INTEGRATING LANDSLIDE SUSCEPTIBILITY INTO LAND CAPABILITY ASSESSMENT FOR SPATIAL PLANNING

A Case Study in Tawangmangu Sub District, Karanganyar Regency, Central Java Province, Indonesia

By:
Sri Eka Wati

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Thesis submitted to the Graduated School, Faculty of Geography, Gadjah Mada University and International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Joint Education Program between Gajah Mada University (UGM)-Yogyakarta-Indonesia and International Institute for Geo-information Science and Earth Observation (ITC)-Enschede-The Netherlands, on Geo-Information for Spatial Planning and Risk Management

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2010

I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

Signed …………………….

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This document describes work undertaken as part of a programme of study at the Double Degree International Program of Geo-information for Spatial Planning and Risk Management, a Joint Education Program of Institute for Geo-information Science and Earth Observation, the Netherlands and Gadjah Mada University, Indonesia. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institutes

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ABSTRACT

Land capability assessment is one of the important points in spatial planning. The assessment is conducted to divide the land into three land use functions (protected, buffer, and cultivated area) and to manage further land use. The present land capability analysis utilizes scoring method from Ministry of Agriculture. This method considers erosion hazard associated with soil type. Since Tawangmangu Sub District is also prone to landslide hazard, the landslide susceptibility information shall be taken into account in land capability. This research is focused on the integration process of landslide susceptibility in land capability assessment.

Landslide susceptibility was analyzed by means of heuristic approach (weighted score method). The parameters were slope, lithology, soil depth, texture, permeability, and land use. The weight was derived from pair wise method and the score was generated from rank method. Those methods are available in ILWIS. A proposed land capability classification was developed based on USDA approach. The susceptibility information was integrated as one additional constraint factor in proposed method. The land capability assessment was developed in general and detailed version. The obtained land capability class was harnessed for dividing land use function and identifying land use deviation. Land capability analysis by means of scoring method was also done in order to compare the obtained result.

More than one third of study area (42%) is categorized as high and very high susceptible to landslide while 43% of total area is classified as moderate susceptible area. The rest is categorized as low susceptible area. General land capability classes for study area are class IV, VI, VII, and VIII whereas the detailed land capability class consists of class III, IV, V, VI, VII, and VIII. General land capability class classifies more than a half of study area (58%) as protected area, 31% is assigned as buffer area, and 11% is apportioned as cultivated area. Besides, detailed land capability class allocates 55% of study area as protected area, 37% as buffer area, and 8% as cultivated area. Moreover, the land use deviation in buffer area is higher than protected area and there is no land use inexpediency in cultivated area. On the other side, general version of scoring method assigns 51% of total area as protected area; 31% as buffer area and 18% as cultivated area whereas the proportion of protected, buffer, and cultivated area based on detailed version is 38%, 45% and 17% respectively. Scoring method also identifies that most land use divergence occurs in buffer area rather than protected and cultivated area.

Key Words: Landslide, Land Capability, Spatial Planning

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LIST OF ABBREVIATION

AMSL	Above Mean Sea Level
BAKOSURTANAL	*Badan Koordinasi Survei dan Pemetaan Nasional* National Coordinating Agency for Surveys and Mapping
BAPPEDA	*Badan Perencanaan dan Pembangunan Daerah* Development and Planning Board
BNPB	*Badan Nasional Penanggulangan Bencana dan Pengungsi* National Agency for Disaster Tackling and Refugee
BPS	*Badan Pusat Statistik* Center of Statistical Bureau
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GIS	Geographic Information System
ICIMOD	International Center for Integrated Mountain Development
ILWIS	Integrated Land and Water Information System
ITC	International Institute for Geo-information Science and Earth Observation
KESBANGLINMAS	*Kesatuan Bangsa dan Perlindungan Masyarakat* National Unity and Community Protection
LCLP	Land Capability and Land Use Planning
Perda	*Peraturan Daerah* Regional Regulation
PUSLITBANG GEOLOGI	*Pusat Penelitian dan Pengembangan Geologi* Geological Research and Development Center
PVMBG	*Pusat Vulkanologi dan Mitigasi Bencana Geologi* Centre of Volcanology and Geological Disaster Mitigation
RDTRK	*Rencana Detail Tata Ruang Kota Kecamatan* Detailed Spatial Plan of Subdistrict City
RTRW	*Rencana Tata Ruang Wilayah* Regional Spatial Plan
RUTRK	*Rencana Umum Tata Ruang Kota Kecamatan* General Spatial Plan of Subdistrict City
SRTM	Shuttle Radar Topographic Mission
UGM	*Universitas Gadjah Mada* Gadjah Mada University
UNISDR	United Nation-International Strategy for Disaster Reduction
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
UUPA	*Undang Undang Pokok Agraria* The Basic Agrarian Law Act
WTU	*Wilayah Tanah Usaha* Exertion Land Region

CHAPTER I
INTRODUCTION

Introduction chapter describes the background of this research. The problem statement emphasizes the actual problems in the study area. Those problems are elaborated in four specific objectives and nine research questions. This chapter also includes thesis structure, significant of the research, and also scope and limitation.

1.1. Background

Hazards can be defined as a potentially damaging physical event, phenomenon or human activity. The hazards may cause the loss of life or injury, property damage, social and economic disruption or environmental damage (UNISDR, 2009). The damages and disruptions are concerned with the magnitude of the hazard and the number of elements at risk.

One of the common hazards is landslide. Landslide is described as a wide variety process that is result in the downward and outward movement of slope-forming materials. The materials including rock, soil, artificial fill, or a combination of these may move by falling, toppling, sliding, spreading, or flowing caused by gravitational forces (Marfai, 2006). Landslide happens as a result of combined preparatory and triggering factors. The preparatory factors are slope, lithology, soil depth, land use, etc while the triggering factors are heavy rainfall or earthquake.

Indonesia has complex circumstances concerned to landslide threat. It exists in the meeting point of three plate tectonics which dynamically move. It is also located in tropical region with 6 months of rainy season and various physical characteristics such as: slope, soil, relief, and land use. The combination of those conditions makes some parts of Indonesia prone to landslide. The statistical data asserts that about 11% of the total disaster events in 2008 were landslide. The events set off 73 casualties and 1,599 affected people (BNPB, 2008).

One of landslide prone areas is Karanganyar Regency. Landslides occurred in several sub districts, for instance Ngargoyoso, Tawangmangu, Jenawi, etc. The most damaging landslide took place in Tawangmangu Sub District on December 26th, 2007. This event caused 34 casualties. The driving factors of the event were slope of more than 40 degree, amount of rainfall 240 mm per day (Hadmoko et al, 2008), moderate level of potential land movement (PVMBG, 2007) and land use function conversion from forest into agriculture (Hadmoko et al, 2008).

Conversion of land use function reveals due to limited land to be used for agricultural purpose. Local community tends to exploit steep slope area as agricultural land (Hadmoko et al, 2008). Land use changes from tight crop to seasonal plant (strawberry, vegetable, cassava, etc.) in upper slope of Lawu Volcano (PVMBG, 2007). The conversion of land use function can be also associated with poor implementation of existing land use function division by local government and less comprehensive land use function decision procedure.

Legal Document of Ministry of Agriculture number 837/Kpts/UM/11/1980 (Anonymous, 1980) and number 683/Kpts/UM/8/1981 (Anonymous, 1981) emphasizes that land use function in spatial planning is generated by means of land capability analysis with scoring method. The analysis considers slope, soil type, and daily rainfall intensity as inhibiting factors. This analysis only deliberates erosion hazard associated with soil type. The landslide susceptibility as a prominent hazard is not explicitly integrated.

The issue of integrating landslide susceptibility and land capability for determining land use function becomes one of essential parts in spatial planning. Land use function is a basis to propose more suitable land use planning. Land use function plays an important rule to recognize the appropriate land use practice. Thereby, the study of determining land capability by involving the landslide susceptibility information turns into the important concern to manage the land in Tawangmangu Sub District. It is also unknown whether incorporating landslide susceptibility into land capability assessment will result in different land use function division.

1.2. Problem Statement

Tawangmangu Sub District is located in south western flank of Lawu Volcano with slope up to more than 65%. This area consists of volcanic breccia and tuff with andecite and basalt fragment. The area is also covered by loam and clay texture, slow-very fast permeability, and easy to collapse. Furthermore, this area has moderate level of potential land movement. It means that land movement often occurs and there is a re-occurrence possibility of the previous land movement, particularly initiated by heavy rainfall (PVMBG, 2007).

Act number 26, 2007 organizes the spatial planning in Indonesia (Anonymous, 2007). Section 6.1a accentuates that spatial planning in Indonesia has to be conducted by considering physical condition of Indonesia which is prone to disaster. It means that the spatial planning of Tawangmangu Sub District shall implicate landslide information since this area is prone to landslide. Moreover, section 5.2d asserts that land use function in spatial planning consists of protected area and cultivated area. Protected areas encompass preserved areas and natural disaster prone areas. Cultivated areas are intended for productive forest, settlement, industry, etc. Thus, spatial planning of Tawangmangu Sub District also has to establish appropriate land use function division which includes landslide prone area as a part of protected areas.

Land use function is one of substansial points in spatial planning process. It is employed as a foundation for further land use plan in spatial planning. Hence, land use function shall be derived from thorough analysis by contemplating sustainable concept. The inclusive analysis must involve potency and limitation of the land. This analysis is known as land capability assessment.

Present land use function in study area is developed through land capability analysis. It is based on Legal Document of Ministry of Agriculture number 837/Kpts/UM/11/1980 (Anonymous, 1980) and number 683/Kpts/UM/8/1981 (Anonymous, 1981). Three factors (slope, soil type, and daily rainfall intensity) are combined. Nevertheless, this analysis is not clearly enough in assessing the land capability. Moreover, the present method only describes erosion hazard related to soil type while the study area is also suffered by landslide hazard.

The improved method of land capability analysis is necessary for the future spatial planning. The idea in assimilating landslide susceptibility into more comprehensive land capability assessment becomes important. However, it is not known yet how to combine these. Therefore, this study tries to examine a way to integrate them.

1.3. Objectives

General objective of this research is to integrate landslide susceptibility information into land capability assessment in spatial planning. The general objective is detailed into four specific objectives, as follow:

a. To generate landslide susceptibility map.
b. To propose an integrated method of land capability classification and landslide susceptibility.
c. To determine land use function based on the proposed method.
d. To evaluate land use deviation by considering the proposed land use function.

1.4. Research Questions

Research questions (Table 1.1) are arranged according to four specific objectives as previously declared.

Table 1.1. Research Questions Associated with Specific Objectives

No	Specific Objective	Research Question
1	To generate landslide susceptibility map	a. What kind of parameters used to generate landslide susceptibility map? b. How is spatial distribution of landslide susceptibility zone (very high, high, moderate, low, and very low)? c. How is the distribution of settlement area regarding to established landslide susceptibility map?
2	To propose an integrated method of land capability classification and landslide susceptibility	a. Which system of land capability classification is used to develop the present land use function at local government? b. What is proposed method for developing land capability classification in this area? c. Which land characteristics shall be involved in proposed land capability classification?
3	To determine land use function based on the proposed method	a. How different are present land use function map and proposed land use function map?

4	To evaluate land use deviation by considering the proposed land use function.	a. How is the present distribution of land use in proposed land use function? b. Is there any land use deviation? and where is it?

1.5. Thesis Structure

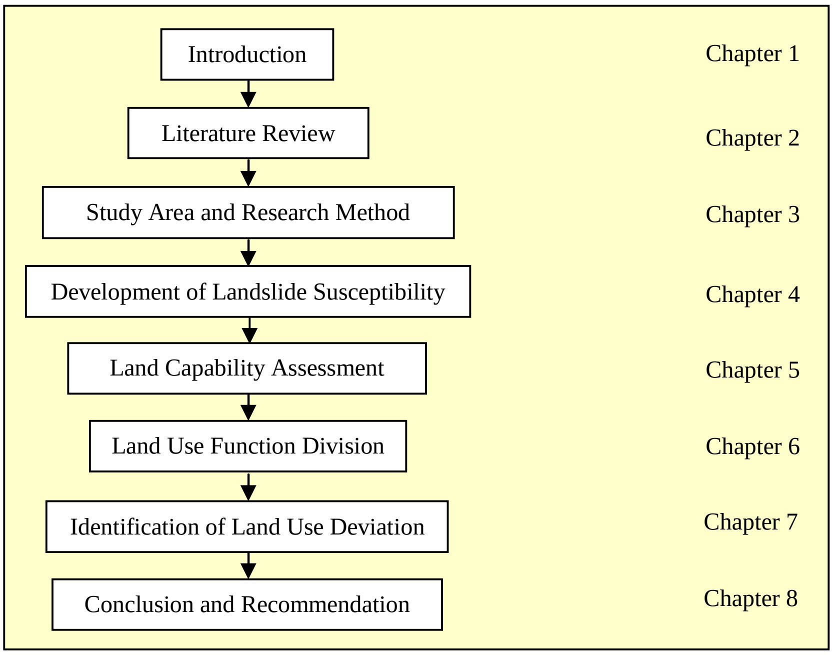


Figure 1.1. Thesis Structure

The thesis is organized in a series of chapter (Figure 1.1). Chapter 1 explains the background, objectives, and research questions derived from the specific objectives. Chapter 2 discusses literature review concerned with this research. Study area and research method are explained in Chapter 3. Chapter 4 confers development of landslide susceptibility information. The integration landslide susceptibility information in land capability classification is described in Chapter 5. The result of this chapter is harnessed to generate land use function (Chapter 6) and land use deviation (Chapter 7). The conclusion and recommendation is presented in Chapter 8.

1.6. Significance of the Research

Landslide susceptibility is one of the crucial information in spatial planning for landslide prone area. It gives a description about spatial probability of landslide. The spatial distribution of susceptible area acts as vital information in arranging proper land use function. The appropriate land use function itself is determined through land capability analysis. Therefore, the combination between landslide susceptibility in land capability assessment is needed to propose suitable land use function.

This research offers a new integrated method which combines landslide susceptibility in land capability appraisal for dividing land use function. The result can be applied by local government to arrange a better land use function division and further land use plan in spatial planning. The result can be also applied to declare a strict regulation for a certain area due to landslide threat. For scientist part, this research conveys knowledge in how to integrate landslide susceptibility in land capability assessment.

1.7. Scope and Limitation

The scope of the research comprises integration landslide susceptibility information into land capability assessment to improve present land capability appraisal in spatial planning process. The integration result is used to develop land use function and to identify land use deviation. On the other hand, the constraints in this research are related to data availability and limited time. The limited time particularly influences the primary data collection for the whole area. Inaccessibility situation is the main limitation to obtain more comprehensive soil data and landslide location.

CHAPTER II
LITERATURE REVIEW

This chapter consists of several theories related to the research topic i.e. natural hazard, landslide, landslide susceptibility, spatial planning and hazard, spatial planning in Indonesia, land capability on spatial planning in Indonesia, and USDA land capability classification.

2.1. Natural Hazard

Smith (2001) describes hazard as a general source of danger. Hazard is a naturally occurring or human-induced process or event with the potential to reveal loss. Hazard is able to create unpredictable losses and damages to be real. This condition is called disaster. The losses and damages can be suffered by people, property, and environment.

Hazard can be divided into natural hazard, human-induced and man-made hazard. The term of natural hazard is related to natural phenomena without human intervention. The kind of natural hazards consists of geologic, hydrologic, atmospheric, and biologic (Table 2.1).

Table 2.1. Some Potentially Hazardous Environmental Elements or Events

No	Kind of Hazards	Elements
1	Geologic	Mass movement (landslides, avalanches, mudflows), earthquake (ground shaking/tsunamis), volcanic eruption (pyroclastic flows, ash falls), rapid sediment movement (severe erosion/siltation).
2	Hydrologic	Flood (freshwater from rivers/lakes/dam bursts), coastal flood (from marine storm surge/sea level rise), wave action (coastal and lakeshore erosion), drought (from rainfall deficit), rapid glacier advance (surges).
3	Atmospheric	Single element (excess rainfall, freezing rain/glaze, hail, heavy snowfalls, high wind speeds, extreme temperatures), combined elements (hurricanes, glaze storms, thunderstorms, blizzards, tornadoes, heat/cold stress).
4	Biologic	Severe epidemic in humans (Ebola fever, AIDS, malaria), severe epidemic in plants, severe epidemics in wild animals, animal and plant invasions (locusts, grasshoppers, weeds), forest and grassland fires.

Source: Modified after Hewitt and Burton (1971) in Smith (2001)

2.2. Landslide

Highland and Bobrowsky (2008) defines landslide as "*a down slope movement of rock or soil, or both, occurring on the surface of rupture—either curved (rotational slide) or planar (translational slide) rupture—in which much of the material often moves as a coherent or semi coherent mass with little internal deformation*".

Landslide can be distinguished based on its type of movement. The types are fall, topple, slide, spread, flow, and complex (Highland and Bobrowsky, 2008). Each type can be divided into three types of material, i.e. bedrock, predominant coarse, and predominant fine (Table 2.2). The scheme of each landslide type is illustrated in Figure 2.1. The characteristic of each landslide type is described below:

a. Fall

The initial process of fall is detachment of soil or rock or both and also from a steep slope along a surface on which little or no shear displacement has occurred. Thereafter, the material goes down mainly by falling, bouncing, or rolling.

b. Topple

A topple is defined as the forward rotation out of a slope of a mass of soil or rock around a point or axis below the center of gravity of the displaced mass. Topples can be complex and composite and the material consist of rock, debris (coarse material), or earth materials (fine-grained material). Topple is not only forced by gravity exerted by the weight of material upslope from the displaced mass but also it is caused by water or ice in cracks in the mass.

c. Slide

A slide can be described as a down slope movement of a soil or rock mass which occurs on surfaces of rupture or on relatively thin zones of intense shear strain. Movement does not initially occur simultaneously over the whole of what eventually becomes the surface of rupture. The volume of displacing material enlarges from an area of local failure.

Table 2.2. Classification of Landslides

Type of Movement	**Type of Material**		
	Bedrock	Engineering Soils	
		Predominantly Coarse	Predominantly Fine
Falls	Rock fall	Debris fall	Earth fall
Topples	Rock topple	Debris topple	Earth topple
Slides a. Rotational (few units) b. Translational	 Rock slump Rock block slide Rock slide	 Debris slump Debris block slide Debris slide	 Earth slump Earth block slide Earth slide
Lateral spreads	Rock spread	Debris spread	Earth spread
Flows	Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
Complex	Combination of two or more principal types of movement		

Source: After Varnes (1978) in Smith (2001)

d. Spread

A spread is an extension of a cohesive soil or rock mass. It is merged with the general subsidence of the fractured mass of cohesive material into softer underlying material. Spreads may result from liquefaction or flow (and extrusion) of the softer underlying material. Several types of spreads are block spreads, liquefaction spreads, and lateral spreads.

e. Flow

A flow is a spatially continuous movement. The surfaces of shear are short-lived, closely spaced, and usually not preserved. The component velocities in the displacing mass of a flow resemble those in a viscous liquid. There is often a gradation of change from slides to flows. This situation depends on the water content, mobility, and evolution of the movement.

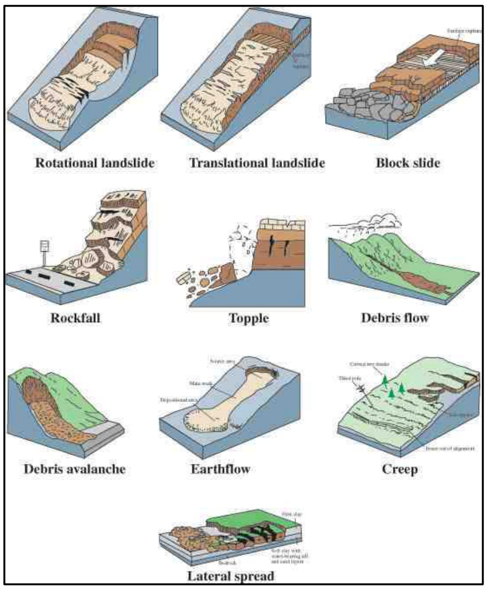


Figure 2.1. Landslide Types (USGS, 2004)

2.3. Landslide Susceptibility

Landslide susceptibility is defined as "*a quantitative or qualitative assessment of the classification, volume (or area), and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding. Although it is expected that landsliding will occur more frequently in the most susceptible areas, in the susceptibility analysis, time frame is explicitly not taken into account*" *(Fell et al, 2008).*

The susceptibility of landslide in a certain area can be estimated by combining several factors. Those factors are grouped into two categories i.e. environmental factors and triggering factors (Van Westen et al, 2008). Each category can be specified into several data layer, as follow:

a. The environmental factors are DEM, slope angle/aspect, internal relief, flow accumulation, lithology, structure, faults, soil types, soil depth, slope hydrology, main geomorphology units, detailed geomorphology units, land use types, and land use changes.
b. The triggering factors are rainfall, temperature/evapo-transpiration, earthquake, and ground acceleration.

The distribution of landslide susceptible area can be assessed by harnessing several methods. Those are inventory method, statistical method, heuristic method, and deterministic method (Soeters and van Westen, 1996). Each method has own characteristic in relation with the required data and data processing.

a. Inventory method

Inventory method is a preliminary approach to most study of landslide. This method compiles landslide occurrences in a certain area. It becomes a basis of most susceptibility mapping. The information of landslide occurrences is collected from historical data or aerial photo interpretation supported by field checking.

b. Statistical method

Statistical method utilizes the combination of several related factors to landslide occurrence in the past. The factors are calculated statistically. The purpose is to establish quantitative prediction for the area which is currently free of landslide but the similar conditions still exist.

Statistical method consists of bivariate and multivariate analysis. Bivariate statistical analysis combines each factor map with landslide distribution map. The weighted values are calculated based on landslide density in each parameter class. Multivariate statistical analysis is generated by using multiple regression analysis and discriminant analysis. This analysis requires continuous data.

c. Heuristic method

Heuristic method can be employed to analyze landslide susceptibility triggered by different mechanisms, complexity of geological condition, and the small number of actual landslides (Ruff and Czurda, 2007). The expert opinion is needed to assess the landslide potential from preparatory variables. The assumption is that the relationships between landslide susceptibility and the preparatory variables are recognized.

One problem in heuristic method is long term data requirement. It is related to actual landslides and the causal factors for the same location or for the similar location with comparable geo-environmental situation. This method also has limitation concerned with the subjectivity of weight and rank of the variables.

d. Deterministic Method

Deterministic method is based on slope instability analysis. It can be divided based on the triggering factor of slope instability, i.e. rainfall and earthquake.

- The model of rainfall-induced failures combine shallow subsurface flow (pore pressure spatial distribution) initiated by rainfalls of various return periods. Moreover, predicted soil thickness and landsliding of the soil mantle are also taken into account.
- The model of earthquake-induced failures uses a conventional seismic hazard analysis to determine Peak Ground Accelerations (PGA) for different return periods. Furthermore, slope stability when subjected to an earthquake with various return periods is observed by utilizing a pseudostatic analysis.

Deterministic method is carried out with prerequisite conditions. This method is usually used to predict landslide susceptibility in a small area. The area must have fairly uniform of ground condition. The landslide type is easy to recognize as well. The method permits quantitative factors of safety to be calculated by considering the variability of soil properties if necessary. On the other sides, deterministic method has several problems. The problems are high degree of simplification, unaffordable data requirement, and impossibility to obtain the data to use the model effectively.

2.4. Spatial Planning and Hazard

Spatial planning is a term to define optimal land utilization in a certain area. The land is managed by taking into account sustainable concept. Land use activities are arranged without disturbing the environmental balance. The disturbance itself is associated with the probability of hazard. Thereby, spatial planning has several important roles in relation with hazard (Fleischhauer et al, 2005), as follow:

a. Keeping a certain area free of development

Development activity in a certain area will attract a lot of people and supporting activities. Mass concentration and many essential activities (trade, business, etc.) put developing area as risk zone as if a particular hazard destructs this area. Thus, development activity must be located in hazard free area. Hazard prone area ought to be kept in natural condition.

b. Differentiating decisions on land use

Hazard prone area is a distinctive situation. It shall be contemplated in distinguishing land use practice. The hazard prone area must be classified as protected area. This region is not allowed to be used for extensive land use practice, such as development of settlement area. Hazard prone areas are better to be allocated as natural preserve rather than agricultural land.

c. Recommending legally binding land-use or zoning plans.

Hazard information is an important consideration in dividing land allocation. This information supports the zoning process of land use. The zoning process is organized based on legal regulation. Hence, the established land allocation must be obediently applied in the field. There are also some punishments for people who break the rule.

d. Reducing hazard potency

The involvement of hazard information is necessary to recognize an appropriate land use. This is intended to alleviate the negative impact of hazard. Some cases illustrate that the hazard becomes a disaster due to improper land use application. For that reason, land use practice must envisage the probability of hazard as a way to minimize the effect.

2.5. Spatial Planning in Indonesia

Spatial planning system in Indonesia is based on Act number 26, 2007 (Anonymous, 2007). This regulation states that the spatial planning system is developed regarding to administrative boundaries. There are four hierarchies of spatial planning, as follow:

a. *RTRW (Rencana Tata Ruang Wilayah /* Regional Spatial Plan*) Nasional* (National Spatial Plan)
b. *RTRW Pulau* (Island Spatial Plan)
c. *RTRW Provinsi* (Provincial Spatial Plan)
d. *RTRW Kabupaten/Kota* (Regency/City Spatial Plan)
e. *RUTRK (Rencana Umum Tata Ruang Kota)Kecamatan* (General Spatial Plan of Sub District City)
f. *RDTRK (Rencana Detail Tata Ruang Kota)Kecamatan* (Detailed Spatial Plan of Sub District City)

The spatial plan of higher administrative level has a function as guidance for the lower one. National Spatial Plan guides the development of Island Spatial Plan. The Island Spatial Plan is a reference for generating Provincial Spatial Plan, and so on.

Two sections in this act are concerned with hazard and land use function. Section 6.1a emphasizes the necessity to incriminate hazard information in all spatial planning levels. The hazard information is implicated in zoning division. The instrument of zoning division consists of specific and strict spatial rules on each region with certain function. Section 5.2d states that zoning division consists of protected and cultivated area. Protected areas encompass preserved areas and natural disaster prone areas. Cultivated areas are intended for productive forest, settlement, industry, etc.

This act also conducts punishment mechanism on any actions against the rules of spatial planning. The sanction is not only given to the permit holder, but also the people who hold the authorization to release the permit for exploitation. The punishment is intended to give positive effect particularly in performing law enforcement and reducing possible losses and damages due to inappropriateness implementation of spatial plan.

The process of spatial planning arrangement in Indonesia consists of nine analyses. All analyzes refer to Legal Document of Ministry of Settlement and Regional Infrastructure number 327/Kpts/M/2002 about Procedures of Province Spatial Planning Arrangement (Anonymous, 2002). Each analysis is carried out for a certain purpose in order to get inclusive result. Those analyzes are explained below:

a. Strategy analysis of development policy

The analysis is intended to explore the aims and goals of development. It is performed to examine national spatial plan in order to determine how well the role of the lower administrative level (province, regency/city) supports the pattern and structure of national space.

b. Regional analysis

This analysis discusses the relationship between province and other areas in terms of social, economic, environment and culture.

c. Economic and prominent sector analysis

The aim of this analysis is to reveal sustained regional economic in relation with local economic within a broader administrative level (national and international). The expected result is the understandings of economical characteristic at province level.

d. Human resource analysis

Human resource analysis is performed to define human intervention related to social and economic development. Social factor that influences regional development is also identified.

e. Man-made resource analysis

Man-made resource analysis is conducted to identify infrastructure condition, possible problem that occurs in the development process. This analysis consists of transportation facility analysis, drainage facility analysis, etc.

f. Natural resource analysis

This analysis is executed to obtain the information about environmental condition. The analysis discusses the development trend in utilizing natural resource and potency which can be improved. The analysis encompasses several sections. Those are land resource, water resource, air resource, forest, and other resources. Land resource section is used to identify the potency of land related to its capability and the recommendation of land use function division (cultivated and protected area).

g. Settlement system analysis

Settlement system analysis is generated to recognize condition, number, type, location, size and interdependency. The result of this analysis is depicted in hierarchy system and function of settlement area.

h. Land use analysis

Land use analysis is intended to find out land utilization and land suitability for protected and cultivated area. This analysis describes the trend of activity in a certain area, for instance in the terms of intensity, changes, occupation, and conflict among regions.

i. Institutional analysis

This analysis describes the capacity of government in conducting development process. The capacity is concerned with organizational structure, human resource, regulation, etc.

The implementation of spatial plan usually meets one crucial problem. The established spatial plan cannot be fully implemented due to land ownership. Land ownership in Indonesia is legalized on *Undang-Undang Pokok Agraria* (UUPA) number 5/1960 (Kartono et al, 1989). This act declares that property right of land allows the owner to utilize the lands and to take some benefits from them. On the other hand, spatial plan, particularly in province/regency/city is legalized on *Peraturan Daerah* (Perda). Act Republic of Indonesia number 10, 2004 section 7 states that hierarchy and type of act and regulation consists of five levels (Anonymous, 2004), as follow:

1. *Undang-Undang Dasar Negara Republik Indonesia Tahun 1945* (1945 Constitution)
2. *Undang-Undang/Peraturan Pemerintah Pengganti Undang-Undang* (Laws/Governmental Regulation in Lieu of law)
3. *Peraturan Pemerintah* (Governmental Regulation)
4. *Peraturan Presiden* (Presidential Regulation)
5. *Peraturan Daerah* (Regional Regulation)

Based on the hierarchies, Perda has lower position than *Undang-Undang*. It means that the force of law of Perda is weaker than *Undang-Undang*. Thereby, spatial plan cannot be completely enforced because community with legal property right has strong legitimacy to exploit the land as they want.

2.6. Land Capability on Spatial Planning in Indonesia

Land capability assessment on spatial planning document in Indonesia is based on Legal Document of Ministry of Agriculture number 837/Kpts/UM/11/1980 (Anonymous, 1980) and number 683/Kpts/UM/8/1981 (Anonymous, 1981). This approach uses scoring method. Three main factors (slope, soil type, and average daily rainfall intensity) are employed to divide a certain area into three land use functions. Those functions are protected area, buffer area, and cultivated area. The cultivated area is subsequently specified into yearly cultivated area, seasonal cultivated area, and settlement area. The classification of used factors is shown in Table 2.3 – Table 2.5).

Table 2.3. Slope Classification

No	Class	Slope	Score
1	Flat	0 – 8%	20
2	Slightly slope	8 – 15%	40
3	Moderately steep	15 – 25%	60
4	Steep	25 – 45%	80
5	Very steep	> 45%	100

Table 2.4. Soil Type Classification

No	Soil Type	Score
1	Aluvial,Glei, Planosol,Hidromerf, Laterik ground water (not sensitive with erosion)	15
2	Latosol (less sensitive with erosion)	30
3	Brown forest soil, non calcic brown mediteran (moderately sensitive with erosion)	45
4	Andosol, Laterit, Grumusol, Podsol, Podsolic (sensitive with erosion)	60
5	Regosol, Lithosol, Organosol, Renzina (very sensitive with erosion)	75

Table 2.5. Average Daily Rainfall Intensity Classification

No	Class	Average Daily Rainfall Intensity (mm/day)	Score
1	Very low	0 – 13.6	10
2	Low	13.6 – 20.7	20
3	Moderate	20.7 – 27.7	30
4	High	27.7 – 34.8	40
5	Very high	> 34.8	50

The classification of land use function is determined based on the accumulative score. The area with score of $\geq$ 175 is classified as protected area. The area with score of 125-174 and the score less than 125 are categorized as buffer area and cultivated area respectively. Some physical characteristics are also used to define the land use function, as follow:

a. Protected area

Protected area is the area with score of $\geq$ 175 or has one or several following characteristics:

- Slope is more than 40%
- Soil type is regosol, lithosol, organosol, and renzina. Those types are very sensitive to erosion.
- The area is riverbank. The distance is 100 meter for main river and 50 meter for stream.
- The area is used to protect water source. The distance from the water source is 200 meter.
- The area is utilized to protect lake/dam. The distance from the lake/dam is 50-100 meter.
- The elevation is more than 2,000 meter above mean sea level.
- The area had been allocated as national park by government.
- The area is established as protected area due to a specific purpose.

b. Buffer area

Buffer area is located between protected area and cultivated area so that it can have two functions i.e., as protected area or cultivated area. Buffer area is the area with score of 125-174 and/or meets a demand of the following general criteria:

- Physical condition of the land can be harnessed as economic cultivated area.
- The location is economically developed as buffer area
- The land gives benefit for the environment/ecology.

c. Cultivated area

The area with accumulative score of less than 125 is classified as cultivated region. This region consists of the three land use functions, i.e. yearly cultivated area, seasonal cultivated area, and settlement area.

- Yearly cultivated area is the area with score less than 125 and slope of 15-40%. This area has general characteristic as buffer area.
- Seasonal cultivated area has score of less than 125. This area is usually employed as seasonal agricultural purpose.
- Settlement area has score of less than 125. The slope for settlement area shall be relatively flat, i.e. 0 - 8%.

Land use function is one of preliminary analyzes in spatial planning. Land use function represents the capability of the land. It is established to support land use planning. On the other words, land use function is a global description which is then elaborated into several appropriate land use practices. Thereby, land use function division shall be properly implemented.

The enforcement of land use function division faces one significant problem as explained in previous sub chapter. Land ownership becomes the major constraint in implementing land use function division and land use planning. In addition, there is no boundary which separates each land use function. This situation probably drives extensive exploitation in improper location.

2.7. United States Department of Agriculture (USDA) Land Capability Classification

Land capability classification is one of the interpretive soil groupings. Those are developed primarily for agricultural purpose, especially farm planning. Land capability classification refers to the potentialities and limitations of soil –what it is capable of. Land capability classifies a certain area based on the degree of limitations. It is intended to establish the suitable land use practice.

The USDA land capability classification establishes three main categories of soil groupings, from most general to most specific. These are capability class, capability subclass, and capability unit (Klingebiel and Montgomery, 1966). Capability class is the general category of land capability classification. It consists of eight classes, class I – VIII. Capability subclass is a grouping of capability units which has similar kinds of limitations and hazards. Those limitations and hazards are erosion hazard (e), wetness/excess water (w), rooting zone limitations (s), and climate limitation (c). The natural hazards recognized are erosion and flooding. Capability unit is a grouping of soils which has the same responses to systems of management of common cultivated crops and pasture plants. In one capability unit, soils are adapted to the same kinds of common cultivated and pasture plants. Also, they require similar alternatives of management for these crops.

USDA land capability classification requires ten parameters for classifying a certain area into a particular land capability class. The parameters are slope, erodibility, actual erosion, soil depth, soil texture, soil permeability, soil drainage, rock fragment, flood threat, and salinity. Those parameters are described below:

a. Slope

Slope is the main topographic feature. It greatly influences the capability of land for intensive purpose. Various land uses can be performed in flat zone while very steep slope area shall not be allowed for extensive utilization due to the risk in disrupting environmental balance. Slope in USDA classification is divided into seven classes as summarized in Table 2.6.

Table 2.6. USDA Slope Classification

Code	Class	Slope
A	Flat	0 – 3%
B	Undulating	3 – 8%
C	Moderately sloping	8 – 15%
D	Hilly	15 – 30%
E	Moderately steep	30 – 45%
F	Steep	45 – 65%
G	Very steep	>65%

b. Erodibility

Erodibility is defined as the soil sensitivity to erosion. One of the methods to calculate erodibility index is proposed by Wischmeier et al (1971, in Asdak, 2007), as below:

$$100K = 2{,}713\ M^{1{,}14}\,(10^{-4})(12-a)+3{,}25(b-2)+2{,}5(c-3)$$

Where:
K = erodibility index
M = (% very fine sand + % silt) x (100-% clay)
a = % organic material
b = code of soil structure
c = code of soil permeability class

Soil structure is categorized into four classes based on the diameter size (Table 2.7). Soil permeability is divided into six classes (Table 2.8). The erodibility index itself is grouped into six classes as seen in Table 2.9.

Table 2.7. Soil Structure Classification

Code	Soil Structure Class / Diameter
1	Very fine granular (<1 mm)
2	Fine granular (1 – 2 mm)
3	Moderate and coarse granular (2 – 10 mm)
4	Blocky, plat, massif

Table 2.8. Soil Permeability Classification

Code	Class	Permeability (cm/hour)
1	Very slow	<0.5
2	Slow	0.5 – 2.0
3	Low to moderate	2.0 – 6.3
4	Moderate	6.3 – 12.7
5	Moderate to fast	12.7 – 25.4
6	Fast	>25.4

Table 2.9. Erodibility Index Classification

Code	Class	Erodibility Index
KE1	Very low	0.00 – 0.10
KE2	Low	0.11 – 0.20
KE3	Moderate	0.21 – 0.32
KE4	Moderately high	0.33 – 0.43
KE5	High	0.44 – 0.55
KE6	Very high	0.56 – 0.64

c. Actual Erosion

Actual erosion is estimated by observing the present situation of soil layer. This parameter is grouped into six classes as shown in Table 2.10.

Table 2.10. Actual Erosion Classification

Code	Class	Erosion Characteristic
e0	No erosion	-
e1	Minor erosion	Less than 25% of topsoil is lost
e2	Moderate erosion	25 - 75 % of topsoil is lost
e3	Moderately severe erosion	More than 75 %of topsoil and less than 25% of subsoil are lost
e4	Severe erosion	More than 25% of subsoil is lost
e5	Very severe erosion	Gully erosion

d. Soil Depth

Effective soil depth is the depth of soil which is good for the growth of root. Soil depth is measured until rock layer which cannot be penetrated by root. The categorization of soil depth is depicted in Table 2.11.

Table 2.11. Soil Depth Classification

Code	Class	Soil Depth (cm)
k0	Deep	More than 90 cm
k1	Moderate	50 – 90 cm
k2	Shallow	25 – 50 cm
k3	Very shallow	< 25 cm

e. Soil Texture

Soil texture is one of important soil characteristics. It influences soil capacity for retaining the water. This parameter also affects soil permeability and other physical and chemical characteristics. Soil texture is categorized into five classes based on the degree of roughness (see Table 2.12). The interpretation of soil texture can be conducted by using the given diagram (Figure 2.2).

Table 2.12. Soil Texture Classification

Code	Class	Soil Texture
t1	Fine-textured	Sandy clay, silty clay, clay
t2	Moderately fine-textured	Clay loam, sandy clay loam, silty clay loam
t3	Medium-textured	Loam, silty loam, silt
t4	Moderately coarse-textured	Fine sandy loam, very fine sandy loam, sandy loam
t5	Coarse-textured	Sands, loamy sands

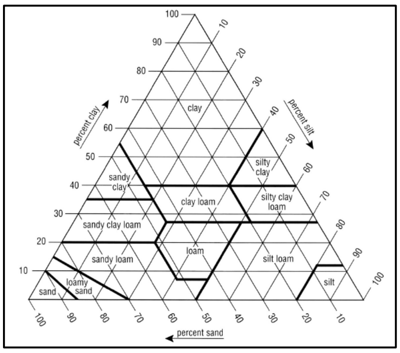


Figure 2.2. Soil Texture Chart (USDA, 1993)

f. Soil Permeability

Soil permeability represents the soil ability to flow the water in saturated condition. The permeability is divided into five classes as figured in Table 2.13.

