Effects of Land cover change on top soil properties and erosion: a case study of Merawu catchment, Indonesia

Diwakar Paudel

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by

Diwakar Paudel

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Thesis Assessment Board

Professor Dr. V.G. Jetten (Chair), AES Department, The Netherlands
Dr. E.A. Addink (External Examiner), Research Group of Environmental Studies and Ecohydrology The Netherlands
Ir. B.G.C.M. Krol (1st Supervisor), AES Department, ITC, The Netherlands
Dr. Dhruba P. Shrestha (2nd Supervisor), AES Department, ITC, The Netherlands

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

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Dedicated to my parents

Abstract

Land cover change is a global phenomenon. The change of forest cover into cropland or settlement has been one of the prominent problems that can have detrimental impact on the environment. To overcome this problem, the counter actions taken by respective stakeholders are very much important and one of the challenging job. The alarming rate of forest resources conversion into cropland not only affects the condition of natural environment but also affects the livelihood of the people from its hazardous effects such as floods, landslide, and soil erosion. So, essential action oriented approach are vital to identify and quantify the areas where utmost actions are required.

This study aims to analyze the effect of land cover change on selected top soil properties and soil erosion by water in the Merawu catchment of Central Java Indonesia. Very limited studies have been done in this aspect. So, this study was conducted in Merawu to identify the land cover change. Besides, study of selected top soil properties were also carried out using field methods. First, the land cover mapping was performed using the Landsat Images of 1991, 2001 and 2009 to assess the land cover change over time. Post classification comparison method was employed to compare the change between two dates. Out of 220309 hectares of total land covers occupying by four classes namely dense forest, shrub land, mixed forest/agro-forestry and crop land. Area coverage of dense forest has reduced from 3247 to 2514 hectares representing 23% reduction of its original size and overall percentage of change of about by 3% change in 18 years of period. Shrub land and sparse trees area has also reduced in size from 7727 to 5836 hectares representing 24.5% of its original area and about 9% of total land area of the catchment. Mixed forest/ Agro-forestry area has increased from 7960 to 9123 which covers about 15% of its original area and overall change is of 5 %. Likewise, cropland has also increased from its 3104 to 4565 hectares which covers 47% of its original size and overall percentage of change is of 7 %. Overall change from year 1991 to 2009 was found 24% within 18 years of period. Another important part of the study was to find out the temporal land cover change trajectories. Overall 22 temporal land cover change trajectories were established as final trajectories from the image data, soil sample locations and historical information obtained from the field. Additionally simple field methods were applied to identify the selected top soil properties such as soil texture, soil compaction, soil strength, soil colour, soil pH, soil aggregate stability, soil structure were applied in the field. The effect of land cover change on top soil properties, soil compaction and soil strength were found significantly different at P value of <0.05. Some erosion evidences and measured soil properties have shown that the effect of land cover change on top soil properties found different d with land cover types. Soil compaction in dense forest particularly planted pine forest shows the higher mean value than other land cover types. Interestingly, OM content in crop land was found higher than other land cover type however the variation is not statistically significant. Although the susceptibility of erosion in croplands is much higher than other land cover types because of anthropogenic as well as inherent properties of soils as well.. Field methods to identify the top soil properties are simple and easier but careful attention with consistency is very much important to adopt the methods correctly.

Key words: Land covers change, change detection, post classification comparison, trajectory, soil properties, and erosion

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1. Introduction

1.1. Land cover change, soil properties and erosion

Environmental degradation resulting from land cover change has become a global concern. Land cover change is considered as one of the responsible factors for climate change as well. Degradation in forest areas is increasing especially in the humid tropical areas. Estimations of GIO-FAO (1996), shows 116,756 km^2 of tropical forest had been deforested per year during 1990–1995 globally. The rate was 47,000 km^2 per year in tropical South America— mainly in Brazil. Indonesia as a tropical country which contains 10% of the world's tropical rainforests (WorldBank, 1994) has also high deforestation problem. In 1996 total coverage of forest of Indonesia was 120.6 million ha. Which was 69 percent of total terrestrial (GIO-FAO, 1996). The forest cover area decreased into about 90 million ha in 2003, equivalent to 46 percent of total land area. Ministry of Forestry of Indonesia (GOI, 2008) also states that the deforestation rate in Indonesia between 1985-1997 was around 1.6 million ha. per year, while between 1997-2000 it was 2.8 million ha per year, and deforestation rate in 2000-2005 was 1.08 million ha per year.

The Island of Java covers about 7 % of total land area of Indonesia and 3 % of the forest. It gives home to 67 % of the total population of Indonesia. So, to feed the huge population, agro-economic and environmental identity is different and dominated by rice and sugarcane (Peluso, 1994). Because of deforestation, the major state forests area which has nearly 23 % out of which 7 % is protected forest and 16 % as production forest much of it is newly plantation and therefore low richness and low diversity with single canopy layer. So, ecologically forest areas of Java are in poor condition. Hence, the potentiality of disastrous effects of these simple and poor ecosystems in terms of vulnerability to pests with loss of biodiversity and flood hazards, slope stability and soil erosion (Lavigne and Gunnell, 2006). According to Badan Pusat Statistik (BPS Indonesia, 2009), the population Java island increased from the year 1995 to 2000 from 115 million to 121 million increased. It illustrates pressure on the forest resources in this island and the effect on land cover change and erosion acceleration.

Deforestation can have a significant impact at various scales on climatic conditions, soil properties and many functions of terrestrial ecosystems. Moreover, land cover change has greatly influenced soil erosion especially caused by water. Soil erosion and sediment transport problems resulting from land cover and land use management changes have attracted attention of many researchers (Cebecauer and Hofierka, 2008). General decline in the soil physical and chemical properties, in turn contributes to soil erosion, reduction of soil fertility and land degradation. There is an urgent need to improve soil properties by reducing land cover change with appropriate land management practices and then it contributes to reduce the rate of soil degradation and ensure long-term sustainability of the farming system(Khresat *et al.*, 2008). It requires action oriented efforts to reduce land cover change and thereby maintain soil properties for better productivity with the reduction of erosion. In this connection, the study of effects of land cover change on top soil properties and erosion could contribute in the planning and decision making process to reduce the severity of soil erosion of the study area - Merawu catchment in Java Island of Indonesia.

The demand for food for an increasing population has created pressure on natural resources particularly on forest resources. Rate of change of forest land into agricultural land is being increased day by day to feed the increased population. Inappropriate cultivation and unplanned land use, such as establishing industrial areas or residential areas on farming land, unplanned urbanization and destruction of forest resources are fundamental factors provoking soil erosion. The land use and land cover change, thus, is one of the major drivers for deteriorating the land in this aspect. The land cover change can result in diminishing quality of soil properties and productivity of the land. In addition, agricultural land cover changes can influence this process (Jordan *et al.*, 2005). . Inappropriate and unplanned land use practice are also occurring in areas with steep topography (Shrestha and Zinck, 2001; K. C., 2008; Suriyaprasit, 2008 ; Solaimani *et al.*, 2009), where they can result in severe land degradation problems.

Soil erosion because of water not only decreases agricultural productivity, but also reduces the water availability in the soil and causes negative downstream impacts on livelihood, infrastructure, lives and property (Shrestha, 2000; Vrieling *et al.*, 2008).In order to overcome these problems protecting or reforming measures are taking place in many developing countries in different way resulting in land cover changes (Ostwald and Chen, 2006). Traditional agricultural practices used by the farmers influence the structure of soil, surface roughness and aggregate strength, while crops cover like vegetation, shrubs, and grasses are factors affecting many processes of erosion as well (Jetten, 2006).

Land cover change can be detected and monitored by using remotely sensed images. Singh (1989) describes that change detection is the process to identify the differences in the state of an object or phenomenon through observing it at different times. Change detection using remote sensing data is useful in applications such as land cover change analysis, monitoring deforestation and assessing shifting cultivation, study of phenology, seasonal changes in pasture production, crop stress detection, damage assessment, disaster monitoring and other environmental changes (Singh, 1989; Ellis, 2007). Several studies have been carried out in land cover change detection (Sarma *et al.*, 2001; Lu *et al.*, 2004; Sharma *et al.*, 2004; Lavigne and Gunnell, 2006; Shalaby and Tateishi, 2007; Zhou *et al.*, 2008; Sarma *et al.*, 2008 ; Alphan *et al.*, 2009; Thapa and Murayama, 2009). In order to identify the changes in land cover, different change detection techniques can be used. These include post classification comparison, image differencing/rationing, vegetation index differencing, principle component analysis and change vector analysis (Singh, 1989). So called land cover change trajectory analysis (Zhou *et al.*, 2008) is used to identify land cover change trajectories that may occur in a particular area over time.

The influence of land cover change on soil properties has been the focus of numerous studies (Egashira *et al.*, 1986; Quiroga *et al.*, 1999; van Ranst *et al.*, 2002; Wang *et al.*, 2003a; Braimoh and Vlek, 2004; Sharma *et al.*, 2004; Celik, 2005; Giertz *et al.*, 2005; Islam, 2006) Effective soil and water conservation strategies are required to minimize the effect of land cover change on soil properties and to reduce soil erosion problems at different spatial scales, as well as at different organizational levels (Morgan, 2005).

Adequate information about land cover change and its effect on soil properties is an important component in any planning process as it provides basic information for planning and taking decisions to develop management projects (Treitz, 2004)1). Appropriate policy and actions can guide the future direction of soil conservation programs in a particular area research. Indeed, output of this study will be beneficial in the whole process of planning and decision making in the study area.

1.2. Problem statement

Land cover change from forest to agricultural land, farming on deforested steep slopes and high rainfall intensity are the major driving forces of water induced soil erosion in the Merawu catchment (Suwartha *et al.*, 2006). Damage to crops, gully formation, occurrence of landslides and loss of fertile soil leading to low productivity are main onsite effects of soil erosion in the area. On the other hand, flooding and sedimentation in low land area specifically in Mrica reservoir downstream are other off site effects (Suwartha *et al.*, 2006). The loss of soil properties, such as organic matter content, soil strength, soil compaction, soil structure, soil pH, soil colour and soil aggregate stability and other properties of soil can have greater influences on soil loss because of land cover change over time (Lal, 1998; Braimoh and Vlek, 2004; Sharma *et al.*, 2004; Celik, 2005; Islam, 2006; Cebecauer and Hofierka, 2008). This phenomenon not only affects the low land area from flood and sedimentation but also decreases the agricultural productivity of the area. The lower the organic matter content, the lower the infiltration of rain water and the higher the accumulation of runoff and much more soil detachment and sedimentation in the erosion process.

So far, studies on the effects of land cover change on soil conditions and soil erosion are very limited and almost lacking in this catchment. This study aims to analyze how the land cover is changing overtime, how it has affected selected top soil properties and soil erosion in the area. The effect of land use/land cover changes relating with spatial and temporal aspect is one of the major challenge in this study. That will be studied using a post classification comparison method. The temporal trajectory analysis method using multi-temporal images together with historical land use changes information can be useful tool in this aspect.

1.3. Objectives of the study

1.3.1. Main objective

The study aims: To analyze the effects of land cover change on selected top soil properties and soil erosion by water in the Merawu catchment. In particular focus is on the following top soil properties: Soil structure, soil texture, soil organic matter content, soil compaction, soil strength, soil aggregate stability, soil pH and soil colour.

1.3.2. Specific Objectives

- ❖ To analyze land cover change pattern in spatial and temporal perspective in the study area;
- ❖ To identify land cover change trajectories that have occurred in the area
- ❖ To identify and analyze the spatial and temporal relationships between selected surfaces and top soil properties and identified land cover change patterns

1.4. Research questions

- ❖ What types of land cover and land cover changes have occurred and do occur in the study area?
- ❖ What types of land cover change trajectories can be established?

- What is the spatio-temporal relationship between land cover and selected surface and top soil properties?
- What types of relationship can be established between selected soil properties?

1.5. Thesis outline

The thesis outline consists of seven chapters. First chapter includes the introduction of land cover change, soil properties and soil erosion by water; the problem statement, objectives of the study, research questions. Second chapter deals with literature reviews related with land cover, land use and land cover change, relation of land cover with soil properties and erosion, land cover information from RS image classification, image classification method, factors affecting water induced erosion and field methods of identifying some top soil properties. In third chapter, the brief information about the study area is mentioned. The methodology part is included in chapter four in step by step. In fifth chapter, the result and discussion image analysis, the result and discussion of soil properties in relation to land cover change is presented in chapter six; the research conclusions with some recommendations are included in chapter seven. Various data, maps, materials used in the study are accompanied in the annexes.

2. Literature Review

This chapter is mainly focused on subsections of land cover; land use and land cover change, land cover change detection, relation of land cover change with selected soil properties, terrain conditions and erosion susceptibility. Besides, terminology of selected top soil properties and other related factors are also defined in the subsection.

2.1. Land cover, land use and land cover change

Food and Agricultural Organization of the United Nations (FAO) defines “land cover as the observed (bio) physical cover that can be seen on the earth's surface”. While Land use is defined as characterization by the arrangements, activities and inputs which are undertaken by the people in a certain land cover type in order to produce change or maintain it. So, the term land use has established its direct linkage between the land cover and the activities taken by people in their own environment. For instance the grass land is itself cover term while the range land and tennis court refer to use of grass land for specific purposes. Specific land use often corresponds to a single land cover e.g. pasture to unimproved grassland. However, a given land cover class may support several distinct land uses for example a forest may be used simultaneously for logging area, slash and burn agriculture, hunting/ gathering, fuel wood collection, recreation, wildlife protection, soil and watershed protection; such a land use typically has multiple purpose (FAO, 2005).

Land use as man’s activities on land that may be directly related to the land (Clawson and Stewart, 1965). While, land cover explains the vegetational and man-made constructions that covers the land surface (Burley, 1961). Concepts of land cover and land use are directly related and in many cases both have been used interchangeably. Generally the land cover types are related based on the purpose of the land use, whether they are forest, agricultural, industrial or residential or other uses. The devices of remote sensing image cannot record activity directly. The remote sensing obtains a response which is based on many image characteristics of the land surface; either they are natural or artificial cover. The interpreter may use various image interpreting elements such as tones, textures, patterns, shapes, and site associations in order to obtain information about land use activities that are basically information about land cover(Anderson *et al.*, 1976).

Land uses include settlement, cultivation, pasture, rangeland, recreation and so on. Land use change at any location may involve either a shift to a different use or an intensification of the existing one. Land cover a concern principally of the natural sciences, denotes the physical state of the land. It holds, for instance, the quantity and type of surface vegetation, water, and earth materials. Land cover changes fall into two ideal types, conversion and modification. The former is a change from one class of land cover to another: from grassland to cropland, for example. The latter is s change of condition within a land cover category such as the thinning of a forest or a change in its composition. Commonly a single land use may relate fairly well to a single of land cover, for example pastoralism to unimproved grassland. Unlikely, a single land cover class may support multiple uses for example forest used for combinations of timbering, fuel wood collection, slash and burn agriculture, hunting/ gathering, wildlife preserve and watershed and soil protection, recreation etc. A single system of use may involve distinct covers and their maintenance. Land use change is likely to cause some changes in land cover but land cover may change, while the land use remains unaltered(Meyer and Turner, 1994).

Net deforestation rates in the world have fallen from the year 1990-2000, but world loses some 13 million hectares forests per year and it also includes 6 million hectares of primary forests (FAO, 2005). FAO further highlights that the regions of Central America were the highest deforestation rate of 1.3% or 285,000 hectares of its forests each year and tropical Asia. Tropical Asian countries e.g. Bangladesh, Bhutan, Brunei, Cambodia, East Timor, India, Indonesia, Laos, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam lost about 1% of its forests each year.

2.2. Land cover change detection

Land cover change can be monitored by remotely sensed images. Change detection using the benefit of remote sensing tools and techniques is one of the prominent methods which have been widely used these days. Singh (1989) describes that change detection is the process to identify the differences in the state of an object or phenomenon through observing it at different times. Timely and accurate change detection is highly important for understanding relationships and interactions of human and natural phenomenon to promote better decision making(Lu et al., 2004). Change detection using remote sensing data is useful in such various applications such as land cover change analysis, monitoring deforestation and assessing shifting cultivation, study of phenology, seasonal changes in pasture production, crop stress detection, damage assessment, disaster monitoring and other environmental changes (Singh, 1989; Lu et al., 2004; Ellis, 2007). Several studies have been carried out in land cover change detection (Sarma et al., 2001; Lu et al., 2004; Sharma et al., 2004; Lavigne and Gunnell, 2006; Shalaby and Tateishi, 2007; Zhou et al., 2008; Sarma et al., 2008 ; Alphan et al., 2009; Thapa and Murayama, 2009). Many change detection methods have been developed such as image differencing, post classification comparison and principal component analysis are the most common methods.

In recent years, artificial neural network, spectral mixture analysis and integration of remote sensing data and geographical information system are becoming more important methods for change detection application (Singh, 1989, Lu, 2004).

Several methods are in practice for detecting and interpreting land cover change by use of remotely sensed images and other sources. However, there are many uncertainties exist including estimates of rates and extend of change of land cover mapped by satellite imagery (Hurtt et al., 2003). Because different change detection techniques have their own advantages and disadvantages and no single technique is optimal and applicable to all cases(Lu,2004) Therefore, it is a little difficult to run a conventional classification algorithm to map land cover in areas with strong topographical variations complicated by over lap of different type of land cover (Shrestha and Zinck, 2001). To identify the land cover change in the area, image classification is one of the major tasks.

2.2.1. Image classification

Jensen (1996) has stated that the standard image processing is useful to extract the information from remotely sensed data. Moreover, land cover classes are typically mapped from digital remotely sensed data through digital image classification and interpretation(Campbelll, 2002). The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand & Kiefer, 2008). In practice, supervised and unsupervised classification methods are common in image classification process. However, the land cover prediction methods are constrained by the spatial resolution of the RS imagery, the mapping method and expert knowledge of the study area (Thapa & Murayama, 2009). Singh (1998) mentions that to extract full information from increased spatial and spectral resolution of Landsat TM that is required to process the data digitally to classify land cover features like vegetation.

Supervised classification method

The maximum likelihood classifier (MLC) method quantitatively evaluates both the variance and covariance of the category spectral patterns when classifying an unknown pixel so that it is considered to be one of the most accurate classifier since it is based on statistical parameters. The MLC is basically based on the probability that a pixel belongs to a particular class and the input bands have normal distribution. It is considered to give more accurate result than parallelepiped method (Ismail and Jusoff, 2008). In supervised classification process, it requires input from an analyst to run the classification algorithm to associate values of pixel with correct land cover category (Jensen, 2005; Lillesand et al., 2008).

Unsupervised classification method

The unsupervised classification approach is an automated classification method that creates a thematic raster layer from a remotely sensed image by letting the software identifies statistical patterns in the data without using any ground truth data (Leica Geosystems, 2005; Lillesand et al, 2008). Clusters are defined with a clustering algorithm that uses all pixels in the input image for analysis. After the classification, the analyst then employs a posteriori knowledge to label the spectral classes into information classes. Interpretation of spectral clusters into land cover types is to some degree dependent upon the land cover classification scheme. So, for the study it is necessary to develop a more detailed land cover classification scheme, as opposed to using an existing generalized global legend (Boles *et al.*, 2004)

2.2.2. Post classification comparison

This method is the most obvious method of change detection. It requires the comparison of independently produced classified images. The post classification comparison method proved to be the most effective technique, because in this method, the data from two dates are separately classified (Shalaby & Tateishi, 2007). Comparison of total area coverage may not always provide the most efficient and accurate analysis of changes. Instead of taking area coverage of each land cover category at each date into account, pixel-based comparison is better one to produce change information on pixel basis (Alphan et al., 2008) and therefore, to interpret the changes more efficiently taking the advantage of " from ,- to " information. It is very important that the pixel based comparison is to have images pair of same spatial resolution.

2.2.3. Land cover change trajectories

Spatial temporal land cover change patterns is one of the active research field (Roy and Tomar, 2001; Weng, 2001) and the concept and methodology of change trajectory has been developed (Mertens and Lambin, 2000; Petit et al., 2001; Liu and Zhou, 2004). Land cover change has been one of the most sensitive indicators that reflects the interactions between anthropogenic activities and natural environment (Zhou *et al.*, 2008). Land use and land cover of the earth is shifting significantly for the cause of human actions and natural calamities. The world's population persists to put up with the effects of deforestation, flooding, food shortage, green house effect, unplanned urban extension etc. These ecological tribulations are repeatedly associated to land cover changes (Muttitanon and Tripathi, 2005). Zhou et al. (2008) explain that the spatial temporal land use/land cover change pattern can be analyzed by using the temporal trajectory of land use change. This method can help to understand the spatial pattern of change due to human activities.

In this particular study the term trajectory of land cover change refers to the change of land cover from one type to another in the two given date. All classified images is combined in GIS spatial analyst tool using the tabulate area to produce the matrices of change from one cover type to another and then the pixel based change trajectories are established based on the number of pixels which has higher number of pixels that can be used to establish the line of land cover change trajectories. Historical land cover change information are also useful to establish the land cover change trajectories in a particular land cover type which can be collected from the field using questionnaires or informal interviews.

2.3. Relation of land cover change with soil properties, terrain condition and erosion succeptaibility

Land cover change affects the soil properties such as soil structure, soil texture, soil strength, soil compaction, soil organic matter content, porosity, infiltration rate, soil aggregate stability, saturated hydraulic conductivity, soil colour, soil pH and many other properties as well(Khresat *et al.*, 2008). Land cover change not only effects the quality of soil properties but also it contributes in accelerating soil erosion.Several studies have been carried out on the effect of land use/land cover change on soil organic matter content and other soil properties in different regions of the world. When forests and pasture lands were converted into cultivation, soil organic matter content, infiltration capacity, soil moisture content and other soil nutrients were significantly reduced (Islam and Weil, 2000; Wang *et al.*, 2003b; Sharma *et al.*, 2004; Giertz *et al.*, 2005; Neguse, 2007; Prachansri, 2007; Sapkota, 2008). Moreover, soil properties are often related to vegetation cover for instance soil organic matter is higher under the forested area than under pasture land (Bewket and Stroosnijder, 2003; Vrieling *et al.*, 2008). The degradation of the highland soils with the restricted depth by the cultivation seriously impaired soil properties and resulted in significant decreases in the soil organic matter, aggregate stability, mean weight diameter and the hydraulic conductivity (Celik, 2005).

The intensity of erosion is more severe in low organic matter content area than high organic matter content one and it also influences the organic matter content of soils (Bewket and Stroosnijder, 2003). The conversion of forests into other land-uses resulted in a remarkable decline in the amounts of soil nutrients and microbial carbon, nitrogen and phosphorus. The microbial nutrients in the mountain region are very sensitive to land-use/cover changes. Therefore, the conversion of forest to agricultural land should be reversed. Agro-forestry systems should be included in agricultural land in mountainous regions(Sharma *et al.*, 2004).

Erodibility is an important property of soil. It can be defined as the vulnerability or susceptibility of the soil to erosion. In other words, it is the function of both physical characteristics and the management of the soil (Hudson, 1981). Resistance of the soil to detachment as well as to transport is called as erodibility. The susceptibility of the soil to erosion or its erodibility is a function of various soil properties such as soil texture, aggregate stability, shear strength, infiltration capacity, organic matter content and chemical constituents of the soil along with some management options such as tillage operations and topographic positioning of the soil. Usually clay sized particles are hard to detach but easy to transport while sand particles are easy to detach but hard to transport. Silt and fine sand sized particles are most vulnerable to soil erosion (Lal, 1994; Morgan, 1995).

For this particular study, soil structure, soil texture, soil compaction, soil strength, soil organic matter content, soil aggregate stability, soil colour, soil pH, are mainly taken into consideration. It is easy to estimate these properties in the field using simple field methods. Other soil properties such as bulk density, saturated hydraulic conductivity, can't be measured directly and or easily in the field but can be estimated from other properties as the indication of those properties. These selected soil properties and factors related to soil erosion such as terrain condition and vegetative cover are described in more detail in the following section.

2.3.1. Soil structure

Soil structure defines "the natural organization of soil particles into discrete soil units (aggregate or peds) which result from pedogenic processes. Pores or voids separate the aggregates from each other" (FAO, 2006).

2.3.2. Soil texture

Soil texture refers to the relative proportion of sand, silt and clay particles in the soil. According to FAO (2006), the textural classes are mainly three categories as shown in the Table 2-1.

Table 2-1 Major textural classes

Textural class	Texture type
Coarse	sands, loamy sand and sandy loams
Medium	sandy loams, loams, sandy clay loams and silt loams
Fine	clays, silty clays, sandy clays, clay loams and silty clay loams

2.3.3. Soil compaction

Soil compaction is the compression of unsaturated soil in which larger soil pores are affected .It reduces the air-filled capacity of the soil and reduces the plant root growth (Marschner 1995). In other words, compaction is the deterioration of soil structure or loss of soil features. It is mainly occurred by mechanical pressure predominantly from agricultural practices (EUROPA, 2010).

2.3.4. Soil strength

Soil strength is defined as "the capacity of a soil to withstand forces without experiencing failure whether by rupture, fragmentation or flow". If a soil is too weak, it will be unable to adequately anchor the plant and it is not able to withstand the forces of water or wind. If the soil is too strong, plant and organism such as earthworms can't penetrate to the soil (Hillel, 1980).

2.3.5. Soil organic matter content

Soil organic matter content is any material produced from originally by living organisms (plant or an animal) that returns to the soil and goes through the decomposition process. At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus (FAO, 2005).

2.3.6. Soil aggregate stability

Soil aggregate stability is the ability of soil aggregates to resist disruption when outside forces(usually associated with water) are applied (USDA, 1996).

2.3.7. Soil colour

Soil colour reflects the composition of both past and present oxidation reduction condition of the soil in the area. It is determined by coating of very fine particles of humified organic matter which seems dark, iron oxides (yellow, brown, orange and red, manganese oxides (black) and others, or may be due to the parent rock. Colour of the soil is recorded in both moist and dry conditions using the notations for hue, value and chroma as given in the Munsell Soil Colour Chart (Munsell, 1975). Here, hue is the dominant spectral colour (red, yellow, green, blue, or violent), value is the lightness or darkness of colour ranging from 1(dark) to 8 (light) and chroma is the purity or strength of colour ranging from(pale) to 8(bright).

2.3.8. Soil pH

pH is a measure of things how they are acidic or basic. It is measured in pH scale between 0-14. The things are considered as acidic having the pH scale in between 0-7 and things are basic with pH 7-14. Pure water is considered as neutral which has pH 7 on the pH scale, sea water is basic(also called alkaline with pH 7-14) and lemon juice is acidic having pH between 0-7(Spector, 2001). Soil pH is identified in the field using indicator liquids (e.g.Hellige) with Soil pH kit (FAO, 2006).

2.3.9. Terrain Conditions

Slope steepness and slope length are the key factors influencing soil erosion. When slope increases, the volume of overland flow also increases. Similarly, as the steepness increases, the velocity of the flow increases which in turn increases the kinetic energy of the overland flow that is responsible for detachment and transport of the particles. Steep slope but short slope length may become less danger as compared to long slope with gentle slope (Wischmeier and Smith, 1978; Morgan, 1995). Slope curvature and the nature of the slope also determine the rate of soil detachment and sedimentation. For instance, if the slope angle decreases as the length increases, soil loss may decreases as a result of deposition.

2.3.10. Vegetative Cover

Vegetative cover has major control over the rate of soil detachment and transport. Its effect can be classified in above ground cover and crown cover. The above ground vegetation plays important role acting as an intercepting agent for the rainfall which in turn decreases the amount of rainfall reaching directly to the soil surface. In the same way, the ground cover reduces rate of runoff and reduces the energy of the overland flow. In addition, the root zone below soil surface provides mechanical strength to the soil (Morgan, 2005). The research study revealed that the erosive power of a single light rainfall event of 20.75 mm $h^{-1}$with a kinetic energy 13.5J $m^{-2}mm^{-1}$ is negligible when plots are covered with vegetation. Although, it creates an average soil loss of 74 kg ha^{-1} when the land is bare soil area (Marques *et al.*, 2007).

3. Study area

3.1. Location

The study area is located in Banjarnegara district of Central Java Province, Indonesia. Geographically it lies between the latitude of 7º10'13'' S to 7º23'29'' S and longitude 109º40'36" E to 109º50'06"' East (Figure 3-1). It covers an area of 236 Km². Naturally, Merawu catchment is one of the major catchment of Serayu river basin.

