# PROPOSING AN APPROPRIATE LAND USE BASED ON HYDROLOGICAL ANALYSIS AND IN ACCORDANCE WITH STATE REGULATIONS

## A Case Study of Samin Watershed, Central Java, Indonesia

Thesis submitted to the Double Degree M.Sc. Programme, Gadjah Mada University and International Institute for Geo-Information Science and Earth Observation in partial fulfillment of the requirement for the degree of Master of Science in Geo-Information for Spatial Planning and Risk Management

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# THESIS

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On ... February 2010

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**DISCLAIMER**

This document describes work undertaken as part of a program of study at the Double Degree International Program of Geo-information for Spatial Planning and Disaster Risk Management, a Joint Program of ITC the Netherlands and UGM, Indonesia. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Cahyolestari, Diah P

## ABSTRACT

Samin Watershed has suffered from flood at the end of December 2007. The land cover change in Samin Watershed is mainly caused by both economic and population growth factors. Farmers are likely to plant the commodity, such as sugarcane plant, that has higher economically value than other plants without taking consideration on soil conservation. The second is population growth which needs more room for settlement and farming. The main objective of this research is to develop a land use assessment model for the Samin Watershed to determine the optimum land use types for overland flow (floods) reduction in accordance with state regulations.

In this study, calculation on actual direct surface runoff employs Curve Number Method of US Soil Conservation Service. Data prepared to estimate Curve Numbers are: land cover, soil texture and infiltration rate, daily rainfall data of year 2006, sub-watershed delineation, information on land treatment and/ or practices, and hydrological condition of each land treatment. Sample points for infiltration measurements and soil texture analysis are based on land mapping unit, which has the same land cover and soil type. Runoff depth is calculated for each sub watershed after Curve Numbers are estimated. Estimated runoff using CN Method over Samin Watershed is 52,522,976.33 milimeters.

Method for calculating peak discharge of the watershed uses a synthetic unit hydrographs, used by Soil Conservation Service. The unit hydrograph is determined by factors, i.e. lag time, time to peak, peak discharge, and base time. Watershed characteristics needed are watershed area, maximum length of travel, and watershed's slope. Discharge calculation is performed for each sub-watershed, since the calculation of runoff depth is done on sub-watershed. The value of watershed's discharge comes from the sum of all sub-watersheds' discharge. Discharge calibration with observational data is conducted within several sub-watershed, since there is only one ungauged discharge station located in the midde of Samin Watershed. Estimated peak discharge in the area is 173,951,504.86 $m^3/s$, Compare to observational discharge data 2006, estimated peak discharge is 73,672,172,699.94 litre/second, which 98 times bigger than observational discharge data.

Four land use models are proposed in accordance with state regulations. Models are developed manually, by using different land treatment. Model-1 reduces surface runoff 38% compare to runoff 2006. Model-2 and Model-4 increase runoff up to 28 times than runoff 2006, while Model-3 increase surface runoff until 200%. Among the four models, Model-1 is the most appropriate land use to reduce surface runoff. Converting paddy field into sugarcane plantation has little significance for increasing runoff, except in Ranjing Sub-watershed. In this area, application of Model-1 and Model-4 increases surface runoff, especially in sugarcane coverage.

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# 1. Introduction

## 1.1 Background

According to Powell (in WICC of Napa County, 2005), watershed is *area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of the community*. Watershed can also be viewed as a management system where it obtains input which is then processed to yield output. Thereby watershed is processor from each rainfall and interfered by human being to produce output which in the form of overflow and sediment yield. Output produced reflects the watershed characteristic.

Floods have happened mostly because main river has not been able to receive and store rainfall and for that reason surface runoff occurs. With this consideration, therefore, watershed management is a necessarily action to reduce surface runoff.

One of watershed management's goals is to be able to overcome watershed degradation and various natural disaster problems, like: floods, drought, erosion, sedimentation, degradation of soil productivity, and landslide. Various handlings of watershed degradation had been done since 1976, at national scale program “Inpres" (Reboisation and Plantation), and since 2003 through similar program at national scale is called "National Movement of Forest and Land's Rehabilitation" (Gerhan). But problems of watershed still continue, the degradation is increasingly extended either as of its swampy forest and also frequency. Every natural disaster happened, information soon gets about the effect is generated, but information why the disaster occurred, both at technical and non technical aspects still have not been revealed.

Response of watershed from precipitation becoming runoff along with result of sediment transported, either natural or intervention influence of human being, has different characteristic among watershed. Difference of the characteristic occurs because of climatic factor difference, watershed morphology, vegetation (land use and land cover), soil, geology and cultural-economical-social of watershed's society. Thereby watershed characteristic is totally result interaction or interrelationship between elements of nature resources and human being as base of watershed management, whether planning aspect, organizational/ institutional aspect, implementation, and monitoring and evaluation.

## 1.2 Problem Statement

Naturally an area, which is easily flooded, is characterized by (1) its landform, (2) the existing of river meandering, (3) narrowing river valley, and/ or river junction, (4) slope of river bank is less than 2% (Anonym, 2007). Samin Watershed is part of groundwater depression of Surakarta and has many tributaries. This certain

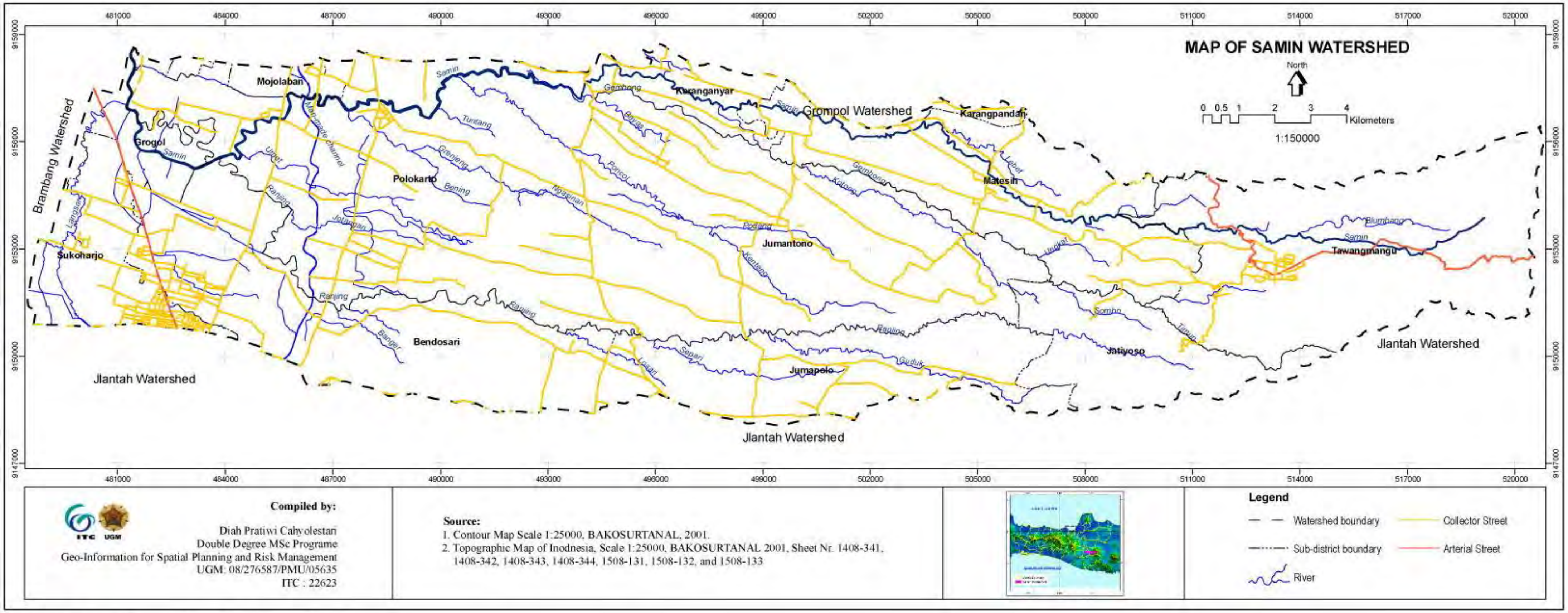



Figure 1.1. Map of Samin Watershed

location makes the area prone to flood whenever a tributary's flow enters main river through the depression.

Samin Watershed has suffered from flood at the end of December 2007. The area is located in two *kabupaten* (district) on Central Java Province, which are Karanganyar and Sukoharjo (see Figure 1). Although mostly Samin River and its tributaries flow through Karanganyar, but the outlet is at Sukoharjo. The area has 31,300 hectares and comprises 12 *kecamatan* (subdistrict) (Watershed Management Center of Solo, 2004). The land cover change in Samin Watershed is mainly caused by both economic and population growth factors. Farmers are likely to plant the commodity, such as sugarcane plant, that has higher economically value than other plants without taking consideration on soil conservation. The second is population growth which needs more room for settlement and farming.

Flood on the downstream of Samin Watershed is hypothetically caused by the effect of land cover change mainly in the upstream. Research about the effect of land cover change to the discharge and flood on the downstream of Samin River have not been conducted yet. This study intends to build land use modeling based on hydrological analysis and in accordance with state regulations.

### 1.3 Research Objectives

The main objective of this research is to develop a land use assessment model for the Samin Watershed to determine the optimum land use types for overland flow (floods) reduction in accordance with state regulations. The detailed research's objectives are described as follows.

1. To identify the actual land cover pattern in the watershed area and to classify land cover on the basis of relevant physical characteristics and land tenure.
2. To calculate actual runoff and discharge.
3. To develop an appropriate land use model in accordance with state regulations.
4. To make a preliminary validation of the thus developed land use model on the basis of existing peak discharge records.

### 1.4 Research Questions

The research questions are presented below:

| Research Objectives | Research Questions |
|---|---|
| 1. To identify actual land cover pattern and to classify land cover. | a. What is the type and density of the current land cover ?<br>b. What is its land tenure ? |
| 2. To calculate an actual runoff and discharge. | a. How is actual runoff based on the Curve Number method of the US Soil Conservation Service?<br>b. How is actual discharge ? |

| | |
|---|---|
| 3. To develop an appropriate land use model in accordance with state regulations. | a. What area best management practices for the area ?<br>b. How to improve actual land use with the selected best management practices ? |
| 4. To make a preliminary validation of the thus developed land use model on the basis of existing peak discharge records. | a. How is runoff after proposing appropriate land use model ?<br>b. How is expected discharge after proposing appropriate land use model ?<br>c. Will the flood still occur when appropriate land use model is applied ? |

# 2. Literature Review

## 2.1. Physical Environment of Watershed Derived from Remotely Sensed Data and Hydrological Response

Linsley, *et.al.* (1975) described a relation between physical environment of watershed and hydrological response. The relation can be used as an approach to predict hydrological response based on physical characteristics of watershed.

Remote sensing techniques can be used to extract data using the approach fisiografik surface physical appearance, because basically remote sensing image illustrates the objects that appear directly on the surface of the earth. In general, objects in the earth's surface will reflect the intensity of electromagnetic waves with different depending on the physical and chemical properties of the material are about energy. Reflections from each object will be received and recorded by the camera sensor. Each object in the image has their own characteristics, commonly referred to spectral characteristics. These characteristic differences caused by the amount of energy absorbed or reflected by objects different. Based on the reflection characteristics, then the objects contained in the digital imagery can be identified.

Digital imagery, both satellite and aerial photographs can be employed to obtain physical characteristics of watershed. The characteristics derived from big-to-medium scale of remotely sensed data are drainage pattern, land cover, landform, and slope.

## 2.2. Hydrological Analysis

Floods have become a social problem since floods occur in medium-to-high populated area. To overcome this problem, it is necessary to study its cause and impacts. Hydrological analysis is one of tools to study floods. The analyses conducted in this research are surface runoff and river discharge at the watershed's outlet.

### 2.2.1. *Prediction of Watershed Runoff*

For watersheds which do not have runoff measurement, the Curve Number Method from United States – Soil Conservation Service can be applied. The method was developed at 1972 and since then is widely used in applied hydrology. The Curve Number Method was developed to be used with daily rainfall data measured with non-recording rain gauges. Factors determining the Curve Number Value are land use, land treatment, hydrological condition, and hydrological soil group (Anonym, 2004).

### 2.2.2. *Runoff Modeling*

Research on watershed scale runoff modeling for flood forecast has been carried out by Kafle, et al (2007). Employing the hydrologic model HEC-HMS to convert the precipitation excess to overland flow and channel runoff, the study was conducted on Bagmati basin in Nepal. The simulation was conducted in June to September 2004. Estimated hydrograph was calibrated against observed one and the model parameters were manually optimized for good simulation. The predicted peak discharge, using rain gauge data, was close to the observed value and the smaller discharges followed the observed trend. Spatial variation in the runoff response of the watershed is a consideration to build model framework. Consequently Curve Numbers is used on a basis of soil type, land use and spatial distribution of rainfall over the whole watershed.

Another research about rainfall-runoff modeling system, especially a semi-distributed one, has conducted by Crooks and Naden (2007). The study explained the development of a semi-distributed rainfall-runoff model, to simulate impacts land-use change effects on flood frequency. The model requires modules for soil moisture balance, drainage response and channel routing. The model is grid-based to allow GIS analysis obtained data sets into the initialisation of parameter values. Runoff's watershed is calculated first on components aggregation of flow within each grid square and then total routed flow from all grid squares. Calibration is performed sequentially for the three modules using different objective functions for each stage.

A study using semi-distributed approach to rainfall-runoff modeling was also done by Kokkonen, *et al* in 2001. This study presents a methodology considering areas of variable characteristics within a catchment. The rainfall-runoff modeling technique is based on dividing a catchment into hydrologically similar units (HSUs). HUSs, have differences in land use, slope, soil and vegetation. These units are characterised by typical cross-sections derived from the available data. The total runoff is routed through the channel network by using a linear reservoir. Calibration is conducted by comparing to observational flow data at the outlet.

In 2002, Jasrotia, et al studied rainfall-runoff modeling using remote sensing and GIS technique. The study area is Tons Watershed, India. In this research, the rainfall-runoff relationship is determined using USDA Soil Conservation Service (SCS) method. There is a high correlation between rainfall and runoff in this study. The runoff potential map was prepared by giving individual class weight and scores input map. Moreover the landuse has open forest, which does not decrease rainfall effects.

## 2.3 Appropriate Land Use in accordance with State Regulations

On hydrological aspect, watershed management is conducted to manage bio-physiography of earth's surface, in such a way that a maximum water yield is obtained, and there is an optimum flow regime which is distributed evenly throughout the year (Siswoyo, 2003).

Related to watershed management, which will be more concern on forested area and other agricultural coverages, it is necessary to pay attention on three basic elements, i.e. land, water/ stream, and management. The land elements consist of overall components form certain geographical or atmospheric unit, water, soil, lithology, vegetation and animal, also people with their activities.

In order to achieve optimum condition of water yield, factors which can be modified within watershed management are (Siswoyo, 2003):

1. Land use and vegetation types;
2. Relief and slope;
3. Soil fertility on certain threshold of soil's physical properties.

There have been many state regulations concerning to overcome land degradation, such as:

1. Law of The Republic of Indonesia Nr. 23 year 1997 concerning Environmental Management;
2. Law of The Republic of Indonesia Nr. 41 year 1999 concerning Forestry;
3. Government Regulation of The Republic of Indonesia Nr. 76 year 2008 concerning Forest Rehabilitation and Reclamation;
4. Regulation of Ministry of Forestry of The Republic of Indonesia Nr. P.32/Menhut-II/2009 concerning Guidelines on Technical Planning of Land and Forest's Rehabilitation of Watershed.

In terms of water management, a watershed is in good condition when observed hydrological parameters on watershed's outlet indicate trends such as (Siswoyo, 2003):

1. Comparison between monthly maximum discharge (Qmax) and monthly minimum discharge (Qmin) within a year, it is a tendency to decrease.
2. Main elements of unit hydrograph show (a) a longer time to peak ($t_p$), (b) a longer time base ($T_b$), and (c) a decreasing peak discharge ($Q_p$).
3. An increasing volume of base flow.
4. A decreasing shortly runoff and annual runoff.

Based on method of unit hydrograph, output of watershed which can be optimized is hydrograph pattern (Siswoyo, 2003). This pattern characterizes bio-physical nature of the watershed. By applying land use modeling on the basis of theory of unit hydrograph synthetic of US SCS, it can be determined an appropriate land use. This model can support watershed preservation.

# 3. STUDY AREA AND RESEARCH METHODS

## 3.1. Study Area

Based on Topographic Map of Indonesia, scale 1:25000, published by BAKOSURTANAL 2001, sheet 1408-341, 1408-342, 1408-343, 1408-344, 1508-131, 1508-132, and 1508-133; Samin watershed is geographically located between latitude 7.597° to 7.707° S and longitude 110.801° to 111.189° E. The watershed is existed on two district in Central Java Province, i.e Sukoharjo and Karanganyar. This area consists of 12 sub-districts, which is 5 sub-districts in Sukoharjo (Sukoharjo, Grogol, Mojolaban, Polokarto, and Bendosari) and 7 sub-districts in Karanganyar (Karanganyar, Jumantono, Jumapolo, Karangpandan, Matesih, Jatiyoso, and Tawangmangu). The drainage map and also administrative provision is presented in Figure 1.1. Overall area of Samin Watershed is about 31,345 hectares.

Geological environment straightly impacts to nature of water resources that will affect generally natural resources. According to van Bemmelen's geological zonation, Samin watershed is mostly placed on Solo Depresion Zone. The depresion has filled with Lawu Vulcan's deposits. Therefore, the area generally has a deep and fertile soil. Based on Geological Map of the Ponorogo Quadrangle, Jawa, scale 1:10000, published by Geological Research and Development Centre 1997, lithology of Samin watershed comprises 9 formations. For clearly illustration, geological map of the area is shown in Figure 3.1, and area of each lithology formation is presented in Table 3.1.

Table 3.1. Lithology distribution on Samin Watershed

| Nr. | Geological Type | Area (hectares) | Area (%) |
|---|---|---|---|
| 1 | Alluvium | 5,798.97 | 18.50 |
| 2 | Andesite | 164.14 | 0.52 |
| 3 | Candradimuka Lava | 374.40 | 1.19 |
| 4 | Jobolarangan Breccia | 85.24 | 0.27 |
| 5 | Jobolarangan Lava | 12.72 | 0.04 |
| 6 | Lawu Lahar | 20,154.29 | 64.30 |
| 7 | Lawu volcanic rock | 2,434.18 | 7.77 |
| 8 | Sidoramping lava | 2,154.43 | 6.87 |
| 9 | Wonosari Formation | 166.48 | 0.53 |
| | Total | 31,344.85 | 100.00 |

Source: GIS computation of digital Geological Map, 2009.

Table 3.1 shows that most of Samin watershed's lithology consist of Lawu lahar, which its lithology is andesite.

Landform is an earth surface formation as a result of shape changing of earth surface by geomorphological processes at the surface. Landform division at the study area is generated from information on height, and lithology of the area. Samin Watershed consists of 13 landforms, as shown in Figure 3.2, and Table 3.2 points up area for each landform division.

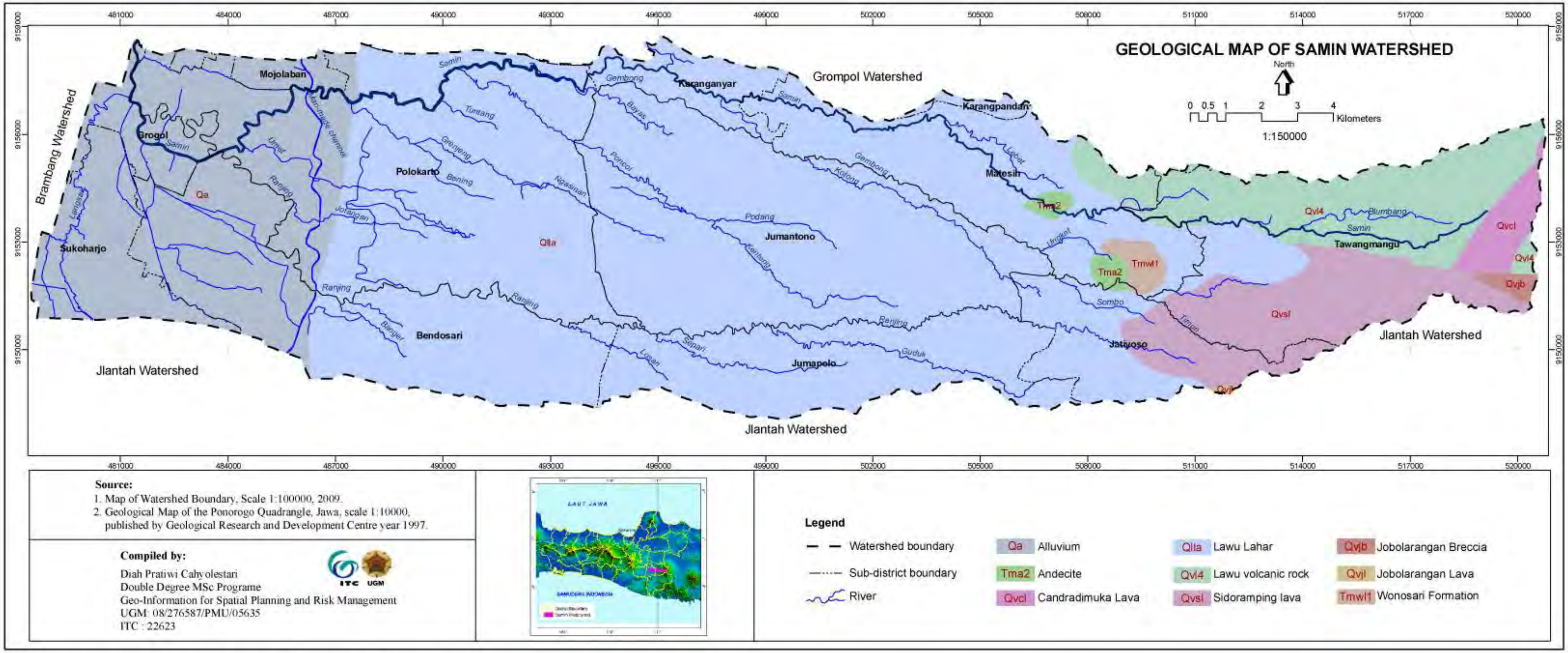



Figure 3.1. Geological Map of Samin Watershed

Table 3.2. Landform distribution of Samin Watershed

| Nr. | LANDFORM | AREA (hectares) | AREA (%) |
|---|---|---|---|
| 1 | Alluvium Plain | 6,983.29 | 22.28 |
| 2 | Andecitic Vulcano Neck | 174.42 | 0.56 |
| 3 | Dissected Lawu Cone and Upper Slope | 223.23 | 0.71 |
| 4 | Dissected Lawu Lower Slope | 779.69 | 2.49 |
| 5 | Dissected Lawu Middle Slope | 1,067.59 | 3.41 |
| 6 | Dissected Sidoramping Middle Slope | 2,724.93 | 8.69 |
| 7 | High Relief Dissected Sidoramping Foot Slope | 5,638.38 | 17.99 |
| 8 | High Relief Dissected Sidoramping Lava | 947.73 | 3.02 |
| 9 | Hilly Sidoramping Lava | 822.11 | 2.62 |
| 10 | Limestone Hill | 115.45 | 0.37 |
| 11 | Low Relief Dissected Sidoramping Lava | 1,128.57 | 3.60 |
| 12 | Low Relief Disssected Sidoramping Foot Slope | 9,826.98 | 31.35 |
| 13 | Undulating Topography of Lawu Lahar | 912.44 | 2.91 |
| | Total | 31,344.85 | 100.00 |

Source: GIS computation of digital Landform Map, 2009.

Landform of low relief dissected Sidoramping foot slope covers mostly of Samin Watershed. Geological type developing this landform is combination of Sidoramping Lava and Lawu Lahar.

Soil distribution of Samin Watershed is presented in Figure 3.3. Soil map is derived from soil map small scale of 1:250000 from Soil and Agroclimate Research Center 2000. For soil distribution, Table 3 shows area for every soil type.

Table 3.3. Soil distribution of Samin Watershed

| Nr. | SOIL | Area (hectares) | Area (%) |
|---|---|---|---|
| 1 | Brown Andosol and Litosol | 679.35 | 2.17 |
| 2 | Brown Latosol | 3,594.33 | 11.47 |
| 3 | Brown Mediteranean | 1,195.62 | 3.81 |
| 4 | Dark Grey Grumusol | 2,220.57 | 7.08 |
| 5 | Dark Grey Grumusol and Reddish Brown Mediteranean | 6,318.68 | 20.16 |
| 6 | Greyish Brown Alluvium | 4,758.45 | 15.18 |
| 7 | Reddish Brown Latosol | 6,491.87 | 20.71 |
| 8 | Reddish Brown Mediteranean | 4,742.99 | 15.13 |
| 9 | Yellowish Brown Andosol | 1,342.99 | 4.28 |
| | Total | 31,344.85 | 100.00 |

Source: GIS computation of digital Soil Map, 2009.

It shows in Table 3.3 that soil type type of Latosol and association of Grumusol and Mediteranean are soil type majority for the watershed. It also located in landform of low relief dissected Sidoramping foot slope.