Table 2.13. Soil Permeability Classification

Code	Class	Soil Permeability (cm/hour)
p1	Slow	< 0.50
p2	Moderately slow	0.5 – 2.0
p3	Moderate	2.0 – 6.25
p4	Moderately fast	6.25 – 12.5
p5	Fast	> 12.5

g. Soil Drainage

Soil drainage is related to soil characteristic to restrain the water. It is associated with air circulation in the soil. Soil drainage condition can be identified from the soil color. The appearance of yellow, brown, or grey spots in the soil indicates poor soil drainage condition (see Table 2.14).

Table 2.14. Soil Drainage Classification

Code	Class	Soil Drainage
d0	Excessively drained	Water is removed very rapidly.
d1	Well drained	Soil has a good air circulation. All soil profile (150 cm) has similar color and there are no yellow, brown, or grey spots.
d2	Moderately well drained	Soil has a good air circulation in the root zone. There are no yellow, brown, or grey spots up to 60 cm from soil surface.
d3	Somewhat poorly drained	Upper layer has a good circulation. There are no yellow, brown, or grey spots up to 40 cm from soil surface.
d4	Poorly drained	There are yellow, brown, or grey spots in the upper layer (near soil surface).
d5	Very poorly drained	All soil layers have yellow, brown, or grey spots.

h. Rock Fragment

Rock fragment refers to coarse materials both in the soil and on the surface. These materials affect the growth of plant. The detailed classification of rock fragment in the soil and rock fragment on the surface is presented below:

- Rock fragment in the soil
  Rock fragment in the soil is observed in upper soil layer (20 cm from the surface). The materials are classified as gravel and small rock. Gravel has diameter of 1.2 – 7.5 cm for circular shape and diameter of 1.2 – 15 cm for flat shape. Small rock has diameter of 7.5 – 25 cm for circular shape and diameter of 15 – 40 cm for flat shape. The classification of rock fragment in the soil is displayed in Table 2.15. The existence of rock fragment in the soil can be estimated by using estimation chart as shown in Figure 2.3.

Table 2.15. Classification of Rock Fragment in the Soil

Code	Class	Rock Fragment in the Soil
b0	No	0 - 15% of soil volume
b1	Moderate	15 – 50% of soil volume
b2	Much	50 – 90% of soil volume
b3	Very much	> 90% of soil volume

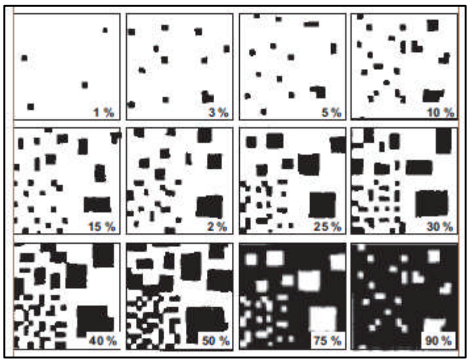


Figure 2.3. Chart for Estimating Proportions of Coarse Fragments and Mottles (FAO, 2006)

- Rock fragment on the surface
  Rock fragment on the surface is divided into two groups. These are stone and rock. Stone freely exists in the surface. It has diameter of more than 25 cm for circular shape and diameter of more than 40 cm for flat shape. On the other side, rock appears on the surface. It is a part of rock sunk in the soil. The classification of stone and rock on the surface is presented in Table 2.16 and Table 2.17 respectively.

Table 2.16. Classification of Stone on the Surface

Code	Class	Stone on the Surface
b0	No	Stones or boulders cover from 0.01 to 0.1% of the surface
b1	Few	Stones or boulders cover from 0.1 to 3% of the surface
b2	Moderate	Stones or boulders cover from 3 to 15% of the surface
b3	Much	Stones or boulders cover from 15 to 90% of the surface
b4	Very Much	Stones or boulders covers more than 90% of the surface

Table 2.17. Classification of Rock on the Surface

Code	Class	Rock on the Surface
b0	No	Rocks cover less than 2% of the surface
b1	Few	Rocks cover from 2 to 10% of the surface
b2	Moderate	Rocks cover from 10 to 50 percent of the surface
b3	Much	Rocks cover from 50 to 90 percent of the surface
b4	Very Much	Rocks covers more than 90 percent of the surface

i. Flood Threat

Flood threat classification is based on the actual flood events in a given area. The flood duration is a key to categorize flood threat (see Table 2.18).

Table 2.18. Classification of Flood Threat

Code	Flood Duration
O0	In a year, the area is never inundated by flood with duration more than 24 hours
O1	Less than one month, the area is not regularly inundated by flood with duration more than 24 hours
O2	In a month per year, the area is regularly inundated by flood with duration more than 24 hours
O3	In 2 – 5 months per year, the area is regularly inundated by flood with duration more than 24 hours
O4	In more than six months per year, the area is regularly inundated by flood with duration more than 24 hours

j. Salinity

Salinity is a particular parameter in land capability classification. This parameter is usually harnessed for the dry season area or coastal area. Salinity is stated as dissolved salt contents or electricity obstruction of soil. Four classes are developed for this parameter as seen Table 2.19.

Table 2.19. Classification of Salinity

Code	Class	Salinity Condition
g0	Free	0 – 0.15% dissolved salt; 0 – 4 (ECx10^3) mmhos per cm on temperature of 25^0C
g1	Slightly influenced	0.15 – 0.35% dissolved salt; 4 – 8 (ECx10^3) mmhos per cm on temperature of 25^0C
g2	Moderately influenced	0.35 – 0.65% dissolved salt; 8 – 15 (ECx10^3) mmhos per cm on temperature of 25^0C
g3	Greatly influenced	>0.65% dissolved salt; >15 (ECx10^3) mmhos per cm on temperature of 25^0C

All parameters are eventually involved in land capability classification table. Land capability classification is a ranked system based on the severity of land limitations. Thus, the table describes the distribution of limitations in every land capability class. The limitation becomes greater from class I to VIII (Table 2. 20).

Land capability class is a starting point to determine the appropriate land use practice. The intensity of land use practice depends on the degree of limitation. The worse limitation causes the lower the intensity of land use practice. The severe inhibiting factor obstructs extensive land utilization in relation with sustainable purpose (Table 2.21).

Table 2.20. Land Capability Classification

No	**Factor**	**Land Capability Classes**							
		I	II	III	IV	V	VI	VII	VIII
1	Slope	A	B	C	D	A	E	F	G
2	Erodibility	KE1, KE2	KE3	KE4, KE5	KE6	*	*	*	*
3	Actual erosion	e0	e1	e2	e3	**	e4	e5	*
4	Soil depth	k0	k1	k2	k2	*	k3	*	*
5	Soil texture	t1/t2/t3	t1/t2/t3	t1/t2/t3/ t4	t1/t2/t3/t4	*	t1/t2/t3/t4	t1/t2/t3/t4	t5
6	Soil permeability	p2/p3	p2/p3	p2/p3/p4	p2/p3/p4	p1	*	*	p5
7	Soil drainage	d1	d2	d3	d4	d5	**	**	d0
8	Rock fragment	b0	b0	b1	b2	b3	*	*	b4
9	Flood threat	O0	O1	O2	O3	O4	**	**	*
10	Salinity***	g0	g1	g2	g3	**	g3	*	*

**It doesn't have particular characteristic, ** Inapplicable*
****it is usually applied in dry season area*

Table 2.21. Land Capability Class Description

Class	**Description**
I	Soils with few limitations
II	Soils with some limitations that reduce the choice of plants or require moderate conservation practices.
III	Soils with severe limitations that reduce the choice of plants or require special conservation practices or both.
IV	Soils with very severe limitations that restrict the choice of plants or require very careful management, or both.
V	Soils with little or no erosion hazard but have other limitations impractical to remove that limit their use largely to pasture, range, woodland or wildlife food and cover.
VI	Soils with severe limitations that make them unsuited to cultivation and limit their use largely to pasture or range, woodland or wildlife food and cover.
VII	Soils with very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, woodland or wildlife.
VIII	Soils and landforms with limitations that preclude their use for commercial plants production and restrict their use to recreation, wildlife, or water supply or to esthetic purposes.

Source: Klingebiel and Montgomery (1966)

CHAPTER III
STUDY AREA AND RESEARCH METHOD

Chapter three explains characteristic of study area and method of the research. The characteristics of study area comprise geographical location, geomorphological and geological condition, land use, rainfall intensity, soil, and demographic condition. The research method is divided into three parts, i.e. data preparation/data collection, data processing, and data analysis.

3.1. Study Area

Tawangmangu Sub District is located in Karanganyar Regency, Central Java Province, Indonesia (Figure 3.1 – 3.2). The width area is 7,003 Ha. This sub district is administratively divided into ten villages. Those are Tengklik, Gondosuli, Plumbon, Bandardawung, Sepanjang, Karanglo, Nglebak, Tawangmangu, Kalisoro, and Blumbang. This area also consists of 42 sub-villages (*dusun*), 86 *dukuh*, 99 *RW (Rukun Warga)*, and 344 *RT (Rukun Tetangga)* (BPS, 2008).

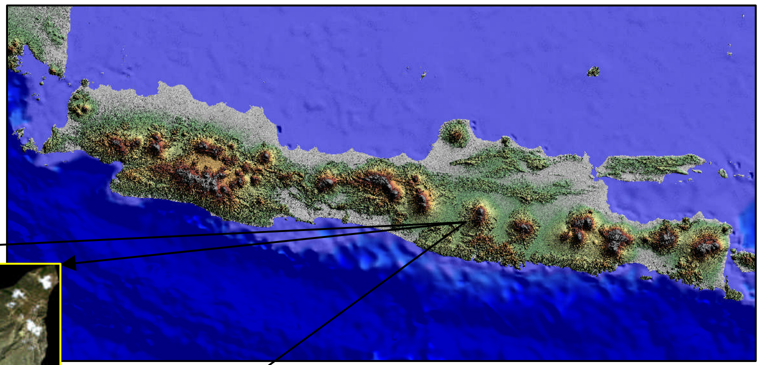


Figure 3.1. SRTM of Java Island

Figure 3.2. Ikonos Image of Tawangmangu Sub District (Google Earth, 2006)

3.1.1. Geographical Location

Tawangmangu Sub District is situated between 513319 – 521443 mE and 9151905 – 9156896 mN (Figure 3.3). It has administrative boarders with Ngargoyoso Sub District in the North, Jatiyoso Sub District in the South, Karangpandan and Matesih Sub District in the West, and East Java Province in the East.

3.1.2. Geomorphological Conditions

Physical condition of Tawangmangu Sub District is geomorphologically influenced by volcanic activity from Lawu Volcano, Mount Sidoramping, and Mount Jobolarangan. The materials from those volcanoes form various environmental features. These features are mainly in terms of lithology and slope. The study area consists of eight geological units. Most of them are composed by andesitic lava, volcanic tuff, breccia, basalt, etc. The area is also characterized by various slopes. Steep (45 – 65%) and very steep (more than 65%) slope is the dominant situation in study area. (Table 3.1).

Table 3.1. Width Area of Each Slope Class

Code	Class	Slope	Width Area (Ha)	Code	Class	Slope	Width Area (Ha)
A	Flat	0 – 3%	11	E	Moderately steep	30 – 45%	1,170
B	Undulating	3 – 8%	336	F	Steep	45 - 65%	1,585
C	Moderately sloping	8 – 15%	638	G	Very steep	> 65%	1,756
D	Hilly	15 – 30%	1,507	**Total**			7,003

Source: Data Analysis (2009)

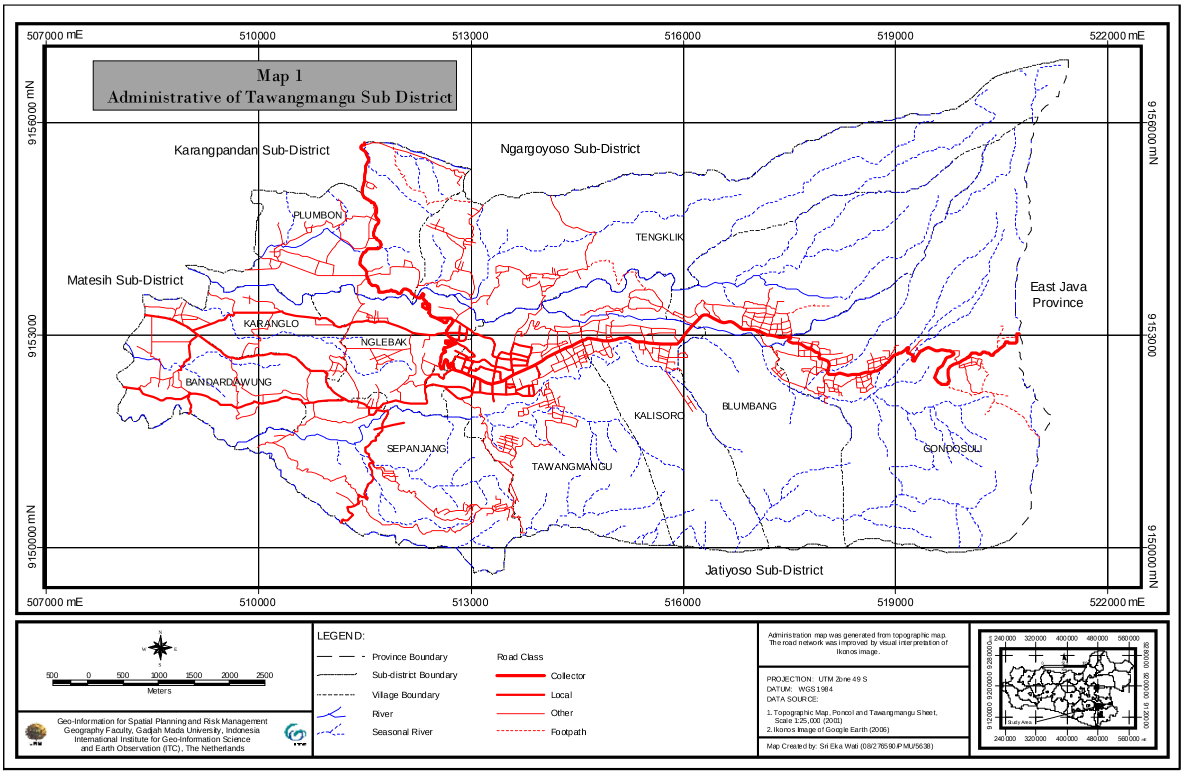


Figure 3.3. Administration Map of Tawangmangu Sub District

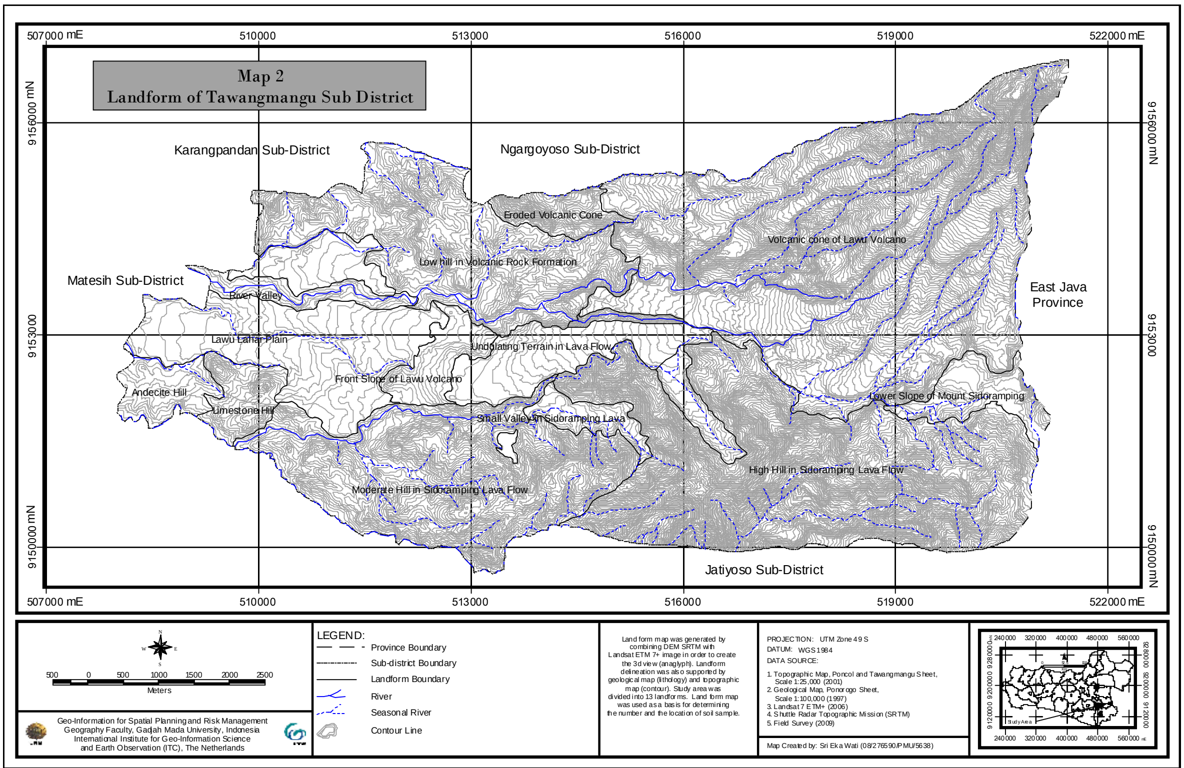


Figure 3.4. Landform Map of Tawangmangu Sub District

The topographic and geological condition is the consideration in determining the landforms in study area. Landform is harnessed as a land mapping unit in this research. The landform is technically obtained from visual interpretation of 3D view of Landsat Image, contour, and geological formation. As a result, study area is classified into 13 landforms (Figure 3.4), as follow:

a. Volcanic cone of Lawu Volcano

Volcanic cone area is concatenation of four zones. Those are summit/cone, upper slope, middle slope, and lower slope. The four zones are assumed as one landform due to low accessibility to reach them. The characteristic of each zone is described below:

- Cone of Lawu Volcano

  The summit area of Lawu Volcano is the highest place in Tawangmangu Sub District. The highest elevation is 3,262.5 amsl. This area is dominated by the slope of more than 65%. Tuff, breccia, and andesitic lava are the parent materials in this zone.

- Upper slope of Lawu Volcano

  Most sections of this landform have slope of more than 65%. The area is geologically formed by Lawu volcanic rock (tuff, breccia, and inserted andesitic lava) combined with andesitic lava from geological unit of Condrodimuko lava. The area is mostly used as forest although some areas are abandoned as bare land.

- Middle slope of Lawu Volcano

  This landform is laid upon Lawu volcanic rock (tuff, breccia, and inserted andesitic lava) and Condrodimuko lava (andesitic lava). Slope in this area is slightly sloping compared with the upper slope. Nevertheless, there are some areas with slope of 45 – 65% and > 65%, particularly in the stream valley. The major land use is forest. Vegetable garden also exists for planting some vegetable and fruit which needs cold temperature to grow, e.g. carrot and strawberry.

- Lower slope of Lawu Volcano

  This region is a part of Lawu volcanic rock formation. The lithology consists of tuff, breccia, and inserted andesitic lava. The area is characterized as hilly and moderately steep slope (15 – 45%). The intensity of steep and very steep slope is getting lower than middle slope zone. Forest spreads out in this area possessed by PERHUTANI.

b. Lower slope of Mount Sidoramping

This landform is situated in hilly and moderately steep area. It exists upon Jobolarangan breccia and Condrodimuko lava. The land is broadly utilized by community as vegetable garden. Kinds of fruit and vegetable are carrot and strawberry. Forest is also kept to reduce erosion process in moderately steep area.

c. Undulating terrain in lava flow

The undulating terrain is located in the middle part of Tawangmangu Sub District. It exists between two landforms, i.e. high hill in Sidoramping lava flow and low hill in volcanic rock formation. This area is geologically set up on Lawu volcanic rock. Most of land is utilized as settlement area and vegetable garden, particularly in the part of region with slope less than 30%. On the other side, areas with slope more than 30% are harnessed as pine plantation.

d. High hill in Sidoramping lava flow

This area is influenced by volcanic activity from Mount Sidoramping. The lava flows toward this area. This landform is dominated by slope more than 65%. The very steep slope hinders intensive land utilization. The land is covered by forest although some barren areas are still found.

e. Moderate hill in Sidoramping lava flow

This area is laid within the path of Sidoramping lava flow. The intensity of steep slope is smaller than high hill area. Some parts of this zone are used as settlement area even though the topographic condition represents unsuitable area to be inhabited. Other areas are employed as vegetable garden and mixed garden.

f. Low hill in volcanic rock formation

The lithology of low hill area comprises with tuff, breccia, and inserted andesitic lava. This area has various slopes from 3% to more than 65%. Hilly areas (15 – 30%) are commonly used as settlement area whereas the others are exploited as mixed garden and mixed paddy field with vegetable garden.

g. Small valley in Sidoramping Lava

Three small valleys exist in Sidoramping lava formation. Those areas are typified as bowl shape. It is a lower area surrounded by higher area. Small valley regions are harnessed as settlement area, vegetable garden, and paddy field. One of those areas is located in Ngledoksari Sub-Village, Tawangmangu Village. This area is known as the location of landslide event occurred on December 26th, 2007.

h. River valley

Study area has two steep river valleys. A river valley is situated in middle part of Tawangmangu Sub District. This area is steeper the other valley. It is geologically laid upon volcanic rock formation. The other river valley is positioned in western part. It is situated in Lawu lahar formation. The land uses in those two river valleys are mixed paddy field with vegetable garden and shrub and bush.

i. Eroded volcanic cone

Eroded volcanic cone is a part of Mount Purung area. It is spatially located between low hill in volcanic rock and volcanic cone of Lawu Volcano. This area is composed by volcanic tuff, breccia, and inserted andesitic lava. Almost all areas are steep with slope of more than 45%. The land is only used as forest.

j. Front slope of Lawu Volcano

This landform confines two landforms, i.e. undulating terrain in lava flow and Lawu lahar plain. This landform geologically acts a meeting point between Lawu volcanic rock and Lawu lahar formation. This area is mostly characterized by undulating and hilly area (8 – 30%). The undulating slope areas are intensively harnessed as settlement area.

k. Lawu lahar plain

Lawu lahar plain areas are formed by andecite, basalt, and minor pumice. The land is relatively flat so that it is commonly exploited as mixed paddy field with vegetable garden. Settlement and paddy field areas are also spread out in this region.

l. Andecite hill

Andecite hill is situated on intrusion rock formation. The area is typified by slope less than 30%. The general land uses in this hill are settlement area, paddy field and mixed paddy field with vegetable garden.

m. Limestone hill

This is a unique landform in study area. Isolated hill composed by limestone exists within andecite material from Lawu Volcano and Mount Sidoramping (Figure 3.5). The lower part of the hill is utilized as settlement area and mixed garden. The southern area is used as vegetable garden. The materials from this hill are mined by local people.

3.1.3. Geological Conditions

Tawangmangu Sub District comprises with a series of young-quaternary volcanic and old-quaternary volcanic. This is influenced by the process of volcanic activity in Pleistocene and Holocene period. The process in Pleistocene and Holocene period reveals old Lawu Volcano and young Lawu Volcano respectively. Those are separated by fault which exists from the south to the west as shown in Figure 3.6.

Study area consists of eight geological units. Each geological unit has own lithological combination. The lithology characteristics influence several physical aspects in study area, e.g. soil development, slope stability, and land productivity. The spatial distribution of geological formation is depicted in Figure 3.7. The characteristics of those geological formations are explained below:

Figure 3.5. Limestone hill

Figure 3.6. Fault from southward to westward (yellow line) which separates Old Lawu Volcano and Young Lawu Volcano

a. Lawu Lahar (Qlla)

Lawu lahar consists of andecite, basalt, and minor pumice. Those elements merge with volcanic sand. This unit spreads out in volcanic foot slope areas and forms several low hills.

b. Condrodimuko Lava (Qvcl)

Condrodimuko Lava formation is composed by andesitic lava. The lava is issued from Condrodimuko Crater to the southwest. The distribution to northwestward is confined by the fault crossing the peak of Lawu Volcano. Moreover, the lava flow to southward is hampered by Cemorosewu Fault.

c. Lawu Volcanic Rock (Qvl)

Lawu volcanic rock mostly encompasses volcanic tuff and breccia inserted by andesitic lava. Volcanic tuff with 2 meter thickness contains andecite, pumice, quartz, feldspar, and minor pyroxene and amphibole fragments. Volcanic breccia with black-grey color comprises with andecite of 5 – 20 cm in diameter and 5 meter thickness. Grey andesitic lava has an average thickness of 1 meter.

d. Jobolarangan Lava (Qvjl)

This formation contains the materials from Mount Jobolarangan. Mount Jobolarangan is the highest peak in Old Lawu Formation. The materials from this mount are andesitic lava with andesine, quartz, feldspar, and minor hornblende.

e. Sidoramping Lava (Qvsl)

Dark grey andesitic lava is released from Mount Sidoramping, Mount Puncakdalang, Mount Kukusan, and Mount Ngampiyungan. The lava flows to the westward. The lava consists of plagioclase, quartz and feldspar in plagioclase microlite and volcanic glass.

f. Jobolarangan Breccia (Qvjb)

This formation is formed by local volcanic breccia intercalated by andesitic lava. This area is mainly distributed in Old Lawu formation with slope of 30 – 50%.

g. Wonosari Formation (Tmwl)

This area consists of reef limestone and calcarente inserted by conglomeratic limestone and marl. The lithology develops several low hills with cone shape. The height of the cone is approximately 20 meter.

h. Andecite (Tma)

This intrusion rocks show particular textures. The textures are porphyritic, sub hedral, and 0.5 – 1 meter in size. This formation contains 45% andesine, 15% orthoclase, 5% quartz, 5% minerals within plagioclase microlite, and 30% volcanic glass.

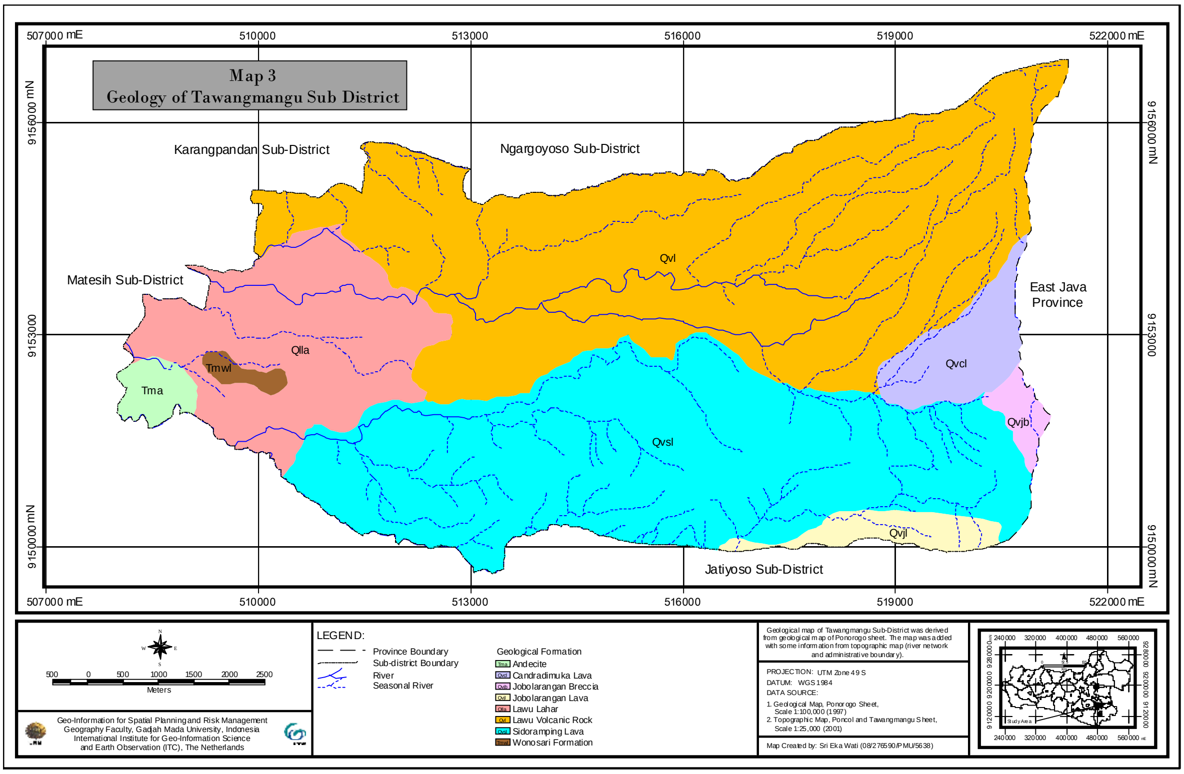


Figure 3.7. Geological Map of Tawangmangu Sub District

3.1.4. Land Use

Land use in Tawangmangu Sub District is classified into ten classes. Those classes are forest, pine plantation, paddy field, mixed garden, vegetable garden, mixed paddy field with vegetable garden, settlement area, shrub and bush, limestone area, and sparse vegetation in forest region (Table 3.2 and Figure 3.8). Land use classification refers to Malingreau (1977) although there are some modified land use classes. The modified classes are adjusted by actual land use in study area. Some land uses in study area is presented in Figure 3.9 – 3.13.

The distribution of land use depends on topographic condition. Land in lower part of Lawu Volcano is intensively used for agricultural activities and settlement area. The agricultural land and settlement are not only found in relatively flat area but also in undulating and hilly area. On the other side, the upper part of Lawu Volcano and steep slope areas are allocated as forest, particularly protected forest (PERHUTANI, 2006).

Table 3.2. Land Use of Tawangmangu Sub District

No	Land Use	Width Area (Ha)
1	Forest	3,417
2	Pine plantation	65
3	Paddy field	176
4	Mixed garden	652
5	Mixed paddy field with vegetable garden	749
6	Settlement area	935
7	Shrub and bush	11
8	Limestone area	8
9	Vegetable garden	800
10	Sparse vegetation in forest region	190
	Total	**7,003**

Source: Visual Interpretation of Ikonos Image of 2006 (2009), Field Checking (2009)

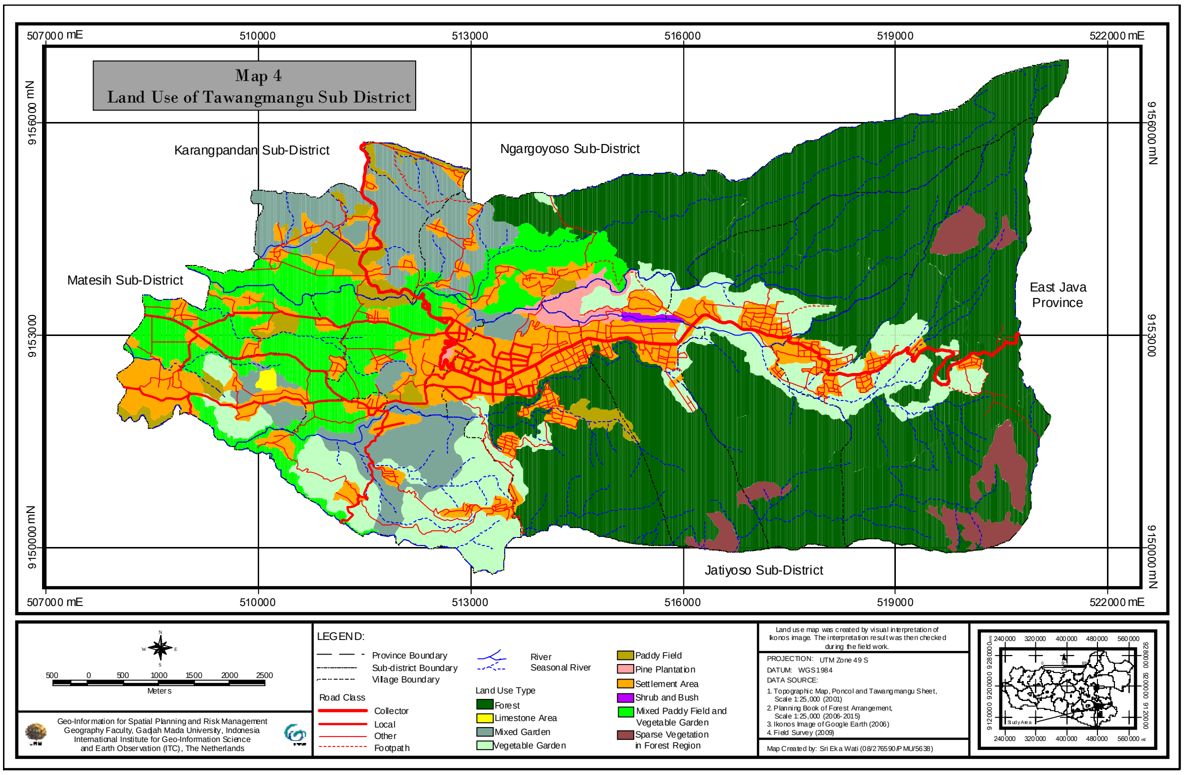


Figure 3.8. Land Use Map of Tawangmangu Sub District

Agricultural activities in study area are dominated by vegetable garden. Some vegetable gardens are mixed with paddy field. The existence of vegetable garden is dispersed in flat up to steep area. Vegetable garden in steep area is performed by terracing technique. The main products of vegetable garden are carrot, Chinese cabbage, sweet potato, strawberry, onion, garlic, broccoli, and cauliflower.

Settlement is the most rapid developed land use in study area. This situation is forced by the increasing of population growth. The growth of settlement area occurs along the road and in distant area. Settlement in remote area has been supported by utility service, particularly electricity. Many local roads are also built to connect the settlement in remote area to center of the city.

Figure 3.9

Figure 3.10

Figure 3.11

Figure 3.12

Figure 3.13

Figure 3.9. Vegetable Garden in Hilly Area
Figure 3.10. Settlement in Undulating Terrain Area
Figure 3.11. Pine Trees in Front Slope of Lawu Volcano Area
Figure 3.12. Mixed Garden at Moderate Hill in Sidoramping Lava
Figure 3.13. Paddy Field at Low Hill in Volcanic Rock Formation

3.1.5. Rainfall Intensity

Rainfall intensity in Tawangmangu Sub District is measured from two rainfall gauges. The gauges are located in Blumbang (Blumbang Village) and Somokado (Tawangmangu Village). The rainfall gauge in Blumbang Village is no longer used since 1993. Thus, the continued measurement is only done in Somokado gauge.

Average monthly rainfall intensity for study area is calculated by using daily rainfall data from 1986 to 2008. For Blumbang gauge, the calculation of average monthly rainfall intensity is done by using data from 1986 to 1992. The result shows that average monthly rainfall intensity in Somokado gauge is higher than Blumbang gauge. Average monthly rainfall intensity for other gauges surrounded study area (Matesih, Jatiyoso, Karangpandan, and Gayamdompo) is also lower than Somokado gauge. Average monthly rainfall intensity for study area and surroundings is shown in Table 3.3 and Figure 3.14.

Table 3.3. Monthly Rainfall Intensity of Tawangmangu Sub District and Surroundings

Rainfall Gauge	Monthly Rainfall Intensity (mm)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Avg**
Somokado	576	561	457	318	141	81	45	65	60	178	319	480	**273**
Blumbang	570	536	365	238	130	99	84	54	52	84	231	373	**235**
Matesih	438	467	396	286	108	92	52	38	30	186	326	398	**235**
Jatiyoso	427	417	377	240	115	77	30	97	52	170	311	354	**222**
Karangpandan	429	434	406	276	140	101	66	39	40	197	291	387	**234**
Gayamdompo	371	371	306	248	126	105	58	29	41	145	254	367	**202**

Source: Public Work Department of Karanganyar Regency (1986-2008)

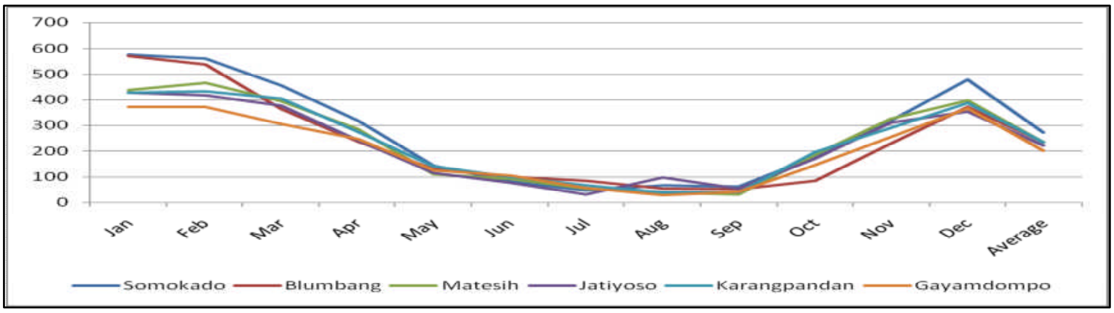


Figure 3.14. Monthly Rainfall Intensity Chart (Data Analysis, 2009)

3.1.6. Soil Characteristics

The observation of soil properties is done as the major requirement in assessing land capability in study area. The explored soil characteristics primarily comprise depth, texture, permeability, soil drainage, and rock fragment. The depth, drainage, and rock fragment are observed in the field. Texture and permeability are analyzed in soil laboratory.

Field observation and laboratory analysis convey several results. Field observation shows that study area mostly has soil depth more than 90 cm. Some particular areas have very shallow soil, for instance limestone hill. Moreover, almost of study area is relatively well drained even though some locations are poorly drained due to the influence of topographic situation. Soil layers in most locations also have rock fragment percentage less than 15%. On the other hand, laboratory analysis states that the texture in study area pervades clay, clay loam, loam, and sandy loam. In addition, the permeability is classified as slow, moderately slow, moderately fast, and fast.

3.1.7. Demographic Conditions

Tawangmangu Sub District is inhabited by 44,892 people (BPS, 2008). The highest populated area is in Tawangmangu Village (8,440 people) whereas the lowest populated area is in Gondosuli Village (3,435 people). In the terms of population density, Tawangmangu Village is the highest dense area (2,504 people/km^2) whilst Gondosuli Village is the lowest dense area (178 people/km^2) (Table 3.4).

Table 3.4. Population Data of Tawangmangu Sub District

No	Village	Width Area (km^2)	The Number of Population (people)	The Number of Family	Population Density ($people/km^2$)
1	Bandardawung	3.01	3,993	1,147	1,327
2	Sepanjang	5.65	3,787	931	670
3	Tawangmangu	3.37	8,440	2,271	2,504
4	Kalisoro	10.58	4,437	1,145	419
5	Blumbang	11.12	3,986	909	358
6	Gondosuli	19.25	3,435	951	178
7	Tengklik	8.10	3,801	1,067	469
8	Nglebak	2.34	5,189	1,391	2,218
9	Karanglo	1.86	3,578	961	1,924
10	Plumbon	4.75	4,246	1,125	894
	Total	**70.03**	**44,892**	**11,898**	**641**

Source: BPS (2008)

3.2. Method

The research was split into three stages. The stages were data preparation/data collection, data processing, and data analysis. Data preparation/data collection and data processing were conducted before and after field work. Data analysis was done after field work. The sequence step of the research is shown in Figure 3.15.

