Soil Erosion Dynamics
Due to Land Use / Land Cover Changes, Case study in Upper Serayu Watershed, Indonesia

Andry Rustanto

February, 2010

Soil Erosion Dynamics Due to Land Use / Land Cover Changes, Case study in Upper Serayu Watersheds, Indonesia

by

Andry Rustanto

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: (fill in the name of the specialisation)

Thesis Assessment Board

Chairperson	: Dr. D.G Rossiter (ITC)
External Examiner	: Dr. E.A Addink (Utrecht University)
First Supervisor	: Dr. Druba P. Shretha (ITC)
Second Supervisor	: Prof. Dr. Victor Jetten (ITC)

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Disclaimer

Abstract

Soil erosion has become a serious problem to the environment and human life. Decreasing of soil fertility, increasing of sedimentation in the reservoir are two most problem because of erosion in the upper Serayu watershed. Decreasing of soil fertility will require more to fertilizer uses and also can be followed by opening new cropping area by deforestation. The aim of this study is assessing land use / land cover changes in the upper Serayu watershed during 1989 to 2009 and relating the changes during that period to the soil erosion. There are 4 main step in this study:1) generating land use / land cover map for 5 years interval during 1989 to 2009; 2) assessing land use / land cover changes during 1989 to 2009; 3)assessing soil erosion of the area based on actual sedimentation data and soil loss prediction model; 4) estimating reservoir lifetime based on actual and predicted sedimentation data.

Major land use / land cover of the upper serayu watershed are: built up area, paddy field, water body, dry land cultivation, forest, shrub, plantation and bare soil. The land use / land cover classification was obtained by employing sequential maximum a posteriori (SMAP) algorithm. This algorithm could increase accuracy assessment by 15 % in this study. To predict land use / land cover of previous period, spectral angle and magnitude of present classified image were using to obtain training/signature area. To obtain the class signatures, all images have to be corrected atmospherically and topographically. Final classification will be processed by SMAP algorithm. Land use / land cover of the upper Serayu watershed has showed changes during 1989 to 2009. Forest has been decreased by 1552.9 ha per year, replaced by growing of dry land cultivation area and plantation forest.

Sedimentation rate in the PBS reservoir during 1989 to 2009 showed to increase. Indicating that soil erosion in the catchment is increasing. Mean sedimentation rate during 1989 to 2009 is about 4 million m^3 per year. Revised Morgan-Morgan and Finney (RMMF) method was used to assess soil loss based on land use / land cover. Bare soil showed the highest rate, followed by dry land cultivation and plantation forest. However the RMMF model needs to be validated. Based on sedimentation report of the reservoir, the reservoir will stop to function on 2023, meanwhile based on modelling result will be stop to fuction on 2051.

Keyword : Land use / land cover changes, reservoir sedimentation, soil loss, reservoir lifetime

Acknowledgements

Alhamdulilahi Rabbil Alamin, all praises belong to Allah SWT, the Most Merciful. Only with Allah SWT will I could finish my study.

First and foremost, I would express thanks and gratitude to my first supervisor, Dr. Druba Pikha Shretha, for his guidance, comments, discussion and the encouragement words during the study. My deep gratitude also goes to my second supervisor for Prof. Dr. Victor G Jetten the constructive input.

My appreciation also goes to the Institute for Geo-information Science and Earth Observation (ITC) for giving me the fellowship to continue my study and conduct the research. Particularly for Drs. Tom Loran as AES course director that already gave me opportunity to study in ITC.

I specially thank to my field coordinator, Nugroho Christanto, thank you for the pleasant discussion during the field work.

My appreciation and deeply love to my mother, father and sister in Indonesia, thank you for everytings.

And finally I want to say thank you to AES mates, thank you for the friendship, and for my Indonesian fellows, thank you for being a family during the stay in the Netherlands.

Andry Rustanto
Enschede, The Netherland
February 2010

Table of contents

List of figures

List of tables

1. Introduction

1.1. Background

Soil erosion is one of the serious environmental problems in Indonesia because of high rainfall intensity. Typical rainfall in Indonesia is convective and orographic which has high intensity in sort time period and frequently occur (Kemling et al. 2005). These types of rainfall have high energy to detach soil and to generate run-off. On the other hand, anthropogenic factor is considered as a significant driving force in accelerating soil erosion. It is caused by increasing population growth which result land use / land cover changes or intensive use of land to satisfy the demands of new settlers. The Indonesian Ministry of Environment reported that 2% in population growth results in the increase of built up area by 3.4% and the increase of prime agriculture area by 11.7% (Djajadilaga et al. 2009). This causes forest degradation of about 1.2 million hectares. Increase of settlements area, agriculture area and forest degradation are not only limited to the lowland but also reaching hilly or mountainous area which is causing soil erosion problem in the uplands.

Loss of top soil causes reduction of crop productivity which requires either excessive application of fertilizers or opening of new farming area by cutting down forest to maintain food demand of the increased population (Wall et al. 1987). Another problem related to soil erosion is the silting-up of river bed causing disturbance to river transportation system. Soil erosion may also reduce reservoir lifetime, thereby affecting irrigation and electricity generation projects. This problem has become common in the area with high density population like Java Island. Some water reservoirs have been accelerated to the dead end of their function.

In order to control the erosion problem it is necessary to achieve a comprehensive understanding of the soil erosion itself (Zhang et al. 2003). Spatial and temporal investigation on the soil erosion problem involves the anthropogenic and climatic factors. Land use / land cover changes and the application of soil conservation techniques are the reflections of anthropogenic and climatic factor or human influence to soil erosion, which play an important role in soil erosion dynamics (Emadodin et al. 2009; Davis et al. 2007). Land degradation depends very much on how humans can manage their land properly and if they can apply any conservation measures.

Considering the trend of human pressure which causes inappropriate land use in the mountainous area and resulting land degradation problem, it is important to analyse land use / land cover changes and its effect on soil erosion. The assessment result will be used to clearly explain the soil erosion dynamics as an impact of human activities on their land, and to identify the spatial and temporal soil erosion yields and its patterns. Furthermore, various scenarios of soil erosion problems as a result of different land use / land cover types and patterns can be generated. This result can be used in land use or regional planning activities or in implementing soil and water conservation.

1.2. Problem Formulation

The upper Serayu watershed catchment area is supplying water for the Panglima Besar Sudirman (PBS) reservoir. Initially, the reservoir was design to contain a maximum of 148 million m^3 of water. The PBS reservoir was built to produce electricity of 580 GWH/year, to irrigate 20,795 hectares of agriculture land and to supply water for 648,176 local residents for their consumption (Ministry of Public Work Republic of Indonesia 2009). This reservoir was planned with the expected for 50 years lifespan when it was started to operate in 1988.

During the reservoir operation, soil erosion rate in upper Serayu watershed has been predicted to be 4.2 million m^3 per year, which reduce the reservoir lifespan estimation to be less than 50 years and disturbing the productivity of the reservoir (Syariman & Soewarno 2008). In addition to the silting up of reservoir, soil erosion problem is threatening the environment by reducing soil fertility. This causes increased use of fertilizer or clearing up the forest to get more land for cultivation. Therefore, erosion need to be assessed properly, both spatially and temporally in order to help in proper land use planning activities or in suggesting suitable conservation applications.

1.3. Objectives

The main objective of this research is to study the pattern of land use / land cover changes and to analyse its effects on soil erosion dynamic in the upper Serayu watershed. Some specific objectives are:

1. To analyse land use / land cover changes pattern in the upper Serayu watershed.
2. To assess soil erosion under different land use / land cover condition.
3. To generate various scenario of reservoir lifespan.

1.4. Research Questions

To achieve main and specific research objectives, and to obtain research output, there are research questions to specify some task to do, as follows:

<table>
<tr><th>Research Objectives</th><th>Research Question</th></tr>
<tr><td rowspan="2">To analyse land use / land cover changes pattern during 1989-2009</td><td>What are the main land use / land cover types in the area?</td></tr>
<tr><td>What are the changes of the land use / land cover during 1989-2009?</td></tr>
<tr><td>To assess soil erosion under different land use / land cover condition</td><td>What are the patterns of soil erosion during 1989-2009?</td></tr>
<tr><td rowspan="2">To generate scenarios of reservoir lifespan</td><td>What is the estimation of reservoir lifespan based on actual sedimentation report?</td></tr>
<tr><td>What is the estimation of reservoir lifespan based on soil erosion prediction?</td></tr>
</table>

1.5. Research Structure

This thesis consist of 7 chapters, those are,

1. Introduction.
   Describing general background as a motivation and generating problem formulation. Objective and research question were decided afterwards to limit and focus methodology and analysis.

2. Literature review.
   Reviewing some literatures related to research objectives, including:
   a) Concept of land use / land cover and its changes.
   b) Principle and application of remote sensing for land use / land cover mapping and its changes detection.
   c) Land use / land cover changes and soil erosion.

3. Material and methods.
   Describing the research approach to reach research objectives, including:
   a) Materials, data and software were used during the research.
   b) The methods were applied to process and to analyse data.
   c) Field data collection.

4. Study area.
   Giving information about study area, including geology and geomorphology, climate, soil, present land use / land cover, social and demographic and The Panglima Besar Sudirman reservoir.

5. Result.
   This chapter describes the result of processing and analysing data of the area during 1989-2009, including:
   a) Land use / land cover and its change pattern.
   b) Erosion dynamic analysis related to land use / land cover changes.
   c) Spatial analysis of erosion prediction.
   d) The reservoir lifespan prediction.

6. Discussion.
   This chapter will discuss:
   a) The influence of Landsat image pre-processing and classification method to the image classification result.
   b) Evaluation of soil erosion prediction.
   c) Social and demographic influence to land use / land cover changes in the area.

7. Conclusion and recommendation.
   Concluding the research result followed by recommendation.

2. Literature Review

2.1. Land Use / Land Cover and it's changes

Land use is described as human activities on land while land cover refers to the vegetation and artificial construction covering the land surface (Anderson et al. 1976). (Gomarasca 2009) defined land cover as physical surface of the earth which has combinations in various feature of natural and cultivated vegetation and man-made infrastructures, while water, glaciers, rocks and bare soil and surface without vegetation though being part of terrestrial surface, and not of land cover, but often considered land cover for practical reasons. On the other hand, land uses are modification of earth biophysical attributes including the reason for which they are altered. Human being is the agent of the land use, and the land use's dynamics are indicator of the land use changes. However, the terminology of land use and land cover often mentioned as an integrated words, since the concepts of land use and land cover are closely related and interchangeably, which the purpose of the land that are being used commonly have associated types of cover (Anderson et al. 1976). It is often difficult or no clear distinction between cover and use to generate univocal and unquestionable separation (Gomarasca 2009).

Land use / land cover (LULC) is an important information for human life, it rules a basic information for many application (Houghton, Joos, and Asner 2004; Rindfuss et al. 2004; Elvidge et al. 2004; Csiszar et al. 2004; Bonan et al. 2004; Hansen, DeFries, and Turner 2004; Mustard and Fisher 2004) that needs to be assessed both spatially and temporarily. It's also necessary to be understood easily by the society, therefore several classification standards has been introduced and used. Several classification systems of land use and land cover in the world could be divided into 2 major group (Gomarasca 2009), which are based on pre-defined classes and based on independent diagnostic criteria. The pre-defined classification system are applied by some major organization concerning the land use / land cover in the world, such as USGS, UNEP/FAO, Global Terrestrial Observing System (GTOS) and European Corine program, meanwhile the independent diagnostic criteria was applied by UNEP/FAO with the Land Cover Classification System (LCCS) program.

Land use / land cover is dynamic because its directly related to the human activity (Ramankutty et al. 2006). The change of LULC could affect the environmental condition and eventually to global change of the climate conditions (Lambin et al. 2006). Furthermore, together with climatic factor, land use / land cover change may also cause problem such as soil erosion, landslide, flooding, and drought. The land use / land cover changes in the global perspective is reported to have negative impact to the environment and human life in general (Chhabra et al. 2006). It is thus important to assess land use / land cover changes continuously as a base to make a decision for land use / land cover policies and projection of the future (Lambin et al. 2001).

2.2. Remote Sensing for Land Use / Land Cover Detection

The basic principle of remote sensing is to measure object properties on earth surface without having direct contact with the object itself, it uses a sensor to capture an electromagnetic reflected signal from the object that propagated from natural energy source or artificial devices (Schowengerdt 2007). Natural energy from the Sun is a common energy source for optical remote sensing which is widely used in land use / land cover detection (Woodcock & Ozdogan 2004). The signal recorded by the sensor at the time of acquisition is dependent on incident radiation of the sun (related to sun position), the objects reflectance and absorption, scattering and absorption effect in the atmosphere (figure 2.1) (Schowengerdt 2007). In digital remote sensing technology, the data are stored into line and column pixel of digital image format for user ready to use.

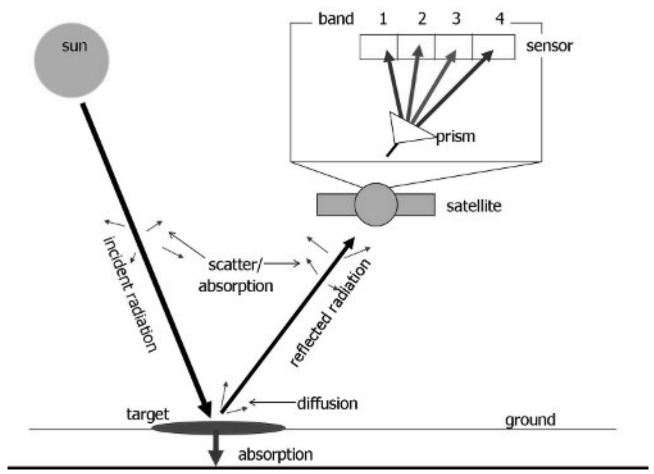


Figure 2.1 Satellite remote sensing principle (http://www.wr.udel.edu 2009)

Remote sensing technology has been used in land use / land cover mapping since the first remote sensing technology introduced aerial photo, then continued by satellite remote sensing technology. Comparing to the old methods of land use / land cover mapping before, remote sensing technology could derive more kinds of new map with various scales (Woodcock & Ozdogan 2004). It also has an ability to compensate the needs of information about dynamic of earth surface (Liang 2008). For long time period observation demands, Landsat data series give more opportunity to conduct a research of land use / land cover observation for the last 30 years, since the first Landsat 1 Multi Spectral Scanner (MSS) was launched in 1972.

Next generation after MSS are Landsat series of thematic mapper (TM) and enhance thematic mapper + (ETM+). Those have increased spatial (30m in multi spectral bands) and spectral resolution (7 to 8 bands spectral channel) data as compared to its predecessor (80 meter resolution in 4 spectral channel). The increasing of resolution in Landsat TM and ETM+ is very much useful to monitor land use / land cover changes for the last 20 years. The specification and application of various Landsat TM and ETM+ bands are shown in table 2.1.

Table 2.1 Landsat Landsat TM and ETM+bands wave lenght and it's application (Landsat 7 handbook 2007)

Band Number	Wavelength (um)	Applications
1	0.45 - 0.52 (visible blue)	coastal water mapping, differentiation of soil from vegetation, has poor penetration through haze
2	0.52 - 0.60 (visible green)	vegetation vigour assessment
3	0.63 - 0.69 (visible red)	vegetation discrimination, also has high iron oxide reflectivity
4	0.76 - 0.90 (near infrared)	determining biomass content and delineation of water bodies
5	1.55 - 1.75 (middle infrared)	vegetation and soil moisture content, differentiation of cloud from snow
6	10.40 - 12.50 (thermal infrared)	vegetation heat stress analysis, soil moisture discrimination, thermal mapping, has limited use as a large percentage of thermal radiation in daytime is reflected
7	2.08 - 2.35 (middle infrared)	discrimination of rock types and hydrothermal clay mapping
8*	0.52 - 0.90 (v.g. - near ir)	textural detail * Pan band only on Landsat 7

To obtain LULC map from Landsat image series, it could be done by doing image classification process, either by using visual interpretation (Lillesand & Kiefer 2000) or digital automated classification algorithm (Mather & Tso 2009). Present classification algorithm and techniques are based on pattern recognition (maximum likelihood, parallelepiped and maximum distance), artificial neural network, fuzzy set theory and modelling context using markov random fields (Mather & Tso 2009). The advantage and weakness of various methods are reported in McCauley and Engel (1995) and Flygare (1997).

2.3. Land Use / Land Cover Change Detection Using Remote Sensing

Change detection methods by using remote sensing imagery are divided into two main approaches at present time. First approach uses post classification comparison technique, and second approach use direct comparison between two images (figure 2.2) (Lam 2008). The critical point for the first approach is in classification process. Intensive supervision and effort are needed to obtain good accuracy. Classification technique and algorithm are also hold important point in this case. However many algorithms and techniques were introduced to increase classification result, such as artificial neural network, fuzzy set theory and modelling context using markov random fields, instead of traditional maximum likelihood.

The second group doesn't need pre-classification process. Some techniques of image differencing, change vector analysis and multidate comparison methods have been introduced and applied (Berberoglu and Akin 2009; Kontoes 2008; Chen et al. 2003). It is necessary to do radiometric and topographic normalisation to make several series of images is comparable for change analysis with those second group methods (Yuan and Elvidge 1996; Lunetta et al. 1995; Song et al. 2000; Olthof et al. 2005). The critical point of that second group is when determining the threshold between two images which will to fall into change or not change category. While it is fall to change then it should be determined the threshold for the “from – to” change type.

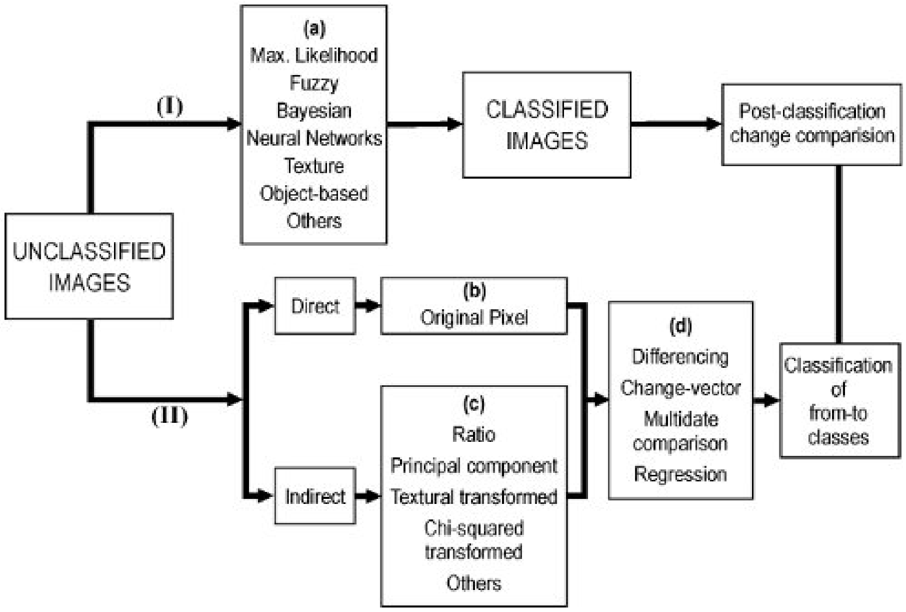


Figure 2.2 A framework for classifying change detection methods (Lam 2008)

2.4. Land Use / Land Cover Changes and Soil Erosion

Soil erosion are the process of detachment of individual soil particle from it's soil mass and the transportation of the detached soil particle by erosive agent (water flow or wind). When the transport capacity reduced, the depositional process takes place (Morgan 2005). Various factors such as rainfall, soil erodibility, topography and the effect of vegetation cover and management factor are involved in erosion process. Those are described below (Morgan 2005):

1. Rainfall

Rainfall amount and intensity are the main factor for soil detachment which is different in each earth climate region. Amount and intensity of rainfall related to the energy of detachment by splashing and run off. Amount of runoff is also necessary related to transport capacity for carrying soil to the downslope.

2. Erodibility

Erodibility is a soil property which defines soil's susceptibility for detachment and transportation. Erodibility depends on soil particle size distribution, aggregate stability, and shear strength of top soil, infiltration capacity and organic and chemical content.

3. Topography

If slope is steep and the slope length is longer, it will increase the velocity and volume of surface run off, which will increase soil erosion.

4. Vegetation cover

Vegetation cover protects soil from raindrop impact. Meanwhile the root system help in maintaining the stability of the slope. Plant cover also help to reduce detachment by surface run off by decreasing run off velocity by imparting roughness to the flow.

Among all the responsible factors, vegetation cover is certainly the most dynamic because of human activity. In other words it is closely related to the land use / land cover condition. However, there is little agreement in the nature about the relationship between soil loss and the change of cover extent (Morgan 2005). On the other hands, there were some evidence have showed land use / land cover changes could affect soil erosion yield in some area (Evans 2006; de Vente et al. 2008; Garc 2009).

In order to get conclusion about the effect of land use / land cover change to the erosion, it is important to study the effect of the land use / land cover change analysis with other factor such as soil erodibility and topographic factor (Verbist et al. 2010; Keesstra et al. 2009; Schnabel & Contador 2009). Study of land use changes in several volcano areas around Java island described the soil erosion in the upper slope and sedimentation in the lower slope were indicated to increase following the increase of land use change for new agricultural area in the upper slope (Lavigne & Gunnell 2006).

