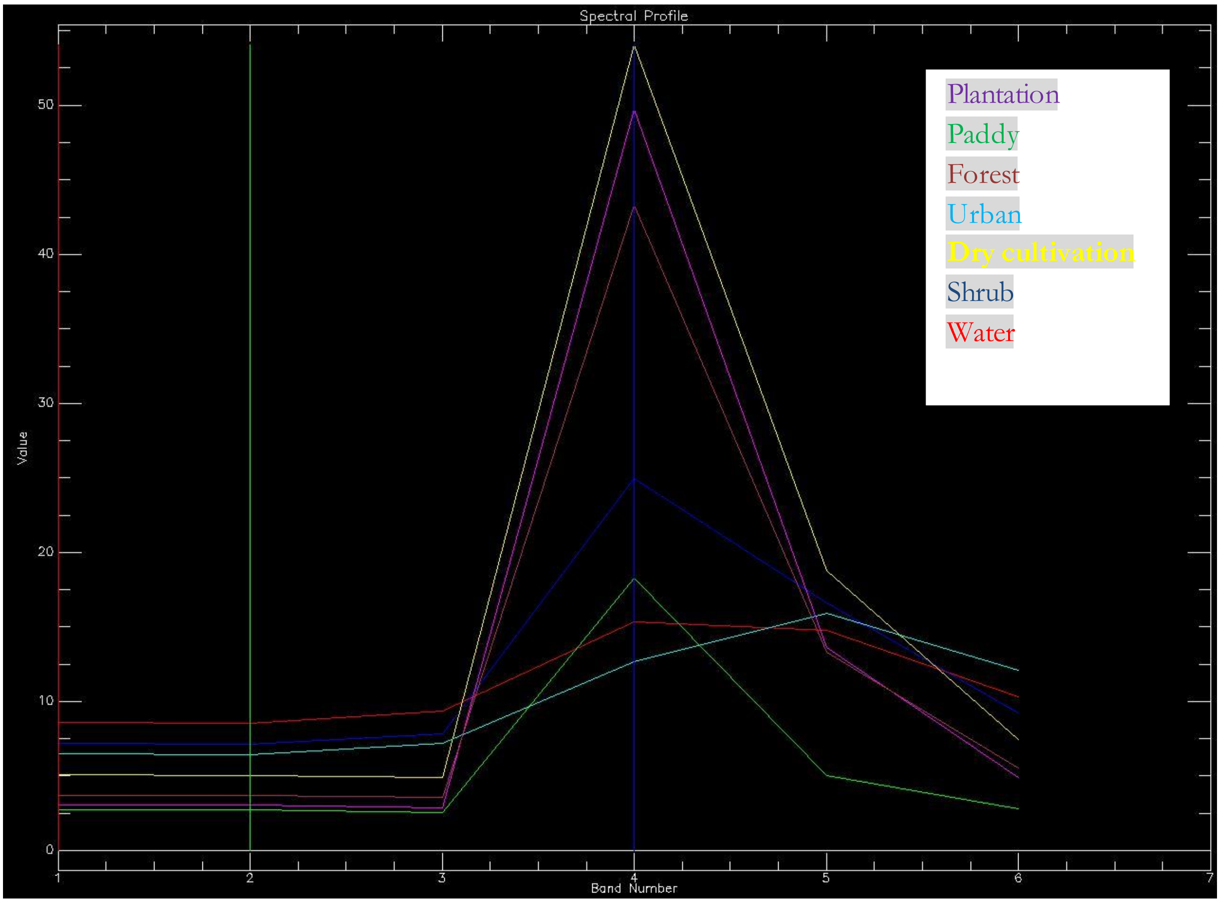

Figure 4. : Derived spectral signatures for land cover classes

4.3 Aggregation of land cover

Generation of land cover maps was done using two methods. First method was done by aggregating the generated pan sharpened image to course resolution in ENVI 4.3, giving three images of resolutions 15m, 30m and 90m. The images were then used to generate land cover maps using the SAM in supervised classification. Land cover map obtained from PhD supervisor was used to identify ground point for the 15m classification; while the generated 15m land cover map was used ground truth point for the courser resolutions .This gave three land cover maps from three different images.

The second method was carried out by first generating the land cover map from the pan sharpened image using SAM method of supervised classification. The generated land cover map is then exported to ILEWIS 3.3 where the 15m land cover map is then aggregated to 30m and 90m using aggregation by predominance.

4.4 Digital Elevation Data in different resolution

To investigate the effect of resolution on DEM. A 15m Dem was generated by interpolation of contour lines in Ilewis using the ordinary kriging which has the exponential as best fit virogram. The created 15m DEM is then aggregated to generate the 30m, 90m resolution DEMS .Two different aggregation methods were used, these are aggregation by average, this method gives the aggregated pixel the average value of all the pixels to aggregated .The second method used is aggregation using the median, this method of aggregation gives the output pixel the mid value of all the aggregated pixels. The aggregated DEMs were compared to 30m ASTER DEM downloaded by PhD supervisor and 90m STRM DEM gotten from USGS. Comparism of these DEM was done by analysis of profile cuts and slope distribution. The aggregation method that gives the closer representation of the original DEM is then considered the better of the two.

To compare the average and median aggregation methods, profile cuts were made on all the DEMs and compared with the profile cut of the original DEMs. Also the DEMs were made into slope maps to see the effect of aggregation on the slope and also to determine which method of aggregation conserves more details and pixel data. The slope maps were classified into five classes of slopes based on their slope degree, these are Class I (0-15 degrees), Class II (15.01-30 degrees), Class III (30.01-45 degrees), Class IV (45.01-60 degrees) and Class V (60.01-75 degrees).This classification is used to see the percentage cover of each slope class.

4.5 Erosion assessment.

The 30m soil map was converted to 15m, 30m and 90m to be used for the modeling at the different resolutions. The 30m soil map was first resampled to 15m using the nearest neighbor in Ilewis 3.3 after which it was aggregated to 30m and 90m by predominate factor in Ilewis 3.3. The generated soil maps of 15m, 30m and 90m were used for running the MMF for 15m, 30m and 90m respectively.

The revised RMMF model will be used in the estimation of soil erosion in all the resolutions and the results of the soil loss, discharge and sediment delivery ratio will be compared. The RMMF model separates soil erosion into two phases, the water phase which accounts for the energy available for rain to detach soil particles and also for runoff. And the sediment phase which accounts for sediment transportation and deposition. The model is also a simple empirical model that is easy to use and understand, and it has a stronger physical base than USLE. The model was calculated in using ILEWIS 3.6 and the flow accumulation was done in PCRaster. Input parameter for RMMF model for this research is described as follows (Table 1).

Table 1. . RMMF soil erosion model Parameters

Factor	Parameter	Remarks
Rainfall	R (Annual rainfall)	Using 3 rainfall stations data from 2009-2010
	Rn (Number of rain days per year)	
	I (Typical value for intensity of erosive rain (mm/hr)	Using literature value (25)
Soil	MS (Soil moisture content at field capacity (% w/w))	Using PhD supervisors data
	BD (Top soil bulk density (Mg/m^3))	
	K (Soil detachability index (g/J))	
	COH (Cohesion of the surface soil (kPa))	Using field measurement data
	EHD (Soil effective hydrological depth (m))	Using literature value based on land cover
Landform	S (Slope)	Derived from DEM
Land Cover	A (Proportion of the rainfall interception by vegetation)	Using value based on land cover
	Et/Eo	
	C (Crop management factor/C and P from USLE)	Literature review and field estimation of PhD supervisor
	CC (Percentage canopy cover)	
	GC (Percentage ground cover)	
	PH (Plant height (m))	

<u>Water phase</u>

Estimation of rainfall energy

To get the effective rainfall we use

$$ER=RA \quad \text{(eq1)}$$

Where

ER=Effective rainfall

R=total annual rainfall

A=rainfall interception

The effective rainfall is divide into direct through fall(DT) which is the rainfall that hits the soil directly without any interference and leaf drainage (LD) which is rainfall intercepted by plant cover before hitting the soil. Effective Rainfall is a function of annual rainfall and rainfall intercepted by canopy cover, i.e. the proportion of the rainfall that is not intercepted by canopy cover. Leaf drainage is obtained by using following equation:

$$LD=ER \times CC \quad \text{(eq2)}$$

Direct through fall is computed by subtracting leaf drainage from effective rainfall

$$DT=ER-LD \qquad \text{(eq3)}$$

Where

CC=canopy cover

The kinetic energy of the direct through fall (KE (DT)) is a function of the rainfall intensity (I) an intensity of 25 was used as gotten from literature (Rustanto .A ,2010).

$$KE\ (DT) = DT\ (11.9+8.7\log I) \qquad \text{(eq4)}$$

The kinetic energy of the leaf drainage (KE (LD) in j/m^2 is a function of the plant height (PH) in m

The kinetic energy increase as plant height increases

$$KE\ (LD) = LD\ (15.8xPH0.5)-5.87 \qquad \text{(eq5)}$$

When this equation is negative, the LD is assumed to be zero

The total kinetic energy (KE) of the effective rainfall (ER) is the sum of the two kinetic energies

$$KE=KE\ (DT) +KE\ (LD) \qquad \text{(eq6)}$$

Estimation of runoff

The volume of annual runoff is a function of soil properties and the mean rainy days. Soil properties is introduced in equation as soil moisture capacity which is in turn calculated by equation including bulk density, effective hydrological depth, ratio of actual to potential evapotranspiration and soil moisture content at field capacity.

The estimation of runoff (Q) in mm is based on the assumption that daily rainfall exceeds the soil storage capacity.

$$Q=ER\exp\ (-Rc/Ro) \qquad \text{(eq7)}$$

Where

Q=annual runoff in mm

Ro =the mean rain per rainy days in mm(R/Rn, where Rn is number of rain days per year).

$$Rc = 1000MS \times BD \times EHD\ (Et/Eo) \qquad \text{(eq8)}$$

Where

MS= soil moisture

BD= bulk density of soil

EHD=effective hydrological depth of the soil (m)

Et/Eo= ratio of actual evapotranspiration to potential evapotranspiration.

According to the meteorological stations records, the number of rainy days in a year was 136 rainy days in the year 2009.

The sediment phase

Soil particle detachment by raindrop

This will be calculated using the formula

$$F = K \times KE \times 10^{-3} \qquad \text{(eq9)}$$

Where

F= detachment by raindrop (Kg/m^2) and K = the erodibility of the soil in g/J.

Soil detachment by runoff

To calculate the soil detachment (H), the runoff (Q), the resistance of the soil (Z) and the slope steepness (S) are considered. The run off used was obtained for the flow accumulation of the LLD in PCRaster.

The soil particle detachment by runoff (H) in kg/m^2 is estimated for

$$H = ZQ1.5 \sin S\ (1-GC) \times 10^{-1} \qquad \text{(eq10)}$$

Where

GC= the percentage ground cover

There is the assumption that detachment by runoff will only occur if the soil is not protected by ground cover.

For Z which is the soil resistance

Z=1/ (0.5COH) where COH is the cohesive force of the soil surface measured in kPa.