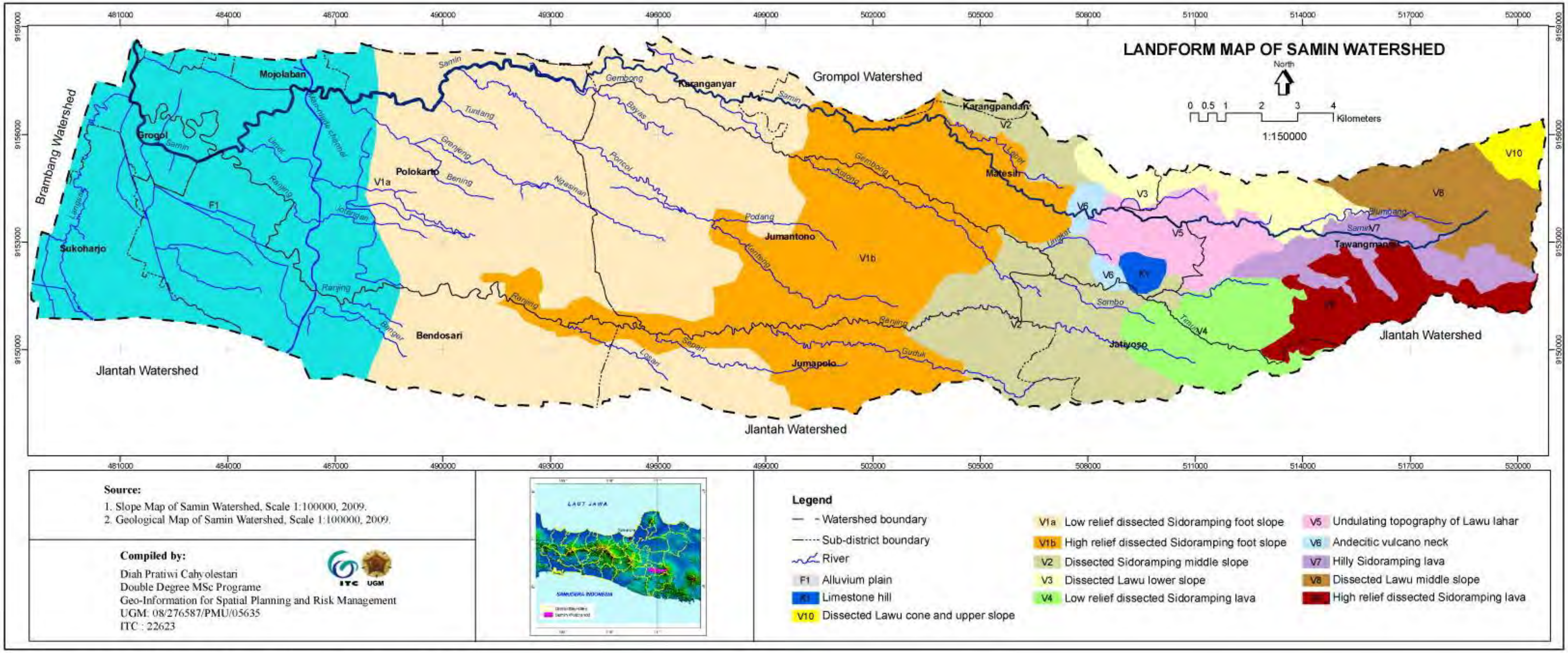



Figure 3.2. Landform Map of Samin Watershed

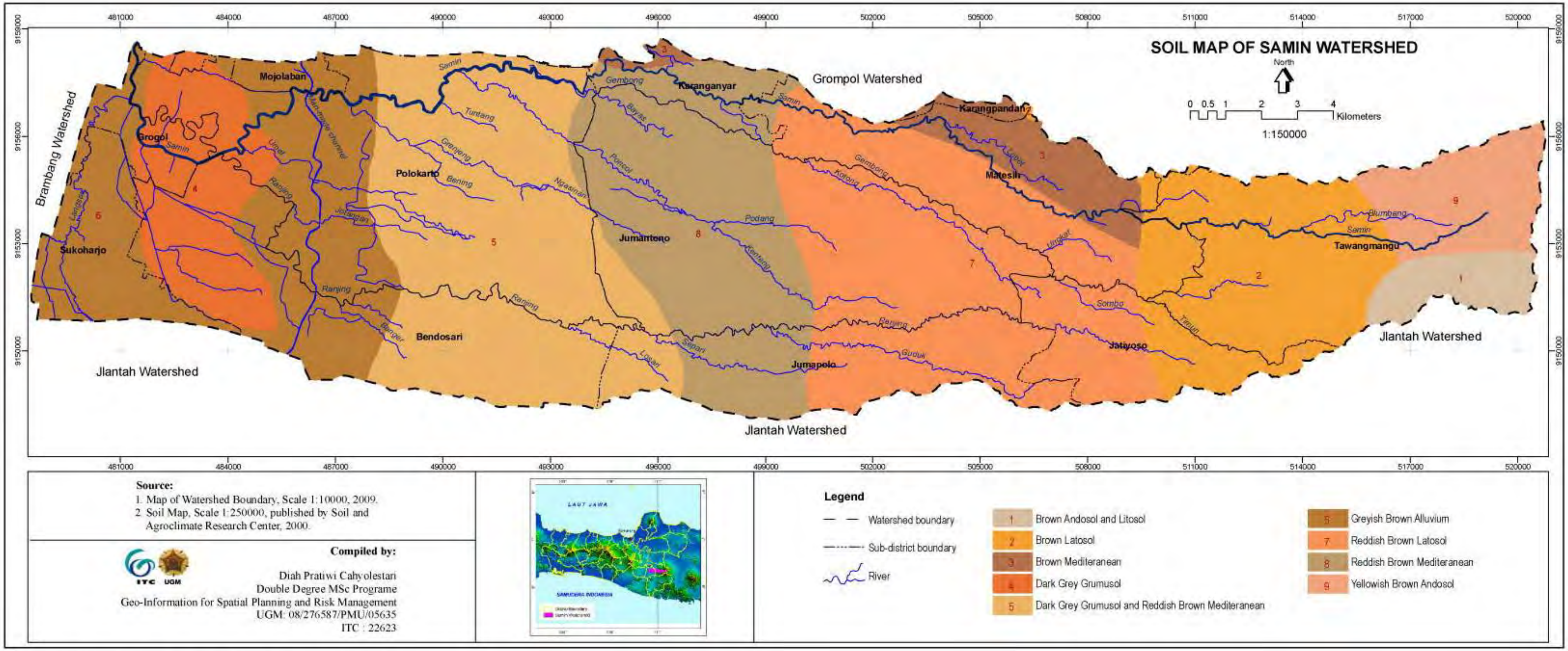



Figure 3.3. Soil Map of Samin Watershed

To get clearly description about slope of the watershed, Figure 3.4 and Table 3.4 illustrates slope distribution of Samin Watershed. Slope classification is based on Arsyad's Classification of 1989. Samin Watershed is mostly flat area, shown as slope of 0% to 3%.

Table 3.4. Slope distribution of Samin Watershed

| Nr. | SLOPE | | AREA | |
|---|---|---|---|---|
| | Class | Name | (hectares) | (%) |
| 1 | 0% - 3% | Flat | 13,999.65 | 44.66 |
| 2 | > 3% - 8% | Gently sloping | 6,463.00 | 20.62 |
| 3 | > 8% - 15% | Undulating | 3,621.55 | 11.55 |
| 4 | > 15% - 30% | Tilted slightly hilly | 3,740.81 | 11.93 |
| 5 | > 30% - 45% | Slightly steep | 1,929.16 | 6.15 |
| 6 | > 45% - 65% | Steep | 1,032.34 | 3.29 |
| 7 | > 65% | Extremely steep | 558.35 | 1.78 |
| | Total | | 31,344.85 | 100.00 |

Source: GIS computation of digital Slope Map, 2009.

For overall picture, Samin Watershed is mostly located in the landform developed by Lawu Vulcan's deposits, soil type predominantly of Latosol and association Grumusol and Mediteranean, and in flat areas. Combine with a great number of river tributaries, the area is prone to be inundated area whenever one event of rainfall in long duration occurs.

## 3.2. Research Methods

This research has methods to answer the research question. Overall research method is illustrated in Figure 3.5. Those methods are described below.

### 3.2.1. *Identification Actual Land Cover and the Classification in accordance with Land Tenure*

Actual land cover is generated from extracting information of remotely sensed images. Those images are recorded in digital form and then apply digital image processing.

A digital image processing comprises image restoration, image enhancement and image classification (Sabins, 1996). Image restoration is employed to make up for data errors, noise and geometric distortions introduced during the scanning, recording, and playback operations. Image enhancement is necessary to adjust the visual impact that the image's character improving the information content. Image classification is done to utilize the decision-making capability of the computer for recognizing and classifying pixels based on their digital signatures.

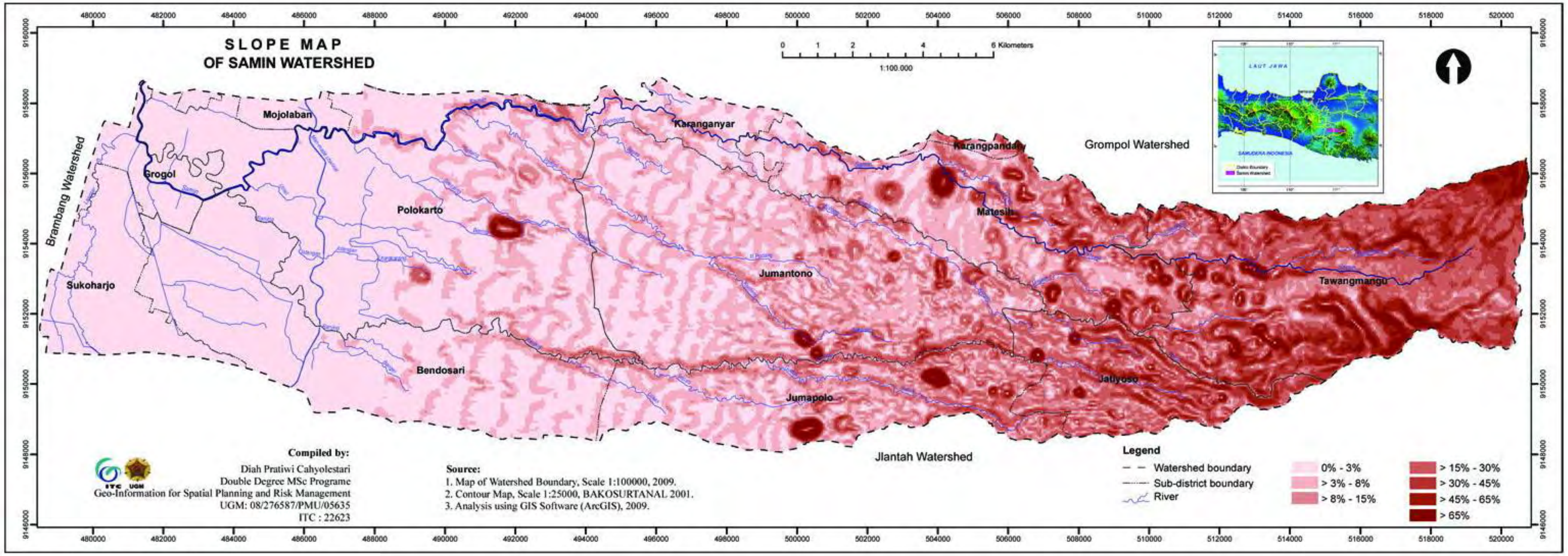


Figure 3.4 Slope Map of Samin Watershed

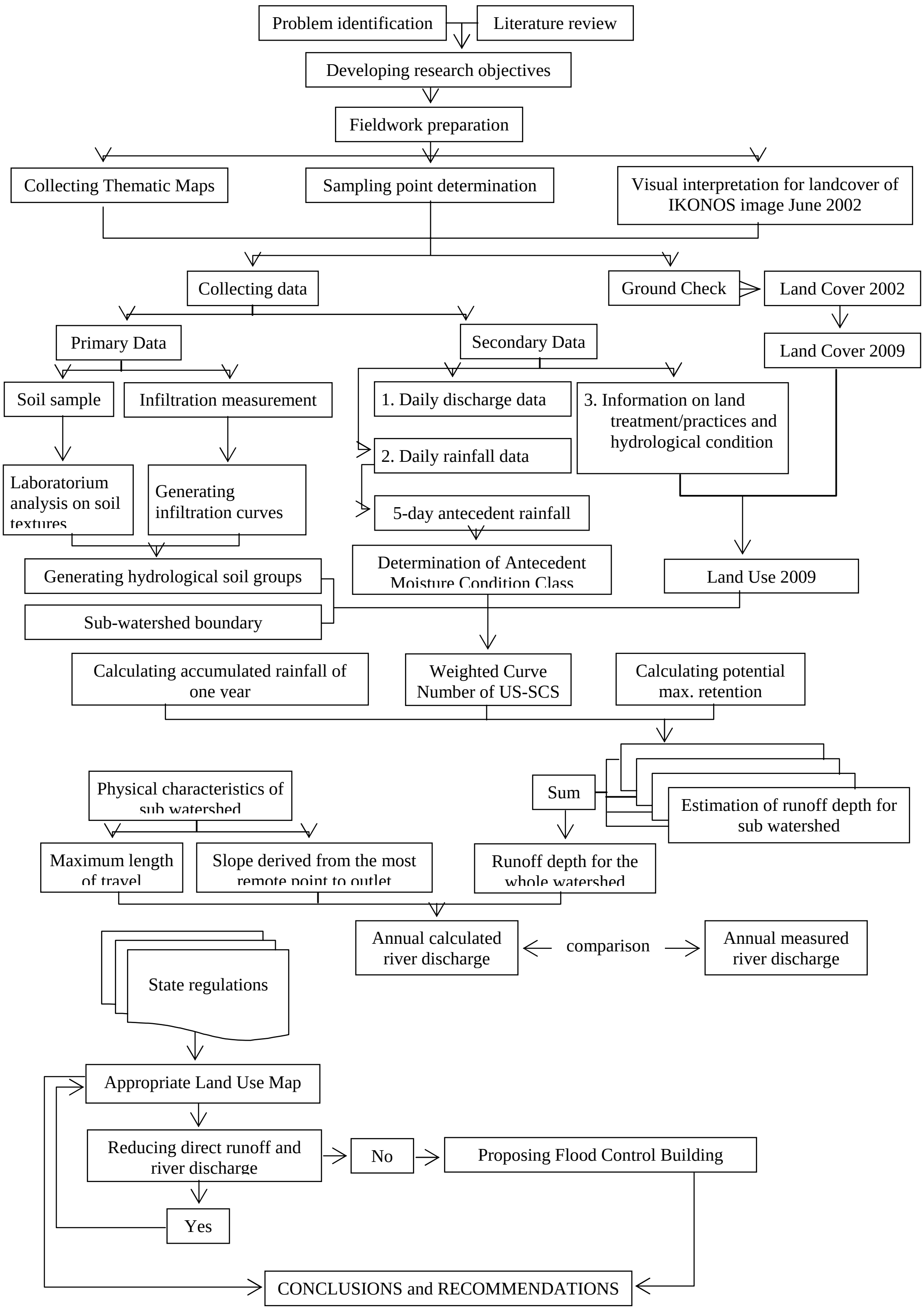



Figure 3.5. Flow chart used for the research approach.

Image classification is conducted on the basis of land use/ land cover classification from Ministry of Forestry of Indonesia. The classification is divided into two big groups, i.e. area with forest coverage and area without forest coverage. A detailed land cover classification is presented as follow.

| Area with forest coverage | Area without forest coverage |
|---|---|
| - Dryland forest<br>- Rubber plantation | - Sugarcane plantation<br>- Settlement area<br>- Mix garden<br>- Paddy field<br>- Fruit and vegetable agricultural |

Source: Ministry of Forestry of Indonesia, 2006 with modification.

Consideration on land tenure is taken since the analysis is divided into forest state area, private plantation area, and property area. The information is collected from authority of districts within the study area and land tenure map is shown in Figure 3.6. From the map, using GIS analysis, the proportion of plantation area is 3%, state forest covers 8%, and property area is 89% of the watershed. The plantation area covers only rubber plantation, managed by a private company.

### 3.2.2 *Calculating Actual Direct Runoff*

In this study, calculation on actual direct surface runoff employs Curve Number Method of US Soil Conservation Service. The curve number (CN) is derived from a function of soil and land use characteristics of the watershed. Beside these two characteristics, other hydrologic condition of the basin such as the vegetal cover is important factor in CN estimation.

Data prepared to estimate curve number value are: land cover, soil texture and infiltration rate, daily rainfall data, sub-watershed delineation, information on land treatment and/ or practices, and hydrological condition of each land treatment. Some data is collected as primary data, such as infiltration rate and soil samples. Land cover is derived from image interpretation. During fieldwork, daily rainfall data and information on land treatment and hydrological condition are collected.

Sample points taken during fieldwork are based on land mapping unit. The unit has the same land cover and soil type. On each land unit, soil samples are taken and are analyzed at soil laboratory to get texture information. Infiltration rate is also measured on each land unit, using both single and double-ring infiltrometer. Afterwards, result of soil texture analysis combining with infiltration data is inputed on each land mapping unit to generate hydrological soil groups. The groups are met to hydrological soil groups from US SCS as presented on Table 3.5.

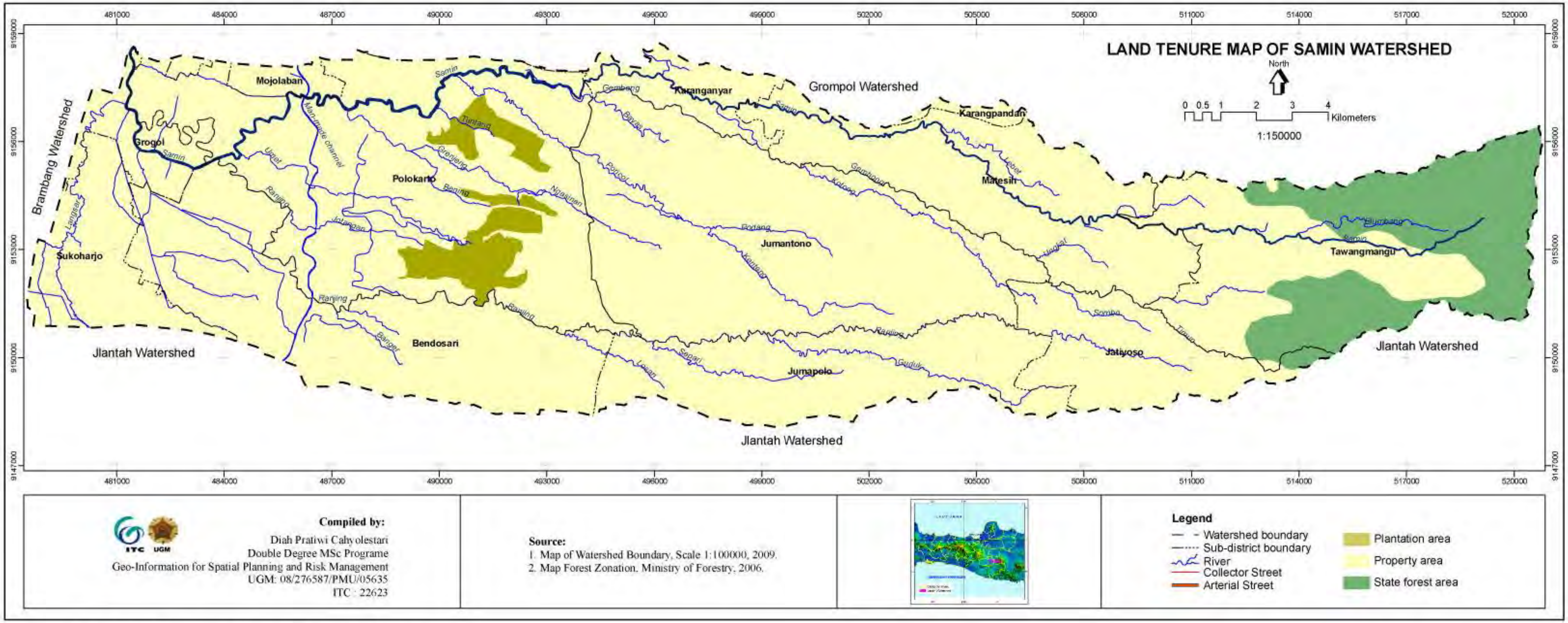



Figure 3.6. Land Tenure Map of Samin Watershed

Table 3.5. Hydrological Soil Groups

| | |
|---|---|
| Group A | Soils having high infiltration rates even when thoroughly wetted and a high rate of water transmission. Examples are deep, well to excessively drained sands or gravels. |
| Group B | Soils having moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. Examples are moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. |
| Group C | Soils having low infiltration rates when thoroughly wetted and a low rate of water transmission. Examples are soils with a layer that impedes the downward movement of water or soils of moderately fine to fine texture. |
| Group D | Soils having very low infiltration rates when thoroughly wetted and a very low rate of water transmission. Examples are clay soils with a high swelling potential, soils with a permanently high watertable, soils with a clay pan or clay layer at or near the surface, or shallow soils over nearly impervious material. |

Source: Anonym, 2004.

An actual land cover is reclassified to meet land use classification of US-SCS. Reclassification is conducted based on land cover classification of cultivated area, land treatment and/ or practices, and hydrological condition. Table 3.6 shows land cover reclassification to meet land use classification of CN method.

Table 3.6. Land use reclassification in relation to land treatment

| Nr. | Land Cover | | Land Treatment/ Management | Hydrological Condition | |
|---|---|---|---|---|---|
| | from image interpretation | US-SCS Classification | | Class | Explanation |
| 1 | Reservoir | Reservoir | - | - | - |
| 2 | Forest | Woodlands | - | Good | Protected from grazing so that litter and shrubs cover the soil |
| 3 | Rubber plantation | Woodlands | - | Fair | Grazed but not burned; there may be some litter |
| 4 | Mix garden | Farm woodlots | - | Fair | Grazed but not burned; there may be some litter |
| 5 | Paddy field | Small grains | Contoured and terraced | Poor | Contain a high proportion of row crops, small grains and fallow |
| 6 | Sugarcane plantation | Rotational meadow | Contoured | Poor | Heavily grazed or having plant cover on less than 50% of the area |
| 7 | Fruit and vegetable agricultural | Row crops | Straight row | Poor | Contain a high proportion of row crops, small grains and fallow |
| | | | Contoured | Poor | Contain a high proportion of row crops, small grains and fallow |
| 8 | Settlement | Farmsteads | - | - | - |

Source: Anonym, 2004, with modification.

Curve Numbers determination is conducted on each sub-watershed. Delineation of sub-watershed is done manually, based on contour lines. Afterwards, a hydrological soil-cover complex map is generated by overlaying landuse reclassification and hydrological soil groups. Table 3.7 show a list of Curve

Numbers for Hydrological Soil-Cover Complexes for Antecedent Moisture Condition II.

Table 3.7. Curve Numbers for Hydrological Soil-Cover Complexes for Antecedent Moisture Condition Class II.

| Nr. | Land Cover | Land Treatment/ Management | Hydrological Condition | Hydrological Soil Groups | | | |
|---|---|---|---|---|---|---|---|
| | | | | A | B | C | D |
| 1 | Reservoir | - | - | 0 | 5 | 8 | 10 |
| 2 | Woodlands | - | Good | 25 | 55 | 70 | 77 |
| 3 | Woodlands | - | Fair | 36 | 60 | 73 | 79 |
| 4 | Farm woodlots | - | Fair | 36 | 60 | 73 | 79 |
| 5 | Small grains | Contoured and terraced | Poor | 61 | 72 | 79 | 82 |
| 6 | Rotational meadow | Contoured | Poor | 64 | 75 | 83 | 85 |
| 7 | Row crops | Straight row | Poor | 72 | 81 | 88 | 91 |
| | | Contoured | Poor | 70 | 79 | 81 | 88 |
| 8 | Farmsteads | - | - | 59 | 74 | 82 | 86 |

Source: Anonym, 2004, with modification.

Daily rainfall data for one year is used to determine 5-day antecedent rainfall. The average value of 5-day antecedent rainfall is met with Table 3.8. The table is employed to determine which Antecedent Moisture Condition (AMC) Class is the most appropriate for Samin Watershed.

Table 3.8. Rainfall limit for AMC Classes based on SCS Method

| Antecedent Moisture Condition Class | 5-day antecedent rainfall (mm) |
|---|---|
| I | < 23 |
| II | 23 – 40 |
| III | > 40 |

Source: Anonym, 2004.

Once AMC is determined, a conversion of Curve Numbers is set up. Table 3.9 presents a conversion table for Curve Numbers from AMC Class II to AMC Class I or Class III. A weighted Curve Number value is derived with regards to sub watershed. It means each Curve Number's value converted is multiply to area of each hydrological soil-cover complexes divided by area of sub watershed.

After weighted Curve Numbers is established, runoff depth is calculated for each sub watershed using the equation as follows.

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad \text{with} \quad I_a = 0.2\,S \quad \text{and} \quad S_{(mm)} = \frac{25400}{weighted\ CN} - 254$$

where Q (mm) is accumulated runoff depth, P (mm) is accumulated rainfall depth for one year, I (mm) is initial abstraction and S (mm) is potential maximum retention. Runoff calculation of the whole Samin Watershed is obtained from the sum of sub watersheds' runoff.

Table 3.9. Conversion for CN from AMC Class II to Class I or Class III

| CN AMC II | CN AMC I | CN AMC III | CN AMC II | CN AMC I | CN AMC III |
|---|---|---|---|---|---|
| 100 | 100 | 100 | 58 | 38 | 76 |
| 98 | 94 | 99 | 56 | 36 | 75 |
| 96 | 89 | 99 | 54 | 34 | 73 |
| 94 | 85 | 98 | 52 | 32 | 71 |
| 92 | 81 | 97 | 50 | 31 | 70 |
| 90 | 78 | 96 | 48 | 29 | 68 |
| 88 | 75 | 95 | 46 | 27 | 66 |
| 86 | 72 | 94 | 44 | 25 | 64 |
| 84 | 68 | 93 | 42 | 24 | 62 |
| 82 | 66 | 92 | 40 | 22 | 60 |
| 80 | 63 | 91 | 38 | 21 | 58 |
| 78 | 60 | 90 | 36 | 19 | 56 |
| 76 | 58 | 89 | 34 | 18 | 54 |
| 74 | 55 | 88 | 32 | 16 | 52 |
| 72 | 53 | 86 | 30 | 15 | 50 |
| 70 | 51 | 85 | 25 | 12 | 43 |
| 68 | 48 | 84 | 20 | 9 | 37 |
| 66 | 46 | 82 | 15 | 6 | 30 |
| 64 | 44 | 81 | 10 | 4 | 22 |
| 62 | 42 | 79 | 5 | 2 | 13 |
| 60 | 40 | 78 | 0 | 0 | 0 |

Source: Anonym, 2004.

### 3.2.3 *Calculating Actual Peak Discharge*

Method for calculating peak discharge of the watershed uses a synthetic unit hydrographs. This method is generally applied on watershed where no runoff has been measured, due to zero existence of automatic rainfall and discharge data.

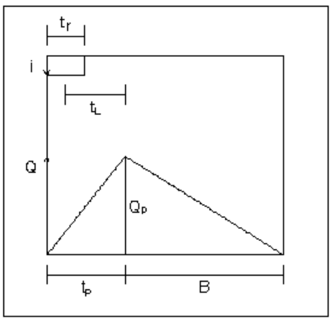



Figure 3.7. SCS Triangular Unit Hydrograph

One of synthetic unit hydrographs (HSS) is one which has been used by Soil Conservation Service, U.S. Department of Agriculture (USDA-SCS), developed by Mockus in 1957 (Anonym, 2004). The hydrograph uses watershed parameter, such as land use, land treatment, hydrological condition, hydrological soil group, and antecedent soil moisture condition in the watershed. The HSS-US SCS is presented simply by developing a triangle with time to peak is faster than time of fall. Figure 3.7 shows this triangle.

US SCS built formulas up by empirical coefficients which connect elements of unit hydrograph and watershed characteristics. The unit hydrograph is determined by factors, i.e. lag time, time to peak, peak discharge, and base time. Watershed characteristics needed are watershed area (A), maximum length of travel (L), and watershed's slope (S). The slope value is derived from a difference of elevation between the most remote point in the watershed and the outlet (H) divided by maximum length of travel (L). The characteristics of watershed are required to considerate because those characteristics are used to estimate time of concentration.

An equation to calculate peak discharge of the HSS-US SCS is described as follows (Anonym, 2004).

$$q_p = 0.208 \frac{A\,Q}{T_p} \quad \text{with} \quad T_p = 0.7\,T_c$$

where $q_p$ is peak discharge unit hydrograph (m³/s), A is area of watershed (sq.km), Q is runoff depth, $T_p$ is time to peak (hour), and $T_c$ is time of concentration.

Time of concentration is defined as the time for runoff to travel from the most remote point in such a watershed to its outlet. In 1940, Kirpich has developed a formula to derive value of time of concentration ($T_c$). The formula is obtained from the physical characteristics of watershed, i.e maximum length of travel and slope of watershed. The formula is given below (Anonym, 2004).

$$T_c = 0.02\,L^{0.77}\,S^{-0.385}$$

Where $T_c$ = time of concentration (minute)
L = maximum length of travel (m)
S = slope, equal to H/L with H is the difference elevation between the most remote point in watershed and the outlet.

Discharge calculation is performed for each sub-watershed, since the calculation of runoff depth is done on sub-watershed. The value of watershed's discharge comes from the sum of all sub-watersheds' discharge.

As a calculated discharge is determined, the value is compared to a measured annual discharge data. Samin Watershed has only one ungauged discharge station, which is located in the middle of the watershed (Figure 3.8). Therefore, a comparison is only conducted between parts of Samin Watershed.

### 3.2.4. *Developing Land Cover Model in accordance with State Regulations*

Appropriate land cover model is proposed in this research since the change of land use/ land cover recently has tendency to increase surface runoff. This trend is responded by government, both central and local government, by establishing state regulations.

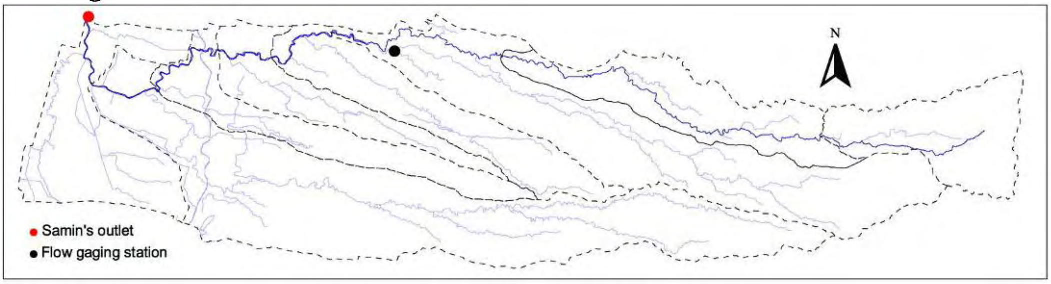



Figure 3.8. Samin Watershed with ungauged discharge station

A model of land use/ land cover is produced within consideration on appropriate land management. Since most part of the watershed is owned by local people, an appropriate land management is offered to meet community's need within consideration of sustainable utilization. Locations of such a kind of appropriate land use/ land cover model are in accordance with state regulations.