3. Materials and Methods

3.1. Research Approach

This research has been conducted to predict the land use / land cover and in the upper Serayu watershed of 5 time periods (2009, 2003, 1999, 1994 and 1989). It is also including land use / land cover changes analysis on those periods to explain soil erosion dynamic in the catchment. The research has involved literatures review, field observation, laboratory work, Landsat series image processing and analysis of land use / land cover changes and soil erosion dynamic. In addition this research also predicted the PBS reservoir lifespan related to soil erosion in the catchment.

For land use / land cover detection and changes analysis, Landsat images data series have been used. All the data are downloaded from free Landsat data source in in the internet. The most present image was classified using sequential maximum a posteriori (SMAP) algorithm with reference/training sample from field observation. The classification result then used to obtain a key signature or end member to predict previous land use / land cover in the area. For this matter, the Landsat data series had to be normalised radiometrically and topographically, also had to be atmospheric corrected. All pre-classification processes are important for the images to make them comparable each other in the term of time series land use / land cover prediction.

In the analysis part of land use / land cover changes, map overlay method has been chosen. Meanwhile, analysis of soil erosion dynamic related to land use / land cover changes used statistic and spatial descriptive approaches. The soil erosion analysis itself has used time series sedimentation data from PBS reservoir operator and soil loss prediction model of Revised Morgan-Morgan-Finney method. Soil loss prediction model could help to explain the potential of erosion problem within different land use / land cover type. All erosion analysis result then would be used to predict the PBS reservoir lifespan with also applied some scenarios of land use / land cover in the water catchment.

Fieldwork has been conducted for 2.5 weeks during the end of September until the middle of October 2009, to observe and obtain some data from 95,173 Ha study area. Those data are soil texture information, soil surface shear strength, soil moisture content at field capacity, ground truth information for image classification input process, sedimentation and rainfall data from PBS reservoir and social demographic data from local government office. Some other soil information such as bulk density couldn't be obtained due to tools limitation. For soil texture analysis, it was also conducted a laboratory analysis to calibrate field investigation by using pipetting method.

The conceptual frame work of this research is explained in the figure 3.1 below.

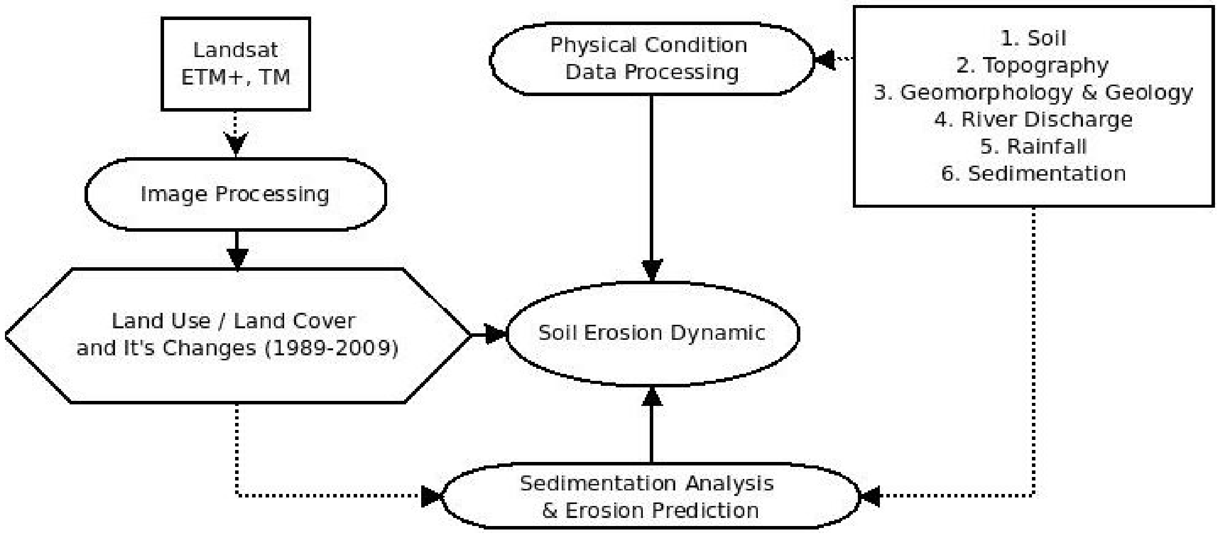


Figure 3.1 Research Conceptual Framework

3.2. Meterials

3.2.1. Data

3.2.1.1. Landsat images

Landsat series data was obtained from freely downloadable source in the internet, except for Landsat 5 TM for 1994. The Landsat data series used for this research are located at path 120 and row 65 of Landsat grid system with the acquisition dates in the same season (dry season). All the data have been corrected geometrically (Level 1 Landsat products (NASA 2007)). The images were used are listed below.

Table 3.1 Landsat image of upper Serayu watershed

No	Acquisition Date	Landsat Serie	Source
1	21. Juni 2009	ETM+	USGS (glovis.usgs.gov)
2	18. Juni 2008	ETM+	USGS (glovis.usgs.gov)
3	7. Juni 2004	ETM+	GLCF University of Maryland (http://glcf.umiacs.umd.edu)
4	20. Mei 2003	ETM+	USGS (glovis.usgs.gov)
6	1. Juli 2001	ETM+	USGS (glovis.usgs.gov)
5	13. Agustus 1999	ETM+	USGS (glovis.usgs.gov)
6	20. Juni 1994	TM 5	LAPAN (Indonesian Space Agency)
7	28. Juni 1991	TM 5	GLCF University of Maryland (http://glcf.umiacs.umd.edu)
8	11. April 1989	TM 4	USGS (glovis.usgs.gov)

3.2.1.2. Maps

Some maps were collected from several source, those are listed below.

Table 3.2 Maps of upper Serayu watershed

No	Map Theme	Publication Year	Scale	Source
1	Geology	1975	100.000	Geological Survey of Indonesia
2	Geomorphology	1978	250.000	ITC-GMU Serayu Valley Project
3	Soil	1984	250.000	Soil and Agroclimate Research Center of Indonesia
4	Topography	2000	25.000	Survey and Mapping Agency of Indonesia

3.2.1.3. Land use / land cover ground truth

Land use / land cover ground truth were collected in the field consist of training sample for image classification and accuracy assessment points to assess the accuracy of classification result (appendix 1). Training sample consist of 38 sample area of 8 land use / land cover classes. Meanwhile accuracy assessment points consist of 309 sample points of 8 land use / land cover classes. The composition of number training sample and accuracy assessment for each land use / land cover classes is described as follow,

Table 3.3 Training sample and Accuracy Assessment points

LULC	Training samples	Accuracy assessment points
Built up area	6	20
Paddy field	6	30
Water body	3	9
Dry land cultivation	7	66
Forest	5	36
Shrub	3	48
Plantation	6	90
Bare Soil	2	10
Total	38	309

3.2.1.4. Soil

Due to tools limitation, only two soil properties could be collected from the field, those are texture and shear strength. Both data were collected from 42 sample points (appendix 2) based on soil unit and geomorphology unit.

3.2.1.5. Rainfall, River Discharge and Sedimentation

The catchment's rainfall data, river discharge and sedimentation data in PBS reservoir have been collected. Those have specification as follow,

a) Rainfall data have been collected and shorted, only 5 year data in relatively good condition (not much gap) from 7 rainfall station inside the watershed.
b) River discharge is complete from 1989 until 2008.
c) Annual sedimentation data from PBS reservoir operator are complete from 1989 until 2008.

3.2.1.6. Social and Demographic

Some social and demographic data have been collected from authorities in the area, consist of,

a) Population with 5 years interval from 1984 until 2007.

b) Profile of the area from statistical report book.
c) Latest regional planning book of the area.
d) Informal interview with local resident about land use / land cover change.

3.2.2. Software

a) GRASS GIS 6.4.0 RC5 and ERDAS imagine 9.2 were used for image processing, change detection analysis and erosion prediction modelling.
b) ArcGIS 9.3 was used for result maps editing and visualisation.
c) R, RKward and Openoffice.org for statistical analysis.
d) Baseflow program from USDA for separating base flow and run off fraction.

3.2.3. Instruments

1. Field instruments
    a) GPS Garmin 12 xl
    b) Compass
    c) Binocular
    d) Vane tester
    e) PVC pipe with 7 cm diameter and 7 cm height
    f) Soil survey book and note book
2. Laboratory instrument

    Set of soil texture analysis laboratory instruments such as water bath, hot plate, end-over-end shaking machine, sieving machine, heavy brass funnel, grass sedimentation, drying oven, moisture tins and stopwatch. It is also include some reagent of hydrogen peroxide (30%) , dispersing agent and calcium chloride solution.

3.3. Methods Applied

3.3.1. Landsat Images Data Processing

The image processing step is aim to produce the series of land use / land cover maps (figure 3.2). This process consists of several operations on pre-image processing, image classification and accuracy assessment of classification result. Pre-image processing aims to reduce the effect of topographic illumination and atmospheric noise, and replacing any gaps because of cloud cover or striping line. By performing this process, the image classification accuracy is expected to increase.

Signature classes in feature space from present image classification result will be used to predict land use / land cover type in the previous images. This process requires the images to be corrected atmospherically and topographically, and to be normalized to the reference image. In this research, the images with acquisition date before 20 June 2009 will be normalized to the image of 20 June 2009 as reference image.

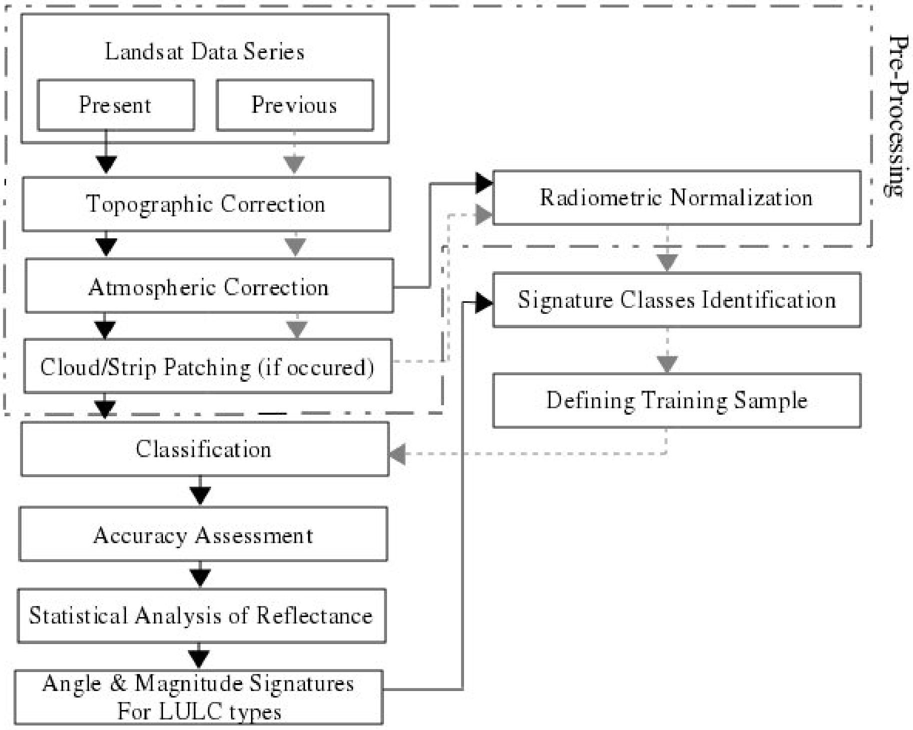


Figure 3.2 Landsat images processing step

3.3.1.1. Topographic Correction

The atmospheric correction should be supported with the assumption of Lambertian surface characteristic (Song et al. 2000). Lambertian surface is occurred when the energy come to the surface then being reflected equally to all direction (figure 3.3), which is very rare in the nature (Landgrebe 2003). Therefore the topographic correction is necessarily to do for non Lambertian surface like upper Serayu watershed before performing atmospheric correction.

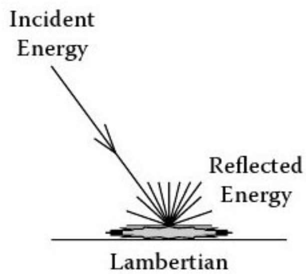


Figure 3.3 Lambertian surface (Tso et al. 2009)

Some methods have been introduced and applied by the expert (Richter, Kellenberger, and Kaufmann 2009), then C correction seem to be the most suitable in tropical region (Twele & Erasmi 2005). The C correction (Teillet et al. 1981) is a semi empirical method which use statistical regression approach between original band reflectance value and the illumination, the C correction formula is,

$$L_H = L_T \frac{\cos(sz) + c}{\cos(i) + c} \tag{3.1}$$

where :

L_H = radiance observed for horizontal surface c = correction parameter

sz= sun zenith angle L_T = radiance observed over sloped terrain

i = sun incidence angle in relation to the normal on a pixel

The c correction factor could be obtain from

$$c = \frac{b}{m} \tag{3.2}$$

where: b = intercept of regression line m = inclination of regression line

b and m were obtained from regression between radiance observed value and surface illumination value for each band. Radiance observed over slope terrain was calculated with Landsat digital number to radiance formula (equation 3.4 and 3.5). Surface illumination was calculated from DEM consider to sun azimuth and sun zenith. This operation could be done with i.landsat.topcorr module in GRASS GIS software.

3.3.1.2. Atmospheric Correction

Rayleigh and Mie are the most influenced atmospheric effect to remote sensing image, where rayleigh scattering mainly caused by haze (Mather & Tso 2009) and Mie scattering mainly cause by aerosol (Richards and Jia 2006).

3.3.1.2.1. Haze Effect Reduction

The haze effect reduction technique applied the regression between landsat bands with the tasseled cap of haze component (tasseled cap 4) based on Crippen (1987) approach. The equation of Haze reduction is (Neteler & Mitasova 2005),

$$\text{dehaze band}_j = \text{band}_j \ (\text{Tasscap } 4 - a_j) \ . \ b_j \tag{3.3}$$

where :

j = band number a_j = intercept of the regression b_j = slope of the regression

This operation could be done in i.landsat.dehaze in GRASS GIS.

3.3.1.2.2. Aerosol Effect Reduction

Dark object subtraction 4 (DOS-4) (Song et al. 2000) was employed to reduce the effect of aerosol. The principle of DOS-4 is assuming that some pixel in the images (usually at least 1000 pixel) should have the reflectance of zero, and that the value recorded for these zero pixel result from scattering effect (Mather & Tso 2009). The formula was adapted to the top of atmospheric radiance (TOAR) equation. To process DN into TOAR, some equation from Landsat handbook (NASA 2007; Markham & John L.Barker 1997) should be applied.

Conversion digital number (DN) into at-sensor radiance,

$$\mathbf{L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/(QCALMAX\text{-}QCALMIN)) * (DN\text{-}QCALMIN) + LMIN_\lambda} \tag{3.4}$$

Where:
L_λ = Spectral Radiance at the sensor's aperture in watts/(meter squared * ster * µm)
$LMIN_\lambda$ = the spectral radiance that is scaled to QCALMIN in watts/(meter squared * ster * µm)
$LMAX_\lambda$ = the spectral radiance that is scaled to QCALMAX in watts/(meter squared * ster * µm)
QCALMIN = the minimum quantized calibrated pixel value (corresponding to $LMIN_\lambda$) in DN
1 for LPGS products, 1 for NLAPS products processed after 4/4/2004, 0 for NLAPS products processed before 4/5/2004
QCALMAX= the maximum quantized calibrated pixel value (corresponding to $LMAX_\lambda$) in DN (255)
LMAX and Lmin parameter could be obtained from Landsat 7 handbook.

Conversion radiance into TOAR,

$$\rho_p = \frac{L_\lambda}{L_{sun}} \quad (3.5)$$

ρ_p = Unitless planetary reflectance L_{sun} = Sun radiance

L_{sun} can be calculated with the equation,

$$L_{sun} = \frac{ESUN_\lambda . \cos(\theta_S)}{\pi . d^2} \quad (3.6)$$

Where:
d = Earth-Sun distance in astronomical units
θ_S = Solar elevation angle in degrees
$ESUN_\lambda$ = Mean solar exoatmospheric irradiances

Solar spectral irradiance and earth-sun distance could be obtained from Landsat 7 handbook (appendix 3).

To apply the aerosol effect reduction, some factor were added when calculating sun radiance, those are: diffuse sky irradiance (*Esky*), the atmospheric transmittance along the path from the sun to the ground surface (*TAUz*), the atmospheric transmittance along the path from the ground surface to the sensor (*TAUv*), and the at-sensor radiance are calculated from the darkest object (at least 1000 pixel) (*radiance_dark*).

Equations for each factor above are,

$TAUv$ = exp[-d/cos(sat_zenith)], TAUz = exp[-d/sin(e)], Esky = PI · *radiance_dark* (3.7, 3.8, 3.9)

Where: e= sun zenith angle in degree

The equation of Sun radiance with aerosol effect reduction (L_{csun}) will be,

$$L_{csun} = TAUv \frac{ESUN_{\lambda}.\cos(\theta_S).TAUz + Esky}{\pi.d^2} \tag{3.10}$$

Calculating path radiance (L_{path}) from dark object radiance with the equation,

$$L_{path} = L_{dark} - 0.01.L_{csun} \tag{3.11}$$

Equation for corrected radiance ($L_{c\lambda}$) will be,

$$L_{c\lambda} = L_{\lambda} - L_{path} \tag{3.12}$$

Equation for corrected reflectance (ρ_{cp}) will be,

$$\rho_{cp} = \frac{L_{c\lambda}}{L_{csun}} \tag{3.13}$$

This operation could be done in i.landsat.toar module in GRASS GIS.

3.3.1.3. Cloud/Strip Patching

The cloud patching was done to replace the part of image were covered by cloud of have striping problem because of the failure of the Landsat scan line corrector. The image to be used as a patching should be has acquisition date in the same season with the main image to avoid too much dissimilarity. The image should be also corrected both atmospherically and topographically. Before patching operation the patching image should be normalized radiometrically toward the main image (section 3.3.5.2), meanwhile the cloud or striping in the main image should be masked out. Then the patching operation could be done by using map calculation.

Patched_image = if(mask=true,<image_patcher>,<image_to_be_patched>) (3.14)

For the Landsat image of 20 June 1994 couldn't be patched due to data limitation. Clouds still exist with extent about 1.5% from total area.

3.3.1.4. Image Classification

Sequential maximum a posteriori (SMAP) algorithm was employed to process the image classification. This algorithm is a combined of radiometric and geometric analysis to classify the image (Neteler & Mitasova 2005). It is mean, besides considering feature space cloud segmentation; it is also considering the spatial context with the neighbour pixel. This process could be done by using i.smap module in GRASS GIS.

First step in this process was to make training sample for each class. Training samples was digitized based on field observation data. Next step was calculating statistic for each training sample to the 6 bands of the Landsat image by using i.gensigset module in GRASS GIS. Final step is to execute classification process by using i.smap module.

3.3.1.5. Accuracy Assessment

Accuracy assessment for the most present time classified image was performed by using kappa statistic and error matrix. 309 field observation points were used in this process (appendix 1). Kappa statistic was used to describe correlation between classification result and the reference data (Congalton 2004). The kappa value are expected positive, which value greater than 80% indicate strong agreement, 40% to 80% indicate moderate agreement and lower than 40% indicate poor agreement. The error matrix was used to explain the accuracy of the image classification result.

3.3.1.6. Previous Land Use / Land Cover Detection

The reflectance characteristic of land use / land cover classes in the most present image (reference image) has been used to detect the land use / land cover types of previous time period. After atmospheric and topographic correction, reflectance on top of canopy cover value for same object in difference time series images should be more or less the same. However, specific condition of an object could be different over the time, for example different in moisture, might cause reflectance value to be different after atmospheric and topographic correction. Therefore radiometric normalisation toward the reference image was needed to be employed also.

3.3.1.6.1 Signatures/End Members Identification from reference Image

Points cloud in feature space of several bands indicates an object in the same class. In a number of bands feature space (mostly more than 3) dimension it is difficult to indicate by graphical feature or combination of bands value. Therefore, by adapting a feature space vector analysis concept (Kontoes 2008; Chen et al. 2003), the signatures / end member of a class could be indicated by a combination of magnitude and angle in n bands dimension (see figure 3.3).

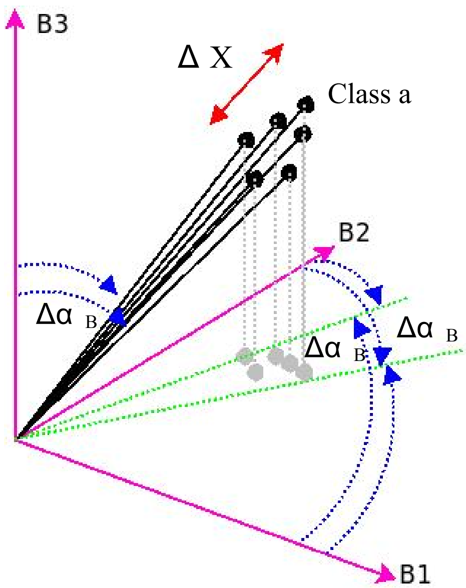


Figure 3.4 Reflectance signature for class a in the feature space

Δ αB n = Angle range from band n for class a   Δ X = Magnitude range forclass a

To calculate magnitude of n bands dimension, could use this equation,

$$X = \sqrt{x_1^2 + x_2^2 + x_3^2 + x_4^2 + x_5^2 ... + x_n^2} \tag{3.14}$$

And the angle of magnitude from each band axis could be calculated as,

$$\theta_X = \arccos\left(\frac{x}{X}\right) \tag{3.15}$$

The magnitudes and angles then should be analysed statistically to determine the range value of signature for each class. The best is to observe and analyse the histogram of each class magnitude and class angles from each band, particularly if the data is not normal distributed (figure 3.6).