Transport capacity of runoff

The crop and plant cover factors are taken into consideration just like in the USLE model in calculating the transport capacity of runoff. (TC).The run off used was obtained for the flow accumulation of the LLD in PCRaster.

$$TC = CQ2\sin S \times 10^{-3} \qquad \text{(eq11)}$$

Where C= is the Crop cover factor and S= the slope angle

Estimation of erosion

To estimate the soil erosion, the total detachment in add together that is F+H and the result is compared to the value of the transport capacity of the runoff.

$$E = MIN\,[(F + H)\ TC] \qquad \text{(eq 12)}$$

Where:

E = annual soil loss rate (kg/m^2)

The lowest value of the two gives the erosion estimate. The soil loss was classified in to four classes which are; soil loss of 0 to 500 tons/year (Low), 500 to 1000 tons/year (Moderate), and 1000 to 1500 tons/year (High) and above 1500 tons/year (very high).

All these procedure are summarized in Figure3.

Sediment delivery ratio (SDR)

The total loss measured is often higher than the gross soil loss, To correct the sediment yield for the reduction effect the soil delivery ratio (SDR) is used .Soil delivery ratio is the fraction of the gross transported erosion at a particular time at a given time interval, it is also a measure of efficiency of sediment transport which gives the actual amount of sediment transported from the source of erosion to the total soil detached in the same area (Zhou, 2008). It is gotten from the formula

$$SDR=Y/E \qquad \text{(eq13)}$$

Where

Y= the average annual sediment yield per unit area

E=the average annual erosion over the same area.

The average annual sediment yield is calculated using equation

$$Y = \frac{Q}{P} \cdot A \qquad \text{(eq14)}$$

Where: Y = Annual Soil loss delivered to the reservoir

A = Total amount of soil loss in the catchment

Q = Total annual discharge in the catchment

P = Total annual rainfall in the catchment

4.6 Flow accumulation incorporation.

The revised Morgan- Morgan –Finney model was might to predict soil loss at field level. To be able to apply the model at a catchment level, it is suggested but Morgan (2001) to subdivide the catchment into hill slope elements that are reasonably homogeneous in their slope, soil and land cover.

The procedure suggested by Morgan operates as follows: the total runoff on an element is the summation of the runoff generated on the element and that received from the elements immediately upslope .The accumulated runoff is now used in determining the transport capacity on the element. Materials upslope can be directed down slope in the same way. This makes flow accumulation important when applying the Morgan- Morgan – Finney model at a catchment level.

To be able to accumulate the flow of runoff from each cell in the upper catchment the use of "accuflux" operation in PCRaster is used. Since the accumulation of materials in PCRaster is dependent on flow direction, the digital elevation model is very important. Figure 6 shows how flow is accumulated from the higher pixels to the lower once.

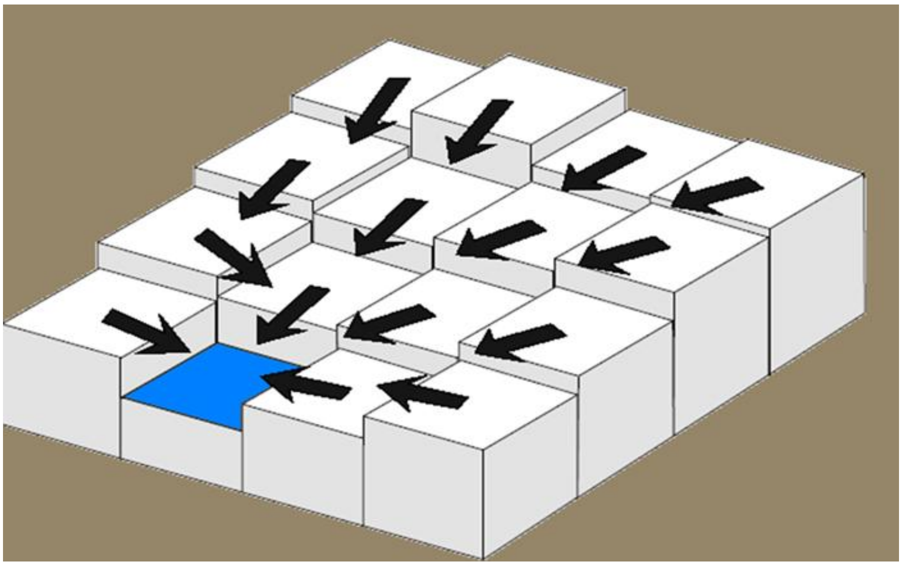

Figure 5. Accumulation diagram show accumulation of flow between pixels.

An overview of the methods used in the erosion modelling is shown in figure 7.

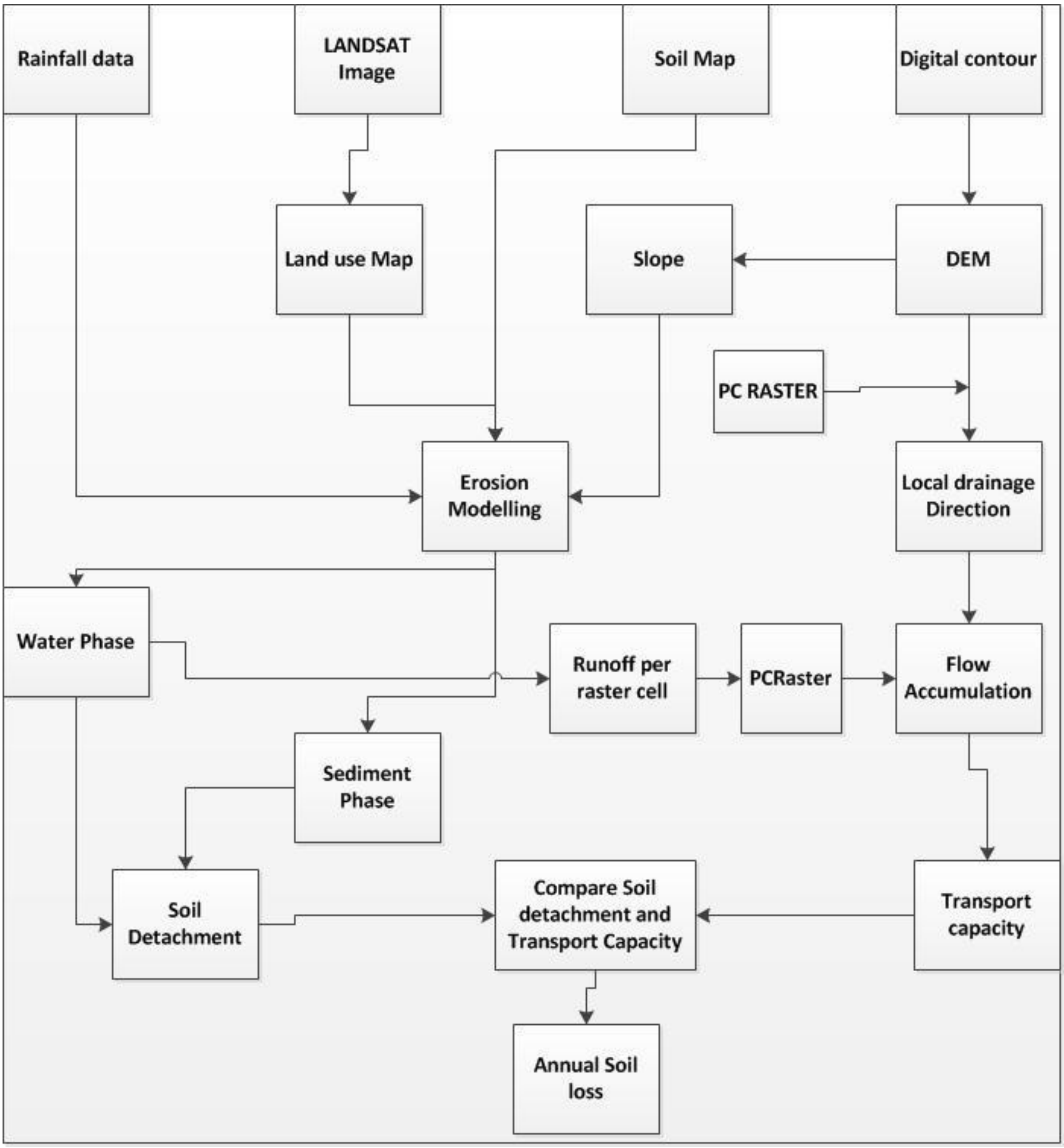

Figure 6. FLOW CHART OF EROSION MODELLING

4.7 Statistical analysis

This section briefly describes confusion matrix, overall accuracy, kappa coefficient, producer accuracy is used to determine the method of land cover acquisition to be used for the remaining part of the research.

ERROR MATRIX

Error matrix also known as confusion matrix is a widespread method for assessing the classification accuracy the error matrix is calculated by comparing of the classification map with the ground truth map or sample field results. From an error matrix different statistical analysis such as; overall accuracy, user and producer's accuracy, kappa coefficient and a lot more can be derived. The main diagonal of the matrix shows the number of pixels which has been correctly classified. This matrix is for not only accuracy assessing of classification maps, but also through it all types of maps like erosion map, or slope map can be evaluated. The overall accuracy, kappa coefficient, and user and producer's accuracy are described in next subsections.

OVERALL ACCURACY AND KAPPA COEFFICIENT

By summing the main diagonal of the matrix (correctly classified pixels) and dividing by the total number of pixels, the overall accuracy is achieved

In contrast to the overall accuracy, kappa coefficient is a measure, which considers also non-diagonal elements (Rosenfield and Fitzpatrick 1986). The Kappa coefficient measures the conformity of classification after removing the chance agreements. Kappa is between one and minus one. A kappa of zero means the classification map has an agreement equal to chance (Fenstermaker, 1991)

PRODUCER ACCURACY

Two approaches for assessing the accuracy of individual classes are producer and user's accuracy. Producer's accuracy indicates the probability that a pixel in the class is correct classified; it reduces when number of pixels left out of the class increase. The user's accuracy shows the reliability of the map; it reduces when number of extra pixels in the class increases (Jensen, 1986).

5.0 RESULTS AND DISCUSSION

The fifth chapter of the thesis focuses on the analysis of the results and discussion.

This chapter is organized as follows. Section 5.1 cover land cover classification generated from predominance aggregation of 15m Land cover map's result and discussion, and section 5.2 shows Land cover classification generated from average-based aggregation satellite imagery data results and discussion. Section 5.3 shows the selection of aggregation method used for erosion Sections 5.4, 5.5, 5.6 and 5.7 are devoted to show the effect of DEM aggregation by average, Dem aggregation median on slope map and section 5.8 shows soil loss prediction along with the sediment delivery ratio.

5.1 Land cover Aggregation results and Discussion

The land cover maps were classified in seven classes; urban, paddy, water, dry cultivation, forest, shrubs and plantation. Figure 8 shows created land cover classification maps from predominance aggregation of the 15m land cover to 30m, and 90m resolution.

The spectral classification of the 15m image done by the spectral angular mapper, shows that the dry cultivation had the highest spectral signature in band 4, followed by plantation, forest, shrub, paddy, and water and urban respectively.

According to Figure 9 , land cover map in 15m resolution was covered by dry cultivation (35.4%), plantation (22.7%), shrub (14.7%), forest and paddy (11.4%), urban (2.7%) followed by water (2.3.%), and respectively. In 30m resolution, the area covered by different classes remains almost constant. In 90m resolution the area covered by dry cultivation increases to 43.1% from 35.4% , the increase is due to apart from having a high signature in band 4 the dry cultivation being the dominate class, so must of the other classes that are in small patches within or around the dry cultivation class is converted to it . Plantation decreased from 22.7% to 18.1%, this decrease is because although plantation also has a high signature in band 4, the class in mostly in patches around within the dry cultivation and thus the part of the plantation is converted to dry cultivation. This is also the case in forest which decreased, shrubs decreases to 14.3%, paddy increased to 12.8%, forest decreased to 7.8% from 11.4%. For , urban which decreased 2.7% to 1.9% and water which decreased to 1.8% from 2.3% , the decrease is due to the fact that they have a low spectral signature in band 4 and also they exist in patch and fragment in the area.