### 3.2.5. *Analysis on the Effect of Applying Land Cover Model to Control Floods*

Some models are built to find the best management practices over the area. Analysis is conducted for each Sub-watershed within Samin Watershed. Estimated runoff and peak discharge after applying models are compared to estimated runoff and peak discharge for actual land cover. If model's application cannot reduce surface, then flood control build is proposed to overcome overland flow.

## 4. Land Use and Land Tenure of Samin Watershed

4.1. <u>Land Use</u>

Ikonos image of June 2002 is used to extract land cover information of 2002. Visual interpretation is conducted to interprete different color and texture on the image. Figure 4.1 and 4.2 shows examples on how to differentiate color and texture into different land cover. Land cover map of year 2002 is, then, presented in Figure 4.3.


Figure 4.1. Example of visual interpretation on settlement, forest, sugarcane plantation, dry field agricultural and shrub/ bush.

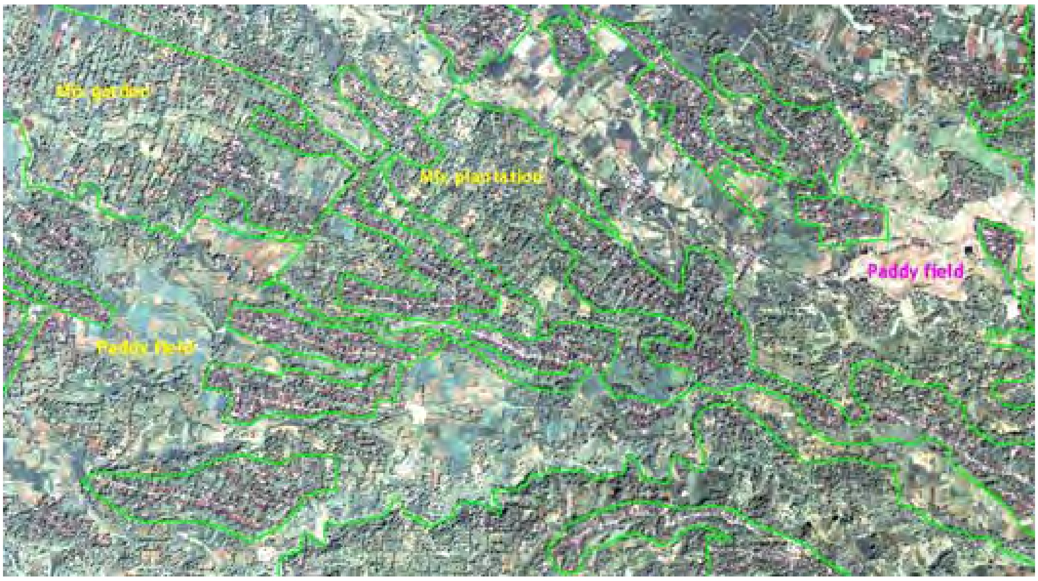



Figure 4.2. Example of visual interpretation on paddy field, mix garden and mix plantation.

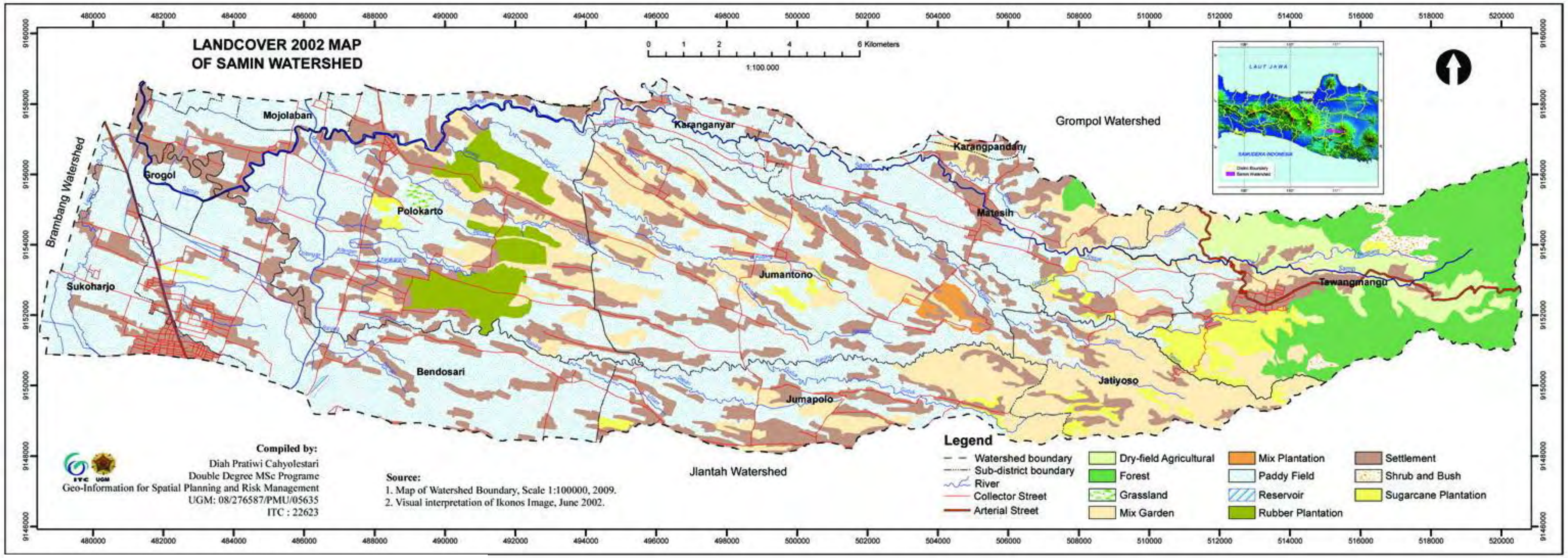


Figure 4.3 Landuse 2002 Map of Samin Watershed

Groundcheck is conducted on August to October 2009. Land cover 2009 based on groundcheck is mapped, as shown in Figure 4.4. There are land cover changes between year 2002 and 2009. Table 4.1 presents land use changes between 2002 and 2009.

Tabel 4.1 Area of each land use 2002 and 2009 and their changes

| Nr. | LANDCOVER | AREA | | | |
|---|---|---|---|---|---|
| | | 2002 | | 2009 | |
| | | (hectares) | (%) | (hectares) | (%) |
| 1 | Dry-field Agricultural | 895.36 | 2.86 | - | - |
| 2 | Forest | 2,097.84 | 6.69 | 2,291.94 | 7.31 |
| 3 | Grassland | 74.75 | 0.24 | - | - |
| 4 | Mix Garden | 4,479.53 | 14.29 | 4,015.38 | 12.81 |
| 5 | Mix Plantation | 98.91 | 0.32 | - | - |
| 6 | Paddy Field | 15,428.50 | 49.22 | 13,787.84 | 43.99 |
| 7 | Reservoir | 13.27 | 0.04 | 16.60 | 0.05 |
| 8 | Rubber Plantation | 805.76 | 2.57 | 836.36 | 2.67 |
| 9 | Settlement | 6,485.00 | 20.69 | 4,320.24 | 13.78 |
| 10 | Shrub and Bush | 189.00 | 0.60 | - | - |
| 11 | Sugarcane Plantation | 776.94 | 2.48 | 5,076.40 | 16.20 |
| 12 | Fruit and Vegetable Agricultural | - | - | 1,000.10 | 3.19 |
| | Total | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: GIS computation of digital map of Landcover 2002 and 2009.

There are some changes regarding to land cover between 2002 and 2009. Sugarcane plantation changes significantly more than any other land cover type, i.e from 2.48% of total watershed into 16.20% of total area. According to local farmers, sugarcane has begun to be planted largely since 2003 because of high economic value. Land cover in 2002 interpreted as grassland changes into sugarcane plantation. Mix garden and mix plantation is differentiated in classification of land cover 2002. Mix gardens are farmers' land planted of both fruit trees and wooden trees, whilst mix plantation's exixtence started from government effort to reduce land degradation. Local farmers were asked to exclude part of his land to plant trees, both fruit trees and wooden trees, given by government. After six years, those tress have grown, so there is no differentiation between mix garden and mix plantation. Figure 4.5 presents various land cover actual verified during groundcheck on August to October 2009.

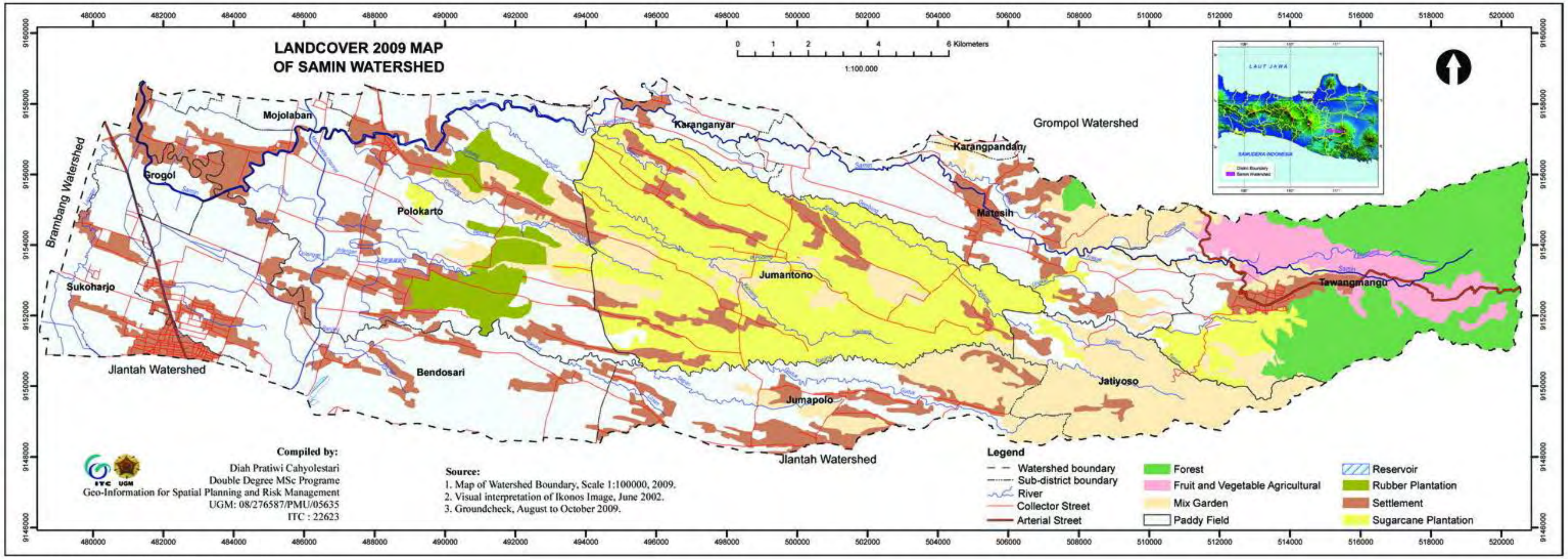



Figure 4.4 Landuse 2009 Map of Samin Watershed

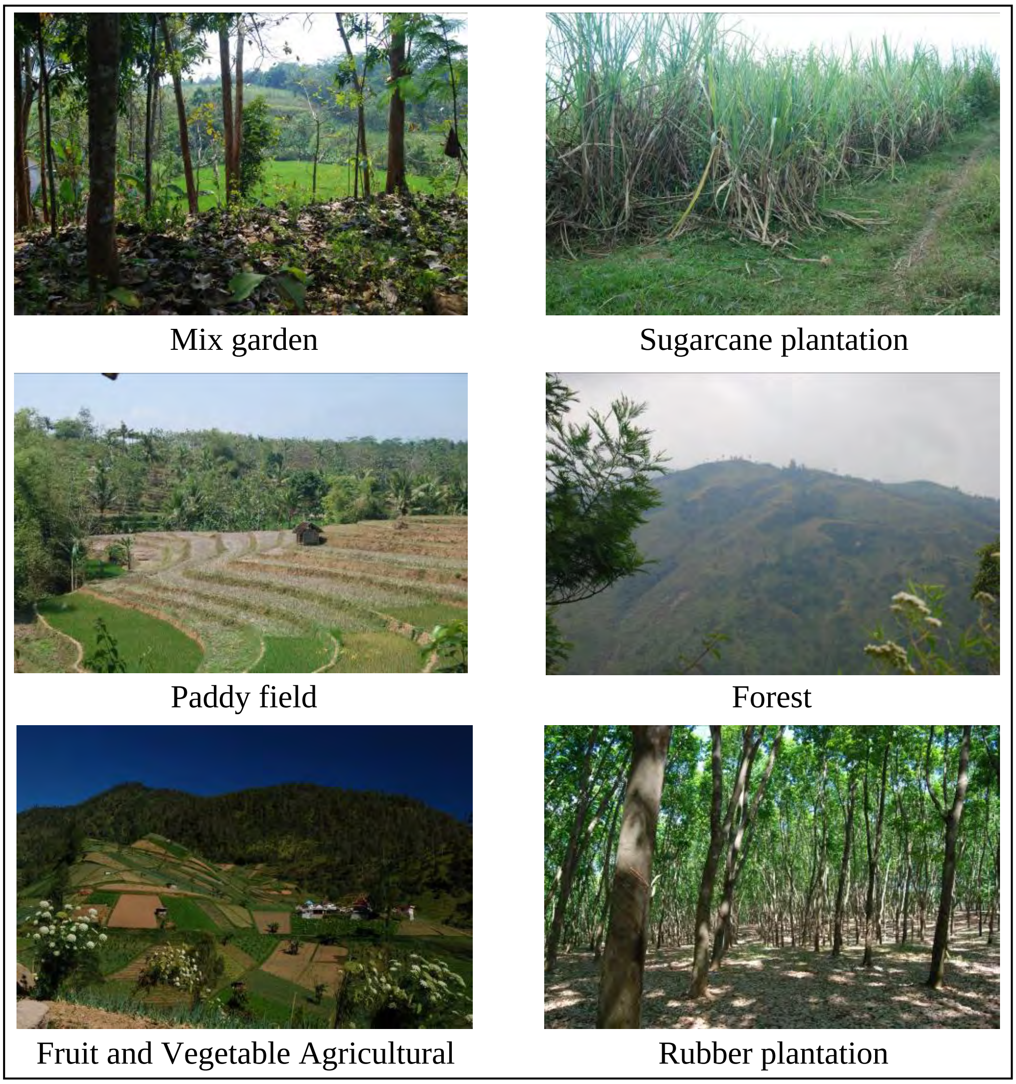



Figure 4.5 Various land cover verified through groundcheck, August to October 2009.

4.2. Land Tenure

Map of forest zonation published by Ministry of Forestry 2006 is employed as a base to map land tenure in Samin Watershed. Over the area, there are spots of government's property, but it has less signifificant because on the government's property it has already been used as public building, such as government offices, and school buildings. Table 11 gives information of land cover area for each land tenure. It is interesting to see that on state forest area, there are other land cover types, such as fruit and vegetable agricultural, mix garden, settlement and sugarcane plantation. A high demands to meet domestic needs make local people use state land. Mix garden located on state forest area is a land managed by Perhutani (a private company) which is prepared to be planted by local farmers.

Table 4.2. Land cover area for each land tenure

| Nr. | Land Tenure | | Landcover type | Area | | |
|---|---|---|---|---|---|---|
| | | | | Hectares | percentage per land tenure | percentage per total watershed |
| 1. | Property area | | | | | |
| | | a. | Forest | 297.10 | 1.03 | 0.95 |
| | | b. | Fruit and Vegetable Agricultural | 592.16 | 2.06 | 1.89 |
| | | c. | Mix Garden | 3,864.70 | 13.46 | 12.33 |
| | | d. | Paddy Field | 13,787.54 | 48.01 | 43.99 |
| | | e. | Reservoir | 16.71 | 0.06 | 0.05 |
| | | f. | Rubber Plantation | 836.47 | 2.91 | 2.67 |
| | | g. | Settlement | 4,319.62 | 15.04 | 13.78 |
| | | h. | Sugarcane Plantation | 5,006.27 | 17.43 | 15.97 |
| | | | Sub total | 28,720.57 | 100.00 | 91.63 |
| 2. | State forest area | | | | | |
| | | a. | Forest | 1,994.79 | 76.01 | 6.36 |
| | | b. | Fruit and Vegetable Agricultural | 408.03 | 15.55 | 1.30 |
| | | c. | Mix Garden | 150.63 | 5.74 | 0.48 |
| | | d. | Settlement | 0.58 | 0.02 | 0.00 |
| | | e. | Sugarcane Plantation | 70.24 | 2.68 | 0.22 |
| | | | Sub total | 2,624.28 | 100.00 | 8.37 |
| | | | Total | 31,344.85 | | 100.00 |

Source: GIS Computation of Land Tenure and Land Cover Map of Samin Watershed, 2009.

# 5. Runoff Depth and River Discharge of Samin Watershed

## 5.1. Runoff Depth of Samin Watershed

Runoff depth calculation is conducted based on CN Method of US-Soil Conservation Service. The calculation performed is based on sub-watershed. Figure 5.1 presents watershed's division. There are 8 (eight) sub-watersheds. Parameters needed for this calculation are land use, land treatment, hydrological condition, hydrological soil groups, and antecedent moisture condition. Each calculation of these parameters is described elaborately as follows.

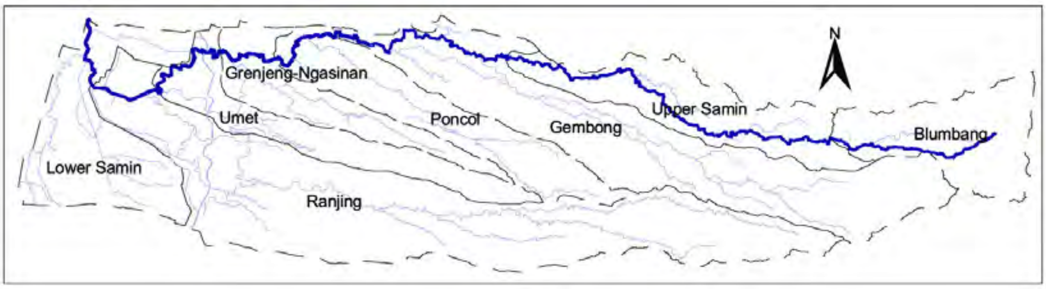



Figure 5.1 Sub watershed division for Samin Watershed.

### 5.1.1 *Determination of Hydrological Soil Groups*

Land mapping unit (as shown in Figure 5.3) is generated from overlaying map of soil type and land cover 2009. Overlay's process results 31 land mapping units. Afterwards, sampling locations is determined; with consideration that one unit is taken one sample. It takes 31 samples of soil and infiltration measurement. Soil samples taken are analyzed at soil laboratory, and infiltration measurement is conducted using single-ring infiltrometer. Figure 5.2 gives picture how to obtain soil sample and infiltration measurement in the field. Result of laboratory analysis and infiltration rates for each sample points is presented in Appendix 1.

Soil sampling | Infiltration measurements

Figure 5.2. Procedure of soil sampling and infiltration measurements.

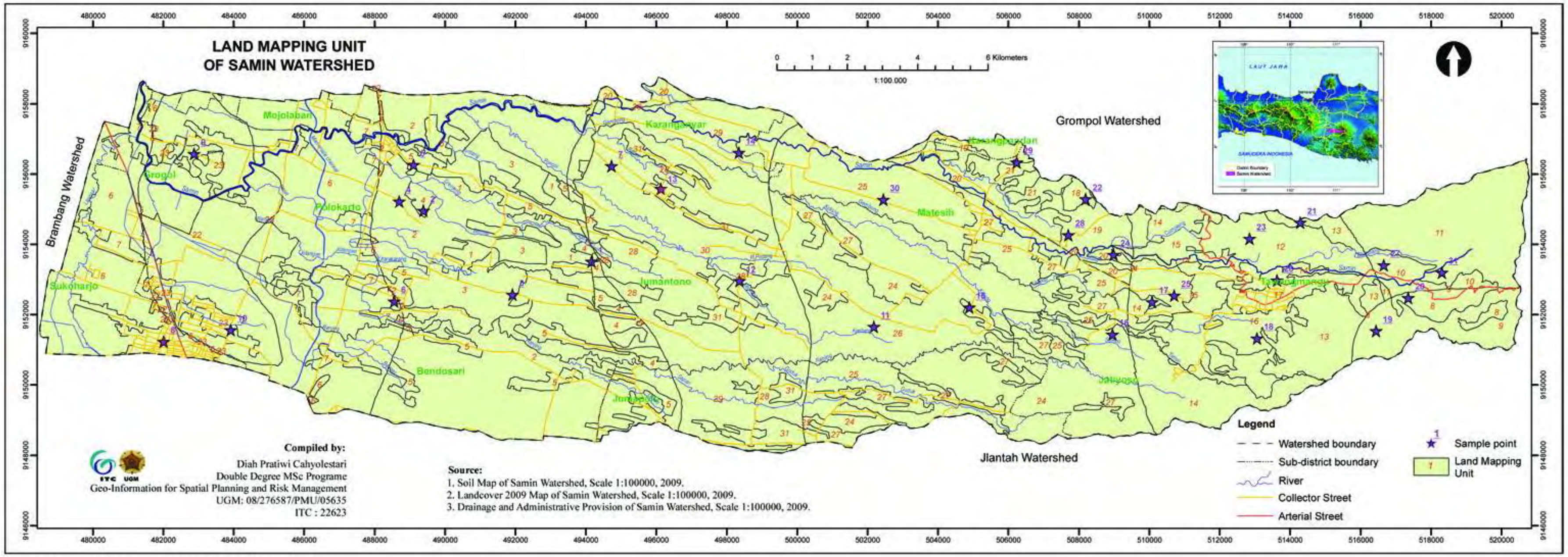
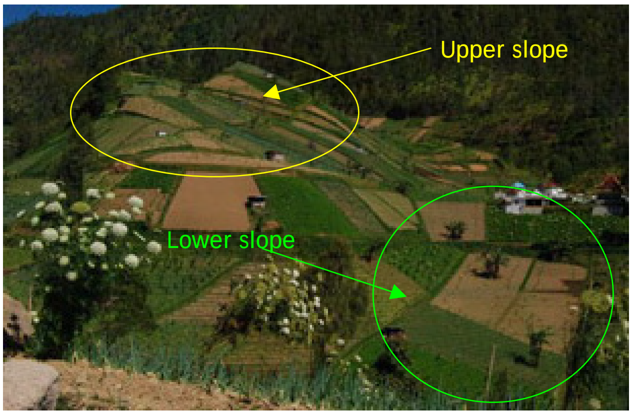



Figure 5.3 Land Mapping Unit of Samin Watershed

After soil texture and infiltration rate is obtained for each sample point, hydrological soil group is determined. Layer of land mapping unit is converted into layer of hydrological soil groups (HSG). Attribute of each polygon is added to meet Table 3.5. Later, the polygons of HSG's layer are dissolved based on field of HSG. Figure 5.4 shows result of this process.

### 5.1.2 *Land Use Reclassification*

Reclassification of land cover 2009 is required to meet US-SCS Classification of Land Cover. Table 3.6 is employed as a base of this reclassification. For landcover of fruit and vegetable agricultural, there is differentiation between one at lower slope and one at upper slope. A photo taken during groundcheck brings a better picture of this.




Fruit and vegetable at upper slope is planted the same as slope direction, whlist one at lower slope is planted the same as contour direction. Based on land treatment classification developed by SCS, garden at the same as slope direction is straight row; while at the same contour direction is contoured.

Table 5.1 gives landuse reclassification with the proportion area of the watershed. Reclassification result is mapped as given on Figure 5.5.

Table 5.1. Landuse reclassification and the proportion of the watershed

| Nr. | | Landcover | Land Use Reclassification | % of watershed area |
|---|---|---|---|---|
| 1 | | Forest | Woodlands _ _ Good | 7.312 |
| 2 | a | Fruit and Vegetable Agricultural_lower slope | Row crops _ Contoured _ Poor | 1.315 |
| | b | Fruit and Vegetable Agricultural_upper slope | Row crops _ Straight row _ Poor | 1.876 |
| 3 | | Mix Garden | Farm woodlots _ _ Fair | 12.810 |
| 4 | | Paddy Field | Small grain _ Contoured and terraced _ Poor | 43.987 |
| 5 | | Reservoir | Swamp with slope <3% | 0.053 |
| 6 | | Rubber Plantation | Woodlands _ _ Fair | 2.669 |
| 7 | | Settlement | Farmsteads | 13.783 |
| 8 | | Sugarcane Plantation | Pasture range _ Contoured _ Fair | 16.196 |

Source: GIS Analysis, 2009

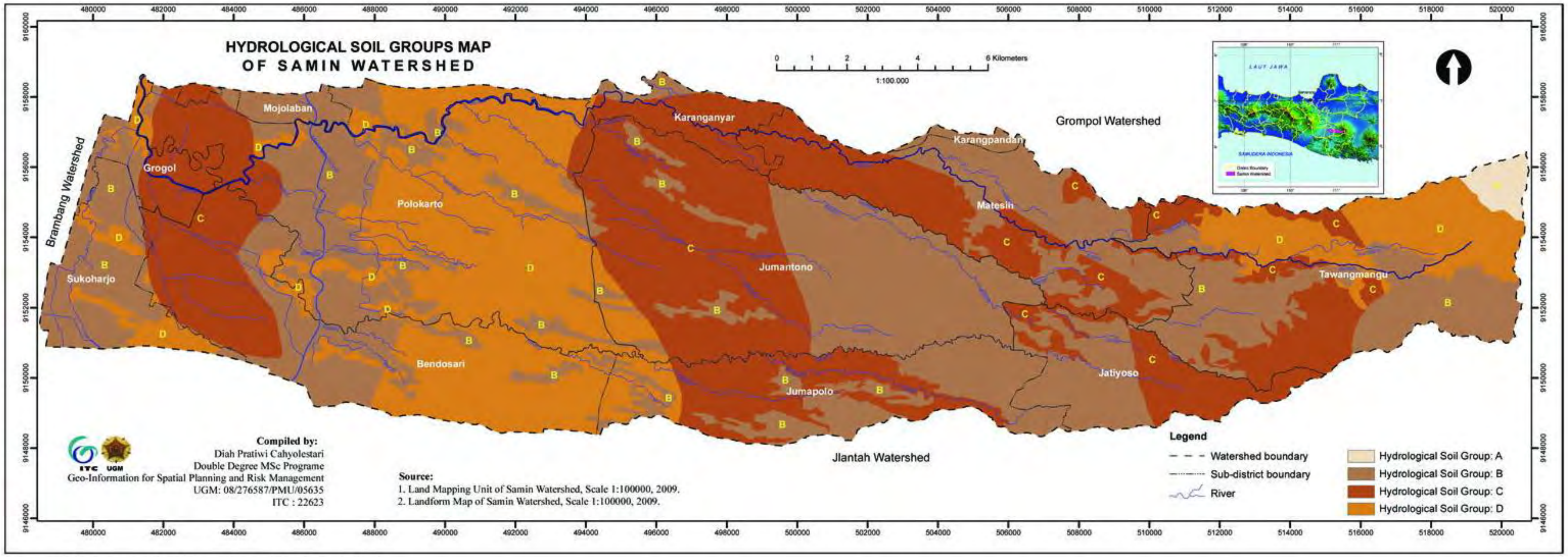


Figure 5.4 Hydrological Soil-Group Map of Samin Watershed

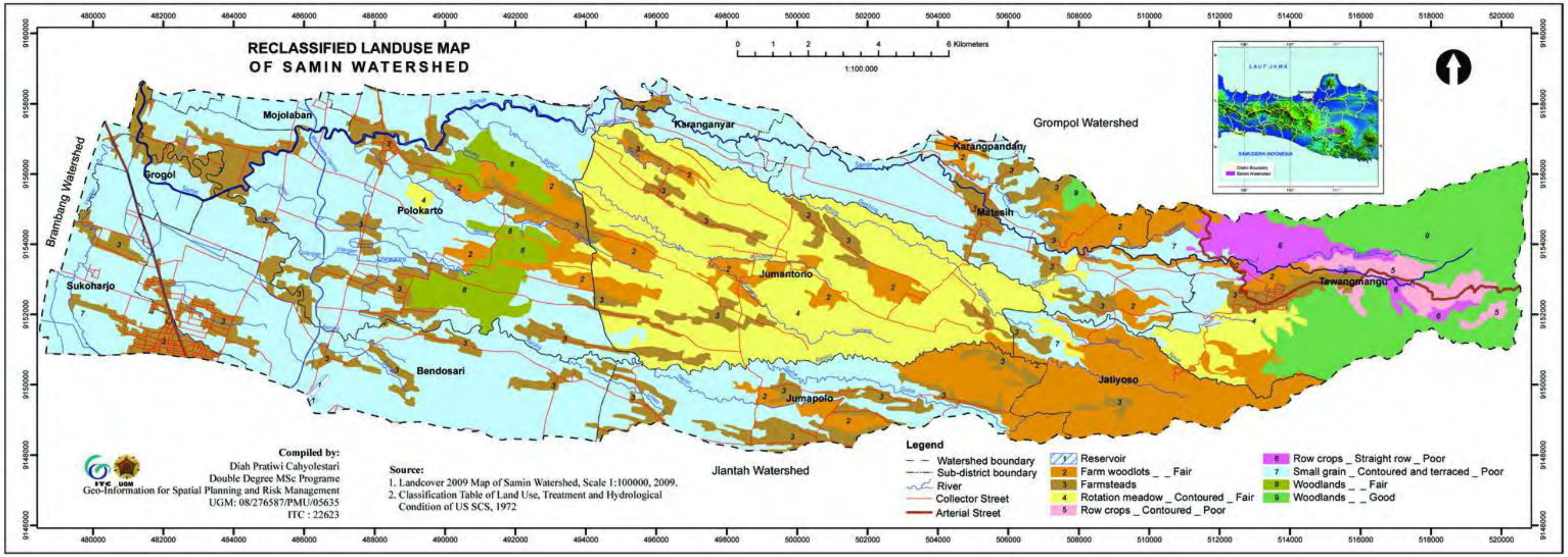


Figure 5.5. Reclassified Landuse Map of Samin Watershed

5.1.3 *Determining Curve Numbers of AMC Class II*

To determine CN values for each sub-watershed, several maps are overlaid. Those maps are Hydrological Soil Groups Map, Sub-watershed Map, and Land Use Reclassification Map. Subsequently, a new map is generated, and its attribute is soon added by field of CN values. Guidelines on CN values determination have already been given on Table 3.7.