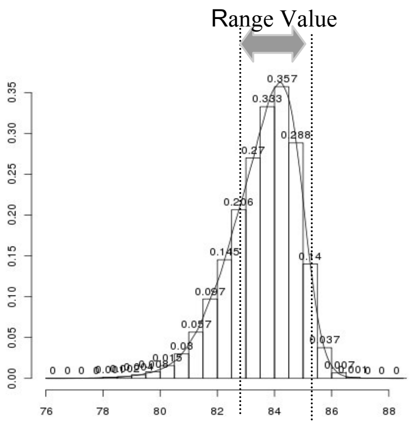


Figure 3.5 Determining range value of magnitude and angle

To test the range value could be done by applying the value to the reference image, if the signature pixel fall to another class (considering the classified image), then the range value should be evaluated and changed until get the optimal result (minimal number of pixel fall to another classes).

From the statistical analysis, the range value for magnitudes and angles for each class are described in the table 3.4

Table 3.4 Magnitude and angle threshold of signatures / end member classes

No	LULC Type Code	Magnitude Range	Angle to axis of Band Range					
			1	2	3	4	5	7
1	Built Up Area	50 – 450	68 – 82	68 – 82	64 – 82	35 – 90	45 – 65	55 – 75
2	Paddy Field	50 – 400	70 – 84	70 – 84	66 – 84	20 – 50	55 – 90	70 – 86
3	Water Body	0 – 90	50 – 75	50 – 75	25 – 70	83 – 90	90	60 – 90
4	Dry land Cultivation	250 – 600	75 – 86	75 – 86	73 – 86	15 – 50	58 – 76	70 – 85
5	Forest	25 – 450	72 – 86	72 – 86	75 – 88	15 – 40	65 – 90	74 – 87
6	Shrub	150 – 750	77 – 86	77 – 87	76 – 87	16 – 40	62 – 78	74 – 85
7	Plantation	250 – 625	82.5 – 87.5	82.5 – 87.5	82 – 87.5	13 – 30	66 – 80	79 – 86.5
8	Bare Soil	250 – 550	77 – 84	77 – 84	76 – 84	28 – 50	54 – 67	70 – 81

Those values were applied to the previous Landsat images to obtain signatures / end member for each type of land use / land cover. The signatures / end member then be used as a training sample for classification process. The classification process could be done by SMAP algorithm after radiometric normalization.

3.3.1.6.2 Radiometric Normalization toward reference image

Radiometric normalisation was performed by using no-change region linear regression (equation 3.15) (Lunetta et al. 1995) for each corrected reflectance band of previous image toward the reference image. By observing all the series of Landsat images, topographic map and fieldwork experience, the no-change area could be determined by using the settlements and water body feature.

$$y = a + bx \qquad (3.15)$$

where :

y = normalized reflectance value of band n

a = regression intercept.

b = regression slope

x = reflectance value of band n

3.3.2. Land Use / Land Cover Changes Detection

Land use / land cover changes detection for upper Serayu watershed area was done by using post classification change comparison method. The types of land use / land cover changes assessment in this research were focused to the types that most probably could increase soil erosion. According to literature and field observation, there are 19 land use / land cover changes in the area were estimated could increase soil erosion problem (see table 3.5). To obtain the land use / land cover change maps, map calculation of two sequence land use / land cover map was employed.

Table 3.5 Land use / land cover changes to be detected

From	To
Forest	Built Up Area
	Dryland Cultivation
	Paddy Field
	Shrub
	Plantation
	Bare Soil
Plantation	Built Up Area
	Dryland Cultivation
	Bare Soil
Shrub	Built Up Area
	Dryland Cultivation
	Paddy Field
	Plantation
	Bare Soil
Paddy Field	Built Up Area
	Dryland Cultivation
	Plantation
	Bare Soil
Dry land Cultivation	Built Up Area
	Bare Soil

3.3.3. Soil Erosion Modelling

To predict the annual soil loss in the area, revised Morgan-Morgan and Finney model (RMMF) was employed. This model predicts the soil loss from field-sized areas on hill-slope. It has two phases in describe soil erosion process, those are a water phase and sediment phase (Morgan 2005). The water phase determines availability of rainfall energy to detach soil particle and run off volume. The sediment phase determines soil particle detachment by rainfall and run off along with the run off transport capacity. Erosion rate is predicted as the lower rate between total particle detachment and transport capacity.

Some limitations existed when running this model in this research. Mainly are the limitation of soil field data due to tools and time limitation during fieldwork. To deal with this, some soil parameter were obtained from literatures based on soil texture and land use / land cover.

Input parameter for RMMF model for this research are described as follow,

Table 3.6 RMMF soil erosion model Parameters

Factor	Parameter	Remarks
Rainfall	R (Annual rainfall)	Using 7 rainfall stations data from 2001-2005
	Rn (Number of rain days per year)	
	I (Typical value for intencity of erosive rain (mm/hr)	Using literature value (25)
Soil	MS (Soil moisture content at field capacity (% w/w))	Using literature value based on soil texture
	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 use/land cover
Landform	S (Slope)	Derived from DEM
Land Cover	A (Proportion of the rainfall interception by vegetation)	Using literature value based on land use/land cover
	Et/Eo	
	C (Crop management factor/C snd P from USLE)	Literature review and field estimation
	CC (Percentage canopy cover)	
	GC (Percentage ground cover)	
	PH (Plant height (m))	

To run the model, some equation related to soil erosion modelling phase should be solved, as follow,

a) Rainfall energy estimation

To calculate rainfall energy estimation, first we calculate effective rainfall as follow,

$$ER \text{ (Effective rainfall)} = R.A \qquad (3.16)$$

ER is then split into direct throughfall (DT) and interception which will become leaf drainage (LD), as follow,

$$LD = ER \times CC \qquad (3.17)$$

$$DT = ER - LD \qquad (3.18)$$

The kinetic energy of direct throughfall (KE(DT)) is determined as a function of the rainfall intensity (I). For this research, equation from kinetic energy investigation in Cebu, Philippine is used (Fornis et al. 2005), as follow,

$$KE(DT) = DT \times (30.8[1 - 0.55 \exp(-0.03 \times I)]) \qquad (3.19)$$

The kinetic energy of leaf drainage (KE(LD)) is dependent to the height of vegetation canopy, the equation is

$$KE(LD) = LD \times (15.8 \times PH^{0.5}) - 5.87 \qquad (3.20)$$

The total energy of effective rainfall (KE; J/m^2) is,

$$KE = KE(DT) + KE\ (LD) \qquad (3.21)$$

b) Estimation of run off

The annual run off (*Q*) is estimated as follow,

$$Q = R \exp(- Rc / Ro) \qquad (3.22)$$

where : *Ro* is the mean rain per rain day (*R / Rn*)

Rc is soil storage capacity, which is estimated from,

$$Rc = 1000MS \times BD \times EHD\ (Et/Eo) \qquad (3.23)$$

c) Soil particle detachment by raindrop impact

Soil particle detachment by raindrop impact (*F;* kg/m^2) is estimated as follow,

$$F = K \times KE \times 10^{-3} \qquad (3.24)$$

d) Soil particle detachment by run off

Soil detachment by run off (*H*, kg/m^2) is estimated as follow,

$$H = Z.Q^{1.5}.\sin S(1 - GC).10^{-3} \qquad (3.25)$$

Z is the resistance of the soil, which is estimated as follow,

$$Z = 1 / (0.5 \times COH) \qquad (3.26)$$

e) Transport capacity of run off

The transport capacity (*TC*) of runoff is estimated as follow,

$$TC = C.Q^2.\sin S \times 10^{-3} \qquad (3.27)$$

f) Estimation of soil loss

The estimation of annual soil loss is defined from the lower value between accumulation of detachment by raindrop impact and by runoff and the annual transport capacity.

Estimation of sediment delivery is estimated as follow,

$$Y = \frac{Q}{P} . A \tag{3.28}$$

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 ctachment

To convert sediment weight into volume metric as sedimentation in the reservoir, sediment specific gravity of PBS reservoir is used. According to Syariman and Soewarno (2008), the value is 1.097 ton / m^3

3.3.4. Reservoir lifespan prediction

To predict PBS reservoir lifespan, some scenario are arranged, as follow,

1. Predicting the reservoir lifespan based on the mean annual actual sedimentation rate.
2. Predicting the reservoir lifespan based on soil erosion prediction result.

3.3.5. Field Data Collection

3.3.5.1. Preparation

Before going for fieldwork, some preparation had to be done, those are,

1. Schedule arrangement and data collection strategy.
2. Providing fieldwork maps.
3. Defining sampling points.
4. Collecting fieldwork tools.

3.3.5.2. Ground Truth Data

Ground data collection was conducted during fieldwork to define training samples and accuracy assessment points. Both data were chosen by stratified random sampling regarding to the preliminary assessment of unsupervised image classification and topographic map. During fieldwork, it was decided 38 locations for classification training sample area and 309 points for accuracy assessment of image classification result (appendix 1). Ground truth data collection in the field was conducted by plotting GPS points for all types of land use / land cover in the area and identification object in the map based on field observations.

3.3.5.3. Soil Data

Soil data collection during field work was conducted to have information of soil texture, soil shear strength and soil permeability data. The sample points had to be collected from 42 points in the entire area. The sample points were chosen with stratified random sampling method based on geomorphology and soil unit (appendix 2 and 4).

a) Soil texture

To investigate soil texture, field observation methods was conducted by shaping moistened soil methods (Ilaco 1989).

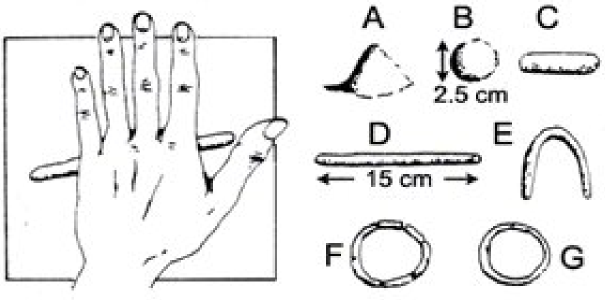


Table 3.7 Field soil texture investigation (Ilaco 1989)

Sand (A) : Soil remains loose and single-grained; can only be heaped into a pyramid.
Loamy sand (B) : The soil contains sufficient silt and clay to become somewhat cohesive; can be shaped into a ball that easily falls apart.
Silt loam (C) : Same as for loamy sand but can be shaped by rolling into a short, thick cylinder.
Loam (D) About equal sand, silt, and clay means the soil can be rolled into a cylinder about 15 cm long that breaks when bent.
Clay loam (E) As for loam, although soil can be bent into a U, but no further, without being broken.
Light clay (F) Soil can be bent into a circle that shows cracks.
Heavy clay (G) Soil can be bent into a circle without showing cracks.

b) Soil shear strength
To investigate soil shear strength, vane taster was used in some locations for each sample point. The average result then noted as the shear strength value of the sampling point in kilo pascal (kpa).

3.3.6. Laboratory Soil Investigation

Laboratory soil investigation was conducted to analyse soil particle size for determining soil texture. This process involved 20 gr soil samples for each 22 sample points (appendix 4). The procedures to process soil sample are,

1. Soil sample preparation.

Before the main process, soil sample need to be crushed and sieve to separate rock and root. Then for each sample point were taken 20 gr to put in the beaker. Sample ready to process.

2. Oxidation of organic matter.

This process aims to decompose organic content by using hydrogen peroxide for stand overnight. Next step was to put beaker on water bath and add more hydrogen peroxide until decomposition of organic matter complete. After complete, hydrogen peroxide need to be removed by boiling process. Then to obtain soil sample separated from remaining water, centrifuge machine was used.

3. Dispersion.

Samples were dispersed by dispersion agent and shaking for 16 hours.

4. Separation of fraction.
   a) Determination sand fraction.
      Sand fraction could be obtain from sieving the sample on >50μm sieve.
   b) Determination silt and clay.
      After sand fraction process, remaining sample should put in the cylinder with 1000 ml water and shaking it. To obtain fraction < 50μm, pipetting should be done immediately after shaking. Meanwhile to obtain fraction < 20μm, pipetting should be done 5 minutes after shaking. Fraction < 2μm could be obtain by pipetting 5.5 hours after shaking. All the pipetting result should be put on the oven with temperature 105^0C and weight.

5. Calculation

Clay (< 2μm)	=	(Hx50)-(Zx50)	(K)
Silt (2–50μm)	=	(Fx50)-(ZX50)-K	(P)
Sand (> 50μm)	=	weight	(N)

Sample weight = K + P + N

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

H = weight 20 ml pipette aliquot of fraction < 2 μm

Z = weight 20 ml pipette aliquot of blank

The proportional amounts of the fraction can be calculated by :

$$\% \text{ Clay } (<2\mu m) = \frac{K \times 100}{\text{sample weight}}$$

$$\% \text{ Silt } (2\text{-}50\mu m) = \frac{P \times 100}{\text{sample weight}}$$

$$\% \text{ Sand } (>50\text{-}2000\ \mu m) = \frac{N \times 100}{\text{sample weight}}$$

4. Study Area

The study area is located in the upper Serayu watershed, Central Java, Indonesia (figure 4.1). It falls into two district: Banjarnegara in the west (41,556 Ha) and Wonosobo (53,617 Ha) in the east. The watershed extent is about 95,173.65 Ha. The east to west axis is about 43 km and north to south corner about 29 km. The elevation varies from 225 m above sea level in the western part (near dam inlet) to 3325 in the top of Sumbing volcanic mountain in the east part.

The main river systems in the area are Merawu river in the west, Tulis river in the middle, Begaluh and Serayu river in the east. Drainage pattern around volcanic cone and volcanic foot slope in the east is radial centrifugal. Drainage pattern in the north, middle and south are dominated by parallel and dentritic patterns. Sub rivers join to the main Serayu river in the south show sub parallel pattern. Drainage density in the catchment is about 0.032 km/Ha.

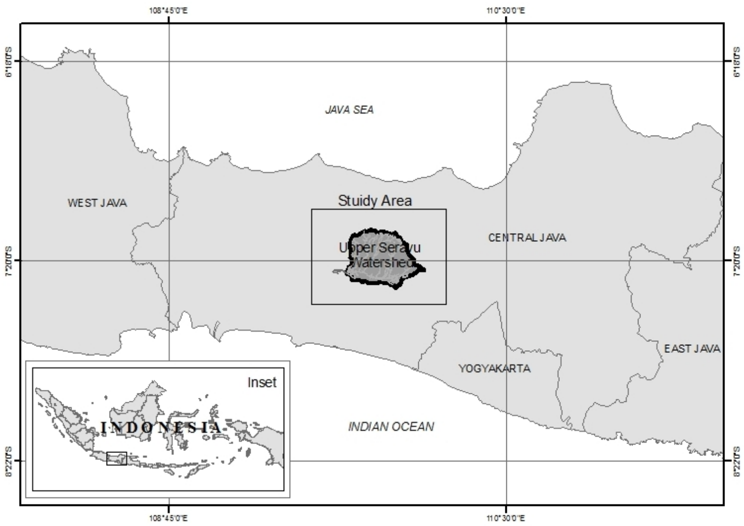


Figure 4.1 Study area

4.1.1. Climate

The climate in the upper Serayu watershed is characterized by having an equator tropical climate with mean annual rainfall varying from 1700 mm up to 4200 mm per year. The area has two main season, mainly rainy season and dry season. Rainy season occurs during November to April, while dry season falls during May to October (figure 4.2). About 73 percent of mean annual rainfall falls in the rainy season. Mean temperature in the area is around 14 up to 27 ^{0}C. At higher elevation and particularly in Dieng plateau it can be cooler with annual mean temperature of 14 ^{0}C.

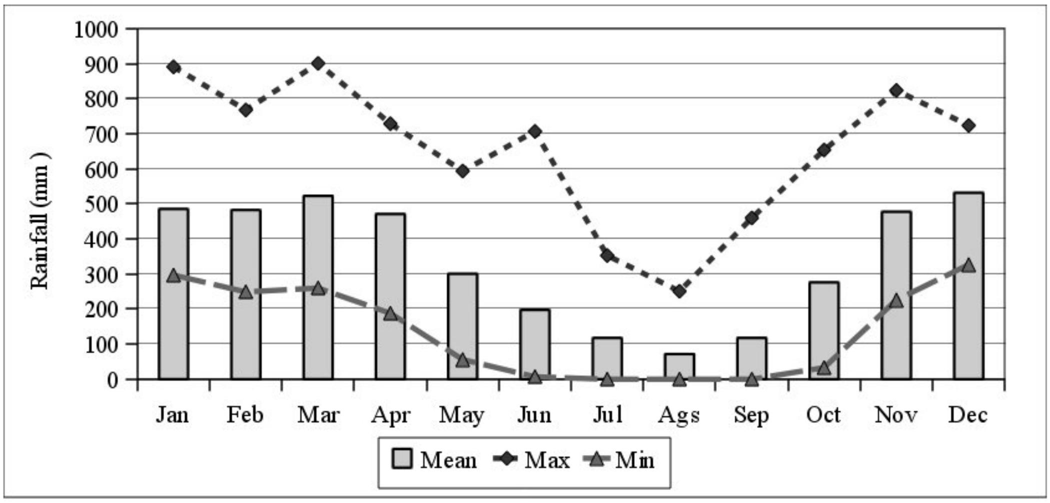


Figure 4.2 Monthly rainfall (source: Wonosobo rain gauge station)

4.1.2. Geology and Geomorphology

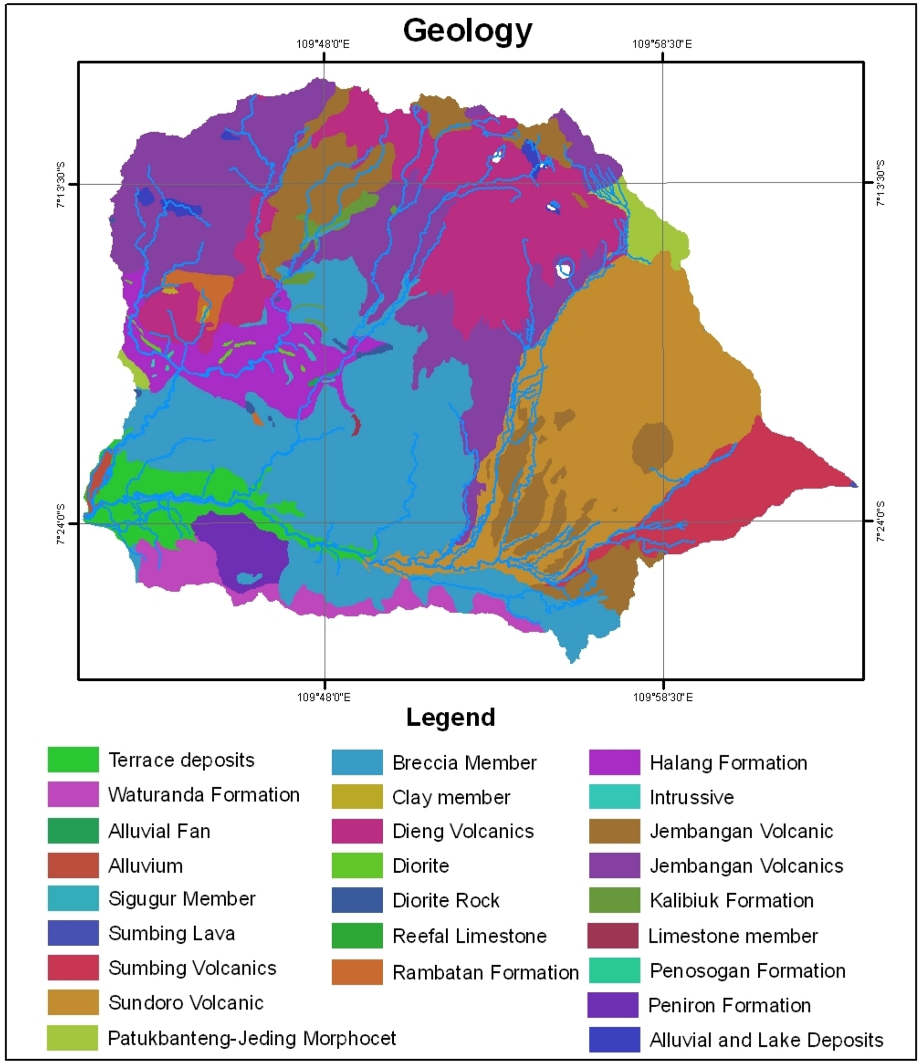
Upper Serayu watershed is surrounded by volcanic complex. Those are Dieng Plateu in the north which still has several active craters, Sindoro and Sumbing volcano in the north-east and east. These volcanic complexes are a part of young volcanic complex of the north Serayu range which has lower tertiary stratigraphy from Eocene (van Bemmelen 1949). Therefore most of rock types of the area are strongly influenced by the volcanic rock from surrounding area (figure 4.3)

(Verstappen 2000) described the geomorphology of the area as strongly eroded volcanic terrain. Meanwhile the main river valley of Serayu is described as alluvial plain which with main drainage direction from north, east and south part and to the west. In detail (figure 4.4), volcanic terrain has 3 geomorphological features, crater depression, volcanic cone at the top (opposite to crater depression), and foot slopes at lower part. The alluvial plain has terraces, alluvial fan and planation surface. The area between volcanic complex and alluvial plain are mostly moderate to high relief eroded complex.