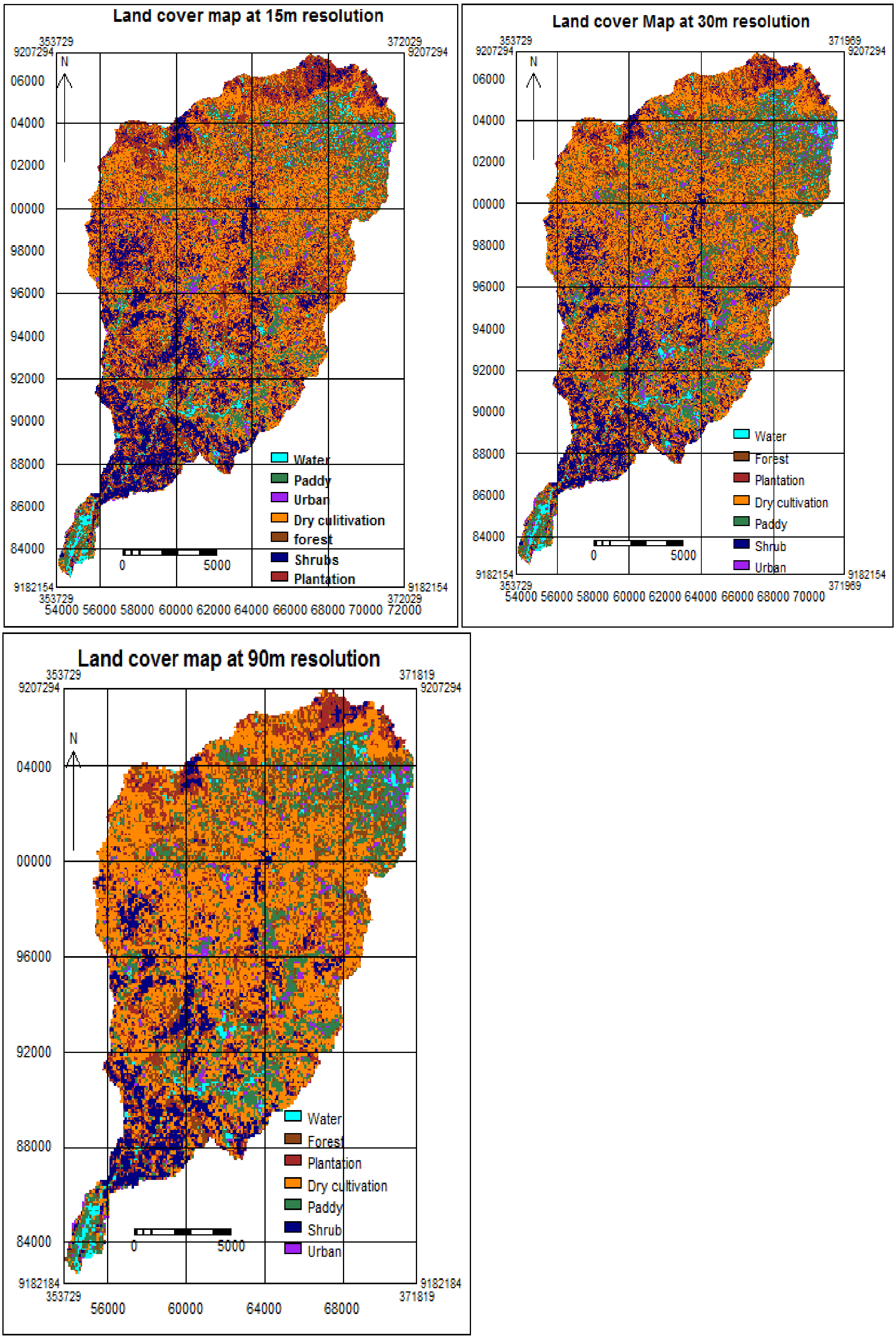

Figure 7. Maps showing land cover classification by land cover aggregation.

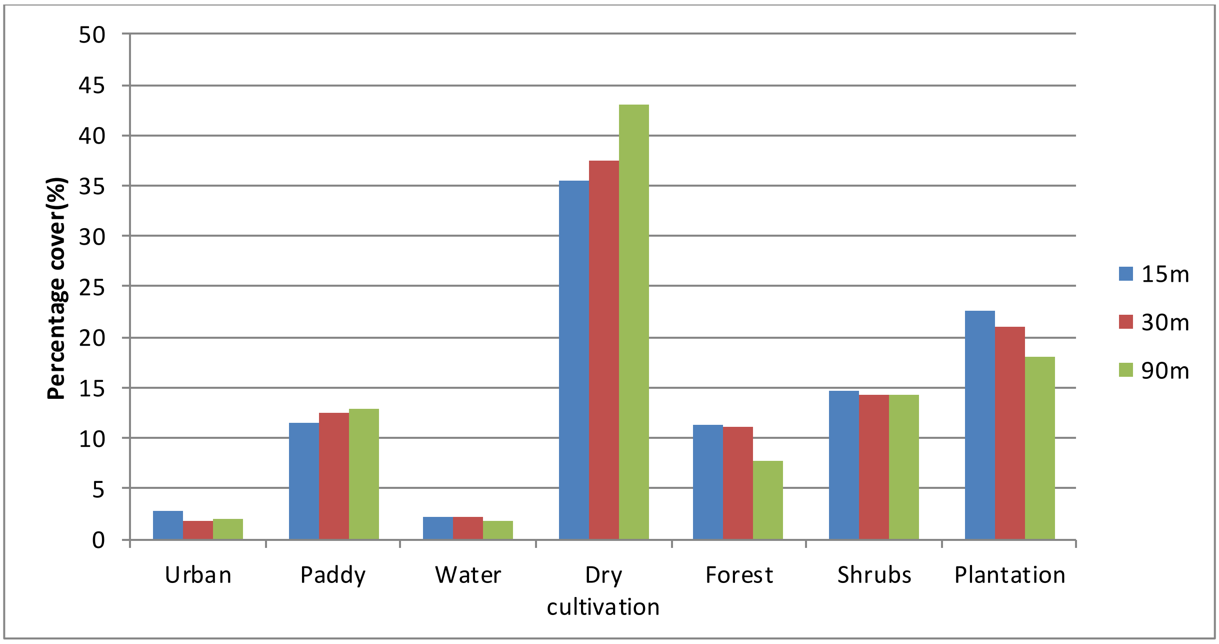

Figure 8. Distributions of land cover from land cover aggregation

It is seen in figure 9 and table 2 that the dry cultivation percentage cover increase above all over land cover after aggregation, the reason for this is the fact that other classes like plantain and forest which also have high spectral signature in band four are in small patches, for this reason they are converted to the dominate class when aggregating by dominate can be seen in figure 12 which shows other classes being converted to the dry cultivation.

Based on the collected ground truth data from previous fieldworks, the accuracy of land cover map in 15m resolution through confusion matrix was assessed (Table 3). Beside from overall accuracy, the kappa coefficients of the classification were also obtained. The overall accuracy of land cover map in 15m resolution was 67% and the kappa coefficient was 0.61 .The reduction in the kappa coefficient in due to the fact that the land cover area changes with aggregation so the leave of conformity to the reference map used for the kappa will be reduced.

Table 2. Distribution of land cover from land use aggregation.

Land cover	15m(%)	30m(%)	90m(%)
Urban	2.7	1.72	1.94
Paddy	11.56	12.41	12.81
water	2.23	2.18	1.88
Dry cultivation	35.40	37.45	43.11
Forest	11.36	11.02	7.83
Shrub	14.71	14.28	14.30
plantation	22.68	20.94	18.14

Table 3 . Confession matrix of land covers classification, with test sample on vertical axis.

Class	Urban	Paddy	Water	Dry cultivation	Forest	Shrub	Plantation	Total	Class accuracy (%)
Urban	**84**	0	22	0	29	0	0	135	37.3
Paddy	10	**63**	43	0	5	0	0	121	80.16
Water	18	28	**121**	0	0	0	0	167	29.63
Dry cultivation	0	18	1	**108**	15	2	6	150	24.67
Forest	10	5	2	0	**133**	0	0	150	72.35
Shrub	0	0	0	0	0	**93**	15	108	55.56
Plantation	0	0	0	17	40	35	**51**	143	65.25
Total	122	144	189	125	222	130	72	**924**	**Overall accuracy= 67**

By assuming the created land cover map in 15m resolution as ground truth image, other classification results in coarser resolutions (30m and 90m) were assessed. The overall accuracy, kappa coefficient and producer's accuracy were computed to analyze the results. There was a downward trend in overall accuracy and kappa coefficient in coarser resolutions (figure 10). The downward trend in the overall accuracy and kappa is due to the aggregation of land cover which changes the cover area of each land cover as the resolution gets courser, the image conformity to the reference image reduces as the resolution gets course. The overall accuracy of the maps reduced from almost 67% in 15m resolution to 58% in 90m resolution; accordingly, the Kappa coefficient decreased from 0.61 in 30m resolution to 0.51 in 90m resolution. And also it is seen that the producer's accuracy also reduces as the resolution becomes courser (figure 11).

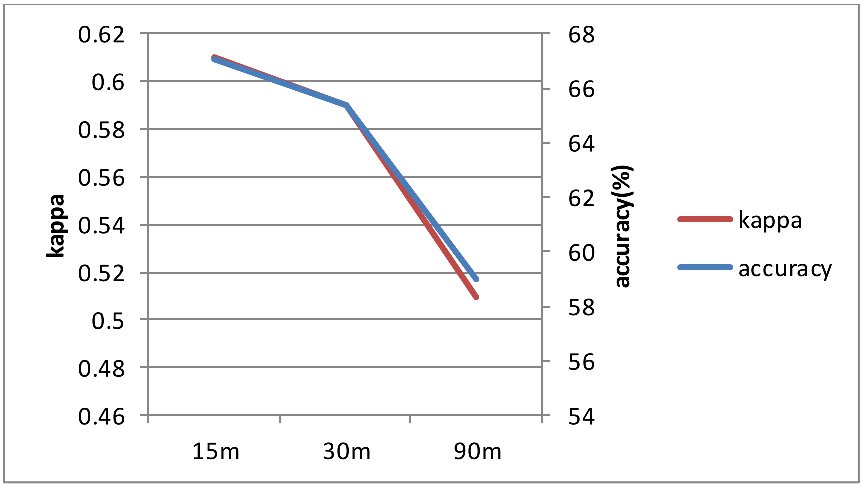

Figure 9. Graph showing kappa and accuracy of classification.