Data preparation/data collection was accomplished to provide required data. Secondary data was achieved by institutional survey. Several institutions were visited to gather the information needed. The primary data were compiled in field work session.

Data processing was performed to manage the obtained data. Some secondary data were processed before the field work. The processed data were tentative result that had to be verified in the field. Apart from that, the other data were processed after the field work. The data particularly need to be analyzed in laboratory (soil properties). Data processing was performed by means of Geographic Information System (GIS) and Remote Sensing application.

Data analysis was intended to achieve the answer of each research question. The analysis was done by using the result from data processing stage. The detailed explanation of research method is described below:

3.2.1. Data Preparation/Data Collection

The research required primary and secondary data. Primary data were associated with soil properties and landslide events. Those data were obtained from field work and laboratory analysis. The secondary data were gathered from some related institutions. The compulsory data are described in Table 3.5. The documentation of several data collection activities is presented in Appendix 4.

a. Secondary data collection

Main secondary data for this research were geological map, topographic map, rainfall intensity, landslide events, and satellite imageries. Other required data which were also collected were erodibility index, soil type, population data and spatial planning document. The obtained spatial planning documents consisted of Regional Spatial Plan (RTRW) of Karanganyar Regency 1997 - 2006, Detailed Spatial Plan of Subdistrict City (RDTRK) of Tawangmangu 2007 - 2016[1], and General Spatial Plan of Subdistrict City (RUTRK) of Tawangmangu 1990/1991 – 2009/2010.

Secondary data collection was also executed through interview session. The interview was conducted with Development and Planning Board (BAPPEDA) of Karanganyar Regency. It was intended to evaluate present land capability classification developed by local government. Based on the result of interview, proposed land capability classification was established by involving landslide susceptibility information.

[1] Mid Report of Detailed Spatial Plan of Subdistrict City of Tawangmangu 2007-2016

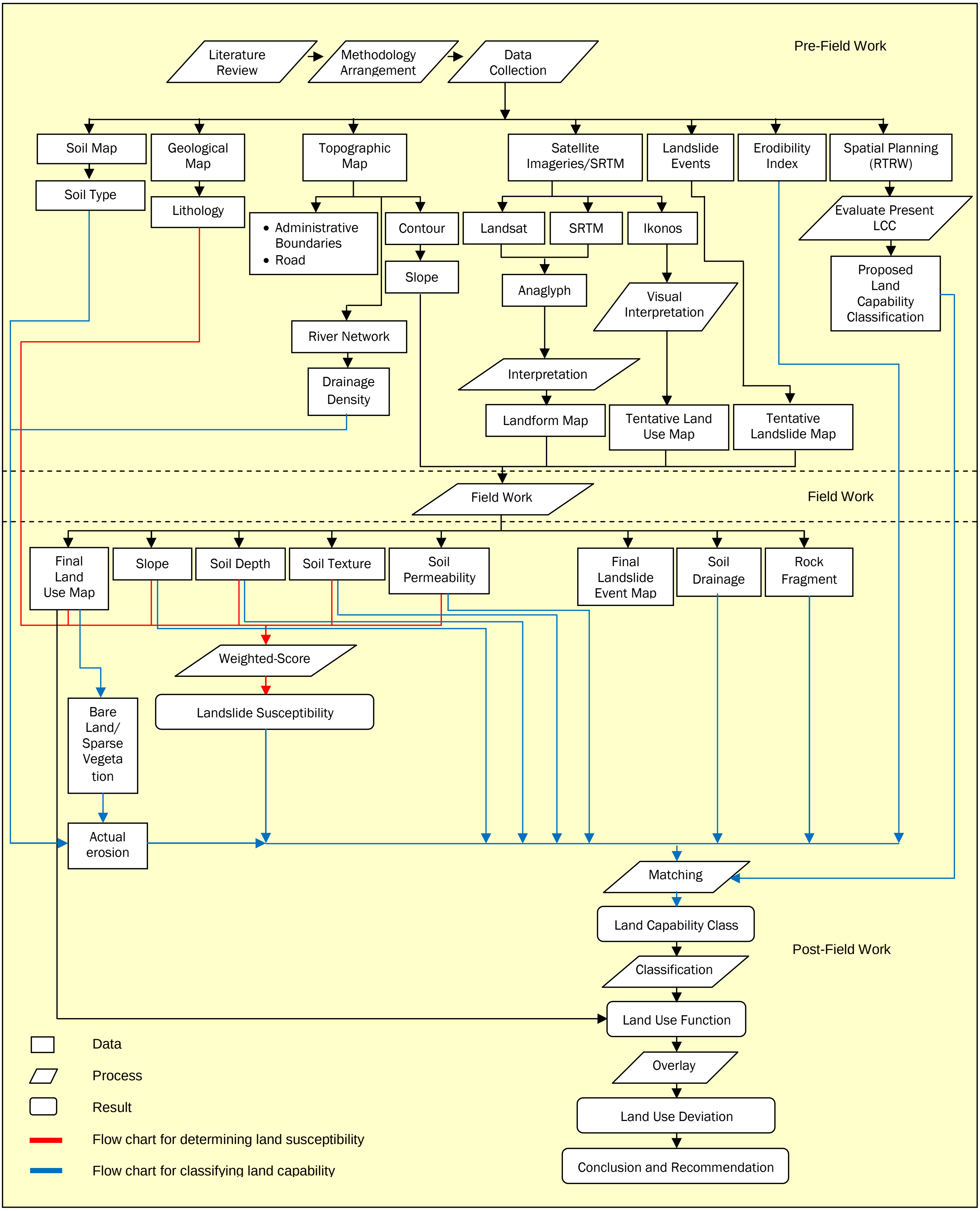


Figure 3.15. Research flowchart

Table 3.5. Data Requirement

No	Data	Information	Source
1	Geological map	Lithology	PUSLITBANG GEOLOGI (Geological Research and Development Center), scale 1:100,000
2	Topographic map	• Administrative boundaries • Contour • Road network • River network	BAKOSURTANAL (National Coordinating Agency for Surveys and Mapping), scale 1:25,000
3	Rainfall	Daily rainfall intensity	Public Work Department of Karanganyar Regency
4	Landslide	Landslide occurrence	• *Dinas KESBANGLINMAS* of Karanganyar Regency • The office of Tawangmangu Sub District • Village offices in Tawangmangu Sub District • Field checking
5	Satellite imageries	• Land use (distribution of settlement area) • Road network • Landform	• Ikonos image (Google Earth , 2006) • Landsat ETM, 2001 • SRTM (Shuttle Radar Topographic Mission) • Field checking
6	Soil properties	• Soil type • Soil depth • Soil texture • Soil permeability	• PUSLITANAK, scale 1:250,000 • Field checking • Laboratory analysis
7	Erodibility	Erodibility	Previous research and literature study
8	Actual erosion	Actual erosion	Field checking and literature study
9	Soil drainage	Soil drainage	Field checking
10	Rock fragment	Rock fragment	Field checking
11	Spatial planning document (RTRW, RUTRK, RDTRK)	Method in determining land capability for land use function	BAPPEDA (Development and Planning Board) of Karanganyar Regency)
12	Statistical data	Population (total, density)	BPS (Center of Statistical Bureau) of Karanganyar Regency

b. Primary data collection

Primary data were acquired from field survey. Two surveys were performed, i.e. soil survey and landslide inventory survey. Soil survey was done to compile the information of soil properties. The information was concerned with depth, texture, permeability, actual erosion, soil drainage, and rock fragment. On the other side, landslide inventory survey was organized to collect the spatial distribution of landslide location.

Soil survey was accomplished for taking 35 soil samples. The number of soil samples for each landform was based on the width area of every landform. The number of samples was obtained by dividing the width area with 4 cm^2 of output scale map. The output scale map is 1:60,000. It means that the width area of each landform should be divided by 144 in order to obtain the number of samples in every landform. Nevertheless, the accessibility was also considered to get the soil sample. Thus, the number of samples for two landforms (volcanic cone of Lawu volcano and high hill in Sidoramping lava) was less than ideal situation due to low accessibility in those areas (Table 3.6 and Figure 3.16).

Table 3.6. The Number of Samples for Each Landform

No	Landform	Width Area (Ha)	The Number of Samples
1	Volcanic cone of Lawu Volcano*	2,134	6
2	Lower slope of Mount Sidoramping	140	1
3	Undulating terrain in lava flow	245	2
4	High hill in Sidoramping lava flow*	1,439	5
5	Moderate hill in Sidoramping lava flow	908	6
6	Low hill in volcanic rock formation	766	5
7	Small valley in Sidoramping lava	160	1
8	River Valley	113	1
9	Eroded Volcanic cone	97	1
10	Front slope of Lawu Volcano	121	1
11	Lawu lahar plain	652	4
12	Andecite hill	116	1
13	Limestone hill	112	1
	Total	**7,003.0**	**35**

*Source: Data Analysis (2009), * not the whole area is accessible*

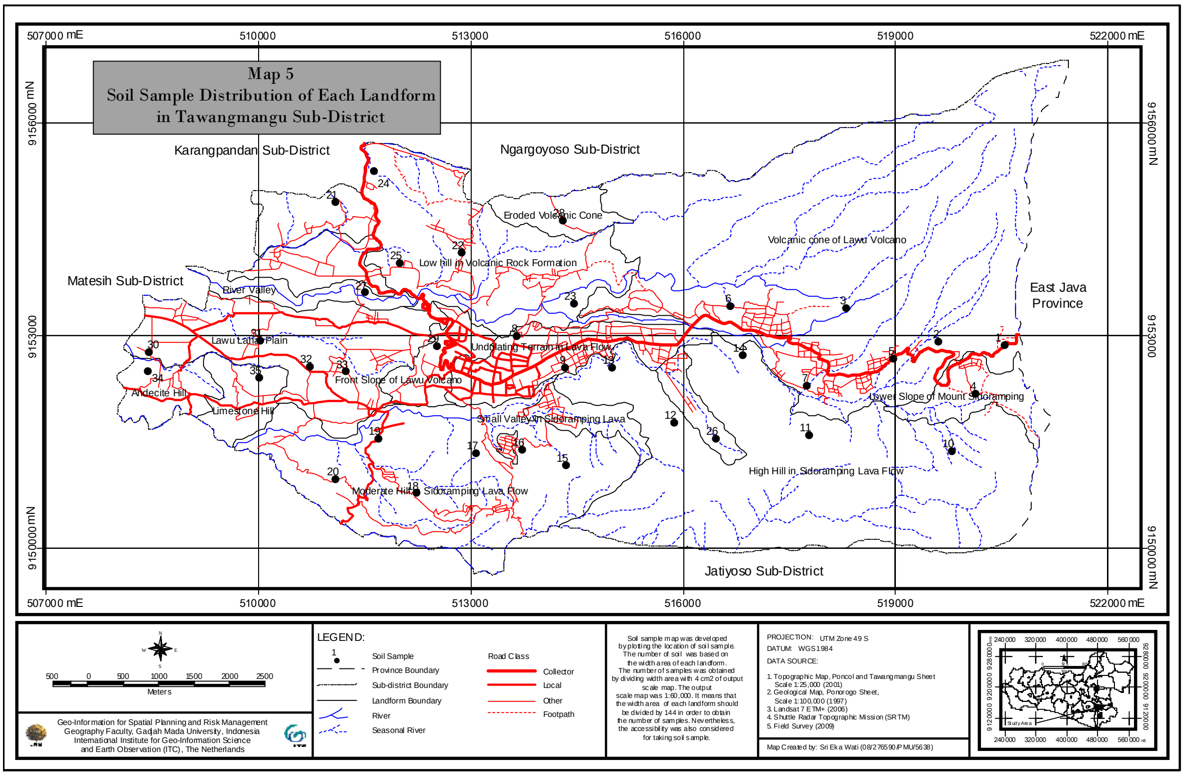


Figure 3.16. Soil Sample Distribution Map of Each Landform in Tawangmangu Sub District

Soil survey was conducted through particular method. Detailed methods in soil survey were:

- Soil depth was measured by using bore. The depth was calculated from the surface to rock layer by considering the assumption that more than 90 cm is classified as deep.
- Soil texture was observed by taking approximately 1 kg soil sample in horizon A. The samples were analyzed in soil laboratory in order to achieve the percentage of very fine sand, sand, silt, and clay.
- Soil permeability was taken by ring permeability. The samples were also sent to laboratory to be analyzed.

- Actual erosion was formerly observed in soil sample point. This observation is not sufficient to estimate the actual erosion in scope of landform. Thereby, this parameter was determined by using three variables, i.e. drainage density, distribution of sparse vegetation/bare land, and soil type.
- Soil drainage condition was recognized based on the appearance of yellow, brown, or grey spots in the soil.
- Rock fragment was evaluated regarding to the existence coarse material in the soil, and rock or stone in the surface. Coarse material in the soil was estimated by harnessing rock fragment chart as shown in Figure 2.3.

The information of landslide events was collected from sub district office, village offices and local community. The landslide data collection by visual interpretation could not be fully done due to the lack of data, especially satellite imageries. The interpretation only harnessed Ikonos image (2006) from Google Earth. Therefore, the data of landslide event was improved by visiting the reachable locations of landslides. The coordinate of the location was taken by using GPS. The result of landslide inventory survey is presented by landslide point map as illustrated in Chapter IV.

3.2.2. Data Processing

The first data processing was performed prior to field work. This activity was done to prepare the preliminary information. This information was checked in the field, i.e. land form map, tentative land use map, and tentative landslide point map. Each of them was derived from the following method:

a. Land form map was generated by combining DEM SRTM with Landsat ETM 7+ image in order to create the 3d view (anaglyph). Landform delineation was also supported by geological map (lithology) and topographic map (contour line pattern). Developed land form map was used as a basis for determining the number and the location of soil sample. The landform map is illustrated in Figure 3.4.
b. Tentative land use map was created by visual interpretation of Ikonos image (2006) from Google Earth. The interpretation result was then checked in the field.
c. The initial landslide information from local government in the level sub district and village was developed as a landslide point map. The map was checked in the field and subsequently evolved by adding the new location of landslide events that was found during the field work.

The second data processing was conducted after field work. All data were processed to come up with the expected result. Landslide susceptibility, land capability, and land use function are the main result in this research. Every required result was processed through particular method, as below:

a. Development of landslide susceptibility map

   Landslide susceptibility map was made by using Heuristic approach with weighted overlay method. Related variables used were slope, lithology, soil depth, soil texture, soil permeability, and land use. Each variable was classified into four classes and was given a certain score and weighted value. The score and weighted value was developed in ILWIS. The score was generated from pair wise method and weighted value was obtained from rank method. Detailed information of landslide susceptibility is described in Chapter IV.

b. Land capability assessment

   Land capability assessment was basically done by using the method from Klingebiel and Montgomery (1966) and Arsyad (1989). This method was modified by including landslide susceptibility information (Table 5.2). The proposed land capability classification acted as a basis to determine land capability of study area. The procedure was by matching the actual situation in study area with proposed land capability classification.

   Land capability was assessed in general and detailed version. Those versions basically used landform as a land mapping unit. However, the method of those versions was a little bit different. The method for each version is illustrated in Table 3.7. Apart from that, this research also examined the other way in determining land capability by involving landslide susceptibility information. Land capability was formerly classified without taking into account landslide susceptibility. The obtained land capability class was subsequently overlaid with landslide susceptibility. All mentioned processes of land capability assessment are fully described in Chapter V.

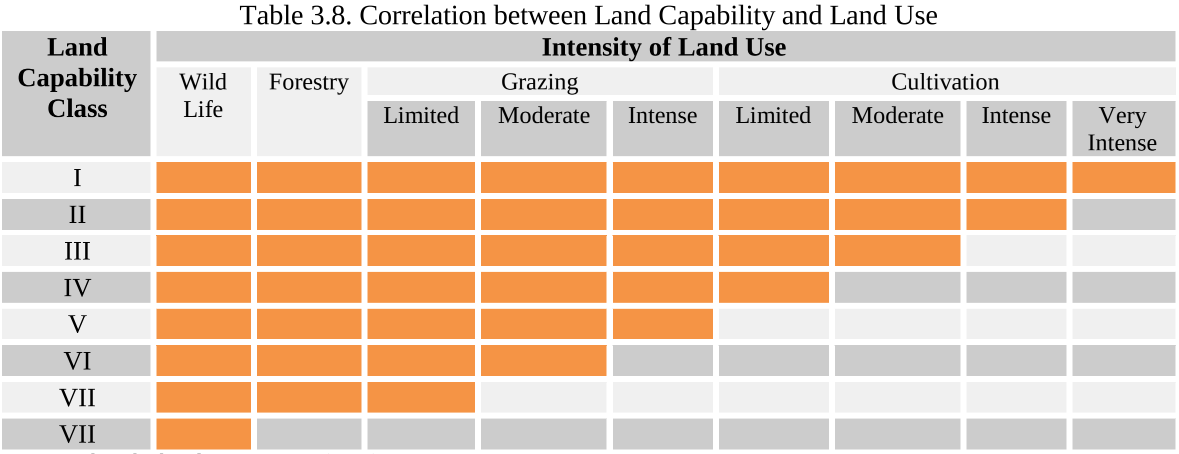
Table 3.7. The Comparison Method of General and Detailed Version in Land Capability Assessment

General Version	Detailed Version
Assumption: One landform has a quite similar characteristic so that one landform is represented by one land capability class. Method: • The dominant value for each land capability's parameter was determined as a representative value in each landform. • The value was then matched with proposed land capability classification.	Assumption: One landform actually has several different land capability classes due to spatial distribution of slope and landside susceptibility. Method: • Land capability was established as in general version. • The general land capability class was overlaid by slope and landslide susceptibility map • The overlay result was then matched with proposed land capability classification.

c. Establishment of land use function

Land use function was developed by using two methods. The methods were Ministry of Agriculture's method (scoring method) and proposed method. Two methods were employed to compare the result. Scoring method employs three variables, i.e. slope, soil type, and average daily rainfall intensity. The classification of each variable is shown in Table 2.3 – 2.5. Land use function is divided based on accumulative score. The score of $\geq$ 175 is categorized as protected area. The score of 125-174 is classified as buffer area and the score of less than 125 is allocated as cultivated area. On the other hand, proposed method harnesses land capability class for determining the land use function. The conversion diagram of land capability class and land use was applied (Table 3.8). Based on the given diagram, class I to IV can be harnessed as cultivated area. Class V to VI shall be applied as grazing area. Otherwise, class VIII has to keep as nature conservation area. The obvious discussion session about land use function is demonstrated in Chapter VI.

Table 3.8. Correlation between Land Capability and Land Use



Source: Klingebiel and Montgomery (1966)

Land use function division was done through general and detailed version. General version classified the land use function according to landform boundary. On the other side, the detailed version ignored the landform boundary. The difference of general and detailed version in land use function division is described in Table 3.9. The clear explanation about land use function is presented in Chapter VI.

Table 3.9. The Difference of General and Detailed Version in Land Use Function Division

Method	General Version	Detailed Version
Ministry of Agriculture's method (scoring method)	• The dominant value for each land use function's variable (slope, soil type, and average daily rainfall intensity) was determined in each landform. • The value was given a certain score. • The score was accumulated in each landform	• Three required variables (slope, soil type, and average daily rainfall intensity) were directly overlaid. Each variable class has been given a certain score. • The score was finally summed.
Proposed method	General land use function was established by using the result of general version of land capability assessment.	Detailed land use function was specified by employing the result of detailed version of land capability assessment.

3.2.3. Data Analysis

The analysis process included several tasks, as follow:

a. Identification of settlement area distribution in each landslide susceptibility class

The identification process was performed by overlying present settlement area distribution and landslide susceptibility. It was proposed to recognize the settlement areas which were situated in high and very high susceptible area to landslide. The result of this analysis can be used as important information for future land management.

b. Explanation of existing and proposed landslide mitigation strategies

Existing landslide mitigation strategies collected in the field was described in order to find the inadequacy strategies for the future. Proposed mitigation strategies were then arranged as a recommendation for local government and local community.

c. Comparison land use function division based on Ministry of Agriculture's method (scoring method) and proposed method

The comparison was accomplished to obtain the differences between two methods. The distinctions between them were descriptively asserted. The comparison was also done for general and detailed version of both methods.

d. Identification of land use deviation

Land use deviation refers to inappropriateness condition between land use function and land use practice. Land use deviation was recognized by comparing land use function map and present land use map. The identification of land use inexpediency was developed for general and detailed version. General and detailed land use deviation was developed based on general and detailed land use function respectively. The identification analysis of land use deviation also included the discussion about the cause of land use deviation. This analysis stage is obviously expressed in Chapter VII.

3.2.4. Equipment and software

Equipment and software employed during the research were:

a. Equipment: computer, scanner, printer, and field work tools (bore, ring permeability, abney level, hammer, Global Positioning System (GPS), digital camera, printed satellite imageries, printed thematic maps, and soil sample forms)
b. Software: Arcview 3.3, ArcGIS 9.2, ILWIS 3.3, ERDAS Imagine 9.1, and Microsoft Office (Word, Excel, Powerpoint).

CHAPTER IV
LANDSLIDE SUSCEPTIBILITY OF TAWANGMANGU SUB DISTRICT

This chapter implicates detailed explanation related to landslide susceptibility. Actual landslides that have been inventoried are presented. The method, result, and analysis of landslide susceptibility concerned with settlement area distribution are briefly described in this chapter.

4.1. Introduction

Landslide susceptibility is defined as spatial probability of landslide occurrence in a certain area. Landslide susceptibility represents the prone degree of landslide. The higher landslide susceptibility level stands for the higher probability of landslide occurrence. The probability of landslide can be estimated by using several approaches (statistic, deterministic, or heuristic). Those approaches analyze a complex combination of some physical-environmental aspects, for instance: slope, lithology, soil properties, and rainfall. In this research, landside susceptibility information was generated by harnessing heuristic approach with weighted-score method.

4.2. Landslide Events in Tawangmangu Sub District

A big landslide occurred on December 26th, 2007 in Ngledoksari Sub-Village, Tawangmangu Village (Figure 4.1). This event caused 34 victims and 105 damaged houses (Local Government of Karanganyar Regency, 2007). This event was the worst landslide in Tawangmangu Sub District within the last five years.

Figure 4.1. Landslide in Ngledoksari Sub-Village

Other landslide events often took place in the study area. There were 34 landslide locations found during the field work (see Table 4.1 and Figure 4.10). Most of landslides were located in Sepanjang and Bandardawung Village (Figure 4.2). However, the revealed damages and looses in those two villages were not as big as in Tawangmangu Sub District.

Several landslides also occurred in remote area. Four locations of landslides were identified through visual interpretation of Ikonos image (2006) from Google Earth (Figure 4.3). The landslides are situated in landform of high hill in Sidoramping lava flow. This area is administratively included in Gondosuli Village. This location is associated with very steep slope (more than 65%) and it is abandoned as sparse vegetated area.

Landslide events are mainly situated in agricultural land (mixed garden and vegetable garden) (Figure 4.4 – 4.5). It means that human intervention in harnessing the available land sometimes reveals negative impact for the environment. One of the crucial conditions is related to development of vegetable garden in steep slope area. Fertile land with good climate supports the expanded land utilization. The demand in providing agricultural commodities for Tawangmangu Sub District and surroundings also drives rapid growth of agricultural land in study area.

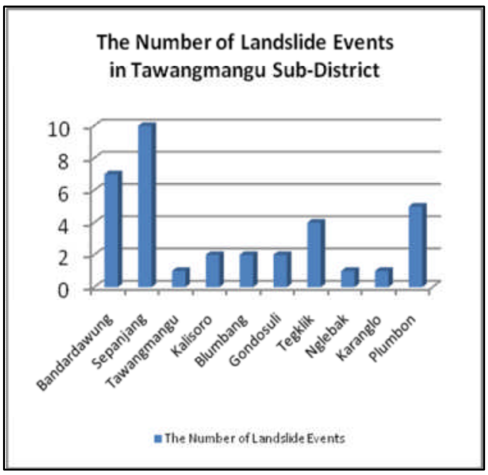


Figure 4.2. The Number of Landslide Events in Each Village (Data Analysis, 2009)

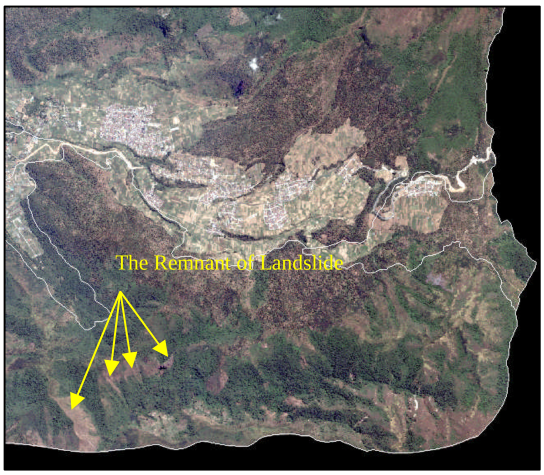


Figure 4.3. The Remnant of Landslide Evidence in Ikonos Image (Google Earth, 2006)

Some landslide events cause damages and disruption in settlement area (Figure 4.6 – 4.9b). The settlement areas are generally located in relatively steep area and in flat area surrounded by steep zone. The damages in settlement area encompass damaged houses and roads. Several damaged houses and roads in those locations can be still identified while the others are not. Most damaged houses due to landslide have been repaired. Almost all damaged roads have been also reconstructed.

Some people in study area have own perception about landslide. They consider landslide as a threat for human but they do not have ability for moving to the safer area. The lower salary and memorable history coerces them to live in the same location. Moreover, they have to adapt to physical condition since there is no other alternative areas as living space. Those perceptions are one of the hindering factors in landslide overcoming strategies, particularly related to the effort in relocating affected people.

Table 4.1. Landslide Events in Tawangmangu Sub District

No	Village	The Number of Landslide Events	Damages and Losses
1	Bandardawung	7	Damaged agricultural land and road
2	Sepanjang	10	12 damaged houses, damaged road, and agricultural land
3	Tawangmangu	1	34 casualties and 105 damaged houses
4	Kalisoro	4	Damaged agricultural land
5	Blumbang	4	Damaged agricultural land
6	Gondosuli	2	Shrub and bush
7	Tegklik	4	35 damaged houses, damaged road and agricultural land
8	Nglebak	1	Damaged road
9	Karanglo	1	Damaged road
10	Plumbon	5	4 damaged houses, damaged road, shrub and bush

Source: Sub District and Village Offices in Tawangmangu Sub District; Field Checking (2009)


Figure 4.4


Figure 4.5


Figure 4.6


Figure 4.7


Figure 4.8


Figure 4.9a


Figure 4.9b

Figure 4.4. Damaged agricultural land (mixed garden) in Bandardawung Village
Figure 4.5. Damaged agricultural land (vegetable garden) in Kalisoro Village
Figure 4.6. Damaged houses and road in Tengklik Village
Figure 4.7. Repaired house because of landslide in Sepanjang Village
Figure 4.8. Direction of landslide and susceptible house in Sepanjang Village
Figure 4.9a. Damaged road due to landslide in Karanglo Village
Figure 4.9b. Direction of landslide and susceptible house in Karanglo Village

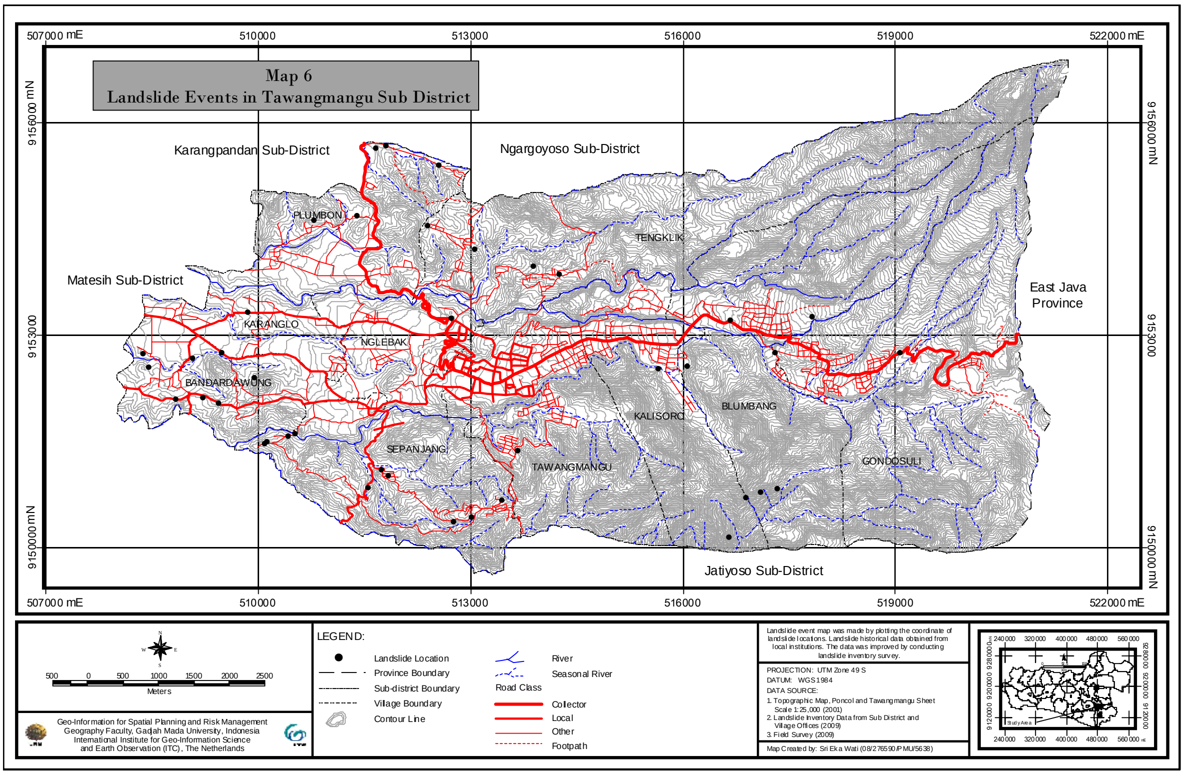


Figure 4.10. Landslide Event Map of Tawangmangu Sub District

4.3. Landslide Type in Tawangmangu Sub District

Landslide type in study area is mainly rotational (Figure 4.11). This type has unique characteristic in which the surface of rupture is curved upward (spoon-shaped). The slide movement is more or less rotational about an axis that is parallel to the slope contour. This landslide type is triggered by rainfall or earthquake. High rainfall intensity forces the increasing of water content in the soil up to saturated condition. In relation with slope, this circumstance finally reduces resistant force and enlarges driving force sliding process (Highland and Bobrowsky, 2008). Figure 4.12 shows rotational landslide in Bandardawung Village.

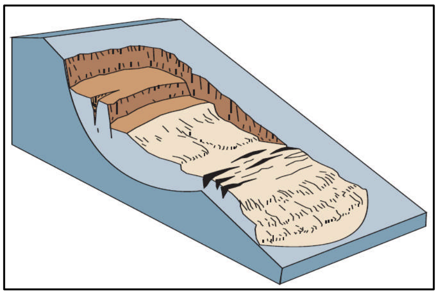


Figure 4.11 Rotational Landslide Scheme (Highland and Bobrowsky, 2008)

Rainfall is the most triggering factor of landslide events in study area. A big landslide in Tawangmangu Sub District was primarily triggered by high rainfall intensity. The recorded daily rainfall intensity from five rainfall gauges on December 27th, 2007 tended to be the highest during the last 23 years. Total rainfall intensity in that day was approximately similar even higher than monthly rainfall intensity. The high rainfall intensity also caused other landslide events in the other villages. Hence, the extreme rainfall intensity plays a main role in landslide mechanism in study area.

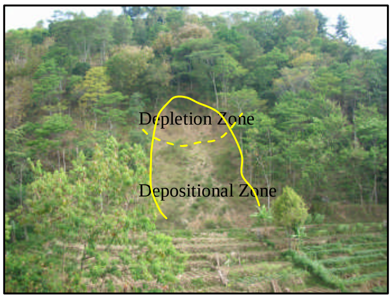


Figure 4.12. Rotational Landslide in Bandardawung Village

The materials of landslide event in study area commonly consist of soil and rock. Soil is the dominant material. The domination of soil material appears as a consequence in terms of deep soil in the study area. On the other hand, landslide with rock material can be particularly identified in limestone hill as seen in Figure 4.4.

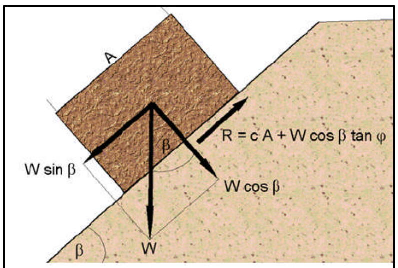
4.4. Development of Landslide Susceptibility Information

Landslide susceptibility information was developed by means of heuristic approach with weighted-score method. The score was obtained from pair wise method whereas weight value was achieved by applying rank method. Both application methods are available in ILWIS. The susceptibility information was executed by involving six parameters, i.e. slope, lithology, soil depth, soil texture, soil permeability, and land use. Each class of parameters was given a certain score which was then multiplied by a weight value. The score and the weight value depict the percentage of influence in landslide occurrence.

Landslide susceptibility parameters used in this research was generated from several sources. Those are topographic map, geological map, and soil analysis. Some of them, i.e. geological map and soil analysis do not have detail information so that the effective scale of the assessment is not as precise as in the result.

The parameters of landslide susceptibility are classified into three groups. Those are topographic, material, and dynamic (Figure 4.13). The topographic condition controls the possibility of mass failure. The materials play two roles, i.e. soil as mass block and lithology as slip surface. Dynamic group takes a part as an indirect factor that influences slope stability. Each group comprises particular parameter (Table 4.2), as follows:

a. Topographic group consists of one parameter, i.e. slope. Slope is the main factor that affects in increasing shear stress and also reducing shear strength. The final weight of landslide susceptibility parameters shows that slope has the highest weight value.
b. Material group is divided into lithology and soil. Lithology is parent material. It plays a role as slip surface. Soil properties refer to depth, texture, and permeability. Soil is mass block upon parent material. Lithology is given the higher weight because well compacted geological formation reduces the soil to collapse.
c. Dynamic group refers to land use. Land use affects the increasing of pressure for soil. The land use practice done without considering slope situation enlarges the possibility of soil to fall down.



$$F = \frac{c\,A + W\cos\beta\,\tan\phi}{W\sin\beta}$$

Where:
F = safety factor
c = cohesion (Pa= N/m2).
A = length of the block (m).
W = weight of the block (kg).
β = slope surface inclination (°).
φ = angle of shearing resistance (°)

Figure 4.13. Slope Stability Diagram (ITC, 2009)

Rainfall is also one of the triggering factors in landslide occurrence. Rain infiltration drives hydrostatic pressure, enlarges water pressure in soil, and induces a change of consistency. This situation reveals a decrease of cohesion and internal angle friction (Sopheap, 2007). On the other words, water absorbed by soil adds water pressure in the soil, forces the escalating of soil mass, and finally increases burden for slope. Since the average monthly rainfall intensity of the study area shows a quite similar condition, rainfall parameter is neglected.

The six parameters are divided into four classes. Each parameter class is ranked according to the sensitivity to landslide mechanism. The sensitivity is determined through several assumptions as explained below:

a. Slope

Slope is the main factor in landslide occurrence. It controls driving force (shear stress) and resisting force (shear strength). The higher of the slope is associated with the higher of the shear stress. It means that the probability of failure is getting bigger. Thereby, the higher slope class is given the higher score. Slope map of study area is portrayed in Figure 4.14.

b. Lithology

Rock type represents some particular characteristics. The hard and massive rock are generally resistant to erosion (Anbalagan and Singh, 2001), e.g. andecite and limestone. Andecite and Wonosari formation (limestone) is set up with the lowest score. On other sides, Lawu lahar and Jobolarangan breccia are more brittle than lava formation (Jobolarangan lava, Sidoramping lava, Candradimuka lava) due to the high amount of sand fragment. Apart from that, rock composed by sandstone is more vulnerable to erosion so that it is more susceptible to landslide. Lawu volcanic rock is geological formation formed by sandstone material. Geological map has been presented in Figure 3.7.

c. Soil depth

Soil depth influences the shear stress and shear strength. The depth of soil is associated with the weight of soil. It is assumed that the deeper the soil, the weightier the mass. Thus, the higher score is allocated to the deeper soil. Soil depth in study area is spatially depicted in Figure 4.15.

d. Soil texture

Soil texture is the weight proportion of the separates for particles less than 2 mm. The texture can be recognized from a laboratory particle-size distribution (USDA, 1993). The soil with fine texture (clayey soil) has small pores and liberates the water gradually. It means that clayey soil is easier to be saturated than sandy soil. Hence, clayey soil is more susceptible to landslide because this soil can retain more water. This condition causes the increasing the weight of soil mass. Classification of soil texture in Tawangmangu Sub District can be seen in Figure 4.16.

e. Soil permeability

Permeability can be defined as the velocity of a certain porous material for flowing the water or other liquids at standard condition (De Boodt, 1971). Soil permeability is related to soil texture. The clayey soil is more vulnerable to landslide because it has lower permeability than silt and sandy soil. Therefore, the slower the permeability represents the higher the possibility of landslide. The soil permeability map is illustrated in Figure 4.17.

f. Land use

Land use is an indirect indicator of slope stability (Anbalagan and Singh, 2001). Sparse vegetation enhances the effect of weathering and erosion. House construction in settlement area also enlarges weight to the slope (Smith, 2001). Vegetable garden in steep slope area increases the susceptibility of landslide as well. Regarding to lithology, limestone area are less prone to landslide. Paddy field is also resistant to erosion and landslide as if it is located in flat area. Present distribution of land use is shown in Figure 3.8.