4.1.3. Soil

According to soil map from Indonesian soil and agro-climate research centre, soils in the area are dominated by regosol, andosol and latosol (cambisol) soil units (figure 4.5). Regosol and andosol are mostly located in the volcanic foot slope, volcanic cone, structural depression and plateu area from west to the north. Latosols dominate in the central part, crossing from south east to the north west in the eroded scarp and mass wasting area.

The soil textures in the area are dominated by loam, sandy loam and clay (figure 4.6). Sandy loams are mostly located in volcanic foot slope, volcanic cone and terraces along the main river channel. Loam texture classes are mostly located in the central part between terraces and volcanic slope area. In the southern part of the terraces, clay textures are dominated.



4.3 Geology map of upper Serayu wattershed

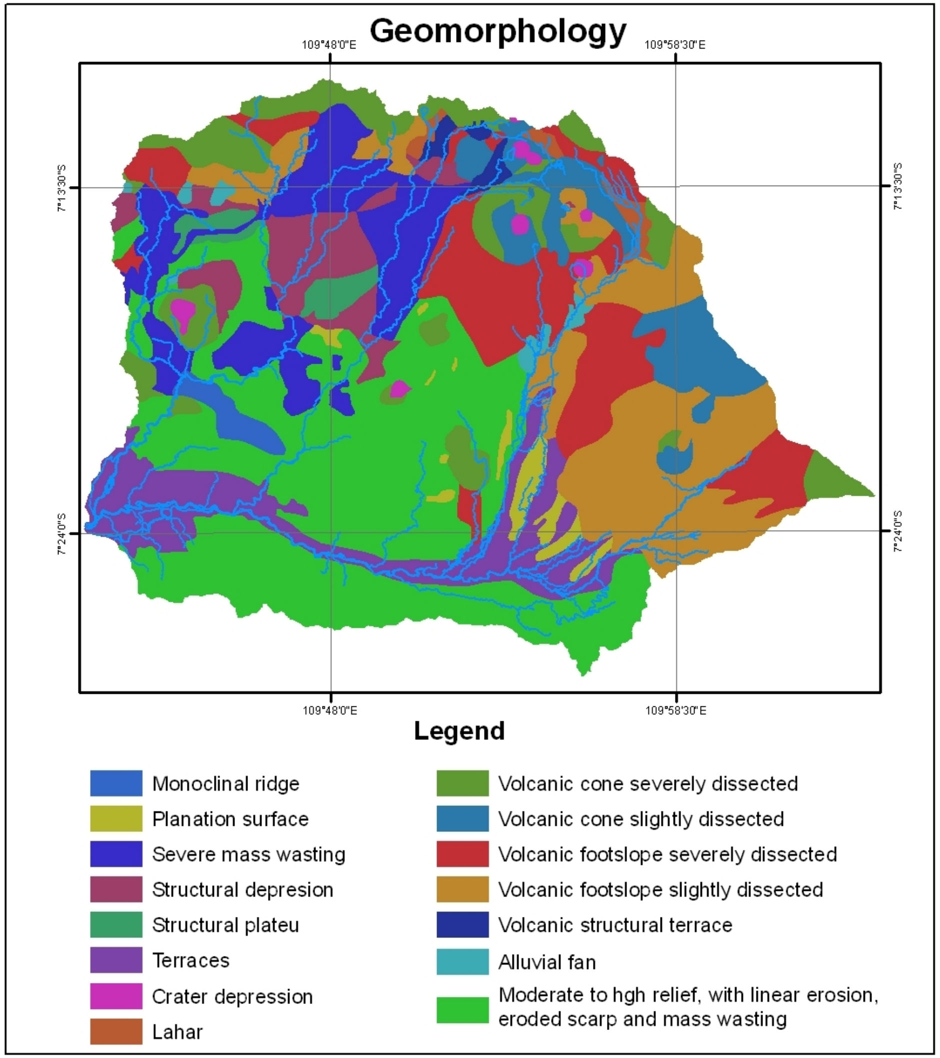


Figure 4.4 Geomorphology map of upper Serayu watershed

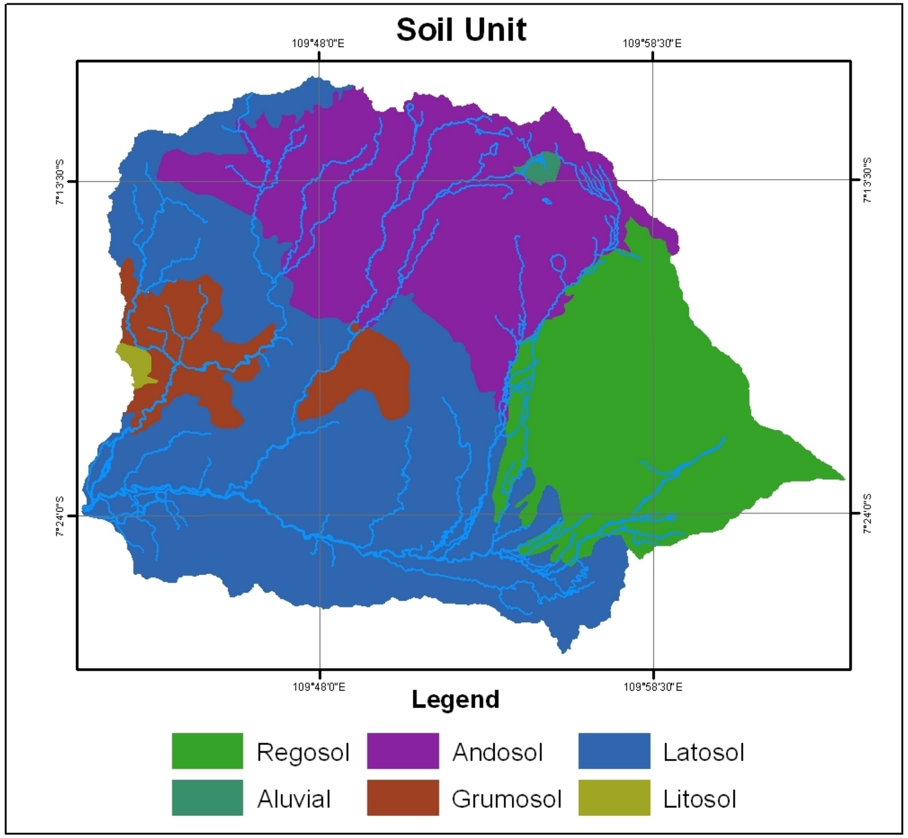


Figure 4.5 Soil units map of upper Serayu wattershed

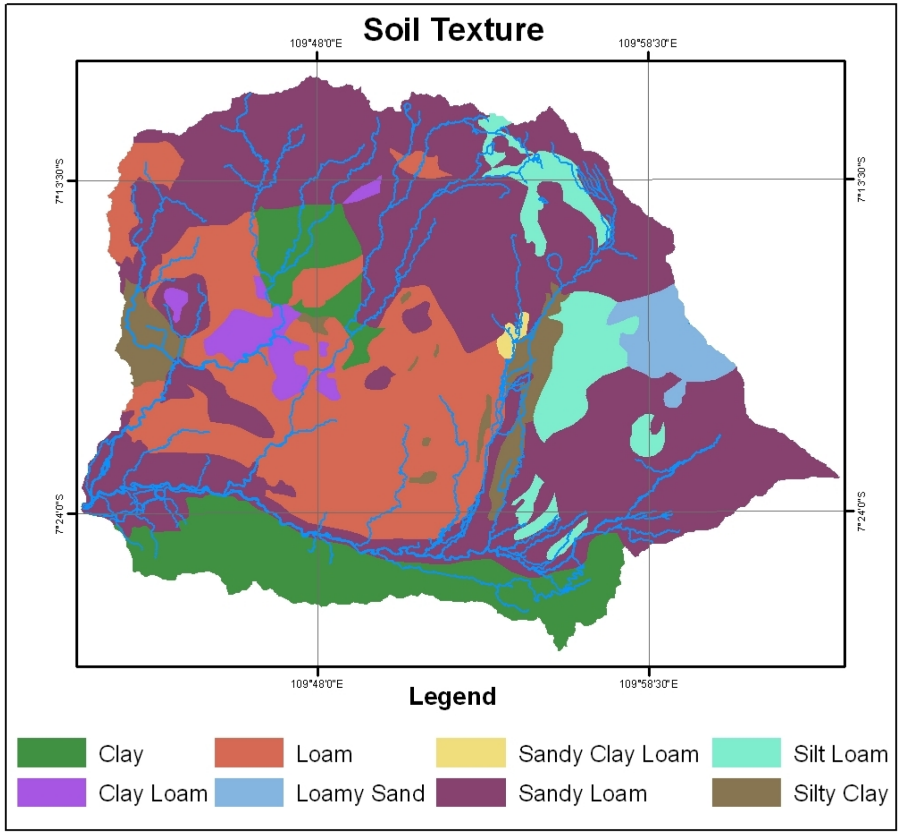
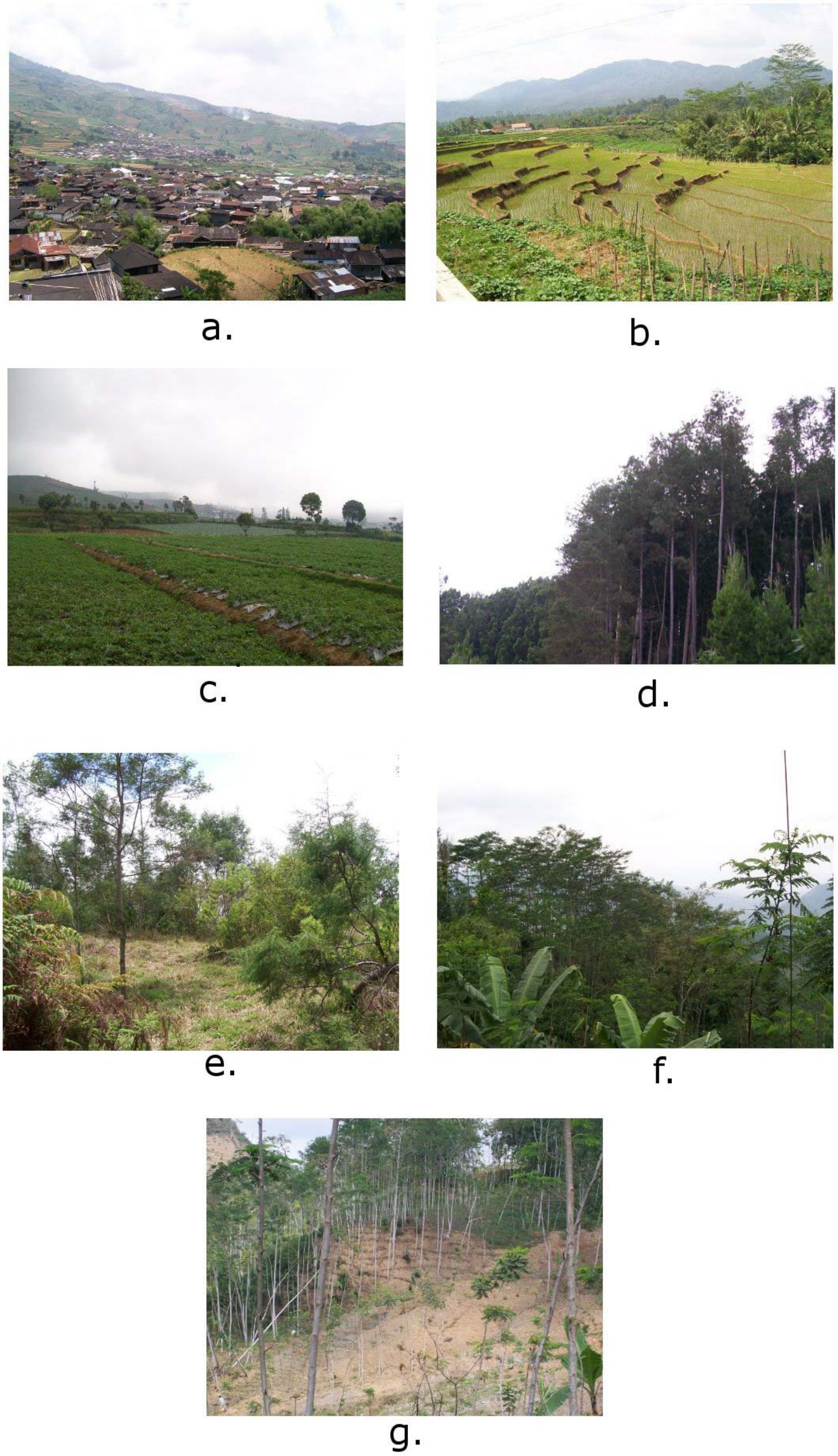


Figure 4.6 Soil textures map of upper Serayu watershed

4.1.4. Present Land Use / Land Cover

There are 7 class of land use / land cover of the area : a. built up area; b. paddy field; c. dry land cultivation; d. forest; e. shrub; f. plantation; g. bare soil; (figure 4.7).



4.7 Land use / land cover types in upper Serayu watershed

Built up area are mainly concentrated in the district capitals of Wonosobo and Banjarnegara, although settlements are spread up in the entire area. Paddy fields are located in the terraces alonng the Serayu river. Dry land cultivation mainly occur in the Dieng plateau and around volcanic foot slope. In the most of dry land cultivation area, potato, and vegetables such as cabbage, chilli and cauliflower are grown. Pine forest could be found mainly in the top of mountains, while *Agathis Dammara* (damar) could be found in the hilly area in the middle part. Shrub land is mostly located in the lower to middle part of volcanic cone, several small volcanic craters and in the river banks. Plantation could be found in the lower part of volcanic foot slope and lower to upper part of hilly area. In the most of plantation tree species such as *Albisia Falcataria* (albasiah/sengon) is grown as commercial log/wood commodity, and *Durio Zibethinus* (durian), *Salacca Zalacca* (snake skin fruit/salak) as commercial fruits. Farmers also cultivate cassave and spices (ginger and galinge).

4.1.5. Social and Demographic Conditions

The Upper Serayu watershed is inhabited by approximately 1.6 million people, according to the statistical report of Banjarnegara dan Wonosobo (2007). Most of population works as a farmer in the rural area. In the district capitals people are involved in trade, public service and tourism. Since 1999 the two districts, Banjarnegara and Wonosobo, got the permission from the central government in Jakarta to be autonomous in making regulations suitable for the regional planning of the area.

Gross regional domestic product (grdp) per capita in the area is 2.16 million rupiah or 180 US$ in 2007. From total grdp in 2007, 43% was contributed from farming sector, 12% from trade, hotel and restaurant, 22% from industry and public services, 12% from transportation and financial services, and the rest are contributed from several other sectors such as mining and construction.

4.1.6. The Panglima Besar Sudirman Reservoir

The Panglima Besar Sudirman Reservoir for hydro-electric power plant (PBS-HEPP) is located in the outlet of upper Serayu watersheds. The reservoir in full capacity covers an area of 10.5 km^2, with total volume about 140 million m^3. The PBS-HEPP was finish to construct in April 1988; it has length of 832m and height of 110m with 50 years lifetime estimation. The reservoir is mainly for electricity generation as a part of the electricity power plant network of Java and Bali Island. In addition, it also supplies water for farming area (mainly paddy field). Other uses are fishery and tourism. Based on sedimentation report (PBS-HEPP operator), the reservoir is estimated to be filled in by about 83,7 million m^3 of the sediments which is more than 50% of the total capacity of the reservoir.

5. Result

5.1. Land Use / Land Cover Classification Result

The land use / land cover classification result obtained from classifying Landsat Images of 2009, 2003, 1999, 1994 and 1989 are displayed in figure 5.1 (a-e). The land use / land cover classes extents during the periods were explained in the table 5.1 below.

Table 5.1 Land use / land cover in upper Serayu watershed during 1989-2009

ID	LULC type	Area Extent (ha)				
		1989	1994	1999	2003	2009
1	Built Up Area	1785,78	1972,08	2926,08	3131,46	4936,95
2	Paddy Field	10548,54	7775,73	8948,34	5496,12	5848,02
3	Water Body	179,91	171,63	171,63	158,40	167,04
4	Dryland Cultivation	19718,73	26391,60	25303,68	26997,39	19290,60
5	Forest	41572,89	27937,35	22097,52	18303,48	10513,17
6	Shrub	2146,86	5723,73	9607,77	16151,31	18327,42
7	Plantation	15678,81	15898,05	21099,87	23575,32	34539,21
8	Bare Soil	3542,13	7983,00	5018,76	1360,17	1551,24
9	Cloud	0,00	1320,48	0,00	0,00	0,00
	Total	95.173,65	95.173,65	95.173,65	95.173,65	95.173,65

The overall accuracy for classified image of 2009 based on error matrix calculation is 85.7 % with kappa statistic of 0.82 (table 5.2). Some errors were because of object reflectance similarity or object resemble. Most of the error took place between water body and paddy field; dry land cultivation, built up area, paddy field, shrub and plantation; and forest, plantation and shrub. Some water body class fell into paddy field which still has water standing. Dry land cultivation has many intersections with many classes since it has various features from bare to planted condition in the same time. It occurred because there is no fix crop calendar. Confusion also occurred between forest, plantation and shrub in some part because those have some reflectance overlap, particularly in infra red bands.

Table 5.2 Error matrix of the 2009 image classified

		Reference Points								Sum	% Comm	% Omm	Est Kappa
		1	2	3	4	5	6	7	8				
Classification Result	1	20	0	0	0	0	0	0	0	20	0,00	20,00	1,00
	2	0	28	0	0	1	1	0	0	30	6,67	12,50	0,93
	3	0	2	7	0	0	0	0	0	9	22,22	0,00	0,77
	4	5	2	0	49	0	7	3	0	66	25,76	5,77	0,69
	5	0	0	0	0	35	1	0	0	36	2,78	22,22	0,97
	6	0	0	0	2	6	32	5	3	48	33,33	25,58	0,61
	7	0	0	0	0	3	2	85	0	90	5,56	8,60	0,92
	8	0	0	0	1	0	0	0	9	10	10,00	25,00	0,90
	Sum	25	32	7	52	45	43	93	12	309			