5.1.4 *Adjustment of Antecedent Moisture Condition Class*

The adjusment is performed based on an average 5-day antecedent rainfall on 8 ungauged rainfall stations. Those stations spread over watershed, as seen in Figure 5.6. Daily rainfall data used is of year 2006. Calculating 5-day antecedent rainfall is conducted to determine an average value. This value, then, is adjusted to Table 3.8. An average 5-day antecedent rainfall in the area is about 61 mm, therefore, is in Antecedent Moisture Condition Class III (AMC-III).

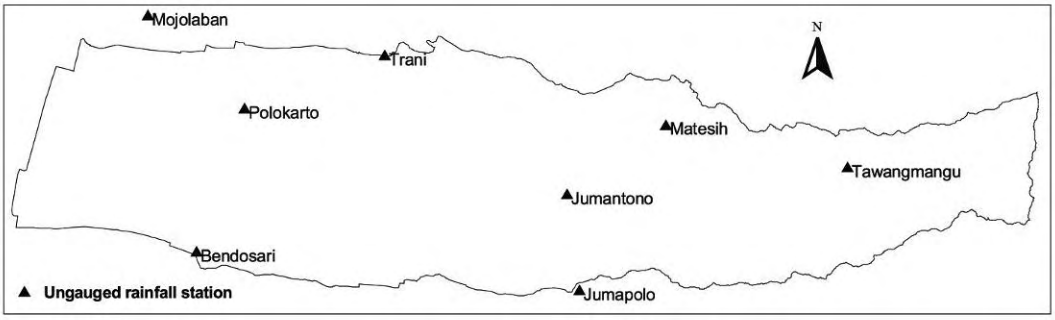


Figure 5.6. Ungauged rainfall stations of Samin Watershed

Once AMC Class is determined, a conversion is performed considering Table 3.9. When Curve Numbers for AMC-III is established, a weighted Curve Numbers is computed. The weighted CNs considers on area proportion for each sub watershed. Together with Curve Numbers for AMC-II, adjustment to Curve Numbers for AMC-III and weighted Curve Numbers are given in Appendix 2. Procedurs giving explanation on adding attribute data through GIS analysis (using ArcView software) are given in Figure 5.7.

5.1.5 *Developing Accumulated Daily Rainfall*

With help of ArcGIS Tools, Spatial Analyst, each point of rainfall stations is interpolated based on annual rainfall. Data used for this calculation is annual rainfall for year 2006.

Interpolation process gives an isohyetal map with the same annual rainfall. This map, subsequently, is reclassified into 10 classes of annual rainfall. Mean value of annual rainfall for each class is determined. This value is applied for calculating runoff depth using SCS formula. Figure 5.8 shows an isohyetal map of annual rainfall 2006.

5.1.6 *Runoff Calculation*

Parameters needed for runoff calculation are accumulated rainfall, initial abstraction, Curve Numbers, and potential maximum retention. Therefore, map of determined weighted Curve Numbers is overlaid to map of annual rainfall. Data attribute as a result of overlaid the two maps is added with parameters of initial abstraction and potential maximum retention. Those parameters are calculated using formula given in Chapter 3. As a result, there are many values of runoff depth. Therefore, those values are classified into 10 classes. These classes are presented in Table 5.2.

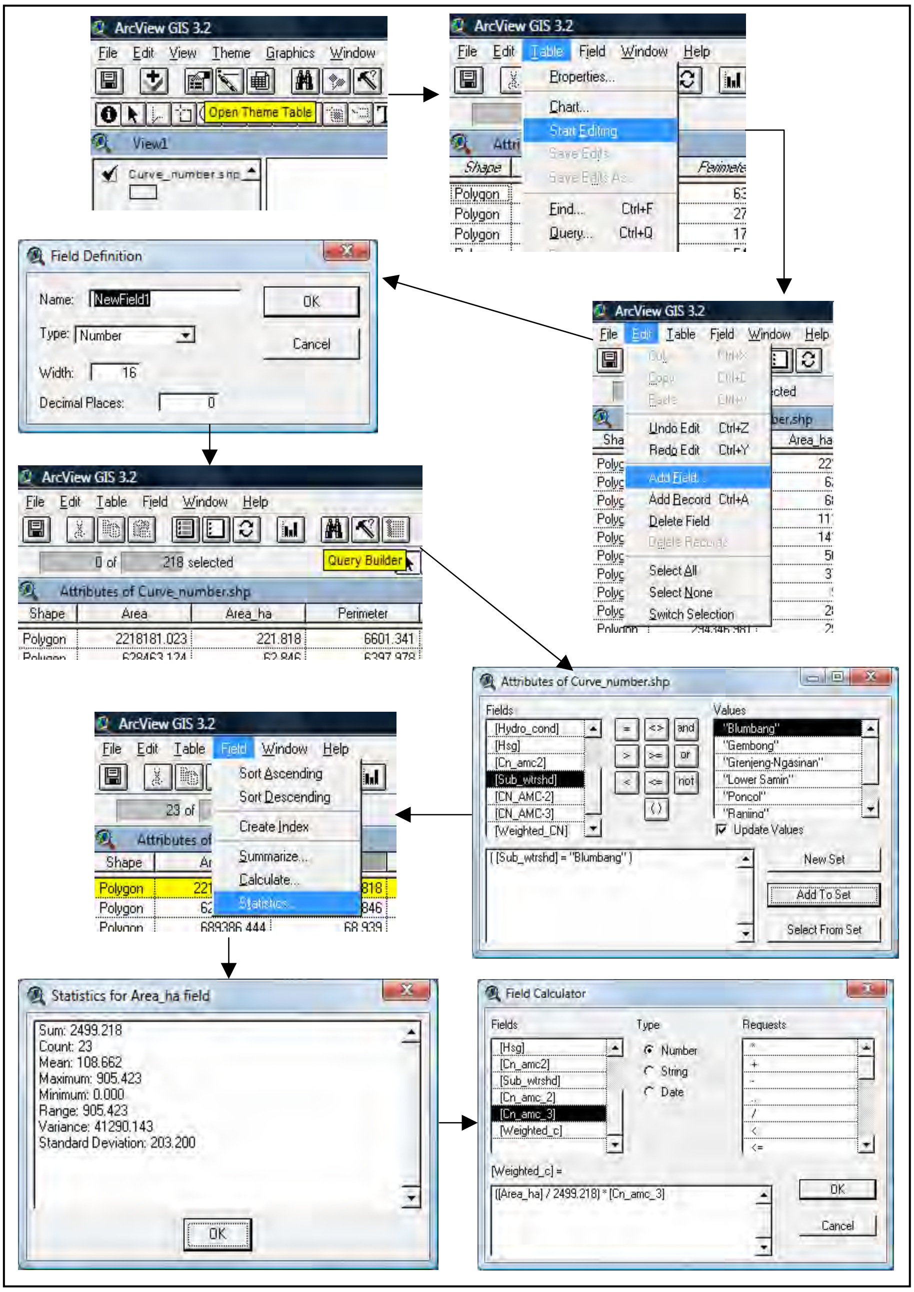



Figure 5.7. ArcView procedurs to add field in attribute data and to determine weighted Curve

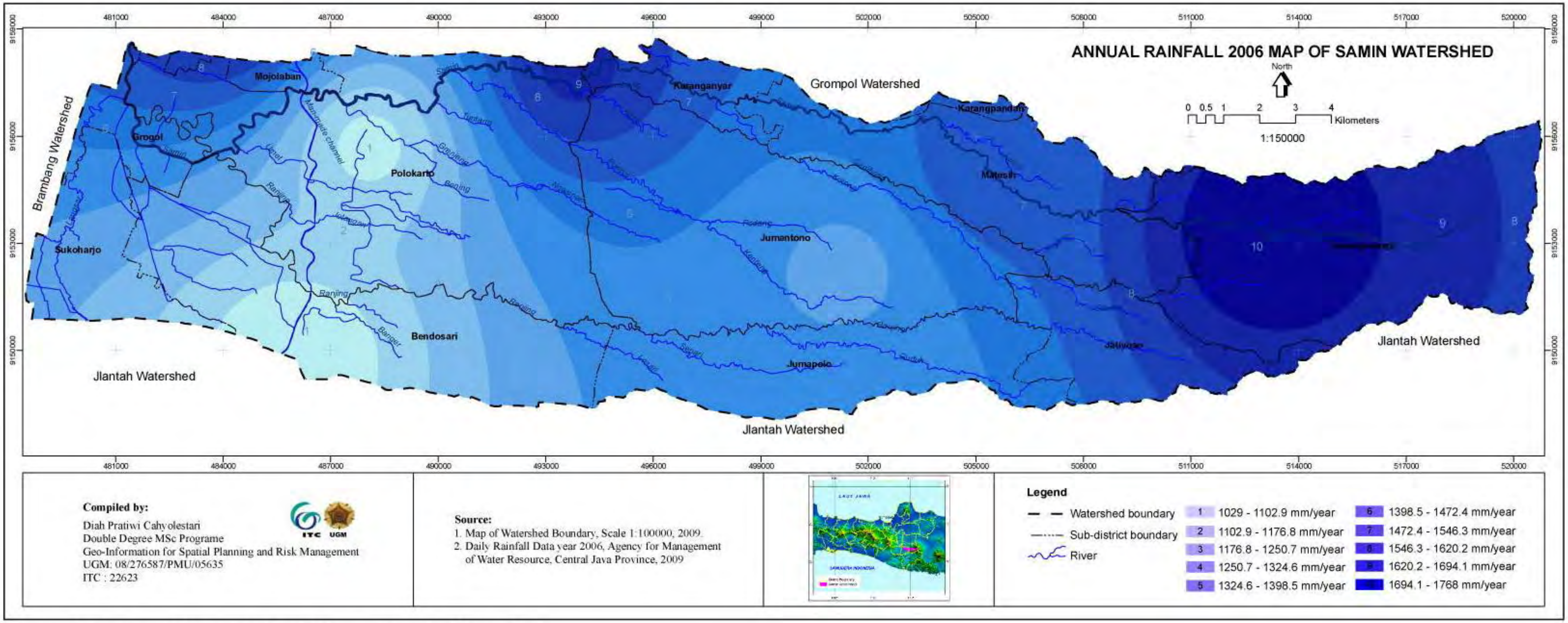



Figure 5.9. Annual Rainfall 2006 Map of Samin Watershed

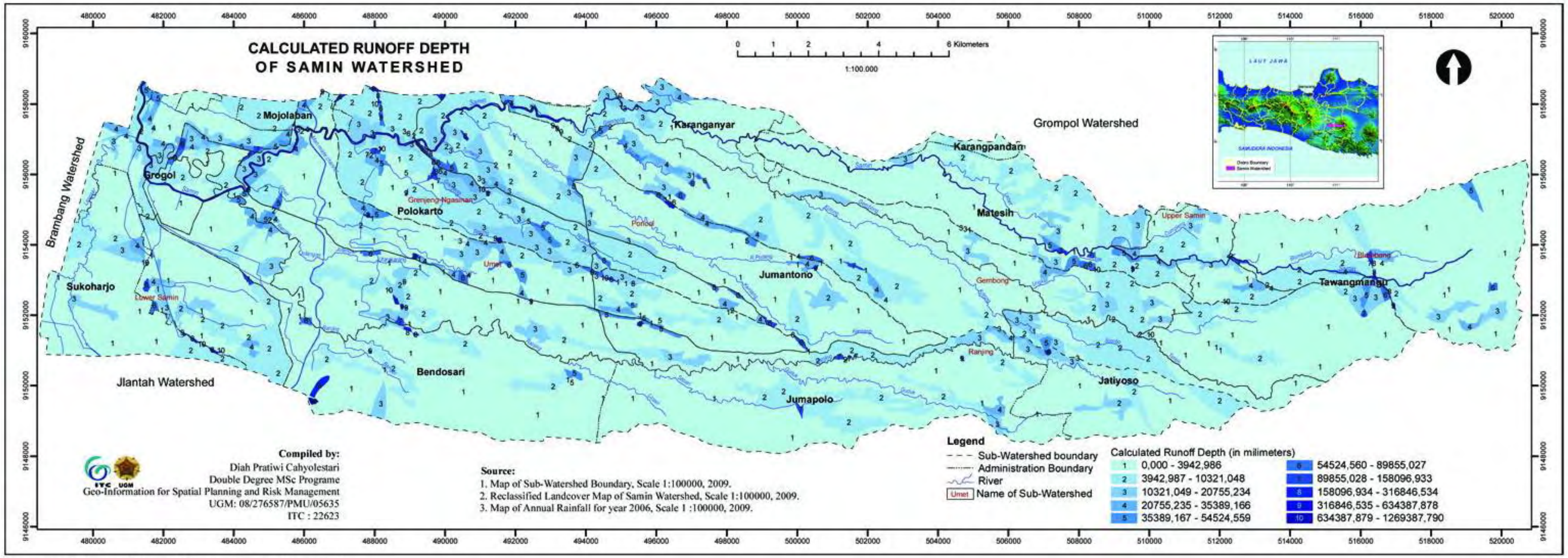


Figure 5.9 Calculated Runoff  Map of Samin Watershed

Table 5.2. Runoff Classification

| Class | Runoff depth (mm) | Class | Runoff depth (mm) |
|---|---|---|---|
| 1 | 9.550 – 3942.986 | 6 | 54524.560 – 89855.027 |
| 2 | 3942.987 – 10321.048 | 7 | 89855.028 – 158096.933 |
| 3 | 10321.049 – 20755.234 | 8 | 158096.934 – 316846.534 |
| 4 | 20755.235 – 35389.166 | 9 | 316846.535 – 634387.878 |
| 5 | 35389.167 – 54524.559 | 10 | 634387.879 – 1269387.790 |

Source: GIS Analysis

In order to determine runoff depth, it is required the single value of annual rainfall. For that reason, each class of annual rainfall is set up a mean value. Calculation of parameters needed to compute runoff depth is conducted by means of GIS software, ArcView. In general, computation result is presented in Table 5.3. Runoff depth based on classification above is mapped as given in Figure 5.10.

Tabel 5.3. Computation result of runoff per sub watershed

| Sub Watershed | Landcover | Runoff Depth (mm) | Runoff percentage to total sub watershed | Area percentage to total sub watershed |
|---|---|---|---|---|
| Blumbang | Forest | 1559102.700 | 53.399 | 60.560 |
| | Fruit and Vegetable Agricultural_lower slope | 631738.334 | 21.637 | 14.930 |
| | Fruit and Vegetable Agricultural_upper slope | 191307.569 | 6.552 | 19.144 |
| | Mix Garden | 102703.954 | 3.518 | 2.816 |
| | Paddy Field | 422347.609 | 14.465 | 0.042 |
| | Settlement | 12539.034 | 0.429 | 2.507 |
| | Sub total | 2919739.200 | 100.000 | 100.000 |
| Gembong | Forest | 123896.508 | 2.035 | 11.025 |
| | Fruit and Vegetable Agricultural_lower slope | 204633.235 | 3.361 | 0.595 |
| | Fruit and Vegetable Agricultural_upper slope | 831.810 | 0.014 | 0.018 |
| | Mix Garden | 811397.977 | 13.326 | 13.151 |
| | Paddy Field | 309492.525 | 5.083 | 29.027 |
| | Settlement | 3245117.797 | 53.296 | 8.937 |
| | Sugarcane Plantation | 1393486.863 | 22.886 | 37.247 |
| | Sub total | 6088856.715 | 100.000 | 100.000 |
| Grenjeng-Ngasinan | Mix Garden | 1289439.509 | 12.443 | 15.034 |
| | Paddy Field | 2714006.067 | 26.189 | 46.423 |
| | Rubber Plantation | 816178.697 | 7.876 | 7.133 |
| | Settlement | 5069913.538 | 48.923 | 15.961 |
| | Sugarcane Plantation | 473422.394 | 4.568 | 15.448 |
| | Sub total | 10362960.205 | 100.000 | 100.000 |
| Lower Samin | Paddy Field | 1469993.131 | 24.137 | 78.422 |
| | Settlement | 4620109.588 | 75.863 | 21.578 |
| | Sub total | 6090102.719 | 100.000 | 100.000 |
| Poncol | Mix Garden | 1421769.157 | 24.897 | 12.697 |
| | Paddy Field | 2731647.369 | 47.835 | 20.689 |
| | Rubber Plantation | 223054.012 | 3.906 | 8.181 |
| | Settlement | 1296296.857 | 22.700 | 6.770 |
| | Sugarcane Plantation | 37822.309 | 0.662 | 51.663 |
| | Sub total | 5710589.704 | 100.000 | 100.000 |

| | | | | |
|---|---|---|---|---|
| Ranjing | Mix Garden | 130953.632 | 1.335 | 17.357 |
| | Paddy Field | 1180764.212 | 12.038 | 55.864 |
| | Reservoir | 1522775.930 | 15.525 | 0.180 |
| | Rubber Plantation | 1910249.063 | 19.475 | 2.991 |
| | Settlement | 5000558.660 | 50.982 | 18.886 |
| | Sugarcane Plantation | 63247.671 | 0.645 | 4.721 |
| | Sub total | 9808549.168 | 100.000 | 100.000 |
| Umet | Mix Garden | 3289817.080 | 41.928 | 9.853 |
| | Paddy Field | 998054.075 | 12.720 | 48.009 |
| | Rubber Plantation | 183706.768 | 2.341 | 8.689 |
| | Settlement | 3016756.707 | 38.448 | 13.745 |
| | Sugarcane Plantation | 358065.451 | 4.563 | 19.705 |
| | Sub total | 7846400.081 | 100.000 | 100.000 |
| Upper Samin | Forest | 7411.757 | 0.201 | 2.055 |
| | Fruit and Vegetable Agricultural_upper slope | 5782.108 | 0.156 | 3.931 |
| | Mix Garden | 706376.265 | 19.113 | 22.184 |
| | Paddy Field | 1572644.142 | 42.552 | 56.766 |
| | Settlement | 1403564.268 | 37.977 | 15.064 |
| | Sub total | 3695778.540 | 100.000 | 100.000 |
| Total | | 52522976.332 | | |

Source: GIS Analysis, 2009

Table 5.3 indicates that Blumbang Sub-watershed contributes 5.6 percent of total runoff for Samin Watershed. The other sub-watershed, i.e Gembong, Grenjeng-Ngasinan, Lower Samin, Poncol, Ranjing, Umet, and Upper Samin supply 11.6 percent, 19.7 percent, 11.6 percent, 10.9 percent, 18.7 percent, 14.9 percent, and 7 percent respectively.

Forest is located in Blumbang, Gembong and Upper Samin Sub-watershed, but they contribute different portion to runoff depth. In Blumbang Sub-watershed, forest is the biggest runoff contributor in the area; whilst at Gembong and Upper Samin Sub-watershed, forest becomes the second smallest runoff depth for the area.

Figure 5.10. Shrub in forest area

Picture in Figure 5.10 is taken during groundcheck, August 2009. On the right and left side of the man, there is shrub, although the area is a forest. There are spots as portrayed in Figure 5.10 at Blumbang Sub-watershed. Most forest in Blumbang Sub-watershed becomes shrub or is changing into shrub, or combination of wooden trees and shrub. This is a usual phenomenon because forest is experiencing of natural succession.

Runoff on sugarcane plantation at Gembong Sub-watershed is the biggest value, compare to the same landcover in other sub-watersheds. It happens because in Gembong Sub-watershed, almost all of paddy field has converted into sugarcane plantation since 2003. Paddy field in other sub-watershed is not converted completely into sugarcane plantation. Overall computation, Samin Watershed has 52,522,976.332 milimeters of runoff depth, relating to annual rainfall 2006 over the watershed.

## 5.2. River Discharge of Samin Watershed

Analysis of river discharge is conducted on comparison of calculated discharge to measured river discharge. Measured data is obtained from daily discharge data from Agency of Water Resources Management of Central Java Province. As accumulated rainfall used for Curve Numbers calculation employs data of 2006, daily measured discharge data also uses data of 2006.

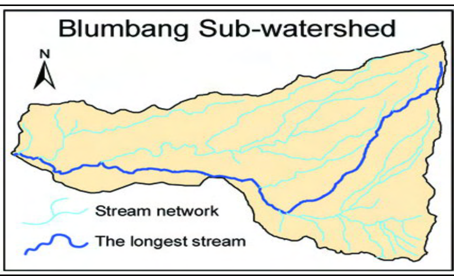
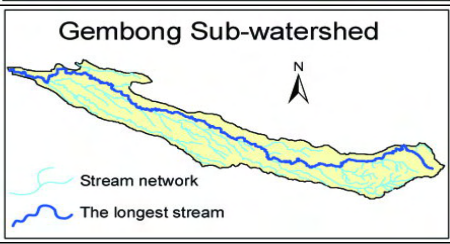
### 5.2.1 *Calculation of River Discharge of Samin Watershed*

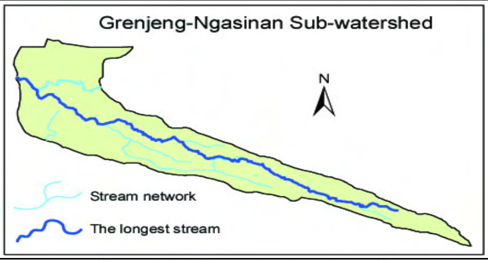
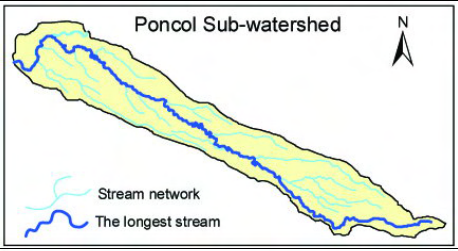
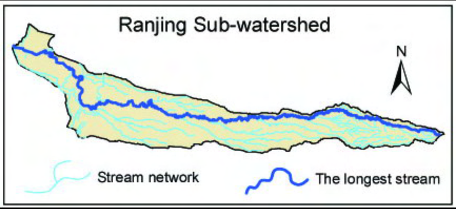
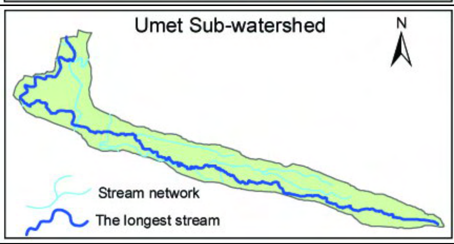
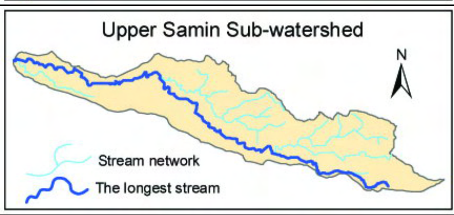
The discharge is calculated regarding to runoff depth, which have been determined through calculation above. Other parameters are needed to calculate river discharge, i.e physical characteristics of watershed and time to peak runoff.

Physical characeristics of watershed required to identify are watershed area (A, in sq.km), the longest stream (L, in mm), and also differences in elevation between the most remote point in the watershed and outlet (H, in mm). These characteristics are determined for each sub watershed.

Time to peak runoff is estimated in terms of time of concentration. A formula developed by Kirpich is applied to estimate time of concentration. This considers physical characteristics, i.e the longest stream and slope. Slope is determined from elevation differences between the most remote point and outlet divided by horizontal distance. Information of elevation is derived from digital contour map with interval of 12.5 meters. Horizontal distance is the same as maximum length of travel. These characteristics are computed by means of GIS analysis.

Table 5.4. Calculation of physical characteristics for each sub-watershed.

| Sub watershed | Physical Characteristics |
|---|---|
|  | A = 24.9916 sq.km<br>L = 11850.8390 m<br>H = 2386.6000 m<br>S = 0.2014 |
|  | A = 65.4625 sq.km<br>L = 36357.8760 m<br>H = 1723.6000 m<br>S = 0.0474 |

| | |
|---|---|
|  | A = 18.7650 sq.km<br>L = 13296.3540 m<br>H = 193.0000 m<br>S = 0.0145 |
|  | A = 33.2328 sq.km<br>L = 12289.6940 m<br>H = 10.2000 m<br>S = 0.0008 |
|  | A = 28.2260 sq.km<br>L = 23088.4950 m<br>H = 366.1000 m<br>S = 0.0159 |
|  | A = 92.8631 sq.km<br>L = 47735.3530 m<br>H = 962.5000 m<br>S = 0.0202 |
|  | A = 22.3267 sq.km<br>L = 24178.1830 m<br>H = 231.4000 m<br>S = 0.0096 |
|  | A = 27.5809 sq.km<br>L = 18556.2390 m<br>H = 836.7000 m<br>S = 0.0451 |

Source: GIS Analysis, 2009

Note: A is area of watershed, L is the longest stream/ maximum length of travel, H is elevation differences, and S is H/L

After physical characteristics of watershed are computed, time of concentration (Tc) for each sub-watershed is calculated. The result computation is in unit of minute, consequently is converted to hour. Afterwards, time to peak runoff (Tp) is determined. Table 5.5 gives calculation of Tc and Tp for each sub-watershed.

Table 5.5. Calculation of Tc and Tp

| Nr. | Sub-watershed | Tc ($0.02\ L^{0.77}\ S^{-0.385}$) | | Tp (0.7 Tc) |
|---|---|---|---|---|
| | | minute | hour | Hour |
| 1. | Blumbang | 50.788 | 0.846 | 0.593 |
| 2. | Gembong | 210.132 | 3.502 | 2.452 |
| 3. | Grenjeng-Ngasinan | 152.757 | 2.546 | 1.782 |
| 4. | Lower Samin | 432.652 | 7.211 | 5.048 |
| 5. | Poncol | 225.822 | 3.764 | 2.635 |
| 6. | Ranjing | 360.148 | 6.002 | 4.202 |
| 7. | Umet | 284.187 | 4.736 | 3.316 |
| 8. | Upper Samin | 127.628 | 2.127 | 1.489 |

Source: Computer analysis, 2009

According to Table 5.5, when rain falls, Lower Samin Sub-watershed has the longest time to reach Samin River; whilst Blumbang Sub-watershed has the fastest time to reach Samin River. Besides, Samin River starts to flow at Blumbang Sub-watershed and ends up at Lower Samin Sub-watershed to join Solo River. A different time of concentration does not imply a different response on rainfall event. A high intensity rainfall fall either on those two sub-watersheds, produce overland flow. Overland flow occurs in Blumbang because of its sloping area tends to make worst regarding to fast time of concentration. Overland flow arises in Lower Samin because it is a fluvial plain and has a tendency to be inundated when river does not able to hold water.