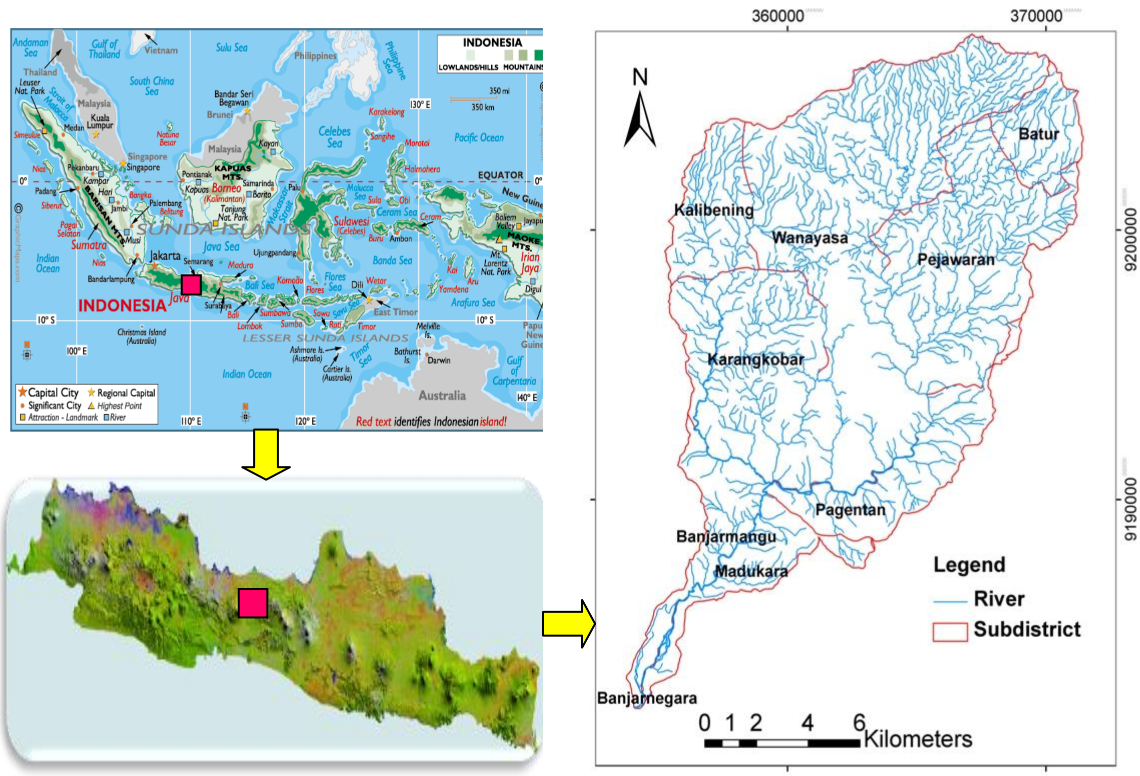


Figure 3-1: Map of study area (Bakosurtanal, 2000; Google, 2009)

3.2. Geological setting, geomorphology and soils

Merawu is one of three sub-watersheds (also known as upper Mrica) within Mrica watershed, in the Serayu river basin (Suwartha et al., 2006). The study area is mountainous in topographic structure, with elevation ranging from 225 –2215 meters a.m.s.l. (Bakosurtanal, 2000). According to the Geological map of the Serayu River basin, Central Java, Indonesia (Heine, 1978b) the catchment of Merawu is formed in breccias which include mainly sand stones, conglomerates and fine to coarse grained breccias as well as some tuffites and lahar deposits. Volcanic products are another main geological material of this catchment (Suwartha *et al.*, 2006). The geo-morphological map in Figure 3-2 presents the geo-morphological setting of the Merawu study area. The major geo-morphological units of the study area are low relief areas and stable slopes, moderate to high relief areas, structural plateau, lava field, volcanic foot slope slightly dissected and volcanic foot slopes with severely dissected and monoclinal ridge.

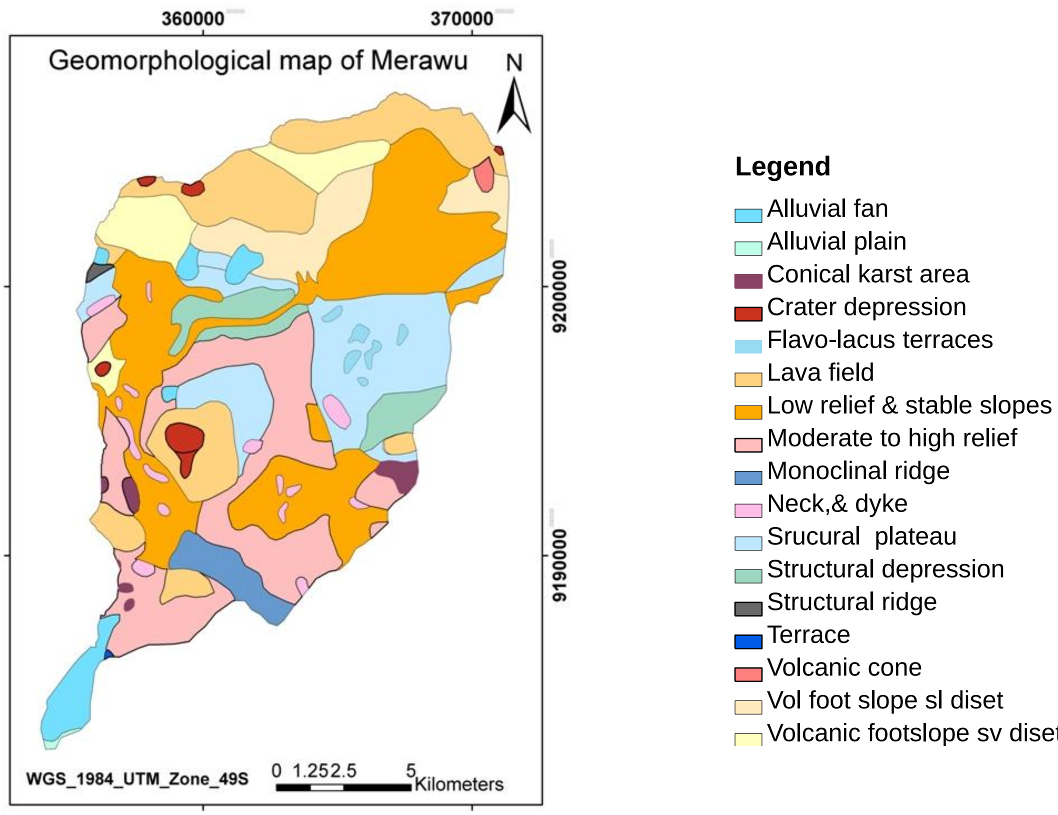


Figure 3-2: Geo-morphological map of the study area (Heine, 1978a)

The low relief and stable slopes is located in the upper northeast part of the area and it extends to the west and to the south. It is mostly covered by cropland and mixed trees with agro-forestry with dense population. Likewise, the moderate to high relief area is located middle to southwest part of the area and it is also mostly occupied by mixed forest with agro-forestry and croplands. Lava field unit is located top of the area and also at the southwest part of the area and mostly covered by shrub land and sparse trees .The structural plateau and volcanic foot slopes with slightly dissected units are also occupied by cropland and mixed forest with agro-forestry land cover categories. The major part of the volcanic foot slopes with severely dissected and the monoclinal ridge are mainly covered by shrub land with sparse trees.

The prevailing soil types in the Mrica watershed are red-brown Latosols and grey Regosols (Suwartha *et al.*, 2006). The major soil types in the area as shown in the Figure 4-2 (Chapter 4) are Latosol, Andosol and Vertisols (Grumosol) with coverage percentage of 44.0 34.0 and 19.0 respectively . These major soils occupy almost 98% while the Alluvial, Litosol and Regosol altogether cover only about 2%.The latosols one of the major soil types of the area as characterized by granular structure and physical properties of this soil is silty clay loam because of high content of kaolin and iron oxide where kaoline groups makes up >50 % of clay fraction together with iron oxide. The abundance of sesquioxides which consist of hydrated iron oxides leads to leaching of minerals in the soil and the rate of leaching is normally high and soil nutrients are low(Sherman, 1959; Townsend and Read, 1971; Lucas, 1993).The another major soil types Andosols are commonly found in volcanic area (FAO, 2001). They are very porous, friable and a crumb or granular structure. Aggregate stability of the soil is good and high permeability. So, relatively resistance to water ersion but where the area is deforested, the highly hydrated types of Andosols get dry out strongly. Consequently, Andosols crumble to hard granules which are easily removed by surface run off. Another major soil of the area Vertisols which is clay textured soil and are normally become hard in dry season and sticky in rainy season. This type of soil is less erodible than Andosols and Latosols.

The presence of volcanic soil types and anthropogenic activities make the area more vulnerable to the effects of high intensity rainfall that may create severe rills and gullies along the courses of runoff (Heine, 1978b).

Suwartha et al (2006) further explain that the land cover changes from forest to crop land and other anthropogenic activities make the area more vulnerable to erosion and sedimentation. It is not only because of volcanic soil types, but also because of intensive cultivation on sloppy areas and poor land management practices as well.

3.3. Climate

The overall climate in Indonesia is of a tropical humid type. However, the study area- Merawu catchment - is located in a mountain area. Therefore, the rainfall and temperature in the study area vary based on elevation. The area is a high rainfall area; however the annual average rainfall is about 2770 mm and maximum and minimum is 1332 - 4453 mm/year with higher variability and the number of rainy days on average 142 days/year (Figure 3-3). According to Koppen's Climate Classification System the climate type of the area is 'tropical moist' (Type A) in which all months have average temperatures above 18° Celsius.

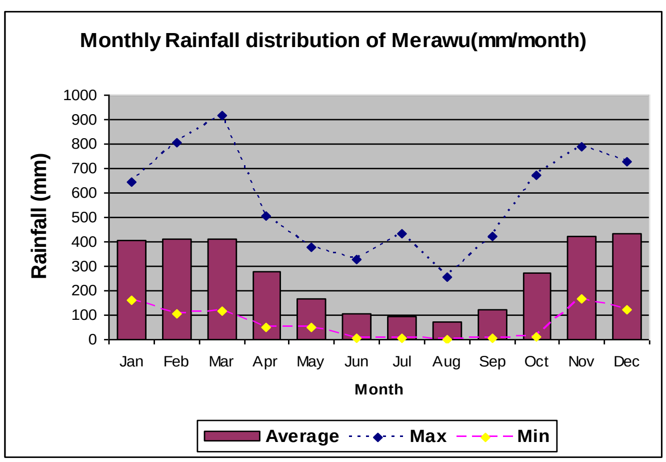


Figure 3-3 Average Monthly rainfall distribution of Merawu for 30 years (Source: Geophysical and Metereological Agency of Indonesia)

3.4. Major land cover/land use types

Table **3-1** reveals that major land cover types include dense forest, shrub and sparse trees, mixed forest/ agro-forestry, cropland, water body, settlement and built up area. The low land area is occupied mostly by shrub land, private garden or an agro-forestry system with salak fruit and Albazia tree species, and in some places rice fields along the river and stream sides. In the upland area the major land use types are also croplands, mainly dry agriculture which is commercially focused on vegetable farming e.g. potato, cabbage and chilli. Mixed trees are found together with agriculture area mainly along the marginal areas and streams sides. The farming practice in upland area is mostly on sloping terrace which is the major cause of erosion in the area. Some pictures of land covers and land use practices can give better impressions of the area as shown in the Figure 3-4.

a. Land preparing in slope

b. Salak and Albazia mixed forest

c. Salak (Snake skin fruit)

d. Plastic mulch for protecting seed and manure

e. Fully grown potato

f. Germinated onions from the plastic mulch

g. Gully formed in single rain storm

h. Small landslide in vegetable field

i. Farmers working on slope

Figure 3-4 Pictures showing the land use practices in the study area

Shrub with sparse trees is middle slope area but scattered throughout the area. The following table presents main land cover types and their area coverage based on the land cover classification with Landsat ETM+ image of 21 June 2009.

Table 3-1: Land cover/Land use of the study area

Land cover type	Area (ha)	Area (%)
Dense forest (DF)	2514	11
Shrub & sparse trees (SST)	5836	27
Mixed forest/Agro-forestry (MF/AF)	9123	41
Crop land (CL)	4565	21
Total	**22039**	**100**

The table above (Table 3-1) illustrates that cropland and mixed forest with agro-forestry covers 62 % of the total coverage while the forest (Dense forest) only occupies 11% and shrub land with sparse trees accounts about one-fourth of the area.

4. Methodology

4.1. Introduction

The main objective of the study is to analyze the effects of land cover change on top soil properties and soil erosion. The study area selected is Merawu catchment which is located in Central Java Island of Indonesia. The research is intended to find out the effect of land cover change particularly on soil properties and there by erosion in the area over time. Besides, temporal trajectories of land cover change are identified based on the field information, interviews, and from the classified land cover data.

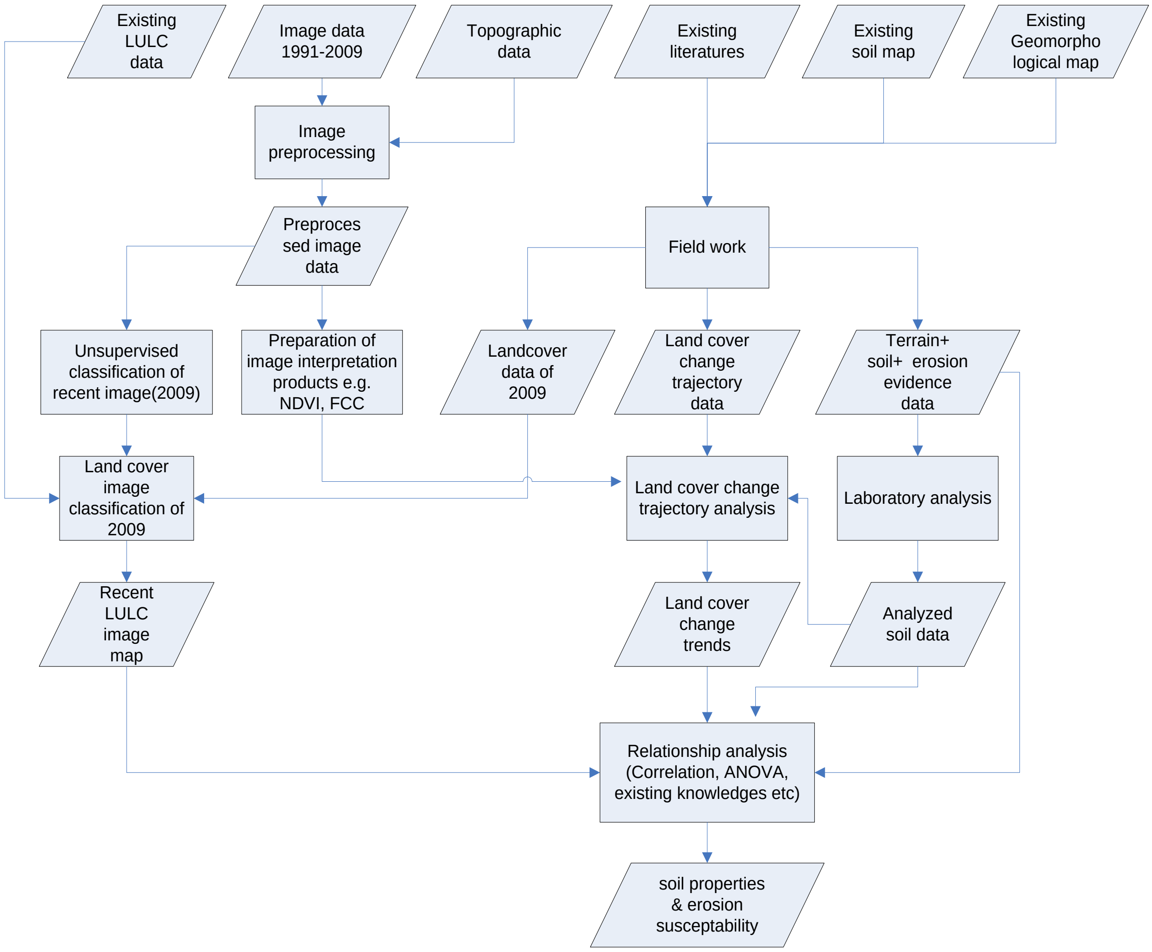


Figure 4-1: Methodological framework

In this way, the study includes in two main methodological steps. (1) Study of selected soil properties and relating these properties in relation to land cover change. In this method we describe using statistical descriptive tools mainly the top soil properties such as soil structure, soil texture, soil colour, soil pH, soil strength, soil soil compaction, soil aggregate stability based on the field methods and also organic matter content and soil particle size distribution through lab analysis. The selection of these aforementioned soil properties for this study answers the study objectives and research questions mentioned in chapter one. Moreover, the selected soil properties can be used to relate them in relation to land cover change in the area where such kind of study has not been carried out yet. (2) Land cover change analysis through post classification comparison method and establishment of land cover change trajectory line based on the historical information collected from informal interviews and image analysis were done. The frame work Figure 4-1 shows the detail methodological steps.

The methodological frame work is a schematic overview of the research activities that took place during the study. First stage is image pre-processing after collecting the basic data and visual interpretation with the use of topographic data and soil map. For ground truthings unsupervised classified maps were prepared from combined image of June 21 2009 and June 18 2008 images from Landsat. The image were prepared using FCC of 453, 451, 321 band combinations to classify the Landsat image. Eight spectral classes were made to locate the ground truthings in the map based on the field situation as a pre-field work.

4.2. Materials used:

Following materials were used in this study:

Table 4-1: Materials used in the study

Dataset	year	Scale/ Resolution	Format	Source
Topographic map/ land use map	2000	1:25,000	Digital vector format	Bakosurtanal(Geological survey of Indonesia)
Geology map		1:100,000	Digital vector format	Geological Research and Development Centre, Bandung
Geo-morphological map	1978	1:250,000	Digital format (JPEG)	ITC and UGM Serayu river basin project
Soil map		1:250,000	Digital vector format	Puslitanah(Centre of Soil Research)
Rainfall(Precipitation, duration and intensity)	1979 - 2009	Daily, monthly and annual	Excel format	BMG (Geophysical and Meteorological Agency of Indonesia)
Landsat image data	2009, 2008 2001 1991	30m 30m 30m 28.5m	Digital raster	USGS/RS lab ITC
Land cover map	2009	1:120,000	Digital raster format	Field surveys, image interpretation and classification from Landsat ETM+
Soil data	2009	Field observation points	Digital	From field survey and lab analysis

The software used for the study was: Arc GIS 9.3 version, ERDAS IMAGINE 9.3, Excel and SPSS for statistical analysis, Microsoft Visio for the production of flowcharts, Microsoft Word for typing the thesis. Field equipments used in the field were: GPS - Garmin Etrex, soil sample collection bags, soil auger, shear vane tester, pocket penetrometer, plastic bottle, plastic transparent box, sunnto clinometers, sunnto compass, Altimeter, field knife, Marker pen, Munsell Soil Color Chart, Field Soil pH kit, FAO Guidelines for soil description, Field Book for Describing and Sampling Soils.

4.3. Primary Field data collection

Primary data such as soil data, erosion evidences and ground truths for land cover mapping were collected using following sampling scheme during field work from October 1- 15 of 2009. The major selected soil properties were estimated using field methods which are described separately in subsection of this part.

4.3.1. Sampling scheme:

Selection of soil sample points and ground truths locations was initial field task in order to collect soil data and ground truths. For this, general reconnaissance survey of the area was done from the lower part of the catchment to upper part to familiarize with the different land cover types of the study area. Then sampling points were selected purposively based on the land cover types, main soil types of the area and the accessibility. Many observation points were not possible to visit and collect the data within the short period of time because of the large study area of 235 Sq. km. Hence, a purposive sampling method was considered as useful sampling method in this study to collect the soil data and ground truths. The main criteria for selecting sample locations were the land cover types and accessibility. Additionally, terrain condition (topographic condition), altitude and landscape types were also taken into account. 61 soil samples and 63 ground truths altogether 124 location points were observed and required data were collected. Furthermore, field tests were performed for selected soil properties targeted. Photographs of erosion evidences and other features were also taken. The spatial distribution of soil sample point locations is shown in Figure 4-2a.

4.3.2. Soil data collection:

To find out the selected soil properties of the area 61 (Figure 4-2a) soil samples were collected as mentioned in section of sampling scheme 4.3.1. Soil field data were collected considering the representation of different land cover/land use types. On this basis, soil in the specific land cover type was collected from the undisturbed area within the depth of 0-20cm because our focus was to describe the top soil properties in relation to land cover change and soil erosion. Soil description was based on the FAO (2006) Guidelines for soil description. The collected data was entered into a field data sheet and then later into the computer for analysis.

In this part of field work, firstly coordinate location of the sampled area was taken using simple GPS - Garmin Etrex. Then, soil auger was also used to see the soil profile and also for the soil sample collection but soil samples were taken to find out the selected top soil properties particularly soil texture, soil structure, soil strength, soil compaction, soil aggregate stability, soil colour, soil pH and soil organic matter content. These selected soil properties are relevant and important to fulfil the objectives of this study. Because the effect of land cover change on these selected soil properties are estimated in the field and analysed to establish the relationship between the properties and land cover types and erosion susceptibility in the area. For organic matter content analysis and to validate the field method of soil texture, about 200gram soil sample from each observation was taken from the top soil (0-20cm) of different spots of the plot and mixed together and then packed in air tight plastic bag. So, to achieve the proposed objectives of the study, some field tests methods were applied to find out the top soil properties of 61 points. Following methods and approaches were applied in the field to find the properties of soil parameters:

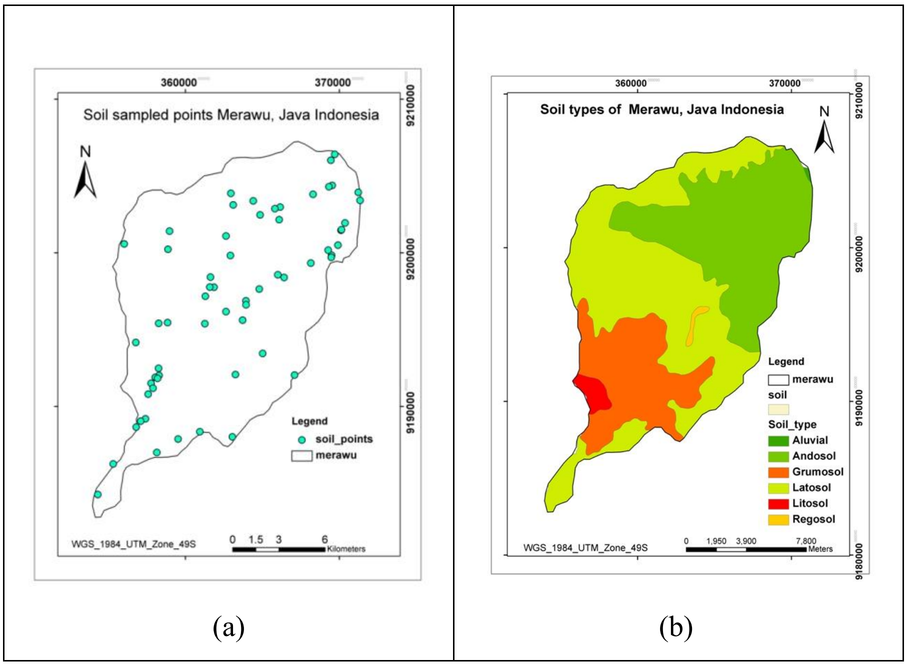


Figure 4-2: showing (a) sampled soil points and (b) main soil types in the study area

(Puslitanah, 1978; Fieldwork, 2009)

<u>Soil Structure</u>

For the field method, we took a lump of soil from the sample area and structure was described mainly in terms of its size and type.

<u>Soil field texture</u>

For the field assessment of top soil texture about one tablespoon of fine soil was held in hand with some drops of water to make moist and then squeezed and rolled the soil until it starts to stick to the hand. A soil texture class was assigned based on the extent to which the soil can be shaped , like simple mound, tablet, roll of 10 cm with cracks, roll of 10 cm without cracks, horse shoe with cracks, horse shoe without cracks and circle (Kunwar et al., 1999). The overview of this classification is given in Table 4-2.

Table 4-2 Field method for identifying soil texture

Form	General texture	Class of availability of erodible material
Simple mound	sand	7
Tablet	Loamy sand	6
Roll of 10cm with cracks	Sandy loam	5
Roll of 10cm without cracks	Loam	4
Horse shoe with cracks	Clay loam	3
Horse shoe without cracks	Silty clay	2
Circle	Clay	1

According to this approach texture of soil was identified as: sand, loamy sand, sandy loam, loam, clay loam, silty clay and clay respectively. This field method is chosen in this study because it is quite simple and useful for non soil-experts to be learned in a short period of time and to be applied to estimate the soil texture in the field.

Soil strength (using Vane tester)

Vane tester was used to find out the shear strength of the soil particularly the clay content through which soil detachability property can be described of the particular soil taken during the study. Using this instrument soil strength is expressed in values of Kilo Pascal (kpa).

The measuring part of the instruments is a spatial spring. When the handle is turned, the spring deforms and the upper part and the lower part of the instruments get a mutual angular displacement. The size of the displacement depends on the torque which is necessary to turn the vane. By means of graduated scale the shear strength of the clay is obtained(ENVCO, 2009). For this study we used the 20x40 mm (standard) vane tester which gives direct readings and measures the shear strength in a range of 0- 130 kpa. The shear vane was driven into the soil to 1cm depth and rotated. The torque required to shear the soil along the surface of a cylinder generated by the blades of the edge. At least three measurements in each sampled location, with three replication measurements, were measured to make sure the consistency of the value in that area and average values were recorded for that area. The results were described in relation to the land cover types in the area using descriptive statistical tools such as maximum, minimum, mean and standard deviation.

Soil compaction (using pocket penetrometer)

Soil compaction of the top soil was estimated using a pocket penetrometer. The penetrometer has a ground and polished ¼ in diameter spring-loaded piston, which is pushed into the ground to a depth of ¼ inch. A calibration mark on the piston indicates the depth of penetration. The area of the piston end is 0.05 inch^2.The compression strength in tons/ft^2 is read on a scale attached to the piston barrel. It is easy to use by pushing the indicating ring to the highest point touching the body. Then piston is inserted until the calibration mark is level with soil and then reading is taken. It is commonly used to find the compaction of soil. So, using this penetrometer compaction strength is taken carefully avoiding gravel or other particles that influence readings(Amacher and O'Neill, 2004).

During field work, at least three measurements with 4-5 replications in every soil sampled location were taken and finally average value of the compaction of that area was determined. The results were described in relation to the land cover types in the area using descriptive statistical tools such as maximum, minimum, mean and standard deviation.

Soil pH (using Heilige pH indicator kit)

Soil pH was estimated in the field using indicator liquids with the Heilige soil pH indicator kit (FAO, 2006). One measurement of soil pH was taken from the top soil (0-20cm) in each observation point. The measurements were recorded as pH 5.0, 6.0 and so on. This method is considered "quick and dirty" but it is simple and cost effective than lab and other methods. The result of field soil pH was described simply based on the pH range criteria (FAO, 2006). Besides, the result was further discussed in relation to land cover types of the area.

Soil colour (using Munsell colour chart)

Soil colour reflects the composition of both past and present oxidation reduction condition of the soil in the area. It is determined by coating of very fine particles of humified organic matter which seems dark, iron oxides (yellow, brown, orange and red, manganese oxides (black) and others, or may be due to the parent rock(FAO, 2006).

Colour of the soil is recorded in both moist and dry conditions using the notations for hue, value and chroma as given in the Munsell Soil Colour Chart (Munsell, 1975). Here hue is the dominant spectral colour (red, yellow, green, blue, or violent), value is the lightness or darkness of colour ranging from 1(dark) to 8 (light) and chroma is the purity or strength of colour ranging from(pale) to 8(bright). For identifying the soil colour in dry condition in this study, Munsell Soil Colour Chart was used. Later on, soil colour was described in relation to land cover types and relationship was established with organic matter content of the sampled soils.

Soil aggregate stability (using crumb test)

In each location one aggregate (clod) of about 1cm diameter soil was taken and the crumb test was performed. A transparent plastic box with normal water was used. The reaction of the clod after five minutes of immersion was observed. The amount of slaking or loss of form by wetting, swelling or air explosion was rated as by the following classes(Kunwar *et al.*, 1999).

Class 1: no change

Class 2: some collapse

Class 3: some stable remnants (in centre)

Class 4: completely collapsed

The result was interpreted in relation to land cover types of the study area.

Soil sampling for lab analysis

After field work, 61 soil samples were prepared for lab analysis purposes. 11 representative samples were selected purposively for particle size analysis(Pipette method) representing land cover types mainly agricultural rice field, dry agricultural land(Potato, maize & vegetable), pine forest, shrub land and private agro-forestry (Salak and Albazia species). Likewise, all 61 samples were used to determine organic matter content. See also section 4.7 for a description of lab analysis techniques.