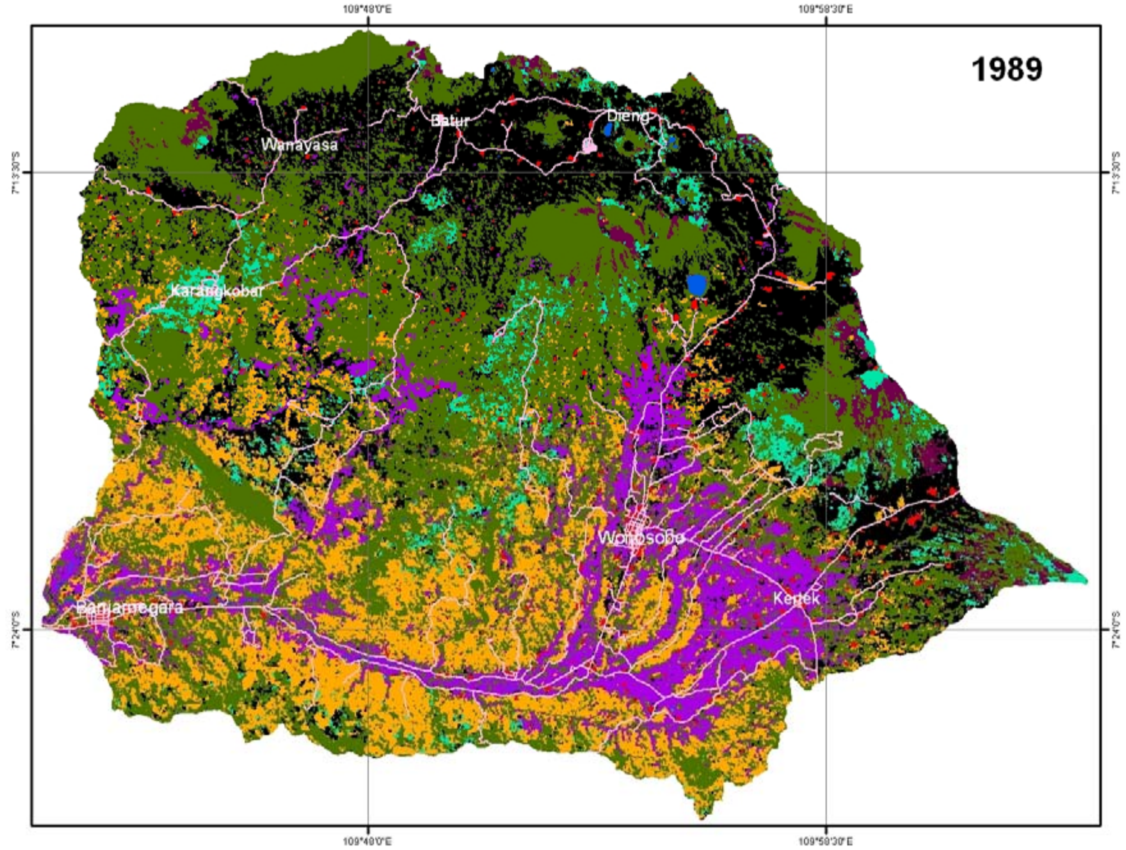


Figure 5.1a Land use / land cover of 1989

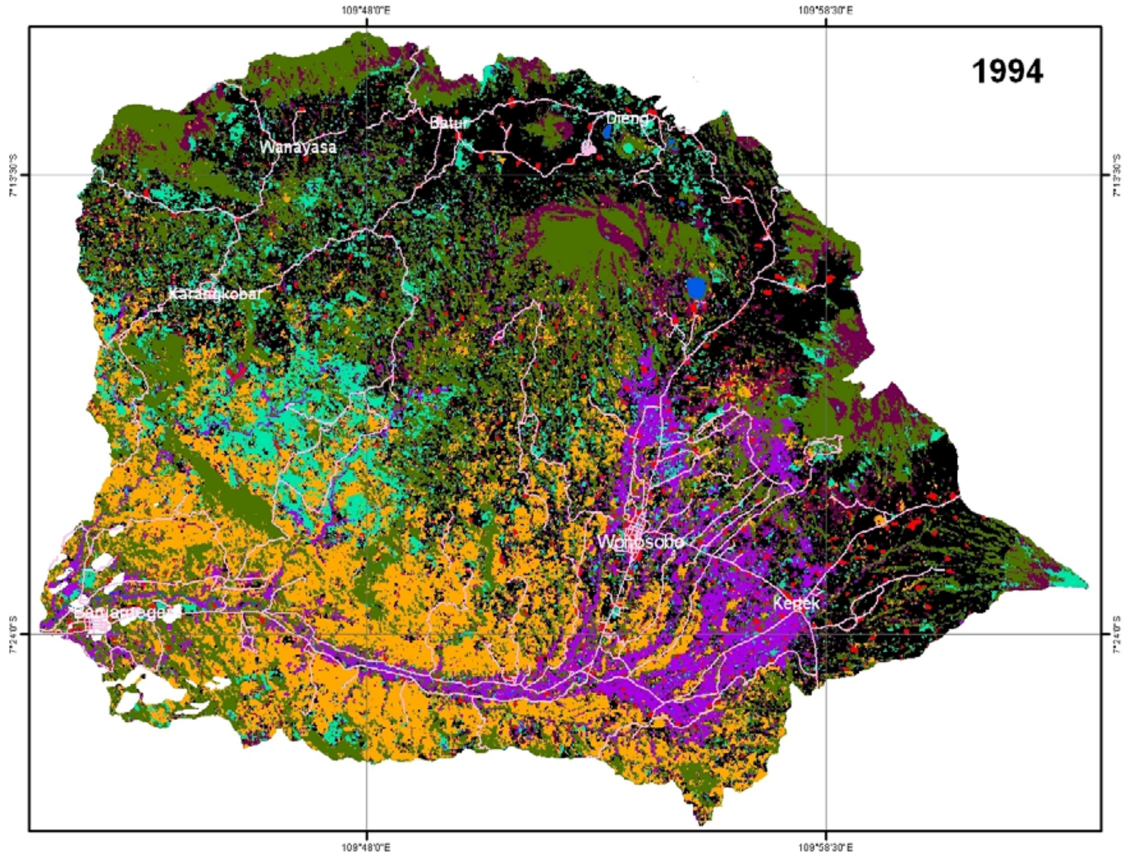


Figure 5.1b Land use / land cover of 1994

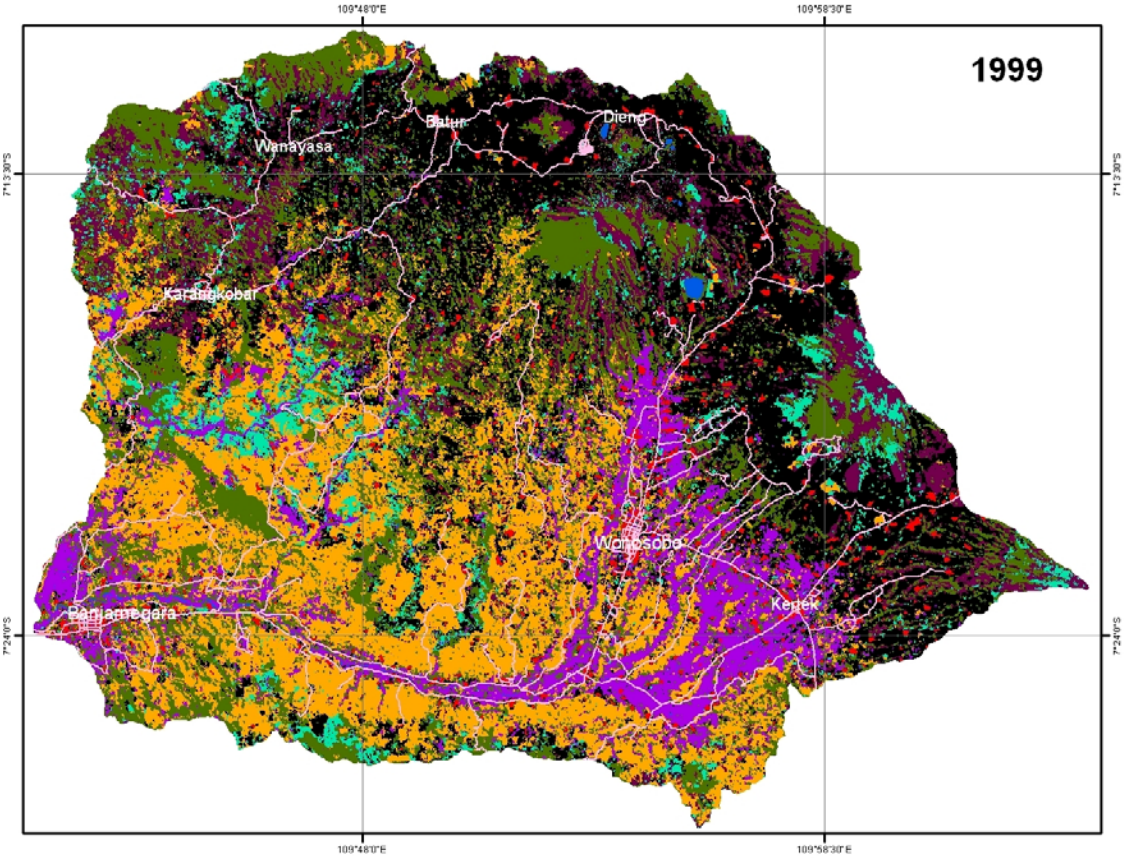


Figure 5.1c Land use / land cover of 1999

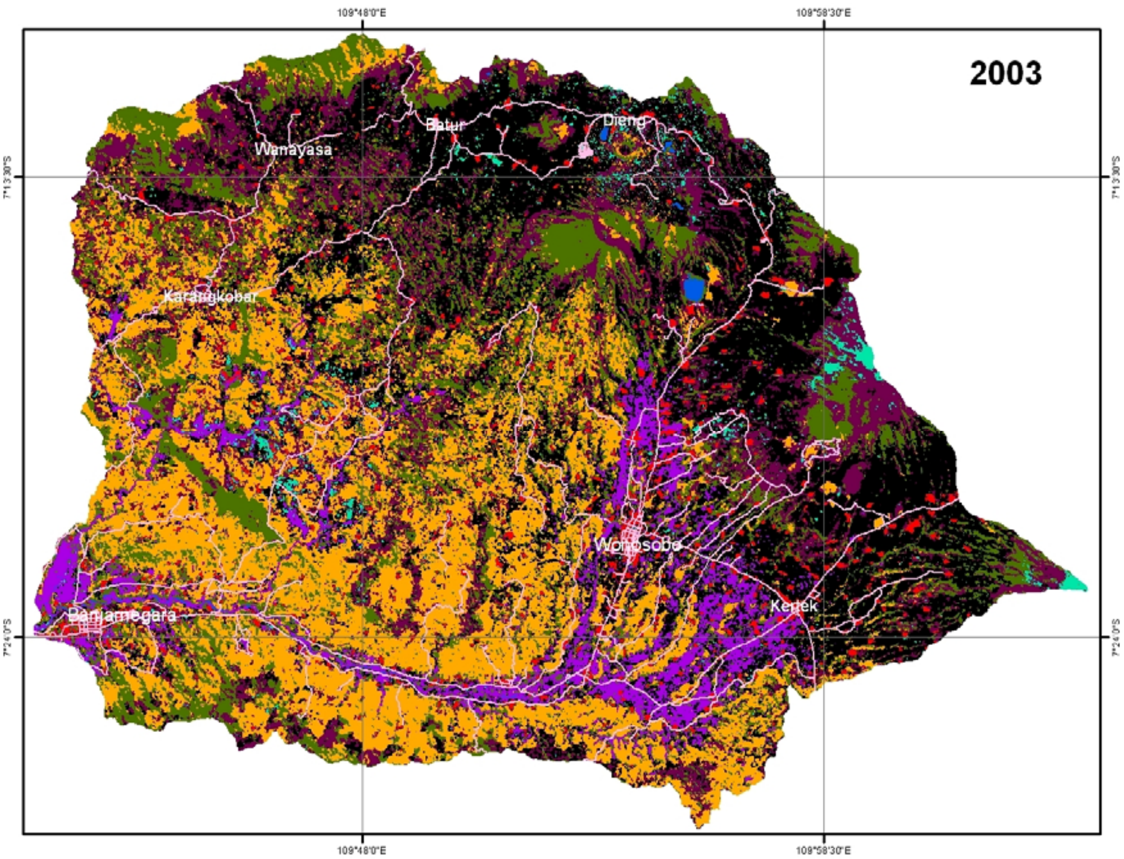


Figure 5.1d Land use / land cover of 2003

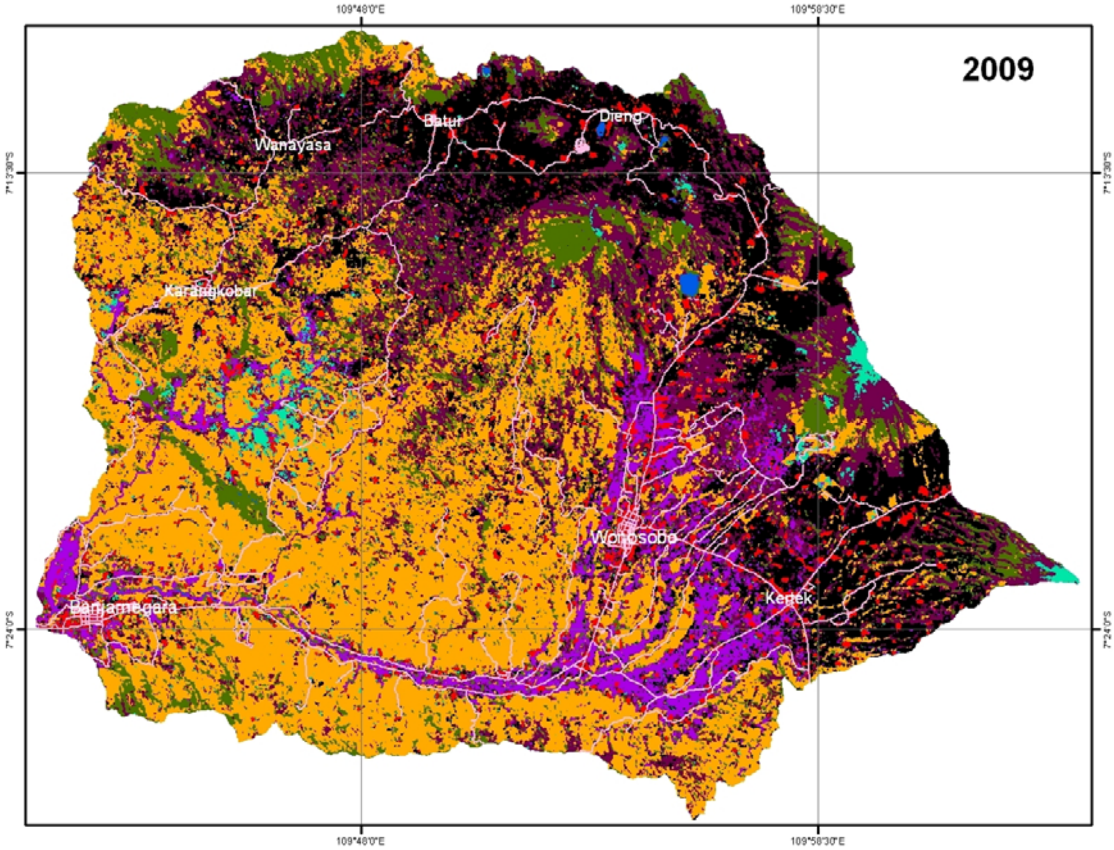


Figure 5.1e Land use / land cover of 2009

5.2. Land Use / Land Cover Changes Analysis

Land use / land cover of Upper Serayu watersheds has underdone a lot of changes during 1989 until 2009 (figure 5.2 and table 5.1).

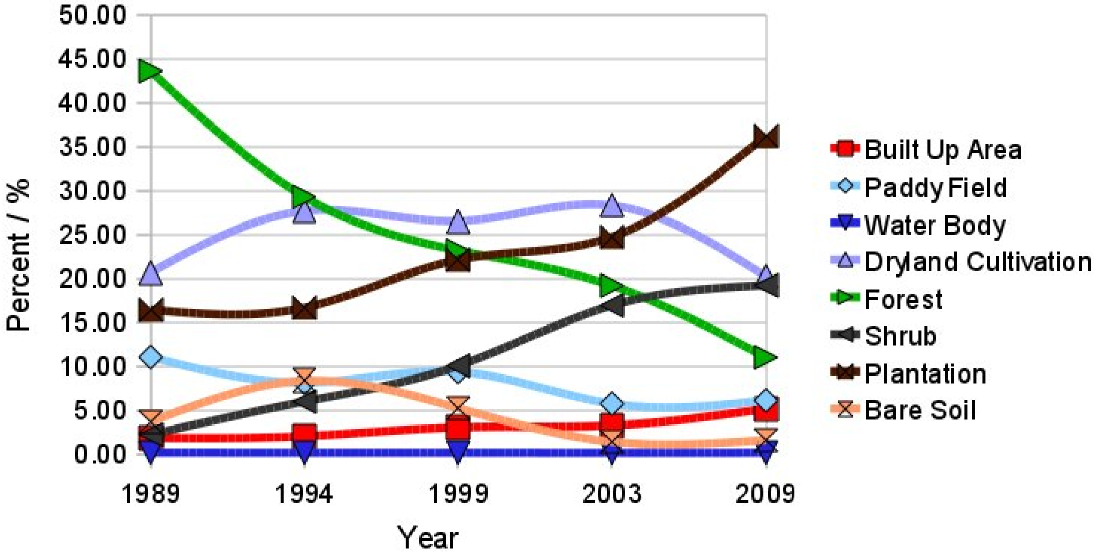


Figure 5.2 Land use land cover dynamic of upper Serayu watershed

In 1989, forest cover was dominated the area, followed by dry land cultivation, plantation and paddy field as the major land use / land cover. In 1994, forest cover still dominated although it was decreasing rapidly, followed by dry land cultivation paddy field and bare soil. For bare soil it could be also paddy field or dry land cultivation after harvesting period. In 1999, domination was taken over by dry land cultivation, followed by forest cover and plantation which almost have same extent and also paddy shrub and paddy field. In 2003 dry land cultivation still dominated land use / land cover of the area and followed by plantation, forest and shrub. In 2009, plantation took over the land use / land cover domination, followed by dry land cultivation, shrub and forest.

From the domination trend of land use / land cover during 1989 to 2009, there are four major changes have been occurred. Forest cover showed decreasing trend from 1989 to 2009. Forest cover in 1989 was 41,572.8 ha and in 2009 it was 10,513.1 ha. The average rate of change was 1552.9 ha per year although the change was rapid during 1989 to 1994. On the other hand, plantation cover showed increasing trend from 1989 to 2009 with annual rate of 943 ha per year. In 1989 plantation cover was 15,678.8 ha and became 34,539.2 ha in 2009. Shrub cover also showed increasing trend. In 1989 it was 2,146.8 ha and in 2009 it was 18,327.4 ha with annual rate of 809 ha per year. Dry land cultivation showed fluctuation during 1989 to 2009. It showed increasing during 1989 to 1994. Dry land cultivation cover was 19,718 ha in 1989 and became 26,391 ha in 1994. It was grew 1334.5 ha per year. During 1994 to 2003, it was relatively not much change. It showed decreasing during 2003 to 2009. In 1999 it was 26,997.4 ha and became 19,290.6 ha in 2009 or decreasing by 1541,4 ha per year. In detail, land use land cover changes of the upper Serayu watershed will be explained in the next section.

5.2.1. Land use / land cover changes during 1989 to 1994

The land use / land cover changes during 1989 to 1994 are showed in table 5.3

Table 5.3Land use / land cover changes during 1989 to 1994

LULC		From				
		Forest	Plantation	Shrub	Paddy Field	Dryland Cultivation
To	Built Up Area	16,2	74,0	0,4	20,3	127,0
	Dryland Cultivation	6.004,9	2.350,7	660,5	2.723,0	
	Paddy Field	879,6		47,1		
	Shrub	1.815,3				
	Plantation	2.952,2		72,6	881,7	
	Bare Soil	1.701,9	739,1	131,5	1.289,8	3.243,9
	Sub Total	13.370,0	3.163,8	912,1	4.914,8	3.370,9
	Total	25.731,5				

Land use / land cover changes during 1989 to 1994 were dominated by conversion of forest, plantation, shrub and paddy field to dry land cultivation. Dry land cultivation and paddy field showed conversion into bare soil in significant extent, but it could also no change in some part since dry land cultivation and paddy field will be looks like bare soil when the satellite captured the area right after harvesting time. Another significant conversion were forest into plantation, forest to shrub and forest to bare soil.

In this time, forest conversion to dry land cultivation and plantation mostly occurred in slope zone more than 15 %. The area of those conversion mostly located in the volcanic foot slope and the eroded scarp between terraces along the Serayu river and Dieng plateau. The general elevation of the forest conversion area is between 800 m up to 1500 m above sea level. Some small part conversion area were located near volcanic cone and ridge in east and north part located in elevation more than 2000m above sea level. Plantation conversion to dry land cultivation mostly occurred in the slope zone more then 8% up to 40% in the middle volcanic foot slope and spread out around eroded scarp area in the middle. Other conversion types were spread out mostly around volcanic foot slope and eroded scarp in the middle part with various slope, but mostly more than 8 %. The conversion of land use / land cover regarding to slope zone are described in table 5.4

Table 5.4 Land use / land cover changes during 1989 to 1994 regarding to the slope zone

Conversion types		Slope Zone (%)						
From	To	0 - 2	>2 - 5	>5 - 8	>8 - 15	>15 - 25	>25 - 40	> 40
Forest	Built Up Area	1,8	2,3	1,6	3,8	3,8	2,3	0,7
	Paddy Field	40,3	101,5	120,8	196,2	183,0	147,5	90,2
	Dryland Cultivation	123,8	252,3	432,8	1.155,8	1.493,8	1.426,6	1.119,6
	Shrub	21,0	37,6	63,1	194,4	333,3	431,6	734,2
	Plantation	45,9	71,9	115,3	373,2	754,7	879,4	711,8
	Bare Soil	28,1	56,6	80,4	266,0	424,8	441,0	404,9
Plantation	Built Up Area	7,7	11,2	12,8	21,4	13,6	6,6	0,8
	Dryland Cultivation	28,6	54,3	72,1	130,8	117,9	74,7	26,2
	Bare Soil	26,5	32,0	49,5	140,4	214,7	183,5	92,5
Shrub	Built Up Area	0,1	0	0,2	0	0	0	0,1
	Paddy Field	1,6	6,8	6,8	8,5	7,3	8,6	7,5
	Dryland Cultivation	5,4	14,2	21,3	100,6	177,0	161,7	179,6
	Plantation	0,4	2,1	2,4	7,5	12,9	17,2	30,2
	Bare Soil	0,7	3,0	4,7	11,8	17,6	24,6	69,1
Paddy Field	Built Up Area	1,4	7,7	6,4	4,2	0,5	0	0
	Dryland Cultivation	140,7	371,6	507,4	724,4	554,0	296,6	128,3
	Plantation	99,4	130,8	102,1	212,5	203,9	104,0	29,1
	Bare Soil	71,6	165,9	205,2	330,7	339,0	140,1	37,3
Dry land Cultivation	Built Up Area	145,9	188,2	211,6	537,6	846,6	772,7	541,4
	Bare Soil	9,6	22,8	24,7	37,5	19,6	9,9	2,9

5.2.2. Land use / land cover changes during 1994 to 1999

The land use / land cover changes during 1994 to 1999 are showed in table 5.5. During 1994 to 1999 period, land use / land cover changes were dominated by conversion of forest, plantation, shrub land and paddy field to dry land cultivation, and conversion of forest to plantation and shrub. Those conversions mostly located around volcanic cone down to volcanic foot slope in the eastern part at slopes mostly more than 8 % and volcanic cone in the north part at slopes more than 40%. The elevation range of those changes was between 1200 m up to 2500 m above sea level. Other changes were spread out mostly near Dieng plateau and at the southern scarp near Banjarnegara city in the south west. Land use / land cover changes during 1994 to 1999 with regarding to slope zone are described in table 5.6.