Table 4.2. The Weighted and Score of Landslide Susceptibility Parameters

No	Parameter	Weighted factor	Parameter's class	Score
1	Slope	40.8	Flat and undulating (0 – 8%) Moderately sloping (8 – 15%) Hilly and moderately steep (15 – 45%) Steep (>45%)	0.103 0.213 0.449 1.000
2	Lithology	24.2	Andecite, Wonosari formation Jobolarangan lava, Sidoramping lava, Candradimuka lava Lawu lahar , Jobolarangan breccia Lawu volcanic rock	0.087 0.202 0.489 1.000
3	Soil Depth	10.3	Very shallow (<25 cm) Shallow (25 – 50 cm) Moderate (50 – 90 cm) Deep (>90 cm)	0.200 0.000 0.000 1.000
4	Soil Texture	6.1	Sandy loam, loamy sand, and sand Loam, silty loam, and silt Sandy clay loam, clay loam, and silty clay loam Sandy clay, silty clay, and clay	0.098 0.208 0.464 1.000
5	Soil Permeability	2.8	Moderately fast, fast (> 6.25 cm per hour) Moderate (2.0 – 6.25 cm per hour) Moderately slow (0.5 - 2.0 cm per hour) Slow (<0.5 cm per hour)	0.103 0.238 0.502 1.000
6	Land Use	15.8	Limestone area, paddy field, pine plantation Shrub and bush, mixed garden, forest Mixed paddy field with vegetable garden Settlement, vegetable garden, sparse vegetation in forest region	0.105 0.236 0.507 1.000

Source: Data Analysis, 2009

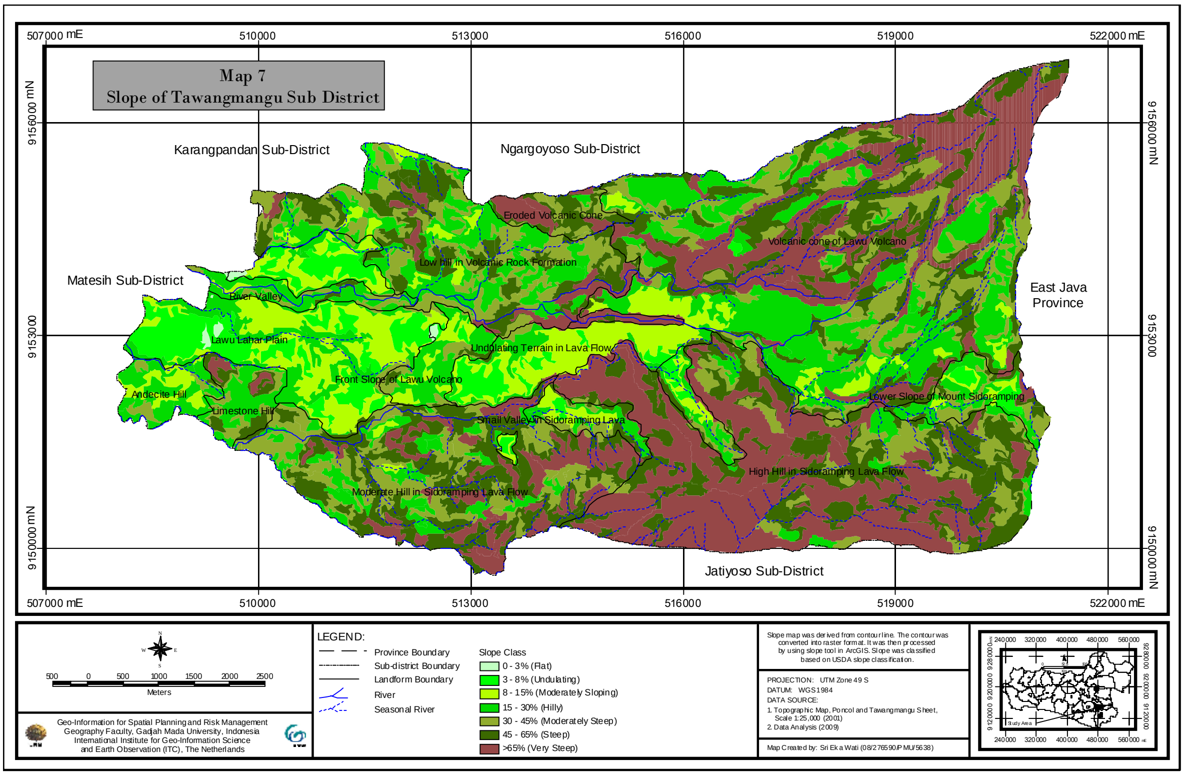


Figure 4.14. Slope Map of Tawangmangu Sub District

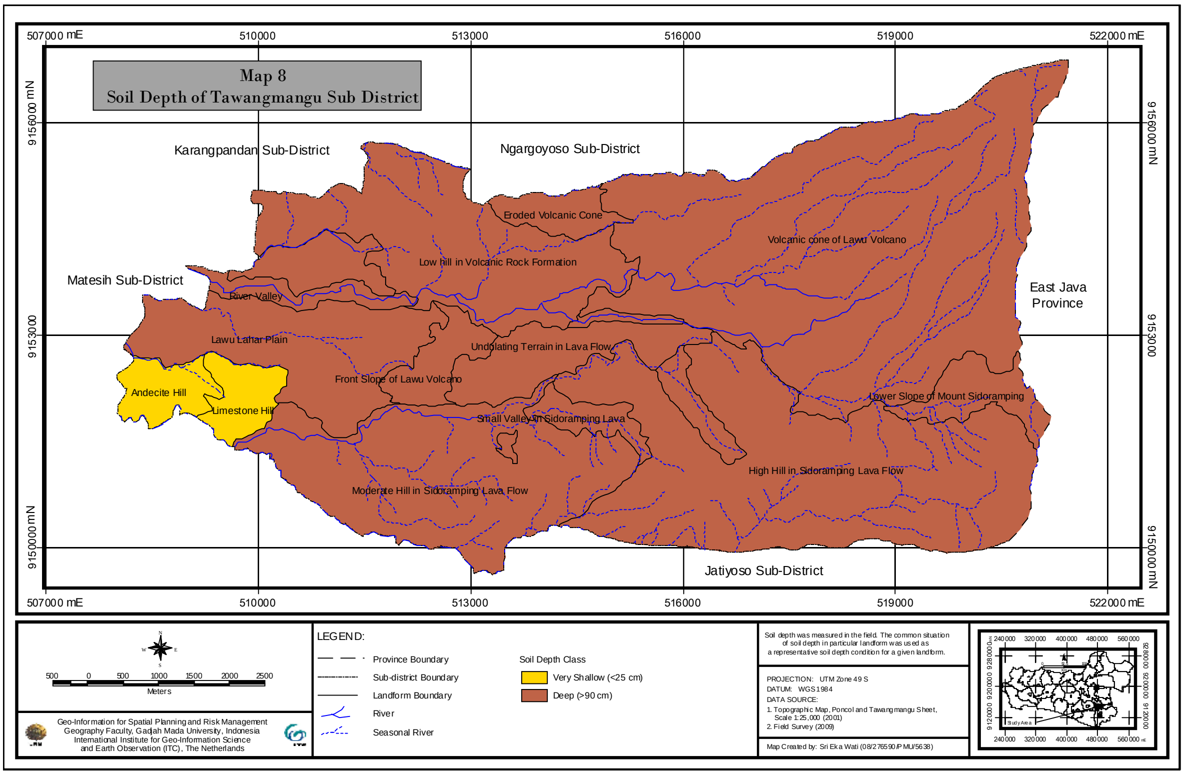


Figure 4.15. Soil Depth Map of Tawangmangu Sub District

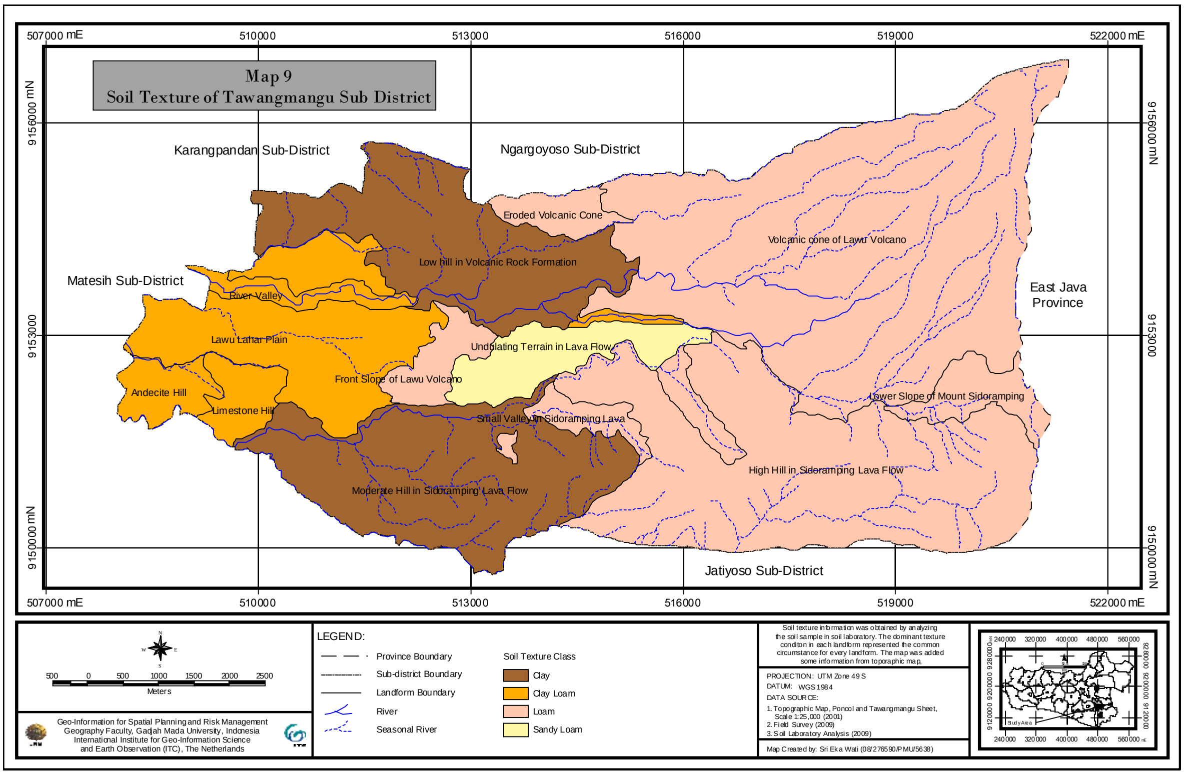


Figure 4.16. Soil Texture Map of Tawangmangu Sub District

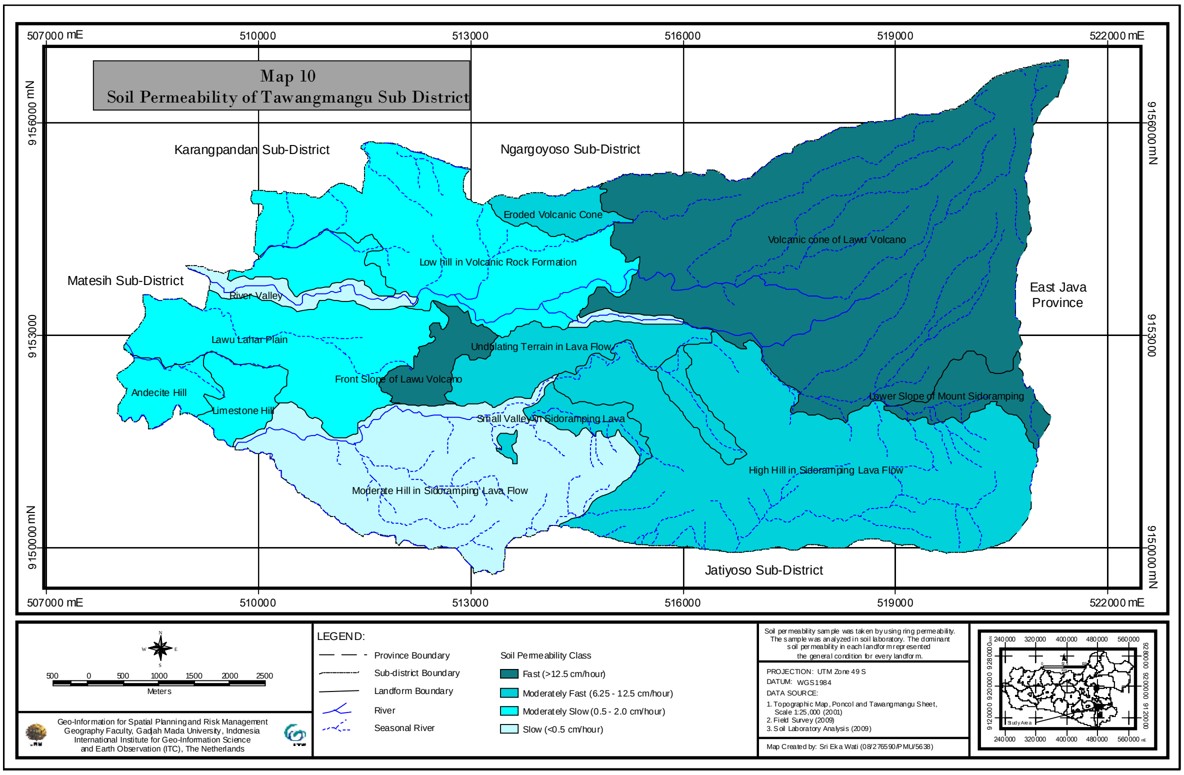


Figure 4.17. Soil Permeability Map of Tawangmangu Sub District

4.5. Landslide Susceptibility Zone

Landslide susceptibility in this research is categorized into five classes. Those classes are very low, low, moderate, high, and very high. Each susceptibility class is divided based on the range of total score. The score range for each class is very low (less than 28), low (28 – 45), moderate (46 – 63), high (64 – 81), and very high (more than 81).

Landslide susceptibility analysis gives several results. Most areas in Tawangmangu Sub District are prone to landslide. More than one third of study area (42%) is classified as high and very high susceptible area. Moderate susceptible zone covers 43% of total area (2,993 Ha). It is only 15% of total area (1,041 Ha) that is included as very low and low susceptible (Table 4.3). Spatial distribution of landslide susceptibility is shown in Figure 4.18. Detailed distribution of each landslide susceptibility class in relation with landform is described below:

Table 4.3. The Width Area of Landslide Susceptibility Class

Susceptibility Class	Width Area (Ha)	Susceptibility Class	Width Area (Ha)
Very Low	24	High	2,609
Low	1,017	Very High	360
Moderate	2,993	**Total**	**7,003**

Source: Data Analysis, 2009

The very low susceptible area is situated in middle part of small valley in Sidoramping lava flow. This zone is utilized as paddy field. The area is typified by moderately sloping (8 – 15%), moderately fast permeability, and loam texture. The existing situations reduce the probability of landslide event in this area.

Low susceptible area exists in most areas of andecite hill, Lawu lahar plain, small valleys in Sidoramping lava flow, and lower slope of Mount Sidoramping. Some areas in northern part of limestone hill are also included in low susceptible zone. Low susceptible areas are mainly located in the slope of 0 – 30%. The land uses are varied, i.e. settlement area, paddy field, vegetable garden (carrot, garlic, onion, and strawberry), mixed paddy field with vegetable garden, and forest. In addition, this area is also characterized by moderately slow up to fast permeability regarding to clay loam and loam texture.

Moderate susceptible area is scattered in more than one third of Tawangmangu Sub District (43% of total area). It is the dominant landslide susceptible class in study area. The area is largely positioned in slope of more than 30%. Nevertheless, some areas in Lawu lahar plain are also included as moderate susceptible even though they have slope of less than 30%. The given condition is affected by the broadly existence of settlement area and mixed paddy field with vegetable garden. Besides, the soil in this area has low permeability because of clay loam texture.

High susceptible areas are mostly located in low hill in volcanic rock formation, moderate hill in Sidoramping lava flow, front slope of Lawu Volcano, and eroded volcanic cone. Large areas in volcanic cone of Lawu Volcano are also categorized in high susceptible region. High susceptible areas generally take place in steep area. Those areas are also dispersed in some land uses, i.e. settlement area, mixed garden, and vegetable garden. The intensive development of those land uses and the brittle parent material enhances the probability of landslide in this zone.

The highest susceptible areas are concentrated in northern part of study area. The areas pervade two landforms, i.e. river valley and low hill in volcanic rock formation. Both are laid upon breakable parent material, i.e. Lawu volcanic rock. Moreover, very steep slope (more than 65%), the broad existence of mixed paddy field with vegetable garden, slow up to moderately slow permeability, and clay-clay loam texture bring the accumulation of the most driving factor of landslide in this area.

4.6. Settlement Area in Landslide Susceptibility Zone

The development of settlement area increases rapidly. It is initiated by population pressure. The increasing number of population enlarges the demand of living space. The need of living place in Tawangmangu Sub District forces local community to harness every possible location for building their houses. Statistical data states that the width area of settlement area increases 4.65% within seven years. The width of settlement area in 2003 was 619.2 Ha (BPS, 2003) and it becomes 935 Ha in 2009 (Data Analysis, 2009). Unfortunately, the development of settlement area sometimes does not take into account the hazard probability.

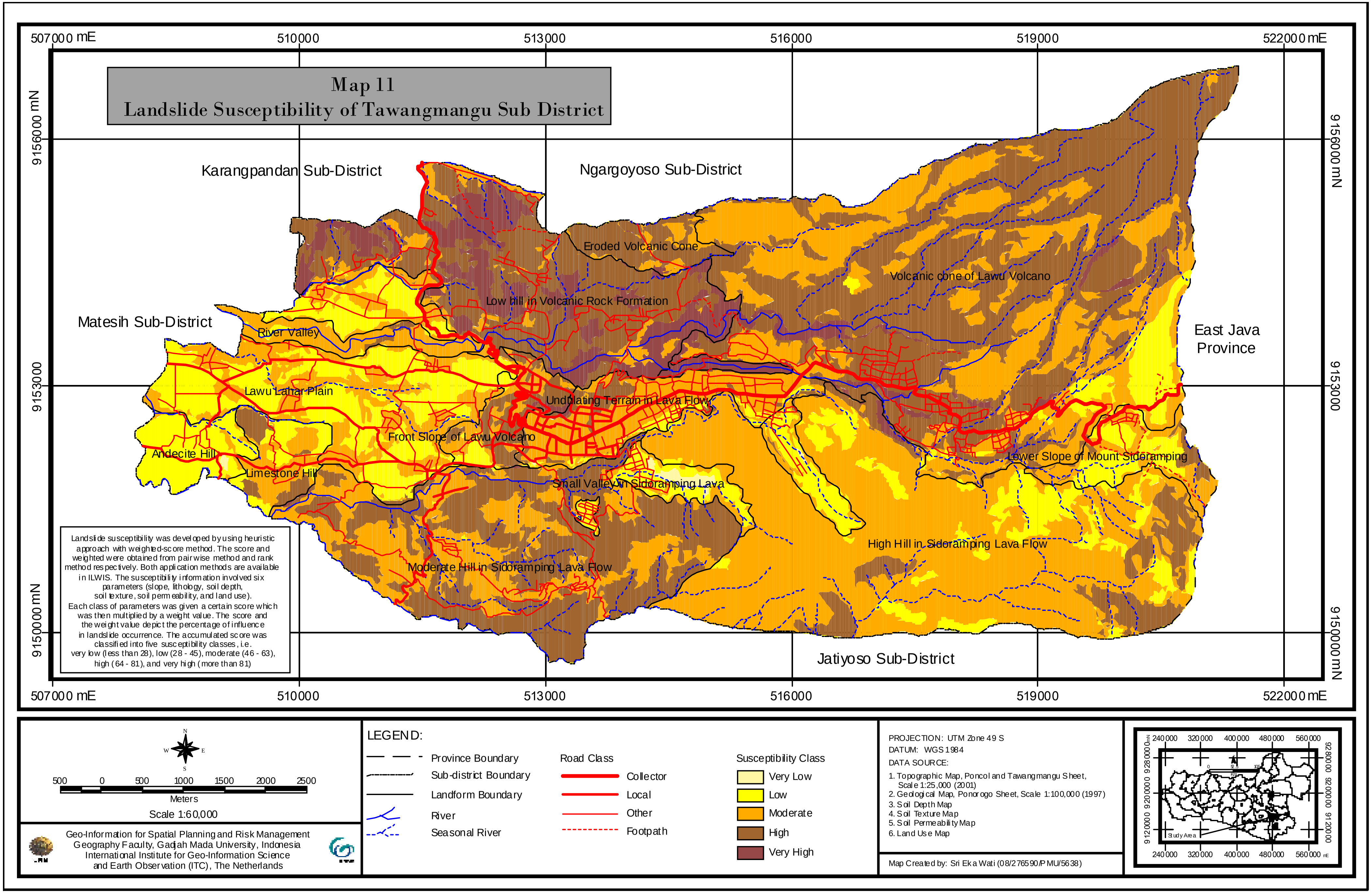


Figure 4.18. Landslide Susceptibility Map of Tawangmangu Sub District

Settlement areas in study area are broadly distributed from flat zone to steep zone. Local people mostly build their houses in relatively flat areas but those flat areas are sometimes surrounded by steep slope. It is found that many settlements areas are constructed in hill side or below the road (Figure 4.19 – 4.21). This circumstance reveals the risk related to landslide threat.

Landslide is one of the prerequisite in determining suitable location for settlement area. USDA (1983, in Hardjowigeno et al, 1994) states well and moderate suitable areas for settlement have to free of landslide (Table 4.4). The area with landslide experience is not recommended as settlement. Therefore, the identification of existing settlement in landslide susceptible area becomes important to spatially find out the unsuitable development of settlement area. It is also intended to gather the distribution of settlement area as a location of exposed population to landslide.

Table 4.4. Land Suitability Criteria for Settlement Purpose

No	Soil Characteristics	Land Suitability		
		Well	Moderate	Poor
1	Subsidence depth (cm)	-	-	30
2	Flood susceptibility	Without	Without	
3	Water table height (cm)	> 75	45 - 75	< 45
4	Shrink-swell value (COLE)	0.03	0.03 – 0.09	> 0.09
5	Soil texture according Unified System			OL, OH, PT
6	Slope (%)	< 8	8 - 15	> 15
7	Soil depth (cm) Hard Soft	 > 100 > 50	 50 – 100 < 50	 < 50 -
8	Soil depth on hardened rock (cm) Thick Thin	 > 100 > 50	 50 – 100 < 50	 < 50 -
9	Gravel-pebble contents (>7.5 mm) (% weight)	< 25	25 - 50	> 50
10	*Landslide*	-	-	*Present*

Source: USDA, 1983 in Hardjowigeno et al, 1994

Figure 4.19. Settlement Area in Hillside in Bandardawung Village

Figure 4.20. Settlement Area below the Road in Blumbang Village

Figure 4.21. Settlement Area in Hillside in Tawangmangu Village

The identification of settlement area in landslide susceptible zone is obtained by overlaying landslide susceptibility map and present settlement area distribution. The result explicitly declares that there are many settlement areas are situated under landslide threat. More than a half of settlement areas (51%) are located in moderate susceptible area. Moreover, 35% of settlement area (330 Ha) exists in high and very high susceptible zone (Table 4.5 and Figure 4.22).

The existence of settlement area in landslide prone area really needs the attention from local government. The number of vulnerable population due to landslide threat must be considered. Local authority is suggested to array mitigation strategies for reducing the negative impact of landslide. One of those strategies is related to land use policy. Land use policy for development of settlement area shall be focused on landslide risk reduction.

Table 4.5. Distribution of Settlement Area in Each Landslide Susceptibility Class

No	Susceptibility Class	Width Area (Ha)	Village	Sub-Village
1	Very Low	-	-	-
2	Low	129	Bandardawung Tawangmangu	Gondang, Bandar, Mloko, Dawung Nglurah, Mogol, Ngledoksari
3	Moderate	476	Bandardawung Karanglo Plumbon Nglebak Sepanjang Tawangmangu Kalisoro Blumbang Gondosuli	Pelas, Gamping, Ngasem, Slojok Karanglo, Blimbing, Barakan, Kongan, Sadakan Lor, Sekuwung, Pedan, Cepogo Cumpleng, Pakem, Watusambang, Karangweru Nglebak, Ngudal, Nglegok, Gondang Margosanten, Genengan, Tapan, Genengrejo, Sendang Bamo, Nano, Ngunut, Beji, Banjarsari Kalisoro, Kramat, Panjat Kidul, Panjat Lor Ombang-ombang Gondosuli Lor, Gondosuli Kidul, Bularejo, Tlogodringo
4	High	306	Plumbon Sepanjang Blumbang Gondosuli Tengklik	Dukuh, Gude, Setugu, Tarakan, Dukun, Pampung Ngledok Blumbang Kidul, Blumbang Lor Dawuhan, Tegalrejo, Tawang, Banaran Atas, Ngledok, Banaran Bawah Dempul, Sendang, Gundolorejo, Ngepeng, Selere, Tengklik, Sodong, Ngemplak, Guyon, Pidar
5	Very High	24	This class is only dispersed at some small areas in Gude (Plumbon Village), Blumbang Kidul (Blumbang Village), and Tegalrejo (Gondosuli Village).	
	Total	**935**		

Source: Data Analysis, 2009

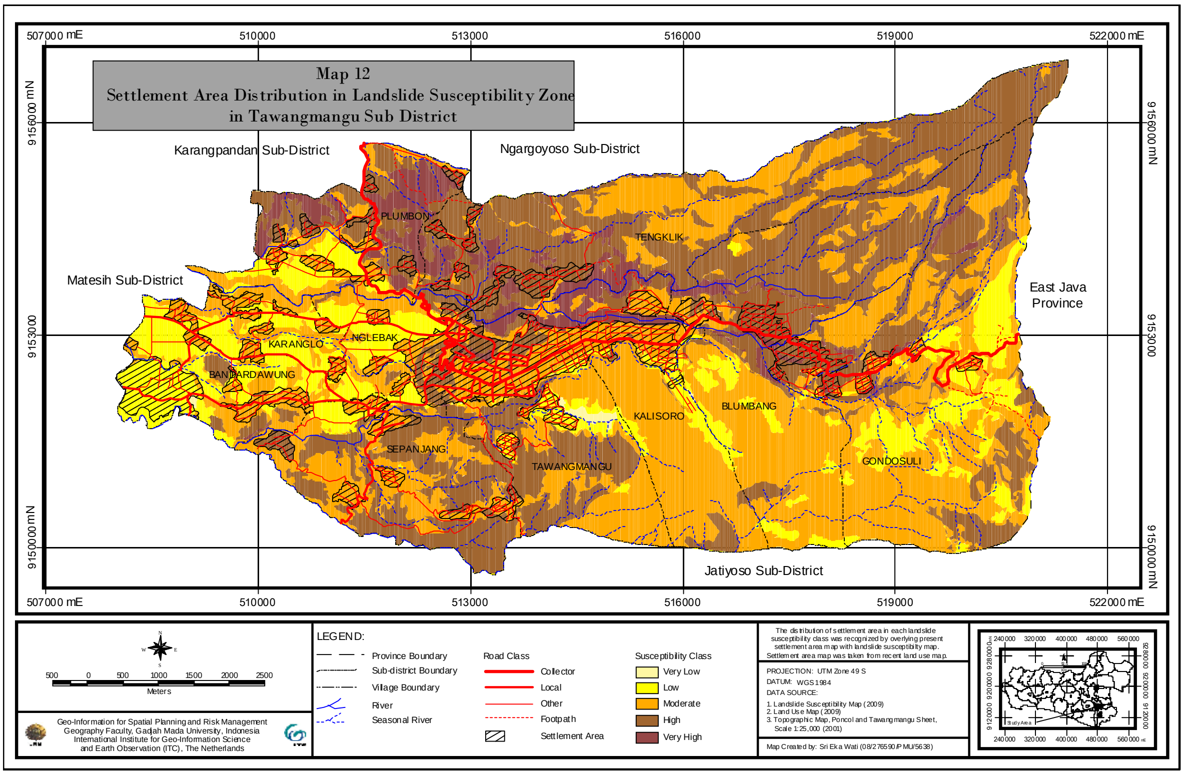


Figure 4.22. Map of Settlement Distribution in Landslide Susceptibility Zone of Tawangmangu Sub District

4.7. Existing Landslide Mitigation Strategies

The number of actual landslide events in Tawangmangu Sub District shows that this area is relatively prone to landslide. Landslides have revealed disturbance and disruption for community. It is not only damaged houses but the number of casualties as well. Thereby, it is important to organize some strategies as a part of prevention action to minimize the landslide impacts.

Local communities and related parties have conducted some activities in relation with landslide mitigation strategies, as follow:

a. Constructed some warning signs in landslide prone area. Warning board is found at landslide location in Tengklik Village (Figure 4.23) and at the edge of the road in Gondosuli Village.
b. Constructed landslide early warning tool. This tool is connected to the land. The tool gives warning sign through loud siren when the land shakes. The tools are positioned in Ngledoksari Sub-Village, Tawangmangu Village and in Guyon Sub-Village, Tengklik Village. It is found that two of three warning tools in Ngledoksari Village are out of order (Figure 4.24). It is recognized from the broken string connection.
c. Developed a landslide susceptibility map. This map is adhered in the office of Tengklik Village because the map is only made for Tengklik Village (Figure 4.25). The map was generated by student during dedication action period to community (*Kuliah Kerja Nyata*, Gadjah Mada University, 2009).
d. Built retaining wall. The retaining wall is constructed for strengthening road construction in steep area. The retaining wall can be found in a new collector road connecting Karanganyar Regency and Magetan Regency (Figure 4.26). Some local roads are also invigorated by combining rock and cement.
e. Disseminated information of landslide. The information consists of landslide hazard overview, evacuation planning, and landslide susceptibility map (Figure 4.27). The information is compiled in landslide information board. This information only exists in Tengklik Village.

Figure 4.23. Landslide Warning Sign in Tengklik Village

Figure 4.24. Landslide Early Warning Tool in Ngledoksari Village

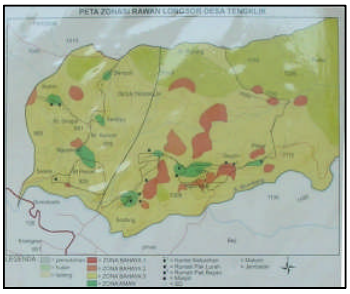


Figure 4.25. Landslide Susceptibility Map of Tengklik Village

Figure 4.26. Retaining Wall in Collector Road between Karanganyar Regency and Magetan Regency

Figure 4.27. Landslide Information Board in Tengkik Village

The present landslide mitigation strategies are not sufficient. The existing landslide mitigation strategies are only locally conducted. It is not adequate regarding to the width of landslide prone area. Thus, the improvement and additional activities shall be performed.

4.8. Proposed Landslide Mitigation Strategies

Proposed landslide mitigation strategies are arranged for improving the existing strategies. The strategies are organized based on common landslide mitigation actions that have been conducted in other regions. Those are divided into two parts, strategies conducted by local government as the authority whether in regency, sub district, or village level and strategies executed by local community as possible affected people. The implementation process needs cooperation between community and government in order to create harmonious practice. The proposed mitigation actions for Tawangmangu Sub District are described below:

4.8.1. Local Government Strategies

a. Develop detailed landslide susceptibility map

The general multi hazard map is available in KESBANGLINMAS office. It is made in regency scale and involves several hazards, such as flood, landslide, and earthquake. Detailed landslide susceptibility map is only obtained in Tengklik Village made by UGM. Hence, a new detailed hazard map shall be established, particularly in scale of sub district. For Tawangmangu Sub District, the map must be focused on landslide hazard since this area is more vulnerable to landslide. Local government can work together with academic institution for the expert assistance.

b. Conduct regular landslide inventory

Some landslide data used in this research are achieved from local government offices in regency, sub district, and village. The available data do not represent all occurred landslide events. Only severe landslide events causing serious destruction and disruption are listed. As a consequence, the independent landslide inventory survey is performed by researcher in order to get more comprehensive data.

The landslide event mapping is urgently needed for Tawangmangu Sub District. It is not only intended to spatially recognize the distribution of landslide event but also to verify the reliability of developed landslide susceptibility map. The landslide inventory can be carried out by field checking or by visual interpretation of satellite imageries.

c. Involve landslide information in spatial planning

Landslide susceptibility and hazard zoning are more likely to be applied in initial stage of development (Fell et al, 2008). The landslide zoning is used as basis information in controlling land allocation in landslide prone area. The land use planning policy can eventually establish restriction rule related to rapid development in landslide susceptible area. The obtained spatial planning documents, RTRW 1997 – 2006 and RDTRK 2007 – 2016, do not bring in hazard information yet. Thereby, the existing spatial planning is suggested to be revised by considering the possible hazard.

d. Construct and maintain landslide early warning system

Landslide early warning system is one of the important tools in landslide mitigation strategies. Some landslide early warning tools have been constructed in Ngledoksari Sub-Village (Tawangmangu Village) and Guyon Sub-Village (Tengklik Village). Some of them recently are no longer functioned. In this manner, it is required to form cooperation in maintaining the system among local government, local community, and other related parties. In addition, the number of the tools shall be added due to the extensiveness of landslide prone area.

e. Build strengthened structure in landslide prone area

Topographic situation is one important consideration in road and building construction. Road construction by cutting the slope and road construction in steep area must contemplate the slope stability. The construction shall be supported by an appropriate structure. The retaining walls from concrete material must be also constructed for keeping the slope stability. Furthermore, the proper geo-technical application in relation with road and building construction has to be applied.

f. Disseminate landslide susceptibility information to the lower authority and local community

Landslide susceptible information can be harnessed to recognize the distribution of susceptible zone. It can be also used to array the recommendation in reducing landslide impacts. It means that developed landslide susceptibility information shall be informed to lower authority and local community. It is proposed to increase the community awareness of landslide probability.

g. Prepare evacuation planning

The evacuation planning consists of the readiness in providing place, route, and supporting material. The evacuation place is positioned in safer area with good accessibility. This location will be used when landslide occurs or the possible landslide is predicted to be happened. Route is planned to facilitate the evacuation session and distribution of social aid. The supporting material encompasses several items that are needed in disaster location and in refuge, such as food, medicine, cloth, and water.

4.8.2. Local Community Strategies

a. Recognize natural sign of landslide

Some natural signs can be identified prior to landslide. Cracks in the land surface, prolonged heavy rain, and earthquake are common conditions before landslide event. After recognizing the landslide precursor, local community shall move in safer area.

b. Avoid extensive land utilization in steep area

Slope is the most important factor in landslide mechanism. The stability of slope can be disturbed by human intervention. Improper land use practice forces the slope to be unstable. Hence, the appropriate method of land utilization has to be precisely defined. The assistance from the expert can be involved for guiding local community towards sustainable land use.

c. Participate in maintaining landslide early warning system

Damaged landslide early warning tools can be evaded through community based participation. Local community is learnt in how to maintain the system. Contact person from related institutions must be also determined for supporting the maintenance process.

d. Report landslide event to local authority

Lack of landslide database can be solved by the involvement of local community. The community is forced to inform all landslide events which occurs in their area. The landslide event is reported to the nearest local authority (Head of *Rukun Tetangga* or *Rukun Warga*). The information is then compiled in higher authority (*dukuh*, *dusun*, village, sub district, and so on).

e. Cultivate several kinds of plants for strengthening the soil

Several kinds of plants can be utilized to increase soil strength. They usually have upside down root with many or few branches (Triwibowo, 2001). Those plants are useful for enhancing the power to retain soil mass movement. The plants are listed in Table 4.6.

Table 4.6. List of Plants for Strengthening the Soil

Upside Down Root with Many Branches	**Upside Down Root with Few Branches**
Kemiri (*Alerius mollucana*)	Mahoni with big leaves (*Swietania macrophyla*)
Laban (*Vitexpubercens*)	Renghas (*Gluta reghas*)
Dlingsem (*Homaium tomentisum*)	Jati (*Tectona grandis*)
Mindi (*Meliaale darach*)	Sono Kembang (*Plerocoupus oleosa*)
Johar (*Cassa stanessa*)	Sonokeling (*Dalbegia latifolia*)
Acsiavillosa	*Cassia fistuta*
Eucalyptus alba	Trengguli (*Bauhina hirsolt*)
Leucana glauta	Tayuman (*Tamarindhus indieus*)
Paraserienthes falcataria	Asam Jawa (*Acacia leucophola*)
Bungur (*Lagerstroemia speciosa*)	Pilang (*Albizzia lebbeck*)
Beringin (*Banyan*)	Kesambi (*Sehlechard*)

Source: Triwibowo, 2001

CHAPTER V
LAND CAPABILITY ASSESSMENT OF TAWANGMANGU SUB DISTRICT

Chapter five explains the integration of landslide susceptibility information in land capability assessment. Land capability analysis is developed in general and detailed version. In addition, the discussion about the existing land capability classification created by local government is described in the initial section.

5.1. Introduction

Land capability assessment is a systematic land appraisal. This is a part of land evaluation process. The concept of land capability is formerly developed for agricultural purpose. It categorizes a certain area based on the potency and inhibiting aspects for sustainable usage (Arsyad, 1989). This method is used to meet the need in recognizing an appropriate land use regarding to actual condition in a certain area. Since spatial planning is also made to properly manage the available land, land capability method is effective to be applied in spatial planning arrangement.

5.2. Land Capability Assessment Developed by Local Government

Local government of Karanganyar Regency has applied land capability method in arranging Regional Spatial Plan (RTRW) of Karanganyar Regency 1997-2006 (BAPPEDA, 1997) and Detailed Spatial Plan of Sub District City (RDTRK) of Tawangmangu 2007-2016 (BAPPEDA, 2007). The interview session with staff of Development and Planning Board (BAPPEDA) gives a result that land capability is harnessed to describe the common land characteristic and to determine land use function.

Land capability assessment in RTRW is made to illustrate the general land characteristic. The general characteristic is then applied for recognizing Exertion Land Region (*Wilayah Tanah Usaha*/WTU). WTU is a policy concept of land use which is adjusted by a particular elevation and natural condition of Indonesia. WTU is merely focused on the land division based on elevation and slope.

Land capability assessment for recognizing general land characteristic is formulated by using five parameters, i.e. slope, soil depth, texture, drainage, and erosion. Every parameter is classified into certain classes as depicted in Table 5.1. Those parameters are overlaid in order to obtain various combinations among them. As a result, general characteristic of land in Karanganyar Regency are: effective soil depth is more than 90 cm; the general soil texture is moderate and fine; the area is never inundated; and the slope variety is from 0 – 2% to more than 40%. For Tawangmangu Sub District, the general land characteristics are slope 15 – 40% and more than 40%; effective soil depth 60 – 90 cm; moderate texture (loam); never inundated; and no erosion. Land capability assessment performed in RTRW is portrayed in Figure 5.1.

Table 5.1. Classification of Land Capability Parameters in RTRW

No	Slope	No	Soil Depth	No	Soil Texture	No	Drainage	No	Erosion
1	0 – 2%	1	>90 cm	1	Moderate (loam)	1	Never inundated	1	No erosion
2	2 – 15%	2	60 – 90 cm	2	Fine (clay)	2	Sometimes inundated	2	Eroded
3	15 – 40%	3	30 – 60 cm	3	Coarse (sand)	3	Inundated		
4	>40%	4	< 30 cm						

Source: BAPPEDA (1997)

Land capability analysis is also conducted to establish land use function. The land use function consists of protected, buffer, and cultivated area (yearly cultivated, seasonal cultivated, and settlement). The used method refers to Legal Document of Ministry of Agriculture number 837/Kpts/UM/11/1980 (Anonymous, 1980) and number 683/Kpts/UM/8/1981 (Anonymous, 1981). This method employs three parameters, i.e. slope, soil type, and average daily rainfall intensity. Those parameters are classified as shown in Table 2.3 – 2.5. The land capability analysis for land use function division is completely presented in Chapter VI.