Erosion evidences

Regarding the erosion evidences in the sampled location, just visual judgment was done and taken the information as present or absent of erosion features like sheet, rill or gully erosion. For recording erosion evidences mainly the types of water erosion such as sheets, rills, gullies and deposition if we saw the evidences at the area then recorded as present or if we did not see the evidences then recorded as absent at the observation points during the field visit time. At each location where erosion evidences were found, 1-2 photographs were taken.

Other field data

Topographic (terrain) information such as elevation, slope percentage and aspect were recorded using altimeter, sunnto clinometer and sunnto compass respectively.

4.4. Collection of land cover ground truthings

Ground truths points were taken with GPS and field observation of the land cover and land use types were noted for supervised land use classification map generation. All together 124 ground truths (including 61 soil sample points and 63 land cover ground truths) were visited, GPS location and land cover/ land use types were recorded as shown in Figure 4-3. The ground truths were recorded as per the specific land use/land cover type and later on they were grouped into broader land cover types as dense forest, shrub and sparse trees, mixed forest/agro-forestry and crop land in land cover mapping process to minimize the complexity.

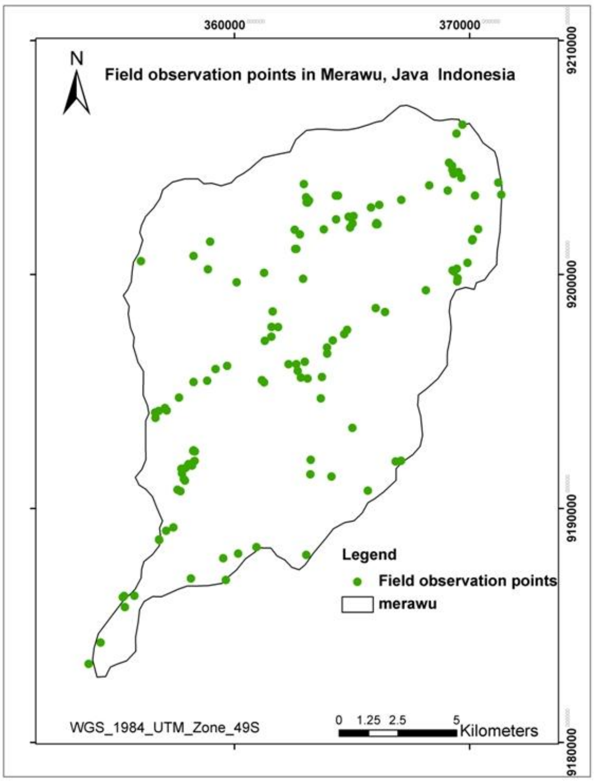


Figure 4-3: Field observation points

4.5. Informal interviews with key informants

For the collection of historical information about land use/ land cover change, thirty informal interviews were planned: with farmers, and with village leaders, farmer's leaders, government representatives and school teachers. The planning was to take interviews with farmers during sample collection time but in some cases it did not work. The informal interviews with village leaders, farmer's leaders, government staff and school teacher, the appointment time was fixed first and then interview was conducted at their offices. However, it was difficult to get the actual information of land use/ land cover change because of the language problem and lack of information with the concerned farmers or people found in the time of visit. Twenty six informal interviews were conducted out of planned thirty interviews. Of these, nineteen interviews with local farmers, interviews with four village leaders, an interview with a farmer's leader, an interview with a government staff and one was with a school teacher as shown in the following Table 4-3.

Table 4-3 Key informants of informal interviews

Key informants	# of key person interviewed
Local farmers	19
Farmer's Leader	1
Village leader	4
Government staff	1
School teacher	1

4.6. Secondary data collection:

Secondary data mainly rainfall data and existing maps, were collected during field work time from concerned offices and agencies as mentioned in the Table 4-1of material used in sub section 3.1.

4.7. Lab analysis:

Particle size distribution and organic matter content of collected top soil samples have been analysed in the laboratory at ITC. The particle size distribution results are used to calibrate field texture data. The organic matter content is one of the important soil properties which is highly affected by land cover change in the area and it is relevant to relate with erosion susceptibility and other soil properties as well. Therefore, it was considered one of the major soil properties selected for this particular study.

4.7.1. Particle size analysis (using pipette method):

The collected soil samples were selected as representative soil samples to check the field method which was applied in the field during field work. 11 samples were selected from out of 61 samples for this purpose. Pipette method was applied in ITC lab to identify the particle size distribution of the soil. The purpose of this method is to determine the quantity of each of sand, silt and clay fractions in samples of soil taken from the study area. Main principles of the method is to separate the mineral part of the soil into various size fractions and determination of the proportion of these fractions. The analysis comprised all material i.e. including gravel and coarser material but the used procedure was applied for the fine earth fraction (<2mm) only. A 2mm sized sieve was used to separate the gravel (coarser than 2mm) from grains less than 2mm in diameter of the selected samples. 20gram fine earth was weighted out and put into 11 beakers and whole process of Pipette method (ISRIC, 2002) was applied and whole method was thoroughly followed. Final result was obtained and used to calibrate and check with field method. The result is interpreted in relation to land cover types prevail in the study area using simple graph figure and bar diagram for the representative samples. In overall samples the interpretation is done on the basis of lab results and is described in relation to land cover types Moreover, statistical tools such as maximum, minimum, mean and standard deviation are used to describe and presented in the summary sheet.

4.7.2. Determination of organic matter content (loss-on-ignition method):

OM analysis was done by using the loss-on-ignition method. Principle behind this method is oxidization of organic matter by heating at 650 ºC and estimation of OM content by weight loss. In the lab, the porcelain crucibles were dried first by heating in 105 ºC and after cooling, the dry weight of crucible was measured. In each crucible 2.5 gram of dried soil sample were put and the crucibles placed in the furnance. The temperature was fixed 650 ºC and left for drying about 30 hours. After that the crucibles with samples were placed in desiccators for 30 minutes to cool and weight was taken to the nearest milligram. Finally, percentage of OM content is determined using the following formula (Hoskins, 2002; Kalra & Maynard, 1991)

*OM content %= (Oven Dried weight- LOI weight)/ Oven dried weight*100*

The collected soil samples were analyzed in the lab and interpreted with respect to the land cover types using different descriptive statistical tools such as maximum, minimum, mean and standard deviation with summary sheet. In addition, relation between OM content and compaction of soil is established and analyzed. Moreover, ANOVA test was performed and box plots with error bars were also used and the result was interpreted.

4.8. Calibration of field texture estimation

To check or validate the field method, we selected 11 representative soil samples purposively based on the different land cover types for texture analysis using the pipette method as lab work. Then, later on the lab results were checked with field results and calibration was done based on the lab results. Basically calibration was done to match with lab results and was interpreted in relation to land cover types. Based on the lab result, it is not easy to calibrate because in some cases we can see the big variation between the result of field method and the lab results. However, decision rule is created in such a way, the result which coincides with lab; there is no need to change the textural class. Likewise, the texture class which is adjacent to each other in textural triangle, they are calibrated based on the lab results. Regarding the quite different textural classes, in this case the field textural classes were overlaid on the soil map of the area, and then the textural class was calibrated as per the characteristics of map unit where the individual sample falls. Here two textural classes such as silty clay loam was the result from the lab but the field texture was loamy sand that is away from each other. In this case the decision was taken as per the map unit, if it is located under the map unit of Andosols, it is then calibrated as sandy loam according the textural characteristics of Andosols (FAO, 2001) and for other field textural classes were calibrated accordingly.

Table 4-4 Textural characteristics of major soil types of Merawu

Major soil map unit	Textural characteristics
Andosols	Sandy loam
Latosols	Silty clay loam
Grumosols(Vertisols)	clay

Source: (FAO, 2001)

4.9. Statistical analysis:

The results of soil strength, soil compaction and soil OM content were analyzed and interpreted by using analysis of variance (ANOVA) and other descriptive statistical tool were also used.

4.10. Land cover mapping and establishing temporal trajectory line

Recent image data (June 21, 2009 and June 18 2008 combined) was used prior to field work using unsupervised classification and interpretation for field work purpose. Initially, the image of 2009 had striping problem and after the consultation with the staff of Remote Sensing lab of ITC, it was suggested to use the combined image of 2008 and 2009 to minimize the uncertainty of image. The time for preparation was also short. So, the available image data were not checked thoroughly. But after field work, it was problem to run the accuracy assessment in the combined image. So, later on further effort was done to destrip the image of 2009 and then it worked properly and then it was used for further land cover mapping process. Likewise, multi-temporal images of 1991& 2001 were used for this study. Hence, the initially provided image data set were not used as shown in the Table 4.5 but another data set given in the Table 4-6 were used for further work of land cover mapping process to classify and find out the land cover change together with establishing temporal trajectories of land cover change with the combination of historical information collected from the field. Post classification comparison method was used for temporal land cover change analysis and for trajectory line analysis together with the field information in general. Supervised classification was employed to classify individual images independently using the maximum likelihood classifier (MLH) and a unified land cover classification scheme to ensure that the classification of the multi-scale, multi-temporal images are compatible to each other (Zhou *et al.*, 2008).

4.10.1. Image classification:

Land cover classes are typically mapped from digital remotely sensed data through digital image classification and interpretation (Campbelll, 2002). The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand and Kiefer, 2008). In this study, supervised and unsupervised classification methods were used for image classification. Figure 4-4 presents the classification frame work that has been applied. This is followed by a detailed description.

The initially available remote sensing image data as in the Table 4-5 were considered to be used in this study. So that, in the beginning of this study the combined image of 2008 and 2009 was used for unsupervised classification prior to go field work to find the possible sample points and image interpretation purposes as described in previous section 4.10. After coming back from the field, the combined image did not work properly while performing accuracy assessment after the image classification process. It might be the effect of it being a combined image. Likewise, other images were checked as shown in the Table 4-6 which were affected by cloud coverage. Another cause behind changing of initially available images was that the available images were not in good condition and the images acquisition dates were of different months. Moreover, in this situation, the multi seasonal image data are not useful because land cover mapping for change detection purpose requires anniversary or nearly anniversary images to eliminate the vegetation phenology changes. So, we tried to find the Landsat images of different date but almost same month or nearly anniversary. Consequently, image of 2009/6/21 was again downloaded and de-striped. Later on it worked properly in the classification process. Likewise, the researcher again tried to find better images using the USGS Global Visualization Viewer (GLOVIS) and then Landsat images of 2001 and 1991 were found. These new images (see Table 4-6) were almost of the same month (anniversary images) which is the basic premise in using remote sensing data. Furthermore, use of landsat data belonging to the same time of the year may reduce the problems of Sun angle differences and vegetation phenology changes (Singh, 1988). Besides, it is because of the possibilities for the classification of land cover types depend on the date an image was acquired. This not only holds for crops which have certain growing cycle but also for other applications (Kerle et al., 2004).

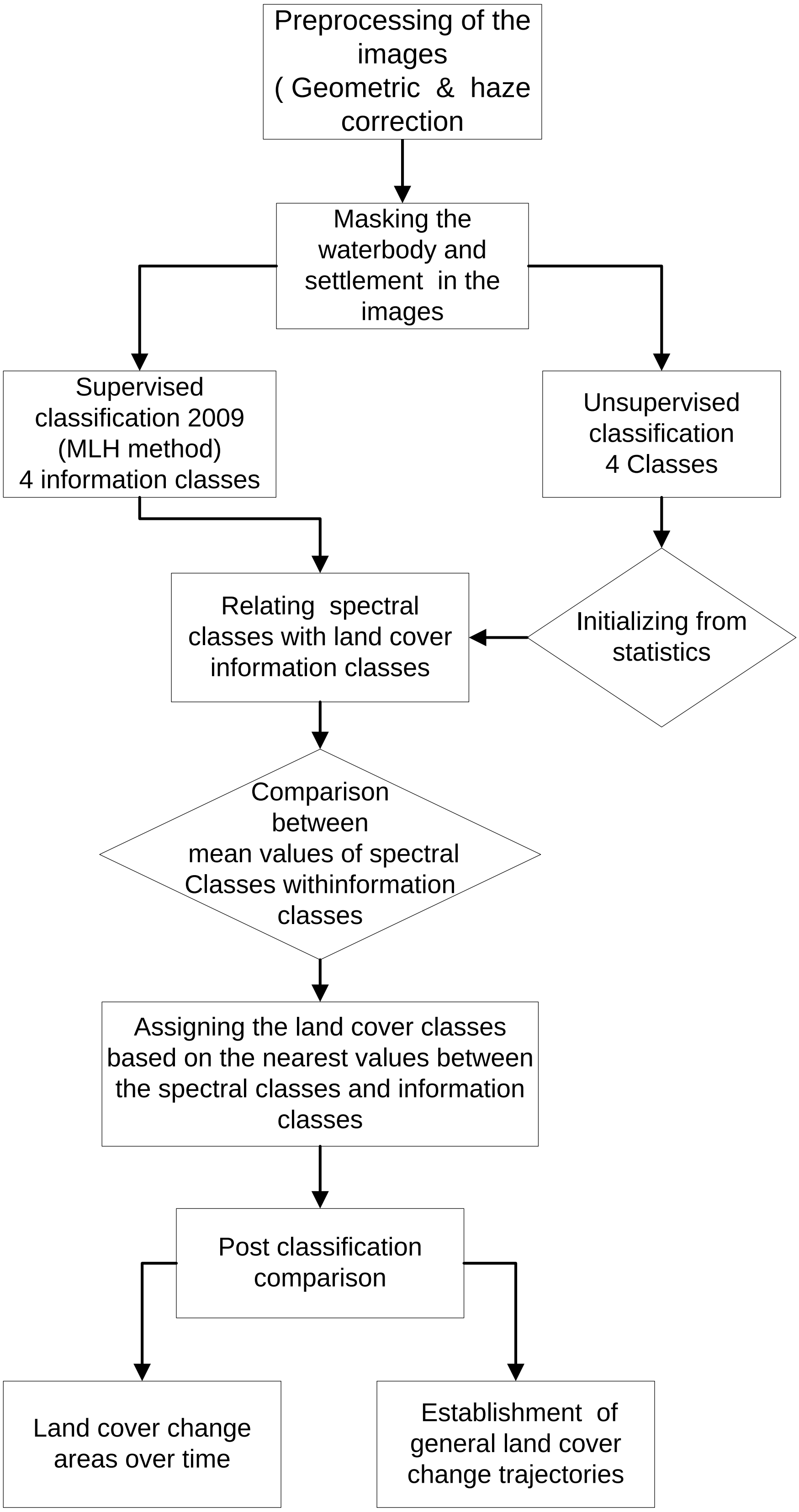


Figure 4-4: Conceptual frame work of image classification

Selection of images

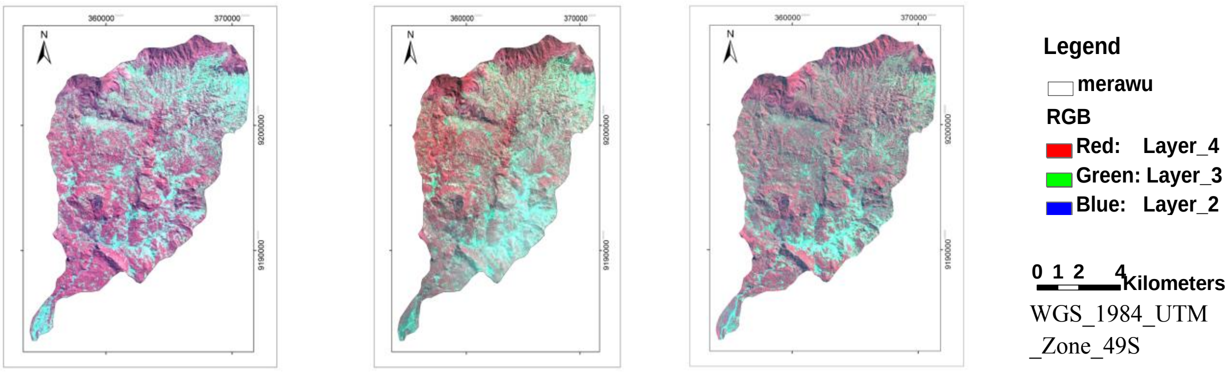
Table 4-5: Image data

Satellite	sensor	path /row	Resolution (m)	Acquisition data	Remarks
Landsat 1	MSS	129/ 65	57	25/04/ 1978	About15-20% cloud cover
Landsat 4	TM	120/65	30	11/04/1989	10 % cloud
Landsat7	ETM	120/65	30	11/05/2000	cloud problem,
Landsat 7	ETM	120/65	30	18/07/2008 & 21/07/2009	stripping problem

Table 4-6: Used image data for land cover mapping and change detection

Satellite	sensor	path /row	Resolution (m)	Acquisition data	Remarks
Landsat- 5	TM	120/ 65	28.5 28.5	28/06/ 1991	No cloud cover
Landsat-7	ETM	120/65	30	01/07/2001	No cloud cover
Landsat7	ETM	120/65	30	21/06/2009	No cloud cover

These images as shown in the above table were comparatively better for this study. These images were selected for this study as these are freely available and give suitable cloud free, spatial coverage and medium resolution in land cover classification. So, the latest available image data (Table 4-6) were in following conditions (Table 4-5), which are comparatively better than previously available images.



a. Image_ 2009 b. Image _2001 c. Image_1991

Figure 4-5 Images of 2009, & 2001 & 1991

Image pre-processing

In this study, already geo-corrected images were used available from the RSG lab of ITC but the projection system was changed to the one applied for Indonesia as shown in the Table 4-7.

Table 4-7: Projection parameter

Projection type	Universal Transverse Mercator
Spheroid name	WGS 84
Datum name	WGS 84
UTM zone	49
South or North	South

As earlier mentioned, all three images used in this study are of near- anniversary dates Table 4-7 to reduce the differences in illumination geometry and vegetation phenology (Singh, 1988; Paolini *et al.*, 2006). The image of 1991 was re-sampled into 30m resolution using Nearest Neighbour Method, to match with the other images. Likewise, the following radiometric enhancements were applied:

Haze reduction

Haze correction was performed in ERDAS IMAGINE 9.3 for all three images e.g. image of 1991, 2001 and 2009 to reduce the haze effect on the images.

Destriping

Destriping was done ERADAS in order to remove the striping problem in the image of 2009 which image had initially striping problem. Strips of image of 2009 were masked out first, and then it was used to clip the 2008 image to fulfil the gaps of strips. Later on, mosaic was made from the masked out image of 2009 and clipped image from 2008 and then output was used for further image classification process.

Masking of water body and settlement

A masking operation was carried out to mask out the water body, settlement and built up area in the images, using the data from the land cover map of 2000. This allowed for an image classification focussing on those land cover types of interest in this study.

In this study, the following image products were applied to improve the visual discrimination of different cover types in the images:
TM321, TM432, TM453 and TM742 contrast stretched false colour composites and NDVI.

Texture, colour and association analysis were done at the beginning to familiar with study area prior to field work for preparing sampling scheme. Furthermore, field survey data, land use map of 2000 and local information from the interviews were carefully analyzed while preparing the image classification scheme.

Definition of land covers classes

The land cover classes to be considered were defined according to the main land cover classes mentioned in the available land cover/ land use map of 2000 of the study area and field information gathered during the field work. It was decided to make four land cover classes namely:

- dense forest,
- shrub & sparse trees and grass,
- mixed forest/ agro-forestry together with private gardens and
- crop land together with dry and bare land of agricultural area

These identified land cover classes are different in terms of aerial cover and in terms of the seasonality/permanence of the cover. These are important aspects of land cover in relation with soil properties and erosion susceptibility of selected land cover types. The Table 4.8 shows the land cover classes defined for this study.

Table 4-8 Land covers Classification scheme and definition of classes:

No.	Class Name	Description
1.	Dense Forest (DF)	Forest in high hill slope and pine forest
2.	Shrub and sparse trees(SST)	Shrub lands, sparsely vegetated areas and grass lands
3.	Mixed forest/Agro-forestry (MF/AF)	Upland agro- forestry, private forest mixed with Salak fruit (Salacca zalacca) trees, Albazia falcataria and other mixed tree species
4.	Croplands(CL)	Agricultural rice fields together with dry and bare agriculture areas

Supervised classification method

The maximum likelihood classifier (MLC) method quantitatively evaluates both the variance and covariance of the category spectral patterns when classifying an unknown pixel so that it is considered to be one of the most accurate classifier since it is based on statistical parameters. The MLC is basically based on the probability that a pixel belongs to a particular class and the input bands have normal distribution. It is considered to give more accurate result than parallelepiped method (Ismail and Jusoff, 2008). In supervised classification process, it requires input from an analyst to run the classification algorithm to associate values of pixel with correct land cover category (Jensen, 2005; Lillesand et al., 2008).

The Supervised classification with Maximum Likelihood decision rule was employed with four numbers of classes as shown in the Table 4-8 in the image of 2009 using 61 samples as training points and 140 as reference points for accuracy assessment purpose. The accuracy assessment was performed according to area of interest (AOI) as the training sites of each land cover class. The reference points representing different land cover types collected during the field work of October 2009 were used to carry out the accuracy assessment. From the help of reference points collected from the field and also generated based on the pictures of the field and reference points from fellow students, altogether 140 points were used to validate the classified image of 2009. In accuracy assessment the classified image was assessed by comparing it to ground truths (Reference data). For this we used ground truths and error matrix was generated. We can’t use the recent ground truths for historical images because recent ground truths represent the reality of present time but not the past. Supervised classification is done to validate the result with real situation in the field from its accuracy percentage how much is the correctness of the classification based on the ground truths. It is used where there are ground truths are available for accuracy assessment to validate the work. The classified image of 2009 was considered as a base image to assign the spectral classes of unsupervised classification of 2009, 2001 and 1991 images.

Unsupervised classification method

The unsupervised classification approach is an automated classification method that creates a thematic raster layer from a remotely sensed image by letting the software identifies statistical patterns in the data without using any ground truth data (Leica Geosystem, 2005; Lillesand and Kiefer, 2008). Clusters are defined with a clustering algorithm that uses all pixels in the input image for analysis.

After the classification, the analyst then employs a posteriori knowledge to label the spectral classes into information classes.

Prior to field work as mentioned in section 4.10.1 of image classification, the combined image of 2008 and 2009 was classified using unsupervised method to familiar with the study area and to make the sampling scheme for the data collection. Later on after field work, the image of 2009 was classified using both methods of supervised and unsupervised classification. The classified image of 2009 is a base image to assign the accurate land cover class of historical images of 1991 and 2001. For this, classification of 2009 image with unsupervised method using same four numbers of classes was compared with the supervised one of same year image. For this, first the mean values of spectral class and information class with respective to their related bands were compared to each other to assign the information class for unsupervised from supervised one. Then, secondly, the mean values of spectral bands of each class were plotted as line graph in EXCE and compared their positions. Based on the position of each class of unsupervised image and supervised image, then comparable class was determined and the class was assigned as per the information class.

Additionally, Euclidian distance(ED) method was also employed to assign the class. To calculate ED, following formula (Pythagorean Theorem) was used:

$$d(X,Y) = \sqrt{(XB_1 - YB_1)^2 + (XB_2 - YB_2)^2 + ...(XB_n - YB_n)^2)}$$

Where,
B_1, B_2… B_n are band values of X and Y images and here the X is considered as supervised classified image of 2009 and Y is unsupervised classified image of 2009, 2001 and 1991 in ED calculation for different combination.

Based on ED method, first we calculated the ED between the supervised and unsupervised images of 2009 and here the lowest ED was considered to assign the class. Based on this idea, certain correlation of the spectral classes and information classes were established and then the EDs for image of year 2001 and 1991 were calculated with supervised image of 2009 using unsupervised classification method with same four classes and then the land cover type classes were assigned accordingly.

<u>Post classification comparison</u>

In this study, post classification change detection method was applied in order to find out the land cover change over time. It requires the comparison of independently produced classified images. The post classification comparison method proved to be the most effective technique for comparing the changes occurred in two dates. Because this method, separately classifies multi-temporal images into thematic maps and implements the comparison of the classified images pixel by pixel. Moreover, it has advantages i.e. it minimizes the impacts of atmospheric, sensor and environmental differences between multi-temporal images and it provides matrix of change information (Lu *et al.*, 2004). By the classification of two date remotely sensed images, we can figured out the land cover changes and relate the change with selected soil properties of the area. So, in this study the images of 1999, 2001 and 2009 were separately classified and comparison was done to figure out the area of change in different land cover category from one date to another date (Shalaby and Tateishi, 2007). Finally, it gives the area of change from one date to another.

Comparison of total area coverage may not always provide the most efficient and accurate analysis of changes. Instead of taking area coverage of each land cover category at each date into account, pixel-based comparison is better one to produce change information on pixel basis (Alphan *et al.*, 2009) and therefore, to interpret the changes more efficiently taking the advantage of " from ,- to " information. So, in this study the post classification comparison pixel by pixel basis was applied in order to find out the spatial and temporal land cover change information from 1991 to 2001 and from 2001 to 2009 in the area which is one of the major objectives of this study.

After the supervised classification, the images of two different periods were crossed in Arc GIS in order to determine the qualitative and quantitative aspects of the changes for the periods from 1991 to 2001 and from 2001 to 2009. The area of change was calculated and converted the pixels into hectare units and presented in the combined table form for all 3 date images. Then the comparison and visual presentation was done using graphs and charts on the output data as illustrated in Result and Discussion chapter.

Later on the result was compared from one date to another. The images used for first period and output shows the conversion of land cover from one to another. In cross tabulation, the first is image cross tabulation in spatial analyst tool in tabulate area function where the categories of one image are compared with another image and tabulation is kept of the number of the cells in each combination. The output of this operation is a table of list showing the tabulation of land cover classes and their conversion from one land cover type to another within the two dates. From the output table, we further improved the table in simple and logical form to interpret it easily.

Establishing the land cover change trajectories

Spatial temporal land cover change patterns is one of the active research field 2001 (Roy and Tomar, 2001; Weng, 2001) and the concept and methodology of change trajectory analysis has been developed (Mertens and Lambin, 2000; Petit *et al.*, 2001; Liu and Zhou, 2004). In this particular study the term trajectory of land cover change refers to the change of land cover from one type to another(Zhou *et al.*, 2008). To establish temporal land cover change patterns, all classified images were combined in ArcGIS particularly in spatial analyst tool using the tabulate area to produce the matrices of change from one cover type to another. Then, we compared the pixel based change from one category to another and found all possible land cover change trajectories and decided to establish the major land cover change trajectories based on the higher number of pixels change from one type to another. For this, a simple and state forward decision rule was made in such a way, which land cover has changed into another land cover type with how many numbers of pixels, first two land cover types which deserve highest number of pixels values were taken to use for establishing change trajectory. Because, the conversion or change from one to another exists in all land cover types. So, to minimize the complexity, the first two highest conversion values were taken to establish the land cover change trajectories. Likewise, field based information were used to establish separate trajectories of land cover change. Finally, the change trajectories derived from two sources such image pixel based trajectories from the conversion table, and interviews –based trajectories were taken as common trajectories and then uncommon trajectories were also taken for combined change trajectories. Finally, the land cover change trajectories were established as combined most common change trajectories of the area. Based on the classification scheme, all possible land use change trajectories are illustrated as outputs described in detail in the chapter of result and discussion.

5. Land cover mapping and image analysis

5.1. Land covers change analysis

One of the objectives of this research is to analyze land cover change pattern in spatial and temporal perspective in the study area. So, to achieve this objective, image classification was done using supervised and unsupervised classification approach after doing image pre-processing as mentioned in the methodology chapter of image classification 4.9.1. For the image of 2009, first we classified the Landsat ETM image of 21 June 2009 and accuracy assessment was performed. First, the result of supervised classification and accuracy assessment is presented and discussed. Secondly, Landsat ETM image of 1 July 2001 and Landsat TM image of 28 June 1991 were also classified using unsupervised classification method and again unsupervised method was employed in the same image of 2009 as well. The results of unsupervised classification of 2009, 2001 and 1991 are presented and discussed together in class assigning process. The classified images from both methods are shown in Figure 5-2.

5.2. Result of 2009 classified image and its accuracy assessment

The image of 2009 was classified employing supervised classification method with Maximum likelihood classifier algorithm. The number of classes is four which includes dense forest (DF), shrub land, sparse trees and grassland (SST), mixed forest/ agro-forestry (MF/AF) and cropland (CL)

Accuracy assessment was done using 140 reference points in the image of 2009 (Figure 5-1).