Table 5.5 Land use / land cover changes during 1994 to 1999

LULC		From				
		Forest	Plantation	Shrub	Paddy Field	Dryland Cultivation
To	Built Up Area	105,0	43,8	9,1	233,9	247,0
	Dryland Cultivation	1.998,4	1.580,7	1.648,5	1.593,5	
	Paddy Field	467,4		295,9		
	Shrub	1.601,8				
	Plantation	1.525,6		963,6	991,5	
	Bare Soil	530,3	537,8	559,5	146,0	1.261,7
	Sub Total	6228,45	2162,34	3476,7	2964,96	1508,67
	Total	16341,12				

Table 5.6 Land use / land cover changes during 1994 to 1999 regarding to the slope zone

Conversion types		Slope Zone (%)						
From	To	0 - 2	>2 - 5	>5 - 8	>8- 15	>15 - 25	>25 - 40	> 40
Forest	Built Up Area	23,0	20,7	15,9	23,9	15,1	4,6	1,9
	Paddy Field	73,7	63,5	51,1	88,3	84,7	60,4	45,7
	Dryland Cultivation	26,9	31,6	65,1	235,2	409,8	531,6	696,5
	Shrub	14,0	15,6	25,5	86,9	217,7	384,2	857,2
	Plantation	41,9	56,3	64,8	180,5	331,8	418,7	431,6
	Bare Soil	6,5	8,7	13,5	35,5	91,3	153,8	221,0
Plantation	Built Up Area	4,7	6,7	7,1	12,1	10,0	2,6	0,7
	Dryland Cultivation	12,2	21,2	37,0	111,7	174,9	194,9	230,4
	Bare Soil	8,6	13,1	19,5	69,8	137,8	161,6	127,4
Shrub	Built Up Area	1,0	1,2	1,9	2,4	1,3	1,2	0,2
	Paddy Field	21,3	54,5	54,1	73,4	57,5	25,9	9,1
	Dryland Cultivation	20,0	48,1	110,3	351,4	378,4	328,0	412,2
	Plantation	14,8	27,5	40,1	128,7	224,6	255,4	272,3
	Bare Soil	4,1	7,7	15,8	48,6	77,0	114,5	291,2
Paddy Field	Built Up Area	21,2	62,5	70,6	52,7	20,8	5,2	0,9
	Dryland Cultivation	50,6	136,2	204,4	438,8	371,7	219,2	172,6
	Plantation	47,2	98,5	118,6	224,7	257,8	177,7	67,1
	Bare Soil	7,2	17,9	15,9	27,1	35,7	25,9	16,2
Dry land Cultivation	Built Up Area	37,9	62,1	95,0	229,3	311,9	290,2	235,3
	Bare Soil	18,1	36,2	47,4	84,9	44,0	12,7	3,7

5.2.3. Land use / land cover changes during 1999 to 2003

In 1999 until 2003 period, conversion from forest, plantation, shrub and paddy field to dry land cultivation were dominated. The forest conversion to dry land cultivation has been decreased then previous period, it was more conversion to plantation and shrub. Meanwhile, conversion from dry land cultivation to built up area, paddy field to plantation and shrub to plantation also showed significant extents. The land use / land cover changes during 1999 to 2003 are showed in table 5.7

Table 5.7 Land use / land cover changes during 1999 to 2003

LULC		From				
		Forest	Plantation	Shrub	Paddy Field	Dryland Cultivation
To	Built Up Area	3,9	14,1	4,0	31,1	477,5
	Dryland Cultivation	645,6	2.592,2	1.978,1	3.408,4	
	Paddy Field	227,5		14,5		
	Shrub	978,6				
	Plantation	1.909,6		2.336,3	685,8	
	Bare Soil	23,5	80,5	214,9	86,5	144,3
	Sub Total	3788,64	2686,77	4547,79	4211,82	621,81
	Total	15856,83				

Many paddy field area became dry land cultivation in the volcanic foot slope down to terraces along river valley (Serayu river) in the east part. A large conversion of shrub to dry land cultivation also occurred more to the upper part into volcanic cone in the same area. Those changes occurred mostly in the terraces near Serayu river up to volcanic foot slope zone at the slopes between 2% to 25%, and in the volcanic cone with slopes more then 15%. Conversion of forest to plantation occurred in the hilly area in the south, scarp area in the middle and mountainous area in the north part. This conversion occurred at > 15 % slopes area. Other changes conversion of plantation to dry land cultivation was spread out across scarp area in the middle part of the watershed. Land use / land cover changes during 1999 to 2003 with regarding to slope zone are described in table 5.8.

Table 5.8 Land use / land cover changes during 1999 to 2003 regarding to the slope zone

Conversion types		Slope Zone (%)						
From	To	0 - 2	>2 - 5	>5 - 8	>8 - 15	>15 - 25	>25 - 40	> 40
Forest	Built Up Area	0,7	0,6	0,8	0,8	0,7	0,2	0
	Paddy Field	22,3	38,3	36,4	55,0	42,0	23,6	10,0
	Dryland Cultivation	21,2	41,6	56,1	125,7	147,4	134,1	119,3
	Shrub	14,9	20,3	33,8	106,7	173,9	255,3	373,5
	Plantation	30,7	44,5	78,5	227,5	423,9	549,1	555,4
	Bare Soil	1,0	1,6	0,9	1,5	4,2	4,1	10,2
Plantation	Built Up Area	2,1	2,3	2,7	3,2	2,7	1,2	0
	Dryland Cultivation	40,7	76,7	70,7	120,5	107,3	47,2	15,4
	Bare Soil	2,7	6,7	6,6	14,4	27,6	16,2	6,3
Shrub	Built Up Area	0	0,2	1,1	1,0	0,5	0,8	0,4
	Paddy Field	0,8	2,0	2,0	2,7	2,5	1,6	2,9
	Dryland Cultivation	47,0	58,3	88,8	326,4	453,3	459,9	543,7
	Plantation	37,4	52,3	87,1	259,7	488,2	608,7	803,0
	Bare Soil	2,0	3,2	4,7	13,7	17,1	37,0	136,5
Paddy Field	Built Up Area	4,1	8,8	11,3	4,2	1,5	0,7	0,5
	Dryland Cultivation	222,5	618,1	789,1	905,3	549,4	234,6	89,4
	Plantation	35,6	60,9	62,9	137,1	184,0	133,1	72,2
	Bare Soil	7,9	15,4	10,5	16,6	19,0	11,0	6,1
Dry land Cultivation	Built Up Area	18,5	24,6	34,8	89,6	105,4	95,9	108,7
	Bare Soil	9,8	17,8	25,0	46,0	29,7	12,7	3,2

5.2.4. Land use / land cover changes during 2003 to 2009

The land use / land cover changes during 1999 to 2003 are showed in table 5.9

Table 5.9 Land use / land cover changes during 2003 to 2009

LULC		From				
		Forest	Plantation	Shrub	Paddy Field	Dryland Cultivation
To	Built Up Area	91,1	23,8	615,2	85,4	839,0
	Dryland Cultivation	497,3	571,4	2.660,8	588,6	
	Paddy Field	268,7		338,9		
	Shrub	2.376,3				
	Plantation	4.451,9		4.638,4	583,7	
	Bare Soil	66,1	114,3	650,6	55,9	311,6
	Sub Total	7751,3	709,4	8903,8	1313,6	1150,5
	Total	19828,89				

In 2003 until 2009 period, the land use / land cover conversion to dry land cultivation has reduced significantly in almost all change types. Significant conversion to dry land cultivation was showed only in from shrub land. There is steady increase of plantation from forest and shrub land conversions and shrub land from forest conversion. Built up area has showed increasing as conversion result from dry land cultivation and shrub.

Table 5.10 Land use / land cover changes during 2003 to 2009 regarding to the slope zone

Conversion types		Slope Zone (%)						
From	To	0 - 2	>2 - 5	>5 - 8	>8 - 15	>15 - 25	>25 - 40	> 40
Forest	Built Up Area	7,1	7,4	9,4	18,1	20,0	17,8	11,3
	Paddy Field	18,4	29,3	26,6	53,5	66,3	51,6	23,0
	Dryland Cultivation	13,9	29,7	39,2	95,3	119,7	106,3	93,2
	Shrub	50,2	76,0	118,2	315,5	438,4	538,5	838,5
	Plantation	107,6	141,1	208,1	582,3	1.059,4	1.227,9	1.125,6
	Bare Soil	2,3	3,1	3,7	11,7	23,6	14,5	7,3
Plantation	Built Up Area	0,7	2,9	1,5	5,6	7,7	3,6	1,8
	Dryland Cultivation	10,1	19,2	14,7	32,6	37,1	21,7	9,0
	Bare Soil	1,5	2,1	4,9	25,0	40,6	34,1	6,1
Shrub	Built Up Area	39,8	57,4	74,6	156,7	147,8	93,5	45,5
	Paddy Field	12,2	19,4	31,4	112,3	84,6	56,8	22,2
	Dryland Cultivation	136,5	145,6	211,9	514,4	647,7	545,0	459,7
	Plantation	78,39	129,87	183,1	615,0	1.105,1	1.247,7	1.279,4
	Bare Soil	23,7	25,6	29,5	93,0	148,6	125,2	205,0
Paddy Field	Built Up Area	15,0	23,5	16,5	12,5	8,2	6,3	3,4
	Dryland Cultivation	57,4	151,2	147,9	128,3	69,0	26,5	8,3
	Plantation	50,8	66,1	64,4	165,1	152,7	66,5	18,2
	Bare Soil	3,7	4,1	5,1	15,0	18,7	8,2	1,0
Dry land Cultivation	Built Up Area	10,1	15,3	22,6	76,7	109,6	57,7	19,6
	Bare Soil	55,5	146,7	164,6	210,9	142,2	82,2	36,9

Plantation grew significantly during 2003 and 2009. Mostly plantation occupied forest area more to the upper part and more to steep slope in the volcanic foot slope and eroded scarp. In the east part, conversions from shrub to dry land cultivation continue in the volcanic footslope and volcanic cone zone. Conversion of dry land cultivation to built up area occurred around Wonosobo city and along the road between Wonosobo to Kertek. This area is volcanic footslope with slope between 2% up to 8%. Land use / land cover changes during 1999 to 2003 with regarding to slope zone are described in table 5.10.

5.3. Soil Erosion Assessment

The effect of land use / land cover changes in upper serayu watershed during 1989 until 2009 increase soil erosion. This is because of decreasing canopy cover and increasing surface exposure to rainfall. The decreasing canopy cover increases the run off volume thus increasing soil detachment and transportation capacity.

5.3.1. Sedimentation in PBS Reservoir during 1989 to 2008

Based on the sedimentation data in the PBS reservoir for the period 1989-2008, the sedimentation in the reservoir in general seems to have increasing trend (figure 5.3). Highest sedimentation (7 million m^3) is in the year 2000, followed by 1998 and 1991. Whether this is related to high rainfalls in those years cannot be verified since reliable data is not available. The comparisons then have to be done by using river discharge data.

As a comparison, figure 5.4 shows the ratio between the annual sedimentation and the annual discharge. It shows that the trend is also the same with the sedimentation rate, means that more higher the discharge will be followed by more sedimentation in the reservoir. Figure 5.5 shows the ratio between annual run off and discharge ratio. It shows that the trend of annual run off in upper serayu watershed is increasing during 1989 to 2009. This could be occurred related to land use / land cover changes which showed of reducing forest cover and increasing of cultivation and plantation area. Increasing of run off could increase the detachment of soil and transport capacity.

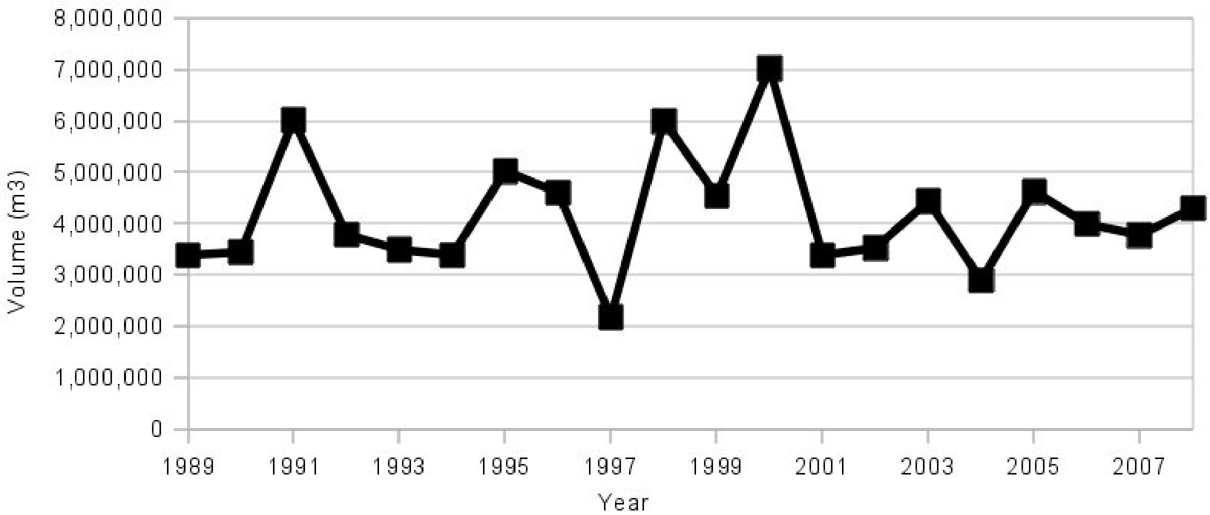


Figure 5.3 Sedimentation in PBS reservoir during 1989 to 2008 (Data source: PT. Indonesia Power UBP Mrica)

Mean	Maximum	Minimum	Standard Deviation
4,189,586	7,027,165	2,174,447	1,158,143

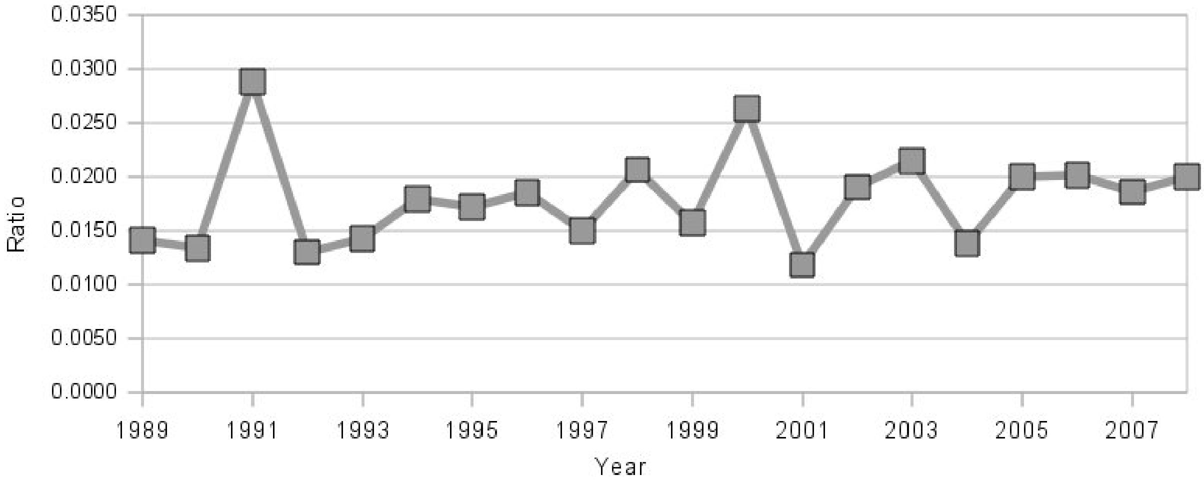


Figure 5.4 Sedimentation and discharge ratio in PBS reservoir during 1989 to 2008 (Data Source : PT. Indonesia Power UBP Mrica)

Mean	Maximum	Minimum	Standard Deviation
0.0018	0.0029	0.0012	0.0004

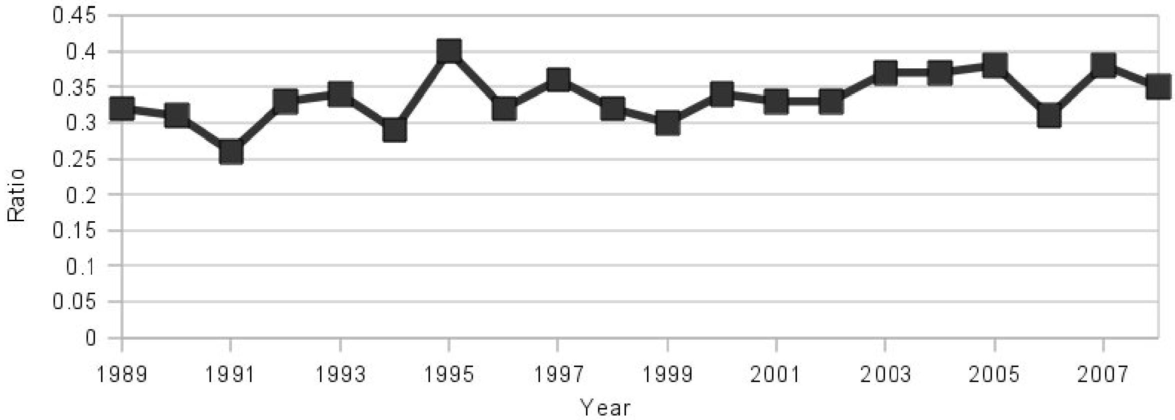


Figure 5.5 Runoff and Discharge Ratio in Upper Serayu Watershed during 1989 to 2008 (Data Source : PT. Indonesia Power UBP Mrica)

Mean	Maximum	Minimum	Standard Deviation
0.3424	0.4000	0.2900	0.0307

From the graph analysis, it can be concluded that erosion in upper Serayu watershed was showing increasing trend during 1989 until 2008. This conclusion is accordance to the land use / land cover changes conclusion due to soil erosion.

In detail, some sediment point observations could be link directly with the pattern of land use / land cover changes. In 1991 there was a high sediment transport into the reservoir. It was accordance with sediment and discharge ratio, but opposite to the run off and discharge ratio. Considering to the land use / land cover changes during 1989 to 1994, there was significant land use / land cover changes to dry land cultivation. In this time also showed the significant decrease of forest cover. This two data is coherent regarding to soil erosion analysis. However, since the land use / land cover observation interval was 5 year, it should be confirmed with the particular year image or land use / land cover information.

In figure 5.6, comparison of sediment and discharge is given for the period before and after 1999. During 1999 until 2003 there was significant changes of land use / land cover into dry land cultivation in the lower slope up to volcanic cone in the upper slope. This results in high sedimentation as compared to the period before 1999.

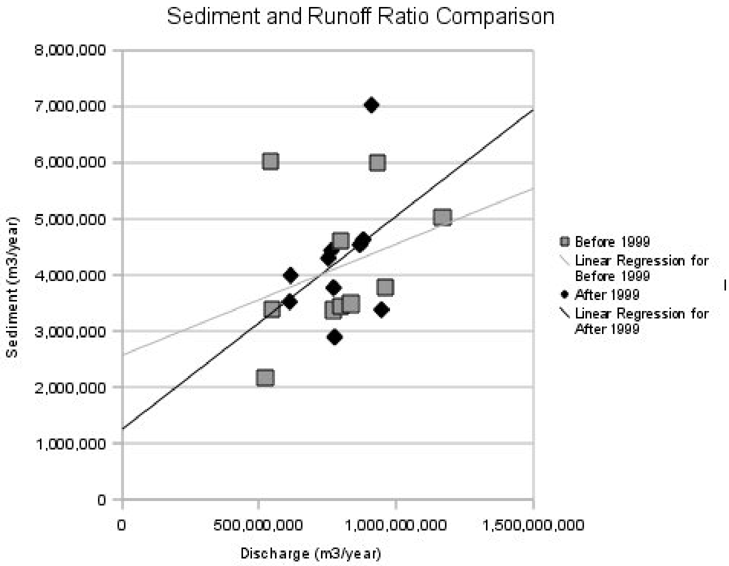


Figure 5.6 Sediment and discharge comparison before and after 1999

The high sedimentation rate in the reservoir is an indication of increasing soil erosion during that period in the area.

5.3.2. Soil Erosion Prediction

Revised Morgan-Morgan and Finney model was applied to estimate soil erosion in the area. Using the land use / land cover classification of the area at 5 years interval it was possible to assess soil erosion for the year 1989, 1994, 1999, 2003 and 2009. The results are shown in the table 5.11, 5.12 and figure 5.7 (for land use / land cover of 2009).

Table 5.11: Soil Loss Estimation in Upper Serayu watershed based on land use / land cover

Land Use / Land Cover	Soil Loss Estimation (ton/ha/yr)				
	1989	1994	1999	2003	2009
Paddy Field	0,04	0,04	0,03	0,03	0,04
Dry land Cultivation	57,70	62,57	59,63	62,18	63,62
Forest	0,24	0,22	0,22	0,23	0,22
Shrub	5,05	3,47	4,04	4,18	4,35
Plantation	16,48	15,41	13,19	14,85	14,56
Bare Soil	369,73	221,76	344,63	432,02	370,37

The total estimated sediment delivery and run off (table 5.12) can only be compared with observed data during 2001 to 2005 due to rainfall data limitation. The results are 0.94 for ratio of estimated and observed runoff, and 0.46 for ratio of estimated and observed sediment delivery.