Once time to peak discharge has determined, river discharge for each sub-watershed is calculated. The calculation uses a dimensionless unit hydrograph of US – SCS developed by Mockus (Anonym, 2004). Table 5.6 presents calculation of river discharge ($q_p$).

Table 5.6. Calculation of $q_p$ (after Mockus, 1957)

| Nr. | Sub-watershed | Area A (sq.km) | Runoff Q (mm) | Tp (hour) | $q_p = 0.208 \frac{A\,Q}{T_p}$ (m³/s) |
|---|---|---|---|---|---|
| 1. | Blumbang | 24.9916 | 2919739.200 | 0.593 | 25614720.614 |
| 2. | Gembong | 65.4625 | 6088856.715 | 2.452 | 33818291.667 |
| 3. | Grenjeng-Ngasinan | 18.7650 | 10362960.205 | 1.782 | 22695899.276 |
| 4. | Lower Samin | 33.2328 | 6090102.719 | 5.048 | 8340061.096 |
| 5. | Poncol | 28.2260 | 5710589.704 | 2.635 | 12725674.009 |
| 6. | Ranjing | 92.8631 | 9808549.168 | 4.202 | 45520331.601 |
| 7. | Umet | 22.3267 | 7846400.081 | 3.316 | 10997366.176 |
| 8. | Upper Samin | 27.5809 | 3695778.540 | 1.489 | 14239160.419 |
| Total watershed | | | | | 173951504.858 |

Source: Computer analysis, 2009

Based on Table 5.6, in 2006, Samin Watershed has a peak river discharge of 173,951,505 m³/s. Lower Samin has the lowest peak discharge, and Ranjing has the highest peak discharge. Ranjing becomes a biggest contributor to supply peak discharge of Samin Watershed because it has the biggest area and the second longest time of concentration.

### 5.2.2 *Comparison between Calculated and Measured River Discharge*

In order to verify the calculated river discharge, an observational data is required. The data is regarded as 'true' value of river discharge. Since Samin Watershed has no flow gauging station in its outlet, this research employs a daily discharge data from a certain point, Trani Dam, at the middle of watershed. According to Figure 3.8, this point is located at Gembong Sub-watershed. Thus, a comparison is not applied for the whole Samin Watershed. Calculated discharge at three sub-watersheds, i.e. Gembong, Blumbang and Upper Samin is used to compare with a measured data. Tabel 5.7 gives an observational discharge data for year 2006, especially on dry season.

Tabel 5.7. Daily discharge data of Trani Dam for the year 2006 (in litre per second)

| Date | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1596 | 4475 | 3951 | 4297 | 3597 | 2216 | 604 | 298 | 0 | 0 | 0 | 2804 |
| 2 | 1596 | 9543 | 4536 | 3297 | 3297 | 2216 | 604 | 298 | 0 | 0 | 0 | 1062 |
| 3 | 1596 | 5267 | 5328 | 3297 | 4297 | 3009 | 604 | 298 | 0 | 0 | 0 | 1108 |
| 4 | 1596 | 5267 | 5328 | 4297 | 4882 | 2216 | 642 | 298 | 0 | 0 | 0 | 2012 |
| 5 | 1596 | 9543 | 4536 | 4882 | 4297 | 2216 | 642 | 298 | 0 | 0 | 0 | 3597 |
| 6 | 1424 | 9536 | 3951 | 4297 | 4297 | 3009 | 680 | 298 | 0 | 0 | 0 | 19744 |
| 7 | 1424 | 4468 | 4085 | 4882 | 4882 | 2216 | 680 | 268 | 0 | 0 | 0 | 4597 |
| 8 | 1424 | 3883 | 4670 | 4882 | 4297 | 2216 | 720 | 240 | 0 | 0 | 0 | 5974 |
| 9 | 1424 | 3883 | 4670 | 4297 | 4766 | 2216 | 720 | 214 | 0 | 0 | 0 | 3597 |
| 10 | 1424 | 4468 | 3085 | 4297 | 4766 | 2216 | 720 | 188 | 0 | 0 | 240 | 2804 |
| 11 | 1712 | 3883 | 3085 | 9950 | 4766 | 1250 | 680 | 162 | 0 | 0 | 162 | 2804 |
| 12 | 1712 | 2883 | 4085 | 5674 | 4181 | 1250 | 642 | 138 | 0 | 0 | 138 | 2012 |
| 13 | 1712 | 4468 | 3085 | 9950 | 4181 | 1108 | 642 | 120 | 0 | 0 | 120 | 3597 |
| 14 | 1712 | 3883 | 4009 | 4882 | 3181 | 1062 | 604 | 120 | 0 | 0 | 0 | 5182 |
| 15 | 1712 | 4468 | 4594 | 4297 | 3181 | 972 | 604 | 96 | 0 | 0 | 0 | 3597 |
| 16 | 1596 | 3900 | 4670 | 4882 | 3085 | 886 | 566 | 96 | 0 | 0 | 0 | 3597 |
| 17 | 1596 | 4485 | 4085 | 4297 | 4670 | 842 | 530 | 96 | 0 | 0 | 0 | 2804 |
| 18 | 1596 | 2900 | 4085 | 4297 | 4085 | 760 | 494 | 72 | 0 | 0 | 0 | 2804 |
| 19 | 1596 | 5277 | 4670 | 4882 | 3085 | 760 | 494 | 72 | 0 | 0 | 0 | 3597 |
| 20 | 1596 | 4485 | 3085 | 4297 | 2292 | 760 | 458 | 72 | 0 | 0 | 0 | 3597 |
| 21 | 1596 | 4485 | 3181 | 4297 | 2292 | 680 | 458 | 58 | 0 | 0 | 0 | 4597 |
| 22 | 1596 | 3900 | 4181 | 3297 | 2292 | 680 | 458 | 58 | 0 | 0 | 0 | 5182 |
| 23 | 1596 | 3900 | 4181 | 3297 | 3085 | 680 | 424 | 0 | 0 | 0 | 0 | 3597 |
| 24 | 1596 | 2900 | 3181 | 4297 | 3085 | 680 | 424 | 0 | 0 | 0 | 268 | 4597 |
| 25 | 1596 | 3900 | 3181 | 5182 | 2292 | 680 | 392 | 0 | 0 | 0 | 324 | 3597 |
| 26 | 1298 | 2900 | 3181 | 5182 | 3085 | 642 | 392 | 0 | 0 | 0 | 162 | 5182 |
| 27 | 1298 | 4485 | 3181 | 4597 | 3085 | 642 | 360 | 0 | 0 | 0 | 96 | 4597 |
| 28 | 1298 | 4485 | 3181 | 4597 | 2292 | 642 | 360 | 0 | 0 | 0 | 96 | 4597 |
| 29 | 1298 | | 4181 | 3597 | 3085 | 680 | 324 | 0 | 0 | 0 | 2012 | 3597 |
| 30 | 1298 | | 3181 | 3597 | 3085 | 680 | 324 | 0 | 0 | 0 | 2012 | 3597 |
| 31 | 1298 | | 4181 | | 2292 | | 324 | 0 | | 0 | | 3597 |
| Monthly | 47408 | 131920 | 122584 | 142073 | 110055 | 40082 | 16570 | 3858 | 0 | 0 | 5630 | 127627 |

Source: Agency of Water Resources Management of Central Java, 2009.

From Table 5.7, annual discharge of Trani Dam of 2006 produces 747,807 litre per second and from three sub-watersheds covering Trani Dam, calculated discharge yields about 73,672,172,699.95 litre per second. It means that calculated discharge is 98 times bigger than measured discharge.

A very little accuracy to estimate river discharge is caused by applying a very general soil map. It implies on land mapping unit development. Land units established turn into more general, so decision of sampling points become less convincing. A poor land unit map produces a poor hydrological soil group map. Eventually, a poor hydrological soil group map makes a bad estimation of Curve Numbers.

# 6. Land Use Modeling and Effectiveness to Reduce Peak Discharge

## 6.1 Development of Land Use Model in Accordance to State Regulations

As mandated by The Constitution of 1945 of The Republic of Indonesia, natural resources should be utilized as much as possible for Indonesian people's prosperity. On the other hand, those resources should be available to meet the need of both present and future generation. Therefore, it is necessary to find the best way for environmentally sound development.

State regulations employed are Law of The Republic of Indonesia Number 41 Year 1999, Government Regulation Number 76 Year 2008, and Regulation of Ministry of Forestry Number P.32/Menhut-II/2009. Mainly, those regulations are established to overcome land degradation, but there are some articles taking consideration on flood hazard analysis.

Land rehabilitation aims to maintain and improve land function that can support sustainibility utilization. Many activities is proposed in land rehabilitation, such as reforestation, plants enrichment, plants maintenance, or soil conservation. Those activities can be conducted, in general, on forest area, expect at natural preservation zone and inner zone of national park.

According to Regulation of Government of The Republic of Indonesia Number 76 Year 2008 Article 9 paragraph (2), watershed, as a management unit, is a base of land rehabilitation. The watershed is a priority watershed, which is specified by Ministry of Forestry, based on, at least consideration of unique bio-physical condition, socioeconomic condition, degraded land at upper part of watershed, and forest area which is prone to climate change effects. A model of land use can be proposed as another form of land rehabilitation.

Therefore, a proposed land use is, also, established by adjusting at bio-physical characteristic, such as elevation, slope, soil type, rootzone, geomorphological condition, and rainfall characteristic. Nevertheless, characteristics of social and cultural of local people are important factors, because most part of the land is property land owned by people. People tend to have their own decision on how to use their land optimally.

A more detailed guideline on land rehabilitation is ruled in Regulation of Ministry of Forestry Number P.32/Menhut-II/2009 concerning Construction of Technical Plan of Watershed's Land and Forest Rehabilitation. The guideline includes how to choose priority location for land rehabilitation and how to recommend technically various activities that are visible.

To choose the right location for the activity, it is necessary to formulate a main problem of such a location. When most part of the location is suffered from floods, then the rehabilitation aims to control flood and increasing base flow/ groundwater flow. Therefore, the analysis for the problem, and a technical plan guidance of land rehabilitation, is based on critical question, i.e how is a critical level of rainfall infiltraton and interception.

## 6.2 Land Use Model Development

Development of Land Use Model is based on unique bio-physical condition, land tenure and local people's demand of their land management. Four models are proposed in order to get the best management practices. Calculation includes runoff and peak discharge. All processes are analyzed for each sub-watershed.

### 6.2.1 *Land Cover Model-1*

Figure 6.1 gives a proposed land cover to overcome overland flow. It considers land tenure; means that in state-forest area, forest is the only allowed land cover. An assumption is a forest with more wooden trees and fewer shrubs will increase infiltration and surface runoff will decrease. Fruit and vegetable agricultural area at the top, then, should convert into forest. In the land cover of mix garden, existing trees should not been harvested, that they play as a forest. Sugarcane plantation will be moderately grazed with 50-70% plant cover. Settlement will not be adjusted into different land cover type. Paddy field will also not be modified into another type. It is because in previsious runoff calculation, paddy field generally contibutes a little runoff for each sub-watershed. Table 6.1 presents a comparison area betweeen land cover 2009 and land cover model-1. It shows that forest area increases, while several land cover, such as fruit and vegetable agricultural, mix garden, and sugarcane plantation, decrease. It happens because some part of those three land cover are now modified into forest.

Table 6.1. Area comparison between land cover 2009 and proposed land cover

| Nr. | LANDCOVER | AREA | | | |
|---|---|---|---|---|---|
| | | 2009 | | Model-1 | |
| | | hectares | % | hectares | % |
| 1 | Forest | 2,291.94 | 7.31 | 2,920.80 | 9.32 |
| 2 | Fruit and Vegetable Agricultural | 1,000.10 | 3.19 | 592.16 | 1.89 |
| 3 | Mix Garden | 4,015.38 | 12.81 | 3,864.73 | 12.33 |
| 4 | Paddy Field | 13,787.84 | 43.99 | 13,787.53 | 43.99 |
| 5 | Reservoir | 16.60 | 0.05 | 16.70 | 0.05 |
| 6 | Rubber Plantation | 836.36 | 2.67 | 836.47 | 2.67 |
| 7 | Settlement | 4,320.24 | 13.78 | 4,320.20 | 13.78 |
| 8 | Sugarcane Plantation | 5,076.40 | 16.20 | 5,006.26 | 15.97 |
| | Total | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: Computer and GIS analysis

After modifying actual land cover, land cover model-1 is converted into land use reclassification regarding hydrological condition, land treatment and hydrological soil groups. This procedure is simply performed by ArcGIS analysis, i.e overlaying hydrological soil group map and proposed land cover map. There are

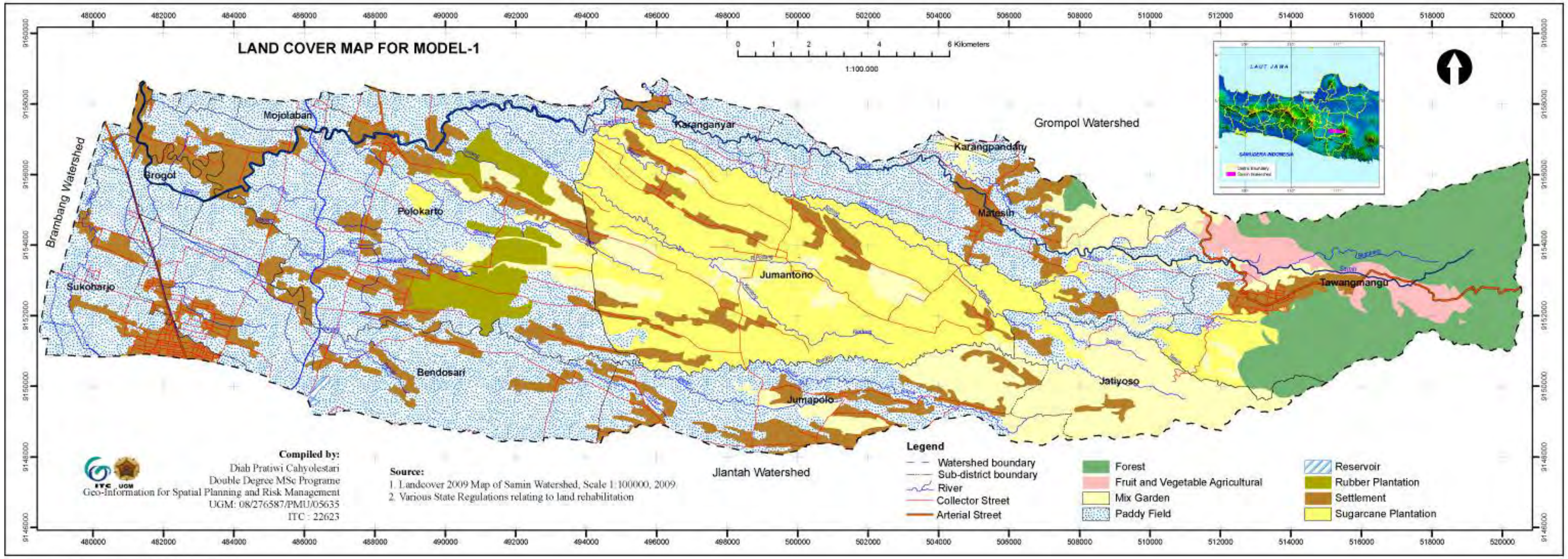



Figure 6.1. Landcover Map for Model-1

changes relating to reclassified land cover. Table 6.2 provides an area changes between reclassified land cover 2009 and reclassified land cover model-1.

Tabel 6.2 Comparison between Reclassified Land Use 2009 and Reclassified Land Use for Model-1

| Nr. | | Hydrological Soil-Cover Complexes in various hydrological soil-group | AREA | | | |
|---|---|---|---|---|---|---|
| | | | 2009 | | Model | |
| | | | hectares | % | hectares | % |
| 1 | a | Farmsteads _ _ _ B | 2,720.43 | 8.68 | 2,720.43 | 8.68 |
| | b | Farmsteads _ _ _ C | 639.40 | 2.04 | 639.40 | 2.04 |
| | c | Farmsteads _ _ _ D | 960.37 | 3.06 | 960.37 | 3.06 |
| 2 | a | Rotation meadow _ Contoured _ Fair _ B | 2,460.60 | 7.85 | 2,390.36 | 7.63 |
| | b | Rotation meadow _ Contoured _ Fair _ C | 2,404.67 | 7.67 | 2,404.67 | 7.67 |
| | c | Rotation meadow _ Contoured _ Fair _ D | 211.24 | 0.67 | 211.24 | 0.67 |
| 3 | a | Row crops _ Contoured _ Poor _ B | 307.33 | 0.98 | 210.99 | 0.67 |
| | b | Row crops _ Contoured _ Poor _ D | 104.78 | 0.33 | 64.77 | 0.21 |
| 4 | a | Row crops _ Straight row _ Poor _ B | 104.66 | 0.33 | 0.00 | 0.00 |
| | b | Row crops _ Straight row _ Poor _ D | 483.43 | 1.54 | 316.40 | 1.01 |
| 5 | a | Small grain _ Contoured and terraced _ Poor _ B | 4,912.12 | 15.67 | 4,912.12 | 15.67 |
| | b | Small grain _ Contoured and terraced _ Poor _ C | 4,995.82 | 15.94 | 4,995.82 | 15.94 |
| | c | Small grain _ Contoured and terraced _ Poor _ D | 3,879.60 | 12.38 | 3,879.60 | 12.38 |
| 6 | a | Swamp _ _ B | 16.71 | 0.05 | 16.71 | 0.05 |
| 7 | a | Woodlands _ _ Fair _ B | 1,941.61 | 6.19 | 0.00 | 0.00 |
| | b | Woodlands _ _ Fair _ C | 1,594.02 | 5.09 | 0.00 | 0.00 |
| | c | Woodlands _ _ Fair _ D | 1,316.21 | 4.20 | 836.47 | 2.67 |
| | d | Woodlands _ _ Good _ A | 221.82 | 0.71 | 221.82 | 0.71 |
| | e | Woodlands _ _ Good _ B | 474.03 | 1.51 | 2,686.88 | 8.57 |
| | f | Woodlands _ _ Good _ C | 681.49 | 2.17 | 2,275.51 | 7.26 |
| | g | Woodlands _ _ Good _ D | 914.57 | 2.92 | 1,601.33 | 5.11 |
| | | Total | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: Computer and GIS Analysis

Mix garden at the land cover model-1 is regarded as woodlands with good hydrological condition; whilst in the 2009 as woodlands with fair hydrological condition. An assumption developed under consideration that in land use model, mix garden will not be harvested that trees continue to grow. Still, local farmers can have some profits, because among those trees are fruit trees. For fuel wood, they still can obtain branches from wooden trees.

To estimate runoff based on applying Model-1, it uses the same annual rainfall 2006 and Curve Numbers for calculating runoff 2006. After Curve Numbers are determined, runoff depth for each sub-watershed is calculated. The calculation is conducted by means of GIS analysis. Runoff depth is presented as 10 classes. The runoff class is given in Table 6.3, the comparison with runoff 2006 is presented in Table 6.4, and runoff map is shown in Figure 6.2.

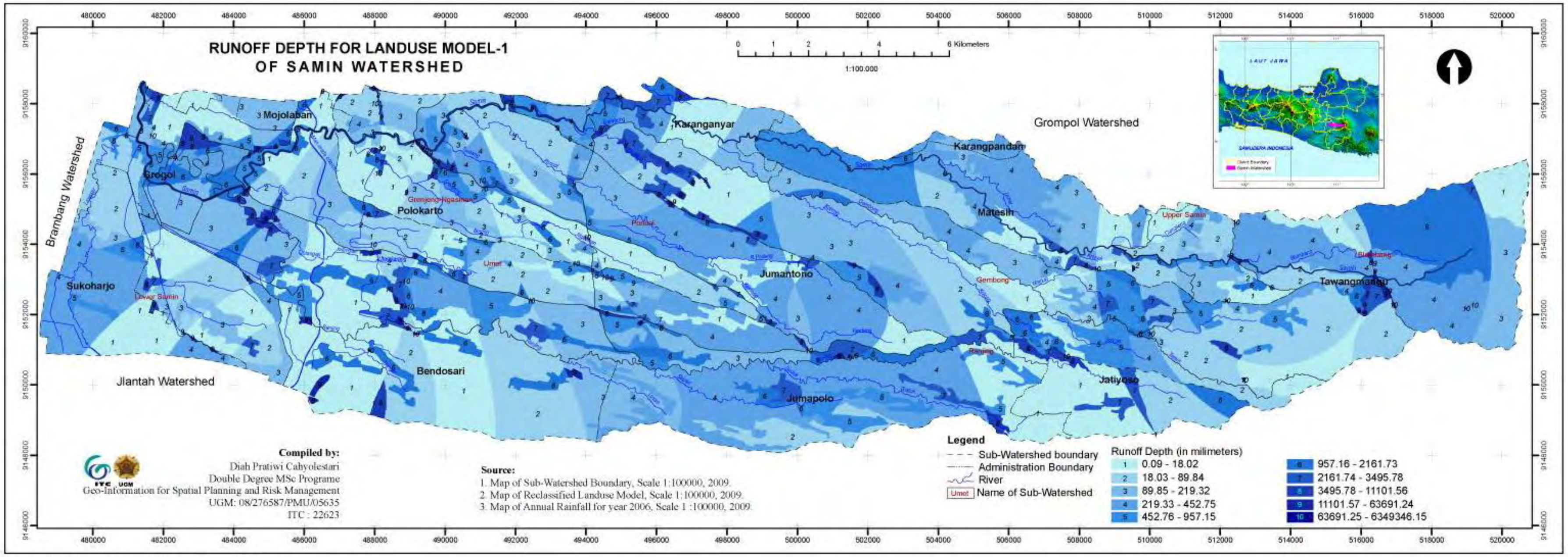



Figure 6.2. Runoff Depth for Landuse Model-1

Table 6.3. Runoff classification for land use Model-1

| Class | Runoff depth (mm) | Class | Runoff depth (mm) |
|---|---|---|---|
| 1 | 0.09 – 18.02 | 6 | 957.16 – 2161.73 |
| 2 | 18.03 – 89.84 | 7 | 2161.74 – 3495.78 |
| 3 | 89.85 – 219.32 | 8 | 3495.79 – 11101.56 |
| 4 | 219.33 – 452.75 | 9 | 11101.57 – 63691.24 |
| 5 | 452.76 – 957.15 | 10 | 63691.25 – 6349346.15 |

Source: GIS Analysis

Tabel 6.4 Comparison Runoff of 2006 and Model-1

| Sub Watershed | Landcover | Runoff depth (mm) | | % Runoff | |
|---|---|---|---|---|---|
| | | 2006 | Model | 2006 | Model |
| Blumbang | Forest | 1559102.700 | 3473585.02 | 53.4 | 81.9 |
| | Fruit and Vegetable Agricultural_lower slope | 631738.334 | 724990.18 | 21.6 | 17.1 |
| | Fruit and Vegetable Agricultural_upper slope | 191307.569 | 325.52 | 6.6 | 0.0 |
| | Mix Garden | 102703.954 | 7323.09 | 3.5 | 0.2 |
| | Paddy Field | 422347.609 | 33912.06 | 14.5 | 0.8 |
| | Settlement | 12539.034 | 25.24 | 0.4 | 0.0 |
| | Sub total | 2919739.200 | 4240161.11 | 100.0 | 100.0 |
| Gembong | Forest | 123896.508 | 175749.86 | 2.0 | 13.4 |
| | Fruit and Vegetable Agricultural_lower slope | 204633.235 | 118635.70 | 3.4 | 9.0 |
| | Fruit and Vegetable Agricultural_upper slope | 831.810 | | 0.0 | |
| | Mix Garden | 811397.977 | 36800.09 | 13.3 | 2.8 |
| | Paddy Field | 309492.525 | 27020.93 | 5.1 | 2.1 |
| | Settlement | 3245117.797 | 416970.83 | 53.3 | 31.7 |
| | Sugarcane Plantation | 1393486.863 | 539753.84 | 22.9 | 41.0 |
| | Sub total | 6088856.715 | 1314931.25 | 100.0 | 100.0 |
| Grenjeng-Ngasinan | Mix Garden | 1289439.509 | 1280511.97 | 12.4 | 21.6 |
| | Paddy Field | 2714006.067 | 1993912.15 | 26.2 | 33.6 |
| | Rubber Plantation | 816178.697 | 12868.89 | 7.9 | 0.2 |
| | Settlement | 5069913.538 | 2385445.94 | 48.9 | 40.2 |
| | Sugarcane Plantation | 473422.394 | 261955.38 | 4.6 | 4.4 |
| | Sub total | 10362960.205 | 5934694.33 | 100.0 | 100.0 |
| Lower Samin | Paddy Field | 1469993.131 | 390170.58 | 24.1 | 89.9 |
| | Settlement | 4620109.588 | 44041.28 | 75.9 | 10.1 |
| | Sub total | 6090102.719 | 434211.86 | 100.0 | 100.0 |
| Poncol | Mix Garden | 1421769.157 | 492216.49 | 24.9 | 29.0 |
| | Paddy Field | 2731647.369 | 70950.97 | 47.8 | 4.2 |
| | Rubber Plantation | 223054.012 | 5212.24 | 3.9 | 0.3 |
| | Settlement | 1296296.857 | 1130338.50 | 22.7 | 66.5 |
| | Sugarcane Plantation | 37822.309 | 1118.66 | 0.7 | 0.1 |
| | Sub total | 5710589.704 | 1699836.86 | 100.0 | 100.0 |
| Ranjing | Mix Garden | 130953.632 | 6658.96 | 1.3 | 0.1 |
| | Paddy Field | 1180764.212 | 7650352.57 | 12.0 | 60.7 |
| | Reservoir | 1522775.930 | 53663.25 | 15.5 | 0.4 |
| | Rubber Plantation | 1910249.063 | 418586.13 | 19.5 | 3.3 |
| | Settlement | 5000558.660 | 1079741.52 | 51.0 | 8.6 |
| | Sugarcane Plantation | 63247.671 | 3392982.62 | 0.6 | 26.9 |
| | Sub total | 9808549.168 | 12601985.05 | 100.0 | 100.0 |

| | | | | | |
|---|---|---|---|---|---|
| Umet | Mix Garden | 3289817.080 | 167551.43 | 41.9 | 9.2 |
| | Paddy Field | 998054.075 | 1474790.46 | 12.7 | 80.7 |
| | Rubber Plantation | 183706.768 | 3606.82 | 2.3 | 0.2 |
| | Settlement | 3016756.707 | 169113.86 | 38.4 | 9.3 |
| | Sugarcane Plantation | 358065.451 | 11878.73 | 4.6 | 0.7 |
| | Sub total | 7846400.081 | 1826941.30 | 100.0 | 100.0 |
| Upper Samin | Forest | 7411.757 | 4232487.40 | 0.2 | 91.4 |
| | Fruit and Vegetable Agricultural_upper slope | 5782.108 | 28.43 | 0.2 | 0.0 |
| | Mix Garden | 706376.265 | 54443.29 | 19.1 | 1.2 |
| | Paddy Field | 1572644.142 | 160065.35 | 42.6 | 3.5 |
| | Settlement | 1403564.268 | 3665.44 | 38.0 | 0.1 |
| | Sugarcane Plantation | | 181107.54 | | 3.9 |
| | Sub total | 3695778.540 | 4631797.45 | 100.0 | 100.0 |
| Total | | 52,522,976.332 | 32,684,559.210 | | |

Source: GIS Analysis, 2009

Thus, total runoff depth after applying land use model over Samin Watershed is 32,684,559.21 milimeters. It means that runoff decreases about 19,838,417 milimeters or 37.77 percent. When we compare, either total runoff per sub-watershed or the percentage to sub-watershed area, not every sub-watershed has decreasing runoff. For example, Blumbang increase 45%, Ranjing and Upper Samin are 28% and 25% respectively. On the other hand, Gembong, Grenjeng-Ngasinan, Lower Samin, Poncol, and Umet decrease 78%, 43%, 93%, 70%, and 76% respectively.