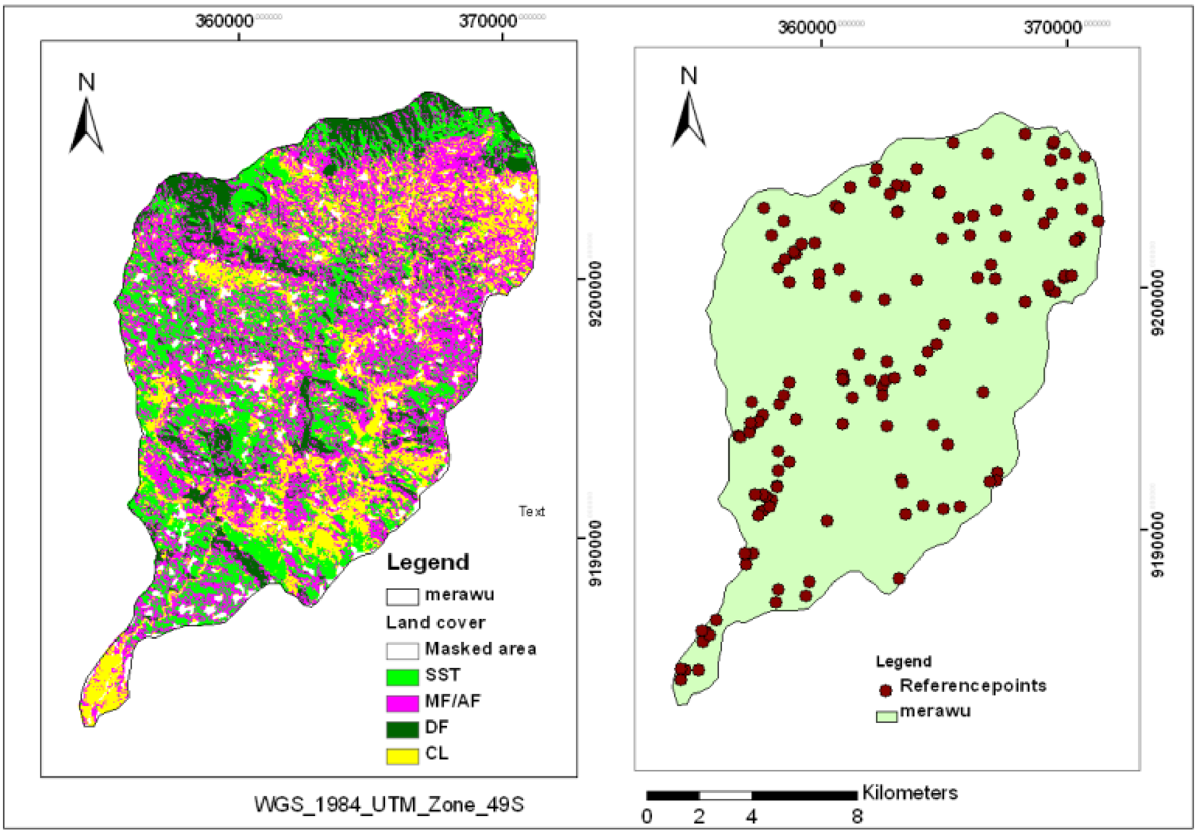


Figure 5-1 classified image 2009 and ground truth points

Regarding the reference points, we again generated some reference points which were based on the field information, FCC displays and pictures taken during the field work and all together 140 reference points were maintained to validate the classification result. The resulting confusion matrix is presented in Table 5-1.

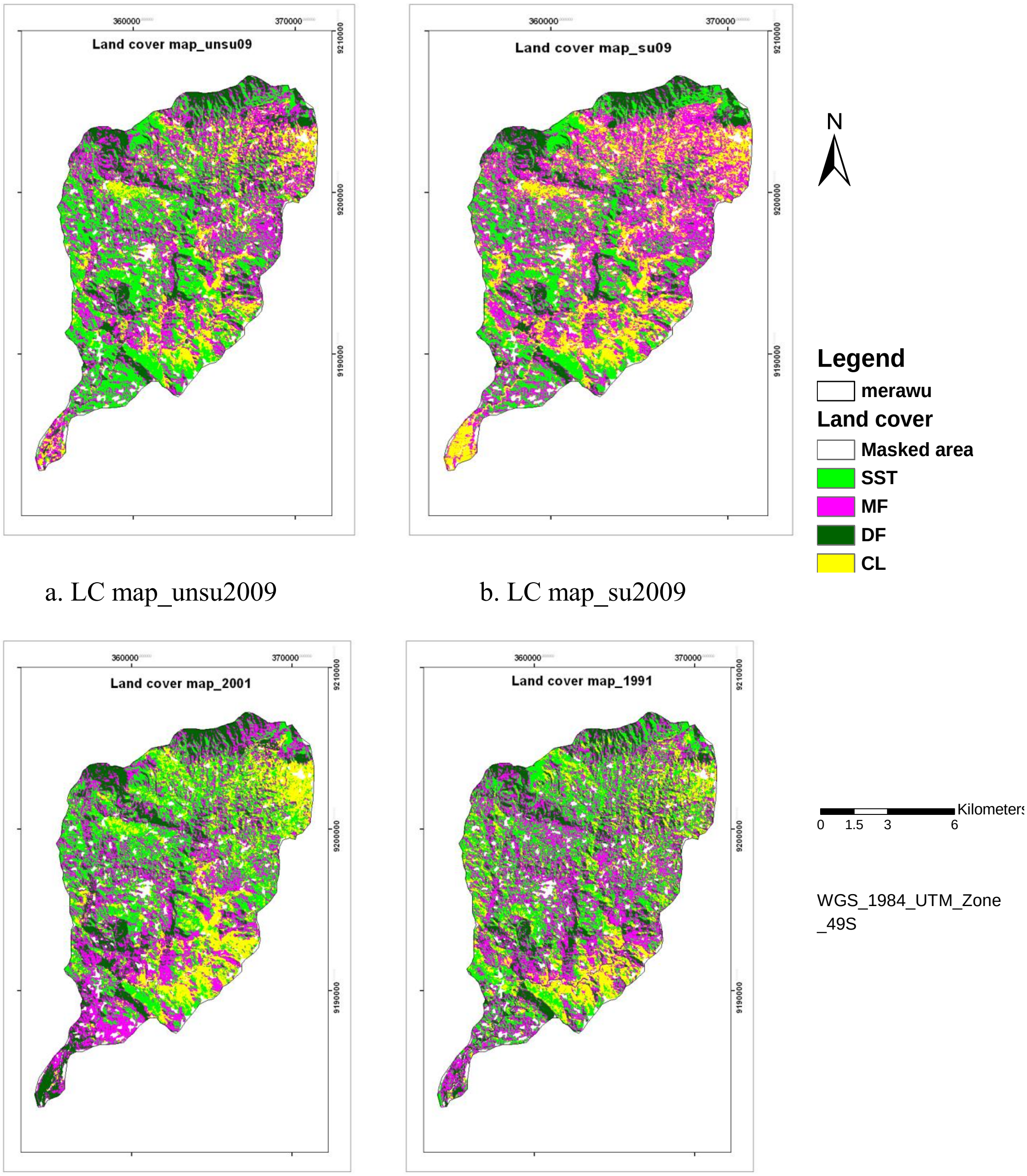
Additionally, a coefficient of agreement between classified image data and field reference data were calculated using kappa statistics. Kappa statistics takes into account a measure of overall accuracy of image classification and individual category accuracy as a means of actual agreement between classification and observation. The value of kappa lies between 0 and 1 where o shows agreement due to chance only and 1 shows complete agreement between the two data sets. It is usually expressed as a percentage (Fitzgerald and & Lees, 1994).

Table 5-1 showing the error matrix of accuracy assessment of classified image of 2009

	Dense forest (DF)	**Shrub & sparse trees (SST)**	**Mixed forest/Agro-forestry (MF/AF)**	**Crop land (CL)**	**R. total**	**Producer Accuracy (%)**	**User Accuracy (%)**	**Kappa**
DF	**28**	0	0	0	28	70.00	100.00	1.00
SST	6	**18**	9	1	34	85.71	52.94	0.45
MF/AF	6	3	**15**	15	38	57.69	39.47	0.26
CL	0	0	2	**37**	39	69.81	94.87	0.92
C. total	40	21	26	53	**140**			

C= column, R= row
Overall accuracy= 70.21 % and overall kappa= 0.60

Here, the overall accuracy of supervised classification of 2009 image is 70.21% and the kappa statistic is 0.60. The values seem to be acceptable, if compared with literature. A review article by Wilkinson (2004) highlights that on an average across so many experiments included in the review article, overall classification accuracy of land cover classification was found to be 72.7% and Kappa 0.64. In this study, these values are not so high, because the study area is located in a very complex tropical area where land use activities and their spatial and temporal changes strongly influence land cover change. So, sometime, they cultivate their land for agricultural crops and sometimes they change their land use behaviour to plantation for income generating fruit and fast growing tree species together as agro-forestry system. Moreover, they don't have fixed and permanent type of crop calendar. In some cases it is difficult to discriminate whether it is crop land area or shrub land or mixed forest/ agro-forestry area. Thus, the user accuracy of individual class is not as high as expected. Consequently, the accuracy of DF (Dense forest), SST (Shrub, sparse trees and grass lands) and MF/AF (Mixed trees, private garden and agro-forestry areas) and CL (Croplands mainly rice field and agricultural bare areas) deserve the producer accuracy as 70.0%, 86.0%, 58.0% and 70.0 respectively. While the user accuracy for those are as 100%, 53%, 39% and 95% respectively. Salak fruit and Albazia falcataria are the main fruit and tree species used as component of agro-forestry in the area. In this case, some researchers explain as normally the overall accuracy in the land cover classification of Landsat image 85-90 % is excellent. In this aspect, Paul (2004) recommended that a standard of 85% accuracy is acceptable level in digital image classification while Story and Congalton (1986) emphasized that the inclusion of error matrices to enable users to compute and interpret the value on their own purpose. According to Landis and Koch (1977), the agreement is poor when K<0.4, good when K is between 0.4 and 0.7 and excellent when Kappa is >0.75. Likewise,(Monserud and Leemans, 1992) categorized agreement scale of Kappa value as <40 % as poor, 40-55 % fair, 55-70 % good and 70-85 % very good and >85% as excellent. Due to the complexity of the various land covers of the study area , the overall accuracy and Kappa value is not as the excellent category however, derived overall accuracy and kappa are not very far but near as explained by previous researchers. Therefore, the overall accuracy and kappa both are considered acceptable and justifiable in this study.



a. LC map_unsu2009 b. LC map_su2009

c. LC map_unsu2001 d. LC map_unsu2001

Figure 5-2 showing the land cover maps, a. Unsupervised 2009, b. supervised 2009, c. unsupervised 2001 and d. unsupervised 1991

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land, LC= land cover, unsu= unsupervised, su=supervised

5.2.1. Assigning the land cover class of unsupervised classification

To assign the spectral classes into information classes the results obtained by using the following 3 methods were applied and then classes were assigned: simple comparison of mean values; line charting of mean values; Euclidian distance method.

Simple comparison of mean values

After unsupervised classification, we assigned the class name comparing the mean values of each spectral bands of each spectral class with the mean values of information class of classified image of 2009 that was classified with supervise method. The class values for different bands were compared as shown in the matrix Figure 5-4 in coming section.

The tables (Table 5-2, Table 5-3, Table 5-4 and Table 5-5) show the mean values of spectral bands of each information class and spectral classes of supervised image and unsupervised classified images of 2009, 2001 and 1991 respectively as shown in the following legend:

Band= spectral band and class= spectral class, DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

Table 5-2 Showing mean spectral values of classes of 2009 image with supervised method

	DF	SST	MF/AF	CL
Band1	49.71	54.58	54.93	60.99
Band 2	34.18	44.58	42.80	52.55
Band 3	24.73	32.37	34.20	47.68
Band 4	40.55	93.23	65.10	68.54
Band 5	31.47	74.79	56.05	75.74
Band 7	17.69	34.48	29.48	43.70

Table 5-3 Showing mean values of spectral classes of unsupervised classified image of 2009

	Class1	Class2	Class3	Class4
Band 1	51.67	54.93	55.17	62.39
Band 2	37.14	42.78	44.28	53.32
Band 3	28.14	34.02	33.13	49.62
Band 4	48.07	64.31	83.81	66.43
Band 5	38.54	55.74	68.72	76.47
Band 7	21.15	29.49	32.93	46.58

Table 5-4 Showing mean values of spectral classes of unsupervised classified image of 2001

	Class1	Class2	Class3	Class4
Band1	57.41	62.42	65.75	75.57
Band 2	44.73	51.10	54.98	65.09
Band 3	35.75	42.47	46.86	62.94
Band 4	52.63	67.10	78.87	70.45
Band 5	42.18	56.90	69.93	76.68
Band 7	25.07	32.65	39.03	49.41

Table 5-5 Showing mean values of spectral classes of unsupervised classified image of 1991

	Class1	Class2	Class3	Class4
Band1	52.53	55.63	56.39	63.33
Band 2	18.70	22.10	23.58	28.96
Band 3	15.76	20.40	21.29	32.28
Band 4	36.77	55.42	75.32	71.69
Band 5	8.73	15.78	18.78	32.05
Band 7	27.55	46.57	58.67	79.99

Band= spectral band, class= spectral class

As shown in the tables (Table 5-2, Table 5-3, Table 5-4 and Table 5-5) spectral values of different bands of supervised and unsupervised classification images, the mean values of spectral classes with information classes were compared. After comparing the values, we could assign the spectral class as per the information classes. When comparing the values of DF in Table 5-2, then it matches very closely with the values of class 1 (Class1 in Table 5-3). Likewise, the spectral values of class 2 matched clearly with the values of MF/AF (Mixed forest/ Agro-forestry). Similarly, class3 was nearly comparable with SST (Shrub & sparse trees/ grass) and values of class 4 are near with the value of CL (crop land) in the same Table 5-2 and Table 5-3. In the case of unsupervised spectral classes of 2001, the class 1=DF, class2= MF/AF, class3= SST and class4= CL. In the case of 1991, image it is not easy to compare the values of different spectral classes with information classes, however, the nearly comparable spectral class1= DF, class2= MF/AF, class3= SST and class4= CL. In this way, we can assign the spectral class into information class from comparing the mean spectral band values of spectral class and information classes of unsupervised classified image and supervised one.

Plotting line chart of mean values

To come up with the accurate information classes, another alternative option was also employed i.e. plotting of mean values in line chart function. For this we plotted the values of individual class for different year image and compared with position of line chart that can be compared with another line chart based on the position which makes the comparison meaningful as shown in the following line charts (Figure 5-3).

Here, we can see the distribution of the mean values in different bands of different classes and comparison can be made very easily. In the line chart, the position of class 1 in all classified images is in the lowest level as compared to other classes which is fit with the position of DF information class in supervised information class. Regarding the class 2, the position of line of class 2 seems more likely in the second lowest position in all classified images as compared to other classes which is regarded as SST in supervised classification. Likewise, the position of class 3 and class 4 occupy the second top most and top most position respectively in all unsupervised classification and they are related with MF/AF and CL of information classes respectively. In this way, we assigned the spectral classes into information classes as given in Figure 5-4 showing different matrices in all unsupervised images of 2009, 2001 and 1991.

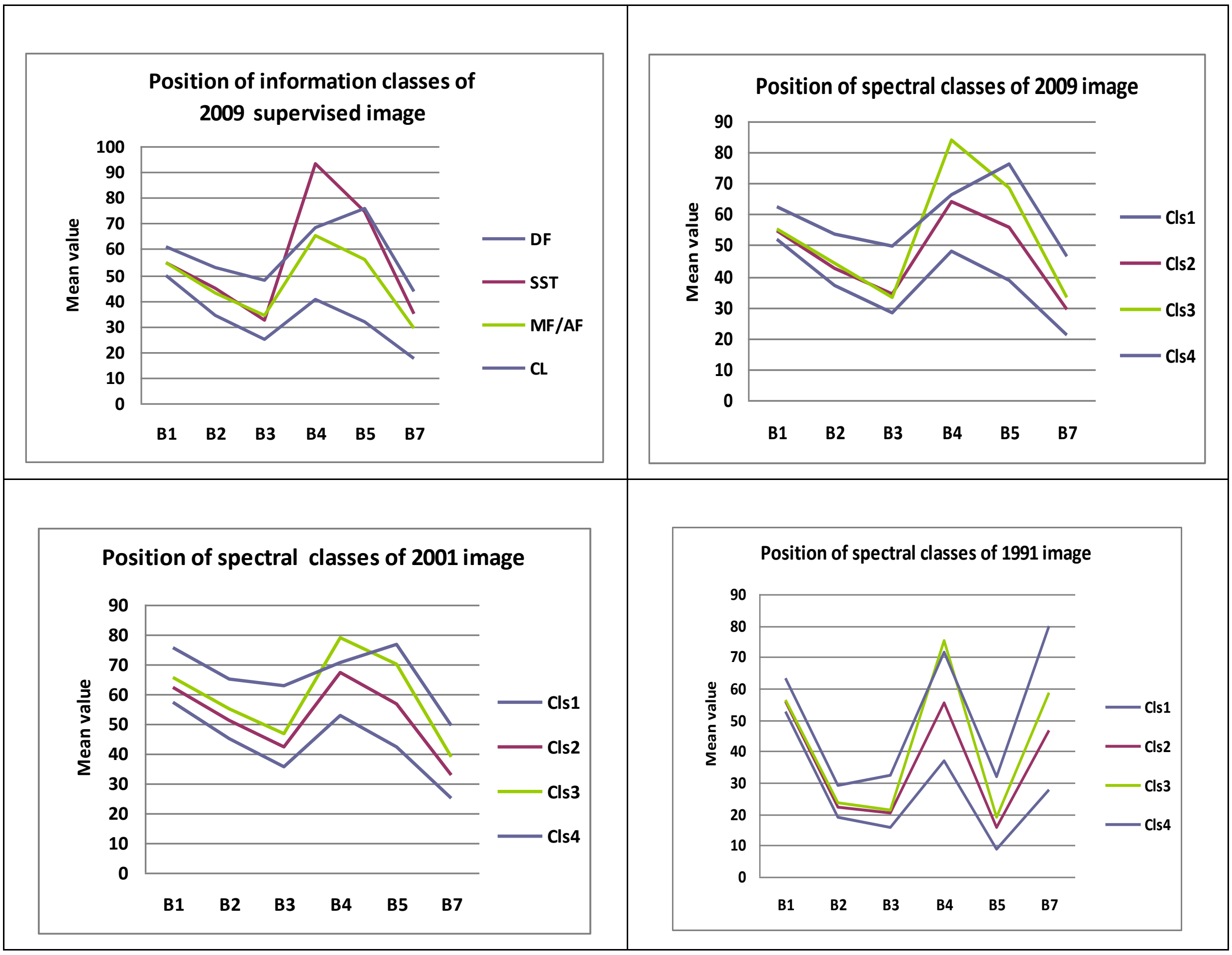


Figure 5-3 Comparing the mean values of bands to come up from spectral classes to information classes

CL= Crop land, cls= spectral class and DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

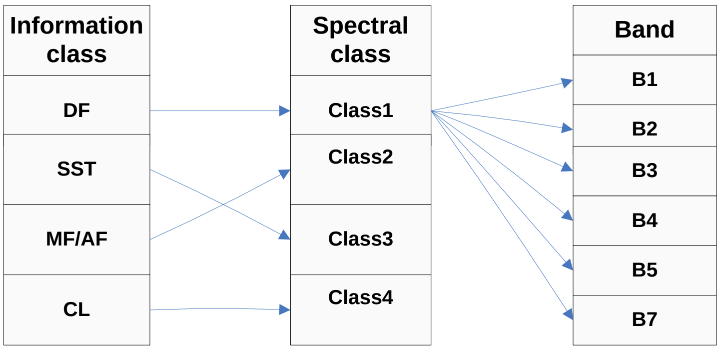


Figure 5-4 Matrix of comparison between information classes and spectral classes

B= Band, class= spectral class, and DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

Based on the matrix idea, it was prepared following relationship of the information classes and spectral classes of respective images according to the position of line chart of different spectral and information classes as final classes as shown in the following Table 5-6.

Table 5-6 Assigning the spectral classes into information classes

Information classes _supervised 2009	Spectral classes Unsuper_2009	Spectral classes Unsuper_2001	Spectral classes Unsuper_1991
DF	Class1	Class1	Class1
SST	Class3	Class3	Class3
MF/AF	Class2	Class2	Class2
CL	Class4	Class4	Class4

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

From the above matrices of relationship of information classes and spectral classes, we conclude that the information classes of supervised classification can be used to assign the spectral classes based on comparison between mean values of information and spectral classes in order to find out the actual information classes.

Euclidian distance method

Euclidian distance (ED) method was also employed with supervised classified image of 2009 and unsupervised classified images of 2009, 2001 and 1991 respectively to calculate the nearest distance for assigning the accurate classes. The results of ED for different classes are presented in Table 5-7, Table 5-8, and Table 5-9.

Table 5-7 showing the ED between supervised classified image 2009 and unsupervised image 2009

DF	SST	MF/AF	CL	ED based Class	Final Class
11.95	60.1	27.3	54.93	Cl1= DF	Cl1= DF
38.48	35.07	30.63	30.63	Cl2=MF/AF	Cl2= MF/AF
60.77	11.35	22.94	26.69	Cl3=MF/AF	Cl3= SST
68.37	36.09	33.39	4.43	Cl4=CL	Cl4= CL

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land, ED= Euclidian distance and cl= spectral class

The table shows that the calculated ED values for between the spectral band values of class1, class2, class3 and class4 with the mean values of DF, SST, MF/AF and CL of information classes of supervised image 2009. It can be seen that the lowest value 11.95 under the column of DF is the possible accurate information class for spectral class1, so, class1= DF as shown in the Table 5-7. Likewise, under the column of SST the lowest value coincides with MF/AF, while looking at under the column of MF/AF, so here class 3 also MF/AF but in both class showed the MF/AF. So here we decided the lower value to assign the class 2 as MF/AF. If we see the ED values under the CL, the class 4 is assigned as CL accordingly and the leftover class 3 was apparently assigned as SST. In this manner, the spectral classes were assigned according the lowest value that fits with information class.

Table 5-8 ED between supervised classified image 2009 and unsupervised image 2001

DF	SST	MF/AF	CL	ED based Class	Final Class
24.64	53.1	19.48	44.07	Cl1= DF	Cl1= DF
48.35	34.81	14.43	22.59	Cl2=MF/AF	Cl2= MF/AF
46.65	26.33	29.99	13.84	Cl3=MF/AF	Cl3= SST
24.64	53.1	19.48	44.07	Cl4=CL	Cl4= CL

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land, ED= Euclidian distance, and cl= spectral class

In the same way, ED values under the column of DF as shown in the Table 5-9 shows that the lowest value coincides with DF as previous case and then class1 was assigned as DF. Likewise, the ED values under the column of SST, class2 has the lowest value and it was regarded as MF/AF. ED value under the MF column, the lowest value coincides with SST. Here we took a decision based on the previous case i.e. the class under the column MF/AF which has the lower value than under the column of SST. Therefore, class3= SST and class2= MF/AF. Regarding the class4, the left over value under CL obviously matched with CL because the CL always deserves the lowest value as in previous case.

Table 5-9 showing the ED between supervised classified image 2009 and unsupervised image1991

DF	SST	MF/AF	CL	ED based Class	Final Class
30.93	92.46	63.02	89.42	Cl1= DF	Cl1= DF
48.35	75.55	51.25	73.99	Cl2=MF/AF	Cl2= MF/AF
67.7	67.89	53.69	71.21	Cl3=MF/AF	Cl3= SST
83.83	68.42	58.62	63.52	Cl4=CL	Cl4= CL

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land, ED= Euclidian distance and cl= spectral class

In the case of 1991 image, the spectral class was assigned as follows based on the Table 5-9. Here, the ED of class1 has shown the lowest value in DF, so, it was assigned as DF. Likewise, the ED of class2 matched with MF/AF and assigned as MF/AF, while the lowest values under the MF/AF coincides with the SST, class3= SST and finally the under the CL the lowest value matched with CL same as in previous both cases.

In this ED method of class assigning from information class, it in some cases, the lowest value was quite clear to assign the class but in some cases the same spectral class matched more than one information classes. So, in that case, the decision was taken as the lowest value for the spectral class. It would not be easy to decide if there are so many information classes and spectral classes while assigning the classes from spectral into information class. So, previous line graph plotting is better than this ED method to assign the class in this study.

5.3. Land cover change from 1991 to 2001

Table 5-10 Land covers area conversion (in ha) from 1991 & 2001

Class name	DF 2001	SST 2001	MF/AF 2001	CL 2001	1991
DF 1991	1809	231	1089	117	3247
SST 1991	338	3832	2327	1230	7727
MF/AF 1991	1220	2024	3710	1007	7960
CL 1991	65	1286	343	1411	3104
2001	3432	7373	7469	3765	22039

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

The land cover change in the period 1991 - 2001, is presented in Table 5-10 as quantities of conversion from previous date to later date. As can be seen from the Table 5-10, the conversion from shrub and sparse tree areas to mixed forest mainly in agro-forestry occurred as large as 2327 ha, that is 31.0 % of total land area to mixed forest/ agro-forestry (MF/AF). Conversions to mixed forest/ agro-forestry were mainly from the shrub land and dense forest with 2327 ha, and 1089 ha, respectively. Likewise, the conversions to cropland were mainly from shrub land and mixed forest/ agro-forestry with 1230 and 1007 ha, respectively. The main cause in both cases might be the tendency of local people to convert shrub land area with sparse trees into either crop land or agro-forestry land, for reasons of subsistence livelihood either from the agricultural crops or from the fruit and forest product selling.

5.4. Land cover change from 2001 to 2009

Table 5-11 Land covers area conversion (in ha) from 2001 & 2009

Class name	DF 2009	SST 2009	MF/AF 2009	CL 2009	2001
DF 2001	1909	89	1143	291	3432
SST 2001	63	3475	2471	1365	7373
MF/AF 2001	526	1722	4590	631	7469
CL 2001	16	551	919	2279	3765
2009	2514	5836	9123	4565	22039

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

The land cover change of this period can be seen from cross Table 5-11 as shown in the land cover conversion from 2001 and 2009, the areas of conversion from dense forest into both croplands and agro-forestry areas which covers as large as 10.5% (1434 ha.) of total area of both land cover classes (13688ha.). The conversion percentage of shrub land into agro-forestry and cropland area seems very high with 28% (3836ha.) if the conversion area of shrub land into agro-forestry and cropland is calculated with total area of both classes (13688ha.) between the year 2001 and 2009. The main cause is that people's focus on shrub land is that the dense forest is located in difficult to access and sloping terrain the most of forest is plantation of pine trees for production purpose. Moreover, the trend of salak fruit plantation with Albazia tree species has also played major role to convert the shrub land and forest area into agro-forestry areas.

5.5. Land cover change from 1991 to 2009

As presented in previous section the conversion of land cover from one class to another from the year 1991 to 2001 and 2001 to 2009 but here it is presented the overall changes between the years 1991 to

2009 within the 18 years period as shown in the Table 5-12. Moreover, it is also presented in brief and different ways about the changes in land cover in the form of percentage, bar diagram and line graph as shown in Figure 5-5, Figure 5-6 and Figure 5-7.

Table 5-12 Land covers change from 1991 to 2009

Year	1991		2001		2009		Overall change	
Land cover	Area (ha.)	% of total	Area (ha.)	% of total	Area (ha.)	% of total	Change area (ha.)	Change %
DF	3247	15	3432	16	2514	11	733	3
SST	7727	35	7373	33	5836	26	1891	9
MF/AF	7960	36	7469	34	9123	41	1163	5
CL	3104	14	3765	17	4565	21	1461	7
Total	22039	100	22039	100	22039	100	5248	24

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

As shown in the Table 5-12 (also see Figure 5-5a and Figure 5-5b), the dense forest cover has increased with a very small percentage from 15% in the year 1991 to 16% in the year 2001 but it has decreased by 5% as compared to the year 2001 with its 11% coverage in total coverage in the year 2009. The forest area of Java Island has decreased in alarming rate (Cited in Lavigne and Gunnel (2006)). However, the result shows that the area of dense forest has increased by 1% which is not so big a change, and not a decrease at alarming rate. The cause behind this small forest cover increase from 1991 to 2001 is that the plantation program and also the dense forest includes the high slope area that is better represented in the image as dense forest and it added some area in dense forest but later on the coverage of dense forest has decreased from its 16% to 11% between 8 years period.