Table 5.12 Total Soil Loss and runoff estimation in Upper Serayu watershed based on land use / land cover

Land Use / Land Cover	Total Soil Loss Estimation (ton/yr)				
	1989	1994	1999	2003	2009
Paddy Field	374	295	274	179	206
Dry land Cultivation	1,137,727	1,651,431	1,508,880	1,678,589	1,227,306
Forest	9,856	6,130	4,958	4,205	2,266
Shrub	10,843	19,852	38,778	67,531	79,712
Plantation	258,432	245,057	278,209	350,055	502,935
Bare Soil	1,309,636	1,770,296	1,729,619	587,614	574,536
Total	2,728,857	3,695,055	3,562,718	2,688,174	2,388,969
Annual Run off Estimation (m3)	826,154,772		858,361,008	751,263,830	818,004,234
Annual Sediment Delivery Estimation (m3)	1,774,484	2,635,838	2,316,715	1,748,029	1,553,466

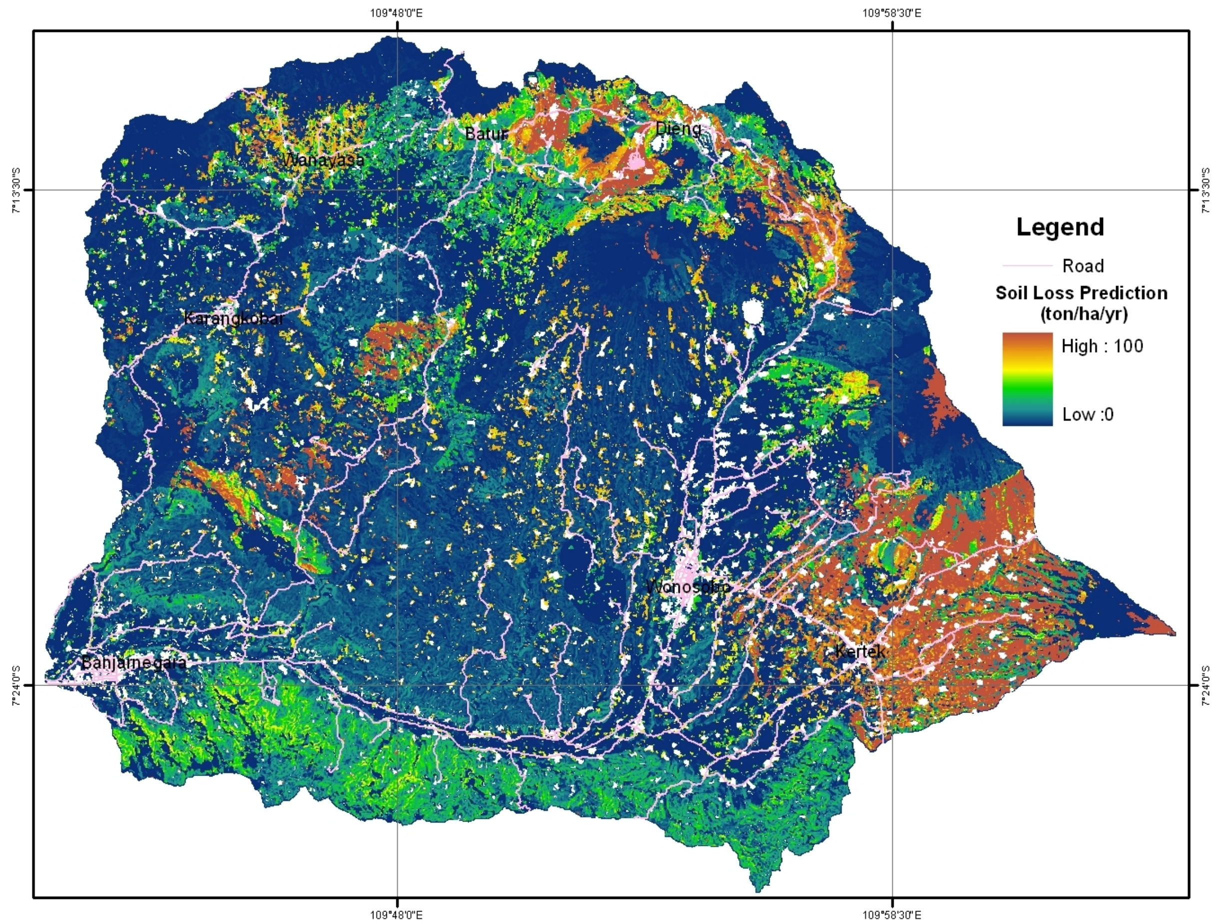


Figure 5.7 Soil loss estimation of 2009 in upper Serayu watershed

The highest soil erosion is in bare soil and followed by dry land cultivation and plantation (table 5.11). Dry land cultivation showed high value because most of it is located in the sloppy area (volcanic foot slope up to lower volcanic cone) and it didn’t apply proper soil conservation (according to field observation). Beside that, canopy cover and ground cover factor of dry land cultivation is the lowest among vegetation cover types. It gives more soil detachment by rain fall and runoff.

Plantation also showed high value because it is located in the sloppy area. Most of plantation is located in the middle and south part which are hilly terrain. Plantation has wide canopy, relatively high and less dense in ground cover. It can result soil detachment from leaf drainage and direct through fall. Less dense in ground cover can also result to more soil detachment by runoff.

Dynamic of soil loss estimation follow the land use / land cover changes. Conversion from forest to dry land cultivation during 1989 to 1999 has increased the soil loss. During 1999 to 2009, soil loss estimation has decreased following the decrease of bare soil and the growth of plantation.

5.4. Reservoir lifetime prediction

The reservoir live time were predicted based on sedimentation rate pattern and based on modelling result. The starting point is in 2008 when the reservoir volume is 64,495,279 m^3.

According to the sedimentation data analysis, the mean value of sedimentation per year is 4,189,586m^3. The live time or the reservoir could be estimated as follow:

$$\text{Lifetime estimation} = \frac{\text{The rest of reservoir volume}}{\text{Sedimentation rate}} \tag{5.1}$$

$$= \frac{64{,}495{,}279\ m^3.}{4{,}189{,}586\ m^3/\text{year.}}$$

$$= 15.39 \text{ years}$$

This mean the reservoir will be in the end of operation in 2023.

According to modelling result, starting point in 2003, when the reservoir volume is 84,084,812 m^3 and estimated sediment delivery is 1,748,029 m^3. The live time or the reservoir could be estimated with equation (5.1), as follow:

$$\text{Lifetime estimation} = \frac{84{,}084{,}812\ m^3.}{1{,}748{,}029\ m^3/\text{year.}}$$

$$\text{Estimation live time} = 48.1 \text{ years}$$

This mean the reservoir will be in the end of operation in 2051.

6. Discussion

6.1. Land Use / Land Cover Classification

6.1.1. The Significant of Classification Methods

This research has used sequential maximum a posteriori (SMAP) algorithm for the classification process which increased the overall accuracy by 15% (appendix 7) as compared with that obtained by applying maximum likelihood classification (MLC) algorithm. Overall classification of 85.7 % was obtain by applying SMAP, meanwhile by using MLC algorithm was only 69.9 %. It was observed visually that the result of SMAP classification yielded larger contiguous area and less speckles as compared to that MLC algorithm. Improvements were increased classification accuracy of forest by 16.5%, shrub by 25.5% and plantation by 18.5%. Classification accuracy of built up area are also increased by 10%, paddy field by 3%, dry land cultivation by 12% and bare soil by 30%. On the other hand, accuracy of classifying water body decrased by 10%, it was confused with paddy field. The result of applying SMAP algorithm confirms with the assessment by McCauley & Engel (1995). Better results obtained in applying SMAP algorithm rather is because both spectral and spatial signatures are considered by this algorithm (Neteler & Mitasova 2005), while MLC is based on only the spectral signatures. Similar results are reported for land use/land cover classification by Bouman & Shapiro (1994).

6.1.2. The Influence of Topographic Correction

Topographic correction was employed to reduce the effect of illumination variations in different topographic positions. Objects facing the Sun will receive more as compared to the objects facing away from the sun. This could cause error in classification results. Magnitude and spatial distribution of topographic effect are dependent on solar incidence angle, solar azimuth and topographic roughness. Classification after topographic correction has shown the increase of overall accuracy by 5.5% (appendix 7). Effect of illumination differences can cause miss-classification. For example forest areas located in mountainous slopes facing the sun has possibility to fall into plantation or shrub because of high illumination. Meanwhile shrub and plantation classes in the shadow area could fall into forest class because of low illumination. Accuracy of forest, shrub and plantation classes after topographic correction increase around 6%, 4% and 16% respectively. The increasing of accuracy assessment show that topographic correction was effective to increase separability in vegetation classification of the area.

In built up area, water body, dry land cultivation and bare soil areas, there is no influence with topographic correction. On the other hand, some paddy field were misclassified as forest and shrub area after topographic correction, most probably due to underestimating paddy field in illuminated area.

6.1.3. Previous Images Classification

This research has been applied a feature space signatures method by using angles and magnitude of reflectance value from classified image to classify previous images. The basic of this method based on principle that every object has unique reflectance signature. If the object not changes, it will show the same reflectance every time. However, this principle should be supported by assuming of no influence between object and sensor. Therefore, atmospheric and topographic correction is necessary to conduct.

In classified image, object reflectance in the same class will be segmented into one area in the feature space. Usually the area of one class in feature space will be indicated by cloud. By assessing the cloud position, it will obtain a signature of an object class. The position of the signature is defined by magnitude of pixel from several bands and angles of the magnitude from each band axis in feature space. By applying this signature in previous image that have atmospheric and topographic correction, it could be obtained class signatures as training sample for further classification process.

6.2. Erosion Prediction Evaluation

RMMF soil erosion modelling has obtained soil loss prediction in upper Serayu watershed. The result could explain soil erosion in the area based on different land use / land cover situation. But it's still needed to be validated and calibrated by field measurement. However, based on comparison with actual sedimentation in PBS reservoir, RMMF model can only explain 46% of annual sediment transport in 2003. In the other hand, RMMF could explain 94% of annual runoff in the same time.

To obtain more realistic sediment transport estimation, it is needed to run flow accumulation principle instead of comparison between discharge and rainfall approach as it is used in this research. By running flow accumulation, soil detachment by runoff and sediment transport will also take into account contribution of the upper slope.

6.3. Social and Demographic Influences to The Land Use / Land Cover Changes

Land use / land cover changes in upper Serayu watershed has been influenced by social and demographic condition of the area and also from external area. According to the Wonosobo and Banjarnegara statistical agency (1981 – 2007), population in the upper Serayu watersheds has increased by 3 % during 1981 until 2007 and the mean annual growth was 0,5 %. Highest population growth of 6% occurred during 1989 until 1999. Then it started to decrease from 2004 by 4% and 2% in 2007. In 2007 estimate population in upper Serayu watershed reached 1.6 million. Most of the population depend on agriculture and contribute 46 % of the gross regional domestic product (GRDP). Other products were from trading, hotel and restaurant, processing industry, public service and construction.

The high population growth (6%) during 1989 until 1999 could explain the increase of dry land cultivation in the area by deforestation. In an average a farmer has only 0.5 Ha of farm land (Dan & Friyatno 2000). This could explain the demand of land for cultivation in the area. According to the local government information, during 1985 until 1995 potato cultivation has reached the peak of glory in the area. The production rate in that time was about 135,000 ton / year just in Dieng plateau area alone, with the cultivation land extent about 6,000 ha. In this time farmer tried to expand their land deforestation. In this situation, farmer and local government could obtain high income. The expansion of cultivation area by converting forest couldn't be avoided by local government, because land owner regulation in the rural area still followed traditional rule from generation to generation. This situation started to end when the price of potato starts to fall down and also because of fertility soil decreasing. According to field observation, farmer doesn't really apply soil conservation practices. They don't make real terraces and still cultivate the crop down to the slope. This condition have made problem to soil erosion. After 1995, when the potato production was decreasing, many people in the area went to urban area such as Jakarta, Semarang, Jogjakarta and Yogyakarta to find job. Some former dry land cultivation which has been decreased in fertility started to plant with albisia falcataria (albasiah/sengon) as commercial log/wood commodity.

In 1997, when Indonesia fell into financial crisis, many industrial companies fell into bankruptcy. Many people in urban area came back to their home villages to find better opportunity. It was also occur in the area when many people came back to their home village from several urban areas. They start to cultivate again their land, but this time they went to upper slope to get better soil fertility or get new land. This situation could be confirmed with the research of Lavigne & Gunnell (2006). From the land use / land cover analysis it also could be confirmed that cultivation land increased from 1994 until 2003 which converted shrub and forest in the foot slope up to lower volcanic cone. This occurred almost in all the area, but more concentrated in the eastern part in the foot slope up to lower volcanic cone of Sumbing and Sundoro. During 2003 until 2009, many farmers in foot slope of volcanic area and middle relief between terraces and Dieng plateu start to make intercroping between dry land crop (cassava, spice and zallaca) and wood plant of albisia falcataria (albasiah/sengon). However, potato and cabbage were still cropped by taking more land to the upper slope. This condition still gives problem to soil erosion as shown in the reservoir sedimentation report (PBS, 2009).

7. Conclusion and Recommendation

7.1. Conclusion

1. Sequential maximum a posteriori classification (SMAP) algorithm gave better result in land use / land cover classification compared with maximum likelihood classification algorithm.

2. Topographic correction in mountainous area is important to increase land use / land cover classification result.

3. Feature space signature by using reflectance angles and magnitudes and SMAP algorithm are useful to predict previous land use / land cover.

4. Land use / land cover changes in upper Serayu watershed has affected to the increase the sedimentation in PBS reservoir.

5. Revised Morgan-Morgan and Finney method could explain soil loss in the area based on different land use / land cover condition. However in total soil loss it still underestimate the actual soil erosion, compared with sedimentation data in the reservoir.

7.2. Recommendation

1. The land use / land cover maps need to be assessed by local expert and local government to increase the reliability.

2. Actual soil loss data are needed to validate model results.

3. Daily sedimentation data in PBS reservoir during the research period are needed to explain more about erosion history in the catchment.

4. The social and demographic analysis and discussion need more input of data and regulation history from local government.

References

Anderson, B.J. et al. 1976. *A Land Use And Land Cover Classification System For Use With Remote Sensor Data* 964 ed. Washington: United States Department of the Interior and USGS.

Banjarnegara and Wonosobo, S.A. 2007. *Statistics of Wonosobo and Banjarnegara 2007*.

Berberoglu, S. et al. 2009. Assessing different remote sensing techniques to detect land use/cover changes in the eastern Mediterranean. *International Journal of Applied Earth Observation and Geoinformation*, **11**(1), pp. 46-53.

Bonan, G.B. et al. 2004. Land Use and Climate in *Land Change Science*. Remote Sensing and Digital Image Processing. Dordrecht: Springer Netherlands, pp. 301-314. Available at:

Bouman, C.a. et al. 1994. A multiscale random field model for Bayesian image segmentation. *IEEE transactions on image processing : a publication of the IEEE Signal Processing Society*, **3**(2), pp. 162-77.

Chen, J. et al. 2003. Land-Use/Land-Cover Change Detection Using Improved Change-Vector Analysis. *Photogrammetric Engineering & Remote Sensing*, **69**(4), pp. 369-379.

Chhabra, A. et al. 2006. Multiple Impacts of Land-Use/Cover Change in *Land-Use and Land-Cover Change*. Global Change - The IGBP Series. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 71-116.

Congalton, R.G. 2004. Putting the Map Back in Map Accuracy Assessment in Lunetta, R. S. et al., *Remote Sensing and GIS Accuracy Assessment*. Boca Raton: CRC Press, p. 305.

Crippen, R.E. 1987. The regression intersection method of adjusting image data for band ratioing. *International Journal of Remote Sensing*, **8**(2), pp. 137-155.

Csiszar, I. et al. 2004. Land Use and Fires in *Land Change Science*. Remote Sensing and Digital Image Processing. Dordrecht: Springer Netherlands, pp. 329-350.

Dan, S. et al. 2000. Analisis keunggulan komparatif dan kompetitif komoditas kentang dan kubis di wonosobo jawa tengah. *Policy Analysis*, (5), pp. 1-30.

Davis, T. et al. 2007. Spatial variability and temporal dynamics analysis of soil erosion due to military land use activities: uncertainty and implications for land management. *Land*, **542**(February), pp. 519-542.

Djajadilaga, M. et al. 2009. Status Lingkungan Hidup Indonesia 2008 (State of Environment Report of Indonesia). , p. 177.

Elvidge, C.D. et al. 2004. Urbanization in *Land Change Science*. Remote Sensing and Digital Image Processing. Dordrecht: Springer Netherlands, pp. 315-328.

Emadodin, I. et al. 2009. Interdisciplinary and multidisciplinary approaches to the study of long-term soil degradation: A case study from Schleswig-Holstein, Germany. *Land Degradation & Development*, **9999**(9999), pp. n/a-n/a. Available at: http://doi.wiley.com/10.1002/ldr.941.

Evans, R. 2006. Land Use, Sediment Delivery and Sediment Yield in England and Wales in Owens, P. et al., *Soil Erosion and Sediment Redistribution in River Catchments*. Wallingford Oxfordshire: CABI, pp. 70-84.

Flygare, a. 1997. A comparison of contextual classification methods using Landsat TM. *International Journal of Remote Sensing*, **18**(18), pp. 3835-3842.

Fornis, R. et al. 2005. Kinetic energy–rainfall intensity relationship for Central Cebu, Philippines for soil erosion studies. *Journal of Hydrology*, **300**(1-4), pp. 20-32.

Garc, D. 2009. Effects of land-use changes in vegetation cover and sidewall erosion in a gully head of the Penedès region (northeast Spain). *EARTH SURFACE PROCESSES AND LANDFORMS*, **1937**(October), pp. 1927-1937.

Gomarasca, M.A. 2009. *Basics of Geomatics*. Dordrecht: Springer Netherlands.

Hansen, A.J. et al. 2004. Land Use Change and Biodiversity: A Synthesis of Rates and Consequences during the Period of Satellite Imagery in *Land Change Science*. Remote Sensing and Digital Image Processing. Dordrecht: Springer Netherlands, pp. 277-299.

Houghton, R.H. et al. 2004. Land Change Science in *Land Change Science*. Remote Sensing and Digital Image Processing. Dordrecht: Springer Netherlands, pp. 237-256.

Ilaco 1989. *Agricultural compendium for rural development in the tropics and subtropics* Third revi. Amsterdam: Elsevier.

Keesstra, S. et al. 2009. Changing sediment dynamics due to natural reforestation in the Dragonja catchment, SW Slovenia. *Catena*, **78**(1), pp. 60-71.

Kemling, M.L. et al. 2005. *Encyclopedia of World Climatology* Encycloped. (J. O. Oliver). Dordrecht: Springer.

Kontoes, C.C. 2008. Operational land cover change detection using change vector analysis. *International Journal of Remote Sensing*, **29**(16), pp. 4757-4779.

Lam, N.S. 2008. *Advances in Land Remote Sensing*. Dordrecht: Springer Netherlands.

Lambin, E. et al. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change*, **11**(4), pp. 261-269. Available at:

Lambin, E.F. et al. 2006. Introduction: Local Processes with Global Impacts in *Land-Use and Land-Cover Change*. Global Change - The IGBP Series. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 1-8.

Landgrebe, D.A. 2003. *Signal Theory Method in Multispectral Remote Sensing*. New Jersey: Wiley & Sons.

Lavigne, F. et al. 2006. Land cover change and abrupt environmental impacts on Javan volcanoes, Indonesia: a long-term perspective on recent events. *Regional Environmental Change*, **6**(1-2), pp. 86-100.

Liang, S. 2008. Recent Advances in Land Remote Sensing: An Overview in *Advances in Land Remote Sensing*. Dordrecht: Springer Netherlands, pp. 1-6.

Lillesand, T. et al. 2000. *Remote sensing and image interpretation* Fourth. New York: Wiley & Sons.

Lunetta, R.S. et al. 1995. Relative Radiometric Normalization Landsat Multispectral Scanner (MSS) Data Using an Automatic Scattergram Controlled Regression. *American Society for Photogrammetry and Remote Sensing*, **61**(10), pp. 1225-1260.

Markham, B.L. et al. 1997. *Landsat MSS and TM Post-Calibration Dynamic Ranges, Exoatmospheric Reflectance and At-Satellite Temperature*. Greenbelt.

Mather, P. et al. 2009. *Classification Methods for Remotely Sensed Data, Second Edition* Second. Boca Raton: CRC Press.

McCauley, J. et al. 1995. Comparison of scene segmentations: SMAP, ECHO, and maximum likelihood. *IEEE Transactions on Geoscience and Remote Sensing*, **33**(6), pp. 1313-1316.

Ministry Of Public Work Republic Of Indonesia, W.R. 2009. Profil Balai Besar Wilayah Sungai Serayu-Opak (Serayu-Opak Rivers Management Board Profile). , p. 22.

Morgan, R.P. 2005. *Soil Erosion and Conservation* Third. Oxford: Blackwell Publishing.

Morgan, R.P. 2005. *Soil erosion and conservation* Third. Oxford: Blackwell Publisher.

Mustard, J.F. et al. 2004. *Land Use and Hydrology*. Dordrecht: Springer Netherlands.