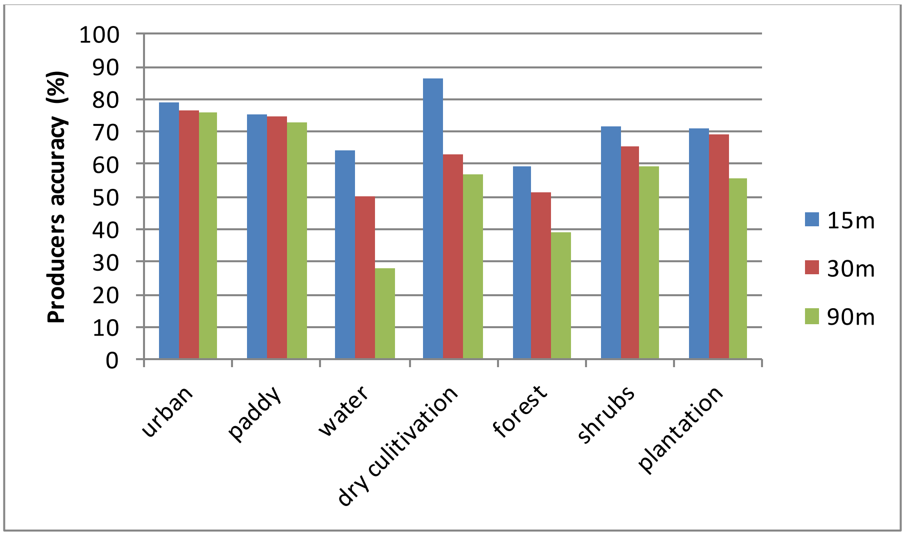

Figure 10. Chart showing producer's accuracy of land use maps

It clearly seen in figure 9 and figure 12 considerable increase of dry cultivation area by decreasing the resolution .High conversion of other classes to dry cultivation was because of its dominancy in the study area. Fragmentation and patch size of land cover classes are the only factors that affect the result of majority-based aggregation; it can aggravate the effect of dominant class in aggregation. In areas with low fragmentation of land cover classes, aggregation has slight effect, conversely in areas with high fragmentation and small patch size of land cover classes, aggregation can cause significant changes. In the study area, forest and especially water and paddy were fragmented a lot, therefore by aggregating to coarser resolutions they converted increasingly to the other classes.

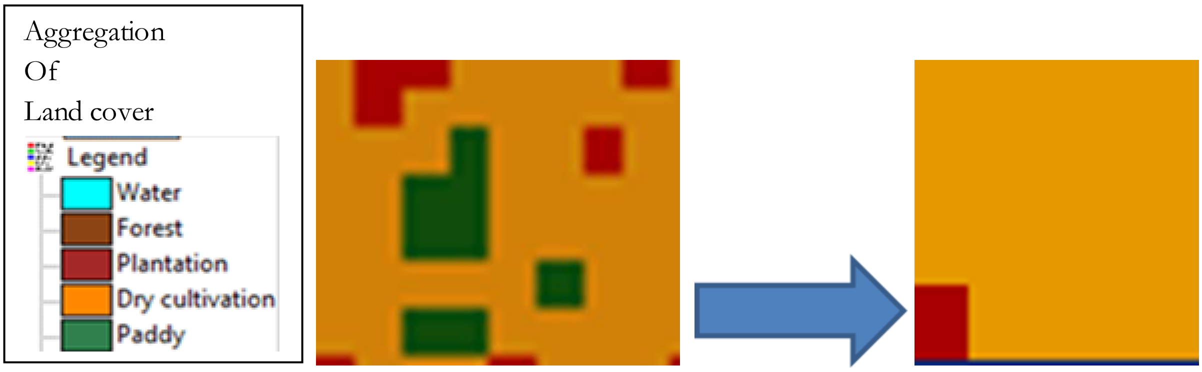

Figure 11 . Conversion of land covers during after aggregation.

5.2 Land cover classification at different spatial resolutions

Land cover classification of the multi-spectral data in 3 spatial resolutions (15m, 30m and 90m) was carried out using SAM classifier (figure13). Individual aggregated satellite image for land cover was done in ENVI and the accuracy assessment was computed using the 15m land cover as ground true image for the 30m and the 90m images. As shown in table3 , Land cover map in 15m resolution was covered by dry cultivation (35.4%), plantation (22.7) shrub (14.7%), forest and paddy (11.4%), urban (2.7%) followed by water (2.3. %), and respectively. In 30m resolution the area covered by dry cultivation reduced to 31% from 35.4%, plantation increased from 22.7% to 34%, shrubs increased from 14.7% to 24%, paddy decreased from 11.4 to 1%, forest decreased from 11.4% to 10%, urban reduce from 2.7% to 2% and reduced water from 2.3% to 1%. In 90m resolution the area covered by dry cultivation increases to 36% from 31%, plantation increased to 35% from 34%, shrubs decreases to 18% from 24%,paddy decreased to 0% from 1%, forest decreased to 7% from 10%, urban to 3% from 2%and water to 0% from 1%.

Table 4 Distribution of land cover in percentage for 15m ,30m and 90m images

Land cover	15m(%)	30m(%)	90m(%)
Dry cultivation	35.4	31	36
forest	11.4	10	7
plantation	22.7	34	35
paddy	11.4	1	0
shrubs	14.7	24	18
Urban	2.7	2	3
water	2.3	1	0

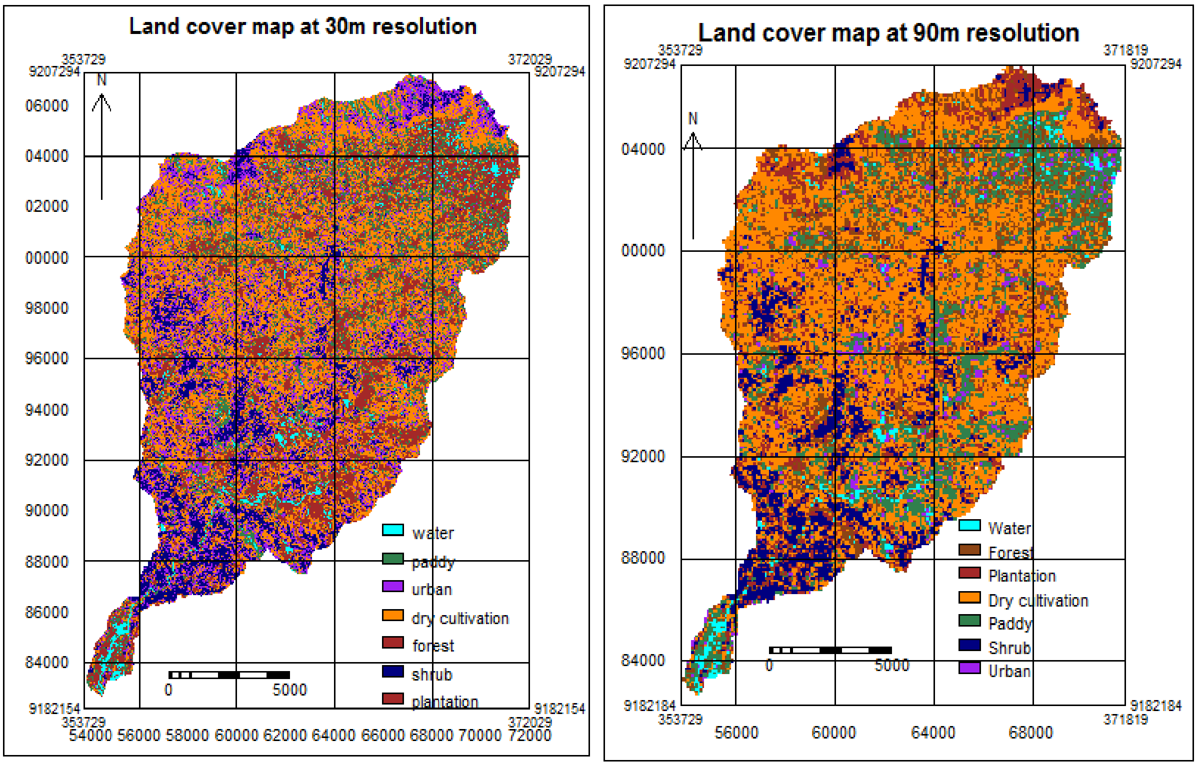

Figure 12. Maps showing land cover classification by aggregated image classification

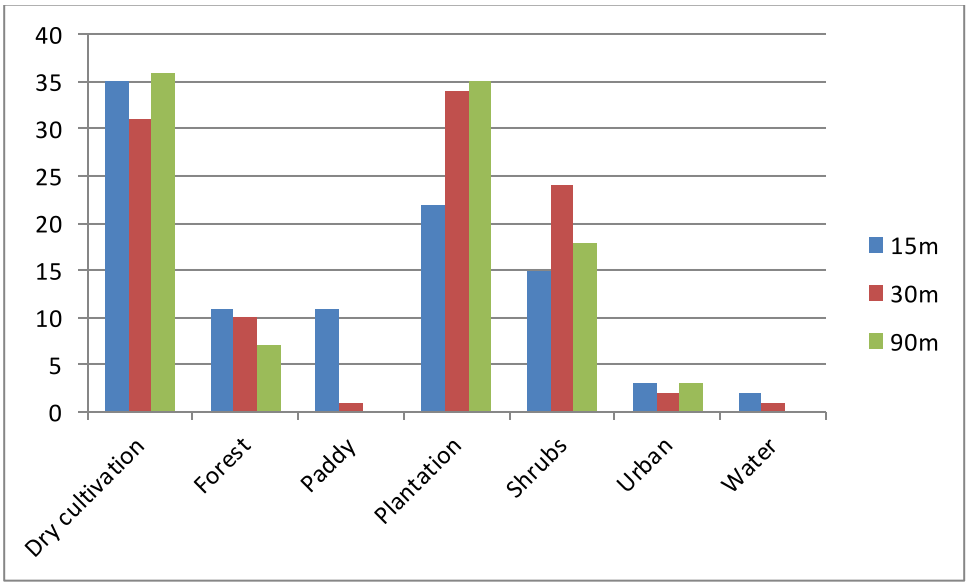

Figure 13. Chart showing land cover distribution of land cover map

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It is observed that the accuracy of the classification went from 67% in the 15m image to 25% in the 90m image which also had a negative kappa co-efficient. According to the obtained results, by increasing the grid size, covered area by urban ,water, plantation and forest decreased considerably conversely, covered area by significantly increased. The simulated satellite imagery data were affected by average-based aggregation in two forms; first, value of a pixel in coarser resolution was the average of all corresponding pixels in finer resolution. Therefore, mean value of a pixel in coarser resolution was likely close to the spectral value that frequently occurred. As about 36% of the whole watershed was covered with dry cultivation and 64% was covered with other cover classes, the averaging caused a very high conversion of other classes to dry cultivation in coarser resolutions. Figure 15 pictorially sums up the aforementioned discussions; obviously can be seen that in 90m resolution all classes were changed to dry cultivation. This conversion was occurred because dry cultivation was the dominant class in 15m resolution; therefore, average value of the pixel in 90m resolution was close to spectral value of dry cultivation. Secondly, it means the range of values in the entire map reduced and became closer to the average value. By aggregating pixels with very high or very low spectral values, consequently urban and water that had minimum spectral values disappeared and converted to the other classes.