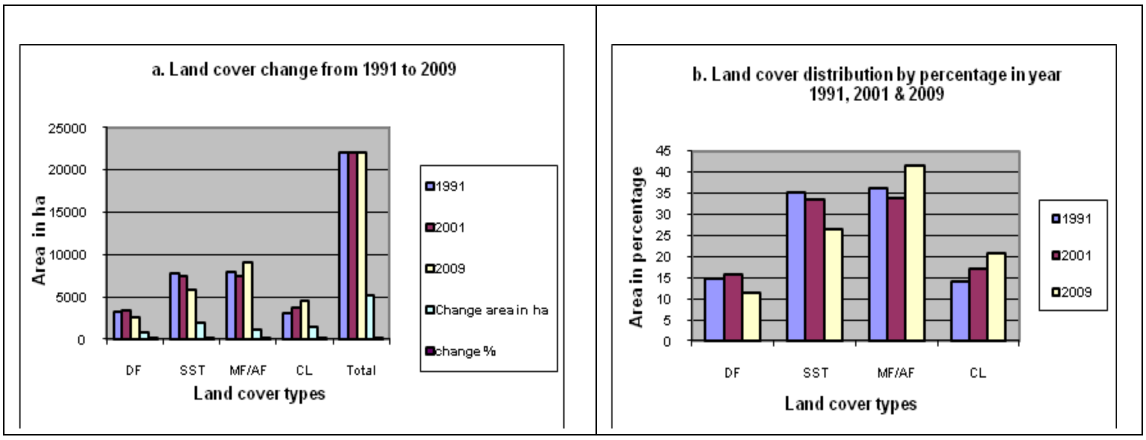


Figure 5-5 Bar diagram showing the land cover change from 1991 to 2009

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

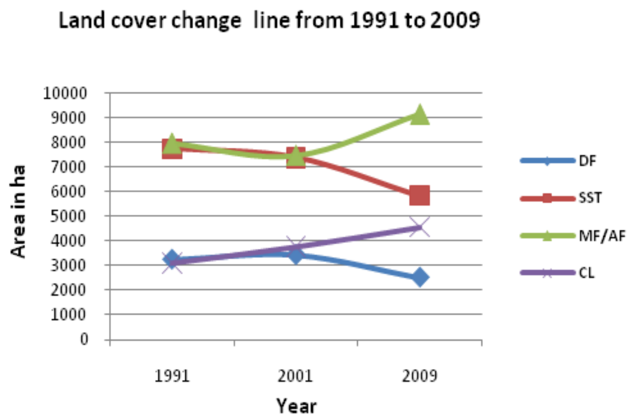


Figure 5-6 Line chart showing the change line different cover types from 1991 to 2009

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

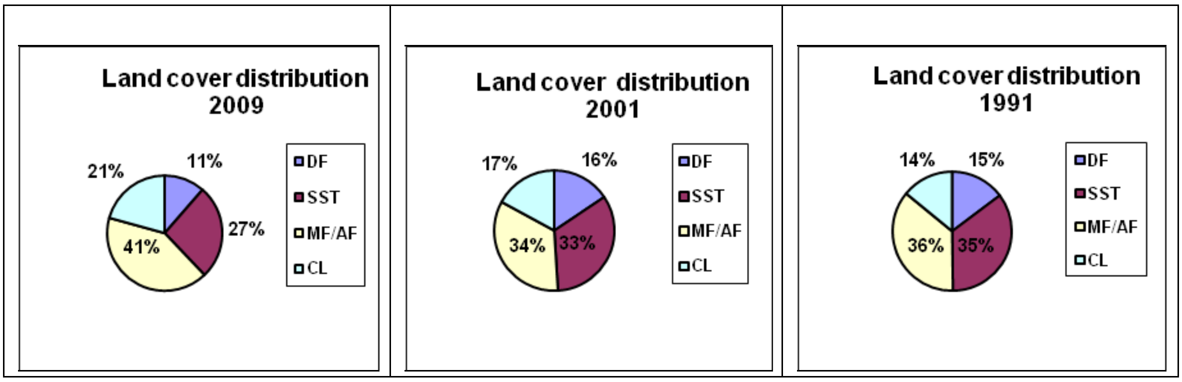


Figure 5-7 Pie chart showing the land cover % in different years

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

As presented in Figure 5-7 and also Table 5-12, area of shrub land has decreased from its coverage of 35% in year 1991 to 33% in year 2001 and 26% in year 2009. Cause behind this is also the people's encroachment towards the shrub land for increasing farming area for their livelihood. In contrary, the area of mixed forest/ agro-forestry has increased from 34% of total coverage in year 2001 to 41 % in the year 2009. The cause behind this is obvious that people of the area used to increase their lands by encroaching dense forest and shrub land for cultivation purpose. Another cause behind this is the introduction of potato cultivation in the study area in early nineties because of high production of potato in the volcanic soil of the study area (Reference based on the field interview). Interesting result can be seen from the line chart (Figure 5-6) we see the coverage area of shrub land and mixed forest/ agro-forestry in the year 2001 both are almost similar (33% and 34% respectively) and has meet in one common point (see Figure 5-6) but after that, shrub land has decreased largely from 33% to 26% while mixed forest/ agro-forestry has increased from 34 % to 41 % (Table 5-12 and Figure 5-7) in the same period. Here, we can see the vice versa relationship between these two land cover types i.e. first one has decreased by 7% as compared to the previous year and second one has increased by same 7% as compared to the same year (Table 5-12 and Figure 5-7). It means that the area of shrub land has changed into mixed forest/ agro-forestry that can be seen in the conversion Table 5-10 and Table 5-11 as well. Another cause behind this change is that introduction of Salak fruit and Albazia tree species in the year of 1990's as income generation and adoption of this system is increasing from that time to date, while the area of crop land has decreased slightly because of changing land use practices of local farmers from crop land to garden of Salak and fast growing Albazia tree species. Likewise, the area of crop land has also increased from 1991 to 2001 and 2001 to 2009 with its coverage of 14% to 17% and 17% to 21% respectively in the respective period (Table 5-12 and Figure 5-7). Therefore, it can be said that the land cover change particularly from dense forest and shrub with sparse trees to areas of mixed forest/agro-forestry and cropland is very common in the area from the year 1991 to 2009. It can be seen that from the classified images of respective years, the trend of change is higher in the upland area than the lowland area (Figure 5-2).

The results showed that land cover change in Merawu catchment reflects reality of the area that occurred over the period of 1991 to 2009. Based on the land cover map and the complied table of land cover change (Table 5-12 and Figure 5-4), out of 220309 hectares of land, 24% underwent change irrespective of type of land cover. Area coverage of dense forest has reduced from 3247 to 2514 hectares representing 23% reduction of its original size and overall percentage of change of about by 3% change. Shrub land and sparse trees area has also reduced in size from 7727 to 5836 hectares representing 24.5% of its original area and about 9% of total land area of the catchment (excluding the masked area of the water body and settlement). Mixed forest/ Agro-forestry area has increased from 7960 to 9123 which covers about 15% of its original area and overall change is of 5 %. Likewise, cropland has also increased from its 3104 to 4565 hectares which covers 47% of its original size and overall percentage of change is of 7%.

5.6. Establishing the land cover change trajectory

To establish land cover change trajectories first the pixel based changes were compared from one category to another and found all possible land cover change trajectories and then decided to establish the major land cover change trajectories based on the higher number of pixels change from one type to another. Likewise, field based information were also used to establish such change trajectories and finally we established the combined change trajectories in the area as shown in the following subsections.

5.6.1. Possible land cover change trajectories

In this particular study the term trajectory of land cover change refers to the change of land cover from one type to another in the two given date images. All classified images were combined in GIS Spatial Analyst tool using the tabulate area to produce the matrices of change from one cover type to another and then the pixel based change trajectories of possible land cover change trajectories were established as shown in Figure 5-8 below.

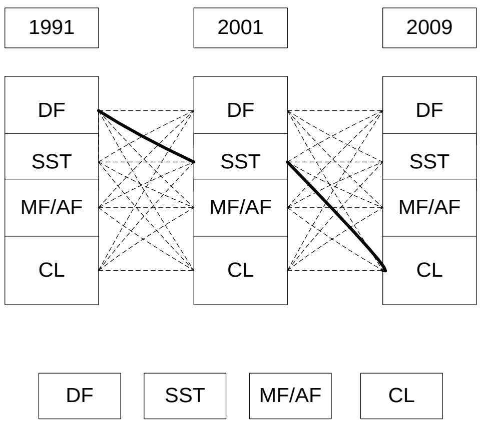


Figure 5-8 All possible land cover change trajectories identified for the study area- Merawu
DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

Based on the Figure 5-8 of trajectory, the highlighted land cover change line shows a change line (Trajectory) as DF→SST→CL, meaning that the land cover was found to be dense forest in 1991, shrub and sparse trees in 2001 and crop land in 2009.

To analyze the temporal change on land cover, we have classified all the possible trajectories into main two classes' namely unchanged and changed areas due to human-induced activities (anthropogenic factors). The unchanged class includes some trajectories such as DF→DF→DF, SST→SST→SST, MF/AF→ MF/AF → MF/AF and CL→CL→CL which indicates the same land cover type was found on the same point over the past 18 years. Some indefinite cases for example SST→CL→SST, or MF/AF →CL→MF/AF are also included in this class considering that possible classification errors may create once only as false classes in trajectory. Anthropogenic change normally includes decisive changes due to human activities e.g. development works and cultivation as well as changing land use practices by local people. Such kinds of changes are often irreversible so that they represent major human impact on the local land cover change pattern. The representative of such trajectories of this class includes e.g. DF→CL→CL; SST→CL→CL; DF→SST→DF; DF→MF/AF→MF/AF and so on.

5.6.2. Image pixel based land cover change trajectories

Land cover change trajectories were established based on the land cover change data obtained from cross tables of two periods (1991-2001 and 2001-2009) as shown in the Table 5-10 and Table 5-11.Table 5-13 was prepared based on the Table 5-10 to find out the land cover change trajectory. So, the land covers change from year 1991 to 2001 in relation to the trajectory; 56% (1809ha.) of dense forest remained unchanged from the year 1991 to 2001(see the Table 5-10 for total area of forest in year 1991) and 44% of dense forest area changed in to other land cover types such as cropland, mixed forest/agro-forestry and shrub land. It remained but 8.0% area remained unchanged by 8% in same year in relation to total area of 22039 ha as shown in the Table 5-13. While the shrub land and mixed forest/ agro-forestry area both remained unchanged with nearly 17% of total area and 6% area of crop land also remained unchanged in the same period as shown in the Table 5-13. Besides, the Table 5-13 reveals that land cover change trajectories from the year 1991 to 2001. All together 16 land cover change trajectories can be seen including four unchanged and twelve changed trajectories.

Table 5-14 illustrates that the land cover change from the year 2001 to 2009 based on the pixel count from one land cover type to another. As it shows that unchanged dense forest, unchanged shrub land, unchanged mixed forest/agro-forestry and unchanged cropland account 9%, 16%, 21% and 10% respectively with the total area of 22039 ha from the year 2001 to 2009. Shrub land changed into mixed forest/agro-forestry with the highest percentage that accounts 11% of total area. Dense forest area has changed into mixed forest/agro-forestry, cropland and shrub land altogether accounts nearly 7% of the total area from same time period. So, change of dense forest to another cover type is not high as compared to other land cover types. The main cause is that the most of remaining dense forest is located in sloppy terrain and it also represents pine plantation areas as visited and recorded during field work.

Table 5-13 Land cover change trajectory data of 1991 to 2001

Pixel count	Area (ha.)	Cover (%)	Trajectory of change
20104	1809	8.2	unchanged DF
13554	1220	5.5	MF/AF-DF
41217	3710	16.8	unchanged MF/AF
25860	2327	10.6	SST-MF/AF
3756	338	1.5	SST-DF
42576	3832	17.4	unchanged SST
12103	1089	4.9	DF-MF/AF
22492	2024	9.2	MF/AF-SST
14293	1286	5.8	CL-SST
3811	343	1.6	CL-MF/AF
717	65	0.3	CL-DF
2565	231	1.0	DF-SST
13669	1230	5.6	SST-CL
15673	1411	6.4	unchanged CL
11185	1007	4.6	MF/AF-CL
1302	117	0.5	DF-CL
Total	22039	100	

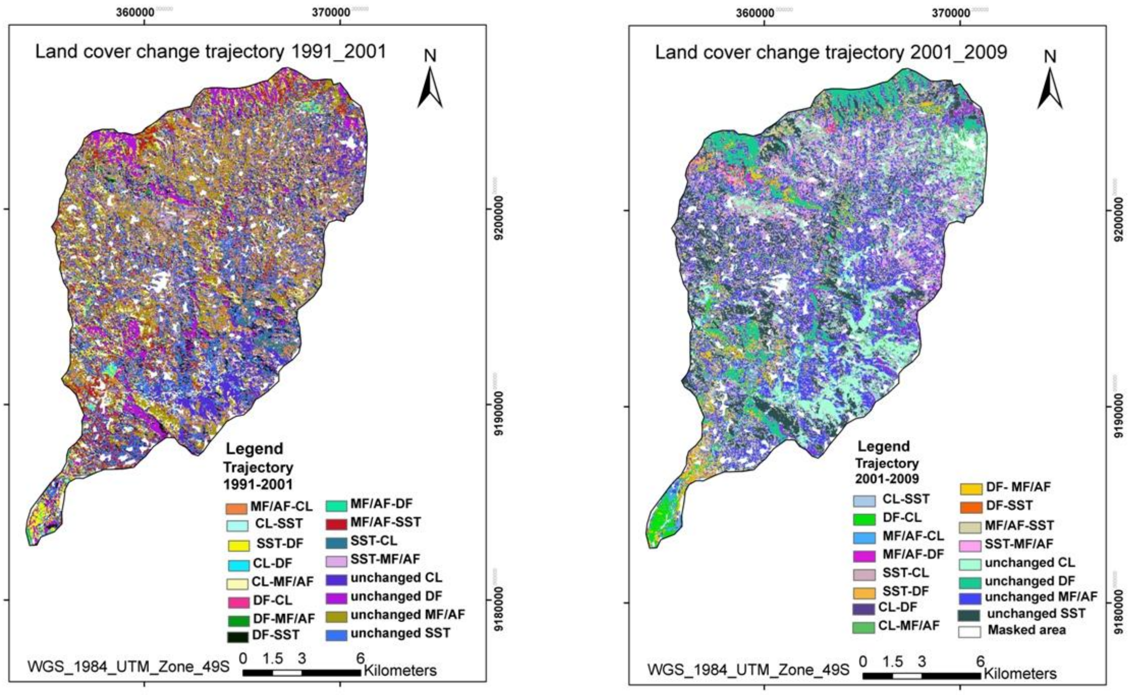
For the both year (1991 and 2001) images, Class ID 1=DF, 2=MF/AF, 3= SST, 4=CL, DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

Table 5-14 Land cover change trajectory data between the year 2001 and 2009

Pixel count	Area (ha.)	Cover (%)	Trajectory of change
21214	1909	8.7	unchanged DF
12703	1143	5.2	DF- MF/AF
51002	4590	20.8	unchanged MF/AF
19134	1722	7.8	MF/AF-SST
5841	526	2.4	MF/AF-DF
38608	3475	15.8	unchanged SST
3228	291	1.3	DF-CL
7014	631	2.9	MF/AF-CL
27452	2471	11.2	SST-MF/AF
986	89	0.4	DF-SST
15162	1365	6.2	SST-CL
10214	919	4.2	CL-MF/AF
25319	2279	10.3	unchanged CL
6119	551	2.5	CL-SST
705	63	0.3	SST-DF
177	16	0.1	CL-DF
Total	22039	100.0	

For the year 2009 image, Class ID, 1=DF, 2=SST, 3=MF/AF, 4=CL & for the year 2001 image, 1= DF, 2=MF/AF, 3=SST, 4=CL, DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

The Figure 5-9 shows the area of land cover change from one cover type to another from 1991 to 2001(Figure 5-9a) and from 2001 to 2009 (Figure 5-9b). The unchanged dense forest area can be seen at upper most part of the Merawu catchment and in some cases it can seen in the middle and lower part of the area where terrain is sloppy. While unchanged cropland area is located mostly in upper east and lower east part of the study area in both period images. Mixed forest/agro-forestry areas are highly concentrated from lower to middle part and upper part of the area.



a. Land cover change trajectory1991-2001 b. Land cover change trajectory2001-2009

Figure 5-9 Spatial distribution of land cover change for two periods (from 1991 to 2001 and 2001 to 2009)

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

As shown in the Table 5-10, DF has changed largely into MF/AF category than other category from the year 1991 to 2001. So, decision was made to establish major trajectory based on the first highest and the second highest number of changed pixels into another category or class. The trajectory of DF was established from 1991 to 2001 expressed as DF→M/AF and DF→SST from 2001 to 2009. It can be seen that the some unchanged area in every category which is regarded as unchanged area. Likewise, other classes were carefully compared and established the lines of changes. In the same way, the land cover change trajectories were established with comparing the conversion area of land cover change between two periods from 1991 to 2001 and from 2001 to 2009 based on the Table 5-10, Table 5-11, Table 5-13, and Table 5-14. Finally we established following temporal trajectories summary as given in the Table 5-15:

Table 5-15 Land cover change trajectories based on the cross table 5-10 &5-11

Land cover class	Description	Trajectory line examples
Unchanged	No change	CL→CL→CL
	No change	DF→DF→DF
	No change	SST→SST→SST
	No change	MF/AF→MF/AF→MF/AF
Changed	Changed to MF/AF and again changed to CL from 2001 to 2009.	DF→MF/AF→CL
	Changed to SST and again changed into CL from 2001 to 2009	DF→SST→CL
	Changed to MF/AF and then further changed into CL	SST→MF/AF→CL
	Changed to and remained as CL after 1991	SST→CL→CL
	Changed to SST and again remained as SST from 1991	MF/AF→SST→SST
	Changed into DF and again changed into CL	MF/AF→DF→CL
	Changed into SST and again changed into MF/AF	CL→SST→MF/AF
	Changed into MF/AF and again changed into SST	CL→MF/AF→SST

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

From the above table 12 number of total land cover change trajectories were identified from the conversion tables of land cover change in the study area from the year 1991 to 2001 and 2001 to 2009. From the conversion tables, that the some areas of every land cover category seem unchanged over the comparison two periods between 1991to 2001 and 2001 to 2009.

5.6.3. Land cover change trajectories based on the field interview data

The land cover change trajectories were established on the field information gathered from the interviews data about land cover change in particular field area (see Annex 9.1)

Table 5-16 Land cover change trajectory table from 1991 to 2009 from interview data

Land cover change trajectories			Soil sample locations id	Total #
1991	2001	2009		
CL	CL	CL	57,24,39,42,17,45,33,50,19,46,51, 32,47,48,36,9,27,3,2,1,4,6,49,26	24
MF/AF	MF/AF	MF/AF	58,59	2
CL	MF/AF	MF/AF	54,35,55,29,25,22,30,21,60	9
SST	SST	SST	28,62	2
SST	DF	DF	40,61	2
SST	SST	DF	23,16	2
CL	CL	MF/AF	53	1
DF	SST	DF	5	1
Total				43

DF= Dense forest, SST= Shrub & sparse trees, MF= Mixed forest/ Agro-forestry and CL= Crop land

As shown in Table 5-16, in total 43 sample locations out of 61 soil sample locations, show the eight different combinations of land cover change trajectory lines in the study area of Merawu catchment. Almost 60% locations show the trajectories of unchanged area from year 1991 to 2009, all 24 locations remained as unchanged area. In nine locations, the land cover was cropland (CL) in 1991, then changed into mixed forest/ Agro-forestry (MF/AF) and remained unchanged as mixed forest/ agro-forestry area. In some locations shrub land remained as unchanged during the same period. Likewise, two locations, shrub land in 1991 changed into dense forest in 2001 and remained dense forest in 2009 as well. In some locations, main cause behind this is that the area is plantation area of pine trees.

Out of visited 61 sample locations, the land cover change information could not be collected at 18 locations where concerned farmers were not found. The information of historical land cover change provided by the farmers did not match with reality because they did not give the actual date of land cover change knowingly or unknowingly. Another cause behind this was change in land ownership due to land selling and purchasing system.

From the result as presented in Table 5-16, the major area of crop land seems unchanged and secondly, in some locations, according to farmer's views they have told that farmers trend of land cover change from cropland to mixed forest/agro-forestry particularly plantation of Salak fruit and fast growing tree species- Albazia in their private lands. The cause of pine plantation (here as dense forest) in shrub land is that pine is also fast growing species and resin also another important non timber forest product of the area for income generation of the local farmers.

5.6.4. Most common land cover change trajectories in the area

Finally the trajectories of land cover change derived from images data and field interview information were combined together to come up with the final temporal land cover change trajectories in the study area from the year 1991 to 2009, the common change trajectories were first selected such as trajectories of unchanged locations or land cover types and then other remaining trajectories were taken into account to make final trajectories of the area.

The Table 5-17 below depicts that the land cover change trajectories as major two types as unchanged area and changed area. The unchanged areas are of all land cover types where they were found to be unchanged from the image data and from interviews data.

As shown in the Table 5-17, if the land cover type was cropland in 1991, it did not change in 2001 and also in 2009. So, such area was placed as unchanged area. In the same way, the changed area such as dense forest land cover, which was forest in the year 1991 but later on it changed into shrub land in the year 2001after human pressure and then again changed into cropland in 2009. Other land cover change trajectories can also be described accordingly. Overall, 17 land cover change trajectories were found, out of which 4 trajectories were found as unchanged and 13 were changed trajectories over time.

Table 5-17 Showing land cover change trajectories in the Merawu area

Land cover class	Description	Trajectory line examples
Unchanged	No change	CL→CL→CL
	No change	DF→DF→DF
	No change	SST→SST→SST
	No change	MF/AF→MF/AF→MF/AF
Changed	Changed to MF/AF and again changed to CL from 2001 to 2009.	DF→MF/AF→CL
	Changed to SST and again changed into CL from 2001 to 2009	DF→SST→CL
	Changed to MF/AF and then further changed into CL	SST→MF/AF→CL
	Changed to and remained as CL after 1991	SST→CL→CL
	Changed to SST and again remained as SST from 1991	MF/AF→SST→SST
	Changed into DF and again changed into CL	MF/AF→DF→CL
	Changed into SST and again changed into MF/AF	CL→SST→MF/AF
	Changed into MF/AF and again changed into SST	CL→MF/AF→SST
	Changed into DF and remained as DF after 2001	SST → DF →DF
	Remained as SST till 2001 and then changed into DF	SST→SST→DF
	Changed into MF/AF and remained as MF/AF	CL→MF/AF→MF/AF
	Cropland until 2001 then changed into MF/AF	CL→CL→MF/AF
	Changed into SST and again reversed into DF	DF→SST→DF

The temporal land cover change trajectories from this study show that the land cover change phenomenon is complex phenomenon which cant' be specified in a limited area of interest. Several factors such as topography, climate, and land use practices as per people's interest and government policies and program are also responsible.

6. Top soil properties and analysis

6.1. Selected soil properties in major land cover types of Merawu catchement

One of the objectives of this study is to identify and analyze the major soil properties of the area and relate them spatially and temporally with the change of land cover types and erosion. As explained in the methodology chapter 4, the main soil properties taken into account in this study were soil structure, soil texture, soil strength, soil compaction, soil pH, soil colour, soil aggregate stability, soil organic matter content (OM) and selected soil erosion features recorded in the study area during the field work. In this chapter, firstly, the field result of soil texture is presented and then more detail analysis of 11 representatively selected soil samples for particle size distribution (PSD) is presented and discussed for further calibration.

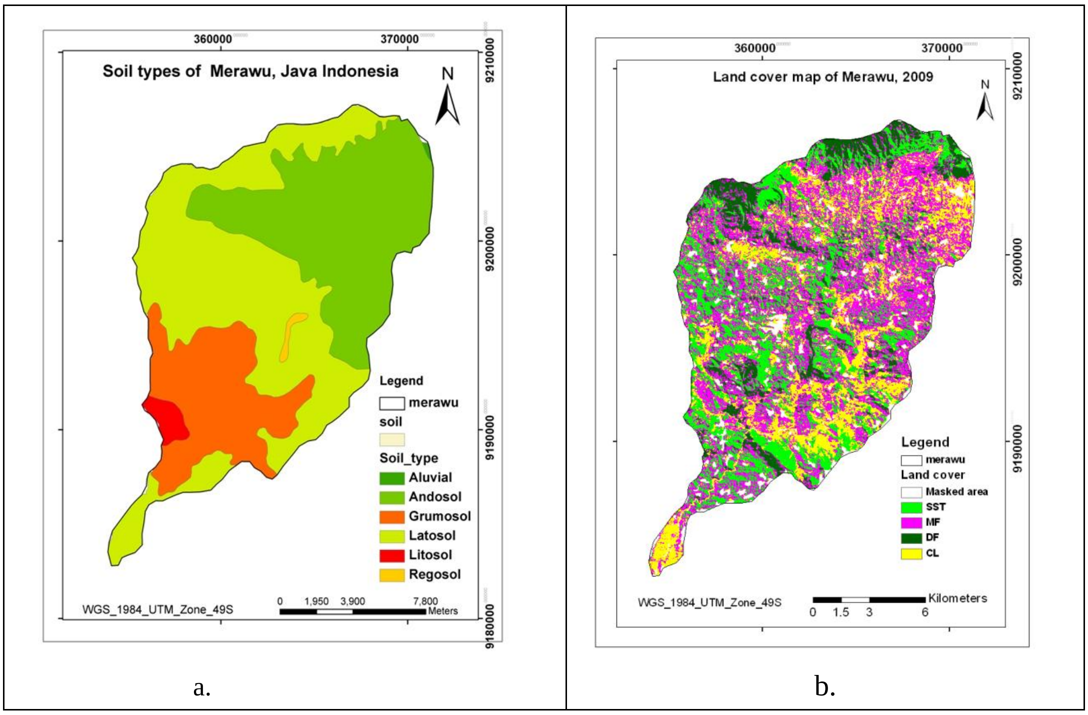


Figure 6-1 Soil map and land cover map of the Merawu area (Bakosurtanal, 2000; Fieldwork, 2009)

Then, calibration was done and the result of calibration of soil textures are described in relation to major soil types (Figure 6-1a) of the area. Specifically detail analysis was done in case of soil texture, soil strength, soil compaction and soil OM content in order to relate these properties with land cover changes and thereby by soil erosion in the area. The results are presented in summary table of statistics and further discussed in relation to land cover types (Figure 6-1b).

In addition to this, soil structure, soil colour, soil pH and soil aggregate stability is also together summarized in table and presented. All these soil properties are described and interpreted in sub sections separately as per their different characteristics relating them with the change in main land cover types of the area. Similarly, soil erosion evidences of the area are briefly described what we found in the field at the soil sampled (61points) locations. They are also presented with relating major land cover types of the area.

Moreover, analysis of variance (ANOVA) is done in relation to soil strength, soil compaction and OM content and results are described. Besides, box plot and error bars are used to show the data distribution of these properties

The relationship between different soil properties, slope percentage and other possible relationships were established and discussed. Furthermore, effect of land cover change on soil properties are discussed as per the obtained results of soil properties and the effect of land cover change on erosion susceptibility was also discussed. Finally, the conclusions were presented.

6.1.1. Soil texture

Soil texture determined from the field method is presented and then it is further discussed with lab result.

Table 6-1 Field method based soil texture

ID	Field texture	ID	Field texture	ID	Field texture	ID	Field texture
1	clay loam	17	sandy loam	33	clay loam	50	clay loam
2	sandy loam	18	sandy loam	34	Sandy loam	51	silty clay
3	sandy loam	19	silty clay	35	clay loam	52	loamy sand
4	sandy loam	20	clay loam	36	loamy sand	53	clay loam
5	clay loam	21	clay loam	37	loam	54	clay
6	sandy loam	22	clay loam	39	loam	55	sandy loam
7	clay loam	23	clay loam	40	sandy loam	56	loam
8	clay loam	24	clay	41	loamy sand	57	clay
9	clay loam	25	sandy loam	42	clay loam	58	clay loam
10	clay loam	26	sandy loam	43	loamy sand	59	loamy sand
11	sandy loam	27	loamy sand	44	loamy sand	60	loamy sand
12	clay loam	28	loamy sand	45	loamy sand	61	clay loam
13	sandy loam	29	clay	46	loamy sand	62	loamy sand
14	sandy loam	30	clay loam	47	loamy sand		
15	loamy sand	31	sandy loam	48	loamy sand		
16	sandy loam	32	silty clay	49	sandy loam		

ID= soil sample identity, soil sample number 38 was from outside of the study area and it was not included.

Soil texture (Filed method)

Soil texture determined in the field as presented in Table 6-1, shows that 61 sample locations were visited to determine the soil properties e. soil texture. Clay loam, sandy loam and loamy sand type of soil textures were the main texture of the sample location. Clay loam was found in 19 locations while sandy loam and loamy sand were found in 17 and 15 locations respectively. Other textural classes found from the field method were clay, silty clay and loam.

Soil texture (lab method)

Table 6-2 shows the result of 11 representative soil samples analyzed in lab using pipette method. It reveals that major soil texture identified from the lab were clay loam, sandy loam, loamy sand, silty clay and loam.