NASA 2007. Landsat 7, Science Data Users Handbook.

Neteler, M. et al. 2005. *Open source GIS: A GRASS GIS Approach* Second Edi. Boston: Kluwer Academic Publisher.

Olthof, I. et al. 2005. Landsat-7 ETM+ radiometric normalization comparison for northern mapping applications. *Remote Sensing of Environment*, **95**(3), pp. 388-398.

Ramankutty, N. et al. 2006. Global Land-Cover Change: Recent Progress, Remaining Challenges in *Land-Use and Land-Cover Change*. Global Change - The IGBP Series. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 9-39.

Richards, J. et al. 2006. *Remote sensing digital image analysis : an introduction* Fourth edi. Berlin: Springer-Verlag.

Richter, R. et al. 2009. Comparison of Topographic Correction Methods. *Remote Sensing*, **1**(3), pp. 184-196.

Rindfuss, R.R. et al. 2004. Land Cover / Use and Population in *Land Change Science*. Remote Sensing and Digital Image Processing. Dordrecht: Springer Netherlands, pp. 351-366.

Schnabel, S. et al. 2009. Gully erosion, land use and topographical thresholds during the last 60 years in a small rangeland catchment in sw spain ´. *Small*, **550**(June), pp. 535-550.

Schowengerdt, R.A. 2007. *Remote Sensing, Models and Methods for Image Processing* Third. San Diego: Academic Press.

Song, C. et al. 2000. Classification and Change Detection Using Landsat TM Data: When and How to Correct Atmospheric Effects? *Remote Sensing of Environment*, **4257**(00).

Syariman, P. et al. 2008. Sedimentation Control: Part II. Intensive Measures The Inside of The Mrica Reservoir, Central Java. *Journal of Applied Sciences in Environmental Sanitation*, **3**(2040), pp. 17-24.

Teillet, P.M. et al. 1981. On the Slope-Aspect Correction of Multispectral Scanner Data. *Symposium A Quarterly Journal In Modern Foreign Literatures*.

Twele, A. et al. 2005. Evaluating topographic correction algorithms for improved land cover discrimination in mountainous areas of central sulawesi. *Remote Sensing and GIS for Environmental Studies*, **113**, pp. 287-295.

Verbist, B. et al. 2010. Factors affecting soil loss at plot scale and sediment yield at catchment scale in a tropical volcanic agroforestry landscape. *Catena*, **80**(1), pp. 34-46.

Verstappen, H.T. 2000. *Outline of The Geomorphology of Indonesia*. Enschede: International Institute for Aerospace Survey and Earth Sciences.

Wall, G. et al. 1987. Soil Erosion - Cause and Effects. *Facts Sheet from Ontario Ministry of Agriculture Food and Rural Affairs*.

Woodcock, C.E. et al. 2004. Trends in Land Cover Mapping and Monitoring in *Land Change Science*. Remote Sensing and Digital Image Processing. Dordrecht: Springer Netherlands, pp. 367-377.

Yuan, D. et al. 1996. Comparison of relative radiometric normalization techniques. *ISPRS Journal of Photogrammetry and Remote Sensing*, **51**(3), p. 117–126.

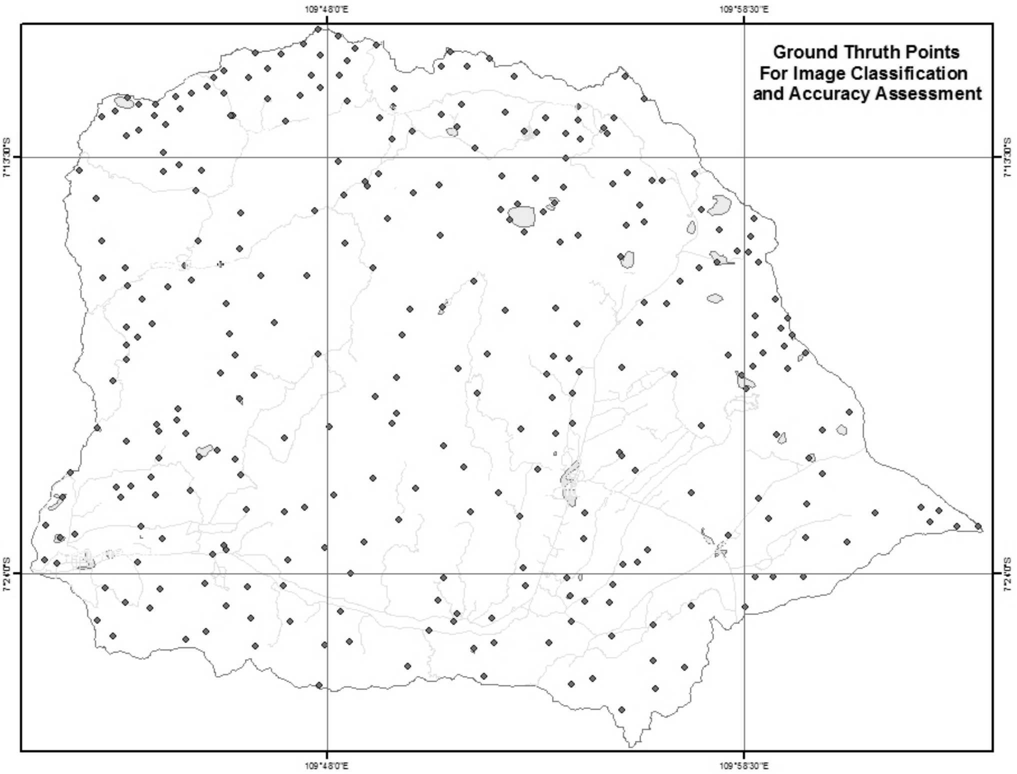
Zhang, X.C. et al. 2003. Using Rare-Earth Oxide Tracers for Studying Soil Erosion Dynamics. *Soil Science Society of America Journal*, **67**(1), pp. 279-288.

de Vente, C. et al. 2008. The Impact Of Land Use Change And Check-dams On Catchment sediment Yield. *Hydrological Processes*, **22**(September), p. 25.

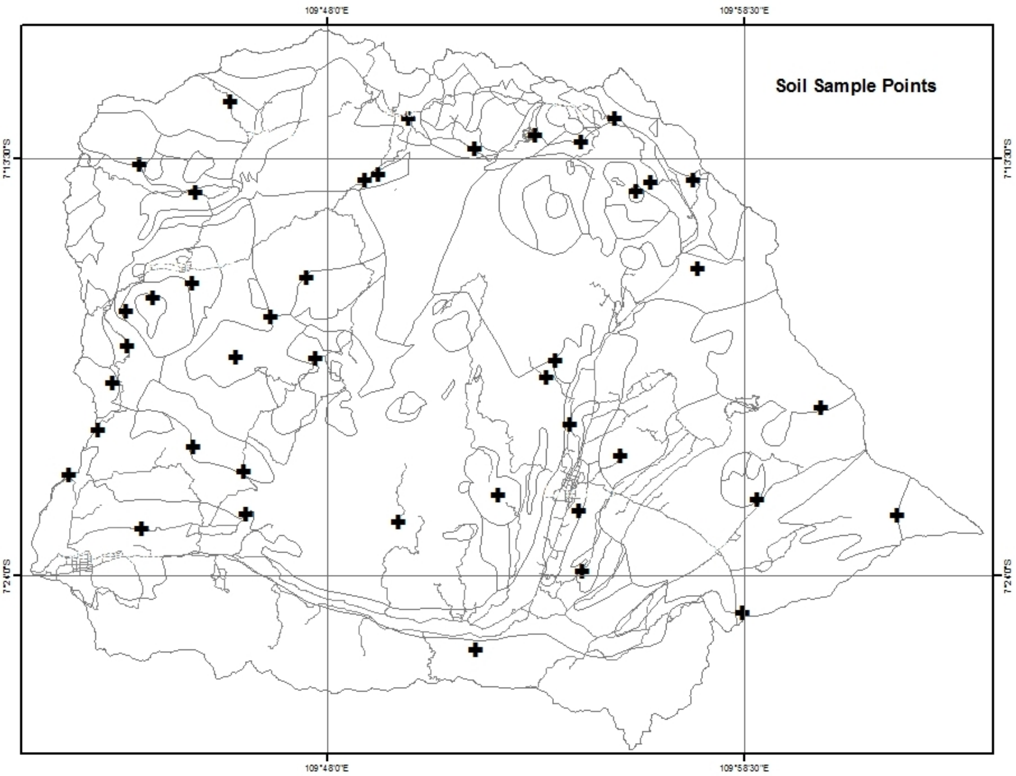
van Bemmelen, R. 1949. *geology of Indonesia : Vol. IA General geology*. The Hague: SDU.

Appendices

Appendix 1



Appendix 2



Appendix 3

Table 11.2 ETM+ Spectral Radiance Range watts/(meter squared * ster * µm)

Band Number	Processed Before July 1, 2000				Proccessed After July 1, 2000			
	Low Gain		High Gain		Low Gain		High Gain	
	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX
1	-6.2	297.5	-6.2	194.3	-6.2	293.7	-6.2	191.6
2	-6.0	303.4	-6.0	202.4	-6.4	300.9	-6.4	196.5
3	-4.5	235.5	-4.5	158.6	-5.0	234.4	-5.0	152.9
4	-4.5	235.0	-4.5	157.5	-5.1	241.1	-5.1	157.4
5	-1.0	47.70	-1.0	31.76	-1.0	47.57	-1.0	31.06
6	0.0	17.04	3.2	12.65	0.0	17.04	3.2	12.65
7	-0.35	16.60	-0.35	10.932	-0.35	16.54	-0.35	10.80
8	-5.0	244.00	-5.0	158.40	-4.7	243.1	-4.7	158.3

(Source : Landsat 7 handbook)

Table 11.3 ETM+ Solar Spectral Irradiances (generated using the Thuillier solar spectrum)

Band	watts/(meter squared * µm)
1	1997
2	1812
3	1533
4	1039
5	230.8
7	84.90
8	1362.

Table 11.4 Earth-Sun Distance in Astronomical Units

Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance
1	.98331	74	.99446	152	1.01403	227	1.01281	305	.99253
15	.98365	91	.99926	166	1.01577	242	1.00969	319	.98916
32	.98536	106	1.00353	182	1.01667	258	1.00566	335	.98608
46	.98774	121	1.00756	196	1.01646	274	1.00119	349	.98426
60	.99084	135	1.01087	213	1.01497	288	.99718	365	.98333

(Source : Landsat 7 handbook)

Appendix 4 Soil Texture Investigation

Texture Summary			**Soil Texture**	
Sand	Silt	Clay	**Lab Investigation**	**Field Investigation**
39,90	58,24	1,86	silt loam	sandy loam
30,04	66,37	3,59	silt loam	sandy loam
7,52	50,41	42,07	silty clay	silty clay
12,97	41,75	45,28	silty clay	clay
21,36	42,16	36,48	clay loam	clay loam
11,35	37,49	51,17	clay	clay
33,60	48,11	18,28	loam	loam
12,27	44,55	43,18	silty clay	clay loam
52,03	41,43	6,54	sandy loam	sandy loam
55,61	37,42	6,97	sandy loam	sandy loam
0,00	0,00	0,00	{ fail }	Blank
22,93	60,06	17,02	silt loam	Control
6,56	21,15	72,29	clay	loam
54,02	44,58	1,41	sandy loam	sandy loam
27,91	57,14	14,96	silt loam	sandy loam
28,25	48,80	22,95	loam	sandy loam
35,42	48,05	16,52	loam	sandy loam
62,19	29,09	8,73	sandy loam	sandy loam
49,68	37,70	12,62	loam	sandy loam
48,42	42,81	8,77	loam	sandy loam
47,05	35,51	17,44	loam	sandy loam
84,56	12,86	2,57	loamy sand	sandy loam
40,21	26,26	33,53	clay loam	loam
0,00	0,00	0,00	{ fail }	Blank
24,77	59,94	15,29	silt loam	Control

Appendix 5 - RMMF Script

```
r.mapcalc <<EOF
R=(0.49*DEM)+3449.67
A=if(<Lu_map>==4,0.14,if(<Lu_map>==5,0.35,if(<Lu_map>==6,0.3,if(<Lu_map>==7
,0.25,0))))
CC=if(<Lu_map>==5,0.98,if(<Lu_map>==6,0.90,if(<Lu_map>==7,0.95,if(<Lu_map>=
=4,0.7,0))))
GC=if(<Lu_map>==4,0.3,if(<Lu_map>==5,0.95,if(<Lu_map>==6,0.8,if(<Lu_map>==7
,0.85,if(<Lu_map>==1,0.9,if(<Lu_map>==2,0.9,0))))))
PH=if(<Lu_map>==4,0.5,if(<Lu_map>==5,30,if(<Lu_map>==6,2.5,if(<Lu_map>==7,1
0,0))))
BD=if(SOIL_TEXT==1,1.1,if(SOIL_TEXT==2 || SOIL_TEXT==3 || SOIL_TEXT==7 ||
SOIL_TEXT==8,1.3,if(SOIL_TEXT==4 || SOIL_TEXT==5,1.4,1.2)))
EHD=if(<Lu_map>==2,0.06,if(<Lu_map>==4,0.13,if(<Lu_map>==5,0.2,if(<Lu_map>=
=6,0.12,if(<Lu_map>==7,0.15,if(<Lu_map>==8,0.09,0))))))
EtEo=if(<Lu_map>==1,0.001,if(<Lu_map>==2,0.05,if(<Lu_map>==4,0.73,if(<Lu_ma
p>==5,0.95,if(<Lu_map>==6,0.9,if(<Lu_map>==7,0.95,0.05))))))
K=if(SOIL_TEXT==1,0.13,if(SOIL_TEXT==2,0.7,if(SOIL_TEXT==3,0.8,if(SOIL_TEXT
==4,0.3,if(SOIL_TEXT==5,0.1,if(SOIL_TEXT==6,0.7,if(SOIL_TEXT==7,0.9,if(SOIL
_TEXT==8,0.5,0.7))))))))
C=if(<Lu_map>==5,0.002,if(<Lu_map>==6,0.005,if(<Lu_map>==7,0.2*0.2,if(<Lu_m
ap>==2,0.1*0.15,if(<Lu_map>==4,0.18,if(<Lu_map>==8,0.9,0))))))
ER=R*A
LD=ER*CC
DT=ER-LD
KEdt=DT*(30.8*(1-(0.55*exp(-0.03*25))))
KEld=if(PH>=0.15,(LD*(15.8*(PH^0.5)))-5.87,0)
KE=KEdt+KEld
Rc=1000*MS*BD*EHD*(EtEo)
Ro=27.0226+(-0.00702669*DEM)
Q=R*exp(-Rc/Ro)
F=K*KE/1000
Z=1/(0.5*COH)
H=Z*(Q^1.5)*sin(slope@11.RMMF)*(1-GC)/1000
TC=C*(Q^2)*sin(slope@11.RMMF)/1000
AD=F+H
SL=min(TC,AD)
SL_ton=SL*10
SL_pixel=SL*0.9
Q_pixel=Q*0.9
EOF
```

Appendix 6 – Reservoir Data

Discharge (m3)	Sedimentation (m^3)	Runoff (m^3)
2.408.836.320,00	3.382.678	770.827.622
2.570.937.408,00	3.441.288	796.990.596
2.089.675.584,00	6.018.471	543.315.652
2.916.185.760,00	3.782.662	962.341.301
2.454.577.344,00	3.487.578	834.556.297
1.892.637.792,00	3.386.697	548.864.960
2.925.491.040,00	5.022.637	1.170.196.416
2.491.413.984,00	4.604.384	797.252.475
1.450.667.232,00	2.174.447	522.240.204
2.913.042.528,00	5.999.578	932.173.609
2.895.550.848,00	4.537.659	868.665.254
2.677.440.960,00	7.027.165	910.329.926
2.871.061.632,00	3.381.701	947.450.339
1.853.665.344,00	3.523.077	611.709.564
2.065.480.992,00	4.435.166	764.227.967
2.097.446.054,40	2.895.168	776.055.040
2.317.721.853,60	4.627.772	880.734.304
1.984.025.527,13	3.992.261	615.047.913
2.032.129.496,80	3.772.284	772.209.209
2.151.706.840,99	4.299.048	753.097.394

Appendix 7 Image Classification Accuracy Assessment

```
LOCATION: Upper_Serayu                          Wed Feb 10 07:47:35 2010
MAPS: MAP1 = Reference Points / Accuracy Assessor
      MAP2 = Classification Result

MAP Category Description
1:  Built Up Area
2:  Paddy Field
3:  Water Body
4:  Dry Land Cultivation
5:  Forest
6:  Shrub
7:  Plantation
8:  Bare Soil

Classification Method : Sequential Maximum A Posteriori Classification

Error Matrix of Classified Image with Topographic Correction
                      MAP1
     cat#    1      2      3      4      5      6      7      8      Row Sum
 M     1     20     0      0      0      0      0      0      0      20
 A     2     0      28     0      0      1      1      0      0      30
 P     3     0      2      7      0      0      0      0      0      9
 2     4     5      2      0      49     0      7      3      0      66
       5     0      0      0      0      35     1      0      0      36
       6     0      0      0      2      6      32     5      3      48
       7     0      0      0      0      3      2      85     0      90
       8     0      0      0      1      0      0      0      9      10
Col Sum             25     32     7      52     45     43     93     12
      309

Cats   % Commission % Ommission  Estimated Kappa            Kappa
       Kappa Variance
1      0.000000     20.000000    1.000000            0.826475     0.000580
2      6.666667     12.500000    0.925632
3      22.222222    0.000000     0.772627            Obs Correct  Total Obs

4      25.757576    5.769231     0.690308            265          309

5      2.777778     22.222222    0.967487
6      33.333333    25.581395    0.612782            % Observed Correct
7      5.555556     8.602151     0.920525            85.760518
8      10.000000    25.000000    0.895960
```

Error Matrix of Classified Image without Topographic Correction

MAP1

	cat#	1	2	3	4	5	6	7	8	Row Sum
M	1	20	0	0	0	0	0	0	0	20
A	2	0	30	0	0	0	0	0	0	30
P	3	1	1	7	0	0	0	0	0	9
2	4	7	1	0	50	1	7	0	0	66
	5	0	0	0	0	33	2	1	0	36
	6	1	0	0	8	7	30	0	2	48
	7	0	1	0	3	4	11	71	0	90
	8	1	0	0	1	0	1	0	7	10
Col Sum			30	33	7	62	45	51	72	9
	309									

Cats	% Commission	% Ommission	Estimated Kappa	Kappa	
	Kappa Variance				
1	0.000000	33.333333	1.000000	0.761701	0.000744
2	0.000000	9.090909	1.000000		
3	22.222222	0.000000	0.772627	Obs Correct	Total Obs
4	24.242424	19.354839	0.696724	248	309
5	8.333333	26.666667	0.902462		
6	37.500000	41.176471	0.550872	% Observed Correct	
7	21.111111	1.388889	0.724754	80.258900	
8	30.000000	22.222222	0.691000		

Classification Method : Maximum Likelihood Classification

Error Matrix of Classified Image with Topographic Correction

		MAP1								
	cat#	1	2	3	4	5	6	7	8	Row Sum
M	1	18	0	0	1	0	0	0	1	20
A	2	0	27	0	0	1	2	0	0	30
P	3	0	1	8	0	0	0	0	0	9
2	4	6	5	0	41	3	7	3	1	66
	5	1	0	0	2	29	3	1	0	36
	6	0	1	0	5	9	19	11	3	48
	7	0	0	0	4	9	9	68	0	90
	8	1	1	0	1	0	1	0	6	10
Col Sum			26	35	8	54	51	41	83	11
	309									

Cats	% Commission Kappa Variance	% Ommission	Estimated Kappa	Kappa	
1	10.000000	30.769231	0.890813	0.635738	0.000993
2	10.000000	22.857143	0.887226		
3	11.111111	0.000000	0.885936	Obs Correct	Total Obs
4	37.878788	24.074074	0.540998	216	309
5	19.444444	43.137255	0.767119		
6	60.416667	53.658537	0.303405	% Observed Correct	
7	24.444444	18.072289	0.665782	69.902913	
8	40.000000	45.454545	0.585235		

Error Matrix of Classified Image without Topographic Correction

					MAP1					
	cat#	1	2	3	4	5	6	7	8	Row Sum
M	1	18	0	0	1	0	0	0	1	20
A	2	0	28	0	0	0	2	0	0	30
P	3	0	1	6	0	0	2	0	0	9
2	4	9	6	0	37	1	8	4	1	66
	5	0	0	0	0	28	6	2	0	36
	6	0	0	0	5	9	25	6	3	48
	7	0	0	0	7	8	11	63	1	90
	8	1	1	0	2	0	0	0	6	10
Col Sum			28	36	6	52	46	54	75	12
	309									

Cats	% Commission	% Ommission	Estimated Kappa	Kappa	
	Kappa Variance				
1	10.000000	35.714286	0.890036	0.617830	0.001020
2	6.666667	22.222222	0.924542		
3	33.333333	0.000000	0.660066	Obs Correct	Total Obs
4	43.939394	28.846154	0.471701	211	309
5	22.222222	39.130435	0.738910		
6	47.916667	53.703704	0.419363	% Observed Correct	
7	30.000000	16.000000	0.603846	68.284790	
8	40.000000	50.000000	0.583838		