Blumbang Sub-watershed has a unique phenomenon. Blumbang has all four hydrological soil-groups, starts from group A at upper part, and ends up by group D at lower part of the sub-watershed. Group D has a very low infiltration. It means that eventhough forest coverage is added by converting fruit and vegetable agricultural, there is still surface runoff.

Ranjing and Upper Samin Sub-watershed have many tributaries. When rain falls over this area, it flows right away through tributaries, and becomes surface runoff. In addition, these sub-watersheds have a group D of hydrological soil-group. Combination of these two facts increases surface runoff.

After runoff depth per sub-watershed is determined, peak discharge is estimated. With the same procedure as runoff calculation of US-SCS, Table 6.5 gives the result.

Table 6.5. Peak discharge calculation after applying land use Model-1

| Nr. | Sub-watershed | Area A (sq.km) | Runoff Q (mm) | Tp (hour) | $q_p = 0.208 \frac{A\,Q}{T_p}$ ($m^3/s$) |
|---|---|---|---|---|---|
| 1. | Blumbang | 24.9916 | 4240161.11 | 0.593 | 37198713.567 |
| 2. | Gembong | 65.4625 | 1314931.25 | 2.452 | 7303296.927 |
| 3. | Grenjeng-Ngasinan | 18.7650 | 5934694.33 | 1.782 | 12997562.673 |
| 4. | Lower Samin | 33.2328 | 434211.86 | 5.048 | 594629.288 |
| 5. | Poncol | 28.2260 | 1699836.86 | 2.635 | 3787974.775 |

| | | | | | |
|---|---|---|---|---|---|
| 6. | Ranjing | 92.8631 | 12601985.05 | 4.202 | 58484341.413 |
| 7. | Umet | 22.3267 | 1826941.3 | 3.316 | 2560606.425 |
| 8. | Upper Samin | 27.5809 | 4631797.45 | 1.489 | 17845470.502 |
| Total watershed | | | | | 140772595.570 |

Source: Computer analysis, 2009.

After applying land use Model-1 for Samin Watershed, peak discharge of Samin River for one year becomes 140,772,595.570 m³/s. With a peak discharge 2006 is 173,951,504.858 m³/s, it means that a discharge flowing Samin River decrease 33,178,909.288 m³/s or 19 percent decrease.

6.2.2 *Land Cover Model-2*

Developing Land Cover Model-2 is conducted by adding area of mix garden, which has the same hydrological soil-cover complexes relating to land treatment with forest. The conversion aims to be more realible for local farmers, because with mix garden, they still can harvest the fruit and branches for domestic use and economical reason. Another conversion done in this model is to convert sugarcane plantation in Ranjing Sub-watershed into mix garden. Ranjing Sub-watershed is chosen because it has high surface runoff, especially contributed by sugarcane coverage. In addition, sugarcane plantation is treated as rotational meadow with heavily harvested. Therefore, this land cover conversion and comparison of reclassified land use regarding land treatment is presented in Table 6.6 and Table 6.7. Reclassified land use is, then, given in Figure 6.3.

Table 6.6 Comparison between land cover 2006 and land cover Model-2

| LANDCOVER | AREA | | | |
|---|---|---|---|---|
| | 2009 | % of total area | Model_2 | % of total area |
| Forest | 2,291.94 | 7.31 | 2,291.94 | 7.31 |
| Fruit and Vegetable Agricultural | 1,000.10 | 3.19 | 1,146.98 | 3.66 |
| Mix Garden | 4,015.38 | 12.81 | 4,307.00 | 13.74 |
| Paddy Field | 13,787.84 | 43.99 | 13,787.84 | 43.99 |
| Reservoir | 16.60 | 0.05 | 16.60 | 0.05 |
| Rubber Plantation | 836.36 | 2.67 | 836.36 | 2.67 |
| Settlement | 4,320.24 | 13.78 | 4,320.24 | 13.78 |
| Sugarcane Plantation | 5,076.40 | 16.20 | 4,637.89 | 14.80 |
| Total | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: GIS Analysis

Table 6.7 Comparison between reclassified land use realing with land treatment of 2009 and Model-2

| Hydrological Soil-Cover Complexes in various Hydrological Soil-Group | AREA | | | |
|---|---|---|---|---|
| | 2009 | % of total area | Model_2 | % of total area |
| Farmsteads _ _ _ B | 2,720.42 | 8.68 | 3,325.65 | 10.61 |
| Farmsteads _ _ _ C | 639.40 | 2.04 | 340.50 | 1.09 |
| Farmsteads _ _ _ D | 960.37 | 3.06 | 654.04 | 2.09 |
| Rotation meadow _ Contoured _ Poor _ B | 2,460.60 | 7.85 | 2,294.37 | 7.32 |
| Rotation meadow _ Contoured _ Poor _ C | 2,404.67 | 7.67 | 2,224.68 | 7.10 |
| Rotation meadow _ Contoured _ Poor _ D | 211.24 | 0.67 | 118.82 | 0.38 |
| Row crops _ Contoured _ Poor _ B | 307.32 | 0.98 | 411.98 | 1.31 |
| Row crops _ Contoured _ Poor _ C | | - | 81.15 | 0.26 |
| Row crops _ Contoured _ Poor _ D | 104.77 | 0.33 | 206.51 | 0.66 |
| Row crops _ Straight row _ Poor _ B | 104.66 | 0.33 | - | - |
| Row crops _ Straight row _ Poor _ C | | - | 65.84 | 0.21 |
| Row crops _ Straight row _ Poor _ D | 483.43 | 1.54 | 381.70 | 1.22 |
| Small grain _ Contoured and terraced _ Poor _ B | 4,912.12 | 15.67 | 4,912.12 | 15.67 |
| Small grain _ Contoured and terraced _ Poor _ C | 4,995.81 | 15.94 | 4,995.81 | 15.94 |
| Small grain _ Contoured and terraced _ Poor _ D | 3,879.60 | 12.38 | 3,879.60 | 12.38 |
| Swamp _ _ B | 16.71 | 0.05 | 16.71 | 0.05 |
| Woodlands _ _ Fair _ B | 1,941.61 | 6.19 | - | - |
| Woodlands _ _ Fair _ C | 1,594.02 | 5.09 | - | - |
| Woodlands _ _ Fair _ D | 1,316.20 | 4.20 | 836.47 | 2.67 |
| Woodlands _ _ Good _ A | 221.82 | 0.71 | 221.82 | 0.71 |
| Woodlands _ _ Good _ B | 474.03 | 1.51 | 2,581.86 | 8.24 |
| Woodlands _ _ Good _ C | 681.49 | 2.17 | 2,308.50 | 7.36 |
| Woodlands _ _ Good _ D | 914.56 | 2.92 | 1,486.72 | 4.74 |
| T o t a l | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: GIS Analysis, 2009

Estimating runoff for Model-2 is conducted for each sub-watershed using CN-SCS Method. Calculation result then is compared with estimated runoff 2006, The result and comparison is presented in Table 6.8.

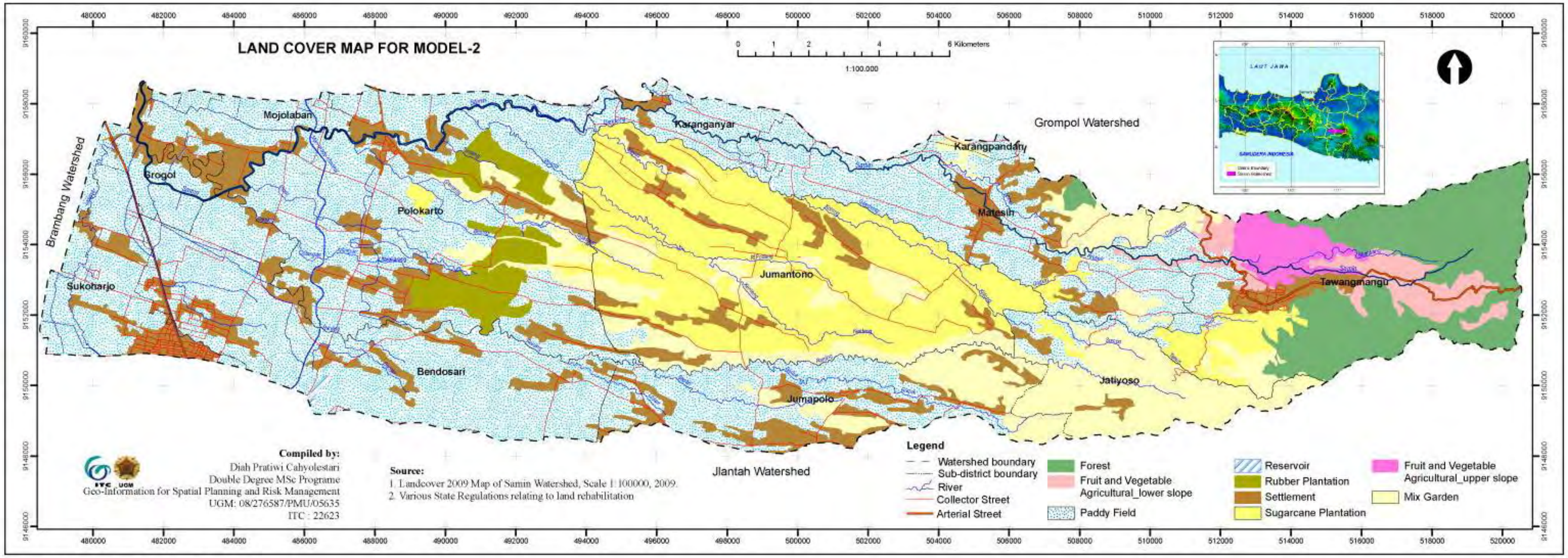



Figure 6.3. Landcover Map for Model-2

Table 6.8 Comparison of Runoff Depth bertween 2006 and Model-2

| Sub-Watershed | Land Cover | Runoff Depth (mm) | | Runoff percentage to total sub watershed | |
|---|---|---|---|---|---|
| | | 2006 | Model_2 | 2006 | Model_2 |
| Blumbang | Forest | 1,559,102.70 | 1,273,423,245.55 | 53.40 | 99.94 |
| | Fruit and Vegetable | 631,738.33 | 699,436.45 | 21.64 | 0.05 |
| | Fruit and Vegetable | 191,307.57 | 19,836.76 | 6.55 | 0.00 |
| | Mix Garden | 102,703.95 | | 3.52 | |
| | Paddy Field | 422,347.61 | 33,923.56 | 14.47 | 0.00 |
| | Settlement | 12,539.03 | 25.23 | 0.43 | 0.00 |
| | Sub total | 2,919,739.20 | 1,274,176,467.55 | 100.00 | 100.00 |
| Gembong | Forest | 123,896.51 | 22,699.02 | 2.03 | 1.99 |
| | Fruit and Vegetable | 204,633.24 | 96,433.96 | 3.36 | 8.48 |
| | Fruit and Vegetable | 831.81 | | 0.01 | |
| | Mix Garden | 811,397.98 | 48,399.79 | 13.33 | 4.25 |
| | Paddy Field | 309,492.53 | 27,022.44 | 5.08 | 2.37 |
| | Settlement | 3,245,117.80 | 438,076.44 | 53.30 | 38.50 |
| | Sugarcane Plantation | 1,393,486.86 | 505,181.75 | 22.89 | 44.40 |
| | Sub total | 6,088,856.72 | 1,137,813.39 | 100.00 | 100.00 |
| Grenjeng-Ngasinan | Mix Garden | 1,289,439.51 | 1,383,973.61 | 12.44 | 19.51 |
| | Paddy Field | 2,714,006.07 | 1,949,142.15 | 26.19 | 27.48 |
| | Rubber Plantation | 816,178.70 | 1,049,482.70 | 7.88 | 14.80 |
| | Settlement | 5,069,913.54 | 2,455,193.37 | 48.92 | 34.61 |
| | Sugarcane Plantation | 473,422.39 | 255,451.93 | 4.57 | 3.60 |
| | Sub total | 10,362,960.21 | 7,093,243.76 | 100.00 | 100.00 |
| Lower Samin | Paddy Field | 1,469,993.13 | 391,766.07 | 24.14 | 0.73 |
| | Settlement | 4,620,109.59 | 53,232,914.49 | 75.86 | 99.27 |
| | Sub total | 6,090,102.72 | 53,624,680.56 | 100.00 | 100.00 |
| Poncol | Mix Garden | 1,421,769.16 | 531,664.45 | 24.90 | 31.03 |
| | Paddy Field | 2,731,647.37 | 71,056.77 | 47.83 | 4.15 |
| | Rubber Plantation | 223,054.01 | 5,211.83 | 3.91 | 0.30 |
| | Settlement | 1,296,296.86 | 1,104,512.48 | 22.70 | 64.46 |
| | Sugarcane Plantation | 37,822.31 | 1,171.33 | 0.66 | 0.07 |
| | Sub total | 5,710,589.70 | 1,713,616.86 | 100.00 | 100.00 |
| Ranjing | Mix Garden | 130,953.63 | 47,349,253.99 | 1.34 | 25.67 |
| | Paddy Field | 1,180,764.21 | 97,617,000.99 | 12.04 | 52.93 |
| | Reservoir | 1,522,775.93 | 323,488.59 | 15.52 | 0.18 |
| | Rubber Plantation | 1,910,249.06 | 420,582.93 | 19.48 | 0.23 |
| | Settlement | 5,000,558.66 | 38,717,569.27 | 50.98 | 20.99 |
| | Sugarcane Plantation | 63,247.67 | | 0.64 | |
| | Sub total | 9,808,549.17 | 184,427,895.76 | 100.00 | 100.00 |
| Umet | Mix Garden | 3,289,817.08 | 171,064.92 | 41.93 | 0.56 |
| | Paddy Field | 998,054.08 | 30,415,534.04 | 12.72 | 98.83 |
| | Rubber Plantation | 183,706.77 | 7,383.54 | 2.34 | 0.02 |
| | Settlement | 3,016,756.71 | 169,146.53 | 38.45 | 0.55 |
| | Sugarcane Plantation | 358,065.45 | 11,468.35 | 4.56 | 0.04 |
| | Sub total | 7,846,400.08 | 30,774,597.38 | 100.00 | 100.00 |
| Upper Samin | Forest | 7,411.76 | 140.41 | 0.20 | 0.04 |
| | Fruit and Vegetable | 5,782.11 | 5,965.30 | 0.16 | 1.51 |
| | Mix Garden | 706,376.27 | 47,754.72 | 19.11 | 12.12 |
| | Paddy Field | 1,572,644.14 | 166,913.45 | 42.55 | 42.36 |
| | Settlement | 1,403,564.27 | 4,814.86 | 37.98 | 1.22 |
| | Sugarcane Plantation | | 168,439.87 | | 42.75 |
| | Sub total | 3,695,778.54 | 394,028.62 | 100.00 | 100.00 |
| T o t a l | | 52,522,976.33 | 1,553,342,343.88 | | |

Source: GIS Analysis, 2009

Total annual runoff after applying Model-3 increases 1,500,819,367.55 milimeters compare with estimated runoff 2006. Table above indicates that Blumbang Sub-watershed experience an extreme increase of runoff. Model-2 converts mix garden into fruit and vegetable agricultural coverage, and makes increasing surface runoff. Model-2 is only effective to decrease runoff in Grenjeng-Ngasinan, Lower Samin, Ranjing and Upper Samin. Runoff calculation is mapped as shown in Figure 6.4. For peak discharge calculation, Table 6.9 presents this.

Table 6.9. Peak discharge calculation after applying land use Model-2

| Nr. | Sub-watershed | Area A (sq.km) | Runoff Q (mm) | Tp (hour) | $q_p = 0.208 \frac{A\,Q}{T_p}$ (m³/s) |
|---|---|---|---|---|---|
| 1. | Blumbang | 24.9916 | 1,274,176,467.55 | 0.593 | 11,178,284,084.17 |
| 2. | Gembong | 65.4625 | 1,137,813.39 | 2.452 | 6,319,561.60 |
| 3. | Grenjeng-Ngasinan | 18.7650 | 7,093,243.76 | 1.782 | 15,534,899.56 |
| 4. | Lower Samin | 33.2328 | 53,624,680.56 | 5.048 | 73,436,054.00 |
| 5. | Poncol | 28.2260 | 1,713,616.86 | 2.635 | 3,818,682.60 |
| 6. | Ranjing | 92.8631 | 184,427,895.76 | 4.202 | 855,908,333.40 |
| 7. | Umet | 22.3267 | 30,774,597.38 | 3.316 | 43,133,094.52 |
| 8. | Upper Samin | 27.5809 | 394,028.62 | 1.489 | 1,518,120.38 |
| Total watershed | | | | | 12,177,952,830.23 |

Source: Computer analysis, 2009.

Peak discharge after applying Model-3 is 12,177,952,830.23 m³/s, when compare to runoff 2006, 173,951,504.858 m³/s, it increases about 12,004,001,325 m³/s, in other word, increases 6900 percent. Therefore, Model-2 is not good enough to be applied to reduce both runoff and peak discharge.

### 6.2.3 *Land Cover Model-3*

Land Cover Model-3 is developed by converting coverage of upper slope’s agricultural to forest. Special treatment is also performed in Model-3, i.e treating sugarcane plantation by moderately grazed with 50-70% plant cover. It is necessary to manage sugarcane harvesting by arranging harvest season, so that there is still plant cover in some part of such a big plantation. In other words, local farmers are asked not to plant sugarcane in the same time. By switching sugarcane treatment, the hydrologic condition changes into “fair”. Reclassified land cover of Model-3 is presented in Figure 6.5 and comparison of reclassified land use regarding land treatment is presented in Table 6.10 and Table 6.11.

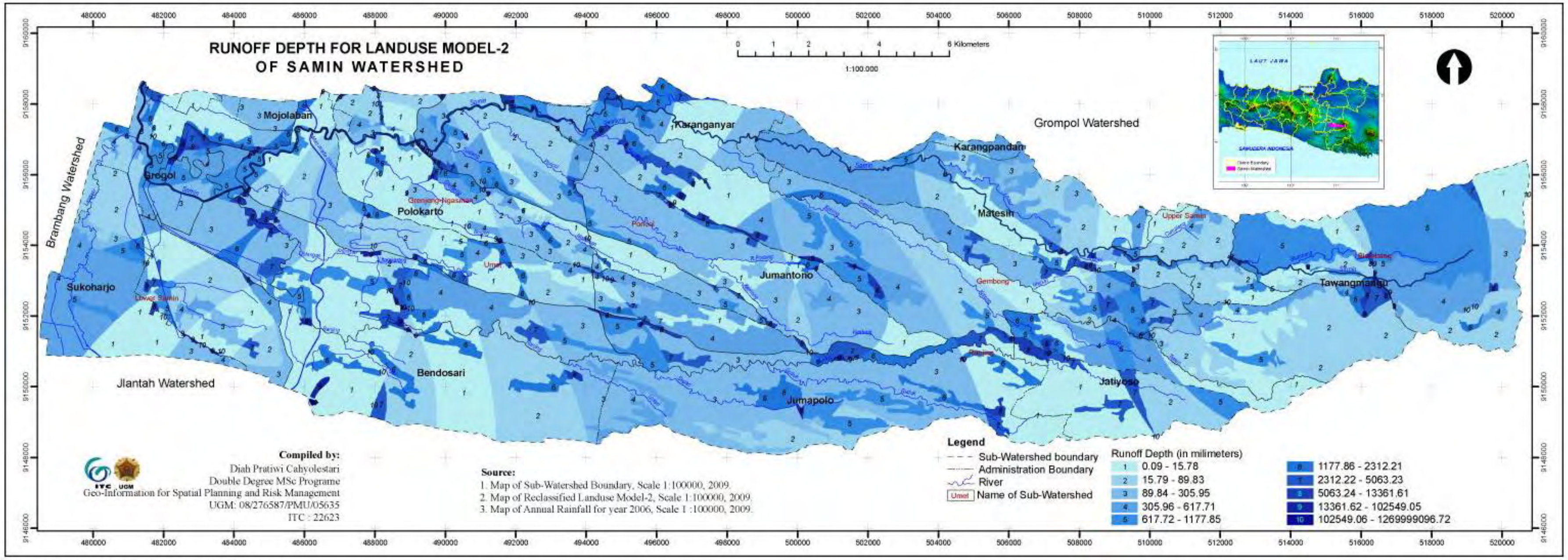


Figure 6.4. Runoff Depth for Landuse Model-2

Table 6.10 Land Cover Comparison between 2006 and Model-3

| LANDCOVER | AREA | | | |
|---|---|---|---|---|
| | 2009 | | Model-3 | |
| Forest | 2,291.94 | 7.31 | 2,739.94 | 8.74 |
| Fruit and Vegetable Agricultural | 1,000.10 | 3.19 | 609.17 | 1.94 |
| Mix Garden | 4,015.38 | 12.81 | 4,015.37 | 12.81 |
| Paddy Field | 13,787.84 | 43.99 | 13,787.54 | 43.99 |
| Reservoir | 16.60 | 0.05 | 16.71 | 0.05 |
| Rubber Plantation | 836.36 | 2.67 | 836.47 | 2.67 |
| Settlement | 4,320.24 | 13.78 | 4,320.20 | 13.78 |
| Sugarcane Plantation | 5,076.40 | 16.20 | 5,019.44 | 16.01 |
| T o t a l | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: GIS Anlysis, 2009

Table 6.10 shows that there are increasing forest coverage. It occurs in Blumbang Sub-watershed since there is increasing runoff after applying Model-2 by converting forest in the sub-watershed into agricultural.

Table 6.11 Reclassified Land Use between 2006 and Model-3

| Hydrological Soil-Cover Complexes in various Hydrological Soil-Groups | Area (hectares) | | | |
|---|---|---|---|---|
| | 2009 | % of total area | Model_2 | % of total area |
| Farmsteads _ _ _ B | 2,720.42 | 8.68 | 2,720.43 | 8.68 |
| Farmsteads _ _ _ C | 639.40 | 2.04 | 639.40 | 2.04 |
| Farmsteads _ _ _ D | 960.37 | 3.06 | 960.37 | 3.06 |
| Rotation meadow _ Contoured _ Fair _ B | 2,460.60 | 7.85 | 2,403.53 | 7.67 |
| Rotation meadow _ Contoured _ Fair _ C | 2,404.67 | 7.67 | 2,404.67 | 7.67 |
| Rotation meadow _ Contoured _ Fair _ D | 211.24 | 0.67 | 211.24 | 0.67 |
| Row crops _ Contoured _ Poor _ B | 307.32 | 0.98 | 145.90 | 0.47 |
| Row crops _ Contoured _ Poor _ D | 104.77 | 0.33 | 76.41 | 0.24 |
| Row crops _ Straight row _ Poor _ B | 104.66 | 0.33 | 84.92 | 0.27 |
| Row crops _ Straight row _ Poor _ D | 483.43 | 1.54 | 301.95 | 0.96 |
| Small grain _ Contoured and terraced _ Poor _ B | 4,912.12 | 15.67 | 4,912.12 | 15.67 |
| Small grain _ Contoured and terraced _ Poor _ C | 4,995.81 | 15.94 | 4,995.82 | 15.94 |
| Small grain _ Contoured and terraced _ Poor _ D | 3,879.60 | 12.38 | 3,879.60 | 12.38 |
| Swamp _ _ B | 16.71 | 0.05 | 16.71 | 0.05 |
| Woodlands _ _ Fair _ B | 1,941.61 | 6.19 | 836.47 | 2.67 |
| Woodlands _ _ Fair _ C | 1,594.02 | 5.09 | - | - |
| Woodlands _ _ Fair _ D | 1,316.20 | 4.20 | - | - |
| Woodlands _ _ Good _ A | 221.82 | 0.71 | 221.82 | 0.71 |
| Woodlands _ _ Good _ B | 474.03 | 1.51 | 2,653.83 | 8.47 |
| Woodlands _ _ Good _ C | 681.49 | 2.17 | 2,275.51 | 7.26 |
| Woodlands _ _ Good _ D | 914.56 | 2.92 | 1,604.15 | 5.12 |
| T o t a l | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: GIS Anlysis, 2009

Table 6.11 explains that row crops coverage of straight row treatment decrease 46 percent, while ones of contoured treatment decrease 34 percent. It is also known that woodlands coverage add up to 195 percent, while rotational meadow decreases 1 percent.

After reclassifying land cover, runoff is started to calculate, still using CN-SCS Method. By overlaying maps of reclassified land use, annual rainfall 2006, and weighted Curves Numbers, the computations is run by means of data attribute modification of overlaid map. Runoff calculation is, then, presented in Table 6.12 along with comparison to runoff 2006.

Table 6.12 Runoff Calculation of Applied Land Cover Model-3 and comparison to runoff 2006

| Sub Watershed | Landcover | Runoff depth (mm) | | % Runoff | |
|---|---|---|---|---|---|
| | | 2006 | Model-3 | 2006 | Model-3 |
| Blumbang | Forest | 1,559,102.700 | 4.83 | 53.399 | 0.013532 |
| | Fruit and Vegetable Agricultural_lower slope | 631,738.334 | 1,571.53 | 21.637 | 4.402755 |
| | Fruit and Vegetable Agricultural_upper slope | 191,307.569 | 146.75 | 6.552 | 0.411131 |
| | Mix Garden | 102,703.954 | 22.34 | 3.518 | 0.062587 |
| | Paddy Field | 422,347.609 | 33,923.56 | 14.465 | 95.03931 |
| | Settlement | 12,539.034 | 25.23 | 0.429 | 0.070684 |
| | Sub total | 2,919,739.200 | 35,694.240 | 100.000 | 100.000 |
| Gembong | Forest | 123,896.508 | 36.61 | 2.035 | 0.044289 |
| | Fruit and Vegetable Agricultural_lower slope | 204,633.235 | 1,651.09 | 3.361 | 1.997419 |
| | Fruit and Vegetable Agricultural_upper slope | 831.810 | 75,856.13 | 0.014 | 91.76755 |
| | Mix Garden | 811,397.977 | 835.76 | 13.326 | 1.011067 |
| | Paddy Field | 309,492.525 | 1,995.02 | 5.083 | 2.413491 |
| | Settlement | 3,245,117.797 | 2,209.55 | 53.296 | 2.67302 |
| | Sugarcane Plantation | 1,393,486.863 | 77.01 | 22.886 | 0.093163 |
| | Sub total | 6,088,856.715 | 82,661.170 | 100.000 | 100.000 |
| Grenjeng-Ngasinan | Mix Garden | 1,289,439.509 | 480.28 | 12.443 | 0.046057 |
| | Paddy Field | 2,714,006.067 | 77.42 | 26.189 | 0.007424 |
| | Rubber Plantation | 816,178.697 | 1,015,304.71 | 7.876 | 97.36277 |
| | Settlement | 5,069,913.538 | 750.44 | 48.923 | 0.071964 |
| | Sugarcane Plantation | 473,422.394 | 26,193.00 | 4.568 | 2.511781 |
| | Sub total | 10,362,960.205 | 1,042,805.850 | 100.000 | 100.000 |
| Lower Samin | Paddy Field | 1,469,993.131 | 4,810.32 | 24.137 | 28.24796 |
| | Settlement | 4,620,109.588 | 12,218.59 | 75.863 | 71.75204 |
| | Sub total | 6,090,102.719 | 17,028.910 | 100.000 | 100.000 |
| Poncol | Mix Garden | 1,421,769.157 | 460.14 | 24.897 | 8.175528 |
| | Paddy Field | 2,731,647.369 | 396.75 | 47.835 | 7.049248 |
| | Rubber Plantation | 223,054.012 | 4,242.28 | 3.906 | 75.37463 |
| | Settlement | 1,296,296.857 | 522.25 | 22.700 | 9.279067 |
| | Sugarcane Plantation | 37,822.309 | 6.84 | 0.662 | 0.12153 |
| | Sub total | 5,710,589.704 | 5,628.260 | 100.000 | 100.000 |
| Ranjing | Mix Garden | 130,953.632 | 2,444.59 | 1.335 | 0.002308 |
| | Paddy Field | 1,180,764.212 | 105,832,721.04 | 12.038 | 99.91831 |
| | Reservoir | 1,522,775.930 | 68,309.92 | 15.525 | 0.064492 |
| | Rubber Plantation | 1,910,249.063 | 316.39 | 19.475 | 0.000299 |
| | Settlement | 5,000,558.660 | 12,449.63 | 50.982 | 0.011754 |
| | Sugarcane Plantation | 63,247.671 | 3,006.63 | 0.645 | 0.002839 |
| | Sub total | 9,808,549.168 | 105,919,248.200 | 100.000 | 100.000 |
| Umet | Mix Garden | 3,289,817.080 | 620.21 | 41.928 | 0.002148 |
| | Paddy Field | 998,054.075 | 28,862,982.50 | 12.720 | 99.98153 |
| | Rubber Plantation | 183,706.768 | 3,496.10 | 2.341 | 0.012111 |
| | Settlement | 3,016,756.707 | 2.67 | 38.448 | 9.25E-06 |

| | | | | | |
|---|---|---|---|---|---|
| | Sugarcane Plantation | 358,065.451 | 1,211.83 | 4.563 | 0.004198 |
| | Sub total | 7,846,400.081 | 28,868,313.310 | 100.000 | 100.000 |
| Upper Samin | Forest | 7,411.757 | 566,961.97 | 0.201 | 2.055634 |
| | Fruit and Vegetable Agricultural_upper slope | 5,782.108 | 1,083,976.64 | 0.156 | 3.930174 |
| | Mix Garden | 706,376.265 | 6,118,465.25 | 19.113 | 22.18372 |
| | Paddy Field | 1,572,644.142 | 15,656,684.77 | 42.552 | 56.76644 |
| | Settlement | 1,403,564.268 | 4,039,299.80 | 37.977 | 14.64529 |
| | Sugarcane Plantation | - | 115,492.22 | - | 0.41874 |
| | Sub total | 3,695,778.540 | 27,465,388.429 | 100.000 | 100.000 |
| T o t a l | | 52,522,976.332 | 163,436,768.369 | | |

Source: GIS Analysis, 2009

Runoff calculation as a result of applying Land Cover Model-3, in fact, does not reduce runoff over Samin Watershed. But when analyzing is done for each sub-watershed, there are sub-watersheds with decreasing runoff, i.e Blumbang, Gembong, Grenjeng-Ngasinan, Lower Samin, and Poncol. For that, converting sugarcane plantation treatment at Ranjing and Umet Sub-watershed has a low significance in terms of runoff decreasing. Runoff is mapped as shown in Figure 6.6.