Table 6-2 Analysis result of particle size distribution, with textural classes of field and lab method

Soil sample ID	Sand %	Silt %	Clay %	Texture from lab	Texture from field
35	11	28	62	clay	clay loam
33	15	52	32	silty clay loam	clay loam
32	3	53	44	silty clay	silty clay
62	15	47	38	silty clay loam	loamy sand
23	5	44	51	silty clay	clay loam
15	56	34	10	sandy loam	loamy sand
1	40	30	30	clay loam	clay loam
26	47	38	15	loam	sandy loam
39	46	34	20	loam	loam
24	39	38	23	loam	clay
16	50	34	16	loam	sandy loam

To come up with the overall soil texture in relation to land cover types, further calibration of leftover soil samples was performed according to the lab results and also soil map (Figure 6-1a) of the area was used as a base to calibrate the textural class correctly.

Calibration of remaining soil samples based on the lab result

The result of particle size distribution of 11 samples obtained from the lab was plotted and visualized in texture triangle (Figure 6-2) to show their positions in texture triangle. The red dots denote the location of soil texture based on the sand and clay fraction. The numbers shown together with red dots are clay fractional value of particular soil texture type.

The lab result was compared with the field result and then textural classes were assigned for remaining 50 soil samples. In this regard, Franzmeir and Owens(2008) has described that comparison of texture estimates –by-feel to laboratory-known values to calibrate fingers is a common practice. It is not easy to assess this field skill consistently and fairly. Therefore, in this study also field result is not exactly same in many cases. So, it was adopted to validate the field method how many samples were estimated correctly or partially correct or incorrect.

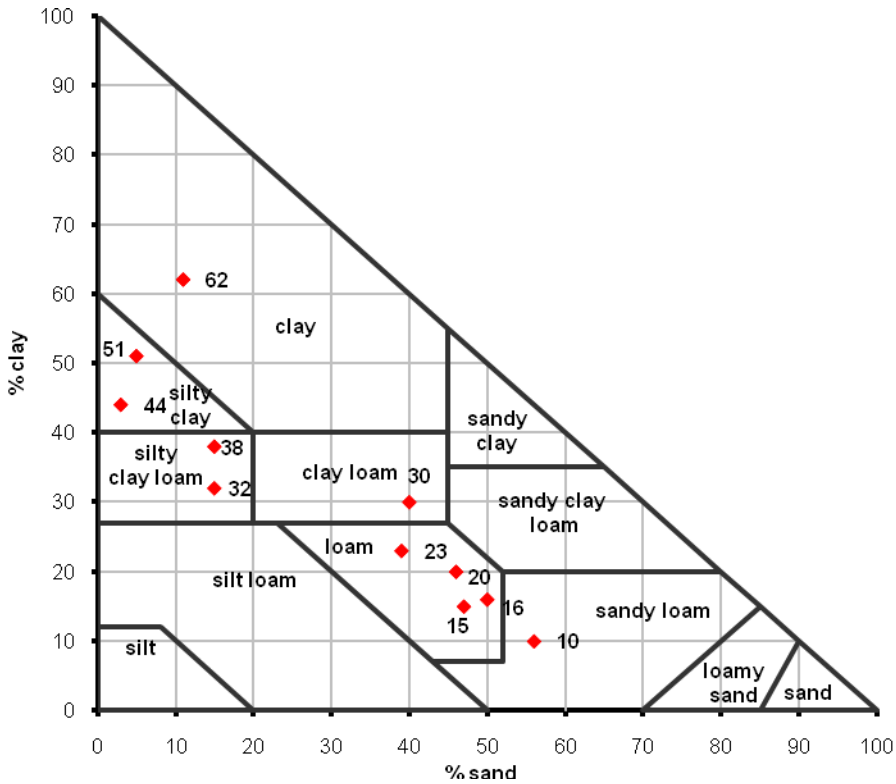


Figure 6-2 Soil texture triangle showing the location of representative soil sample

Number near red dot denotes clay % of particular soil texture of sample location see the Table 6-2.

Comparing the result of field and lab as shown in Table 6-2, result of some of textural classes (3classes i.e. clay loam, silty clay and loam) matched exactly with the lab results which account 27.3% as correct classes among total representative soil samples. Likewise, clay loam, loamy sand and sandy loam of field textural classes matched with very near and adjoining classes or closeness to nearby texture. These nearby textures were considered as partly correct texture classes that ccupied about 54.5 % of total classes of lab results. While some field results versus actual lab results like loam versus clay and loamy sand versus silty clay loam seem very opposite result a when the result was compared with lab results. This incorrect texture accounts 18.2% of total lab results. So, altogether about 82% of the field feel texture method was found as correct and partly correct textural classes comparing with lab result. So, the calibration was done according to the lab results which are fully correct, and then final textural class was assigned accordingly. In case of nearly closed textural classes such as loamy sand assigned as sandy loam due to very similar characteristics as they were regarded partly correct texture. Based on this idea, for further calibration of remaining 50 soil samples were calibrated accordingly as correct and partly correct textural classes.

For the field estimated textural classes which were found as a far away from the actual textural class comparing with the lab result of particular textural class, in this case, decision was made based on the soil map of the study area as per where the individual field textural class falls in individual soil map unit. To come up with the final calibration, field textural classes of all 61 soil samples were overlaid on the soil map (Figure 6-3) and displayed the textural class which seem far away from the lab result and then they were calibrated according to the soil map unit where they located. The Table 6-3 shows that the location of textural classes which were not matched with lab results. The sampled points which were under the Andosols soil type and their textural class was loamy sand, and then textural classes of those sampled were regarded as sandy loam because of physical characteristics of Andosols (FAO, 2001). Likewise, the soil sampled located at Latosols were calibrated as silty clay loam as per the physical characteristics of Latosols and the soil located at Grumosols(Vertisols) as calibrated as clay because of their physical properties(FAO, 2001). The soil located at Litosols was calibrated as clay per the field texture because sampled area was highly dominated by parent clay materials where a big land slide was also recorded during the field work.

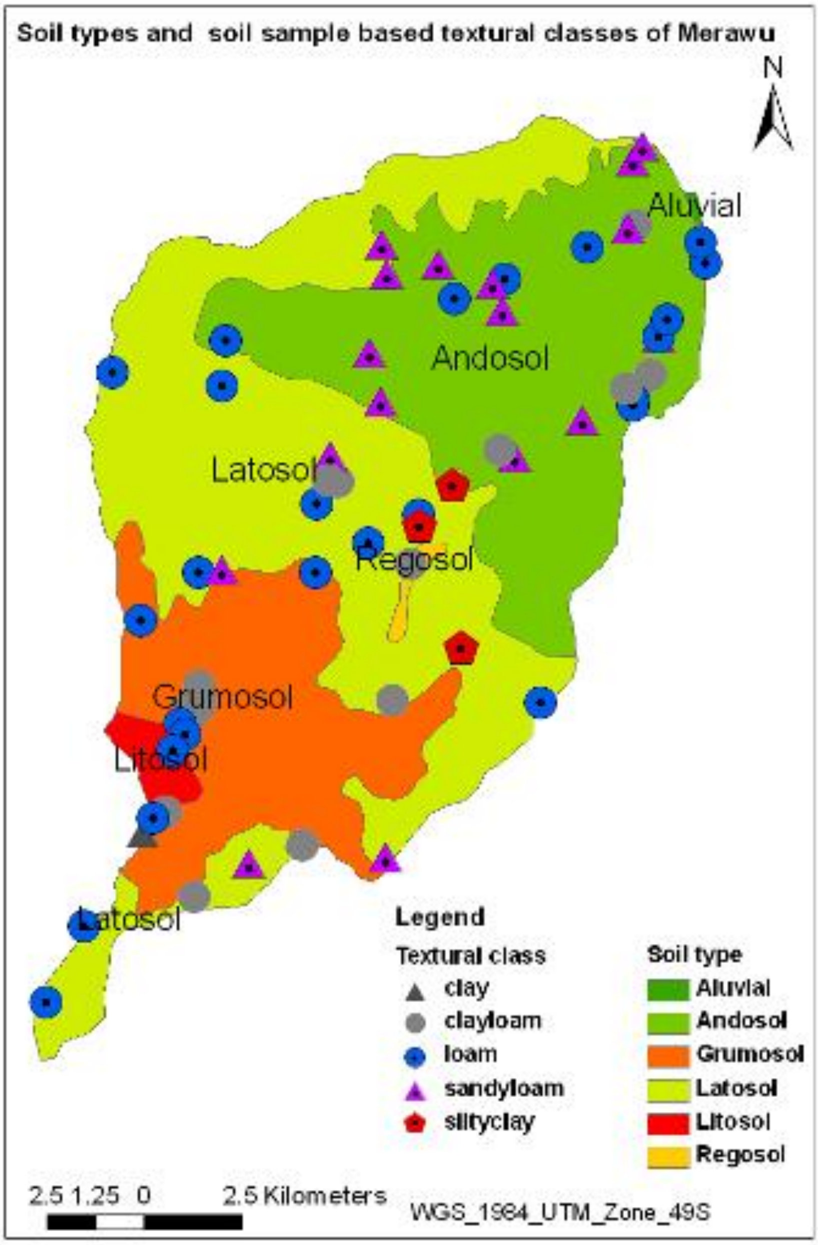


Figure 6-3 Figure showing the soil textural classes based on soil samples

Table 6-3 Showing the soil textural results of sample soils with field location and soil types

X	Y	Field texture	Calibration as per lab result	Soil Type	Final calibration
362926	9199820	loamy sand	sandy loam	Andosols	sandy loam*
369328	9204302	loamy sand	sandy loam	Andosols	sandy loam*
366160	9202974	loamy sand	loam	Andosols	sandy loam*
364410	9203374	loamy sand	sandy loam	Andosols	sandy loam*
365814	9202866	loamy sand	sandy loam	Andosols	sandy loam*
366091	9202152	loamy sand	sandy loam	Andosols	sandy loam*
369449	9206022	loamy sand	sandy loam	Andosols	sandy loam*
369702	9206406	loamy sand	sandy loam	Andosols	sandy loam*
361633	9198420	loamy sand	sandy loam	Latosol	silty clay loam**
363107	9203114	loamy sand	sandy loam	Latosol	silty clay loam**
362955	9203866	loamy sand	sandy loam	Latosol	silty clay loam**
358846	9195460	loamy sand	sandy loam	Latosol	silty clay loam**
354313	9184268	clay	loam	Latosol	silty clay** loam
359528	9187876	loamy sand	sandy loam	Latosol	silty clay loam**
363055	9188018	loamy sand	sandy loam	Latosol	silty clay loam
357581	9190798	clay	loam	Litosol	clay***

Note: * Soil texture calibrated based on the Andosol,* soil texture calibrated based on the Latosol, *** Soil texture calibrated based on the litosol.

The final textural classes as presented in Table 6-4 were found after calibration. Out of 61 locations, more than 1/3 soil texture was found loam type on 21 locations, clay loam was found in 15 locations and sandy loam in 13, silty clay 3 and clay 2 locations respectively.

Table 6-4 Final soil texture type after calibration

ID	Final text.	ID	Final text.	ID	Final text.	ID	Final text.
1	clay loam	17	sandy loam	33	clay loam	50	clay loam
2	loam	18	loam	34	loam	51	silty clay
3	loam	19	silty clay	35	clay	52	sitly clay loam
4	sandy loam	20	clay loam	36	sandy loam	53	clay loam
5	loam	21	clay loam	37	loam	54	loam
6	loam	22	clay loam	39	loam	55	loam
7	clay loam	23	clay loam	40	loam	56	loam
8	sandy loam	24	loam	41	silty clay loam	57	silty clay loam
9	sandy loam	25	sandy loam	42	clay loam	58	clay loam
10	clay loam	26	loam	43	loam	59	silty clay loam
11	loam	27	sandy loam	44	sitly clay loam	60	silty clay loam
12	clay loam	28	sandy loam	45	sitly clay loam	61	clay loam
13	loam	29	clay	46	sandy loam	62	sandy loam
14	loam	30	clay loam	47	sandy loam		
15	sandy loam	31	loam	48	sandy loam		
16	loam	32	silty clay	49	loam		

The soil texture in relation to land cover type as shown in Table 6-5, the dense forest area is mostly characterized by loam and clay loam while shrub land with sparse trees and cropland are mostly dominated by loam and sandy loam textural classes. On the other hand, the mixed forest with agro-forestry cover type has textural dominancy of clay loam and loam.

Table 6-5 Soil textural class in relation to land cover type

Land cover type	Main soil textural class
Dense forest	loam, clay loam
Shrub land and sparse trees	loam, sandy loam
Mixed forest/ Agro-forestry	Clay loam, loam
Cropland	loam, sandy loam

6.1.2. Soil OM content

The results of OM content grouped per land cover class are presented in Table 6-6. OM content of the area varies with 1.05 to 3.77 percent with as per the land cover type. OM content in dense forest varies with its minimum of 1.35 and maximum of 2.8 % while in shrub land, the minimum is almost same with 1.34 but maximum is higher than forest and other land cover types. From the summary Table 6-6, the minimum OM content with 1.05 % is under crop land cover type and maximum with 3.77 % is also under same cover type. However, the result depicts that OM content in shrub land is the highest than in others land cover type followed by the dense forest, cropland and mixed forest with agro-forestry but the difference is not so significant between land cover types. It can be seen that there is a little variability in OM content as per the land cover type (see Annex 9.4 for detail).

The variation of OM content in different location of same cover types is also different from the minimum and maximum value. The Main cause behind for the highest mean value of OM content in shrub land is that the sampled shrub lands were highly covered by small bushes where the soil was fully covered where the chance of decomposition of organic materials from dead plants and organisms is much higher than the partially covered or bare areas. Furthermore, the effect of erosion is also less under the fully covered land cover class due to its protective function against rainfall effect. Likewise, the OM content in cropland is little higher than the dense forest area, however it is not so big. Contrary, minimum value of OM content is the lowest one in cropland. So, variation of OM content in crop land seems higher than other land cover type.

Regarding the higher percentage of mean OM content in cropland, the use of organic fertilizers particularly for commercial vegetable farming is increasing according to the farmer’s saying of the area. It can be seen from the picture of fertilizer sacks (Figure 6-4) ready to use on the prepared crop field. Moreover, farmer’s lands use practices of using plastic mulch (see Figure 6-4) to protect seeds or seedling and fertilizer from rainfall effects. Location of the sampled points, land use practices and geo-morphological setting of the area have also played major roles in the variation of OM content in different land cover types.

Table 6-6 Summary statistics OM content, soil compaction and soil strength

Land cover	OM content (%)				Compaction(kg/cm²)				Strength(kpa)				count
	mean	SD	min	max	mean	SD	min	max	mean	SD	min	max	
DF	2.22	0.56	1.35	2.8	2.72	0.51	1.9	3.5	4.6	1.4	3.1	6.6	8
SST	2.78	1.1	1.34	3.64	2.13	0.86	1.3	3.31	3.8	0.8	2.7	4.5	4
MF/AF	1.96	0.53	1.14	2.86	2.48	0.73	0.94	4.06	4.7	1.4	2.8	6.8	15
CL	2.37	0.82	1.05	3.77	1.37	0.5	0.48	2.25	3.5	1.2	1	6.9	34



Figure 6-4 Farmer's land use practices in Merawu

6.1.3. Soil compaction

The summary Table 6-6 presents the result of soil compaction. The soil compaction in dense forest area seems is highest with its mean value of 2.72 kg/cm²) than other land cover types while the crop land has 1.37 kg/cm² mean compaction. However, the variation between the minimum and maximum value is lesser than other land cover types. From the field observation, the dense forest areas were mostly pine plantation area and in some cases it was found that resin collection in the area was also common practice. It means human activities can contribute in the soil compaction to make it higher. The compaction in the cropland is the lowest one because of agricultural practices. Conversely, the highest mean value in dense forest is mainly caused by raindrops effect from the height of canopy cover of large trees to the soil surface during rainfall and low ground cover due to monoculture of pine plantation. In general, soil compaction is highly affected by the presence of clay materials in the soil(William and Lamont, 1991). The organic matter content also affects the soil compaction of the soil. The cropland in the area is extensive farming area where farmer use more organic fertilizers and also the crop and plant residues also reduce the soil compaction. Moreover, the soil texture in the most of the croplands is of sandy loam and loam types as shown in Table 6-5 (see Annex 9.5 for detail). So, the compaction of soil reduces as the increase of sand fraction in the soil. Use of plastic mulching in vegetable farming also contributes the less compaction(William and Lamont, 1991).

6.1.4. Soil strength

It can be seen (Table 6-6) the mean strength varies with minimum of 1.0 to maximum of 6.9 kpa in different land cover types. The strength in cropland is the lowest than other land cover types with its value of 3.5 kpa while in dense forest and mixed forest with agro-forestry cover types show almost similar mean value. The reason behind this might be the land use practices in the cropland area leads to low strength while in the mixed forest and agro-forestry areas deserves the highest strength value and dense forest (Mostly Pine trees) has the second highest soil strength. This is because of the specific field situation in the areas; dense forest with bigger trees but less ground cover and also low canopy cover (61%) and the mixed forest area mostly occupied by medium sized trees with higher ground cover percentage (79%) of salak fruit and fast growing Albazia and other broad-leaved tree species that are dominant in the area.

6.1.5. Soil structure

As shown in the Table 6-7, it is presented soil structure in relation to land cover type of the area. Accordingly, soil structure of dense forest was found fine and medium size in seven cases together out of eight cases. Soil structure of the shrub land is mostly medium type while the mixed forest/agro-forestry is of medium size in most cases (nine out of fifteen cases). In cropland area, fine and medium size structured soil is most prominent followed by fine. Normally rice field areas are characterised by fine soil and dry agricultural areas are by medium structured soil types. Additionally, the soil structure in relation to its type is of granular type in the area that is highly dominant structure type in the area.

Table 6-7 Soil structure size and land cover type

Land cover type	Number of observations as per soil structure			Total no of observation
	Fine	**Medium**	**Coarse**	
DF	3	4	1	8
SST	0	3	1	4
MF/AF	4	9	2	15
CL	10	22	2	34
Total	17	38	6	61

6.1.6. Soil colour

The result of soil colour is presented (in Table 6-8) as per the land cover type. The soil colour is different in different land cover types. The soil in dense forests of the study area, were found mostly brown and dark brown colour but in cropland area most common soil colour found was of dark yellowish brown however variation of colour in cropland seems higher. So, dark brown, very dark brown and gray colours were also found in cropland area. In mixed forest/agro-forestry areas, the major soil colour was found dark yellowish brown. It can’t be established a relationship of colour and land cover types because of various factors such as geomorphology, soil types, organic matter content, rainfall and anthropogenic activities. Normally in dense forest area, soil colour is brown and dark brown but as per the land cover change its colour also changes from dark to light.

Table 6-8 Soil colour found based on land cover type

Land cover	Soil colour											Total obs.
	B	**DB**	**DOB**	**DRB**	**DYB**	**G**	**RB**	**SB**	**VDB**	**VDGB**	**YR**	
DF	4	3	-	-	1	-	-	-	-	-	-	8
SST	-	1	1	1	1	-	-	-	-	-	-	4
MF/AF	3	3	-	1	6	-	-	1	-	1		15
CL	4	5	2	2	7	3	2	2	4	2	1	34
Total												61

B=brown, DB= dark brown, DOB= dark olive brown, DRB= dark reddish brown, DYB= dark yellowish brown, G= gray, RB= reddish brown, SB= strong brown, VDB= very dark brown, VDGB= very dark grayish brown, YR= yellowish red and obs.= observation

6.1.7. Soil pH

Soil pH results derived from the analysis (Table 6-9) exhibits that the soil pH found in the dense forest and shrub land both have acidic category with pH value of 5.0- 6.0 while soil pH in mixed forest/agro-forestry and cropland was identified as acidic and neutral category(FAO,2006). The majority of the crop land area, the soil was found as acidic but in some cases neutral also found.

Table 6-9: Soil pH as per land cover type

Land cover type	**Soil pH range**		
	5	6	7
Dense forest	7	1	0
Shrub, sparse trees and grass	2	2	0
Mixed forest/Agro-forestry	6	5	4
Crop land	20	9	5
Total	35	17	9

6.1.8. Soil aggregate stability

Soil aggregate stability class determined from crumb test method presented in Table 6-10 shows that nearly 50 % soil aggregate stability in dense forest and cropland was found of class2 type while in shrub land it was found in 25 % cases and in mixed forest with agro-forestry it was 40 % cases. In all land cover types, class 1 type of aggregate stability is almost more than 25 % cases. In case of shrub land, class 4 seems the highest with 50% followed by 21 % of crop land. In cropland the most cases of class 4 types was mainly found in potato and maize field (for detail see Annex 9.5). The main cause behind this might be the soil aggregate stability is affected by the various factors e.g. land use practices, ground coverage, organic matter content and soil textures play role to create pore space between the particles and that aggregates of soil particles are regarded as soil aggregate(USDA, 1996). In this study, it was not easy to establish the relationship between the land cover type and aggregate stability of the soil. However, it was observed that dense forest was found to be class 2 category mainly and this property in shrub land was found mostly class 4 categories. Class 2 and 1 categories were found mostly in croplands and mixed forest/agro-forestry land cover type. The lower aggregate stability means more susceptibility to erosion.

Table 6-10: Soil aggregate stability according to land cover type

Stability class	**Class1**		**Class2**		**Class3**		**Class4**		**Total**	
Land cover type	# of obs.	%	# of obs.	%	# of obs.	%	# of obs.	%	# of obs.	%
DF	2	25.0	4	50.0	1	12.5	1	12.5	8	100
SST	1	25.0	1	25.0	0	0.0	2	50.0	4	100
MF/AF	5	33.3	6	40.0	2	13.3	2	13.3	15	100
CL	9	26.5	16	47.1	2	5.9	7	20.6	34	100

DF= dense forest, SST= shrub land and sparse trees and grass land, MF/AF= mixed forest with agro-forestry and CL= cropland and # of obs. = number of observation

6.2. Statistical analysis of soil properties

Analysis of variance (ANOVA) particularly of soil strength, soil compaction and soil OM content is presented in Table 6-12 as summary table. As presented in the Table 6-12 soil strength seems significantly different between groups of four land cover type namely dense forest, shrub land, and mixed forest/agro-forestry and crop land.

Table 6-11 summary table of soil strength, soil compaction and OM content

LC type	# of location	Soil strength			Soil compaction			Soil OM content		
		Sum	Mean	Variance	Sum	Mean	Variance	Sum	Mean	Variance
DF	8	36.38	4.55	1.92	21.72	2.72	0.26	17.73	2.22	0.31
SST	4	15.30	3.82	0.64	8.50	2.13	0.75	11.10	2.78	1.20
MF/AF	15	70.02	4.67	1.96	37.16	2.48	0.54	29.47	1.96	0.28
CL	34	120.25	3.54	1.38	46.66	1.37	0.25	80.67	2.37	0.67
Total	61									

Table 6-12 ANOVA table of soil strength, soil compaction and OM content

Type of soil property	Source of Variation	SS	df	MS	F	P-value	F crit
Soil strength	Between Groups	16.44	3	5.48	3.54	0.02	2.77
	Within Groups	88.18	57	1.55			
	Total	104.61	60				
Soil compaction	Between Groups	19.93	3	6.64	19.11	0.00	2.77
	Within Groups	19.81	57	0.35			
	Total	39.74	60				
Soil OM content	Between Groups	2.80	3	0.93	1.68	0.18	2.77
	Within Groups	31.70	57	0.56			
	Total	34.50	60				

SS= Sum of square, df= degree of freedom,, MS=means of square, F= variance of group means measured value, P-value= probability, Significance*; NS=Non- significance

Groups refer to land cover type where, DF=dense forest, SST= shrub, sparse trees and grass, MF/AF= mixed forest and agro-forestry

ANOVA test result of soil compaction reveals that the measured values of different land cover classes are significantly different however there is no significant statistical difference or variability between the means of soil OM content in different land cover classes (Table 6-12). For detail of the analysis see Annex 9.8, 9.9 and 9.10 respectively.

As illustrated by summary Table 6-6 in subsection 5.1 of soil OM content, soil compaction and strength, variability of these parameters as per the land cover type can be seen from their minimum, maximum, mean and standard deviation values of respective cover types. For example the minimum and maximum value of OM content in dense forest is not much difference but in other land cover type's variability is higher. However, the mean value of OM content in this category is lower than shrub land and cropland. The main cause behind this, the cropland is highly affected by use of organic fertilizers. In mixed forest/ agro-forestry land cover class has the lowest OM content because this land cover type normally farmers use less fertilizer. Regarding the soil compaction, dense forest has highest soil compaction than other land cover types followed by mixed forest/agro-forestry cover type and shrub land. Amacher and O'Neill (2004) have indicated that soil compression strength (compaction) is influenced by soil moisture content and forest area possibly have low moisture content due to bigger trees. In contrary, cropland shows the lowest soil compaction. Soil strength in dense forest and mixed forest/agro-forestry both show almost similar mean value. While the shrub land and croplands both have lower mean value than the forest. So, land cover change from forest to shrub land and also into cropland affects the soil properties (see Table 6-6).

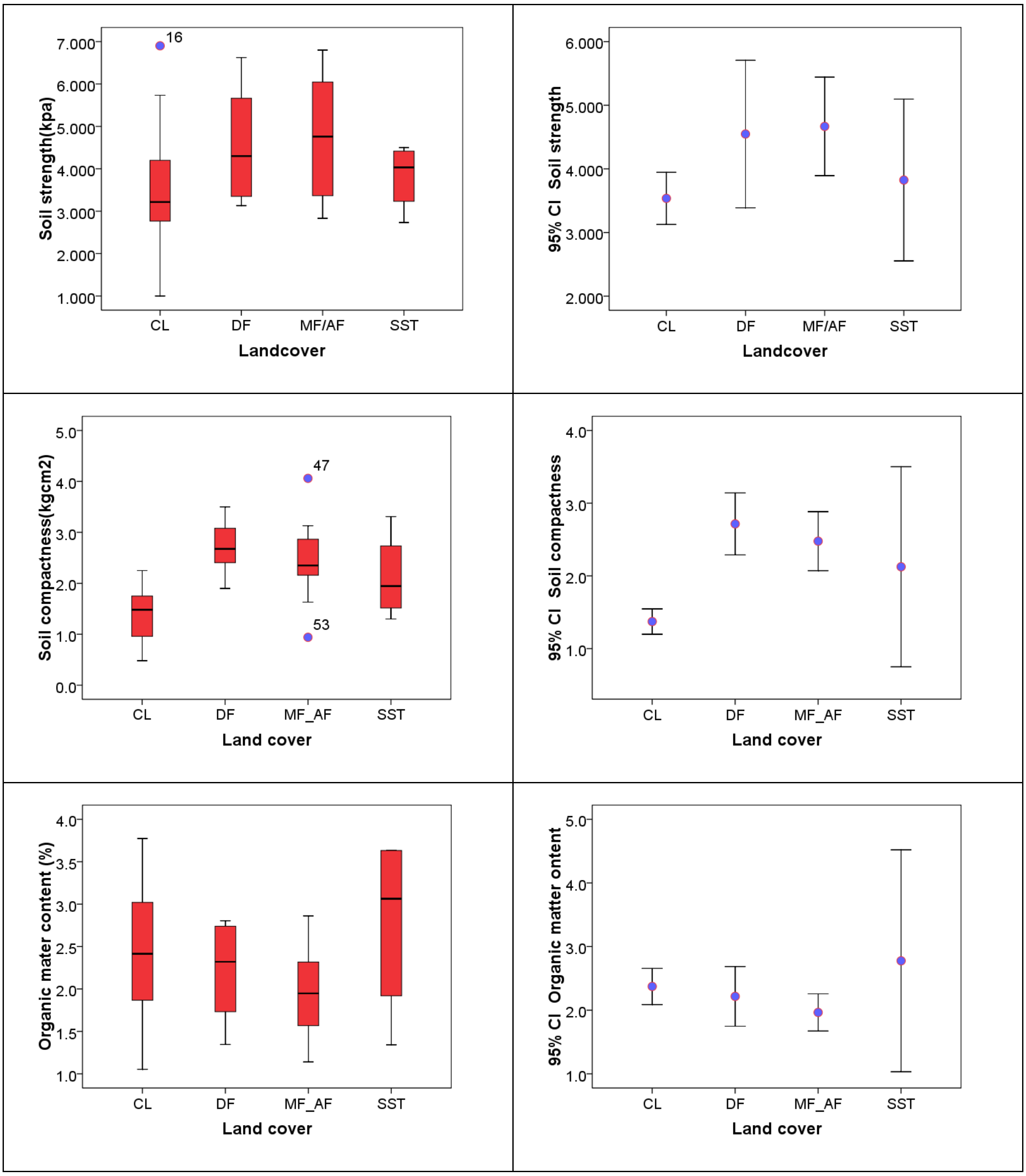


Figure 6-5 The box plots in the left and error bars in the right (CI 95%) of soil strength, soil compaction and OM content by land cover

DF= dense forest, SST= shrub land and sparse trees and grass land, MF/AF= mixed forest with agro-forestry and CL= cropland

Moreover, the variability in the soil parameters is also described by box plots (Figure 6-5). It shows that the data distribution and their occurrences in the box. The box plots (Figure 6-5) of soil strength, soil compactness and soil OM content illustrate that the 25th and 75th percentiles are shown as box centred, about 50th percentile as median and the 10th and 90th percentiles are shown as error bars and the 5th and 95 percentiles are shown outliers as points. From the figure, soil strength data set of cropland, dense forest and shrub land found not well distributed .It means that data set of cropland and dense forest has skewed right meaning that most of the data set are in the right upper part of box plot while in case of shrub land just opposite to previous case, it is left skewed. On the other hand, mixed forest/agro-forestry shows symmetrical meaning that data are well distributed within the box plot. Likewise, in soil compaction data of all land cover types are also not distributed well. But in case of data of OM content of cropland and mixed forest/agro-forestry is normally distributed while in other land cover types it seems as skewed. There is one outlier in the data set of cropland in strength and two outliers of mixed forest in soil compaction. These outliers show that the deviation from the rest of the sample in their respective data set. Indeed, the data set of these aforementioned are not well distributed to all land cover types.