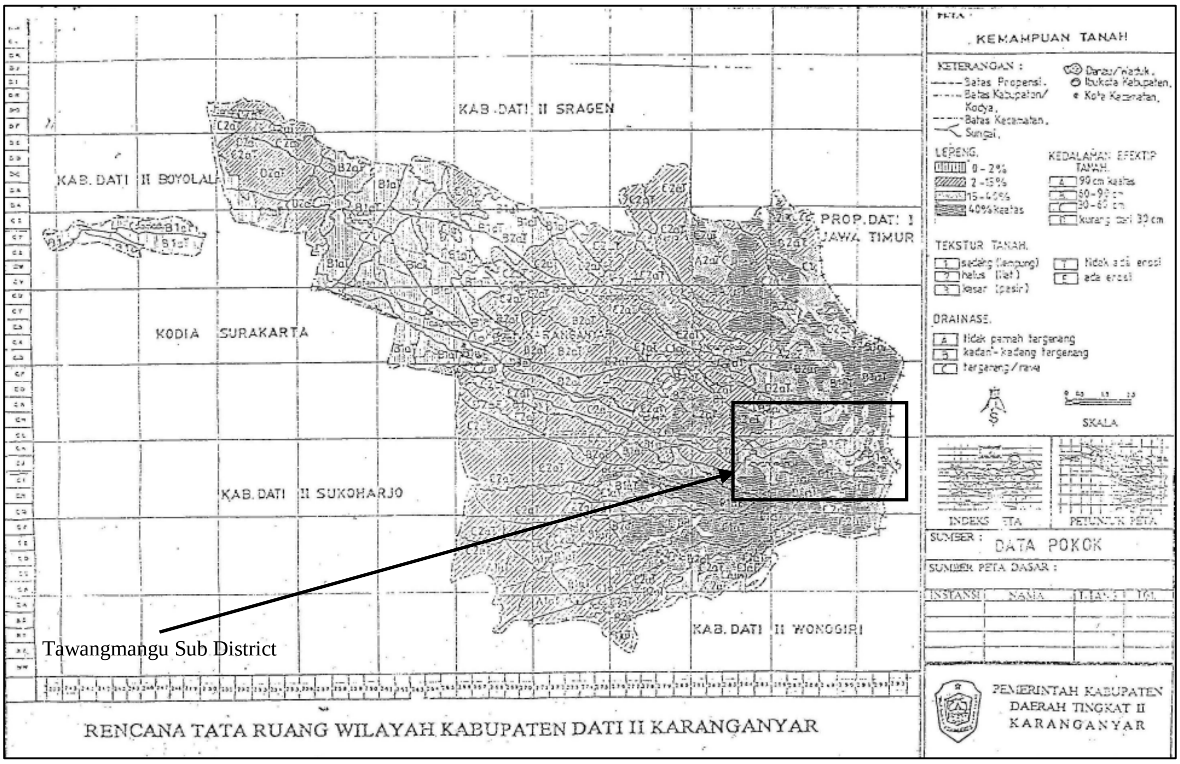


Figure 5.1. Land Capability Map Developed by Local Government in Regency Scale (BAPPEDA, 1997)

5.3. Proposed Land Capability Classification

Act number 26, 2007 emphasizes the involvement of hazard information in spatial planning (Anonymous, 2007). Hazard information is needed to control extensive land use practice, particularly in hazard prone area. Hazard information is also urgently required as a part of mitigation strategies to reduce the hazard impact. Thereby, hazard information is supposed to portray not only the transpired hazard but also the probability of hazard in the future.

RTRW of Karanganyar Regency 1997-2006 and RDTRK of Tawangmangu 2007-2016 do not clearly include hazard information. It is only erosion that is already considered in land capability assessment in RTRW. RDTRK also merely uses soil type as a parameter representing sensitivity to erosion. Thus, the present spatial plan shall be improved because study area is not only suffered by erosion but also by landslide hazard.

Landslide, as a prominent threat in study area, shall be integrated in the spatial planning in order to meet the prerequisite from Act number 26, 2007. Landslide susceptibility information is needed to organize the existing land for sustainable purpose. The type and intensity of land use practice shall be distinguished based on the susceptible degree to landslide. It means that landslide susceptibility has to be mixed with other land characteristics to determine the proper land use in a certain area.

Proper land use can be generated from land capability analysis. This analysis is done by using several physical land traits (topographic, soil, and hazard). The existing land capability assessment, as mentioned before, unfortunately does not use comprehensive land characteristic. Landslide information is not yet included as well. Therefore, a new proposed method is developed according to USDA approach.

The proposed method is intended to obtain thorough description of land capability by considering landslide hazard. Landslide susceptibility is added as one of inhibiting factors. The proposed land capability classification omits two factors, i.e. flood threat and salinity. Flood is not the important hazard in study area. On the other hand, salinity is not applied because it is only valid for dry season area. Proposed method also implicates landslide susceptibility in sub class division. Sub class represents the worst condition as the most influencing factor in land capability. The sub class refers to the rule from Klingebiel and Montgomery (1966) and Arsyad (1989). For proposed sub class division, landslide susceptibility is included in sub class "e" together with slope, erodibility, and actual erosion. The sub class classification is mentioned below:

- Sub class "e" is intended to slope, erodibility, actual erosion, and landslide susceptibility.
- Sub class "w" is allocated for soil drainage and flood threat.
- Sub class "s" is for soil depth, texture, permeability, rock fragment, and salinity.
- Sub class "c" is owed by climate factor (temperature and rainfall).

The proposed land capability classification assumes that the increasing of susceptibility level is in line with the increasing of constraint factor (Table 5.2). Very low landslide susceptibility is set up in class I and II. The existence of settlement areas prosecutes the lowest landslide probability so that very low susceptibility of landslide is recommended for those classes. Low susceptibility of landside is allocated for class III and IV. Moderate, high, and very high susceptibility are added in class VI, VII, and VIII respectively. Landslide susceptibility level is not included in class V because this class is associated as inundation zone.

Table 5.2. Proposed Land Capability Classification

No	Inhibiting Factor	Land Capability Class							
		I	II	III	IV	V	VI	VII	VIII
1	Slope	A	B	C	D	A	E	F	G
2	Erodibility	KE1, KE2	KE3	KE4, KE5	KE6	*	*	*	*
3	Actual erosion	e0	e1	e2	e3	**	e4	e5	*
4	Soil depth	k0	k1	k2	k2	*	k3	*	*
5	Soil texture	t1/t2/t3	t1/t2/ t3	t1/t2/t3/t4	t1/t2/t3/t4	*	t1/t2/t3/t4	t1/t2/ t3/t4	t5
6	Soil permeability	p2/p3	p2/p3	p2/p3/p4	p2/p3/p4	p1	*	*	p5
7	Soil drainage	d1	d2	d3	d4	d5	**	**	d0
8	Rock fragment	b0	b0	b1	b2	b3	*	*	b4
9	Landslide susceptibility	LS1	LS1	LS2	LS2	**	LS3	LS4	LS5

** It doesn't have particular characteristics, ** Inapplicable*
Source: Klingebiel and Montgomery (1966), Arsyad (1989), and Modified (2009)

5.4. General Land Capability Class Based on Proposed Method

General land capability assessment is performed based on landform. It is assumed that the area classified as the similar landform has relatively akin characteristics. Regarding to the number of soil samples in each landform, the dominant value for each inhibiting factor is established as a common circumstance in each landform. The overview of constraint factors is presented below:

a. Slope

Slope is one of crucial factors in land capability appraisal. Slope plays a role in restricting intensive land utilization, particularly in steep slope area. This is concerned with the probability in disturbing slope stability. Slope stability is highly correlated with landslide hazard. Hence, slope is the most consideration in managing the land for avoiding landslide impact.

Study area is mainly dominated by four slope classes, i.e. hilly, moderately steep, steep, and very steep (Table 3.1). Those areas mostly exist in northern and southern parts of study area. On the other hand, the middle part of study area is characterized by flat, undulating, and moderately sloping zone. In relation with landform, the slope in each landform is varied. One landform consists of numerous slope classes. Therefore, the generalization process was done in order to define typical slope in each landform.

The generalized slope comprises with four classes, i.e. class C, D, F, and G. Slope of 8 – 15% (class C) exists in landform Lawu lahar plain while class D (15 – 30%) is spread in eight landforms. Slope of more than 45% (class F and G) largely exists in four landforms which are directly associated to Lawu Volcano and Mount Sidoramping. Those landforms are volcanic cone of Lawu Volcano, eroded volcano cone, high hill and moderate hill in Sidoramping lava flow.

b. Erodibility

Erodibility describes the soil resistance to both detachment and transport (Morgan, 1995). The resistance is associated with soil type. Some types of soil are more sensitive to erosion than the other. As an example, lithosol is very sensitive to erosion. Andosol is more sensitive to erosion than latosol (Legal Document of Ministry of Agriculture number 837/Kpts/UM/11/1980 and number 683/Kpts/UM/8/1981).

Study area is laid upon several soil types. Those types are andosol (yellow brown andosol and brown andosol), latosol (brown latosol and red brown latosol), lithosol, and brown mediteran. Andosol soil exists in volcanic cone of Lawu Volcano, lower slope of Mount Sidoramping, and small valley in Sidoramping lava. Latosol soil can be found in lower part of Lawu Volcano (Lawu lahar plain, moderate hill in Sidoramping lava flow, low hill in volcanic rock formation, river valley, front slope of Lawu Volcano, eroded volcanic cone, undulating terrain in lava flow, and andecite hill). Lithosol is located in high hill of Sidoramping lava flow while brown mediteran soil is only located in limestone hill.

The erodibility index in this research is estimated by using soil type approach. Secondary data from previous research and literature are employed (Table 5.3 and Table 5.4). The achieved erodibility index data is then linked with landform as a mapping unit. The result shows that the study area consists of two erodibility classes, i.e. low (0.11 – 0.20) and moderate (0.21 – 0.32) (Table 5.5). Low erodible areas are concentrated in northern part of study area whereas moderate erodible areas are situated in southern part (Figure 5.2).

Table 5.3. Erodibility Index Based on Soil Type and Geological Formation

Soil Type	Geology Formation	Erodibility Index
Andosol	Lawu Lahar (Qlla) Lawu Volcanic Rock (Qvl) Sidoramping Lava (Qvsl) Jobolarangan Breccia (Qvjb) Condrodimuko Lava (Qvcl) Wonosari Formation (Tmwl)	0.15 0.16 0.14 0.19 0.19 0.17
Latosol	Lawu Lahar (Qlla) Lawu Volcanic Rock (Qvl) Sidoramping Lava (Qvsl) Andecite (Tma) Wonosari Formation (Tmwl)	0.19 0.17 0.23 0.17 0.17
Mediteran	Lawu Lahar (Qlla) Lawu Volcanic Rock (Qvl)	0.21 0.16
Lithosol	Jobolarangan Breccia (Qvjb)	0.20

Source: Hartono (2008)

Table 5.4. Erodibility Index Based on Soil Type

Soil Type	Erodibility Index	Soil Type	Erodibility Index
Red Latosol	0.12	Gley Humic	0.13
Yellow Red Latosol	0.26	Gley Humic	0.26
Brown Latosol	0.23	Gley Humic	0.20
Latosol	0.31	Lithosol	0.29
Regosol	0.12 – 0.16	Grumusol	0.21
Regosol	0.29	Grey Hydromorf	0.20
Regosol	0.31		

Source: Asdak (2007)

Table 5.5. Erodibility Class for Each Landform

Landform	Soil Type – Geological Formation	Erodibility Index – Erodibility Class
Volcanic cone of Lawu Volcano	Yellow Brown Andosol - Qvl	0.16 - KE2
Lower slope of Mount Sidoramping	Brown Andosol - Qvjb	0.19 - KE2
Undulating terrain in lava flow	Brown Latosol - Qvl	0.17 - KE2
High hill in Sidoramping lava flow	Lithosol - Qvsl	0.29 - KE3
Moderate hill in Sidoramping lava flow	Brown Latosol - Qvsl	0.23 - KE3
Low hill in volcanic rock formation	Brown Latosol - Qvl	0.17 - KE2
Small valley in Sidoramping lava	Brown Andosol - Qvsl	0.14 - KE2
River Valley	Brown Latosol - Qlla	0.19 - KE2
Eroded Volcanic cone	Brown Latosol - Qvl	0.17 - KE2
Front slope of Lawu Volcano	Brown Latosol - Qvl	0.17 - KE2
Lawu lahar plain	Brown Latosol - Qlla	0.19 - KE2
Andecite hill	Red Brown Latosol - Tma	0.17 - KE2
Limestone hill	Brown Mediteran - Tmwl	0.21 - KE3

Source: Data Analysis (2009)

c. Actual erosion

Erosion can be defined as the process of detachment and movement of soil material. The process of erosion is controlled by local landscape and weather conditions (USDA, 1993). Those factors determine the erosion velocity in a certain area. In addition, erosion is also influenced by human intervention. Improper agricultural land use practice can force rapid erosion.

Actual erosion represents common condition of eroded area. Those conditions can be associated with drainage density and sparse vegetation/bare land distribution. Besides, soil type is also related to soil sensitivity to erosion. Thereby, those three variables are assumed as clues in accordance with actual erosion in study area.

Drainage density means the quotient of cumulative stream length to the total drainage area. This variable is stated in length per unit area (Choubey and Jain, 1992). The higher drainage density stands for a rapid storm response and a favorable condition for higher erosion from the catchment (Jain and Goel, 2002). In this research, drainage density is classified into three classes, i.e. low (less than 1.80 km/km^2), moderate (1.80 – 2.58 km/km^2), and high (more than 2.58 km/km^2). The classes are symbolized by code L, M, and H respectively.

Vegetation has a basic function as a protective layer between the atmosphere and the soil (Morgan, 1995). The existence of leaves reduces the velocity of rainfall because of the ability to absorb the energy of rain drops. It means that the power of rainfall in detaching the soil is getting lower. Thereby, the wider the width area of sparse vegetation/bare land represents the higher probability of erosion. The distribution of sparse vegetation/bare land is obtained from present land use map.

Soil type determines the sensitivity level to erosion. The physical properties of each soil type influence the infiltration capacity and to which extent the soil can be detached, dispersed, and transported (Jain and Goel, 2002). Lithosol, as an example, is shallow soil which exists upon hard rock. The development of this soil is hampered due to severe erosion. The classification of soil sensitivity to erosion is adapted from Legal Document of Ministry of Agriculture number 837/Kpts/UM/11/1980 and number 683/Kpts/UM/8/1981 (Table 2.4).

The combination of three variables gives some conclusions. The study area comprises with three actual erosion classes, i.e. minor (e1), moderate (e2), and moderately severe erosion (e3). Minor erosion occurs in five landforms while moderate erosion happens in six landforms. The moderately severe erosion only pervades two landforms (volcanic cone of Lawu Volcano and high hill in Sidoramping lava flow) since those landforms have all erosion clues (medium drainage density, the existence of sparse vegetation/bare land, and sensitive soil to erosion). The classification of actual erosion for study area is presented in Figure 5.3 and Table 5.6.

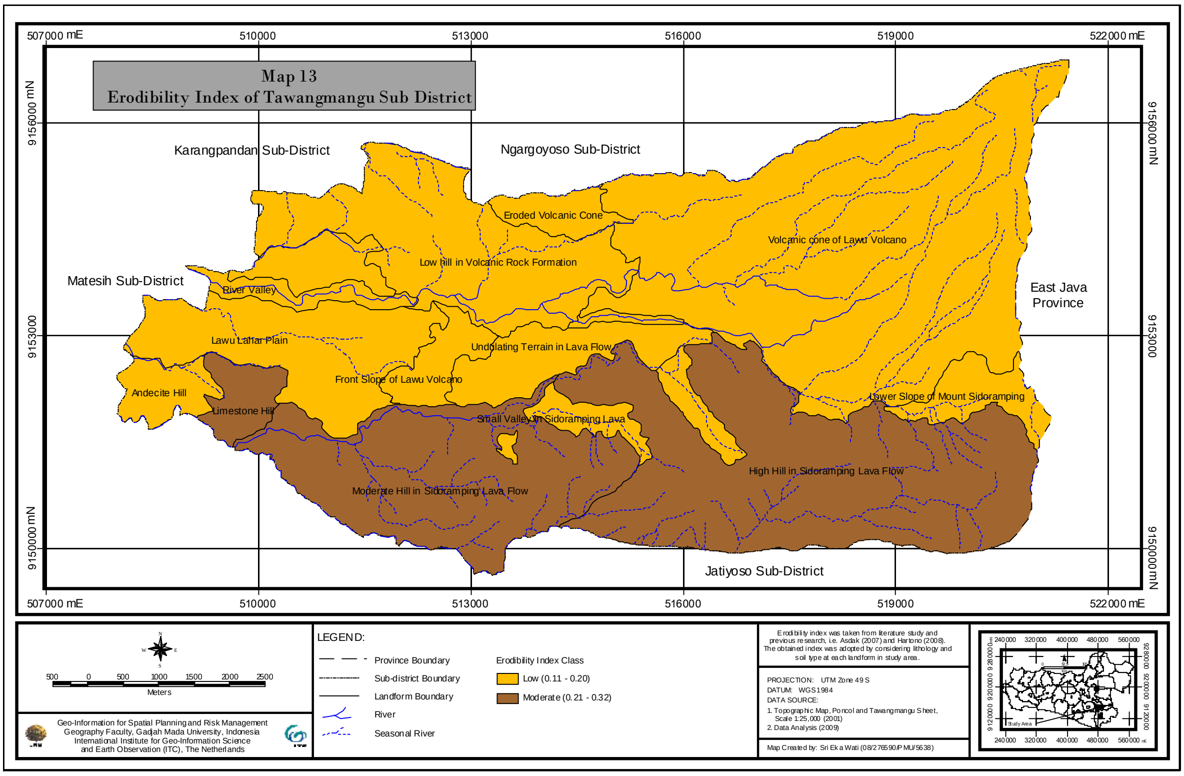


Figure 5.2. Erodibility Index Map of Tawangmangu Sub District

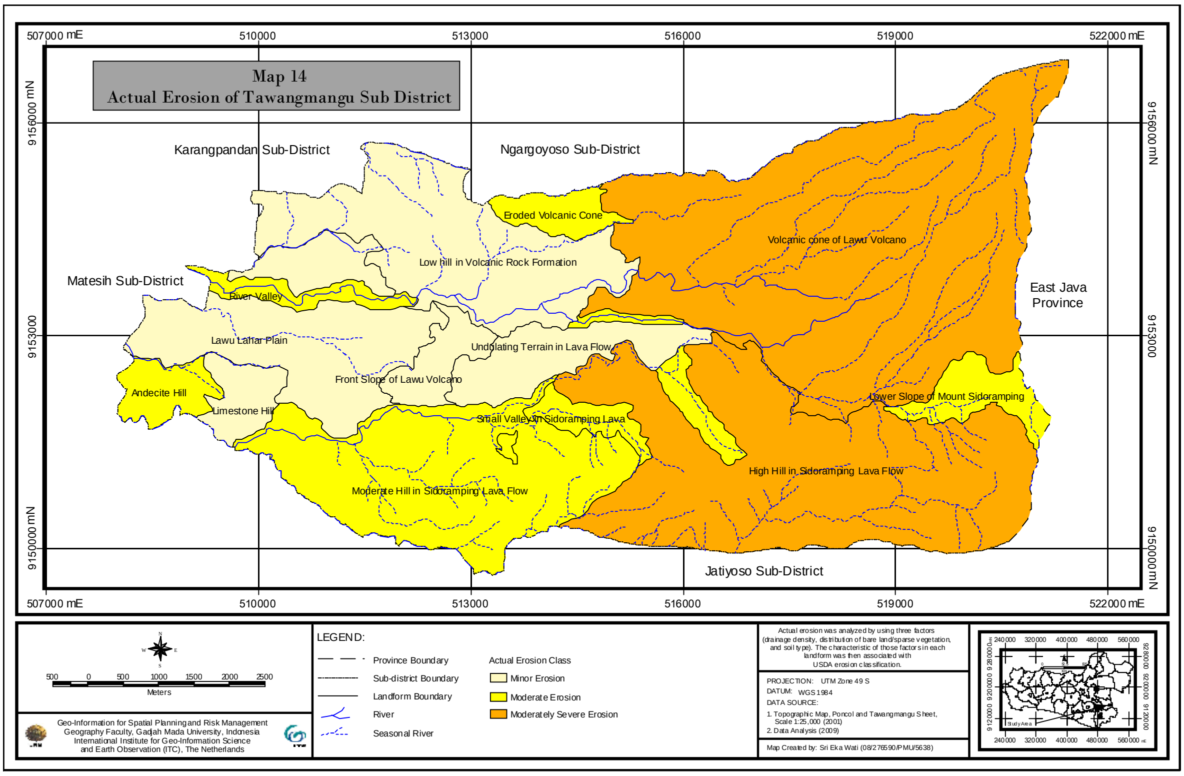


Figure 5.3. Actual Erosion Map of Tawangmangu Sub District

Table 5.6. Actual Erosion Class for Each Landform

Landform	Drainage Density (km/km^2)	Percentage of Sparse Vegetation/ Bare Land	Soil Type* (Generalized)	Actual Erosion Class
Volcanic cone of Lawu Volcano	2.56/ M	2.30	Andosol / S	e3
Lower slope of Mount Sidoramping	3.27/ H	-	Andosol / S	e2
Undulating terrain in lava flow	2.51/ M	-	Latosol / LS	e1
High hill in Sidoramping lava flow	1.94/ M	9.77	Lithosol / VS	e3
Moderate hill in Sidoramping lava flow	2.82/ H	-	Latosol / LS	e2
Low hill in volcanic rock formation	2.48/ M	-	Latosol / LS	e1
Small valley in Sidoramping lava	4.73/ H	-	Andosol / S	e2
River Valley	5.54/ H	-	Latosol / LS	e2
Eroded Volcanic cone	2.89/ H	-	Latosol / LS	e2
Front slope of Lawu Volcano	0.16/ L	-	Latosol / LS	e1
Lawu lahar plain	1.02/ L	-	Latosol / LS	e1
Andecite hill	2.76/ H	-	Latosol / LS	e2
Limestone hill	1.78/ L	-	Mediteran / MS	e1

**Sensitivity to erosion, i.e. LS: Less Sensitive; MS: Moderately Sensitive; S: Sensitive; VS: Very Sensitive*
Source: Data Analysis (2009)

d. Soil depth

Soil depth has general pattern concerned with topographic circumstance. Soil in foot slope area is usually deeper than upper slope area (Wahyuningrum et al, 2003). This situation is triggered by the more intensive erosion processes in upper part. The upper part becomes detachment area and lower part as depositional area.

The soil depth land capability concept has two functions. First, soil depth is related to the space for root penetration. Second, the soil depth influences the growth of crops associated with the ability in providing water and supporting material. It means that deep soil is needed in land processing manner for agricultural purpose. The shallow soil will hamper intensive land utilization.

The study area mainly consists of soil depth of more than 90 cm (deep). Almost all landforms have deep soil. The very shallow soil (less than 25 cm) is only found in andecite hill and limestone area. In this area, the soil is formed by organic materials. Those organic materials are emanated from decaying leaves.

e. Soil texture

Soil texture is defined as to the proportion of the various particle size classes in a certain soil volume (FAO, 2006). The size refers to the diameter of soil fragment (sand, silt, and clay). The diameter of sand is the biggest size, i.e. 0.05 - <2 mm. The diameter of silt fragment silt is 0.05 – 0.002 mm and clay is less than 0.002 mm.

Soil texture is one of important considerations in utilizing the land. Texture affects the soil capacity to keep the water as a vital substance for crops. Soil fragment with big diameter size tends to rapidly release the water. Therefore, sandy soil is not appropriate for agricultural purpose since it cannot retain the water for supporting the growth of plant.

The condition of soil texture in study area is concerned with geological and topographic condition. The geological formation in study area is affected by volcanic activity. The volcanic material is characterized by fine grained and the existence of glass (Munir, 2003). Andecite with fine grained structure dominates almost all areas. It is mixed with other volcanic materials, for instance volcanic sand (Lawu lahar), and volcanic tuff and breccia (Lawu volcanic rock). This condition puts sand and silt as dominant fragment in soil texture. On the other hand, topographic situation is also affects soil texture. Steep slope area has coarser soil texture than relatively flat area (Wahyuningrum, et. al, 2003). It is caused by detachment process of fine materials in steep area. The fine materials are then deposited in flat zone. Medium structure (loam) in study area largely exists in steep slope area, for example, volcanic cone of Lawu Volcano and high hill in Sidoramping lava flow while moderate fine texture (clay loam) is found in flat area.

Tawangmangu Sub District generally consists of four texture classes. Those are clay (moderate hill in Sidoramping lava flow and low hill in volcanic rock formation), clay loam (Lawu lahar plain, river valley, andecite hill, and limestone hill), loam (volcanic cone of Lawu Volcano, lower slope of Mount Sidoramping, high hill and small valley in Sidoramping lava flow, eroded volcanic cone, and front slope of Lawu Volcano), and sandy loam (undulating terrain in lava flow).

f. Soil permeability

Soil permeability is associated with soil texture. The coarser texture is fairly inclined to show faster permeability compared with fine texture. It means that sandy soil has higher permeability than silty and clayey soil since sandy soil is coarser than silty and clayey soil.

The permeability is one of significant points for intensive land use purpose. Moderate or somewhat slow permeability are relatively more needed in correlation with the soil ability for retaining the water. Soil with fast permeability cannot intensively used because the soil is not able to provide adequate water for the growth of crop.

Soil permeability in study area is commonly moderately slow and moderately fast. This situation explicitly supports the intensive land utilization in study area. Slow permeability areas only exist in river valley and moderate hill in Sidoramping lava flow. The areas with moderately slow permeability pervade andecite hill, limestone hill, Lawu lahar plain and low hill in volcanic rock formation. Besides, soil with moderately fast permeability exists in four landforms, i.e. undulating terrain, high hill and small valley in Sidoramping lava flow, and eroded volcanic cone. The rest areas are classified as fast permeability areas.

g. Soil drainage

Soil drainage describes air circulation and water movement in the soil. The soil drainage condition can be recognized from the appearance of particular color spot, i.e. yellow, brown, or grey. The color is associated with corrosion process in the soil due to water concentration. The closer the existence of color spot to the surface depicts the worse soil drainage in a given location.

Soil drainage is linked with topographic condition and lithology. Bowl-shaped and flat area usually has worse drainage than sloping area. In bowl-shaped area, water inundate for a long time whereas in sloping area, water dynamically moves. In study area, most areas with sloping situation are classified as well drained area. There is no color spot emergence in those areas. Nevertheless, some areas are categorized as poorly drained area, i.e. andecite hill, Lawu lahar plain, and river valley. Those areas are typified with relatively flat and bowl-shaped areas. Concerned with lithology, the parent material also determines the soil drainage. The area composed by limestone quickly releases the water (Wahyuningrum et al, 2003). This condition exists in study area at which limestone hill in Tawangmangu Sub District belongs to excessively drained area (Figure 5.4).

h. Rock fragment

Rock fragment implicates the existence of rock both on the surface and in the soil. Those conditions affect the capability of the land for intensive land use practice. The number of rock outcrops on the surface is corresponded to erosion process. If the number of rock outcrops is getting bigger, the erosion process is also more intense. Hence, the land is less suitable to be used as agricultural land. In addition, rock fragment in the soil hampers the root penetration disturbs the growth of plant. The distribution of coarse fragment in the soil and on the surface decreases land quality for cultivation purpose. It declines the width of cultivated area because a certain agricultural practice cannot be conducted

This study is focused on the condition of rock fragment in the soil. The distribution of coarse fragment in the soil is estimated by using the chart as shown in Figure 2.3. As a result, it is only a small number of coarse fragments in the soil for most areas. A moderate percentage of coarse fragments are located in low hill in volcanic rock format, small valley in Sidoramping lava flow, and front slope of Lawu Volcano. On the other side, a fair much of coarse fragments exist in andecite hill (50-90% of soil volume) and limestone hill (>90% of soil volume) (Figure 5.5).

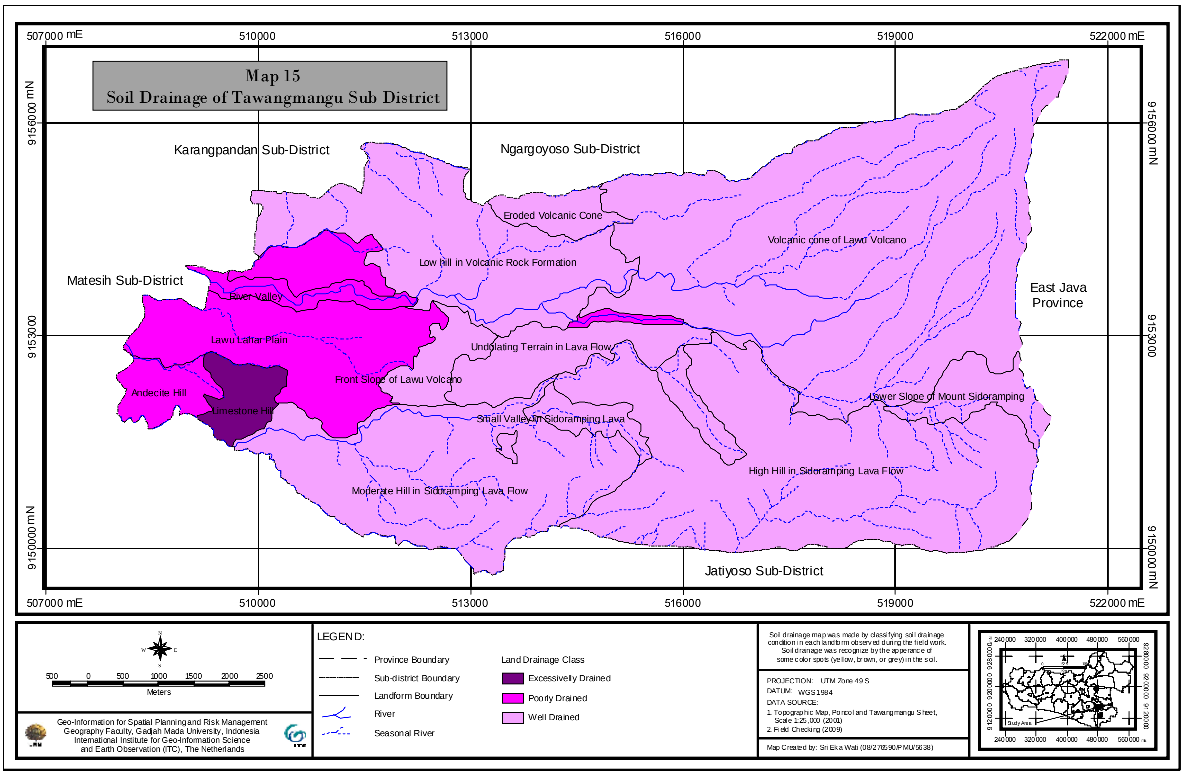


Figure 5.4. Soil Drainage Map of Tawangmangu Sub District

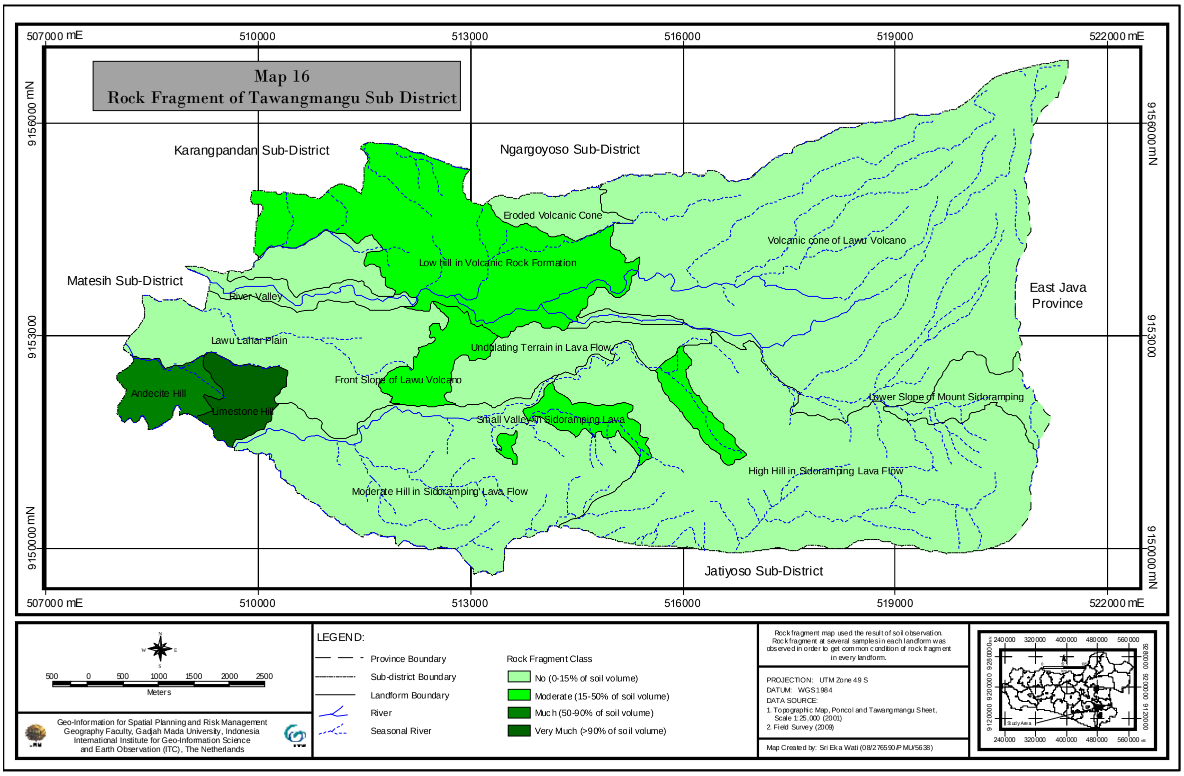


Figure 5.5. Rock Fragment Map of Tawangmangu Sub District

i. Landslide susceptibility

Landslide is a common hazard in study area. This hazard reveals as a consequence of slope instability. One of causal factors in slope instability is related to improper land use practice. Therefore, landslide information is required to be implicated in land capability assessment as a way in determining more suitable land use practice.

Landslide susceptibility is a new parameter in proposed land capability classification. This parameter plays as one of hindering factors in conducting a certain land use practice. If landslide susceptibility is well recognized, more comprehensive land capability and proper land use practice can be established to minimize future risk due to landslide threat.

Study area has been classified into five landslide susceptibility classes. Each landslide susceptibility class is randomly dispersed. One dominant class in each landform is decided as a representative value. As a result of generalization process, study area consists of three dominant landslide susceptibility classes, i.e. low, moderate, and high. Low susceptible areas exist in relatively flat zone (lower slope of Mount Sidoramping, small valley in Sidoramping lava, Lawu lahar plain, and andecite hill). Moderate susceptible zones are positioned in undulating terrain in lava flow, high hill in Sidoramping lava flow, river valley, and limestone hill. The rest areas are categorized as high susceptible to landslide.

Land Capability Assessment

Land capability assessment was done by matching technique. All parameters are corresponded with proposed land capability classification. The result shows that study area generally consists of four classes, i.e. class IV, VI, VII, and VIII (Figure 5.6). The worst condition in each class is then added as sub class. The worst situation mainly refers to soil depth, permeability, slope, and landslide susceptibility so that sub class “s” and “e” are assigned to those land capability classes. Thereby, land capability class and subclass for study area comprises with IVe, VIe, VIs, VIIe, VIIIe, VIIIs, and VIIIw (Table 5.7). The detailed explanation of land capability class and sub class is presented below.

Table 5.7. General Land Capability Class and Subclass for Tawangmangu Sub District

Landform	Inhibiting Factors*									Class and Subclass
	1	2	3	4	5	6	7	8	9	
Volcanic cone of Lawu Volcano	G	KE2	e3	k0	t3	p5	d1	b0	LS4	**VIIIe**
Lower slope of Mount Sidoramping	D	KE2	e2	k0	t3	p5	d1	b0	LS2	**VIIIs**
Undulating terrain in lava flow	D	KE2	e1	k0	t4	p4	d1	b0	LS3	**VIe**
High hill in Sidoramping lava flow	G	KE3	e3	k0	t3	p4	d1	b0	LS3	**VIIIe**
Moderate hill in Sidoramping lava flow	F	KE3	e2	k0	t1	p1	d1	b0	LS4	**VIIe**
Low hill in volcanic rock formation	D	KE2	e1	k0	t1	p2	d1	b1	LS4	**VIIe**
Small valley in Sidoramping lava	D	KE2	e2	k0	t3	p4	d1	b1	LS2	**IVe**
River valley	D	KE2	e2	k0	t2	p1	d4	b0	LS3	**VIe**
Eroded volcanic cone	G	KE2	e2	k0	t3	p4	d1	b0	LS4	**VIIIe**
Front slope of Lawu Volcano	D	KE2	e1	k0	t3	p5	d1	b1	LS4	**VIIIe**
Lawu lahar plain	C	KE2	e1	k0	t2	p2	d4	b0	LS2	**IVe**
Andecite hill	D	KE2	e2	k3	t2	p2	d4	b2	LS2	**VIs**
Limestone hill	D	KE3	e1	k3	t2	p2	d0	b3	LS3	**VIIIw**

**1=slope, 2=erodibility, 3=actual erosion, 4=soil depth, 5= texture, 6=permeability, 7=soil drainage, 8=rock fragment, 9=landslide susceptibility.*
Source: Data Analysis (2009)

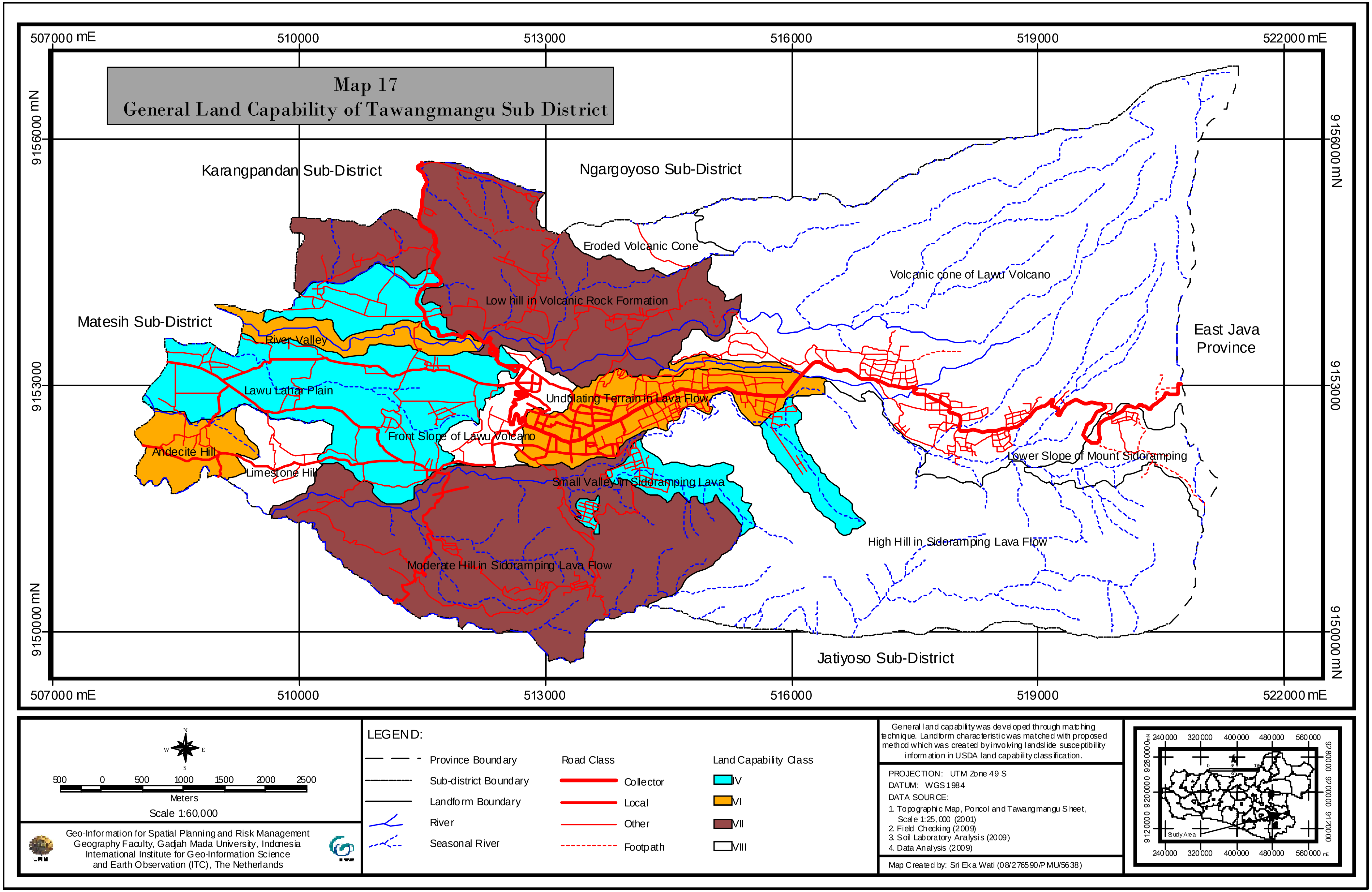


Figure 5.6. Land Capability Map of Tawangmangu Sub District

Class IV implicates the area in Lawu lahar plain and small valley in Sidoramping lava flow. Lawu lahar plain area is characterized by minor erosion (e1), moderately fine texture (t2), and moderately slow permeability (p2), poorly drained (d4), and low susceptible to landslide (LS2). The area generally has several supporting factors for land use practice but low susceptible to landslide reduces its capability for intensive purpose. On the other hand, small valley area basically has circumstances that allows for intensive land use, i.e. deep soil (k0), medium texture (t3), moderately fast permeability (p4). Nonetheless, the implementation of land utilization shall consider hilly condition which is possible to be unstable. Those characteristics show that low susceptible to landslide acts as the main adverse factors in Lawu lahar plain whereas hilly slope is the most constraint factor in small valley area. Thus, all areas in class IV are joined in sub class IVe.