Peak discharge estimation is, then, conducted under consideration of calculated runoff for Model-3. The calculation is presented in Table 6.13 as follows.

Table 6.13. Peak discharge calculation after applying land use Model-3

| Nr. | Sub-watershed | Area A (sq.km) | Runoff Q (mm) | Tp (hour) | $q_p = 0.208 \frac{A\,Q}{T_p}$ (m³/s) |
|---|---|---|---|---|---|
| 1. | Blumbang | 24.9916 | 35,694.24 | 0.593 | 313,143.72 |
| 2. | Gembong | 65.4625 | 82,661.17 | 2.452 | 459,110.75 |
| 3. | Grenjeng-Ngasinan | 18.7650 | 1,042,805.85 | 1.782 | 2,283,847.10 |
| 4. | Lower Samin | 33.2328 | 17,028.91 | 5.048 | 23,320.16 |
| 5. | Poncol | 28.2260 | 5,628.26 | 2.635 | 12,542.21 |
| 6. | Ranjing | 92.8631 | 105,919,248.20 | 4.202 | 491,558,865.48 |
| 7. | Umet | 22.3267 | 28,868,313.31 | 3.316 | 40,461,282.76 |
| 8. | Upper Samin | 27.5809 | 27,465,388.43 | 1.489 | 105,819,130.55 |
| Total watershed | | | | | 640,931,242.71 |

Source: Computer analysis, 2009.

Ranjing, Umet and Upper Samin Sub-watershed do not have decreasing peak discharge after land cover Model-3 is applied. Overall, peak discharge under this model is increase 268 percent compare to runoff 2006. Ranjing Sub-watershed is the biggest contibutor for increasing discharge over Samin Watershed, followed by Upper Samin Sub-watershed. Because of the shape of watershed and its tributaries, Ranjing has already has a high peak discharge. A solution proposed to overcome overland flow in Ranjing is strengtening river embankment and/ or natural levee so water will not flow over right-and-left side of river.

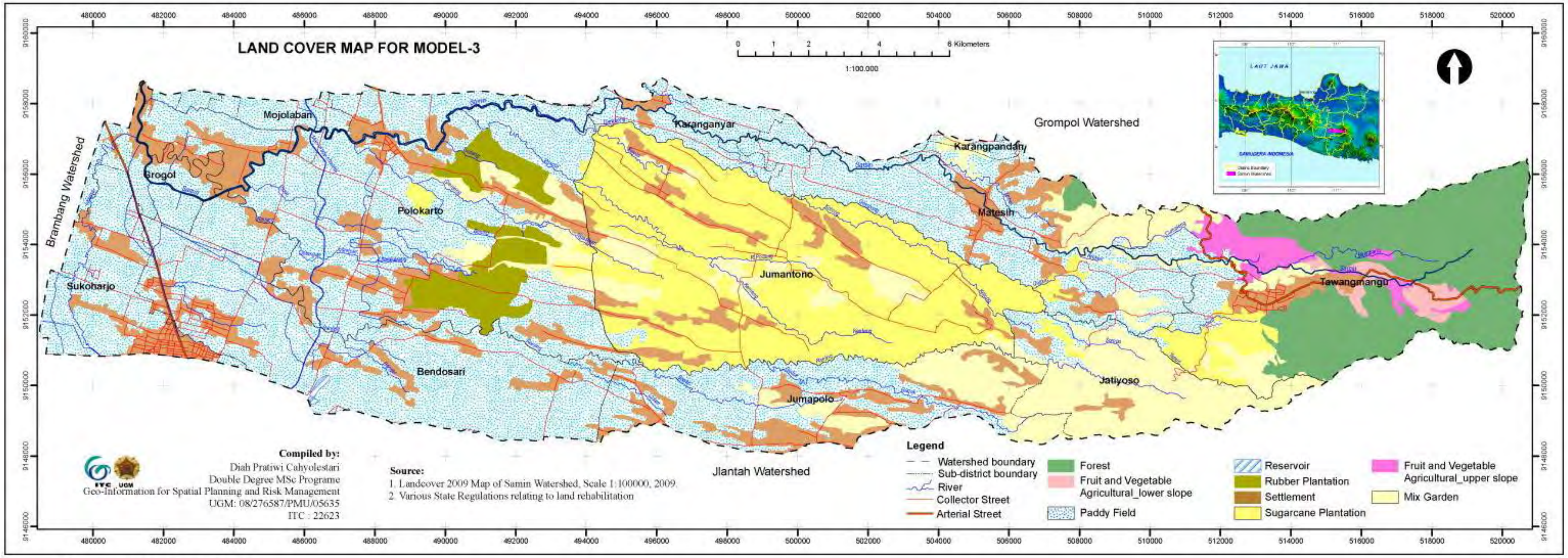


Figure 6.5. Landcover Map for Model-3

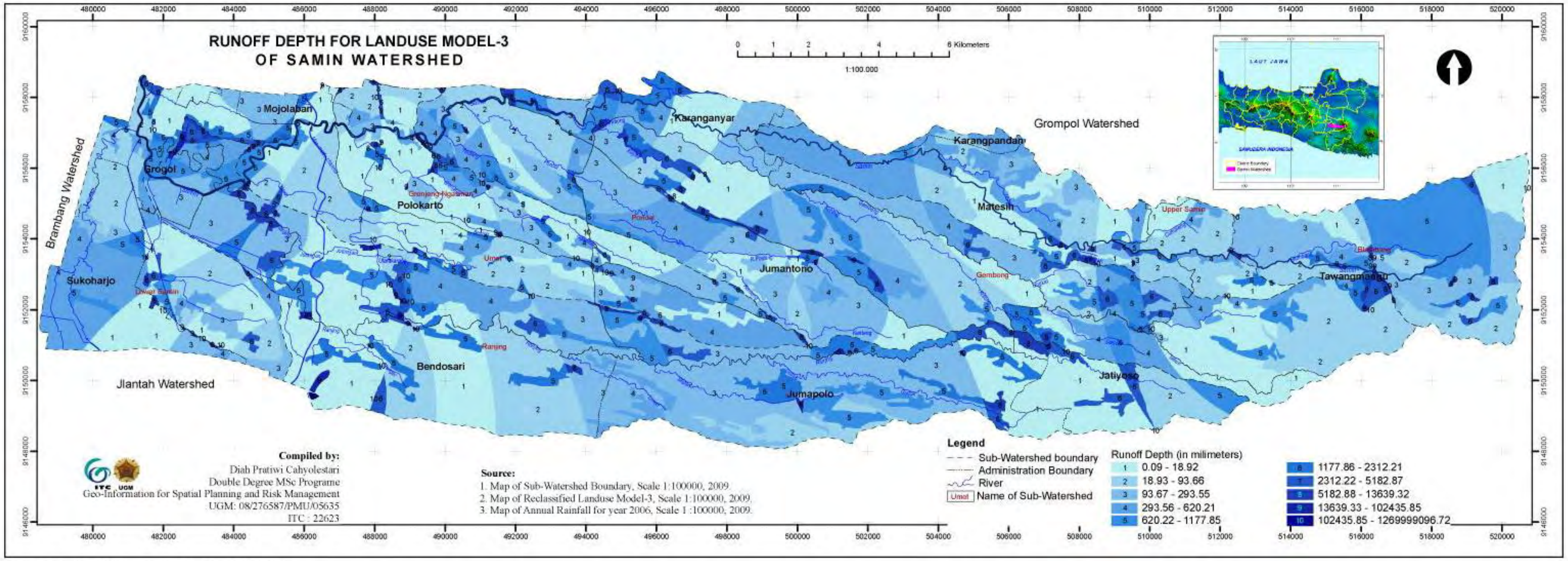



Figure 6.6. Runoff Depth for Landuse Model-3

### 6.2.4 Land Cover Model-4

This model is build by an assumption that each sub-watershed has individul land cover type. Different type of land cover developed in the three models before is analyzed regarding to the ability to reduce runoff. Table 6.14 shows runoff for each sub-watershed relating to three models developed.

Table 6.14 Runoff for each Sub-watershed regarding to Model's Application

| Sub Watershed | Runoff Depth (mm) | | | |
|---|---|---|---|---|
| | 2006 | Model 1 | Model 2 | Model 3 |
| Blumbang | 2,919,739.200 | 4,240,161.110 | 1,274,176,467.549 | 35,694.24 |
| Gembong | 6,088,856.715 | 1,314,931.250 | 1,137,813.390 | 82,661.17 |
| Grenjeng-Ngasinan | 10,362,960.205 | 5,934,694.330 | 7,093,243.763 | 1,042,805.85 |
| Lower Samin | 6,090,102.719 | 434,211.860 | 53,624,680.555 | 17,028.91 |
| Poncol | 5,710,589.704 | 1,699,836.860 | 1,713,616.860 | 5,628.26 |
| Ranjing | 9,808,549.168 | 12,601,985.050 | 184,427,895.764 | 105,919,248.20 |
| Umet | 7,846,400.081 | 1,826,941.300 | 30,774,597.375 | 28,868,313.31 |
| Upper Samin | 3,695,778.540 | 4,631,797.450 | 394,028.622 | 27,580,880.65 |

Compare to runoff 2006, Blumbang, Gembong, Grenjeng-Ngasinan, Lower Samin and Poncol have decreasing runoff after applying Model-3. Umet reduce its runoff following application of Model-1, and Model-2 is effective to reduce runoff in Upper Samin. To choose which type of land cover is the most appropriate to reduce runoff in Ranjing, the lowest value is taken, i.e after applying Model-1.

Land cover for each model in each sub-watershed is selected. Then these sub-watersheds is combined with ArcGIS's Analysis tools, union operation. After the whole watershed is build, then attribute data is added a new field of reclassified land use. The result is presented in Figure 6.7. Comparison of land cover and reclassified land use are presented in Table 6.15 and Table 6.16 respectively.

Table 6.15 Land Cover Comparison of 2009 and Model-4

| LANDCOVER | AREA | | | |
|---|---|---|---|---|
| | 2009 | % of total area | Model_4 | % of total area |
| Forest | 2,291.94 | 7.31 | 2,739.93 | 8.74 |
| Fruit and Vegetable Agricultural_lower slope | 1,000.10 | 3.19 | 685.81 | 2.19 |
| Mix Garden | 4,015.38 | 12.81 | 3,938.74 | 12.57 |
| Paddy Field | 13,787.84 | 43.99 | 13,787.54 | 43.99 |
| Reservoir | 16.60 | 0.05 | 16.71 | 0.05 |
| Rubber Plantation | 836.36 | 2.67 | 836.47 | 2.67 |
| Settlement | 4,320.24 | 13.78 | 4,320.20 | 13.78 |
| Sugarcane Plantation | 5,076.40 | 16.20 | 5,019.44 | 16.01 |
| Total | 31,345.00 | 100.00 | 31,344.85 | 100.00 |

Source: GIS Analysis

Table 6.16 Reclassified Land Use for Model-4 and Compare to one for year 2009

| Hydrological Soil-Cover Complexes in various Hydrological Soil-Groups | AREA | | | |
|---|---|---|---|---|
| | 2009 | % of total | Model-4 | % of total |
| Farmstead _ B | 2,720.42 | 8.68 | 2,720.43 | 8.68 |
| Farmsteads _ _ _ C | 639.40 | 2.04 | 639.40 | 2.04 |
| Farmsteads _ _ _ D | 960.37 | 3.06 | 960.37 | 3.06 |
| Pasture range _ contoured _ poor _ B | - | - | 2,237.31 | 7.14 |
| Pasture range _ contoured _ poor _ C | - | - | 1,832.16 | 5.85 |
| Pasture range _ contoured _ poor _ D | - | - | 71.41 | 0.23 |
| Pasture range _ Contoured _Fair _ B | 2,460.60 | 7.85 | 166.22 | 0.53 |
| Pasture range _ Contoured _Fair _ C | 2,404.67 | 7.67 | 572.51 | 1.83 |
| Pasture range _ Contoured _Fair _ D | 211.24 | 0.67 | 139.82 | 0.45 |
| Row crops _ contoured _ poor _ B | 307.32 | 0.98 | 145.90 | 0.47 |
| Row crops _ contoured _ poor _ C | | 0.00 | 76.62 | 0.24 |
| Row crops _ contoured _ poor _ D | 104.77 | 0.33 | 184.82 | 0.59 |
| Row crops _ straight row _ poor _ B | 104.66 | 0.33 | 84.92 | 0.27 |
| Row crops _ straight row _ poor _ D | 483.43 | 1.54 | 193.55 | 0.62 |
| Small grain _ Contoured/ terraced _ Poor _ B | 4,912.12 | 15.67 | 4,912.12 | 15.67 |
| Small grain _ Contoured/ terraced _ Poor _ C | 4,995.81 | 15.94 | 4,995.82 | 15.94 |
| Small grain _ Contoured/ terraced _ Poor _ D | 3,879.60 | 12.38 | 3,879.60 | 12.38 |
| Swamp _ B | 16.71 | 0.05 | 16.71 | 0.05 |
| Woodlands _ _ Fair _ B | 1,941.61 | 6.19 | - | - |
| Woodlands _ _ Fair _ C | 1,594.02 | 5.09 | - | - |
| Woodlands _ _ Fair _ D | 1,316.20 | 4.20 | 836.47 | 2.67 |
| Woodlands _ _ good _ A | 221.82 | 0.71 | 221.82 | 0.71 |
| Woodlands _ _ Good _ B | 474.03 | 1.51 | 2,653.83 | 8.47 |
| Woodlands _ _ Good _ C | 681.49 | 2.17 | 2,198.89 | 7.02 |
| Woodlands _ _ Good _ D | 914.56 | 2.92 | 1,604.14 | 5.12 |
| Total | 31,344.85 | 100.00 | 31,344.85 | 100.00 |

Source: GIS Analysis, 2009

In Model-4, there are still many sugarcane plantations treated as heavily grazed.or having plant cover on less than 50% of the plantation area. There is only few plantation treated as moderately grazed or 50-70% is covered by plant. In addition, forest and/ or mix garden coverage increases very much.

Runoff estimation regarding to Model-4 implementation is conducted with Curve Numbers Method from US-SCS. Since the result is compared to runoff 2006, then annual rainfall of 2006 is employed. Estimated runoff for Model-4 is mapped in Figure 6.8. Meanwhile, Table 6.17 gives this calculation and comparison to runoff 2006.

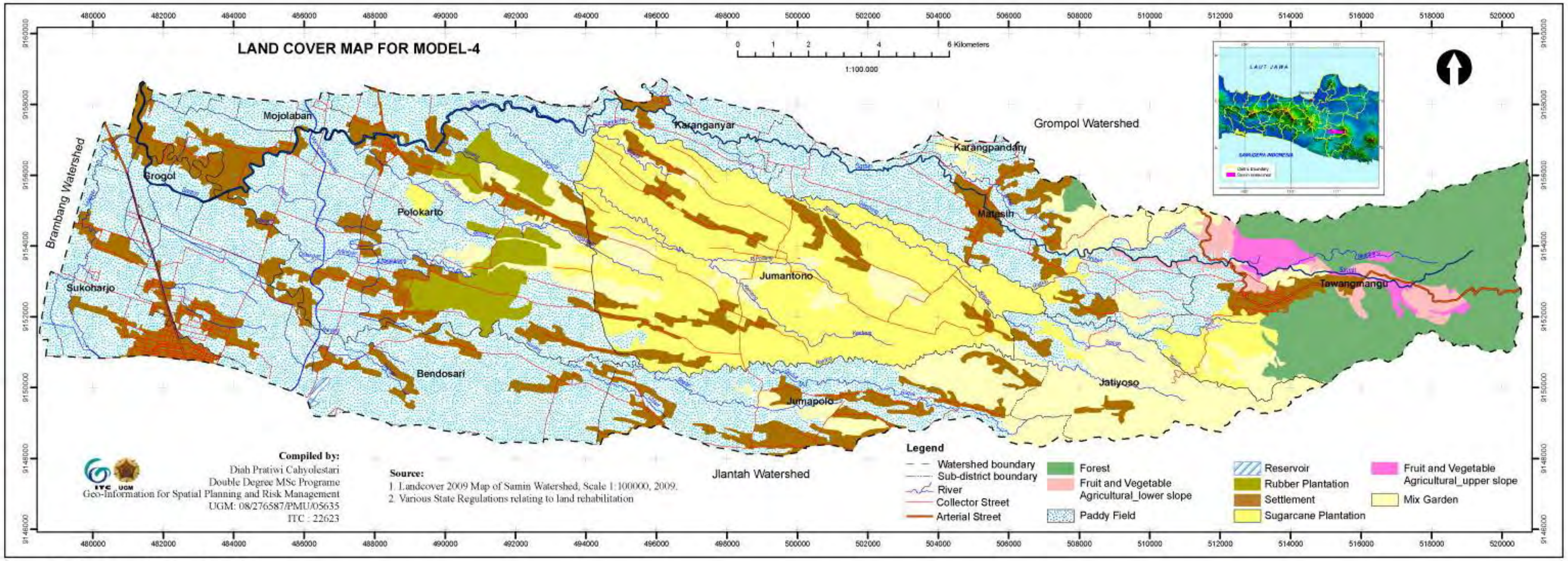



Figure 6.7. Landcover Map for Model-4

Table 6.17 Runoff for Model-4 Compare with Runoff 2006

| Sub Watershed | Landcover | Runoff depth (mm) | | % Runoff | |
|---|---|---|---|---|---|
| | | 2006 | Model-3 | 2006 | Model-3 |
| Blumbang | Forest | 1,559,102.70 | 1,272,778,312.51 | 53.40 | 99.98 |
| | Fruit and Vegetable Agricultural_lower slope | 631,738.33 | 63,402.48 | 21.64 | 0.00 |
| | Fruit and Vegetable Agricultural_upper slope | 191,307.57 | 136,930.08 | 6.55 | 0.01 |
| | Mix Garden | 102,703.95 | 7,321.81 | 3.52 | 0.00 |
| | Paddy Field | 422,347.61 | 33,923.56 | 14.47 | 0.00 |
| | Settlement | 12,539.03 | 25.23 | 0.43 | 0.00 |
| | Sub total | 2,919,739.20 | 1,273,019,915.67 | 100.00 | 100.00 |
| Gembong | Forest | 123,896.51 | 23,822.94 | 2.03 | 0.33 |
| | Fruit and Vegetable Agricultural_lower slope | 204,633.24 | 4,556,058.52 | 3.36 | 62.29 |
| | Fruit and Vegetable Agricultural_upper slope | 831.81 | 1,715,738.32 | 0.01 | 23.46 |
| | Mix Garden | 811,397.98 | 48,399.78 | 13.33 | 0.66 |
| | Paddy Field | 309,492.53 | 27,022.44 | 5.08 | 0.37 |
| | Settlement | 3,245,117.80 | 438,076.44 | 53.30 | 5.99 |
| | Sugarcane Plantation | 1,393,486.86 | 505,198.42 | 22.89 | 6.91 |
| | Sub total | 6,088,856.72 | 7,314,316.86 | 100.00 | 100.00 |
| Grenjeng-Ngasinan | Mix Garden | 1,289,439.51 | 1,383,973.62 | 12.44 | 19.51 |
| | Paddy Field | 2,714,006.07 | 1,949,142.15 | 26.19 | 27.48 |
| | Rubber Plantation | 816,178.70 | 1,049,482.70 | 7.88 | 14.80 |
| | Settlement | 5,069,913.54 | 2,455,193.37 | 48.92 | 34.61 |
| | Sugarcane Plantation | 473,422.39 | 255,451.93 | 4.57 | 3.60 |
| | Sub total | 10,362,960.21 | 7,093,243.77 | 100.00 | 100.00 |
| Lower Samin | Paddy Field | 1,469,993.13 | 391,766.03 | 24.14 | 0.73 |
| | Settlement | 4,620,109.59 | 53,232,914.49 | 75.86 | 99.27 |
| | Sub total | 6,090,102.72 | 53,624,680.52 | 100.00 | 100.00 |
| Poncol | Mix Garden | 1,421,769.16 | 531,664.46 | 24.90 | 31.03 |
| | Paddy Field | 2,731,647.37 | 71,056.76 | 47.83 | 4.15 |
| | Rubber Plantation | 223,054.01 | 5,211.82 | 3.91 | 0.30 |
| | Settlement | 1,296,296.86 | 1,104,512.49 | 22.70 | 64.46 |
| | Sugarcane Plantation | 37,822.31 | 1,171.35 | 0.66 | 0.07 |
| | Sub total | 5,710,589.70 | 1,713,616.88 | 100.00 | 100.00 |
| Ranjing | Mix Garden | 130,953.63 | 43,798,901.14 | 1.34 | 23.86 |
| | Paddy Field | 1,180,764.21 | 97,617,001.00 | 12.04 | 53.18 |
| | Reservoir | 1,522,775.93 | 53,681.81 | 15.52 | 0.03 |
| | Rubber Plantation | 1,910,249.06 | 420,582.93 | 19.48 | 0.23 |
| | Settlement | 5,000,558.66 | 38,437,665.76 | 50.98 | 20.94 |
| | Sugarcane Plantation | 63,247.67 | 3,220,900.31 | 0.64 | 1.75 |
| | Sub total | 9,808,549.17 | 183,548,732.95 | 100.00 | 100.00 |
| Umet | Mix Garden | 3,289,817.08 | 167,022.81 | 41.93 | 0.54 |
| | Paddy Field | 998,054.08 | 30,415,534.03 | 12.72 | 98.86 |
| | Rubber Plantation | 183,706.77 | 3,607.14 | 2.34 | 0.01 |
| | Settlement | 3,016,756.71 | 169,146.54 | 38.45 | 0.55 |
| | Sugarcane Plantation | 358,065.45 | 11,468.34 | 4.56 | 0.04 |
| | Sub total | 7,846,400.08 | 30,766,778.86 | 100.00 | 100.00 |

| | | | | | |
|---|---|---|---|---|---|
| Upper Samin | Forest | 7,411.76 | 140.41 | 0.20 | 0.04 |
| | Fruit and Vegetable | | | | |
| | Agricultural_upper slope | 5,782.11 | 5,965.30 | 0.16 | 1.51 |
| | Mix Garden | 706,376.27 | 47,754.72 | 19.11 | 12.12 |
| | Paddy Field | 1,572,644.14 | 166,913.46 | 42.55 | 42.36 |
| | Settlement | 1,403,564.27 | 4,814.86 | 37.98 | 1.22 |
| | Sugarcane Plantation | | 168,439.87 | | 42.75 |
| | Sub total | 3,695,778.54 | 225,588.75 | 100.00 | 57.25 |
| T o t a l | | 52,522,976.33 | 1,557,306,874.26 | | |

Source: GIS Analysis, 2009

Runoff over Samin Watershed calculated after applying Model-4, in fact, increases very much. Developing land cover model on a basis of sub-watershed's runoff is not reliable to reduce runoff. The following table gives calculation of peak discharge after applying Model-4.

Table 6.18 Discharge Calcultion after Model-4 Implementation

| Nr. | Sub-watershed | Area A (sq.km) | Runoff Q (mm) | Tp (hour) | $q_p = 0.208 \frac{A\,Q}{T_p}$ ($m^3/s$) |
|---|---|---|---|---|---|
| 1. | Blumbang | 24.9916 | 1,273,019,915.67 | 0.593 | 11,168,137,714.49 |
| 2. | Gembong | 65.4625 | 7,314,316.86 | 2.452 | 40,624,654.59 |
| 3. | Grenjeng-Ngasinan | 18.7650 | 7,093,243.77 | 1.782 | 15,534,899.58 |
| 4. | Lower Samin | 33.2328 | 53,624,680.52 | 5.048 | 73,436,053.94 |
| 5. | Poncol | 28.2260 | 1,713,616.88 | 2.635 | 3,818,682.64 |
| 6. | Ranjing | 92.8631 | 183,548,732.95 | 4.202 | 851,828,241.44 |
| 7. | Umet | 22.3267 | 30,766,778.86 | 3.316 | 43,122,136.23 |
| 8. | Upper Samin | 27.5809 | 225,588.75 | 1.489 | 869,152.30 |
| Total watershed | | | | | |

Source: Computer analysis, 2009.

Overall, the most reliable land cover model to reduce runoff and peak discharge is Model-1. The model is built under consideration of biophysical conditions, such as elevation, slope, and soil type. Land management adjusted to physical characteristics is proven to reduce surface runoff.

## 6.3 Model Effectiveness on Reducing Peak Discharge

One of four land use models proposed on Samin Watershed is able to decrease both runoff and peak discharge over the whole watershed, i.e Model-1. The model is proven to reduce about 37.8 percent. The problem when Model-1 is applied that surface runoff over Blumbang Sub-watershed increase 45 percent compare with estimated runoff 2006.

When all of four models is implemented, surface runoff over Ranjing Sub-watershed does not reduce. Still, when Model-1 is applied, Ranjing's runoff only raises about 45 percent. This increasing runoff is the lowest value compare with other models, can rise until 900 percent from runoff 2006.