The error bar shows that the uncertainty or error in the data measurement. The Figure 6-5 shows that the number of samples of shrub land was very few and the error bar seems longer than other land cover types.

6.3. Erosion evidences

The analysis of erosion features collected from the field was plotted in soil map Figure 6-6 that shows that in 27 locations erosion evidences were found. Out of which in 17 locations sheets were found as the form of erosion and in 10 locations combinations of sheets, rills and gullies were found. Specifically erosion evidences were not found at 34 locations because of rainfall season was about one and half month away when doing the fieldwork in October 2009.

Sheet erosion was found as the most common erosion type in the cropland as compared to other land cover types as shown in **Error! Reference source not found.**.

Table 6-13 Erosion features recorded during field work October 2009

Land cover type	Erosion features		
	Present		Absent
	Sheet	Sheets, rills and gullies	
Dense forest	2	0	6
Shrub and sparse trees		1	3
Mixed forest/ agro-forestry		2	12
Cropland	15	7	13
Total	17	10	34

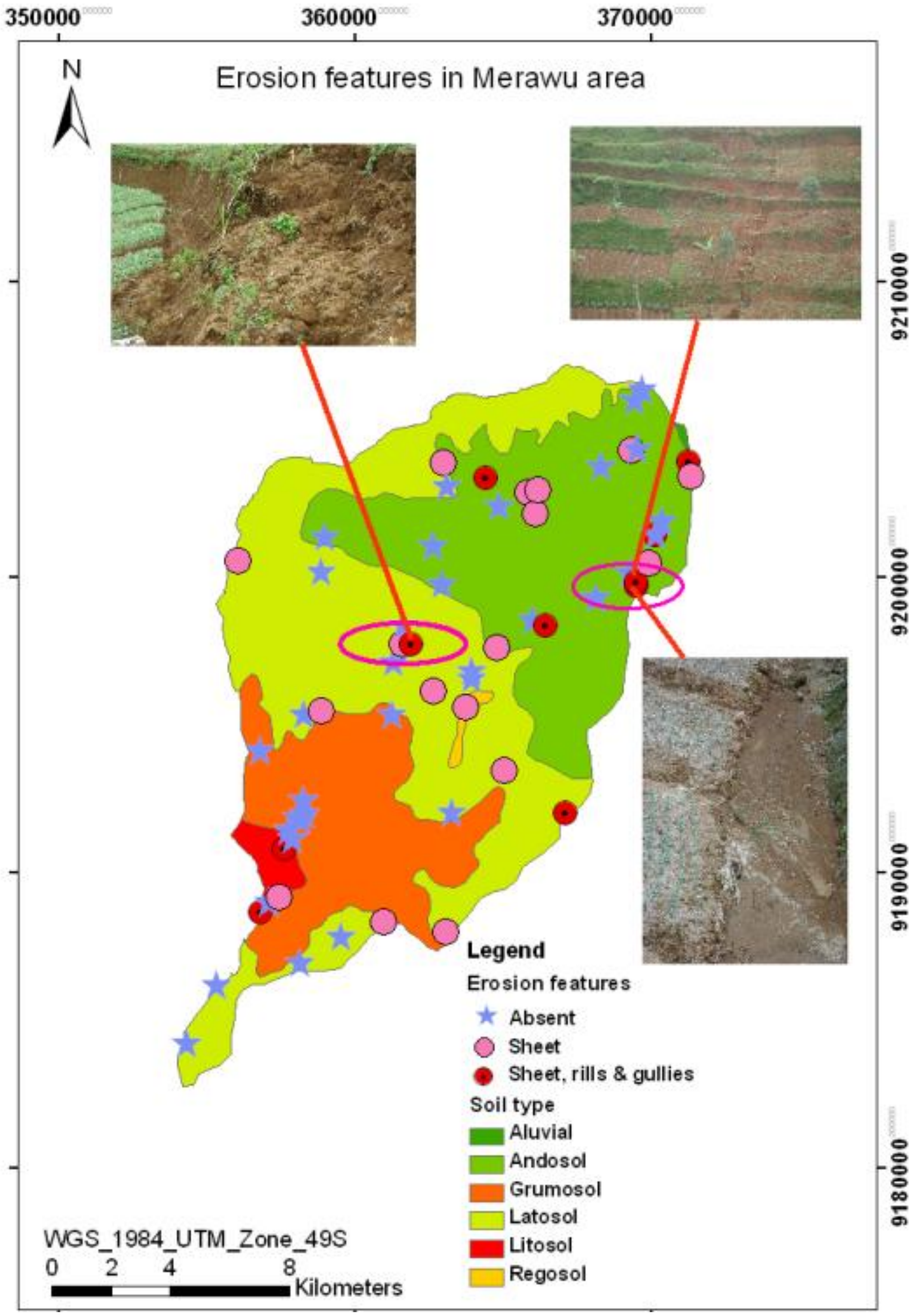


Figure 6-6 Erosion features encountered during field work

Rills and gullies were also found mostly in this land cover type in 7 locations out of 10 observed locations followed by mixed forest/agro-forestry. Therefore, soil erosion is very common phenomenon in cropland area where land is not fully covered by crops in the form ground cover. So, effect of water induced erosion can be seen even in a very short single rainstorm where the land is almost bare and sloping agricultural practice is very common as well illustrated by Figure 6-7.

Figure 6-7 photographs of erosion evidences caused by anthropogenic factors

Regarding the crusting index and soil deposition in the area, it was not seen abundantly and almost absent of both parameters because rainfall season was not started and also very low rainfall during field work time.

6.4. Relationship between soil properties

Soil properties such as OM content, soil compaction, soil strength, soil aggregate stability and soil colour are related to each other. In this subsection, the relation between OM content and soil strength, relation between soil colour and OM content, relation between soil texture and soil compaction, soil strength and soil OM content are also presented. These soil properties are interrelated or affected from one to another. They can have positive role in controlling or reducing erosion. So, in this connection, as land cover changes from forest to cropland or other bare land cover type, soil properties such as soil compaction, soil strength, soil aggregate stability, soil OM content, soil porosity also affected negatively. The bare areas without plant coverage normally have high erosion susceptibility. From this study also shows that the cropland area where erosion problem was very serious within single storm of rainfall because the sloping agricultural land use practice is not suitable in the area however; the cropland area shows higher mean OM content. OM content alone cannot control erosion in sloping area without applying conservation measures.

Normally, if the soil OM content increases in the soil, the soil becomes more porous high aggregate stability and infiltration increases during rainfall time and low chance of runoff (USDA, 1996; Lickacz and Penny, 2001). Eventually erosion decreases or low susceptible to erosion. Sandy soils have less aggregation and more readily erodible by water.

6.4.1. Relation between soil OM content and soil strength

As shown in the scatter plot (Figure 6-8) of soil OM content and soil strength, it shows weak linear relationship (r= 0.50) between two parameters. In general, the high OM content ensures high soil strength. Increased soil strength supports to reduce soil detachability or erodibility of the soil. But from this study it cannot be conclude that OM content has strong relationship with soil strength as shown in Figure 6-8 from the measured data of both parameters. In relation to soil erodibility, normally as soil OM content increases, soil physical properties like soil strength also chance of soil particle detachment is lower but if soil OM content is decreased then soil strength also decreases then more prone to erosion (Braimoh and Vlek, 2004; Khresat *et al.*, 2008).

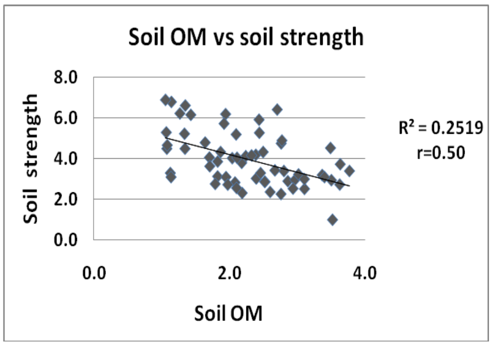


Figure 6-8 Relation between OM content and soil strength

6.4.2. Relation between soil colour and OM content

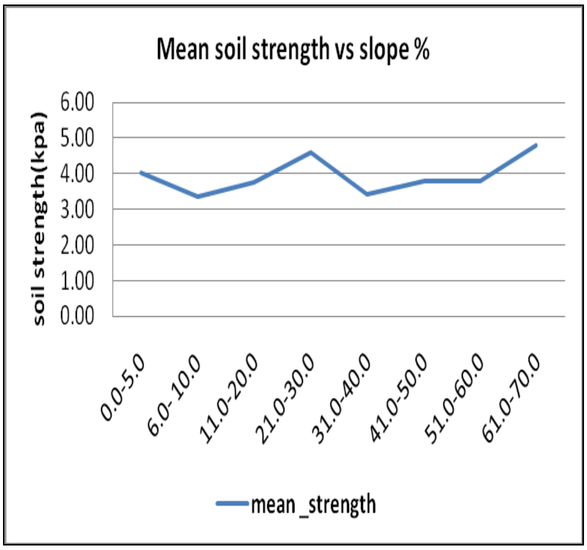
The presented Table 6-14 depicts that main soil colours in relation to the mean OM content in particular soil colour type. Hence, the Table 6-14 illustrates that very dark brown and very dark grayish brown both colours have the highest OM content with 2.99 % followed by dark reddish brown and dark brown with 2.7 and 2.5% respectively. It means that higher percentage of OM content, the much darker soil. Much darker soil, high infiltration is possible and then erosion may be less but only soil colour alone doesn't fully responsible to erosion reduction; other factors such as ground cover, topography, rainfall intensity and land use practices are also responsible.

Table 6-14 Major soil colour in relation to OM content

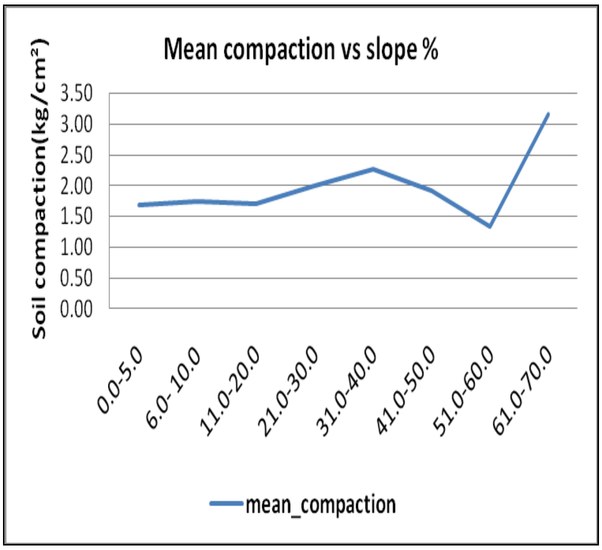
Soil colour type	# of observation	%	Mean OM
Brown	11	18	1.91
Dark brown	12	20	2.50
Dark olive brown	3	5	2.21
Dark reddish brown	4	7	2.70
Dark yellowish brown	15	25	2.26
Gray	3	5	1.06
Reddish brown	2	3	1.95
Strong brown	3	5	2.12
Very dark brown	4	7	2.99
Very dark grayish brown	3	5	2.99
Yellowish red	1	2	2.1
Total	61	100	

6.5. Relation between soil properties and slope

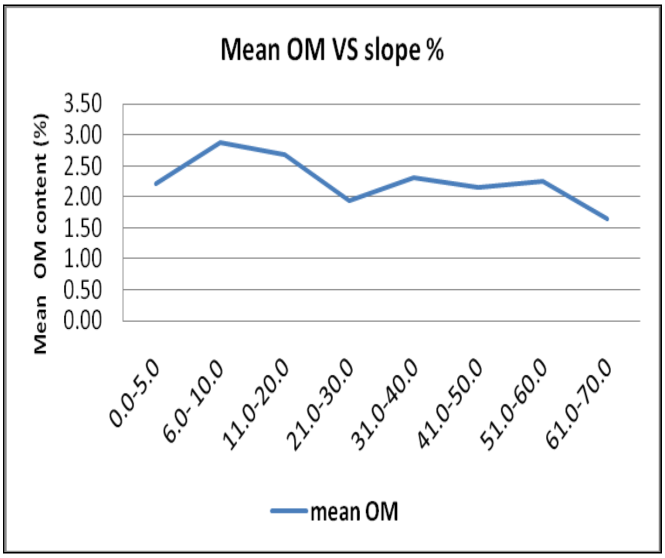
Slope is one of the major factors in erosion process. Higher percentage of slope is more prone to erosion. So, the soil parameters such as soil strength, soil compaction and soil OM content might be affected by slope. Hence, to see their relationship how slope affects these properties on the data set of this study. As shown in the Figure 6-9**,** mean soil strength, mean soil compaction and mean OM content were plotted separately against slope percentage in X-axis to see how these soil parameters change as changes in slope percentage. The line graph (Figure 6-9a) of mean strength shows that there is not any consistency in the decrease or increase of soil strength as changes in slope percentage. In case of soil compaction, the line graph (Figure 6-9b) depicts that the overall change in mean value seems higher but it has increased sharply after 60% slope. The line graph (Figure 6-9c) of OM content shows that the overall trend of change seems lower or decreasing orders. However, it is also not highly affected with the increase or decrease in slope but it shows slightly decreasing manner. Therefore, it is not easy to establish clear relationship between these soil properties and slope percentage.



a. Mean soil strength versus slope



c. Mean compactio versus slope



c.Mean OM versus slope

Figure 6-9 Relationship of slope percentage with soil parameters

6.5.1. Relation between soil texture, soil compaction, OM content and soil strength

Table 6-15 presents the result of mean soil compaction, mean strength and mean OM content in relation to soil texture types found from the field study in the Merawu area. The results illustrates that fine textured soil(soil with high clay fraction) has normally higher mean compaction than other soil classes and the coarse textured soils such as silty clay and sandy loam both have lower mean value than clay content soil. Regarding the mean OM content, the coarser textured soil i.e. sandy loam has the highest OM content while the fine textured silty clay has the lowest mean value. Soil strength in fine textured soil (silty clay) has highest mean value followed by clay loam and clay. Normally clay materials make the soil more compact and higher strength because of its binding characteristic.

Table 6-15 Mean value of soil parameters in relation to soil textural classes

Soil texture type	mean compaction (kg/cm²)	Mean OM (%)	mean strength (kpa)
Clay	1.8	1.9	4.1
Clay loam	2.3	1.8	4.6
Loam	1.9	2.3	3.8
Sandy loam	1.5	2.9	3.4
Silty clay	1.5	1.4	5.2
Silty clay loam	1.8	2.4	3.6

6.6. Effect of land cover change on soil properties and erosion succeptibilty

The textural distribution of the soil in the study area, the lower part of Merawu is characterized by clay textured and upper middle part is highly dominated by silty clay loam. Basically, latosols are of high content of kaoline and iron oxide and leaching of mineral nutrients is much higher. Subseqently the soil becomes poor in this class. The upper most part of the Merawu is highly dominated by sandy loam and loam textured soils where Andosols soil is main soil types of the area (**Figure 6-1**) and originally it is volcanic material and characterized by volcanic ash. The soil is also more acidic type (van Ranst *et al.*, 2002). The volcanic ash type of soil is more erosion prone or highly susceptibility to erosion or it is easily erodible. After deforestation Andosols type of soils become crumbles to hard granules and easily removed with surface runoff (FAO, 2001).So, soil erosion rate at upper part of the Merawu is much higher than other parts. From the study soil texture analysis based on the field samples and also the major soil types of the upper Merawu area where sandy loam and loam soils are very common. So, erodibility of the sandy loam soil is also higher. Moreover, the Figure 6-10 shows that the erodibility classes based on the erodible material available in particular soil texture (Kunwar et al., 1999). It was prepared according to the field soil sample locations overlaid on land cover map 2009. In addition to this, the Figure 6-6 also illustrates the area where more erosion features were encountered during field work of 2009. The figure gives some impression of erodibility characteristics of soil in the area. The red points show the highly susceptible area based on the erodible materials available in the soil. Clay and silty clay soils have least and slightly erodible material. Clay dominant soils are mostly found in low land area and middle part of the area where erosion is less severe as compared to upper Merawu particularly upper eastern part.

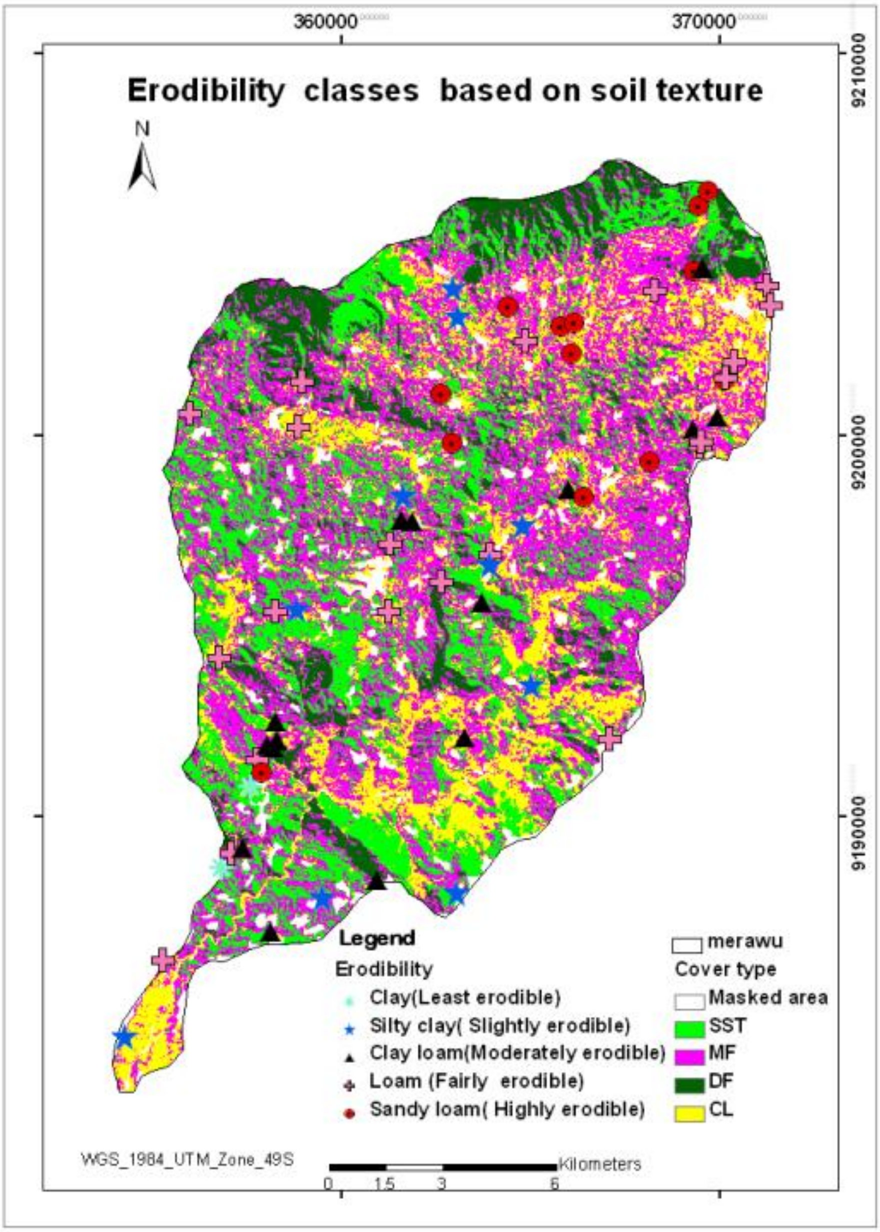


Figure 6-10 Soil erodibility classes of sample locations based on erodible materials in soil texture

DF= dense forest, SST= shrub land and sparse trees and grass land, MF/AF= mixed forest with agro-forestry and CL= cropland

Besides, the land cover change from forest to shrub land or cropland, susceptibility of erosion may be higher as compared to forest area because cropland or shrub land in most cases generally has less coverage to protect the soil. The erosion features found during field work as described in previous sections can also prove the erosion susceptibility is higher in crop land because crop land in upper Merawu mostly characterized by loam and sandy loam type. The content of erodible material in sandy loam is higher with its value of five as compared to other soil texture type. So, it is more susceptible to erosion (Table 2-1). The numbers of locations visited was highly susceptible area in relation to erosion.

Table 6-16 Erodible material as per the soil texture type (adapted from Kunwar et al. (1999)

Soil texture type	**Value for erodible material available in the soil**	**Number of locations**
Clay	1	2
Silty clay	2	10
Clay loam	3	15
Loam	4	21
Sandy loam	5	13

Furthermore, Table 5-13 and Table 5-14 in previous chapter section 5.6.4 show that the land cover change trajectories from 1991to 2001 but Figure 6-11 shows the land cover change trajctory from 2001 to 2009 in spatial aspect. If the land covers changes such as forest to cropland or forest to mixed forest/agro-forestry, the soil properties also change accordingly. In cropland normally have less ground cover and more susceptible to erosion but in forest land soil strength, soil porosity, aggregate stability are also higher than the cropland and eventually erosion is lower than the cropland. The land cover change trajectories (see Table 5-17) such as SST- CL-CL, SST-MF/AF-CL, MF/AF-CL-CL and DF-MF/AF-MF/AF which are more sensitive to erosion. For example the land cover found as shrub land (SST) in 1991 changed into cropland in 2001 and continued as cropland till 2009 where soil properties also changes as per the land cover change and quality of soil properties decreases. Ultimately, erosion process in these areas may be common due to the land cover change.

The area is characterized by volcanic soil mainly sandy loam, loam, silty clay loam, clay loam and clay textured types but more dominant soils are sandy loam, loam and silty clay loam. Hence, the erosion susceptibility is much higher in the area. Soil with faster infiltration rates, high organic matter content and improved soil structure generally has a greater resistance to erosion (OMAFARA, 2003). In this study, however, the crop land areas are characterized by higher OM content than other land cover type but it doesn't only fully control the erosion in the area. Other factors such as ground coverage, land use practices, topography, rainfall characteristics and other physical soil properties play important role in this aspect.

Crop field in the area which was changed from forest to cropland is mostly located at high slope area. Besides, the land use practices and land management system of the area is also not scientific because farmers don't care about the slope but they only concern about to protect the crop seeds and fertilizers they used. Therefore, chance of erosion in the crop field is obviously higher than other land cover types.

In normal condition, sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils. As explained in earlier subsections about the soil properties relating with land cover types, the dense forest and mixed forest/ agro-forestry areas are less susceptible to erosion than croplands and shrub land. Once the forest changes into degraded forest (shrub land) or cropland, the soil OM content, soil structure and other parameters are decreased and disturbed which lead into erosion. Moreover, ground cover which is considered as protective cover of the land is also lower in crop land (52%). So, the chance of erosion in the cropland is much higher and more susceptible to erosion than other land cover types because the soil with low strength is easily eroded when rainfall occurs. Soil detachability is lower as increased in the soil strength and vice versa (Misra and Rose, 1995; Cruse *et al.*, 2000).

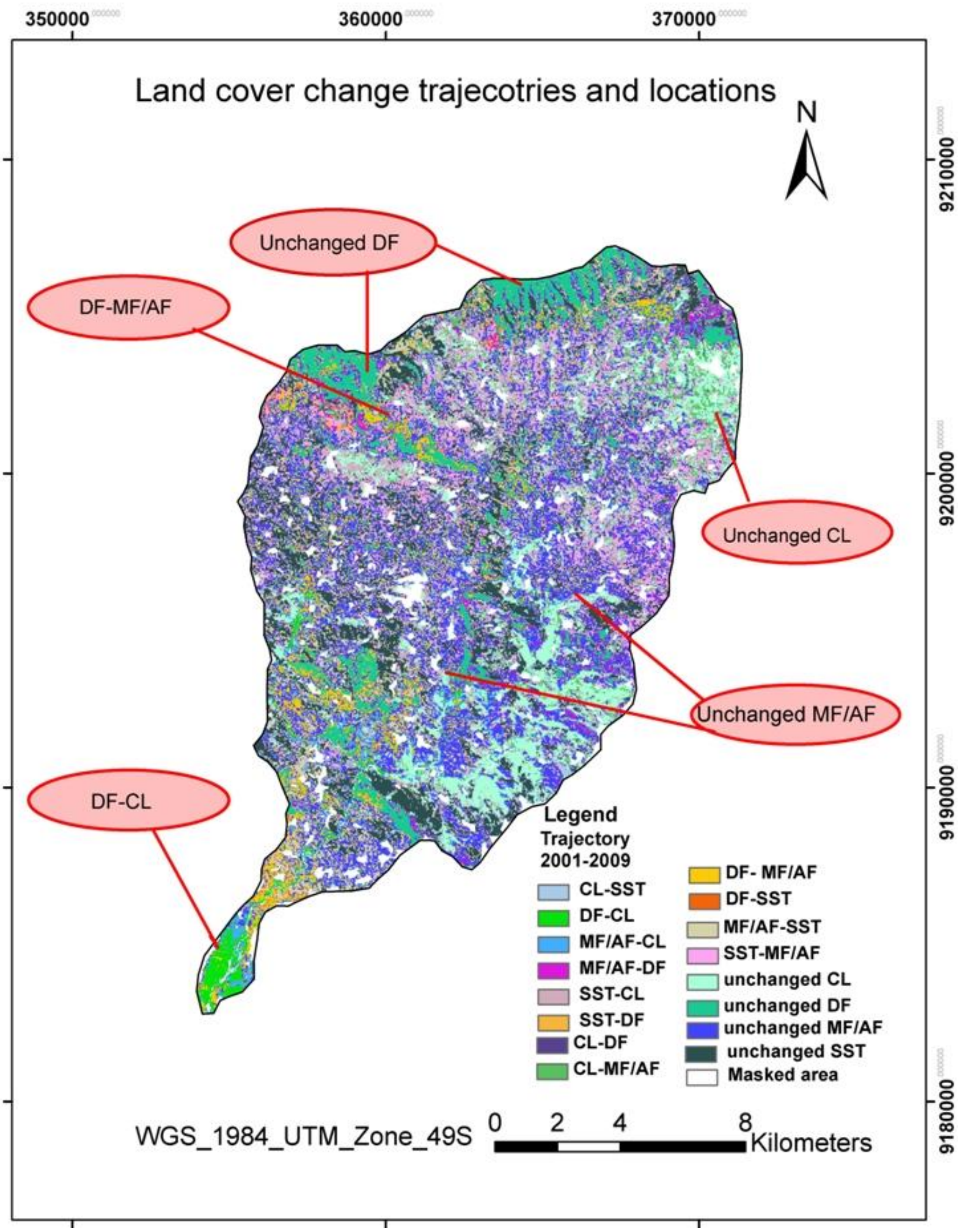


Figure 6-11 Land cover change area from year 2001 to 2009

The upper north east part of the Merawu is mainly dominated by cropland and agro-forestry (see Figure 5-1). As mentioned before, the crop land is more susceptible to erosion as compared to agro-forestry area. Agro-forestry land cover category is considered the best land use practices to control erosion than the monoculture which tends to have high erosion rate because of less canopy cover (Tarigan, 2002). When soil is more compacted, the erodibility decreases and also the formation of rill is absent (Misra and Rose, 1995).