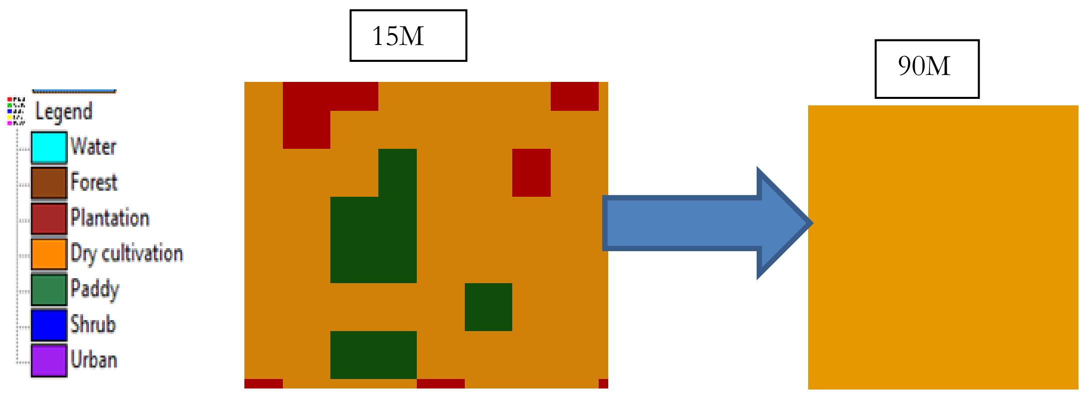


Figure 14. Aggregation of land cover

5.2 Selection of classification method to be used

The selection of the classification method to be used for further analysis in this research was selected according to the accuracy of classification. The accuracy of the aggregation of 15m to courser land cover and the land cover generation for individual aggregated satellite images were compared and the better of the two which was the aggregation of the 15m land cover map was chosen to be used. A section of the different land use maps was taken and zoomed to see the how the pixels are affected by the two methods of classification.

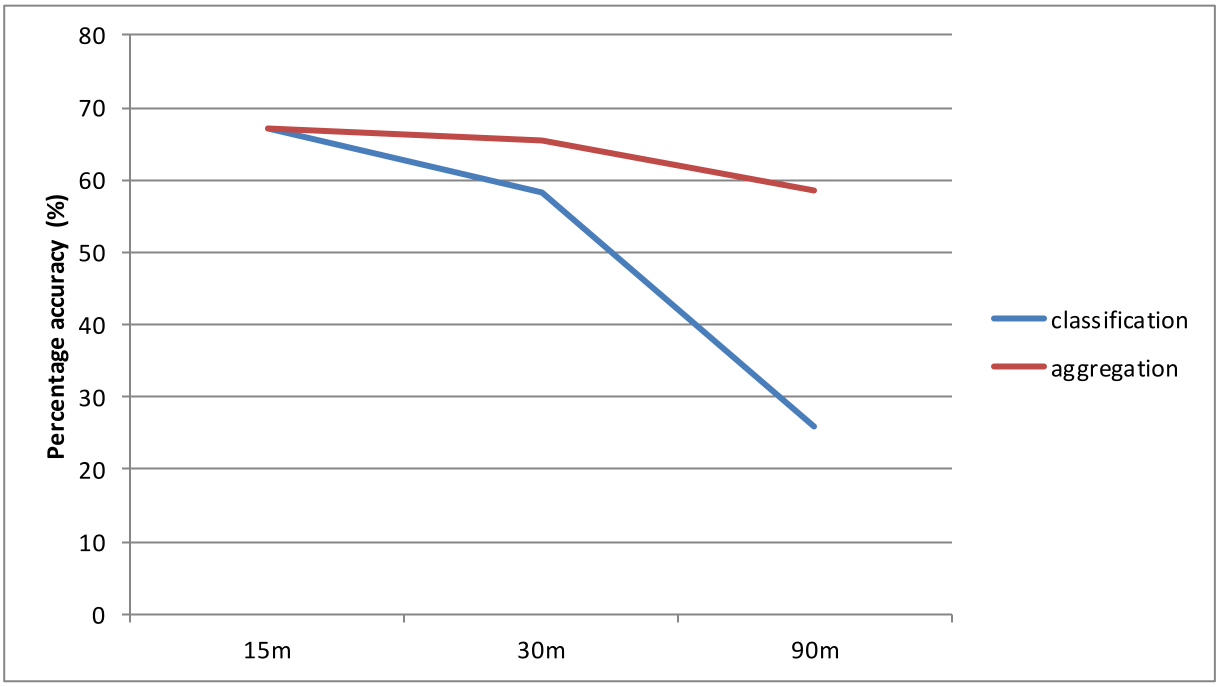


Figure 15. Graph showing comparism of accuracy of land cover classification by aggregation and satellite image classification

It is noticed that the aggregation of Land cover map gave higher accuracy result than the individual classification as shown in figure 16, although aggregation is expected to result in quality loss of an image. Aggregation of 15m Land cover map by pre dominance was used for this research since it gave a higher accuracy.

The high heterogeneity of land cover classes with small patch sizes caused an increase in covered area by Dry cultivation when the resolution is increased. This result is similar to that of Mayaux and Lambin (1995). Moody and Woodcock (1994, 1995). Similarly, Pax-Lenny and Woodcock (1997) revealed that in coarser resolutions Urban area, which are in smaller size patches cause lower accuracy in the land cover classification while dry cultivation in larger size patches cause higher accuracy in the classification maps. This is not the case with my research which show a lower accuracy in land classification even in the 30m and 90m land cover classification where the urban areas have being reduced.

5.3 Result of DEM aggregation using average

The 15m Dem obtained from contour interpolation was aggregated using by average pixel value to 30m and 90m. The effect was observed by making a profile cut of the various DEM resolutions. The average aggregation assigns a common value to pixels aggregated in the courser resolution .The result of the profile cut show that when pixels with high elevation values are aggregated together there is either an over exaggeration or under exaggeration of the actual elevation in the aggregated pixel of the course resolution .This is because if the pixels with high variations are aggregated together the average value usually gotten will not be a good representation of higher elevation if most of the pixels have low elevation, and also if most of the pixels have a high elevation the low elevations are smoothed out to represent the higher elevations .The profile cuts(figure 17) show this smoothening effect, it is observed that the slopes are aggregated to pixel values that make them even out when aggregated to courser resolutions .

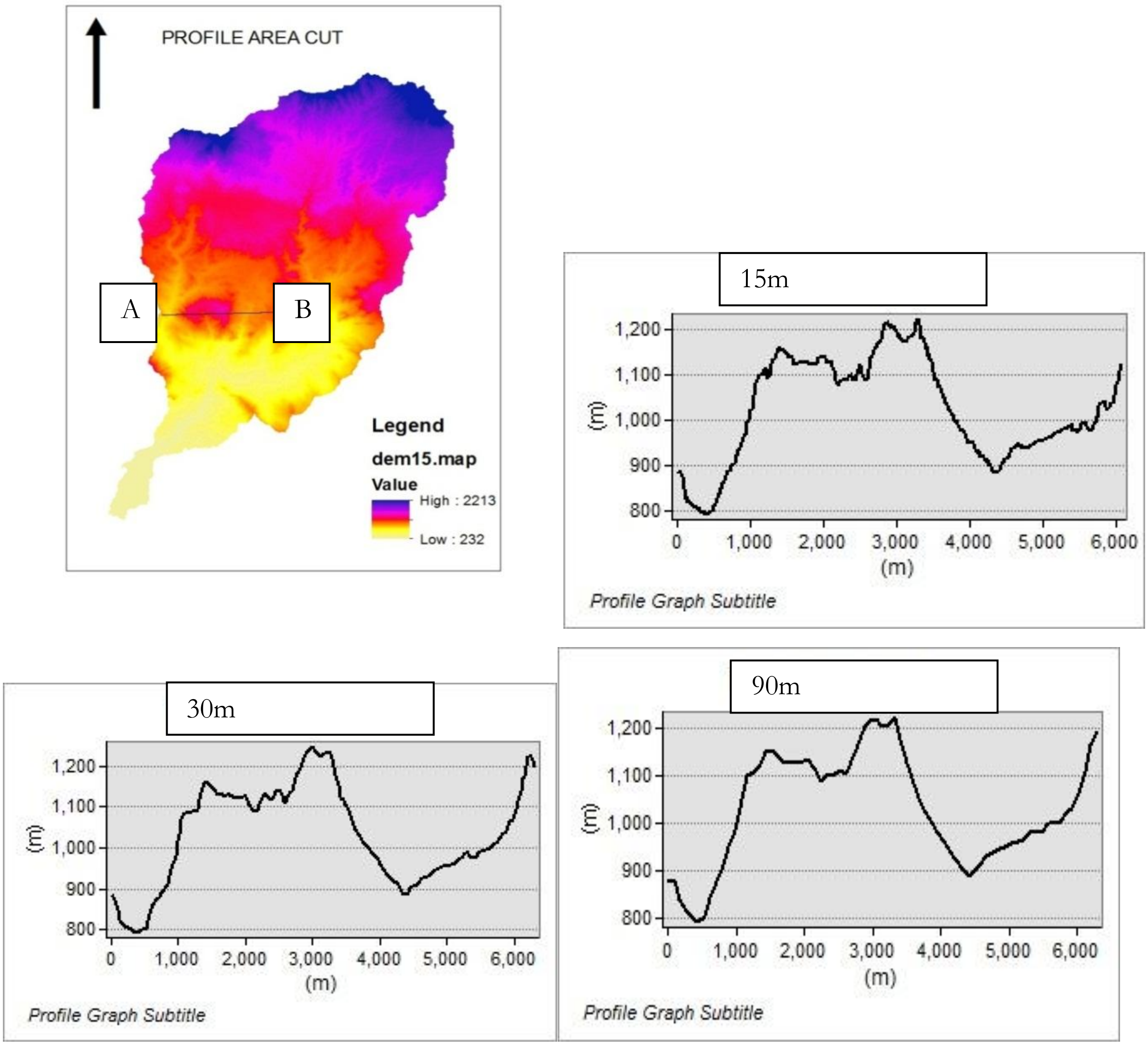


Figure 16. Profile cut and profile graphs of DEMs from average aggregation

Slope maps were generated at different spatial resolutions (15, 30 and 90m) for the DEMs and were compared. The same smoothening effect seen in the DEM comparism was also noticed in the slope profiles ,with the 15m slope profile having very high variation of slope which evens out as the resolution becomes courser in the 30m and 90m (figure18). This smoothing effect gives a higher potential for soil loss to occur as the slope gets evened out.