Three landforms in study area are classified in class VI. Those are undulating terrain in lava flow, river valley, and andecite hill. Undulating terrain is typified by low erodibility (KE2), deep soil (k0), well drained (d1), less than 15% of rock fragment (b0), and moderate susceptible to landslide (LS3). River valley area has several characteristics, i.e. moderate erosion (e2), poorly drained (d4), and moderate susceptible to landslide (LS3). The present condition reveals that moderate susceptible to landslide is the major constraint factor in both landforms. Thus, undulating terrain and river valley are classified in sub class VIe. On the other side, andecite hill has different main limitation. Very shallow soil (less than 25 cm) in this area hinders exhaustive land use. The very shallow soil decreases land capacity for providing water, supporting material, and space for root penetration. Therefore, this area is included in sub class VIs.

Land capability class VII pervades two landforms, i.e. moderate hill of Sidoramping lava flow and low hill in volcanic rock formation. Moderate hill area exists in steep slope (F) with moderate erodibility (KE3), moderate erosion (e2), and high susceptible to landslide (LS4). Low hill area is typified by hilly area (D), low erodibility (KE2), moderate appearance of rock in the soil (b1), and high susceptible to landslide (LS4). Those situations describe that slope and high susceptible to landslide are the highest hindering factor for moderate hill and low hill area respectively. Hence, both landforms are assigned sub class VIIe.

Class VIII is the most dominant land capability class in study area. This class covers six landforms, i.e. volcanic cone of Lawu Volcano, high hill in Sidoramping lava flow, eroded volcanic cone, lower slope of Mount Sidoramping, front slope of Lawu Volcano, and limestone hill. In volcanic cone of Lawu Volcano, very steep slope (G), fast permeability (p5), and high susceptible to landslide (LS4) obstruct intensive land use practice in this area. The high hill in Sidoramping lava flow and eroded volcanic cone are also deterred by very steep slope. Hence, those three landforms are categorized in sub class VIIIe since slope acts as the major impediment factor. On the other hand, lower slope of Mount Sidoramping is characterized by low erodibility (KE2), deep soil (k0), medium textured (t3), well drained (d1), and fast permeability (p5). Land use practice in front slope is hampered by fast permeability (p5) as well. Based on the existing of fast permeability factor, both landforms are included in sub class VIIIs. In addition, limestone hill is getting worse due to excessively drained condition (d0) so that this landform is categorized as sub class VIIIw.

5.5. Detailed Land Capability Class Based on Proposed Method

Detailed land capability assessment is an effort to specify the general land capability class to obtain more elaborate result. This analysis takes an assumption that one general land capability class comprises some detailed land capability classes. It is associated with the spatial distribution of slope and landslide susceptibility. The elaborate class reveals the possibility in establishing more comprehensive land use.

Detailed land capability assessment employs the result from general land capability appraisal. The detailed class is obtained by overlying general land capability class with slope and landslide susceptibility class. The result is then matched with proposed land capability classification. The flowchart of detailed land capability assessment is depicted in Figure 5.7.

The detailed assessment gives different result compared with general version. Study area consists of six land capability classes, i.e. class III, IV, V, VI, VII, and VIII. Several areas can be elaborated into several classes while the others are not. This circumstance is caused by the main constraint factor in the given areas. Five landforms (volcanic cone in Lawu Volcano, lower slope of Mount Sidoramping, front slope of Lawu Volcano, andecite hill, and limestone hill) have major limitation related to soil properties. The most constraint in three landforms (volcanic cone in Lawu

Volcano, lower slope of Mount Sidoramping, and front slope of Lawu Volcano) are fast permeability whereas limestone hill is hampered by excessively drained condition. The existing limitations automatically classify those areas as class VIII. Besides, andecite hill areas are still categorized as class VI even though this area is typified by relatively hilly area and low landslide susceptibility. In this case, very shallow soil still acts as the most constraint in andecite hill. On the other hand, other landforms in study area can be itemized into various classes. Low hill in volcanic rock formation, as an example, is formerly categorized as class VII. This area is then specifically divided into three classes, i.e. class VI, VII, and VIII. The width area for each class is 73 Ha, 434 Ha, and 259 Ha respectively. Another example is eroded volcanic cone area. This landform consists of three specified classes, i.e. class VI, VII, and VIII although this area is previously categorized as class VIII (Table 5.8). Those results describes that detailed land capability assessment is able to provide more elaborate information for managing the land. The spatial distribution of detailed land capability class can be harnessed for establishing more comprehensive land use planning. The detailed land capability class is illustrated in Figure 5.8.

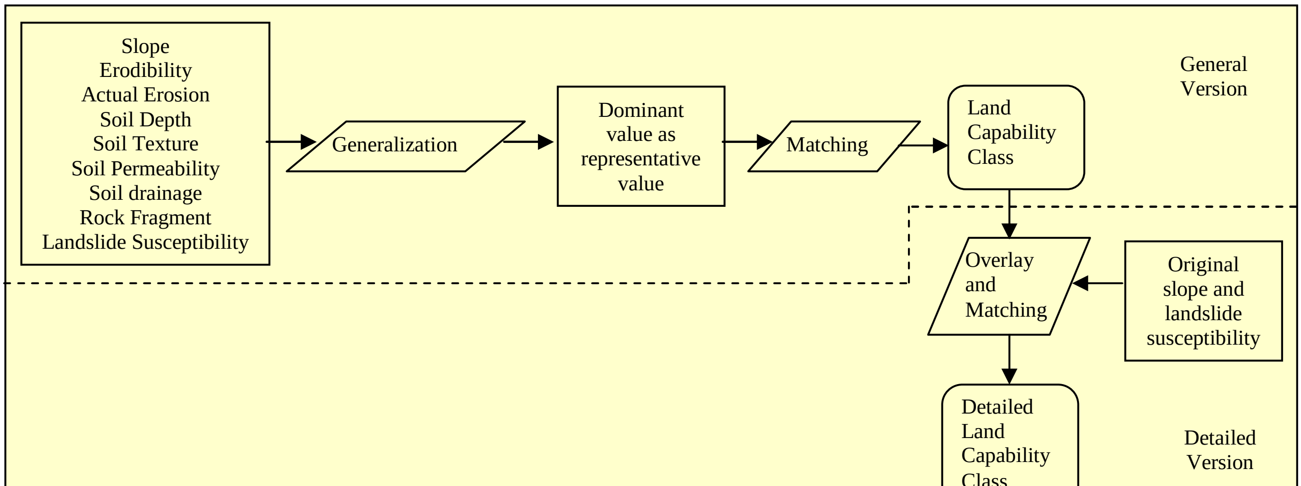


Figure 5.7. Flowchart of Detailed Land Capability Assessment

Table 5.8. Detailed Land Capability Class Based on Proposed Method

Landform	General Land Capability Class	Detailed Land Capability Class and Width Area (Ha)
Volcanic cone of Lawu Volcano	VIII	VIII (2,134)
Lower slope of Mount Sidoramping	VIII	VIII (140)
Undulating terrain in lava flow	VI	IV (22), VI (179), VII (36), VIII (8)
High hill in Sidoramping lava flow	VIII	IV (47), VI (163), VII (437), VIII (792)
Moderate hill in Sidoramping lava flow	VII	VI (349), VII (355), VIII (204)
Low hill in volcanic rock formation	VII	VI (73), VII (434), VIII (259)
Small valley in Sidoramping lava	IV	III (13), IV (81), VI (32), VII (26), VIII (8)
River valley	VI	V (6), VI (78), VII (6), VIII (23)
Eroded volcanic cone	VIII	VI (21), VII (38), VIII (38)
Front slope of Lawu Volcano	VIII	VIII (121)
Lawu lahar plain	IV	IV (378), VI (266), VII (8)
Andecite hill	VI	VI (116)
Limestone hill	VIII	VIII (112)

Source: Data Analysis (2009)

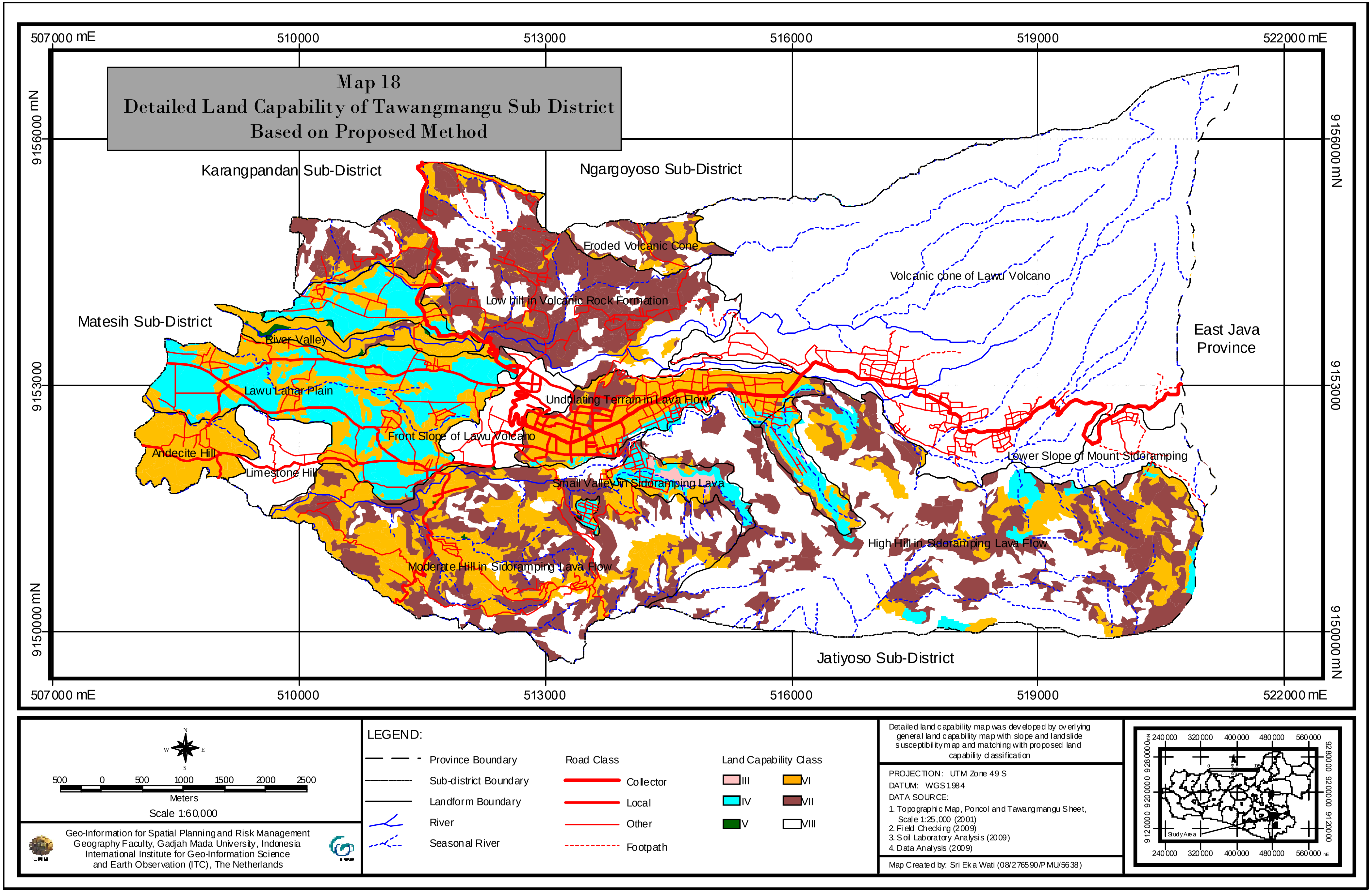


Figure 5.8. Detailed Land Capability Map of Tawangmangu Sub District Based on Proposed Method

5.6. The Other Alternative in Land Capability Assessment

An alternative method is applied in integrating landslide susceptibility into land capability assessment. This method harnesses the similar constraint factors. However, landslide susceptibility is not directly included in estimating land capability. The susceptibility information is added after land capability class is obtained. It is intended to specify land capability class by considering the distribution of landslide susceptibility. The flowchart of an alternative method is depicted in Figure 5.9.

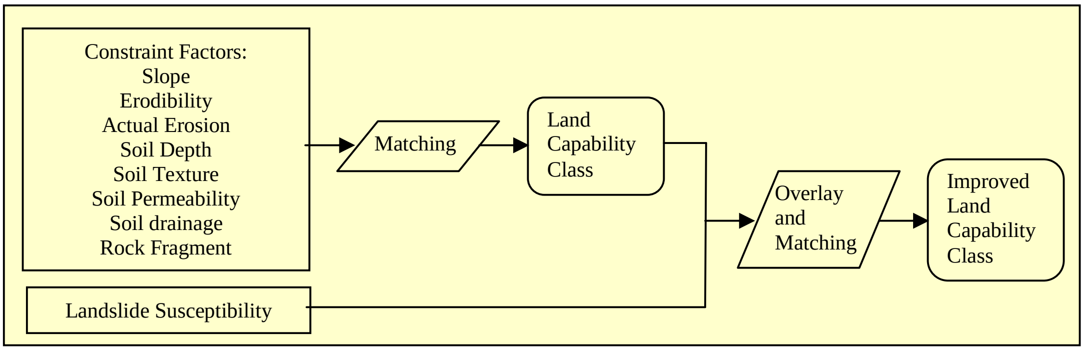


Figure 5.9. Flowchart of an Alternative Method

This method reveals some general results. There are four landforms included in class IV, i.e. undulating terrain, low hill in volcanic rock formation, small valley in Sidoramping lava, and Lawu lahar plain. The most constraint factor in those landforms is hilly situation. It is only Lawu lahar plain area that is hampered by poorly drained condition. Class V just pervades river valley area. The river valley area is typified by slow permeability. Andecite hill area is classified as class VI whilst moderate hill in Sidoramping lava flow is categorized in class VII. Land use practice in andecite hill is obstructed by very shallow soil condition while moderate hill area is hindered by steep slope. In addition, the rest areas in Tawangmangu Sub District are included in class VIII.

This method also shows several specified results. Some landforms can be elaborated into several classes. Undulating terrain area consists of three specified classes, i.e. class IV, VI, and VII. The similar situation as in undulating terrain area exists in Lawu lahar plain. The general land capability class in low hill area is specified into three classes, i.e. class VI, VII, VIII. Small valley area is categorized into class IV and class VI whereas river valleys areas are detailed into class V, VI, VII, and VIII. Those results illustrate that the elaboration process tends to give higher land capability classes. As a case, if a certain landform is formerly classified as class IV, the improved land capability class can comprise class IV, VI, and VII. The complete result of this method is described in Table 5.9 and it is portrayed in Figure 5.10.

Table 5.9. Land Capability Class Based on Alternative Method

Landform	Land Capability Class	Specified Land Capability Class and Width Area (Ha)
Volcanic cone of Lawu Volcano	VIII	VIII (2,134)
Lower slope of Mount Sidoramping	VIII	VIII (140)
Undulating terrain in lava flow	IV	IV (22), VI (183), VII (40)
High hill in Sidoramping lava flow	VIII	VIII (1,439)
Moderate hill in Sidoramping lava flow	VII	VII (908)
Low hill in volcanic rock formation	IV	VI (72), VII (433), VIII (259)
Small valley in Sidoramping lava	IV	IV (115), VI (45)
River valley	V	V (6), VI (78), VII (5), VIII (24)
Eroded volcanic cone	VIII	VIII (97)
Front slope of Lawu Volcano	VIII	VIII (121)
Lawu lahar plain	IV	IV (378), VI (266), VII (8)
Andecite hill	VI	VI (116)
Limestone hill	VIII	VIII (112)

Source: Data Analysis (2009)

Some areas cannot be elaborate into specified land capability. The worst situation hampers those areas to be elaborated into various classes. This situation occurs in eight landforms, i.e. volcanic cone of Lawu Volcano, lower slope of Mount Sidoramping, high hill in Sidoramping lava flow, moderate hill in Sidoramping lava flow, eroded volcanic, front slope of Lawu Volcano, andecite hill, and limestone hill. Steep and very steep slope, fast permeability, very shallow soil, and excessively drained condition hinder intensive land use practice. On the other word, landslide susceptibility factor does not have influence in determining specified land capability class in the given areas.

The next discussion in this research does not use the result from alternative method. This technique does not give more detail result compared with proposed method. Even so, the alternative method can be still harnessed as an optional way in elaborating general land capability class in a certain area.

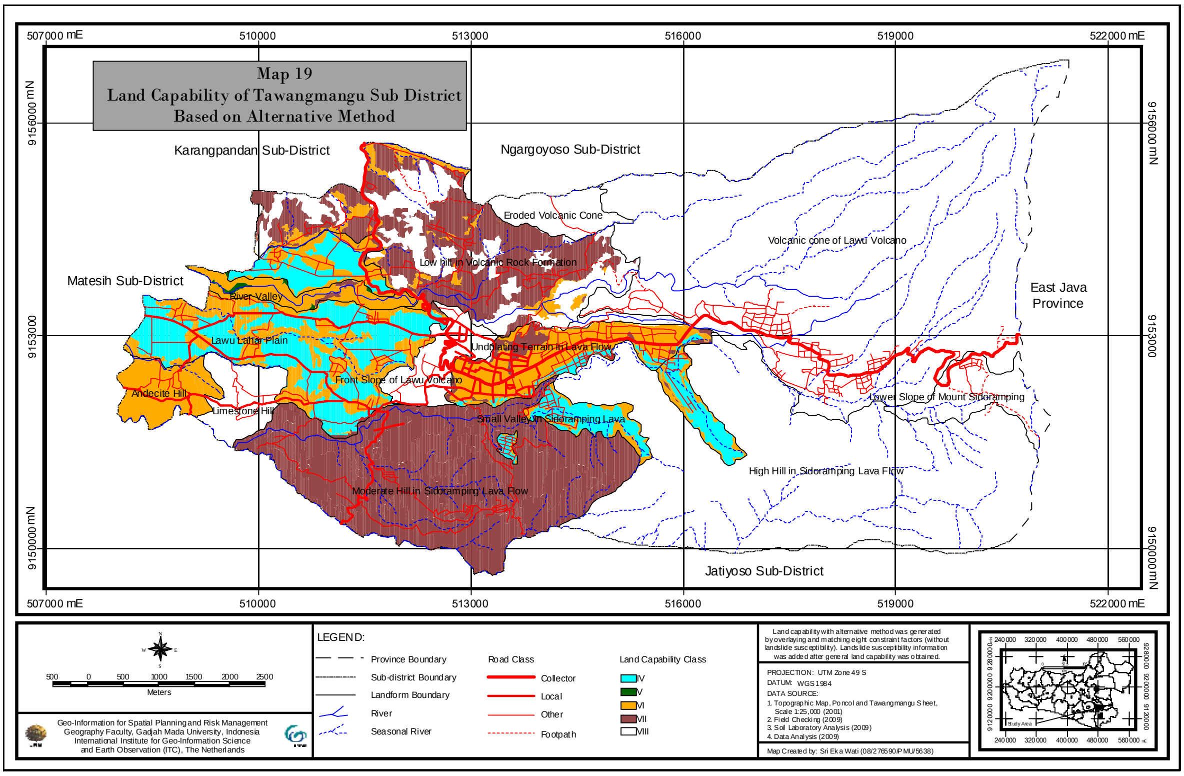


Figure 5.10. Land Capability Map of Tawangmangu Sub District Based on Alternative Method

CHAPTER VI
LAND USE FUNCTION OF TAWANGMANGU SUB DISTRICT

This chapter specifies the previous chapter by applying the result of land capability assessment in determining land use function. Land use function division based on government's method is also done. Both methods are developed in general and detailed version. The result from both methods is then descriptively compared.

6.1. Introduction

Land use function is a general zoning of land. It distinguishes a certain area into three functions, i.e. protected, buffer, and cultivated area. The division of land use function is employed to determine the further land utilization. Each land use function shall be exploited for appropriate land use in order to keep the sustainable usage.

Spatial planning in Indonesia applies land use function as a basis in determining proper land use. All spatial planning documents implicate land use function analysis for arranging further land use in a given area. In government view, land use function is determined by using scoring method from Ministry agriculture. Meanwhile, land use function in this research is recognized as an expanded result of land capability assessment.

6.2. Land Use Function Developed by Local Government

Karanganyar Regency has emphasized the involvement of land use function analysis in spatial planning. RTRW of Karanganyar Regency 1997-2006 and RDTRK of Tawangmangu 2007-2016 assert that land use function in Karanganyar Regency is derived through land capability assessment. The land capability appraisal is conducted by scoring method. This method is declared on Legal Document of Ministry of Agriculture number 837/Kpts/UM/11/1980 (Anonymous, 1980) and number 683/Kpts/UM/8/1981 (Anonymous, 1981). Scoring method uses three variables i.e. slope, soil type, and average daily rainfall intensity. Each variable is elaborated into several classes as shown in Table 2.3 – 2.5. The classes are given a certain score which is then accumulated to divide a certain area into three land use functions, as follow:

- Protected area involves the area with score of ≥ 175. Protected area is provided for natural preserve purpose.
- Buffer area includes the area with score of 125-174. The buffer area has double functions, as protected or cultivated area. However, cultivation activity is not as intense as cultivated area.
- Cultivated area is applied for the area with score of less than 125. Cultivated area itself consists of yearly and seasonal cultivated area. For settlement area, there is an additional requirement which is the slope must be less than 8%.

The land use function division in RTRW of Karanganyar Regency is illustrated in the allocation map of protected area and cultivated area. The allocation map of protected area (Figure 6.1) depicts that protected area is specified into protected forest area, protected hydrology area, special area, cultural life area, river side area, water spring area, and dam area. On the other side, allocation map of cultivated area (Figure 6.2) itemizes cultivated area into nine classes, i.e. urban settlement area, rural settlement area, wet land area, dry land area, yearly cultivated area, production forest area, industrial estate, industrial development area, and industrial zone. Based on those maps, Tawangmangu Sub District is mostly assigned as protected forest area, especially in northern and southern part. The middle part is proposed as yearly cultivated area and urban settlement area

RDTRK of Tawangmangu has developed land capability analysis for development area of Tawangmangu. The mapping area involves three villages, i.e. Tawangmangu, Kalisoro, and Nglebak. The analysis states that the range of score is from 90 to 165 so that those areas are possible to be developed as settlement area, seasonal cultivated area, yearly cultivated area, and buffer area. The present land use function division in RDTRK unfortunately does not encompass the whole area in Tawangmangu Sub District. Thereby, land use function map generated with scoring method is performed to overcome the lack of data for the whole study area.

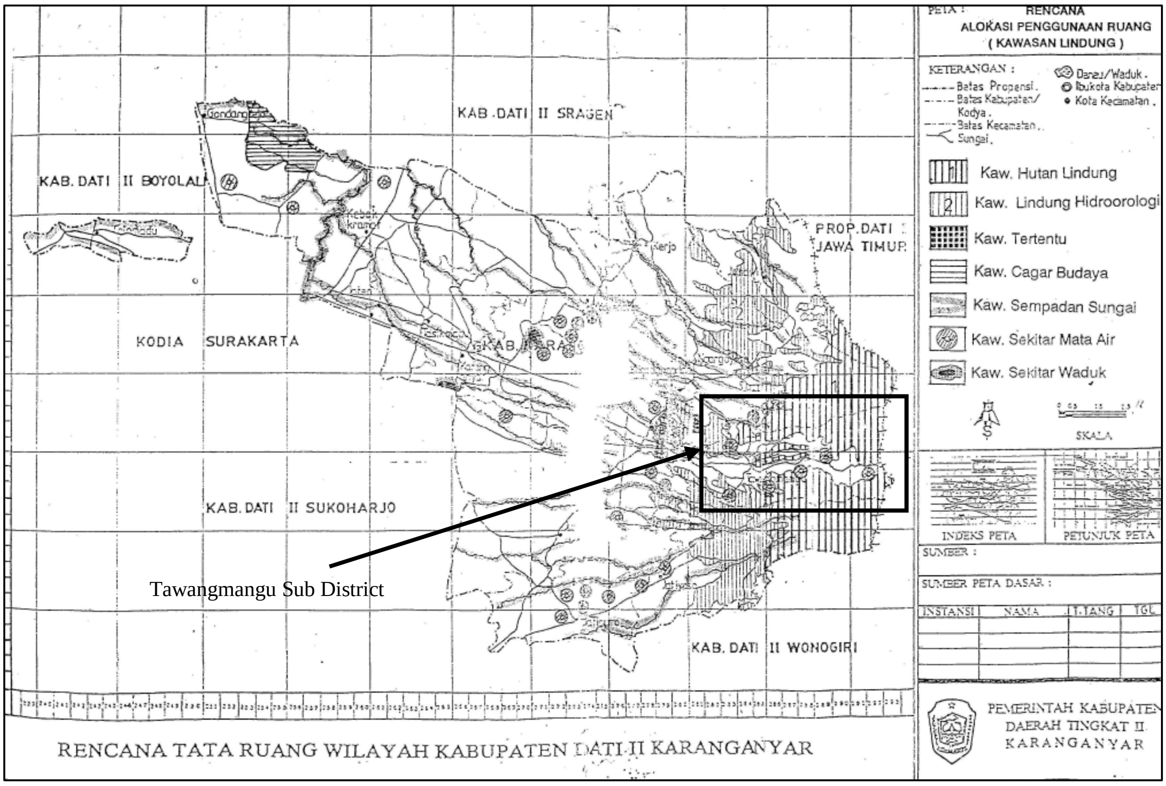


Figure 6.1. Allocation Map of Protected Area in Regency Scale (BAPPEDA, 1997)

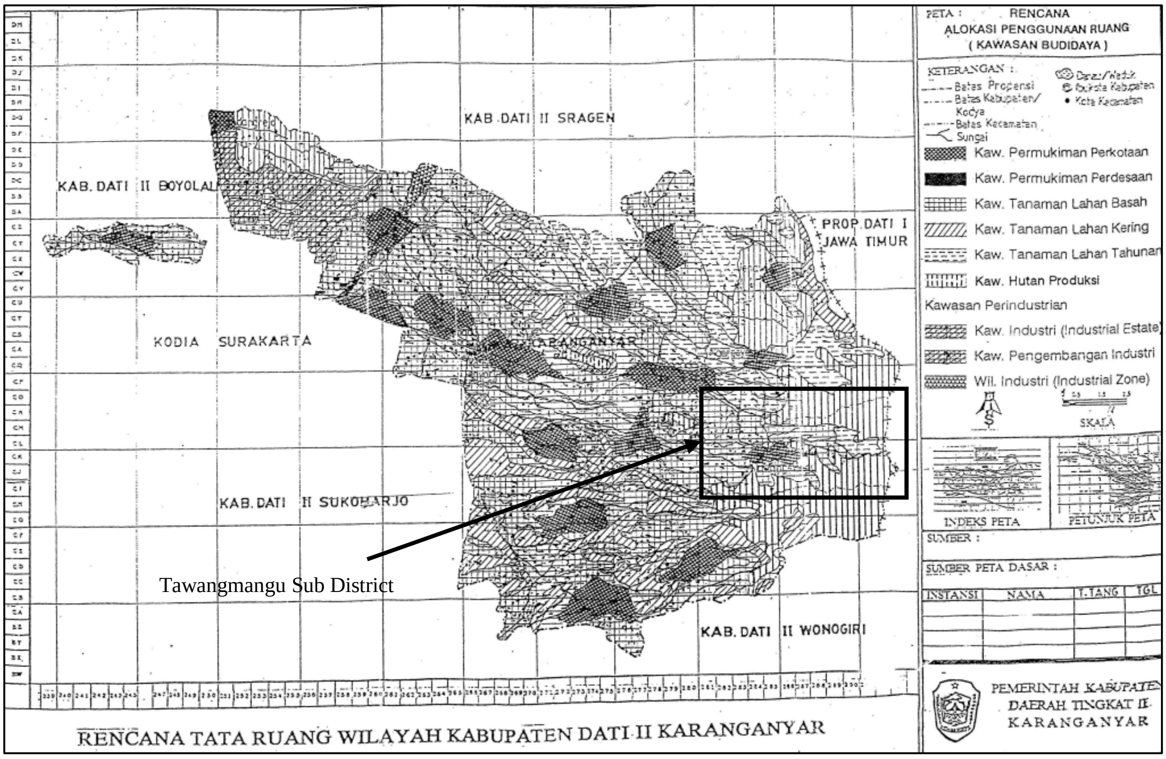


Figure 6.2. Allocation Map of Cultivated Area in Regency Scale (BAPPEDA, 1997)

6.3. Development of General Land Use Function

General land use function is generated by using landform as a land mapping unit. This mapping unit is applied to both methods, i.e. Ministry of Agriculture's method (scoring method) and proposed method. By using the similar analysis unit, the result from both methods can be properly compared. The comparison itself is intended to descriptively define the differences between both methods.

6.3.1. General Land Use Function Based on Ministry of Agriculture's Method (Scoring Method)

Scoring method makes use of three variables (slope, soil type, and average daily rainfall intensity). Slope in this research is developed from contour data derived from topographic map while soil type is taken from soil map (Appendix 2). Average daily rainfall is calculated from daily rainfall intensity for 23 years (1986-2008). The rainfall data is achieved from Somokado gauge (Tawangmangu Village) since this is the one functioned gauge in study area. All required variables are classified and given a certain score. The score is amassed for identifying land use function.

The obtained score is in the range of 90 – 195 (Table 6.1). It means that study area can be divided into three land use functions. Protected area comprises 51% of total area (3,573 Ha). Buffer and cultivated area pervades 31% (2,183 Ha) and 18% (1,247 Ha) of total area respectively. Protected and buffer areas spatially exist in northern, southern, and eastern part of Tawangmangu Sub District. The rest areas are assigned as cultivated area. In relation with landform, two landforms (volcanic cone of Lawu volcano and high hill in Sidoramping lava flow) are classified as protected area. Six landforms (lower slope of Mount Sidoramping, moderate hill in Sidoramping lava flow, low hill in volcanic rock formation, small valley in Sidoramping lava, eroded volcanic cone, and limestone hill) are included in buffer area and the rest five landforms are allocated as cultivated area. Land use function distribution based on Ministry of agriculture's method is portrayed in Figure 6.3.

Table 6.1. Land Use Function Based on Ministry of Agriculture's Method

Landform	Characteristic and Score			Total	Land Use Function
	Slope	Soil Type	Daily Rainfall		
Volcanic cone of Lawu Volcano	>45% (100)	Andosol (60)	18 mm/day (20)	180	Protected area
Lower slope of Mount Sidoramping	15 – 25% (60)	Andosol (60)	18 mm/day (20)	140	Buffer area
Undulating terrain in lava flow	8– 15% (40)	Latosol (30)	18 mm/day (20)	90	Cultivated area
High hill in Sidoramping lava flow	>45% (100)	Litosol (75)	18 mm/day (20)	195	Protected area
Moderate hill in Sidoramping lava flow	>45% (100)	Latosol (30)	18 mm/day (20)	150	Buffer area
Low hill in volcanic rock formation	25 – 45% (80)	Latosol (30)	18 mm/day (20)	130	Buffer area
Small valley in Sidoramping lava	15 – 25% (60)	Andosol (60)	18 mm/day (20)	140	Buffer area
River valley	15 – 25% (60)	Latosol (30)	18 mm/day (20)	110	Cultivated area
Eroded volcanic cone	>45% (100)	Latosol (30)	18 mm/day (20)	150	Buffer area
Front slope of Lawu Volcano	15 – 25% (60)	Latosol (30)	18 mm/day (20)	110	Cultivated area
Lawu lahar plain	8 – 15% (40)	Latosol (30)	18 mm/day (20)	90	Cultivated area
Andecite hill	15 – 25% (60)	Latosol (30)	18 mm/day (20)	110	Cultivated area
Limestone hill	15 – 25% (60)	Mediteran (45)	18 mm/day (20)	125	Buffer area

Source: Data Analysis (2009)

6.3.2. General Land Use Function Based on Proposed Method

Proposed land capability classification has classified the study area into four general land capability classes. The classes are IV, VI, VII, and VIII. The different land capability class is especially concerned with different land management (land use function and land use practice). Hence, land capability is used as basic information to discern appropriate land use manner.

Land capability class can be converted into particular land use function. The conversion analysis utilizes the scheme of correlation between land capability and intensity of land use from Klingebiel and Montgomery (1966) (Table 3.8). According to the given scheme, it can be assumed that class I – IV is classified in arable class while class V – VIII is included in non arable land. The arable land is proposed as cultivated area whereas non-arable land is supposed as buffer and protected area. For non-arable land, class V - VII is classified as buffer area because those classes can be used as natural preserve/wildlife, limited production forest, and limited grazing. Class VIII is included as protected area since it is only apportioned as natural preserve/protected forest.

The study area is commonly classified as non arable land. Nine landforms are included as non-arable area whilst the rest areas are possible to be developed for cultivation and built up area (Table 6.2. and Figure 6.4). The division of land use function in Tawangmangu Sub District is below explained:

a. Protected area covers 58% of total area (4,043 Ha). It pervades volcanic cone of Lawu Volcano, lower slope of Mount Sidoramping, eroded volcanic cone, front slope of Lawu Volcano, limestone hill, and high hill in Sidoramping lava flow. The areas are mostly hampered by slope and landslide susceptibility. Thus, it is better to keep those areas in natural condition rather than to exploit the land.
b. Buffer area encompasses 31% of total area (2,148 Ha). This zone is located in several regions, i.e. undulating terrain in lava flow, river valley, moderate hill in Sidoramping lava flow, low hill in volcanic rock formation, and andecite hill.
c. Cultivated area implicates 11% of total area (812 Ha). It is only two landforms that can be exploited as cultivated area. Those areas are small valley in Sidoramping lava flow and Lawu lahar plain.

Table 6.2. Land Use Function Based on Proposed Method

Landform	Class and Subclass	General Category*	Land Use Intensity*									Land Use Function**
			1	2	3	4	5	6	7	8	9	
Volcanic cone of Lawu Volcano	VIIIe	Non Arable										Protected area
Lower slope of Mount Sidoramping	VIIIs	Non Arable										Protected area
Undulating terrain in lava flow	VIe	Non Arable										Buffer area
High hill in Sidoramping lava flow	VIIIe	Non Arable										Protected area
Moderate hill in Sidoramping lava flow	VIIe	Non Arable										Buffer area
Low hill in volcanic rock formation	VIIe	Non Arable										Buffer area
Small valley in Sidoramping lava	IVe	Arable										Cultivated area
River valley	VIe	Non Arable										Buffer area
Eroded volcanic cone	VIIIe	Non Arable										Protected area
Front slope of Lawu Volcano	VIIIe	Non Arable										Protected area
Lawu lahar plain	IVe	Arable										Cultivated area
Andecite hill	VIs	Non Arable										Buffer area
Limestone hill	VIIIw	Non Arable										Protected area

**Kliengebiel and Montgomery (1966), ** Ministry of Agriculture Regulation (1980/1981)*
1:wildlife, 2:forestry, 3:limited grazing, 4:moderate grazing, 5:intense grazing, 6:limited cultivation, 7:moderate cultivation, 8:intense cultivation, 9:very intense cultivation
Source: Data Analysis (2009)

6.3.3. The Comparison of General Land Use Function Developed by Scoring and Proposed Method

Both methods reveal a quite similar result. Almost all areas have similar land use function. Concerned with landform, five landforms are classified in the same land use function and the rest are different (Table 6.3). The landforms with similar land use function are volcanic cone of Lawu Volcano and high hill in Sidoramping lava flow. Both landforms are allocated as protected area. Besides, moderate hill and low hill areas are apportioned as buffer area while Lawu lahar plain is proposed as cultivated area.

The different land use function division can be also identified in some areas. Lower slope of Mount Sidoramping, eroded volcanic cone, and limestone hill are included as buffer area based on scoring method whereas they are categorized as protected area regarding to proposed method. Apart from that, undulating terrain in lava flow, river valley, and andecite hill are assigned as cultivated areas in scoring method and as buffer areas in proposed method. Front slope is categorized as protected area based on proposed method. In scoring method, this area becomes a part of cultivated area. In addition, proposed method allocates small valley area as cultivated area while scoring method classifies this area as buffer area.

Table 6.3. General Land Use Function Comparison

Landform	General Land Use Function	
	Ministry of Agriculture's Method/ Scoring Method	Proposed Method
Volcanic cone of Lawu Volcano	Protected area	Protected area
Lower slope of Mount Sidoramping	Buffer area	Protected area
Undulating terrain in lava flow	Cultivated area	Buffer area
High hill in Sidoramping lava flow	Protected area	Protected area
Moderate hill in Sidoramping lava flow	Buffer area	Buffer area
Low hill in volcanic rock formation	Buffer area	Buffer area
Small valley in Sidoramping lava	Buffer area	Cultivated area
River valley	Cultivated area	Buffer area
Eroded volcanic cone	Buffer area	Protected area
Front slope of Lawu Volcano	Cultivated area	Protected area
Lawu lahar plain	Cultivated area	Cultivated area
Andecite hill	Cultivated area	Buffer area
Limestone hill	Buffer area	Protected area

Source: Data Analysis (2009)

The existing disparities implicitly affirm a particular problem. Scoring method is not clear enough in describing the worst situation obstructing intensive land utilization. This method merely considers topographic situation and sensitivity to erosion as limitation factor in a certain area. On the other side, proposed method adds more comprehensive constraints. It is not only topographic and erosion, but hazard probability and soil properties as well. Nevertheless, both methods can accomplish one to another. The scoring method can be improved by identifying the most constraint as illustrated in proposed method. The improvement of scoring method is explained through following examples:

- Lower slope of Mount Sidoramping is classified as buffer area (scoring method) and as protected area (proposed method). Proposed method allocates this area as protected region due to fast permeability condition. It means that the function of buffer area as stated in scoring method has to be conducted with special priority. The area can be used for limited land use practice but it must deliberate conservation concept.
- Undulating terrain is implicated as cultivated area (scoring method) and buffer area (proposed method). Factor of moderate susceptible to landslide has to be taken into account as if this area will be used as cultivation zone. The proper agricultural technique must be applied in order to avoid slope instability in this area.
- Small valley in Sidoramping lava flow is categorized as buffer area (scoring method) and cultivated area (proposed method). This landform is quite suitable to be intensively exploited as cultivated area because it is supported by relative flat area and low susceptible to landslide.