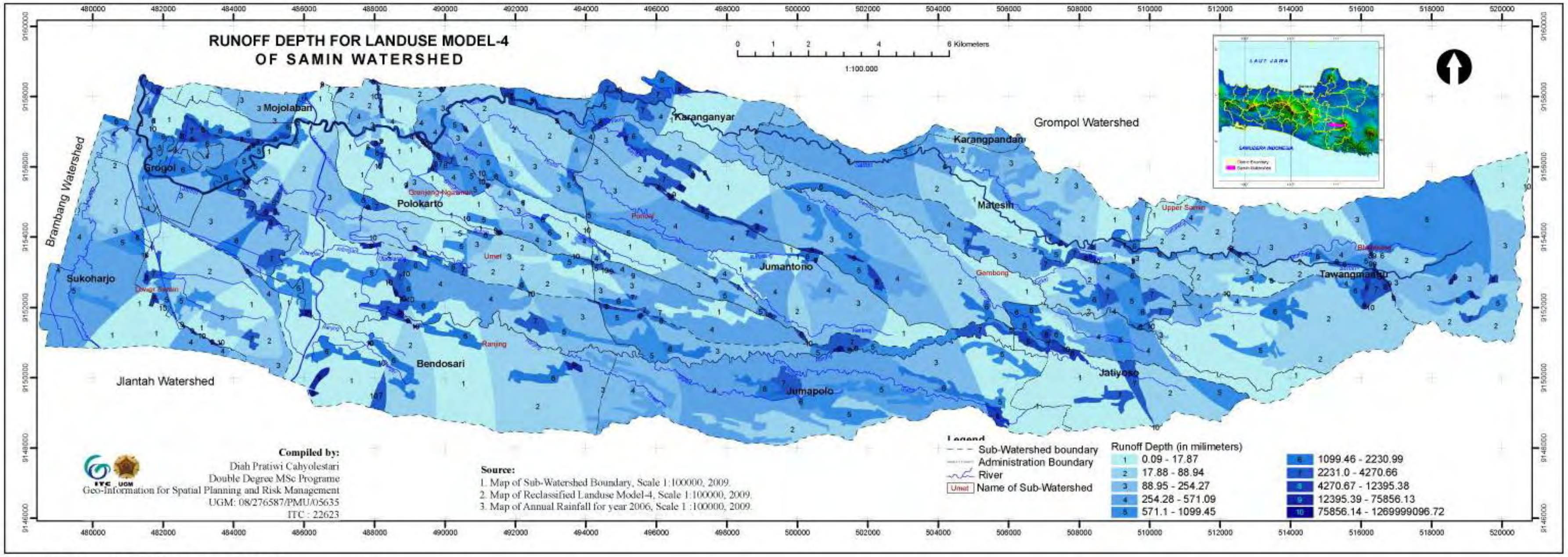


Figure 6.8. Runoff Depth for Landuse Model-4

Decision on developing land use model has affected calculation result of runoff and peak discharge. It is necessary to detect the best way of land management on a soil type with low infiltration characteristics. Considerations include specific characteristics of certain tree, such as appropriate root type and shape of canopy trees. It is usefull to convert land cover into land use reclassification relating to treatment and hydrologic condition developed by US SCS for estimating Curve Numbers.

# 7. Conclusions and Recommendations

## 7.1 Conclusions

Land use over Samin Watershed has greatly changed since 2003. In certain parts of the middle of the watershed local farmers has converted their land from paddy field into sugarcane plantation. The high economic value is one of reason for changing their land management. Sugarcane is harvested twice a year, then burned before planted in the next season. Hence, there is a period where sugarcane plantation is bareland, with almost no plant cover. Sometime bareland occurs in wet season, and sometime it occurs in dry season.

Runoff calculating use Curve Numbers Method developed by US-Soil Conservation Service. To get a more reliable result, determining hydrological soil-group is a critical point. This research employs a general soil map to be adjusted to hydrological soil-group. Runoff is estimated on year 2006 since discharge data availability is data of year 2006. Estimated runoff over Samin Watershed is 52,522,976.332 milimeters.

Peak discharge estimation needs other paramater, i.e annual rainfall. Annual rainfall 2006 is used for the calculation. Estimated peak discharge also requires watershed characteristic, such as area, the longest stream, and slope. Peak discharge computation results 14,239,160,418.93 litre per second. To compare with observational discharge, it only takes peak discharge of three sub-watersheds, i.e Blumbang, Gembong and Upper Samin. The accumulative peak discharge of those watersheds is 73,672,172,699.95 litre/second. Annual discharge of ungauged discharge stations of year 2006 is 747,807 litre per second. It means that estimated discharge has 98 times bigger than observational discharge data.

Various state regulations have been established to overcome land degradation. Three of those regulations are used as a basis to develop land cover model. Basically, to build a model, information on specific biophysical condiion, such as elevation, slope, soil type, rootzone, geomorphological condition, and rainfall characteristic. On the other hand, characteristics of social and cultural of local people are important factors, as a decision maker for land treatment.

There are four land cover models proposed to reduce runoff. Model-1 is built by taking into account for biophysical condition of each sub-watershed, e.g slope, the longest stream and soil type. Model-1 convert agricultural coverage at the upper slope into forest coverage. Sugarcane plantation in Model-1 is treated as moderatly harvested, which there is 50-70% plant cover. Model-1 application reduces runoff 37.8 percent from runoff 2006.

Model-2 is developed by adjusting mix garden as forest, so trees will not cut. Another adjustment is done in Ranjing Sub-watershed perticularly. In this area, sugarcane is converted into mix garden. After applying Model-2, calculated runoff increases 28 times from runoff 2006. Land Cover Model-3 is developed by converting two land cover. First, coverage of upper slope's agricultural into forest, and second, treating sugarcane plantation as moderately harvested with 50-70% plant cover. Runoff calculated increases 200 percent from runoff 2006.

The last model is generated by an assumption that each sub-watershed has individul land cover type. Different type of land cover developed in the three models before is analyzed regarding to the ability to reduce runoff. Model's application increases 28 times from runoff 2006.

Converting paddy field into sugarcane plantation has little significance for increasing runoff, except in Ranjing Sub-watershed. In this area, application of Model-1 and Model-4 increases surface runoff, especially in sugarcane coverage.

## 7.2 Recommendations

It is necessary to generate a detailed study of surface runoff and peak discharge for sub-watershed coverage, since this study produces extreme different value between observed and calculated data. To get a better accuracy, it is needed the same scale of input maps for estimating Curve Numbers.

Overall application, Model-1 is the most appropriate model to reduce surface runoff. Hence, the most appropriate way to treat land is land treatment considering a specific biophysical characteristic. Hence, the most appropriate way to treat land is land management considering a specific biophysical characteristic. Local wisdom is also required to build a land use model, since most part of the area is not state-land.

State regulations are used as guidelines to develop land cover model. Therefore, a more detailed regulation is useful for selecting locations and methods. A guideline should be developed under a reliable research.

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# Appendices

Appendix 1. Laboratory Analysis Result of Soil Sample and Infiltration Rate for each Land Mapping Unit

| LMU Nr. | Coordinate | | Landform | Soil type |
|---|---|---|---|---|
| | Latitude | Longitude | | |
| 1 | 494158 | 9153506 | Low relief dissected Sidoramping foot slope | Dark grey Grumusol and Reddish brown Mediteranean |
| 2 | 489383 | 9154970 | Low relief dissected Sidoramping foot slope | Dark grey Grumusol and Reddish brown Mediteranean |
| 3 | 491917 | 9152567 | Low relief dissected Sidoramping foot slope | Dark grey Grumusol and Reddish brown Mediteranean |
| 4 | 488700 | 9155222 | Low relief dissected Sidoramping foot slope | Dark grey Grumusol and Reddish brown Mediteranean |
| 5 | 489103 | 9156272 | Low relief dissected Sidoramping foot slope | Dark grey Grumusol and Reddish brown Mediteranean |
| 6 | 488555 | 9152375 | Alluvium plain | Greyish brown Alluvium |
| 7 | 494725 | 9156228 | Low relief dissected Sidoramping foot slope | Reddish brown Mediteranean |
| 8 | 482011 | 9151231 | Alluvium plain | Greyish brown Alluvium |
| 9 | 482876 | 9156572 | Alluvium plain | Dark grey Grumusol |
| 10 | 483912 | 9151583 | Alluvium plain | Dark grey Grumusol |
| 11 | 502175 | 9151654 | High relief dissected Sidoramping foot slope | Reddish brown Latosol |
| 12 | 498356 | 9152956 | High relief dissected Sidoramping foot slope | Reddish brown Mediteranean |
| 13 | 496109 | 9155595 | Low relief dissected Sidoramping foot slope | Reddish brown Mediteranean |
| 14 | 498341 | 9156622 | Low relief dissected Sidoramping foot slope | Reddish brown Mediteranean |
| 15 | 504886 | 9152203 | High relief dissected Sidoramping foot slope | Reddish brown Latosol |
| 16 | 508952 | 9151438 | Dissected Sidoramping middle slope | Reddish brown Latosol |
| 17 | 510078 | 9152359 | Limestone hill | Brown Latosol |
| 18 | 513063 | 9151328 | Low relief dissected Sidoramping | Brown Latosol |
| 19 | 516440 | 9151535 | Hilly Sidoramping lava | Brown Andosol and Litosol |
| 20 | 517353 | 9152475 | Hilly Sidoramping lava | Brown Andosol and Litosol |
| 21 | 514288 | 9154616 | Dissected Lawu lower slope | Brown Latosol |
| 22 | 508192 | 9155293 | Dissected Lawu lower slope | Brown Mediteranean |
| 23 | 512851 | 9154161 | Dissected Lawu lower slope | Brown Latosol |
| 24 | 508983 | 9153704 | Undulating topography of Lawu lahar | Brown Mediteranean |
| 25 | 510710 | 9152543 | Undulating topography of Lawu lahar | Brown Latosol |
| 26 | 513629 | 9152972 | Hilly Sidoramping lava | Brown Latosol |
| 27 | 516658 | 9153409 | Hilly Sidoramping lava | Yellowish brown Andosol |
| 28 | 507701 | 9154267 | Andecitic vulcano neck | Brown Mediteranean |
| 29 | 506231 | 9156332 | Dissected Sidoramping middle slope | Brown Mediteranean |
| 30 | 502446 | 9155268 | High relief dissected Sidoramping foot slope | Reddish brown Latosol |
| 31 | 518306 | 9153227 | Dissected Lawu middle slope | Yellowish brown Andosol |

Appendix 1. ……contd.

| LMU Nr. | Land Use | Soil Texture (%) | | | | Infiltration rate (cm/min) | Hydrological Soil Group |
|---|---|---|---|---|---|---|---|
| | | Clay | Silt | Sand | Texture | | |
| 1 | Mix garden | 92.25 | 7.18 | 0.56 | Very fine | 0.41 | D |
| 2 | Sugarcane | 68.93 | 16.78 | 14.29 | Very fine | 0.30 | D |
| 3 | Rubber plantation | 79.50 | 15.13 | 5.36 | Very fine | 0.30 | D |
| 4 | Paddy field | 64.12 | 17.34 | 18.55 | Very fine | 0.21 | D |
| 5 | Settlement | 53.00 | 18.79 | 28.20 | Moderately | 0.17 | B |
| 6 | Paddy field | 58.87 | 15.15 | 25.98 | Moderately | 0.16 | B |
| 7 | Sugarcane | 83.95 | 11.68 | 4.37 | Very fine | 0.22 | D |
| 8 | Settlement | 41.66 | 28.08 | 30.26 | Moderately | 0.07 | B |
| 9 | Paddy field | 43.71 | 32.84 | 23.45 | Moderately | 0.03 | B |
| 10 | Settlement | 58.28 | 36.24 | 5.47 | Moderately | 0.04 | B |
| 11 | Sugarcane | 82.20 | 12.80 | 5.00 | Very fine | 0.20 | D |
| 12 | Mix garden | 78.06 | 15.80 | 6.14 | Very fine | 0.40 | D |
| 13 | Settlement | 74.38 | 16.42 | 9.19 | Fine | 0.28 | C |
| 14 | Paddy field | 79.57 | 12.55 | 7.88 | Fine | 0.25 | C |
| 15 | Settlement | 27.01 | 28.51 | 44.49 | Moderately | 1.00 | B |
| 16 | Mix garden | 12.45 | 24.54 | 63.00 | Moderately | 0.10 | B |
| 17 | Mix garden | 12.22 | 26.21 | 61.57 | Moderately | 2.18 | B |
| 18 | Sugarcane | 50.02 | 27.45 | 22.53 | Fine | 2.60 | C |
| 19 | Forest | 15.52 | 32.23 | 52.25 | Moderately | 5.00 | B |
| 20 | Fruit and | 21.79 | 35.47 | 42.47 | Moderately | 3.00 | B |
| 21 | Forest | 21.50 | 33.06 | 45.43 | Moderately | 0.70 | B |
| 22 | Forest | 58.74 | 25.57 | 15.69 | Fine | 0.40 | C |
| 23 | Fruit and | 46.46 | 29.88 | 23.66 | Fine | 1.20 | C |
| 24 | Paddy field | 18.14 | 41.54 | 40.32 | Moderately | 0.05 | B |
| 25 | Paddy field | 27.86 | 41.97 | 30.17 | Fine | 0.10 | C |
| 26 | Settlement | 22.47 | 31.45 | 46.07 | Moderately | 0.70 | B |
| 27 | Fruit and | 20.16 | 30.96 | 48.87 | Moderately | 0.10 | B |
| 28 | Mix garden | 55.51 | 33.14 | 11.35 | Fine | 1.02 | C |
| 29 | Settlement | 33.54 | 43.70 | 22.76 | Fine | 0.20 | C |
| 30 | Paddy field | 30.97 | 29.17 | 39.86 | Fine | 0.25 | C |
| 31 | Forest | 57.31 | 21.62 | 21.06 | Moderately | 0.46 | B |

Appendix 2. Antecedent Moisture Condition Class Determination of Year 2006

| Polokarto | Bendosari | Mojolaban | Jumantono | Jumapolo | Matesih | Trani | Tawangmangu |
|---|---|---|---|---|---|---|---|
| 34 | 16 | 126 | 87 | 176 | 82 | 111 | 189 |
| 36 | 22 | 108 | 75 | 175 | 65 | 90 | 163 |
| 71 | 34 | 139 | 66 | 164 | 56 | 92 | 151 |
| 55 | 55 | 132 | 74 | 97 | 77 | 86 | 170 |
| 50 | 71 | 128 | 12 | 101 | 67 | 81 | 72 |
| 106 | 80 | 102 | 37 | 71 | 14 | 59 | 76 |
| 102 | 142 | 105 | 55 | 86 | 41 | 71 | 86 |
| 33 | 165 | 79 | 81 | 120 | 59 | 61 | 105 |
| 65 | 138 | 95 | 77 | 118 | 80 | 111 | 157 |
| 16 | 134 | 48 | 110 | 135 | 94 | 103 | 118 |
| 29 | 7 | 104 | 35 | 92 | 102 | 103 | 129 |
| 101 | 9 | 145 | 64 | 85 | 99 | 91 | 139 |
| 117 | 13 | 179 | 44 | 84 | 90 | 22 | 162 |
| 57 | 18 | 176 | 37 | 120 | 81 | 35 | 113 |
| 62 | 25 | 192 | 30 | 46 | 36 | 34 | 87 |
| 64 | 28 | 88 | 43 | 60 | 60 | 42 | 68 |
| 2 | 6 | 110 | 3 | 111 | 71 | 41 | 63 |
| 59 | 11 | 109 | 7 | 123 | 89 | 45 | 79 |
| 65 | 7 | 123 | 9 | 92 | 82 | 21 | 120 |
| 79 | 29 | 134 | 46 | 27 | 37 | 26 | 100 |
| 18 | 54 | 105 | 69 | 18 | 39 | 26 | 109 |
| 28 | 64 | 52 | 9 | 52 | 34 | 29 | 84 |
| 14 | 65 | 49 | 24 | 62 | 38 | 32 | 66 |
| 4 | 8 | 59 | 33 | 20 | 54 | 25 | 28 |
| 28 | 35 | 40 | 37 | 35 | 53 | 12 | 40 |
| 39 | 42 | 40 | 40 | 38 | 41 | 12 | 49 |
| 58 | 44 | 32 | 49 | 105 | 47 | 34 | 39 |
| 60 | 46 | 49 | 28 | 130 | 26 | 31 | 48 |
| 33 | 46 | 42 | 36 | 151 | 149 | 30 | 57 |
| 64 | 20 | 48 | 31 | 168 | 156 | 54 | 57 |
| 59 | 14 | 46 | 49 | 72 | 49 | 34 | 49 |
| 91 | 8 | 54 | 32 | 80 | 19 | 35 | 33 |
| 56 | 33 | 19 | 13 | 94 | 40 | 12 | 47 |
| 43 | 47 | 58 | 21 | 34 | 48 | 11 | 95 |
| 65 | 55 | 131 | 35 | 29 | 60 | 30 | 102 |
| 9 | 32 | 163 | 34 | 39 | 23 | 26 | 115 |
| 14 | 28 | 164 | 59 | 50 | 55 | 10 | 83 |
| 58 | 32 | 21 | 64 | 32 | 60 | 82 | 68 |
| 71 | 56 | 38 | 143 | 57 | 60 | 110 | 118 |
| 17 | 66 | 46 | 129 | 20 | 72 | 118 | 143 |
| 11 | 46 | 58 | 173 | 51 | 15 | 113 | 150 |
| 26 | 48 | 84 | 195 | 64 | 20 | 11 | 151 |
| 18 | 86 | 16 | 108 | 39 | 35 | 6 | 10 |
| 20 | 94 | 50 | 28 | 43 | 47 | 48 | 7 |
| 24 | 130 | 59 | 76 | 60 | 60 | 55 | 12 |
| 16 | 129 | 60 | 9 | 36 | 67 | 60 | 22 |
| 62 | 116 | 23 | 82 | 38 | 90 | 65 | 25 |
| 52 | 104 | 37 | 94 | 44 | 165 | 21 | 26 |
| 8 | 52 | 29 | 36 | 36 | 211 | 16 | 32 |
| 26 | 34 | 15 | 68 | 41 | 215 | 5 | 38 |
| 68 | 26 | 29 | 104 | 54 | 151 | 6 | 39 |
|  | 23 | 42 | 42 | 40 | 100 | 52 | 22 |
|  | 25 | 29 | 19 | 40 | 80 | 60 | 30 |
|  | 76 | 40 | 30 | 32 | 62 | 70 | 33 |
|  | 99 | 71 | 59 | 17 | 40 | 19 | 37 |
|  | 109 | 89 | 63 | 20 | 72 | 22 | 41 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 88 | 100 | 45 | 28 | 87 | 28 | 34 | |
| | | 87 | 118 | 45 | 39 | 80 | 14 | 26 | |
| | | 32 | 112 | 51 | | 7 | 15 | 2 | |
| | | 2 | 105 | 11 | | 21 | 18 | 2 | |
| | | 50 | 116 | | | 74 | 16 | 7 | |
| | | 72 | 83 | | | 81 | 12 | 21 | |
| | | 81 | 51 | | | 89 | 15 | 24 | |
| | | | 14 | | | 8 | 21 | 27 | |
| | | | 18 | | | 25 | 35 | 38 | |
| | | | 64 | | | 39 | 41 | 44 | |
| | | | 76 | | | | 59 | 51 | |
| | | | 97 | | | | 72 | 52 | |
| | | | 88 | | | | 60 | 60 | |
| | | | 46 | | | | 89 | 68 | |
| | | | 59 | | | | 84 | 93 | |
| | | | 32 | | | | 79 | 91 | |
| | | | 43 | | | | 99 | 111 | |
| | | | 38 | | | | 55 | 108 | |
| | | | 52 | | | | 62 | 86 | |
| | | | | | | | 48 | 51 | |
| | | | | | | | 56 | 63 | |
| | | | | | | | 48 | 88 | |
| | | | | | | | 10 | 95 | |
| | | | | | | | 17 | 122 | |
| | | | | | | | 53 | 127 | |
| | | | | | | | 66 | 110 | |
| | | | | | | | 77 | 76 | |
| | | | | | | | 84 | 71 | |
| | | | | | | | 70 | 15 | |
| | | | | | | | 36 | 30 | |
| | | | | | | | 27 | 51 | |
| | | | | | | | 23 | 63 | |
| | | | | | | | 25 | 93 | |
| | | | | | | | 13 | 86 | |
| | | | | | | | 26 | 79 | |
| | | | | | | | 29 | 64 | |
| | | | | | | | 39 | 62 | |
| | | | | | | | | 72 | |
| | | | | | | | | 66 | |
| | | | | | | | | 21 | |
| | | | | | | | | 98 | |
| | | | | | | | | 158 | |
| | | | | | | | | 198 | |
| | | | | | | | | 178 | |
| | | | | | | | | 106 | |
| | | | | | | | | 54 | |
| | | | | | | | | 20 | |
| | | | | | | | | 25 | |
| | | | | | | | | 41 | |
| | | | | | | | | 19 | |
| | | | | | | | | 15 | |
| Total | 2363 | 3414 | 5721 | 3265 | 4091 | 4446 | 4328 | 7814 | 35442 |
| Average | 46.33 | 54.19 | 76.28 | 54.42 | 69.34 | 67.36 | 46.54 | 73.03 | 61.85 |

Appendix 3. Daily Rainfall Data of Year 2006 over Samin Watershed
(Source: Agency of Water Resources Management of Central Java, 2009)

Ungauged Rain Station: Polokarto

| Date | Month | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 34 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 2 | 0 | 2 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 0 | 0 | 0 | 0 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 21 | 32 | 0 | 28 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 20 | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | |
| 10 | 86 | 0 | 0 | 1 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 0 | 16 | 0 | 42 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 0 | 13 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 46 | 0 | |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 0 | 0 | 2 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | |
| 16 | 0 | 0 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 0 | 0 | 6 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 0 | 101 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 0 | 16 | 16 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 0 | 0 | 2 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | |
| 25 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | |
| 26 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 0 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 0 | | 2 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | |
| 30 | 0 | | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 0 | | 0 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 86 | 101 | 57 | 57 | 44 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 101 |
| Total rainfall | 193 | 273 | 99 | 226 | 139 | 0 | 0 | 0 | 0 | 0 | 144 | 0 | 1074 |
| Rainfall event | 7 | 8 | 9 | 12 | 9 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 51 |

Appendix 3. ….contd.

Ungauged Rain Station: Jumapolo

| Date | Month | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 20 | 12 | 8 | 57 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 28 | 0 | 0 | 0 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 23 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 26 | 34 | 12 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 0 | 22 | 3 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 24 | 0 | 0 | 31 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 21 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 41 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 34 | 0 | 0 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 22 | 20 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 17 | 15 | 39 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 19 | 0 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 27 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 21 | 23 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 53 | 82 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 0 | 25 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 0 | 21 | 0 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 0 | 0 | 0 | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 14 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 12 | 72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 15 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 0 | | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 | 0 | | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 0 | | 0 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 53 | 82 | 39 | 57 | 36 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 82 |
| Total rainfall | 514 | 349 | 117 | 212 | 141 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 1344 |
| Rainfall event | 19 | 12 | 8 | 10 | 9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 59 |

Appendix 3. ….contd

Ungauged Rain Station: Bendosari

| Date | Month | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 16 | 7 | 2 | 52 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 0 | 2 | 7 | 0 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 6 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 12 | 5 | 4 | 0 | 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 21 | 7 | 0 | 14 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 32 | 10 | 3 | 32 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 9 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 80 | 0 | 0 | 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 44 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 5 | 6 | 0 | 68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 0 | 0 | 8 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 0 | 2 | 25 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 0 | 27 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 0 | 10 | 16 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 3 | 2 | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 0 | 30 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 0 | 7 | 4 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 0 | | 0 | 0 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 | 0 | | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 0 | | 0 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 80 | 30 | 28 | 68 | 51 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 80 |
| Total rainfall | 230 | 155 | 113 | 306 | 216 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 1029 |
| Rainfall event | 10 | 16 | 11 | 13 | 11 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 62 |

Appendix 3. ….contd

Ungauged Rain Station: Matesih

| Date | Month | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 14 | 20 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 0 | 0 | 0 | 0 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 18 | 0 | 0 | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 10 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 35 | 14 | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 4 | 24 | 19 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 0 | 0 | 21 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 0 | 0 | 0 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 27 | 0 | 0 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 18 | 37 | 0 | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 21 | 0 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 14 | 0 | 0 | 46 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 22 | 4 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 24 | 6 | 12 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 9 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 0 | 57 | 11 | 24 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 26 | 40 | 32 | 0 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 11 | 5 | 30 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 0 | 0 | 12 | 8 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 10 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 0 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 18 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 3 | 0 | 15 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 | 16 | | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 0 | | 5 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 37 | 57 | 48 | 90 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 90 |
| Total rainfall | 364 | 294 | 192 | 385 | 287 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1522 |
| Rainfall event | 20 | 12 | 11 | 12 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 67 |

Appendix 3. ….contd

Ungauged Rain Station: Mojolaban

| Date | Month | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 38 | 21 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 6 | 0 | 12 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 43 | 0 | 38 | 0 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 14 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 27 | 28 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 12 | 14 | 0 | 24 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 9 | 6 | 0 | 31 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 0 | 0 | 0 | 18 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 58 | 0 | 0 | 27 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 0 | 0 | 0 | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 0 | 46 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 16 | 0 | 16 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 11 | 0 | 0 | 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 56 | 0 | 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 62 | 8 | 9 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 34 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 13 | 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 27 | 73 | 17 | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 32 | 0 | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 0 | 9 | 6 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 48 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 26 | 0 | 9 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 14 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 11 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 19 | 8 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 0 | | 0 | 0 | 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 | 8 | | 23 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 11 | | 0 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 62 | 73 | 38 | 42 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 73 |
| Total rainfall | 619 | 333 | 184 | 310 | 230 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1676 |
| Rainfall event | 24 | 14 | 11 | 13 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 73 |

Appendix 3. ….contd

Ungauged Rain Station: Trani

| Date | Month | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 32 | 25 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 3 | 0 | 5 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 11 | 1 | 9 | 0 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 14 | 1 | 1 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 22 | 26 | 0 | 23 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 9 | 5 | 1 | 18 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 15 | 1 | 0 | 18 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 15 | 0 | 0 | 12 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 72 | 0 | 0 | 11 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 1 | 10 | 0 | 47 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 15 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 0 | 18 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 4 | 0 | 5 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 3 | 0 | 1 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 13 | 0 | 46 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 15 | 7 | 8 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 8 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 3 | 72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 6 | 28 | 16 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 8 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 0 | 2 | 3 | 1 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 11 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 8 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 6 | 1 | 2 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 3 | 45 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 4 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 0 | | 1 | 0 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 | 2 | | 5 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 3 | | 0 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 72 | 72 | 46 | 47 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 72 |
| Total rainfall | 300 | 791 | 121 | 260 | 174 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1646 |
| Rainfall event | 26 | 19 | 18 | 16 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 93 |

Appendix 3. ….contd

Ungauged Rain Station: Jumantono

| Date | Month | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 25 | 22 | 9 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 0 | 0 | 4 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 13 | 0 | 0 | 0 | 73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 8 | 8 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 28 | 13 | 27 | 21 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 0 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 0 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 12 | 0 | 0 | 26 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 25 | 0 | 0 | 0 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 0 | 0 | 0 | 92 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 18 | 0 | 28 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 38 | 3 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 21 | 4 | 8 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 33 | 2 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 0 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 0 | 23 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 0 | 0 | 23 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 0 | 0 | 23 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 0 | 0 | 0 | 53 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 35 | 0 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 0 | 0 | 6 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 0 | 0 | 0 | 0 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 15 | 15 | 7 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 0 | | 0 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 38 | 37 | 28 | 92 | 73 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 92 |
| Total rainfall | 300 | 136 | 156 | 375 | 318 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 1296 |
| Rainfall event | 13 | 10 | 10 | 12 | 14 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |

Appendix 3. ….contd

Ungauged Rain Station: Tawangmangu

| Date | Month | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 3 | 2 | 5 | 3 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 10 | 10 | 0 | 4 | 15 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 13 | 12 | 0 | 0 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 54 | 14 | 0 | 17 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 0 | 11 | 0 | 20 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 0 | 0 | 0 | 10 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 0 | 0 | 22 | 5 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 0 | 8 | 0 | 8 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 72 | 0 | 0 | 25 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 4 | 0 | 0 | 45 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 10 | 39 | 0 | 8 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 19 | 48 | 0 | 25 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 52 | 0 | 25 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 33 | 15 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 15 | 13 | 6 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 20 | 7 | 6 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 42 | 33 | 1 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 3 | 50 | 8 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 0 | 40 | 9 | 30 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 22 | 20 | 9 | 15 | 77 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 1 | 8 | 10 | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 37 | 0 | 5 | 16 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 23 | 19 | 0 | 1 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 24 | 41 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 2 | 2 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 10 | 5 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 27 | 12 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 28 | 1 | 0 | 1 | 0 | 5 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | |
| 29 | 3 | | 1 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 | 14 | | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 31 | 19 | | 14 | | 0 | | 0 | 0 | | 0 | | 0 | |
| Max daily rainfall | 72 | 50 | 25 | 50 | 77 | 5 | 15 | 0 | 0 | 0 | 0 | 0 | 77 |
| Total rainfall | 531 | 337 | 130 | 341 | 407 | 7 | 15 | 0 | 0 | 0 | 0 | 0 | 1768 |
| Rainfall event | 26 | 18 | 18 | 22 | 21 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 108 |