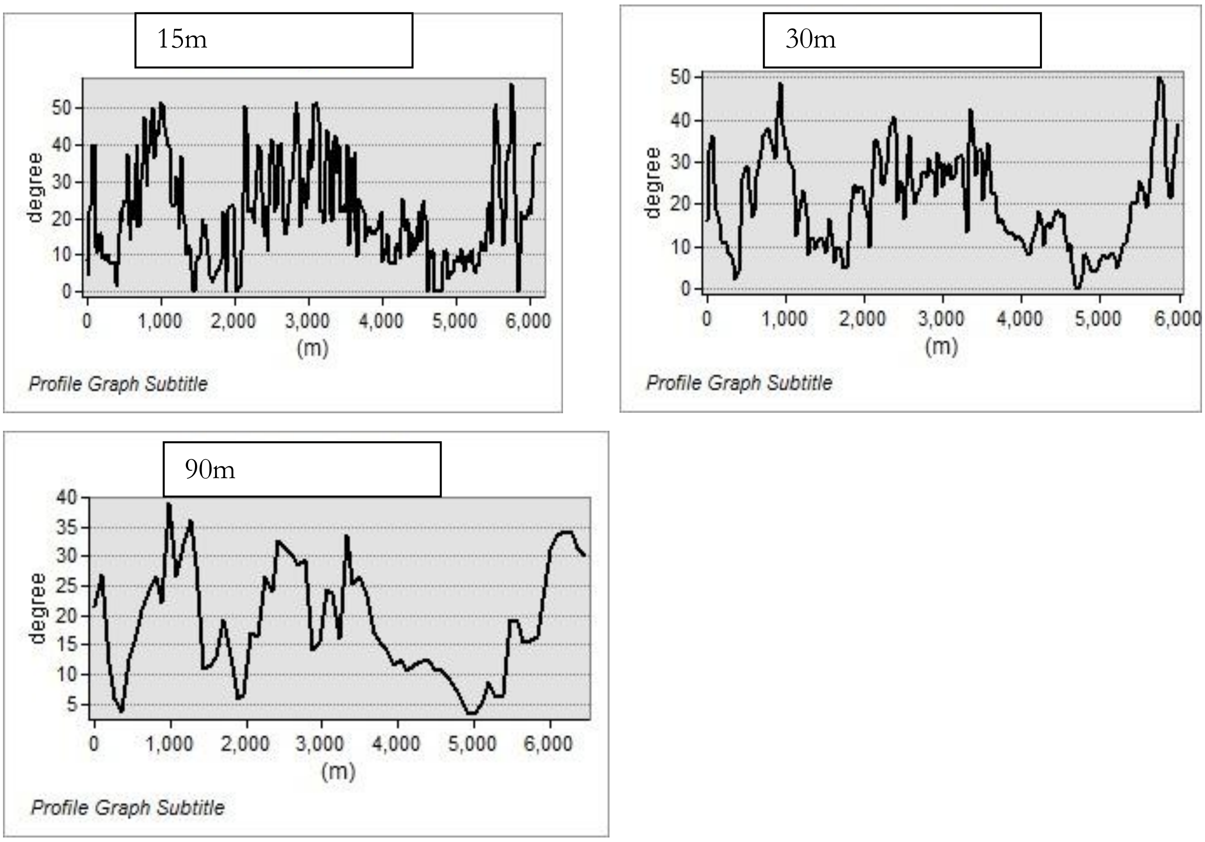


Figure 17. Profile graphs of slope maps from average aggregation

Using the aggregation of pixels by average for erosion modeling tends to increase the runoff as the image gets courser, with the 15m slope giving a runoff of 10138mm and the 90m giving a runoff of 12678mm.This is because the variation in elevation which reduces the volume of runoff and the runoff speed due to obstructions along the way has being reduced. At larger grid size (30m and 90m) there is also this smoothing effect of slopes which also gives runoff more slope length to run without obstruction thereby increasing the runoff velocity.

5.4 Result of DEM aggregation by median

Profile cross sections of the median aggregated DEMs were also analyzed to see the effect of pixel size difference. It is noticed that the same smoothening effect is seen in the average aggregation in also present in the median aggregation (figure19). The 30m pixel has variations in its profile which is smoothened out after aggregation to 90m. During the median aggregation the median value of the pixels that are aggregated to get is given to the courser pixels, thereby reducing the variation of the pixel value as shown in figure18, the profile of the 90m DEM as a more or less even slopes with little variations.

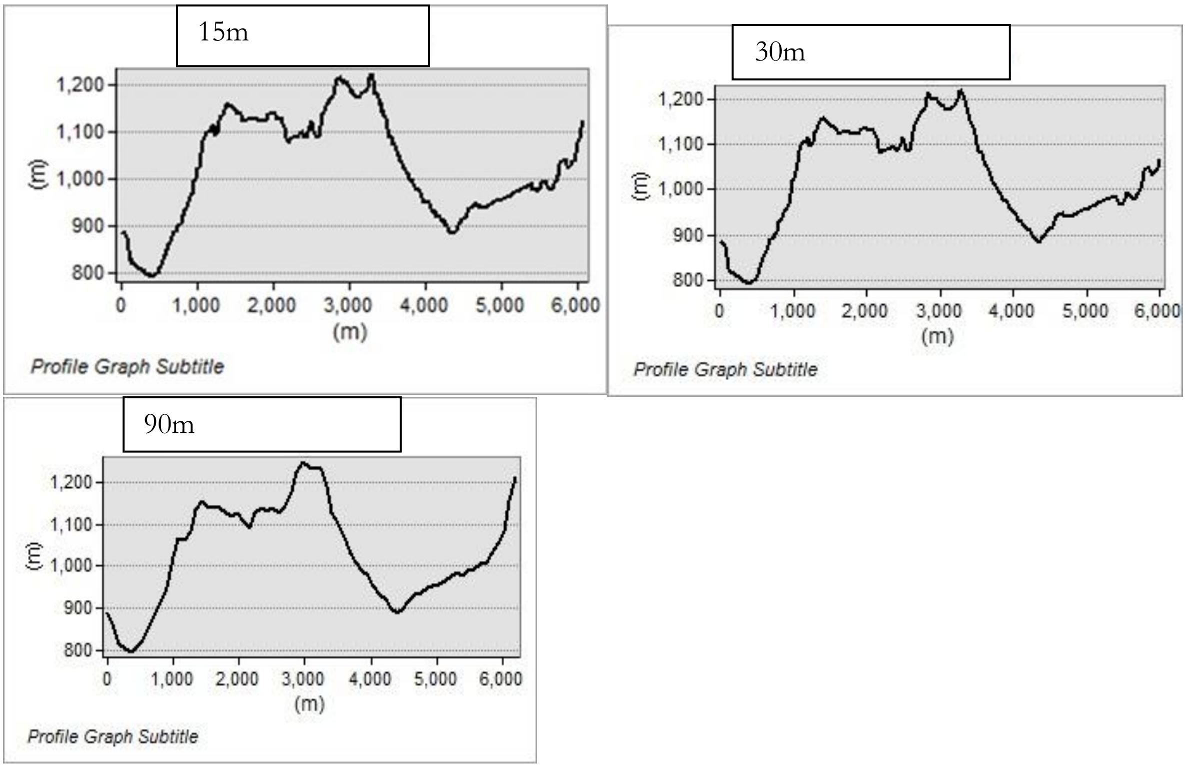


Figure 18. Profile graphs of DEMs from median aggregation

Figure 20 shows the profile of the slope maps generated for the 30m and 90m median aggregation. Here the same reduction in profile variation as seen in their respective DEMs is also observed with the 90m having a smoothened profile.

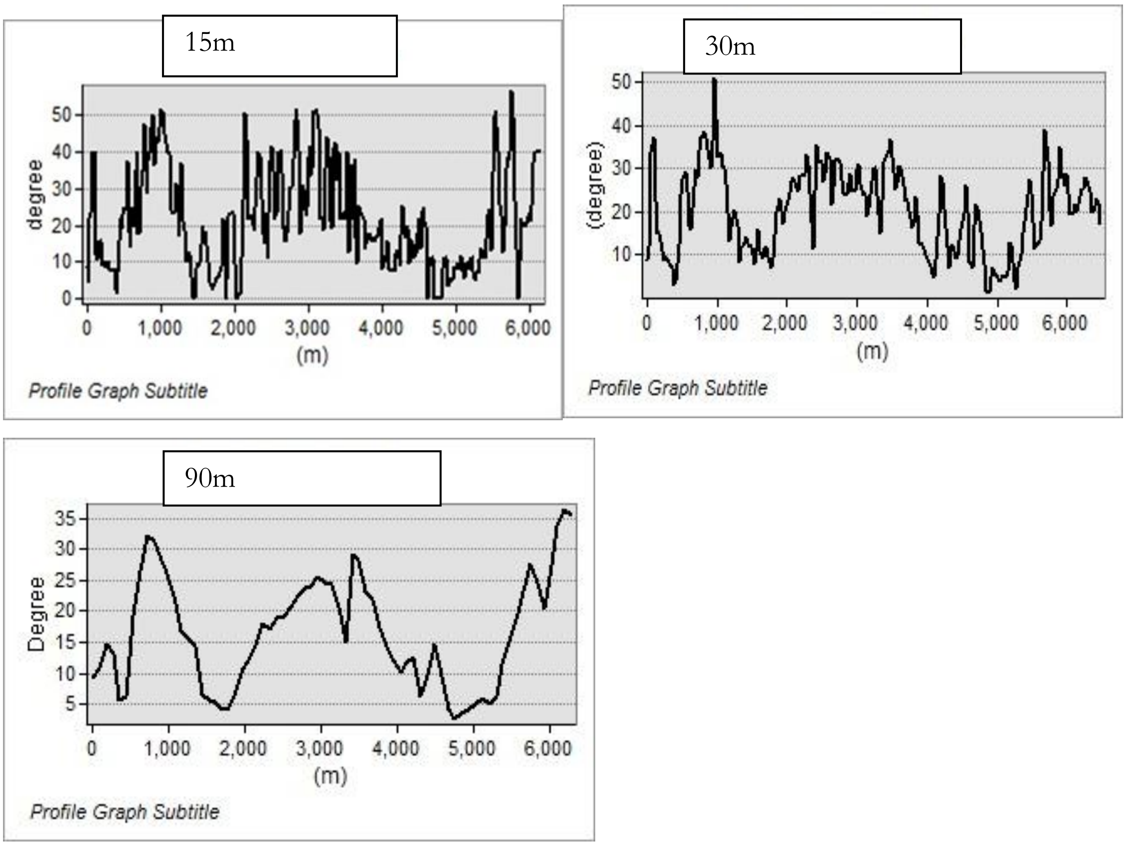


Figure 19. Profile graphs of slopes from median aggregation

5.5 Results of DEM comparism with ASTER 30m.

The Aggregated Dems were compared with 30m ASTER DEM and STRM DEM. The 30m aggregated images were compared with an ASTER 30m image ,while the 90m images were compared to SRTM image to see how similar or different they are. This comparism is done as a form of verification that the DEMs are true representation of original images.

A cross section of the ASTER DEM was made and compared with the two 30m aggregation. Figure 21 show the ASTER cross session and also the 30m DEMs.