As discussed previous subsections, mean value of soil compaction in dense forest is highest than other land cover types. It is apparent that the soil compaction in the cropland is the lowest one because of agricultural practices to cultivate the crops. Conversely, dense forest shows the highest soil compaction in this study because low ground cover due to monoculture of pine plantation. Out of eight cases of dense forest six locations were pure pine plantation. In addition to this, soil texture of dense forest type was found mostly clay loam texture in 50% cases. So, the compaction is highly affected by the presence of clay materials in the soil(William and Lamont, 1991). The organic matter content also affects the soil compaction of the soil. The cropland in the area is extensive farming area where farmer use more organic fertilizers and also the crop and plant residues also reduce the soil compaction of the soil. The aggregate stability of the soil in the forest was class 1 and class 2 types in most cases. It means that in normal condition the soil in the forest is not easily detached by rain drops. Based on the soil properties of dense forest areas as described in previous paragraph, the erosion susceptibility in the forest is lower than the cropland. Because the cropland is normally less ground cover as compared to forest and other land cover types of the area.

Soil colour also another property which is an indicator of soil organic matter content. As mentioned in previous section, in normal situation forest area consists of darker soils with high organic matter content than other land cover types. So, taking into consideration of soil texture, structure, soil OM content, soil compaction, soil strength, soil colour and soil aggregate stability of the forest area as described in detail in previous sub-sections, it can be said that the erosion susceptibility is lower in forest area and higher in cropland area. Darker soil colour, more organic matter content and low susceptible to erosion and conservation of top soil properties reduces the chance of erosion. Dark soils are usually indicative of high organic matter content (FitzPatrick, 1978; Braimoh and Vlek, 2004). Generally, higher Munsell values has been obtained on eroded soils because of the removal of top soil and subsequent decrease in organic matter content (Escadafal, 1993). So, the land cover with darker colour has more infiltration and high permeability and thereby less chance to erosion. Furthermore, the recorded soil erosion evidences are also highlights the susceptibility of erosion in crop fields than other land cover types.

7. Conclusions and Recommendations

7.1. Conclusions

Based on the results and discussions in previous section 5 and 6, following conclusions were drawn:

- Area coverage of dense forest has reduced from 3247 to 2514 hectares representing 23% reduction of its original size and overall percentage of change of about by 3% change. Shrub land and sparse trees area has also reduced in size from 7727 to 5836 hectares representing 24.5% of its original area and about 9% of total land area of the catchment (excluding the masked area of the water body and settlement). Mixed forest/ Agro-forestry area has increased from 7960 to 9123 which covers about 15% of its original area and overall change is of 5 %. Likewise, cropland has also increased from its 3104 to 4565 hectares which covers 47% of its original size and overall percentage of change is of 7 %.

  Out of 220309 hectares of total land covers for four classes, overall 24% underwent change irrespective of type of land cover

- The overall accuracy of land cover classification was found to be 70 % with 0.60 kappa statistics which was assessed by 140 ground truths. This accuracy seems acceptable with compared to other research findings.

- The major land cover change trajectories found from the image data and field information interviews data are similar and common when compared to each other but not same in all cases. The trend of land cover change trajectories as discussed in previous chapter of result and discussion, it can be found that the major trajectories are unchanged categories and in another changed categories mainly from the shrub land to cropland and also shrub land to mixed forest/agro-forestry land cover types are exists. Other also exist but not in significant numbers. Change pattern from forest to cropland is very small as indicated by land cover classification result but the change pattern from shrub land to mixed forest/ agro-forestry is higher. It shows that the forest area in the Merawu is almost in difficult terrain area and also it includes the pine plantation which is normally focused production purposes such as on resin and wood production. So, the major pressure was found more under the shrub land.

- Overall, 17 land cover change trajectories were found, out of which 4 trajectories were found as unchanged and 13 were changed trajectories over time.

- Based on this study we conclude that the field method of soil texture analysis is a fast way to identify the general textural class that can be applied in the case of limited resources and time however it requires consistency of analyst and more practice in field method.

- The top soil properties in the Merawu area, differs as per the land cover change but not in all cases. Regarding the soil texture, it can’t be said that it texture changes as per the change in land cover types because it is permanent properties of soil which is normally dictated and influenced by its parent materials.

- Major soil texture in the area is characterized mainly by medium and coarse textured in upper hilly region and fine textured soil (high clay content) in middle part and low land of south west of the catchment.

- Soil strength of the study area showed that there is significant difference between land cover types. Lower soil strength of cropland leads to more detachment of soil particle in the area. The higher soil strength in mixed forest with agro-forestry and dense forest area has less chance of soil detachment than cropland and shrub land.

- Conversely, soil compaction result showed that the variation is highly significant between the land cover types. The dense forest area has higher compaction but normally it should not be like this. However, the main cause behind this might be the forest area of low ground cover percentage; monoculture (mostly Pine trees) out of eight observations, 6 were planted pine forest areas and soil texture of dense forest area was clay loam type in 50% cases. Besides, locations of forest mainly in the sloppy terrain are major factors in this particular case. Another, cause might be the sampling error in the data collection.

- In case of OM content, it is not statistically significant between land cover categories. However, we can see that the certain level of variation in mean value exists. The OM content in the shrub land is higher than the forest and other land cover types. Because of the less sample size as compared to other land cover types and the ground cover percentage of shrub land location was more than 80%. The cropland has also higher OM content than the forest areas because of use of organic fertilizers in the intensive farming area where more samples were taken during the study. However, the crop land has the highest the susceptibility to the water induced soil erosion in the area as indicated by erosion features recorded and observed in the field work. Because of loose soil(less strength), farming practices along the slope and also the soil texture mainly dominated with sandy loam and loam in upper part of the catchment where intensive farming is in practice. As the land cover change from forest to shrub land or cropland the soil strength decreases and erosion susceptibility increases accordingly

7.2. Limitations

- Image data: mainly cloudy images and striping problem

- Language problem in the field work to collect primary as well as secondary data

- Difficult to get information from forestry staff through informal interviews regarding the LC change historical information

- Limited secondary data about land cover change

- Very limited information from local people about LC change information

- Limited time for field work

7.3. Recommendations

Better accuracy can be derived in land cover mapping which is mostly depending on quality of image data. Additionally, number of ground truths should be higher to increase the accuracy of result. In this aspect more time is required to collect necessary primary data and other alternative methods may be used to increase accuracy of the land cover map.

The study reveals that land cover change affects on top soil properties and that may cause erosion in the area. To reduce the erosion susceptibility in crop land, agro-forestry is better practice to conserve the soil properties in sustainable way and also to increase the productivity of land. However, it has been used by the farmers as a combination of salak fruit and fast growing - Albazia falcataria tree species.

In the collection of top soil properties from the field method, more time is required to collect the data in a sufficient numbers which can be further used to analyze using appropriate statistical tools such as geo-statistical techniques.

To quantify the erosion in different land cover types of whole catchment area, further erosion modelling is required which was not possible to use in this study.

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9. Annexes

9.1. Trajectories from informal interviews

X	Y	Soil ID	Tajectories from interviews
354313	9184268	57	CL-CL-CL
356780	9194166	54	CL-MF/AF-MF/AF
356804	9188654	35	CL-MF/AF-MF/AF
357097	9189046	55	CL-MF/AF-MF/AF
357411	9189194	53	CL-CL-MF/AF
357581	9190798	29	CL-MF/AF-MF/AF
357776	9191502	24	CL-CL-CL
357901	9191188	25	CL-MF/AF-MF/AF
358047	9191896	22	CL-MF/AF-MF/AF
358150	9187004	58	MF/AF-MF/AF-MF/AF
358199	9191832	23	SST-SST-DF
358263	9192482	30	CL-MF/AF-MF/AF
358291	9192020	21	CL-MF/AF-MF/AF
358874	9200226	39	CL-CL-CL
358974	9201408	40	SST-DF-DF
359528	9187876	59	MF/AF-MF/AF-MF/AF
360940	9188352	61	SST-DF-DF
361299	9197168	16	SST-SST-DF
361584	9197766	42	CL-CL-CL
362642	9201094	17	CL-CL-CL
362955	9203866	45	CL-CL-CL
363055	9188018	60	CL-MF/AF-MF/AF
363253	9192076	33	CL-CL-CL
363724	9195616	50	CL-CL-CL
363946	9196616	19	CL-CL-CL
364410	9203374	46	CL-CL-CL
364797	9197636	51	CL-CL-CL
365021	9193448	32	CL-CL-CL
365814	9202866	47	CL-CL-CL
366091	9202152	48	CL-CL-CL
366160	9202974	36	CL-CL-CL
366410	9198394	9	CL-CL-CL
369328	9204302	27	CL-CL-CL
369449	9206022	28	SST-SST-SST
369477	9199706	3	CL-CL-CL
369498	9199841	2	CL-CL-CL
369702	9206406	62	SST-SST-SST
369914	9200498	1	CL-CL-CL

370112	9201461	4	CL-CL-CL
370140	9201506	5	DF-SST-DF
370372	9201940	6	CL-CL-CL
371230	9203932	49	CL-CL-CL
371350	9203412	26	CL-CL-CL

9.2. Land cover change trajectories based on sample locations

X	Y	Soil sample_ID	Trajectory line(91,01 & 09)
354313	9184268	57	CL-CL-CL
356780	9194166	54	CL-CL-CL
357776	9191502	24	CL-CL-CL
358874	9200226	39	CL-CL-CL
363946	9196616	19	CL-CL-CL
364797	9197636	51	CL-CL-CL
365021	9193448	32	CL-CL-CL
366091	9202152	48	CL-CL-CL
366160	9202974	36	CL-CL-CL
368291	9203808	13	CL-CL-CL
370372	9201940	6	CL-CL-CL
371230	9203932	49	CL-CL-CL
371350	9203412	26	CL-CL-CL
365814	9202866	47	CL-MF/AF-CL
356804	9188654	35	CL-MF/AF-MF/AF
357097	9189046	55	CL-MF/AF-MF/AF
357581	9190798	29	CL-MF/AF-MF/AF
357901	9191188	25	CL-MF/AF-MF/AF
357411	9189194	53	DF-DF-DF
358199	9191832	23	DF-DF-DF
358974	9201408	40	DF-DF-DF
360940	9188352	61	DF-DF-DF
370140	9201506	5	DF-MF/AF-DF
358291	9192020	21	DF-MF/AF-MF/AF
369539	9204384	12	DF-MF/AF-MF/AF
363107	9203114	44	MF/AF-CL-CL
363253	9192076	33	MF/AF-CL-CL
368147	9199328	8	MF/AF-CL-CL
369328	9204302	27	MF/AF-CL-CL
369914	9200498	1	MF/AF-CL-CL
366008	9198568	10	MF/AF-CL-DF
369279	9200172	7	MF/AF-CL-MF/AF
358846	9195460	52	MF/AF-MF/AF-CL
361860	9197758	20	MF/AF-MF/AF-CL
364857	9202468	14	MF/AF-MF/AF-CL
370112	9201461	4	MF/AF-MF/AF-CL
358047	9191896	22	MF/AF-MF/AF-MF/AF
358150	9187004	58	MF/AF-MF/AF-MF/AF
358267	9195408	11	MF/AF-MF/AF-MF/AF

361267	9195388	31	MF/AF-MF/AF-MF/AF
361299	9197168	16	MF/AF-MF/AF-MF/AF
363937	9196880	18	MF/AF-MF/AF-MF/AF
369449	9206022	28	MF/AF-MF/AF-SST
362642	9201094	17	MF/AF-SST-CL
362642	9196168	43	MF/AF-SST-DF
362955	9203866	45	SST-CL-CL
363724	9195616	50	SST-CL-CL
364410	9203374	46	SST-CL-CL
366410	9198394	9	SST-CL-CL
369477	9199706	3	SST-CL-CL
369498	9199841	2	SST-CL-CL
361584	9197766	42	SST-MF/AF-CL
362926	9199820	15	SST-MF/AF-CL
358263	9192482	30	SST-MF/AF-MF/AF
359528	9187876	59	SST-MF/AF-MF/AF
363055	9188018	60	SST-MF/AF-MF/AF
355315	9186258	56	SST-MF/AF-SST
356027	9200572	37	SST-SST-CL
361633	9198420	41	SST-SST-CL
367092	9192040	34	SST-SST-CL
369702	9206406	62	SST-SST-SST

9.3. Land cover change trajectory data between the year 1991 and 2001

Pixel count	Area (ha.)	Cover (%)	Class ID 1991	Class ID 2001	Trajectory of change
20104	1809	8.2	1	1	unchanged DF
13554	1220	5.5	2	1	MF/AF-DF
41217	3710	16.8	2	2	unchanged MF/AF
25860	2327	10.6	3	2	SST-MF/AF
3756	338	1.5	3	1	SST-DF
42576	3832	17.4	3	3	unchanged SST
12103	1089	4.9	1	2	DF-MF/AF
22492	2024	9.2	2	3	MF/AF-SST
14293	1286	5.8	4	3	CL-SST
3811	343	1.6	4	2	CL-MF/AF
717	65	0.3	4	1	CL-DF
2565	231	1.0	1	3	DF-SST
13669	1230	5.6	3	4	SST-CL
15673	1411	6.4	4	4	unchanged CL
11185	1007	4.6	2	4	MF/AF-CL
1302	117	0.5	1	4	DF-CL
	22039	100			

For the both year images, Class ID 1=DF, 2=MF/AF, 3= SST, 4=CL

9.4. Land cover change trajectory data between the year 2001 and 2009

Pixel count	Area (ha.)	Cover (%)	Class ID 2001	Class ID 2009	Trajectory of change
21214	1909	8.7	1	1	unchanged DF
12703	1143	5.2	1	3	DF- MF/AF
51002	4590	20.8	2	3	MF/AF-MF/AF
19134	1722	7.8	2	2	MF/AF-SST
5841	526	2.4	2	1	MF/AF-DF
38608	3475	15.8	3	2	unchanged SST
3228	291	1.3	1	4	DF-CL
7014	631	2.9	2	4	MF/AF-CL
27452	2471	11.2	3	3	SST-MF/AF
986	89	0.4	1	2	DF-SST
15162	1365	6.2	3	4	SST-CL
10214	919	4.2	4	3	CL-MF/AF
25319	2279	10.3	4	4	unchanged CL
6119	551	2.5	4	2	CL-SST
705	63	0.3	3	1	SST-DF
177	16	0.1	4	1	CL-DF
	22039	100.0			

For the year 2009 image, Class ID, 1=DF, 2=SST, 3=MF/AF, 4=CL &
for the year 2001 image, 1= DF, 2=MF/AF, 3=SST, 4=CL

9.5. The final calibration of soil textural class

X	Y	Field texture	Calib_ texture_lab	Soil Type	Final calibration	Degree of correct
362926	9199820	loamy sand	sandy loam	Andosols	sandy loam*	2
369328	9204302	loamy sand	sandy loam	Andosols	sandy loam*	2
366160	9202974	loamy sand	loam	Andosols	sandy loam*	2
364410	9203374	loamy sand	sandy loam	Andosols	sandy loam*	2
365814	9202866	loamy sand	sandy loam	Andosols	sandy loam*	2
366091	9202152	loamy sand	sandy loam	Andosols	sandy loam*	2
369449	9206022	loamy sand	sandy loam	Andosols	sandy loam*	2
369702	9206406	loamy sand	sandy loam	Andosols	sandy loam*	2
361633	9198420	loamy sand	sandy loam	Latosol	silty clay loam**	3
363107	9203114	loamy sand	sandy loam	Latosol	silty clay loam**	3
362955	9203866	loamy sand	sandy loam	Latosol	silty clay loam**	3
358846	9195460	loamy sand	sandy loam	Latosol	silty clay loam**	3
354313	9184268	clay	loam	Latosol	silty clay** loam	2
359528	9187876	loamy sand	sandy loam	Latosol	silty clay loam**	3
363055	9188018	loamy sand	sandy loam	Latosol	silty clay loam	3

357581	9190798	clay	loam	Litosol	clay***	1
369914	9200498	clay loam	clay loam		clay loam	1
369498	9199841	sandy loam	loam		loam	2
369477	9199706	sandy loam	loam		loam	2
370112	9201461	sandy loam	Sandy loam		sandy loam	1
370372	9201940	sandy loam	loam		loam	2
368147	9199328	Sandy clay loam	sandy loam		sandy loam	1
366410	9198394	sandyclay loam	sandy loam		sandy loam	2
368291	9203808	sandy loam	loam		loam	2
364857	9202468	sandy loam	loam		loam	2
363946	9196616	silty clay	silty clay		silty clay	1
361860	9197758	clay loam	clay loam		clay loam	1
357776	9191502	clay	loam		loam	3
371350	9203412	sandy loam	loam		loam	2
365021	9193448	silty clay	silty clay		silty clay	1
363253	9192076	clay loam	clay loam		clay loam	1
367092	9192040	sandy loam	loam		loam	2
356027	9200572	loam	loam		loam	1
358874	9200226	loam	loam		loam	1
361584	9197766	clay loam	clay loam		clay loam	1
362642	9201094	loamy sand	sandy loam		sandy loam	2
371230	9203932	sandy loam	loam		loam	2
363724	9195616	clay loam	clay loam		clay loam	1
364797	9197636	silty clay	silty clay		silty clay	1
356780	9194166	clay	loam		loam	3
370140	9201506	sandy loam	loam		loam	2
366008	9198568	clay loam	clay loam		clay loam	1
361299	9197168	sandy loam	loam		loam	2
362642	9196168	sandy loam	loam		loam	2
358199	9191832	clay loam	clay loam		clay loam	1
358974	9201408	sandy loam	loam		loam	2
357411	9189194	clay loam	clay loam		clay loam	1
360940	9188352	clay loam	clay loam		clay loam	1
369279	9200172	clay loam	clay loam		clay loam	1
358267	9195408	sandy loam	loam		loam	2
369539	9204384	clay loam	clay loam		clay loam	1
363937	9196880	Sandy loam	loam		loam	2
358291	9192020	clay loam	clay loam		clay loam	1
358047	9191896	clay loam	clay loam		clay loam	1
357901	9191188	sandy loam	loam		sandy loam	1
358263	9192482	clay loam	clay loam		clay loam	1
361267	9195388	sandy loam	loam		loam	2
356804	9188654	clay loam	clay		clay	2

357097	9189046	sandy loam	loam		loam	2
355315	9186258	loam	loam		loam	1
358150	9187004	clay loam	clay loam		clay loam	1

Note: * Soil texture calibrated based on the Andosol, ** soil texture calibrated based on the Latosol, *** Soil texture calibrated based on the litosol and 1= 100% correct, 2= partially correct and 3= incorrect

9.6. etail of soil sample parameters

sample ID	LC	Elevation	Slope%	pH	Structure	Texture_final	compaction (kg/cm²)	OM %	Strength (kpa)	color
57	CL	310	0	7	fine	silty clay loam	1.35	1.08	4.67	dark olive brown
56	SST	370	38	6	medium	loam	3.31	2.50	4.33	dark brown
37	CL	1320	50	5	medium	loam	1.5	1.79		strong brown
54	CL	782	15	7	medium	loam	1.91	1.12	2.77	brown
35	MF/AF	525	25	6	medium	clay	0.94	2.39	3.03	dark yellowish brown
55	MF/AF	595	25	7	medium	loam	2.76	1.94	6.20	dark brown
53	DF	630	37	5	medium	clay loam	1.9	1.82	3.13	dark brown
29	MF/AF	670	25	7	coarse	clay	2.75	1.33	5.23	brown
24	CL	605	5	7	fine	loam	1.68	1.07	5.30	gray
25	MF/AF	700	40	5	medium	sandy loam	2.25	2.24	4.13	dark brown
22	MF/AF	712	23	6	medium	clay loam	3.13	1.27	6.23	brown
58	MF/AF	450	25	5	fine	clay loam	2.16	2.08	2.83	very dark grayish brown
23	DF	740	22	6	fine	clay loam	3.5	1.35	6.62	brown
30	MF/AF	740	0	6	fine	clay loam	1.63	1.43	6.17	brown
11	MF/AF	890	41	5	fine	loam	2.24	2.76	4.76	dark yellowish brown
21	MF/AF	730	0	5	coarse	clay loam	4.06	1.14	6.80	dark brown
52	CL	945	52	5	medium	silty clay loam	1.50	2.52	2.87	dark brown
39	CL	1105	0	5	medium	loam	1.50	1.70	4.07	strong brown
40	DF	1220	0	5	medium	loam	2.41	2.18	3.80	dark brown
59	MF/AF	580	35	6	medium	silty clay loam	2.35	1.82	3.87	dark reddish brown
61	DF	705	65	5	coarse	clay loam	3.16	1.64	4.80	dark yellowish brown
31	MF/AF	980	0	5	fine	loam	2.85	2.86	2.90	strong brown
16	DF	1108	12	5	fine	loam	2.85	2.71	6.43	brown
42	CL	1215	58	6	medium	clay loam	1.28	1.87	4.33	reddish brown
41	CL	1210	12	5	medium	silty clay loam	0.75	2.94	2.53	dark yellowish brown
20	CL	1185	60	6	medium	clay loam	1.20	2.39	4.20	dark yellowish brown
17	CL	1072	10	5	fine	sandy loam	1.68	2.76	2.27	brown
43	DF	1350	25	5	medium	loam	2.5	2.78	4.90	very dark brown
15	CL	1150	14	5	fine	sandy loam	0.76	3.40	3.10	dark brown
45	CL	1390	12	5	medium	silty clay loam	2.08	3.49	4.53	very dark brown
60	MF/AF	855	45	7	medium	silty clay loam	2.88	1.71	3.63	dark yellowish brown

44	CL	1380	10	5	medium	silty clay loam	1.46	3.11	3.00	dark brown
33	CL	700	23	6	fine	clay loam	1.20	1.07	4.50	gray
50	CL	1000	12	5	medium	clay loam	2.06	2.10	2.57	yellowish red
18	MF/AF	965	36.5	6	medium	loam	2.16	1.95	3.10	dark yellowish brown
19	CL	920	0	7	fine	silty clay	0.48	1.92	5.73	olive brown & dark gray
46	CL	1390	22	5	medium	sandy loam	1.75	2.67	3.43	brown
51	CL	1040	50	6	coarse	silty clay	2.25	1.13	3.10	brown
14	CL	1320	0	5	fine	loam	1.06	2.97	2.97	dark brown
32	CL	800	24	6	medium	silty clay	1.68	1.05	6.90	gray
47	CL	1383	20	6	medium	sandy loam	0.96	2.60	2.37	very dark brown
10	DF	1045	12.5	5	medium	clay loam	3.00	2.80	3.40	brown
48	CL	1458	0	6	medium	sandy loam	1.75	3.02	3.23	dark reddish brown
36	CL	1400	15	5	medium	sandy loam	1.01	2.33	4.17	dark reddish brown
9	CL	1100	15	7	medium	sandy loam	1.26	2.44	5.28	brown
34	SST	950	30	6	coarse	loam	1.30	1.34	4.50	dark yellowish brown
8	CL	1120	0	5	medium	sandy loam	1.60	2.11	4.05	dark yellowish brown
13	CL	1550	25	5	fine	loam	1.9	3.37	3.20	very dark grayish brown
7	MF/AF	1300	9	7	medium	clay loam	3.10	2.10	5.20	dark yellowish brown
27	CL	1767	0	5	medium	sandy loam	1.83	3.77	3.40	dark brown
28	SST	1912	20	5	medium	sandy loam	2.16	3.64	3.73	dark olive brown
3	CL	1350	38	5	medium	loam	2	1.97	2.73	dark yellowish brown
2	CL	1305	30	5	medium	loam	0.62	2.52	2.88	dark yellowish brown
12	MF/AF	1702	45	5	medium	clay loam	1.9	2.44	5.93	dark yellowish brown
62	SST	2000	35	5	medium	sandy loam	1.73	3.63	2.73	dark reddish brown
1	CL	1378	0	5	fine	clay loam	0.5	2.19	2.32	dark yellowish brown
4	CL	1420	44	5	fine	sandy loam	0.79	3.11	2.52	very dark brown
5	DF	1428	40	5	medium	loam	2.4	2.46	3.30	dark brown
6	CL	1505	0	6	medium	loam	0.75	3.52	1.00	very darkgrayish brown
49	CL	1675	25	5	coarse	loam	1.8	2.04	4.03	reddish brown
26	CL	1602	7	6	fine	loam	0.76	3.51	2.95	dark yellowish brown

9.7. Soil aggregate stability test as per land cover and crop types

X	Y	Land cover	Crop type	Crumb test
371230	9203932	CL	tomato+ cabbage but harvested	class1
363946	9196616	CL	Irrigated rice field	class1
357776	9191502	CL	Irrigated rice field	class1
363253	9192076	CL	irrigated rice field	class1
358874	9200226	CL	cabbage	class1
364410	9203374	CL	maize field	class1
356780	9194166	CL	rainfed rice field	class1

354313	9184268	CL	Irrigated rice field	class1
363107	9203114	CL	tea garden	class1
365021	9193448	CL	maize field	class2
366160	9202974	CL	potato field covered with white plastic sheets	class2
361584	9197766	CL	cabbage seedling's nursery	class2
362642	9201094	CL	vegetable-cabbage	class2
362955	9203866	CL	vegetable-bean	class2
369914	9200498	CL	carrot, tobbaco	class2
369498	9199841	CL	tobbaco	class2
369477	9199706	CL	maize	class2
370112	9201461	CL	maize	class2
368147	9199328	CL	bare	class2
361860	9197758	CL	cabbage field	class2
356027	9200572	CL	maize + sweet potato	class2
366091	9202152	CL	potato ready to harvest	class2
363724	9195616	CL	harvested maize	class2
364797	9197636	CL	maize +vegetables	class2
358846	9195460	CL	maize with banana +some trees	class2
361633	9198420	CL	harvested cabbage+maize	class3
365814	9202866	CL	maize	class3
370372	9201940	CL	potato	class4
364857	9202468	CL	maize	class4
362926	9199820	CL	potato	class4
369328	9204302	CL	potato	class4
366410	9198394	CL	maize	class4
368291	9203808	CL	maize with stump of tea	class4
371350	9203412	CL	potato	class4
358974	9201408	DF	pine plantation	class1
360940	9188352	DF	pine plantation	class1
357411	9189194	DF	Demar species	class2
370140	9201506	DF	Leucaena , Acacia	class2
366008	9198568	DF	pine plantation	class2
358199	9191832	DF	pine plantation	class2
361299	9197168	DF	pine plantation	class3
362642	9196168	DF	pine plantation	class4
358291	9192020	MF/AF	salak with Leucaena species	class1
357581	9190798	MF/AF	salak with Albazia &landslide area	class1
358263	9192482	MF/AF	small salak with Albazia	class1
356804	9188654	MF/AF	salak with Albazia	class1
358150	9187004	MF/AF	more salak & very few Albazia	class1
369279	9200172	MF/AF	mixed treeswith some grass	class2
363937	9196880	MF/AF	salak with Albazia species	class2
358047	9191896	MF/AF	Albazia species only	class2

357097	9189046	MF/AF	more salak & very few Albazia	class2
359528	9187876	MF/AF	more salak & very few Albazia	class2
363055	9188018	MF/AF	salak with Albazia	class2
369539	9204384	MF/AF	mixed species	class3
361267	9195388	MF/AF	Leucaena and bamboo	class3
358267	9195408	MF/AF	Albazia+ Coffee	class4
357901	9191188	MF/AF	salak with Albazia specie	class4
355315	9186258	SST	sparse forest with Durian species	class1
367092	9192040	SST	sparse trees	class2
369702	9206406	SST	shrub with some broad leaved species	class4
369449	9206022	SST	shrub with some Cryptomeria species	class4

9.8. Statistical analysis of soil strength

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
DF	8	36.38	4.55	1.92
SST	4	15.30	3.82	0.64
MF/AF	15	70.02	4.67	1.96
CL	34	120.25	3.54	1.38

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16.44	3	5.48	3.54	0.02	2.77
Within Groups	88.18	57	1.55			
Total	104.61	60				

9.9. Statistical analysis of soil compaction

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
DF	8	21.72	2.72	0.26
SST	4	8.50	2.13	0.75
MF/AF	15	37.16	2.48	0.54
CL	34	46.66	1.37	0.25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.93	3	6.64	19.11	0.00	2.77
Within Groups	19.81	57	0.35			
Total	39.74	60				

9.10. Statistical analysis of OM content

Groups	*Count*	*Sum*	*Average*	*Variance*
DF	8	17.73	2.22	0.31
SST	4	11.10	2.78	1.20
MF/AF	15	29.47	1.96	0.28
CL	34	80.67	2.37	0.67

ANOVA result

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.80	3	0.93	1.68	0.18	2.77
Within Groups	31.70	57	0.56			
Total	34.50	60				

9.11. Canopy cover/ground cover

LC	Canopy cover %
DF	60.625
SST	66.25
MF/AF	78.66667
CL	52.05882
Overall CC mean	64.40012