- Eroded volcanic cone is classified as buffer area (scoring method) and protected area (proposed method). Since buffer area is transition zone between protected and cultivated area; this area can be advised to be reclassified as protected area by considering very steep slope as the major constraint in this landform.

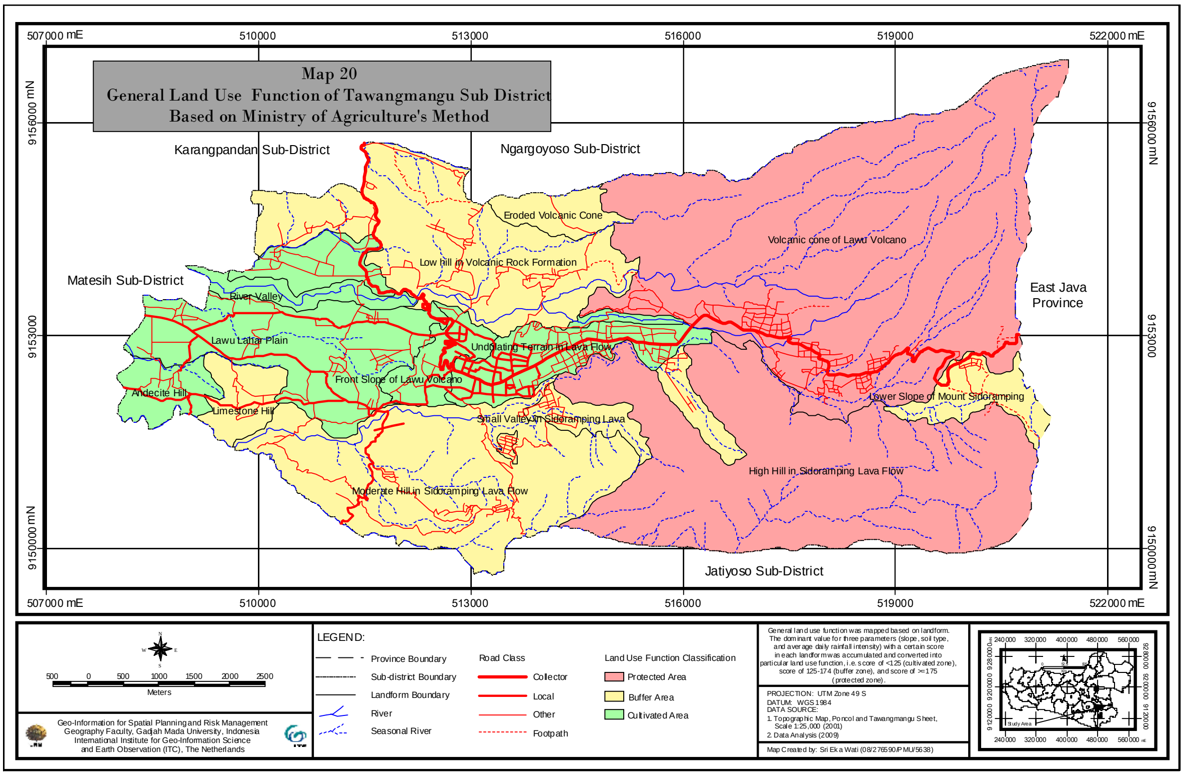


Figure 6.3. General Land Use Function Map of Tawangmangu Sub District Based on Ministry of Agriculture's Method

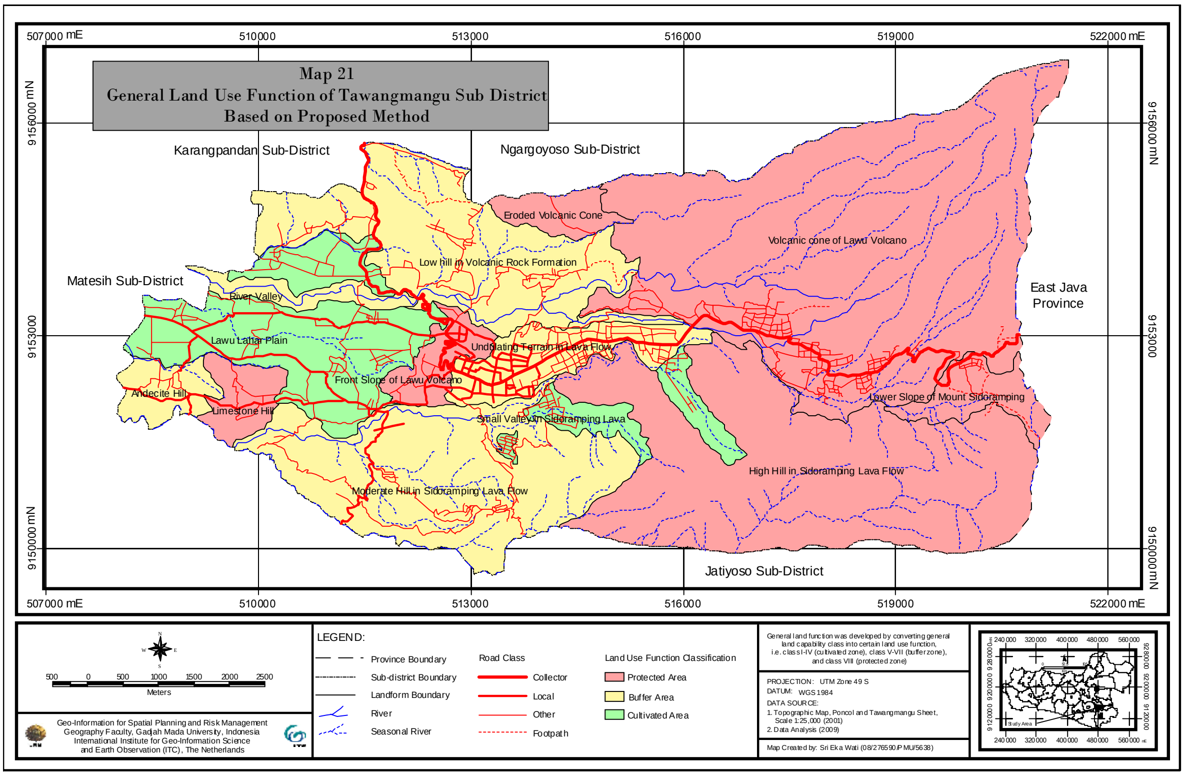


Figure 6.4. General Land Use Function Map of Tawangmangu Sub District Based on Proposed Method

6.4. Development of Detailed Land Use Function

The development of elaborate land use function is aimed to obtain more detail result compared with general land use function. The specified result is an improvement to properly perform land use function division. In consequence, comprehensive land use planning for regional development can be appropriately done.

Detailed land use function is also generated by means of scoring and proposed method. Each method still applies the similar variable. Detailed land use function through scoring method is conducted by directly overlying all variables. The slope is not generalized as done in general version. On the other hand, proposed method divides land use function by applying the result of detailed land capability assessment.

6.4.1. Detailed Land Use Function Based on Ministry of Agriculture's Method (Scoring Method)

The detailed version is proposed to spatially attain more specific location particular land use function. It is assumed that one landform can be harnessed for more than one function due to spatial distribution of slope. As a result, various land uses are possible to be performed in this area. In addition, the land can be effectively used.

The detailed version gives a quite different result compared with general version. This version reveals the score range 70 – 195 while the general version has score range 90 – 195. Protected areas are mainly located in eastern part of study area. They are associated with high hill in Sidoramping lava flow and volcanic cone of Lawu Volcano. The areas are characterized by slope of more than 45% and soil type of andosol and lithosol. On the other side, buffer areas are largely positioned in western part and at some areas in eastern part. This zone exists in moderate hill in Sidoramping lava flow, low hill in volcanic rock formation, and limestone hill. Buffer areas are typified by various slopes from flat to very steep and latosol and mediteran as the main soil type. In addition, cultivated region covers less than 20% of study area. It is generally situated in middle part of study area. The relative flat area and latosol as major soil type supports its function as a cultivated area. Width area for each land use function is 2,659 Ha (38% of total study area) for protected area; 3,136 Ha (45% of total study area) for buffer area; 1,208 Ha (17% of total study area) for cultivated area. The description of detailed land use function division is presented in Table 6.4 and Figure 6.5.

Table 6.4. Distribution of Detailed Land Use Function Based on Ministry of Agriculture's Method

Landform	General Land Use Function	Detailed Land Use Function and Width Area (Ha)		
		Protected Area	Buffer Area	Cultivated Area
Volcanic cone of Lawu Volcano	Protected area	1,150	878	106
Lower slope of Mount Sidoramping	Buffer area	26	88	26
Undulating terrain in lava flow	Cultivated area	-	30	215
High hill in Sidoramping lava flow	Protected area	1,427	12	-
Moderate hill in Sidoramping lava flow	Buffer area	-	902	6
Low hill in volcanic rock formation	Buffer area	-	697	69
Small valley in Sidoramping lava	Buffer area	56	43	61
River valley	Cultivated area	-	97	16
Eroded volcanic cone	Buffer area	-	97	-
Front slope of Lawu Volcano	Cultivated area	-	76	45
Lawu lahar plain	Cultivated area	-	59	593
Andecite hill	Cultivated area	-	47	69
Limestone hill	Buffer area	-	110	2
Total		**2,659**	**3,136**	**1,208**

Source: Data Analysis (2009)

6.4.2. Detailed Land Use Function Based on Proposed Method

Detailed land capability assessment has categorized the study area into several elaborate classes. The specified class is acquired by spatially considering slope and landslide susceptibility distribution. These classes are class III, IV, V, VI, VII, and VIII. The elaborate land capability class is subsequently used to produce detailed land use function division.

The detailed land use function division commonly shows that the dominant land use function is protected area. Protected area covers more than a half of total area. The areas are typified by very steep slope and high susceptible to landslide. On the other side, buffer and cultivated areas are mainly located in western part of study area. Buffer areas are characterized by moderate-high landslide susceptible and/or moderately steep-steep slope while cultivated areas are typified by very low-low landslide susceptibility and flat-hilly area.

The detailed land capability class has itemized the general land use function in some areas. Undulating terrain actually can be harnessed as cultivated area although the basic function of this land is buffer area. High hill in Sidoramping lava flow is not fully apportioned as protected because some areas are suitable for buffer and cultivated area. Besides, moderate hill areas have to segregate some locations to be allocated as protected area. The complete description of detailed land use function is summarized in Table 6.5 and Figure 6.6.

Table 6.5. Distribution of Detailed Land Use Function Based on Proposed Method

Landform	General Land Use Function	Detailed Land Use Function and Width Area (Ha)		
		Protected Area	Buffer Area	Cultivated Area
Volcanic cone of Lawu Volcano	Protected area	2,134	-	-
Lower slope of Mount Sidoramping	Protected area	140	-	-
Undulating terrain in lava flow	Buffer area	8	215	22
High hill in Sidoramping lava flow	Protected area	792	600	47
Moderate hill in Sidoramping lava flow	Buffer area	204	704	-
Low hill in volcanic rock formation	Buffer area	259	507	-
Small valley in Sidoramping lava	Cultivated area	8	58	94
River valley	Buffer area	23	90	-
Eroded volcanic cone	Protected area	38	59	-
Front slope of Lawu Volcano	Protected area	121	-	-
Lawu lahar plain	Cultivated area	-	274	378
Andecite hill	Buffer area	-	116	-
Limestone hill	Protected area	112	-	-
Total		**3,839**	**2,623**	**541**

Source: Data Analysis (2009)

6.4.3. The Comparison of Detailed Land Use Function Developed by Scoring and Proposed Method

Both detailed methods present disparity result. The distribution of detailed land use function from scoring method has a tendency to be concentrated in a certain part whereas proposed method is fragmented. Protected area based on scoring method is relatively agglomerated in eastern part whilst protected areas in proposed method exist in many separated places in study area. Furthermore, buffer area classified from proposed method is separately located in several areas. In scoring method, western part tends to be allocated as buffer area. The cultivated area based on scoring method exists along the middle part of study area while proposed method puts cultivated area in western part of study area.

The differences between both methods are related to variables used. Scoring method only uses slope distribution for elaborating the general version. On the other hand, proposed method harnesses detailed land capability class. This class is formerly obtained from comprehensive analysis of physical land properties combined with hazard information. Nevertheless, the overall result from both methods illustrates an advantage in developing more detail identification of land use function. The elaborate way brings an opportunity in establishing specific and effective land use planning rather than general version. Thereby, the detailed result is more needed for spatial planning for comprehensively managing the land.

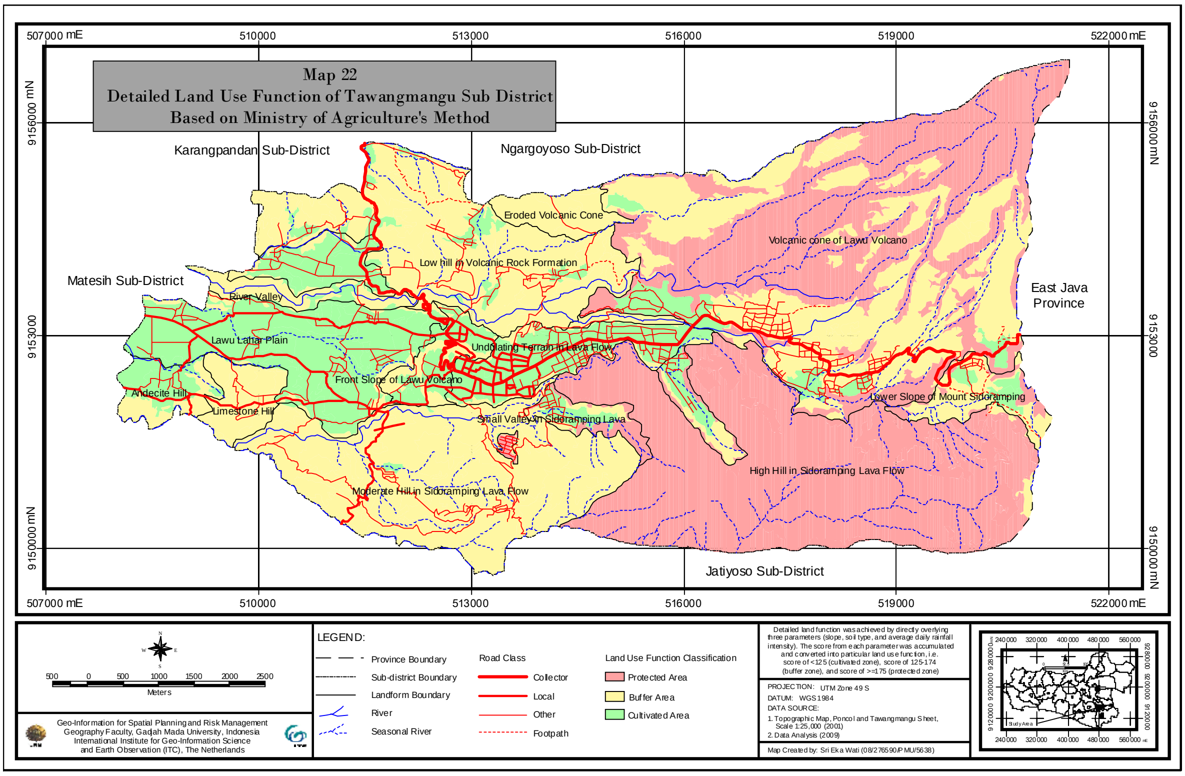


Figure 6.5. Detailed Land Use Function Map of Tawangmangu Sub District Based on Ministry of Agriculture's Method

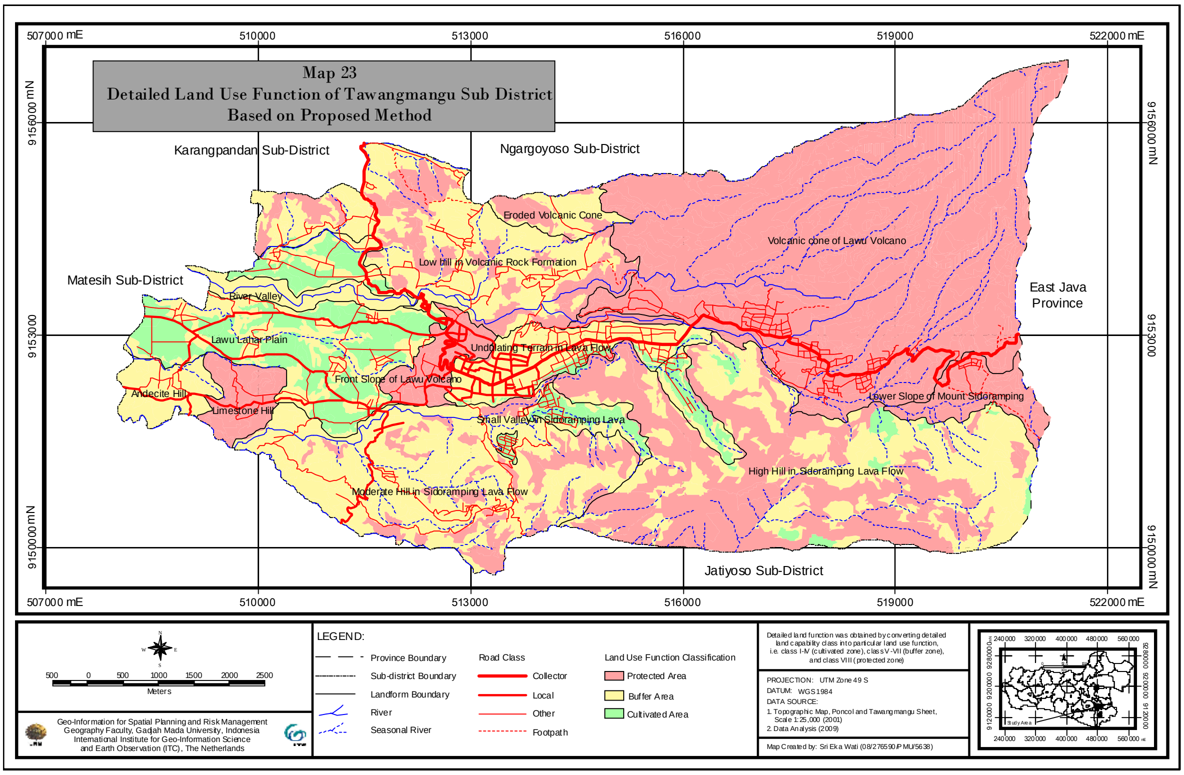


Figure 6.6. Detailed Land Use Function Map of Tawangmangu Sub District Based on Proposed Method

CHAPTER VII
LAND USE DEVIATION IN TAWANGMANGU SUB DISTRICT

Chapter seven defines the land use deviation by identifying present land use which is not suitable with land use function. Since the land use function is developed by scoring method and proposed method; land use divergence is also observed based on scoring and proposed method. General and detailed version is included as well. Moreover, this chapter explains the cause of land use deviation and the application of research result on spatial planning.

7.1. Introduction

Land use deviation can be described as inappropriateness of land use application regarding to the zoning of land use function. Unsuitable land use practice in a certain land use function can reveal the negative effect for the environment because the land is not used based on its capability. The negative effects encompass land degradation, disaster, etc. Thereby, identification process in terms of land use deviation becomes important to avoid unpredictable situation due to incorrectness land use practice.

The land use digression is the crucial issue in land management. This information can be used for reforming present inappropriate circumstances. The result also acts as supporting information in evaluating the implementation of established land use function as asserted in RTRW and RDTRK.

7.2. The Suitability between Land Use Function and Land Use Practice

Land use function is a term for dividing a particular region into three functions, i.e. protected, buffer, and cultivated area. Land use function is basically used as guidance in determining appropriate land use in a certain area. The zoning of land use function not only represents the land limitation, but also proper land utilization and further land use application in a given area.

Each land use function is intended to a certain situation. Protected area must be kept in natural condition. The intensive land use practices are not allowed. Buffer area can be harnessed as cultivation zone and protected area. However, the intensity of land utilization activity is lower than cultivated area and the activity must not disrupt the environmental balance. Cultivated area is the most appropriate land both for agricultural purpose and built up purpose.

The regulation from Ministry of Agriculture suggests several land use practices in relation with land use function. Protected area can be applied for protected forest, preserved forest, and recreational forest. Buffer area is possible for the following land use: limited production forest, plantation (tight crops), and mixed garden. Cultivated area is allocated for permanent production forest, plantation (tight crops), fruit plantation, other seasonal crops, and settlement area.

Klingebiel and Montgomery (1966) also recommend some particular land use applications concerned with land capability. Cultivated area (class I - IV) is arable land which is advised to be used from limited cultivated area into very intense cultivated area. Buffer area (class V – VII) is non arable land. This area is proposed as grazing area and forestry. Protected area (class VIII) shall be utilized for wildlife/natural preserve. The compatibility between land capability and land use function has been illustrated in Table 3.8.

The suitability between land use and land use function is formed by considering the regulation from Ministry of Agriculture and the recommendation of Klingebiel and Montgomery (1966). Protected area is suitable forest, pine plantation, shrub and bush, and limestone area. The proper land use for buffer area might be forest, pine plantation, mixed garden, shrub and bush, and limestone area. In addition, cultivated area can be used effectively for settlement area, paddy field, mixed garden, vegetable garden, pine plantation, forest, and also mixed paddy field with vegetable garden. Sparse vegetation in forest region is not included in suitability analysis because this land use is certainly embedded with forest. The appropriateness between land use and land use function is completely summarized in Table 7.1.

Table 7.1. The Suitability between Land Use and Land Use Function

Land Use	**Land Use Function**		
	Protected Area	**Buffer Area**	**Cultivated Area**
Forest	suitable	suitable	suitable
Pine plantation	suitable	suitable	suitable
Paddy field	not suitable	not suitable	suitable
Mixed garden	not suitable	suitable	suitable
Mixed paddy field with vegetable garden	not suitable	not suitable	suitable
Settlement area	not suitable	not suitable	suitable
Shrub and bush	suitable	suitable	not suitable
Limestone area	suitable	suitable	not suitable
Vegetable garden	not suitable	not suitable	suitable
Sparse vegetation in forest region	-	-	-

Source: Kliengebiel and Montgomery (1966), Arsyad (1989), Ministry of Agriculture Regulation (1980/1981)

7.3. The Identification of General Land Use Deviation

The identification of general land use deviation is aimed to obtain general description of land use divergence in study area. The inexpediency is detected by comparing present land use and general land use function generated from scoring and proposed method.

7.3.1. General Land Use Deviation Based on Scoring Method

General land use function based on scoring method has divided the study area into protected, buffer, and cultivated area. Eastern part of Tawangmangu Sub District is mostly allocated as protected area whereas western part of study area is apportioned as buffer area. The cultivated area is plotted in the mid western part.

The comparison of general land use function and present land use practice illustrates some results. Most of land use divergence occurs in buffer and protected area. The deviation intensity in buffer area is bigger than protected area (Table 7.2 and Figure 7.1). Land use divergence for protected area is marked by the appearance of settlement area and vegetable garden. Those land uses are not permitted to be applied in protected region. They are correctly practiced in cultivated area. Apart from that, the deviation in buffer area is caused by the presence of paddy field. More than one third of total paddy field in study area (43%) is located in buffer area. It is not suitable because paddy field as seasonal crops shall be planted in cultivation zone. The other digression cases are recognized through existence of vegetable garden, mixed paddy field with vegetable garden, and settlement area. In fact, 32% of mixed paddy field with vegetable garden, 27% of settlement area, and 57% of vegetable garden exist in buffer area. In addition, land use inexpediency in cultivated area is not significant. The deviation in this area is only represented by the existence of shrub and bush.

The land use deviation administratively exists in almost all villages. The worst situation occurs in Blumbang and Gondosuli Village. Settlement area and vegetable garden in this location exist in protected area. A small number of vegetable gardens also presents in buffer area. Besides, a large number of vegetable gardens together with settlement area and mixed paddy field with vegetable garden in Sepanjang Village are found in buffer area. A quite similar situation as in Sepanjang Village happens in Tawangmangu and Bandardawung Village at which vegetable garden and settlement are situated in buffer area. Land use digression in Plumbon and Tengklik Village is characterized by presence of settlement and mixed paddy field with vegetable garden in buffer area.

The existing land use digression ultimately describes a central problem. The problem is related to the presence of settlement area and vegetable garden in protected and buffer region. The development of settlement area in those areas is not in line with the rule from Ministry of Agriculture. This regulation states that settlement area shall be built in cultivated area with slope of 0 – 8%. Vegetable garden is also not allowed in protected area. This land use is more advised to be practiced in cultivated area rather than in buffer area. Hence, it is needed to force a better implementation of land use function as a guide in developing the land.

Table 7.2. The Width Area of General Land Use Deviation Based on Scoring Method

Land Use	Land Use Function (Ha)		
	Protected Area	**Buffer Area**	**Cultivated Area**
Forest	2,908	501	8
Pine plantation	2	48	15
Paddy field	-	75	101
Mixed garden	-	609	43
Mixed paddy field with vegetable garden	-	239	510
Settlement area	142	249	544
Shrub and bush	-	-	11
Limestone area	-	8	-
Vegetable garden	331	454	15
Sparse vegetation in forest region	190	-	-
Total	**3,573**	**2,183**	**1,247**

Source: Data Analysis (2009)

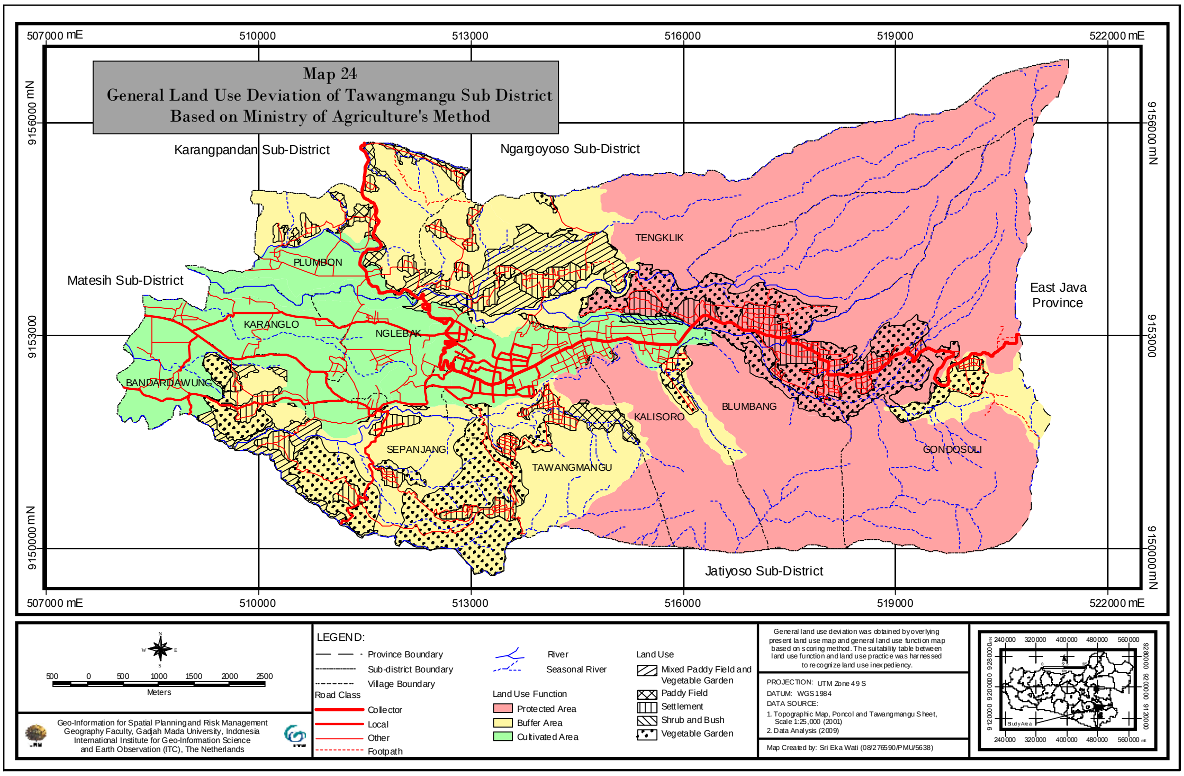


Figure 7.1. General Land Use Deviation Map of Tawangmangu Sub District Based on Ministry of Agriculture's Method

7.3.2. General land Use Deviation Based on Proposed Method

Proposed method has generally classified Tawangmangu Sub District into three land use functions. The land use function division has been determined based on general land capability class. As a result, protected area is allocated in eastern part. Some small areas in western part are also pointed as protected area. Buffer area is situated in western part while cultivated area exists in mid western part of study area.

The comparison between land use function and present land use identifies some land use deviations. The divergence only occurs in protected and buffer area. The deviation in buffer area is the biggest. In contrast, there is no land use inexpediency in cultivated area (Table 7.3 and Figure 7.2). The inappropriate land use in protected area comprises paddy field, mixed garden, mixed paddy field with vegetable garden, settlement area, and vegetable garden. Land use digression in protected area commonly occurs in several villages, i.e. Blumbang, Kalisoro, Bandardawung, and Gondosuli. The deviation in those areas is typified by the presence of settlement and vegetable garden. On the other hand, the unsuitable land use in buffer area consists of paddy field, mixed paddy field with vegetable garden, settlement area, and vegetable garden. Paddy field in buffer area is randomly situated at small area in Tengklik, Plumbon, Nglebak, and Bandardawung Village. Mixed paddy field with vegetable garden is mostly located in Tengklik Village whilst several settlement areas in buffer area exist in Tawangmangu, Bandardawung, Tengklik, and Sepanjang Village. In addition, the existence of vegetable garden in buffer area can be recognized in Sepanjang and Tawangmangu Village.

Present land use deviation in proposed method gives a similar interesting issue as in scoring method. The issue is concerned with presence of settlement area and vegetable garden in protected and buffer area. Table 7.3 illustrates that more than a half of total settlement area in study area (53%) is situated in buffer area while 28% is located in protected area. Besides, almost all vegetable gardens are located in protected and buffer area. Those conditions shall be given more attention since the basic function of those areas is not appropriate for settlement area and vegetable garden.

Table 7.3. The Width Area of General Land Use Deviation Based on Proposed Method

Land Use	Land Use Function (Ha)		
	Protected Area	Buffer Area	Cultivated Area
Forest	3,091	247	79
Pine plantation	5	60	-
Paddy field	13	83	80
Mixed garden	33	595	24
Mixed paddy field with vegetable garden	28	296	425
Settlement area	258	495	182
Shrub and bush	-	11	-
Limestone area	8	-	-
Vegetable garden	417	361	22
Sparse vegetation in forest region	190	-	-
Total	**4,043**	**2,148**	**812**

Source: Data Analysis (2009)

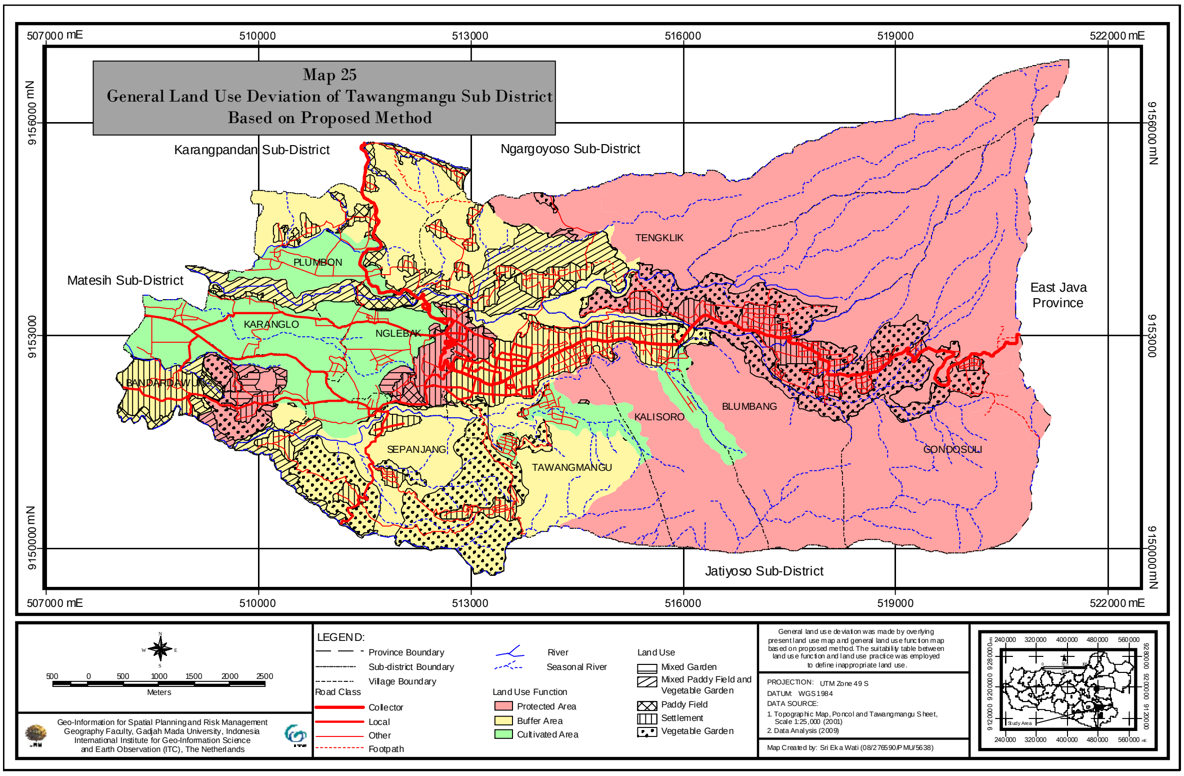


Figure 7.2. General Land Use Deviation Map of Tawangmangu Sub District Based on Proposed Method

7.4. The Identification of Detailed Land Use Deviation

The land use function in study area has been elaborated by means of particular technique. It is intended to obtain detailed distribution of land use function. The specified result is employed to discover the digression land use in a certain land use function. The detailed land use deviation brings a prospect to improve existing land use function implementation.

7.4.1. Detailed Land Use Deviation Based on Scoring Method

Scoring method has established elaborate land use function for Tawangmangu Sub District. The result asserts that eastern part of study area is proposed as protected area. Western part and some areas in eastern part are apportioned for buffer area while middle part of study area has a function as cultivated area.

The evaluation between detailed land use function and land use reveals several digressions. The land use inexpediency occurs in protected and buffer area. The intensity of land use divergence in buffer area is much higher than in protected area. Inappropriate land use in protected area is represented by the presence of paddy field, settlement area, and vegetable garden. Those land uses are not allowed to be done in protected area. Apart from that, land use divergence in buffer area pervades paddy field, mixed paddy field with vegetable garden, settlement area, and vegetable garden. Buffer area has been permanently used as settlement area. More than one third of settlement area is located in buffer area. The expansion settlement area is associated with the development of vegetable garden, paddy field, and mixed paddy field with vegetable garden. Detailed land use deviation is summarized in Table 7.4 and it is spatially depicted in Figure 7.3.

Table 7.4. The Width Area of Detailed Land Use Deviation Based on Scoring Method

Land Use	Detailed Land Use Function (Ha)		
	Protected Area	**Buffer Area**	**Cultivated Area**
Forest	2,357	1,007	53
Pine plantation	3	62	-
Paddy field	10	83	83
Mixed garden	-	612	40
Mixed paddy field with vegetable garden	-	318	431
Settlement area	18	394	523
Shrub and bush	-	11	-
Limestone area	-	8	-
Vegetable garden	124	598	78
Sparse vegetation in forest region	147	43	-
Total	**2,659**	**3,136**	**1,208**

Source: Data Analysis (2009)

Land use deviation takes place in every village. The highest intensity of land use divergence is located in Sepanjang Village whilst the lowest intensity is situated in Karanglo Village. Land use inexpediency in Sepanjang Village is mostly caused by the presence of vegetable garden in buffer area. On the other hand, the divergence in Karanglo Village is represented by a small number of settlements and mixed paddy field with vegetable garden. Apart from that, the major land the distribution of land use divergence in each village is completely presented in Table 7.5.

Identification of detailed land use digression gives important information. The information is associated with growth of settlement area and the development of agricultural activities in outside of cultivated area. This situation cannot be tolerated since it is not in line with the existing legal regulation and sustainable concept. Therefore, local government ought to consider the strict enforcement of land use function realization.

Table 7.5. The Existence of Detailed Land Use Deviation
Based on Scoring Method in Each Village

Village	The Existence of Land Use Deviation						
	Protected			Buffer			
	Paddy Field	Settlement	Vegetable Garden	Paddy Field	Mixed Paddy Field and Vegetable Garden	Settlement	Vegetable Garden
Bandardawung							
Sepanjang							
Tawangmangu							
Kalisoro							
Blumbang							
Gondosuli							
Tengklik							
Nglebak							
Karanglo							
Plumbon							

Source: Data Analysis (2009)

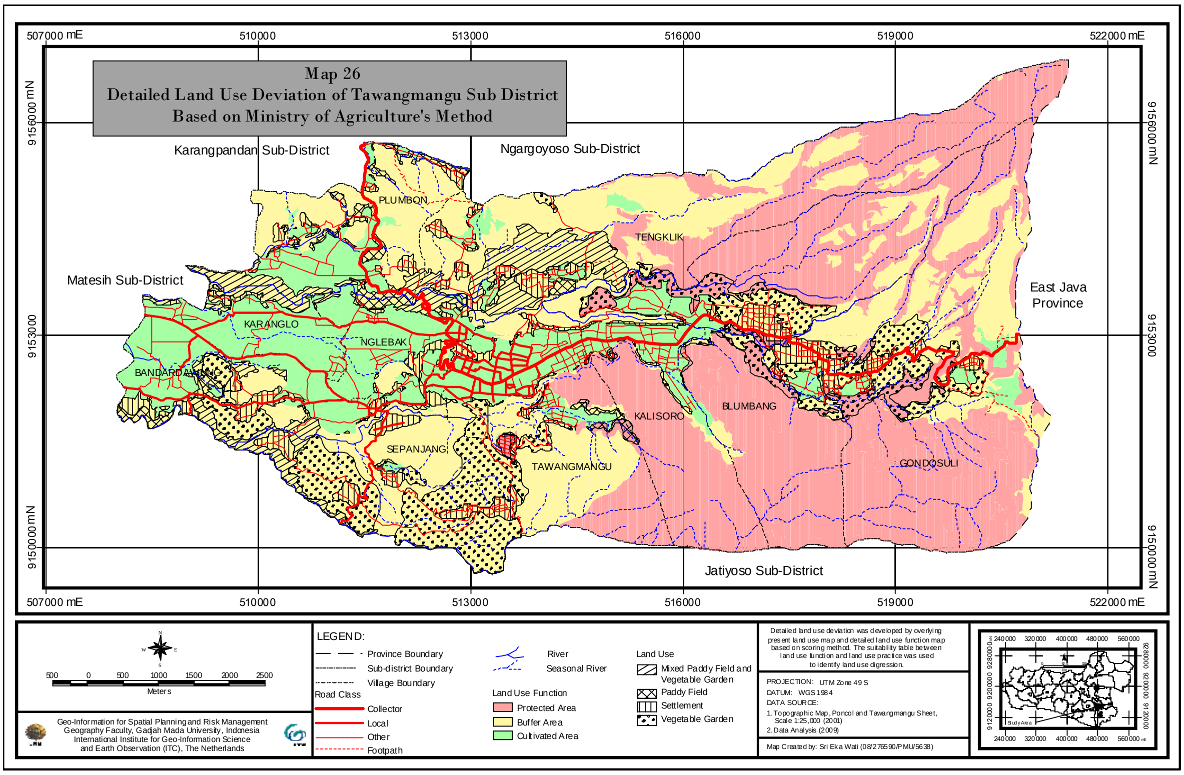


Figure 7.3. Detailed Land Use Deviation Map of Tawangmangu Sub District Based on Ministry of Agriculture's Method

7.4.2. Detailed Land Use Deviation Based on Proposed Method

Detailed land use function is generated from detailed land capability class. The detailed class considers spatial distribution of slope and landslide susceptibility. Consequently, the land use functions tend to be fragmented. The protected areas are spread out from west to east although most of those protected areas are allocated in eastern part of Tawangmangu Sub District. Furthermore, buffer and cultivated areas are situated in western part of study area.