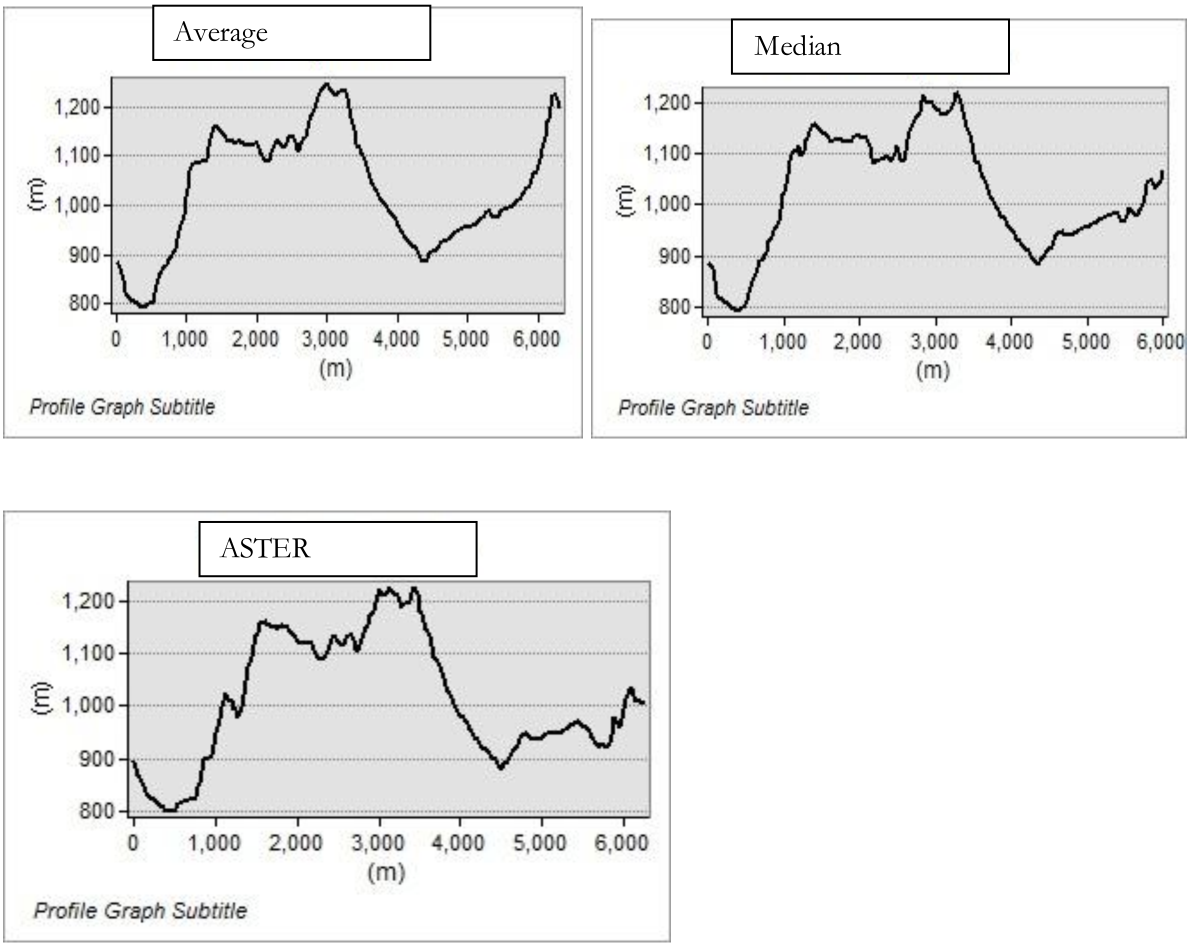


Figure 20. Profile graphs of 30m DEMs and 30m ASTER DEM

The slopes of the 30m aggregation was also compared with the slope generated from the Aster DEM. Figure 15 shows that the slope distribution of the 30m median aggregation give a closer result to the ASTER slope than the average aggregation slope . The median aggregation gives a better result than average aggregation as seen in figure 22. A reason why the median aggregation gave a better reason may be due to the fact that there is more possibility of over exaggeration or under prediction with the average aggregation .Since the mean of the aggregated pixel are assign to the pixel, when aggregation areas with high slopes and low slopes together the mean value that will be gotten will either be a better representation of the high pixel or a better representation of the low pixels and not represent both properly. On the other hand the median aggregation assigns a mid-value for the aggregated pixel, which gives an equal representation of but the high and low pixels.

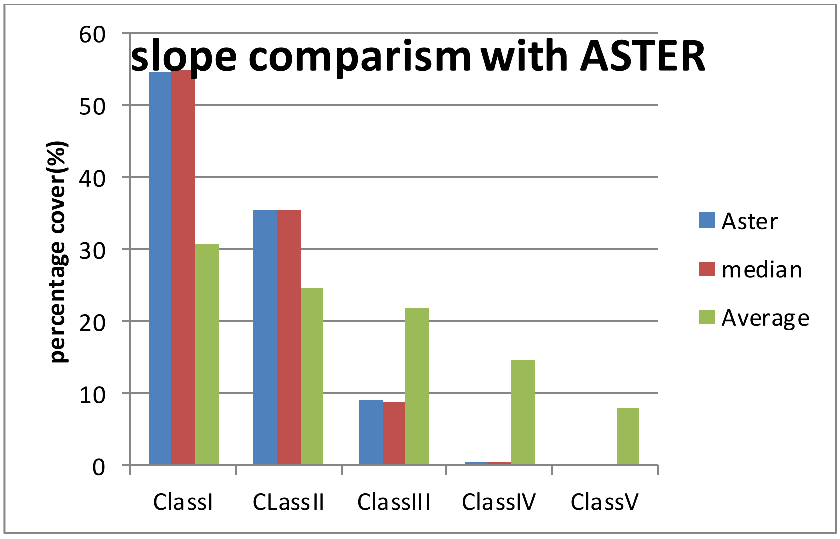


Figure 21. Chart showing comparism percentage cover of slope classes of 30m aggregations and ASTER

5.6 Result of DEM comparism with SRTM

The 90m DEMs generated were compared with an SRTM image to see which method of aggregation gives a good representation of the 90m DEM. The profile cut of the DEMs where made and compared with the profile cut of the SRTM. The profile cuts show a similar variation between the three DEMs without no significant differences (Figure 23), but looking at the slope maps generated from these DEMs a clear difference is seen in there profiles, figure 24 shows the slope classification into slope classes, it is seen that the median aggregation of the 90m gives a much similar distribution as the SRTM than the average aggregation. The distribution of the average classification is more spread across the class than the SRTM and the medium aggregation slope.

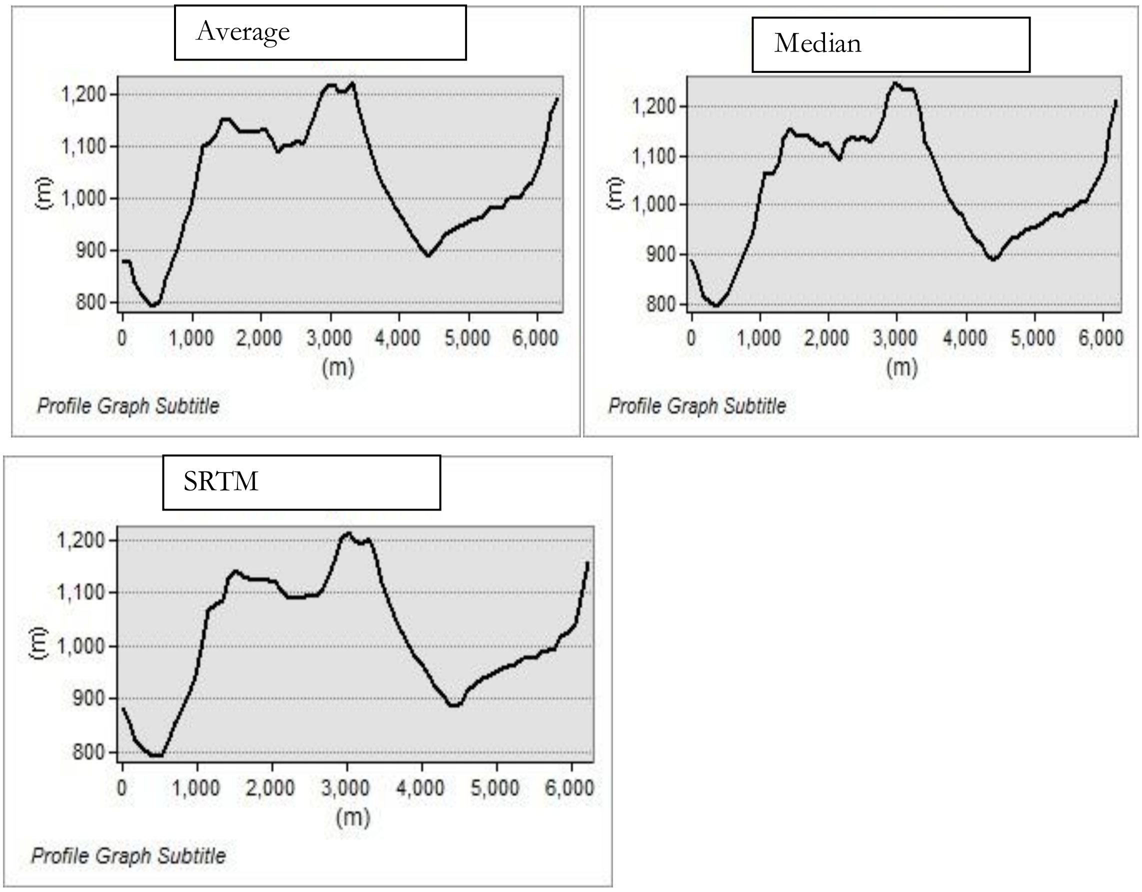


Figure 22 . Profile graphs of 90m DEMs and SRTM

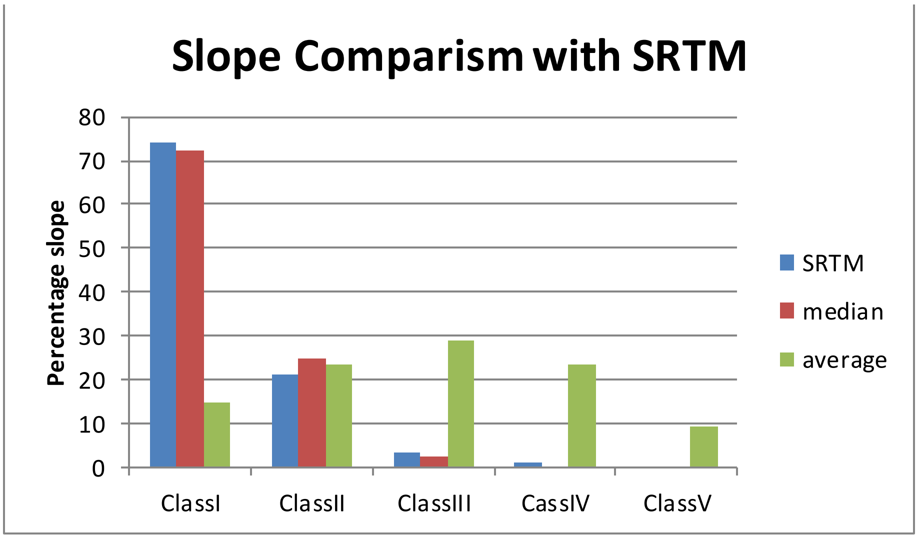


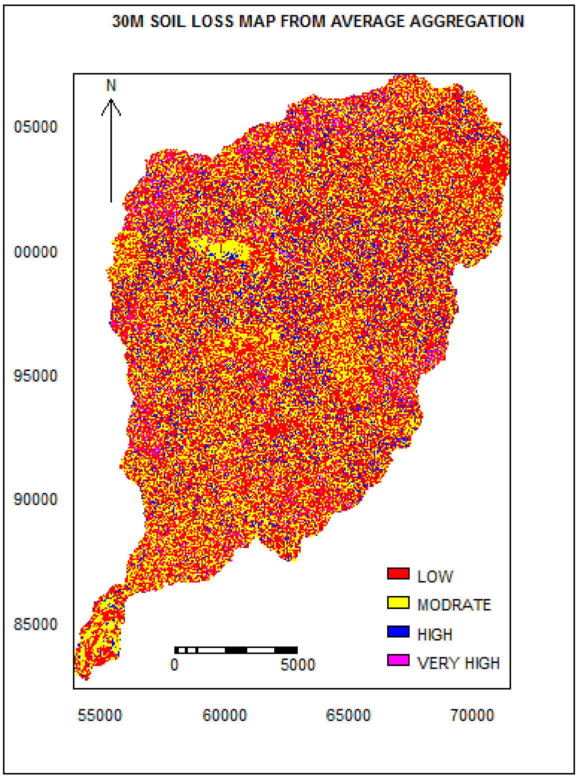
Figure 23. Chart showing comparism percentage cover of slope classes of 90m aggregations and SRTM.

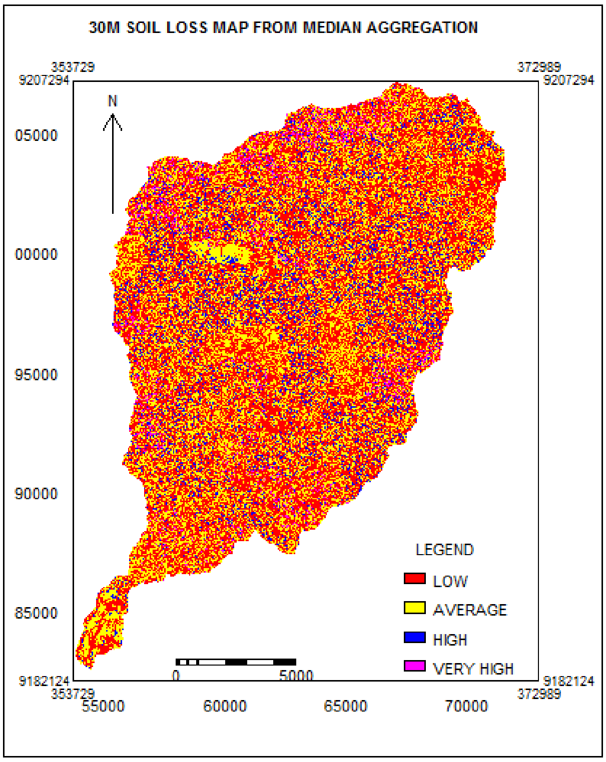
By increasing the cell size of DEM, the variation in the slope is reduced. This is also reported by Fahsi (1989), Chang and Tsai (1991), Wolock and Price (1994), Thieken, et al., (1999), Molnar and Julien (2000), and Zhang, et al., (2008). In addition, the distribution of slope maps derived from coarser DEM resolutions was different from those in finer resolutions. This finding is consistent with the observation of Molnar and Julien (2000).

5.7 Effect of different DEM resolutions on soil loss assessment

The soil erosion using the 30m and 90m DEM and slope gotten from the two methods of aggregation was calculated using the RMMF model**,** the soil loss maps are shown in figure 23.

The soil loss was classified into lower, moderate, high and very high for easy analysis .The table 4 shows similar distribution of soil loss between the two methods of aggregation.





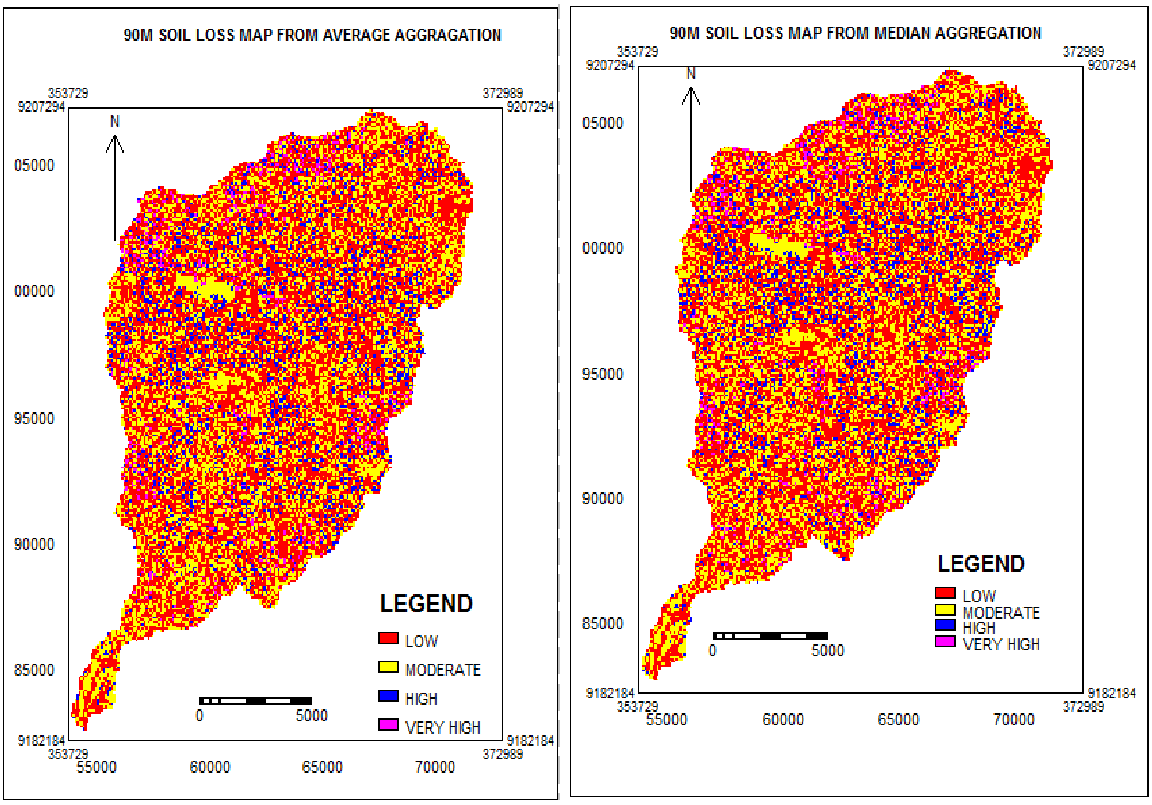


Figure 23. Soil loss Maps from average and median aggregation.

Table 5. Showing percentage soil loss distribution

	15m (%)	30m (average) (%)	30m (median) (%)	90m (average) (%)	90m (median) (%)
LOW	56.81	53.16	53.14	51.81	51.53
MODRATE	39.67	35.47	35.45	34.94	35.12
HIGH	0.52	9.06	9.08	10.74	10.84
VERY HIGH	3	2.31	2.3	2.51	2.52

The two methods had the highest distribution being at the low level after aggregation to 30m and this remains unchanged in the 90m aggregations but it observed as expected that the percentage of areas with high and very high soil loss increases in the 90m aggregation will the low and the moderate reduces. This is due to the smoothen effect of the slope as explained seen earlier , the slopes gives more chance for high erosion to take place in the 90m since the slopes are expected to be smoother and longer at bigger grid sizes.

Table 6 . Table showing erosion assessment results.

	15m	30m(average)	30m(median)	90m(average)	90m(median)
SOIL LOSS (tons/hec/year)	24.8	32.91	19.28	30.05	29.28
Discharge (m^3/year)	3138	5885	5877	5678	5520
Sediment yield (tons/hec/year)	4.31	5.17	3.03	4.56	4.33
Sediment delivery(tons/hec/year)	0.17	0.16	0.16	0.15	0.15

As shown in table 5 , the soil loss from the 30m average aggregation gives is higher than the 30m median aggregation .This is because as shown in the DEM results ,averaging of pixels of high variation of high slope and low slope give a aggregated value which either over exaggerates or underestimates the representative value of the pixel .Though the median aggregation result is close to that of the average aggregation it gives a better representation of the aggregated pixels by assigning a median value to the pixel . The average aggregation obviously assigned a higher slope value to the aggregated pixels there by allowing for a higher runoff velocity and also a longer slope length for runoff which in turn gives a higher soil loss.

It is observed that the soil loss of the average aggregation increases when aggregating from 24.8 ton/hec/year in 15m to 32.91 ton/hec/year in 30m and the drops when aggregating from the 30m to 30.05 ton/hec/year in the 90m, while in the median aggregation the soil loss value reduces when aggregating from 24.8 ton/hec/year in 15m to 19.28 ton/hec/year in 30 meters then increases when aggregating from the 30m to 29.28 ton/hec/year in in the 90m. This is result shows that while because of the different method of aggregation used, the effect of aggregation on the on the slope is different .It was expected that both method will follow an increasing trend of soil loss as the resolution increases, but this wasn't the case . This reaction maybe due to other factors like the kind of land covers on a particular slope. When looking at the aggregation at 90m for the two methods , it is observed that there is an increase from 24.8 ton/hec/year in the 15m resolution to 30.05 ton/hec/year in the 90m average aggregation and 29.28 ton/hec/year in the 90m median aggregation

5.8 Sediment delivery ratio results

From the Sediment delivery ratio (SDR) calculated for both method of aggregation is observed that the two methods of aggregations have the same sediment delivery ratio. Both the median and the average aggregation had a SDR of 0.16 at 30m and at 90m they both had a value of 0.15 .this result show that as the grid size is being increased the SDR is reduced as the grid size becomes bigger. This is realistic because since the sediment delivery ratio is the ratio of the sediment yield to the soil loss ,not significant change is really expected since both the Soil loss and the sediment yield increases as the grid size becomes bigger .

Comparism of results with field data.

The Soil loss and the discharge results are compared to the actually field measurements to see which method of aggregation best relates to the field results. (Table 6).

Table 7 . Showing comparism of calculated results to field results

	30m average	30m median	90m average	90m median	Field Data
Discharge(m^3/year)	5885	5877	5678	5520	5309
Soil loss (ton/hec/year)	32.91	19.28	30.05	29.28	21.78

The results shows that the 30m median aggregation gives the closest result to the actually field value of the sediment yield ,while the 90m median aggregation gives the best discharge result as compared to the field data. Both results from the median aggregation gives closer results to the field data than the average aggregation for soil loss, this might be because of exaggeration of slope during aggregation.

The discharge result which gives the actual sediment leaving the area by run off at the output point is seen to have a better result from the 90m aggregations with the median aggregation being the better method. This implies that the 90m aggregation gives a better representation of sediment transport than the 30m aggregation.

Although, using DEM data in different resolutions affected the output of the erosion model, the large-scale patterns of predicted soil erosion in coarser resolutions were similar to those with fine resolution DEM. This result is in agreement with the findings of both Renschler and Harbor (2002) who used WEPP model to predict soil erosion and sediment yield.

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this chapter, I will be showing the conclusion drawn from my research in relation to my research questions.

1. The first research question to answer from research is the question of "what is the effect of aggregation on land cover?" As seen from my results , land cover aggregation aggregates pixels together and give then the same pixel value, which is the value of the dominate pixel population in the aggregated pixel.as seen , pixels of water, urban and paddies were aggregated to pixel values of more dominate plantation, forest and shrubs . This gives the pixel the properties of the pixels they are aggregated to.
2. Next is the question of "What is the effect of pixels size on DEM and slope Map?" My research shows that at 15m grid size Dem and slope the variation in the topography of the area is high but when the Dem is aggregated to 30m and 90m, the topography is smoothened out giving less variation as the grid size becomes larger.
3. The erosion result shows that as grid size increases the soil detachment and the soil loss of the area increase, this is due to the smoothen effect which give more energy and length for runoff.
4. When we look at the result of the sediment yield and the sediment delivery ratio, although the sediment delivery ratio are all almost the same all through the 3 grid sizes .it is seen that as grid size increases sediment delivery ratio decreases.
5. The final research question that was raised to that of "What scales of erosion assessment of the watersheds gives close results to the actual field condition?" this is actually a form of verification and suggestion of the best method of aggregation that will give a good result of erosion assessment. From my research this question can be answered. The result of comparism with the actual soil loss and discharge of the area show that to get a good soil loss result the median method of aggregation is better with 30m and 90m median aggregation giving a better result than the average aggregation. Also the results of the discharge show that the median aggregation gives the best result for discharge. So in order to get a good erosion assessment and a good sediment transport representation, the median aggregation gave a better result when erosion assessment is done at 30m grid size and when sediment transport assessment is done at 90m grid size.

6.2 Limitations

- The used rainfall data could not realistically represent the spatial variability of the rainfall in the study area because the same rainfall volume was used for the whole water shed.
- The land cover parameters were only specified for seven land cover classes, while different vegetation types have different protective effects against soil erosion.
- This study was carried out without any fieldwork, so the reliability of the results depends on the quality of provided data.

6.3 Recommendation

- Most of the input parameters for running the RMMF model were obtained from literature. Therefore, to increase the reliability of results more field measurements are suggested.
- Another recommendation is to consider more than one image for classification to extract more appropriate training points.

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