The assessment of detailed land deviation based on proposed method declares that land use divergence exists in protected and buffer area. The number of land use inexpediencies in buffer area is higher than in protected area. The deviation in protected area is identified from the presence of paddy field, mixed garden, mixed paddy field with vegetable garden, settlement, and vegetable garden. Besides, the digression in buffer area reveals due to the extensive development of paddy field, mixed paddy field with vegetable garden, settlement area, and vegetable garden. The distribution of detailed land use digression can be seen in Table 7.6.

Table 7.6. The Width Area of Detailed Land Use Deviation Based on Proposed Method

Land Use	Detailed Land Use Function (Ha)		
	Protected Area	**Buffer Area**	**Cultivated Area**
Forest	2,595	740	82
Pine plantation	51	14	-
Paddy field	22	93	61
Mixed garden	224	420	8
Mixed paddy field with vegetable garden	65	355	329
Settlement area	274	617	44
Shrub and bush	11	-	-
Limestone area	8	-	-
Vegetable garden	472	311	17
Sparse vegetation in forest region	117	73	-
Total	**3,839**	**2,623**	**541**

Source: Data Analysis (2009)

The detailed land use deviation can be identified in each village. The inappropriate land use practice occurs at most areas in western part of Tawangmangu Sub District. Those areas particularly implicate several villages, i.e. Plumbon, Nglebak, Karanglo, Bandardawung, and Sepanjang. Despite those villages, land use inexpediency also exists in other villages located in eastern part of study area. The distribution of land use deviation in each village is summarized in Table 7.7.

The overall result of identification of land use inexpediency asserts a significant point. Improper land use practice must be controlled. It can trigger unexpected situation in terms of environmental damage and disruption. Even the appropriate mechanism for conducting agricultural activities in a certain area is available; it is recommended that land use application is adjusted to the land capability and established land use function.

Table 7.7. The Existence of Detailed Land Use Deviation
Based on Proposed Method in Each Village

Village	The Existence of Land Use Deviation								
	Protected					**Buffer**			
	Paddy Field	**Mixed Paddy Field and Vegetable Garden**	**Settlement**	**Vegetable Garden**	**Mixed Garden**	**Paddy Field**	**Mixed Paddy Field and Vegetable Garden**	**Settlement**	**Vegetable Garden**
Bandardawung									
Sepanjang									
Tawangmangu									
Kalisoro									
Blumbang									
Gondosuli									
Tengklik									
Nglebak									
Karanglo									
Plumbon									

Source: Data Analysis (2009)

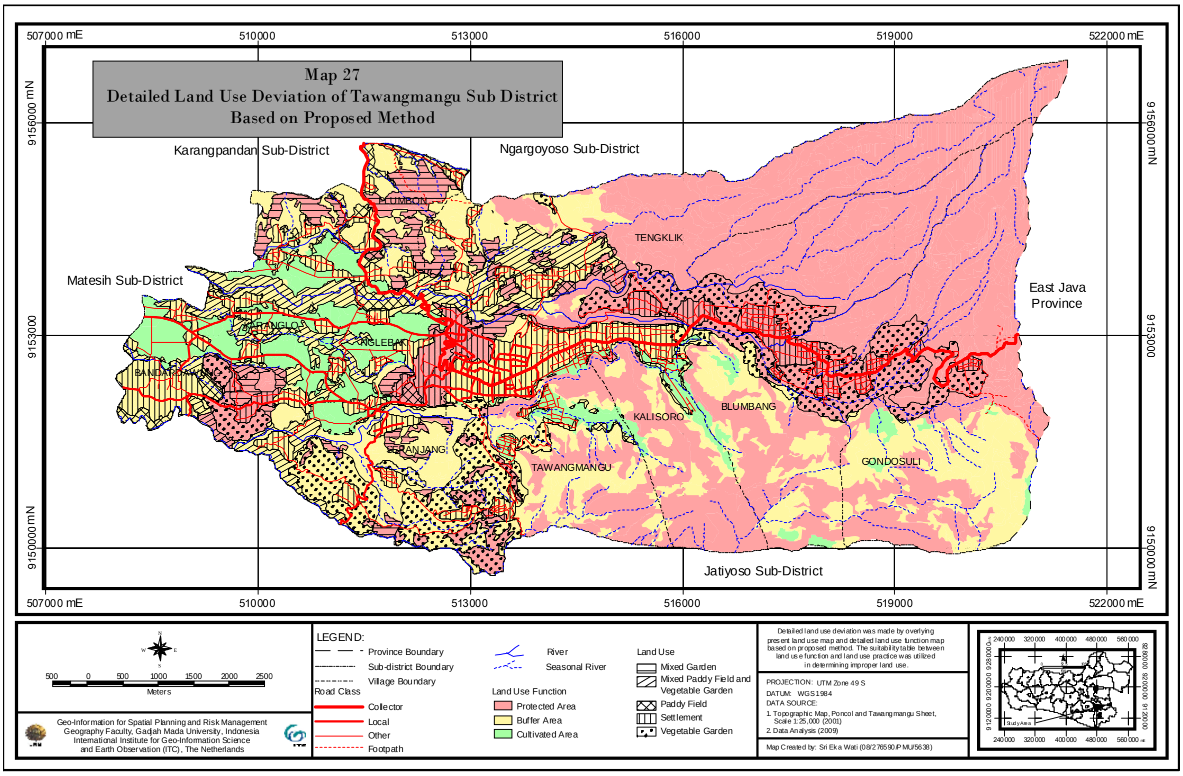


Figure 7.4. Detailed Land Use Deviation Map of Tawangmangu Sub District Based on Proposed Method

7.5. The Cause of Land Use Deviation

Mountainous areas are characterized by six conditions. The conditions are significant consideration in developing mountainous area. Those conditions are accessibility, fragility, marginality, heterogeneity or diversity, niche or natural suitability, and human adaptation mechanisms (Nangju in Arsyad, 1992). Niche or natural suitability and human adaptation mechanism are related to responses or adaptations to the other mountain characteristics.

One of the inappropriate responses to mountainous area condition is represented by inexpediency of land use practice. The deviation is associated with human intervention in utilizing the available land without contemplating land capability and land suitability. The digression brings some risks to environment, e.g. land degradation and hazard. Therefore, human adaptation to environment shall be properly conducted.

Tawangmangu Sub District is located in south western flank of Lawu Volcano. The area is typified as mountainous region with many potencies and limitations. The potencies are related to land fertility, water availability, climate, etc. On the other side, the constraints are particularly linked with various topographic situation and hazard susceptibility. The existing potencies and limitations force local people to establish adaption mechanisms in intensively utilizing the land to fulfill human needs.

Intensive land utilization in study area is closely related to the increasing of population number. Population growth in study area is relatively fast. It had been projected that the number of population will reach 47,877 people in 2016 (BAPPEDA, 2007). The increasing of population is in line with the enlarging of human needs. Doner (1987) states that population growth usually causes a growing demand for food, wood and other raw materials, and for living space. Thus, local community tends to harness every possible and accessible place to meet human needs.

Intensive land use practice in Tawangmangu Sub District is also related to the economical function of this area for surroundings. RDTRK of Tawangmangu 2007 – 2016 states that Tawangmangu plays a role as producer and as a collection zone of agricultural commodities. The agricultural products are then distributed to Karanganyar City, Surakarta City, and other cities. This situation indicates that study area contributes accomplishment of food crops in Tawangmangu Sub District and surroundings. As a result, this function drives rapid development of agricultural land in this area.

Some land use practices are not always properly done. It is found some deviations in study area. The capability and suitability of the land are sometimes ignored. The demand of human needs and limited space for obtaining the required need influences exhaustive land use practice in unsuitable zone. One of the crucial deviations is recognized from the development of settlement area. Ministry of Agriculture asserts that settlement shall be located in slope of less than 8%. USDA, 1983 (in Hardjowigeno, 1994) also establish that suitable area for settlement is in the slope of 0 - 8%. The area with slope of 8 -15% is moderate suitable while the area with slope more than 15% is poor suitable for settlement. Regarding to existing situation, more than a half of total settlement area (54.5%) is located in poor suitable zone for settlement. Those areas exist in slope of more than 15% (Figure 7.5). It is only 13% of settlement area located in suitable zone. The expansion of settlement area in poor suitable zone is probably caused by limited area in suitable zone.

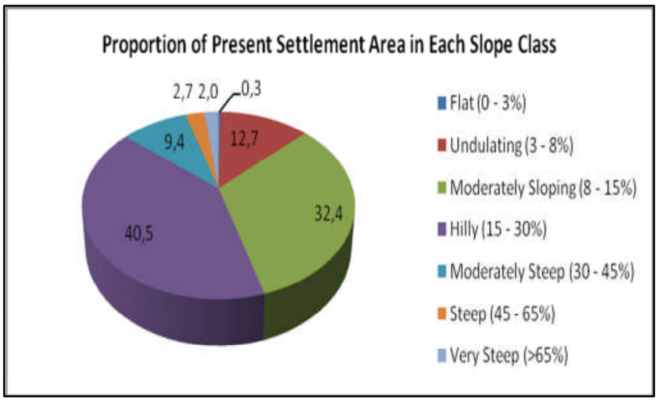


Figure 7.5. Proportion Chart of Present Settlement Area in Each Slope Class (Data Analysis, 2009)

The land use deviation cases are not fully caused by local community's behavior in utilizing the land. The deviation is also concerned with the procedure in determining land use function and land use planning. Less comprehensive procedure gives less reliable result. The existing land capability method for land use function division does not take into account inclusive environmental parameter. It can be assumed that the result may be less accurate. As an example, some areas which some constraints (hazard probability or soil properties) are classified as productive area since those constraints are not considered yet. Therefore, thorough investigation in establishing land use function and land use planning must be done.

7.6. The Application of the Result of the Research on Spatial Planning

Spatial planning in Indonesia is composed through a particular procedure. Legal Document of Ministry of Settlement and Regional Infrastructure number 327/Kpts/M/2002 declares that nine analyzes must be conducted to compile comprehensive information in a given area (Anonymous, 2002). The analyzes consist of strategy and development analysis, regional analysis, economic and prominent sector analysis, human resource analysis, man-made resource analysis, natural resources analysis, settlement system analysis, land use analysis, and institutional analysis.

Two of nine required analyzes are directly related to this research. Those are natural resource analysis and land use analysis. Natural resource analysis discusses the identification of land potency for further utilization in relation with land capability. The recommendation of land use function division is also ascertained. Furthermore, land use analysis is conducted to determine the suitable land use practice for protected and cultivated area.

Act number 26, 2007 highlights the necessity of hazard information in spatial planning (Anonymous, 2007). Hazard information becomes a major requirement to well recognize hazard prone area. This is intended to anticipate and to minimize unpredictable damages and disruptions. Therefore, the involvement of landslide susceptibility information in establishing land capability, land use function, and further land use practice for Tawangmangu Sub District explicitly describes the appropriate way in supporting spatial planning arrangement.

RTRW of Karanganyar Regency 1997-2006 conducts three analyzes for spatial planning (BAPPEDA, 1997). Those analyzes are analysis of development policy, regional analysis, and analysis of spatial structure of Karanganyar Regency. Each analysis discusses a particular issue, as follows:

a. *Analysis of Development Policy* discusses two topics. The topics are the function and role of Karanganyar Regency; the status and role of sub districts in Karanganyar Regency.
b. *Regional Analysis* consists of six important subjects. Those are analysis of physical and environment's support capability, demographic analysis, analysis of social community, development institution, economical analysis, and the infrastructure of social and economical service.

c. *Analysis of spatial structure of Karanganyar Regency* concerns with the settlement system, identification of priority region, and land use function and development trend.

RDTRK of Tawangmangu 2007 – 2016 also presents several regular analyzes (BAPPEDA, 2007). Those analyzes are grouped into macro analysis and micro analysis. Macro analysis comprises regional constellation and the relationship with surrounded area. Moreover, micro analysis encompasses 13 important analyzes. Those are physical basic analysis (physical analysis and the analysis of environment's support capability), land use and building analysis, demographic analysis, economical analysis, spatial analysis, transportation system analysis, infrastructure analysis, utility, assessment analysis of service center, analysis of spatial planning structure, building parcel analysis, hot spot analysis, and tourism analysis.

Land capability assessment and land use function division in RTRW are conferred in the analysis of physical and environment's support capability. Land capability assessment in this analysis is generated by using five variables, i.e. slope, soil depth, soil texture, drainage, and erosion. Land use function is developed through Ministry of Agriculture's method (scoring method). On the other hand, land capability assessment RDTRK is explained in the analysis of environment's support capability. This assessment is intended to the land use function in Tawangmangu. The land capability appraisal is done by scoring method. Thus, it is proved that the result of this research can be involved within certain analysis in spatial planning process. The proposed method from this research can be utilized to improve the existing method.

CHAPTER VIII
CONCLUSIONS AND RECOMMENDATIONS

This chapter explains some brief conclusions and recommendations. The recommendations are particularly intended for future research and further usage of method harnessed in this research.

8.1. Conclusions

This research gives some valuable results concerned with the research objectives and questions. The results are summarized into following conclusions.

- Landslide susceptibility analysis asserts that 43% of total area is classified as moderate susceptible whereas 42% is categorized as high and very high susceptible. The result also shows that more than a half total settlement area is situated in moderate susceptible while 35% is located in high and very high susceptible. Regarding to the extent of settlement area in landside susceptible zone, the some mitigation strategies are also proposed to minimize the impacts.
- Land capability assessment generally classifies the study area into class IV, VI, VII, and VIII. The general classes are overlaid by slope and landslide susceptibility to define detailed land capability class. The result illustrates that one general land capability class can be specified into several land capability classes. Detailed land capability class for study area consists of class III, IV, V, VI, VI, and VIII.
- Land use function based on scoring method generally demonstrates that the range of score is 90 – 195 in which 51% of total area is protected area; 31% is buffer area and the rest is cultivated region. Besides, detailed version gives score range 70 – 195 in which 38% is assigned as protected area; 45% and 17% is apportioned as buffer and cultivated area respectively. On the other hand, general land capability class based on proposed method allocates 58% of study area as protected area; 31% as buffer area and 11% as cultivated area while detailed method assigns 55% of study area as protected region, 37% as buffer region, and 8% as cultivated region.
- General land use deviation based on scoring method states that the inappropriate land use practice can be found in all land use functions. Land use deviation in buffer area is higher than in protected and cultivated area. Land use deviation in buffer area is represented by the appearance of paddy field, mixed paddy field with vegetable garden, settlement, and vegetable garden. Besides, there are some inappropriate land use practices in protected area, i.e. settlement, and vegetable garden. Apart from that, proposed method declares that land use divergence in buffer area is much higher than in protected area. There is no land use deviation in cultivated area. The most land use inexpediency in protected area consists of vegetable garden and settlement. Land use divergence in buffer area can be identified based on the existence of paddy field, mixed paddy field with vegetable garden, settlement, and vegetable garden. On the other side, detailed version of both method shows that there is no land use divergence in cultivated area. Land use digression in buffer area is also much higher than protected area. According to scoring method, unsuitable land uses in protected and buffer area are paddy field, settlement, vegetable garden, and mixed paddy field with vegetable garden. Furthermore, proposed method identifies some inappropriate land uses in protected and buffer area, i.e. paddy field, mixed paddy field with vegetable garden, settlement area, vegetable garden, and mixed garden. The existing land use inexpediency appears as a consequence of the increasing of human intervention to the environment. It is related to the enlarging of human needs (food, space for living, etc.). Exhaustive land utilization shall be managed in order to minimize the future risk, especially associated with landslide threat.
- Land capability assessment based on USDA approach is able to support the decision in dividing land use function. The choice either general or detailed version can be applied. The detailed version will present the elaborate result. The involvement of landslide susceptibility information is also useful to reveal more comprehensive result.

8.2. Recommendations

The research has been done to integrate landslide susceptibility information in assessing land capability. The findings during the research are used to make some recommendations for better research. The recommendation about implementation of spatial plan is also proposed. Those recommendations are mentioned below:

- The landslide susceptibility method in this research is possible to be used in every administrative level. The established weight and score can be adapted or modified depending on the scale and purpose. It is recommended to compile more specified data, particularly related to soil properties, in order to get better result and precision. The minimum required data for generating landslide susceptibility information are presented in this research. Therefore, future research can involve other variables, such as rainfall, lithological structure, earthquake, etc.

- Proposed land capability assessment can be utilized as an alternative way in determining land use function. The contribution of landslide susceptibility information in this method meets the requirement of Act number 26, 2007. This method can be also applied to enhance present land capability analysis. The method is applicable on two analyzes in spatial planning process, i.e. natural resource analysis and land use analysis. To improve the result, all variables in land capability assessment shall be fulfilled. Those are slope, erodibility, actual erosion, soil depth, soil permeability, soil texture, soil drainage, and rock fragment. Hazard information can be adjusted with common hazard characteristic in a given area. In addition, soil survey to obtain required information is recommended to be elaborate conducted. It is intended to get more comprehensive result about existing constraints.
- Land use function division shall be clearly defined in the field. Some warning signs and land allocation maps can be constructed in order to disseminate land use function division. Local community is guided to use the land based on its function.

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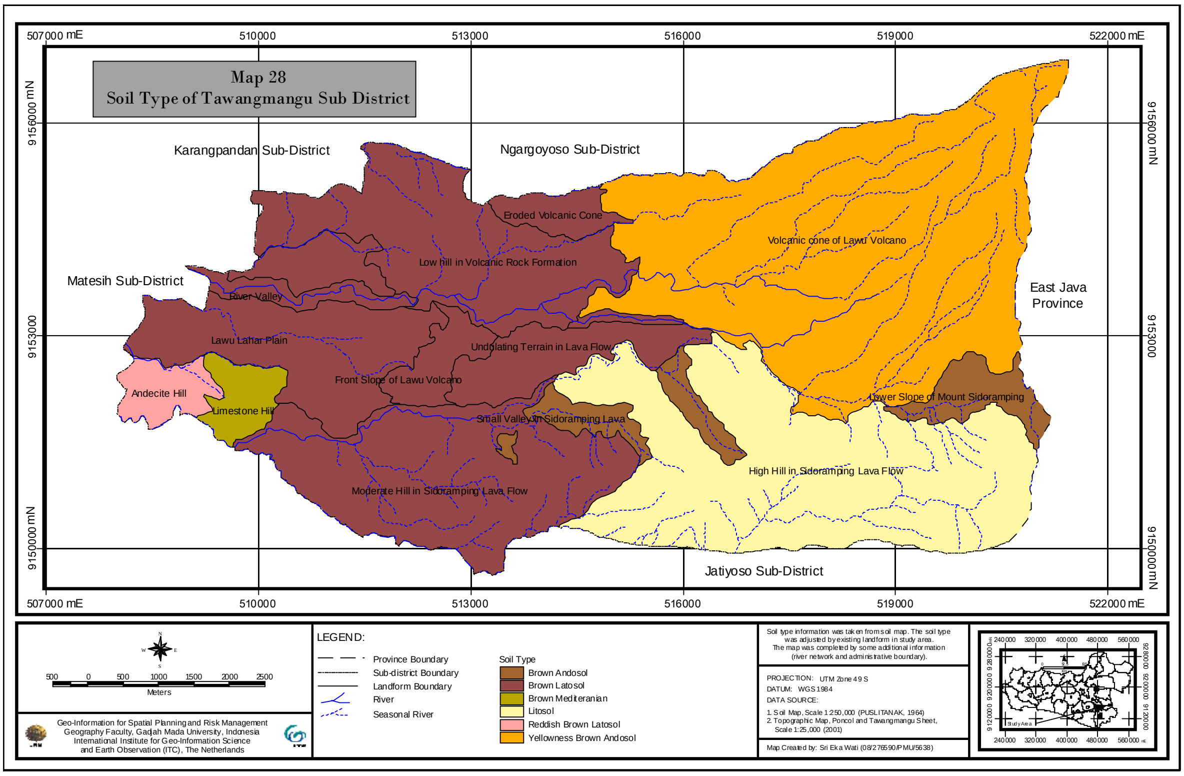
Appendix 1

Field Data

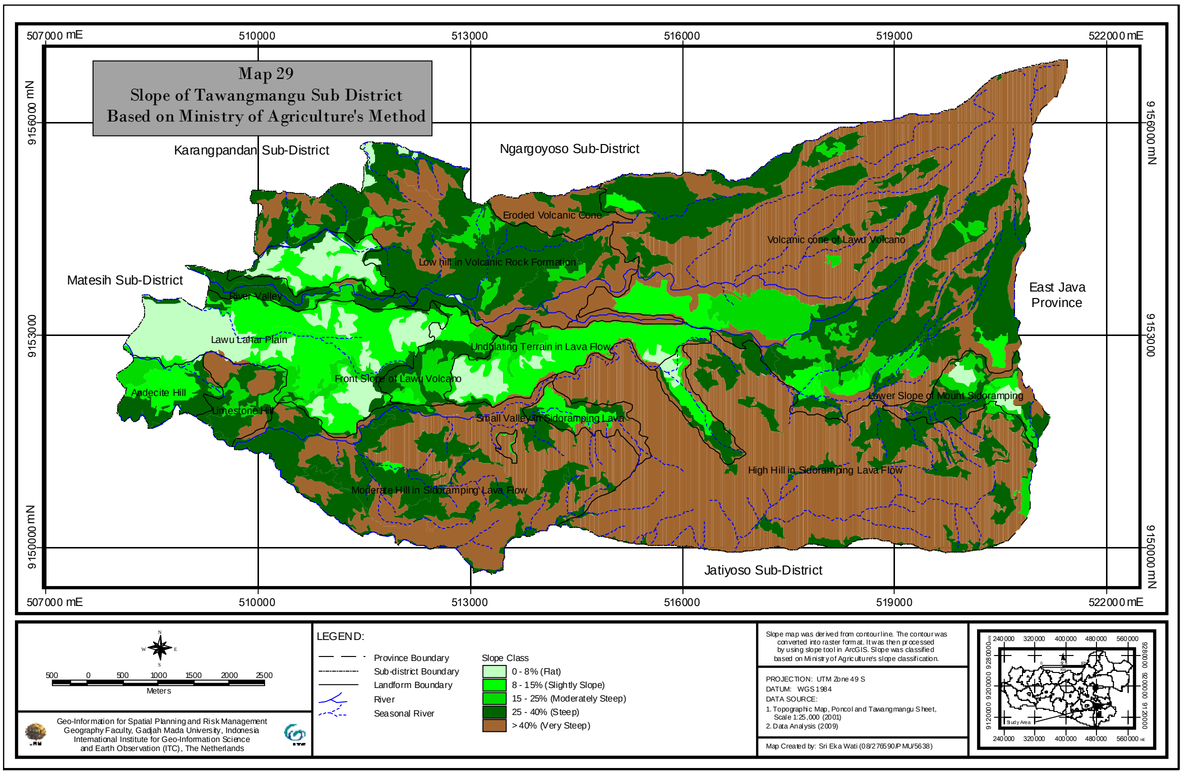
No	Coordinate		Soil Depth	Soil Texture					Soil Permeability	Soil drainage	Rock Fragment
	Latitude	Longitude		Very Fine Sand	Sand	Silt	Clay	Texture			
1	520530	9152857	> 90	52,05	55,29	25,65	19,06	Sandy loam	73,73	well	no
2	519585	9152904	> 90	42,47	43,81	35,93	20,26	Loam	2,83	well	no
3	518281	9153373	> 90	49,62	50,74	31,88	17,38	Loam	15,26	well	no
5	518951	9152660	> 90	60,17	65,48	20,20	14,33	Sandy loam	9,32	well	no
6	516658	9153409	> 90	46,94	48,87	30,96	20,16	Loam	0,07	well	no
4	520111	9152173	> 90	41,36	41,78	48,19	10,02	Loam	25,81	well	no
7	517729	9152281	> 90	61,6	69,52	15,11	15,37	Sandy loam	24,18	well	no
8	513629	9152972	> 90	43,92	46,07	31,45	22,47	Loam	17,56	well	no
9	514312	9152540	> 90	56,57	57,27	28,16	14,57	Sandy loam	12,4	well	no
10	519779	9151354	> 90	49,9	50,60	31,01	18,39	Loam	67,87	well	no
11	517768	9151584	> 90	61,38	67,34	20,51	12,14	Sandy loam	6,66	well	no
12	515857	9151749	> 90	53,34	57,31	21,62	21,06	Sandy clay loam	32,3	well	15 - 50%
13	514985	9152529	> 90	45,88	46,28	29,25	24,47	Loam	8,28	well	no
14	516828	9152710	> 90	51,1	52,20	29,76	18,03	Loam	18,48	well	15 - 50%
15	514330	9151144	> 90	25,14	26,47	39,58	33,95	Clay loam	7,58	well	no
16	513710	9151377	> 90	29,28	32,30	30,52	37,18	Clay loam	0,07	well	15 - 50%
17	513063	9151328	> 90	21,87	22,53	27,45	50,02	Clay	18,82	well	no
18	512212	9150762	> 90	15,91	17,21	27,06	55,73	Clay	15,52	poorly	no
19	511675	9151529	< 25	16,94	18,34	30,64	51,01	Clay	0,18	poorly	> 90%
20	511081	9150956	25 - 50	16,8	17,82	27,61	54,56	Clay	60,43	well	no
21	511073	9154867	50 - 90	37,26	40,12	32,79	27,09	Clay loam	4,06	well	15 - 50%
22	512851	9154161	> 90	22,22	23,66	29,88	46,46	Clay	2,31	well	no
23	514443	9153446	> 90	63,46	66,98	18,30	14,72	Sandy loam	0,52	well	no
24	511618	9155310	> 90	11,16	11,56	50,68	37,76	Silty clay loam	3,53	well	15 - 50%
25	511977	9154014	> 90	20,3	21,83	33,72	44,45	Clay	0,93	well	15 - 50%
26	516440	9151535	> 90	48,84	52,25	32,23	15,52	Loam	9,81	well	15 - 50%
27	511487	9153590	> 90	28,99	31,67	36,55	31,78	Clay loam	0,14	poorly	no
28	514288	9154616	> 90	42,6	45,43	33,06	21,50	Loam	8,31	well	no
29	512500	9152836	> 90	48,02	50,19	38,24	11,57	Loam	13,62	well	15 - 50%
30	508437	9152760	25 - 50	24,65	25,75	41,31	32,94	Clay loam	4,68	poorly	no
31	510003	9152920	> 90	37,17	40,22	35,42	24,35	Loam	failed	poorly	no
32	510710	9152543	> 90	28,38	30,17	41,97	27,86	Clay loam	1,13	moderately well	no
33	511215	9152477	< 25	44,52	48,78	29,96	21,26	Loam	5,85	poorly	> 90%
34	508421	9152477	< 25	29,87	32,88	31,39	35,73	Clay loam	1,85	poorly	50 - 90%
35	509989	9152393	< 25	37,45	41,51	21,77	36,72	Clay loam	1,52	excessivelly	> 90%

Source: Field Work and Soil Laboratory Analysis (2009)

Appendix 2



Soil Type Map of Tawangmangu Sub District



Slope Map of Tawangmangu Sub District Based on Ministry of Agriculture's Method

Appendix 3

Monthly Rainfall Intensity

Month	Somokado Rainfall Gauge																							Average per Month
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
January	0	745	602	429	777	739	694	693	457	576	567	580	512	755	659	481	561	438	569	639	531	191	475	576
February	0	593	782	729	334	624	438	295	443	824	562	629	613	478	827	418	395	575	0	422	337	879	594	561
March	0	427	492	257	261	356	658	454	759	512	293	213	588	483	361	338	424	390	0	500	130	446	1253	457
April	0	224	225	175	343	442	405	289	250	195	239	332	354	269	562	256	581	103	0	301	341	477	317	318
May	85	66	202	298	339	84	77	68	57	136	49	94	174	205	161	84	44	73	229	57	407	105	147	141
June	196	42	49	109	78	0	33	105	0	325	28	0	194	53	41	67	4	61	15	150	7	62	7	81
September	79	7	24	180	106	0	6	3	0	26	16	10	14	14	16	130	0	0	0	103	15	9	0	45
August	67	0	58	168	18	0	214	8	0	9	167	0	0	61	56	0	7	0	0	0	0	9	9	65
September	302	17	17	68	18	16	140	29	0	63	27	0	138	0	17	97	0	4	11	45	0	0	7	60
October	391	0	101	140	48	3	370	46	5	213	291	34	362	184	170	520	27	179	7	229	0	102	323	178
November	248	300	413	170	175	429	357	331	196	594	527	101	221	1152	204	422	229	221	0	106	92	212	0	319
December	260	535	237	398	658	297	566	605	268	343	234	434	389	1155	134	302	390	400	607	857	638	851	0	480
Total	**1368**	**2956**	**3202**	**3121**	**3155**	**2990**	**3958**	**2926**	**2435**	**3816**	**3000**	**2427**	**3559**	**4809**	**3208**	**3115**	**2662**	**2444**	**1438**	**3409**	**2498**	**3343**	**3132**	**273**

Month	Matesih Rainfall Gauge																							Average per Month
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
January	0	476	402	303	533	467	459	544	413	723	427	476	197	592	467	560	557	0	0	0	294	142	285	438
February	0	447	403	616	575	437	450	258	525	674	753	516	659	373	429	293	404	0	0	0	182	636	243	467
March	0	187	484	98	217	186	477	579	724	352	318	95	549	374	777	403	541	0	0	443	385	203	529	396
April	0	82	113	277	318	219	550	361	267	177	333	260	303	154	527	540	388	0	0	167	287	115	276	286
May	9	62	287	231	158	68	80	115	17	193	17	134	183	110	111	113	59	0	0	8	0	73	137	108
June	172	0	94	110	39	0	55	220	25	164	0	0	192	18	25	125	19	0	0	191	0	23	5	92
September	43	31	39	180	14	0	100	6	0	25	0	0	0	37	8	65	0	0	0	121	0	8	0	52
August	3	0	31	9	0	0	212	2	0	0	65	0	0	18	48	0	13	0	0	38	0	8	10	38
September	73	0	3	37	10	11	80	34	0	52	15	0	0	0	20	34	0	0	0	24	0	0	2	30
October	122	0	200	152	9	0	468	16	18	233	206	0	0	246	278	208	0	0	0	187	0	149	294	186
November	432	214	348	479	57	277	456	426	213	636	441	122	0	449	510	427	0	0	0	219	73	146	278	326
December	315	614	248	291	584	380	446	486	384	288	229	404	0	374	291	312	0	0	0	660	20	845	0	398
Total	**1169**	**2113**	**2652**	**2783**	**2514**	**2045**	**3833**	**3047**	**2586**	**3517**	**2804**	**2007**	**2083**	**2745**	**3491**	**3080**	**1981**	**0**	**0**	**2058**	**1241**	**2348**	**2059**	**235**

Month	Blumbang Rainfall Gauge																							Average per Month
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
January	0	752	527	538	763	406	436	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	570
February	0	462	759	653	564	589	188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	536
March	0	389	484	278	317	380	344	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	365
April	0	166	233	211	229	257	333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	238
May	69	34	171	249	244	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	130
June	227	69	22	102	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
September	73	7	26	318	125	4	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84
August	18	0	24	88	33	0	109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54
September	137	4	1	23	0	0	94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52
October	156	0	67	27	66	0	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84
November	135	179	321	106	63	458	353	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	231
December	121	495	317	255	657	274	492	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	373
Total	**936**	**2557**	**2952**	**2848**	**3136**	**2378**	**2489**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**235**

Month	Jatiyoso Rainfall Gauge																							Average per Month
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
January	0	808	272	457	573	566	340	529	433	417	262	392	245	302	357	517	516	430	301	0	674	156	0	427
February	0	524	590	554	267	492	411	312	454	521	509	308	573	313	326	251	263	420	0	0	282	514	448	417
March	0	324	452	235	214	225	415	482	575	289	324	128	518	264	823	464	296	324	388	0	247	335	593	377
April	0	94	173	208	404	277	297	284	112	253	259	213	338	130	463	207	201	39	98	0	400	343	257	240
May	111	50	525	186	62	88	42	77	23	84	16	82	116	148	199	56	37	0	176	44	286	60	55	115
June	206	19	96	94	68	0	82	51	0	144	38	0	0	0	0	0	0	8	0	0	0	43	0	77
September	35	22	12	53	77	0	6	0	0	18	18	0	0	0	0	0	0	0	0	0	0	0	0	30
August	0	0	0	69	0	0	257	0	0	0	63	0	52	0	133	0	0	0	0	0	0	10	0	97
September	313	0	9	9	13	8	112	17	0	20	50	0	46	0	0	24	0	0	12	47	0	0	0	52
October	295	0	153	23	7	0	267	21	37	230	380	0	137	176	292	199	0	163	30	0	0	0	317	170
November	409	198	412	302	210	291	378	430	224	505	387	112	0	218	397	211	224	310	298	148	0	0	556	311
December	814	479	135	184	515	302	350	319	298	197	89	180	220	262	134	114	755	328	0	454	665	829	159	354
Total	**2183**	**2518**	**2829**	**2374**	**2410**	**2249**	**2957**	**2522**	**2156**	**2678**	**2395**	**1415**	**2245**	**1813**	**3124**	**2043**	**2292**	**2022**	**1303**	**693**	**2554**	**2290**	**2385**	**222**

Month	Karang Pandan Rainfall Gauge																							Average per Month
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
January	0	692	449	477	612	642	434	610	400	896	85	205	284	504	448	416	352	287	0	0	358	156	275	429
February	0	402	529	668	493	516	516	310	456	938	262	440	641	273	388	240	298	292	0	0	274	478	271	434
March	0	232	491	267	265	392	551	542	869	742	309	78	649	436	562	339	414	240	0	356	90	242	453	406
April	0	265	199	277	232	459	247	296	140	333	80	449	465	154	346	443	356	22	0	319	294	193	226	276
May	77	65	395	287	199	14	75	117	15	301	19	198	250	120	139	95	55	45	0	45	382	69	111	140
June	223	37	108	206	79	0	43	58	23	368	0	0	180	8	61	135	0	0	0	117	15	43	9	101
September	87	0	107	173	48	0	42	0	0	8	0	0	0	0	4	89	0	0	0	92	0	6	0	66
August	0	0	15	34	40	0	215	0	0	6	110	0	0	18	1	6	23	0	0	20	0	8	13	39
September	130	0	11	60	23	21	84	15	0	40	19	0	58	0	34	26	0	0	0	41	0	0	4	40
October	139	0	189	221	29	0	299	59	0	159	105	0	367	259	124	380	0	0	0	142	0	91	396	197
November	374	71	455	322	152	386	635	475	188	594	189	32	242	538	275	268	158	0	0	245	42	171	0	291
December	260	473	275	469	613	558	412	513	367	166	197	422	250	442	91	133	256	0	0	418	589	832	0	387
Total	**1290**	**2237**	**3223**	**3461**	**2785**	**2988**	**3553**	**2995**	**2458**	**4551**	**1375**	**1824**	**3386**	**2752**	**2473**	**2570**	**1912**	**886**	**0**	**1795**	**2044**	**2289**	**1758**	**234**

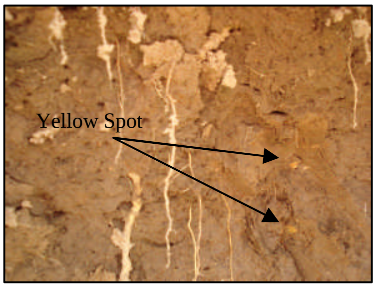
Month	Gayamdompo Rainfall Gauge																							Average per Month
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
January	0	385	418	431	585	452	366	330	483	482	0	157	180	352	0	0	0	0	0	292	386	253	386	371
February	0	470	241	475	310	309	335	352	289	493	0	415	337	379	0	0	0	0	0	307	335	550	335	371
March	0	199	313	46	176	113	181	328	659	356	0	30	477	363	0	0	0	0	0	82	195	279	1099	306
April	0	36	226	102	216	316	365	268	258	96	0	104	284	186	0	0	0	0	0	178	404	592	341	248
May	30	34	539	147	101	0	15	117	0	127	0	76	108	151	0	0	0	0	0	0	142	72	105	126
June	185	30	102	188	61	0	25	88	0	115	0	0	0	29	0	0	0	0	0	140	0	195	0	105
September	70	0	0	97	64	0	15	0	0	0	0	0	0	30	0	0	0	0	0	124	0	7	0	58
August	9	0	15	17	0	0	94	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	29
September	116	0	0	30	5	0	15	0	0	0	0	0	0	17	0	0	0	0	0	62	0	0	0	41
October	102	0	170	164	9	0	142	0	0	67	201	0	0	225	0	0	0	0	0	130	0	67	315	145
November	296	64	408	259	103	31	351	580	110	253	163	59	0	354	0	0	0	0	0	159	232	375	520	254
December	182	272	194	152	679	278	536	580	264	0	137	247	0	346	0	0	0	0	0	518	385	872	229	367
Total	**990**	**1490**	**2626**	**2108**	**2309**	**1499**	**2440**	**2643**	**2063**	**1989**	**501**	**1088**	**1386**	**2444**	**0**	**0**	**0**	**0**	**0**	**1992**	**2079**	**3262**	**3330**	**202**

Appendix 4

Documentation of Field Work Activity

Land Use Observation from Limestone Hill

Interview Session with Staff of BAPPEDA



Identification of Yellow Spot in the Soil as a Description of Soil Drainage Condition

Soil Depth Measurement in Soil Survey

Identification of Soil Structure (The Picture Depicts Blocky Structure in Study Area)