Soil Conservation Strategy for Potentially Landslide Areas in Gintung Sub-Watershed, Central Java Province, Indonesia

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Abstract

Landslide is one of significant hazards in Indonesia. This hazard becomes the most destructive natural haz ards in hilly and/or mountainous terrain environments. Gintung sub-Watershed is one of landslide prone areas in Central Java Province.

This paper is aimed at giving a small contribution to the integrated watershed management. Setting down a good recommendation of land use activities becomes a significant aspect in soil sustainability consideration. Therefore, appropriate land use planning could be one of soil conservation strategies. The methods applied on this research were survey method and statistical method. Survey method was conducted to collect landslides distribution data. Statistical method and GIS was generally conducted for all data processing. The statistical method was used to assess the density of landslides

The biggest number of landslide events is occurred on mixed garden. There are 45 points distributed within this landuse type. Appropriate conservation should be developed by keeping the soil stability in a slope. The changing in proposed land uses is applied for other uses except settlement. Some gardens located in a lower slope would be better if it is changed into dryland agriculture. While, in the upper slope of hilly, garden could be changed into conservative forest. In the middle slope of hilly, garden would be appropriate if it combines with shrub and bush. Paddy field which is planted in a slope area should be followed by a proper management. Otherwise, the saturated soil on the field could diminish soil retaining then it tends to trigger landslides.

Keywords: soil conservation, landslide, watershed management

Introduction

Landslide is the most damaging natural hazards in hilly and/or mountainous terrain environments. It becomes one of significant hazards in Indonesia. Cruden and Varnes (1996) defined a landslide as a mass movement of rock, debris, or earth material downing a slope. It occurred under the control of gravitation force. Steep slopes as the dominant topography construct Indonesia to prone to landslides. Moreover, high rainfall intensities enable to trigger the slope stability failure in particular sites. Consequently, Indonesia's characteristics could create landslides easily.

One of areas frequently suffered by landslides is Gintung Sub-Watershed. Gintung Sub-Watershed is located in Purworejo Regency, among three districts such as Loano,

Purworejo, and Kaligesing. Karnawati (2005) stated that Purworejo Regency has a high potential of landslides. Some of them were located in Gintung Sub-Watershed boundary. Numerous events in the study area could be used as the main indicator of high landslide potential.

Landslide occurrences are the proof that soil becomes insecure. Soil is anisotropic natural bodies (Schlichting, 1982; Sommer & Schlichting, 1996) which has specific capability on accommodating any activities on its surface. The number of landslide could be worse when land use activities do not fit with soil capability. Soil becomes the principal object of landslide event except slopes. The properties of soils vary with direction in catena. Assessment of the soil landscape sensitivity to further change must also take into account in both space and time.

Impacts of human activity are superimposed on soil properties changes. Soil dynamically changes either mechanically or chemically. Human impacts are most related to changing patterns of land use. Improper land uses could aggravate landslide potential. The significant condition of the study is the result of human-induced contributions for destabilizing slopes and threatening soil sustainability.

Appropriate land use planning becomes one of soil conservation strategies. Setting down a good recommendation of land use activities is a crucial aspect in soil sustainability consideration. The conservation guidelines could be made according to landslides distribution in the study area. Therefore, applying soil conservation strategy is expected to be a consideration for reducing significant landslide in that particular area.

This paper will examine the strategy of soil conservation on potentially landslide area. Through this research is intended to give a small contribution to the integrated watershed management and further is aimed as an input for land use planning in local government.

Materials and methods

Material

The materials required on this research is shown in Table 1.

Table 1 Data Requirement

No	Data Types	Attributes	Aims	Tools	Sources
1.	Geomorphology				
	a.Geomorphology unit	Landform	Geomorphology map, Landslides susceptibility map	Global Positioning System (GPS), Arc GIS Software.	Topography map, Digital Elevation Model (DEM)
	b.Landslides	Position, type, and morphometry of landslides	Landslides distribution map, Landslides inventory data	Laser ace, Abney level, GPS, Ms. Excel Software.	Field measuring, Ancillary data
2.	Geology	Geology formation and type of lithology	Geology map of research area	GPS, Geology hammer, Arc GIS	Geology map, Field checking
3.	Topography				
	a.DEM	3D topography: resolution 12.5m	Slope map	Arc GIS	Topography map
	b.Slope direction	Slope direction	Slope direction	Geology compass, GPS, Arc GIS	Field checking
4.	Land Use	Type of land use	Existing land use map	Arc GIS	Field checking
5.	Soil	Type of soil, soil texture, soil structure	Soil map	Soil test kit, Munsell color chart	Field checking, Secondary data
6.	Rainfall data	Precipitation intensity	Rainfall inventory	Ms. Excel	Secondary data
7.	Spatial Planning	RUTRW of Purworejo 2003-2013	Proposed land use	Ms. Word	Regional Planning and Development Agency, Purworejo

Samples

There are 5 periods of landslide point data analyzed in Gintung Sub-Watershed (Table 2). The total number of landslide distribution along 5 periods is 64 point. Landslide distribution in this study area was observed directly to the field.

Table 2 Landslide Distribution Within 5 Periods

Year	Number of landslide point
2007	12
2008	11
2009	19
2010	17
2011	5

Methods

Data Collecting Method

Survey method was conducted to collect landslides distribution data. Direct checking to the field and gaining data from the institutions were carried out in this method. The aspects measured on field survey were landslide morphometric and landslide position (Figure 1). Moreover, map interpretation was also conducted to produce the tentative map. Topographycal map, geologycal map, and soil map were used to assist field surveying.

Figure 1 Landslide Morphometric and Position Measurement

Data Processing Method

Statistical method and GIS were generally conducted for all data processing. The statistical method was used to assess the density of landslides. Landslide density was derived from the distribution of landslide in the study area. There were two types of landslide density, area density and number density. Landslide area density was chosen in this research. The area density expressed the number of pixel of landslide in specified mapping with the number of landslide pixel within the parameter classes. Landslide area density was applied for each landslide controlling factor.

Landslides Density Analysis

$$D_{area} = 1000 \frac{Npix(SX_i)}{Npix(X_i)}$$

D*area* = Area density per millage
Npix (SXi) = Number of pixels with mass movements within variable class Xi
Npix (Xi) = Number of pixels within variable class Xi

Data analysis

Generally, two data should be analyzed here such as landslide distribution and landslide density. They were used to assist the assessment of susceptible area. Landslide distribution was used for analyzing spatial pattern of existing landslide then the distribution was further used to identify landslide behavior in each typical of land use. The density area of landslide could determine how potential the landslides occurred in such land use type.

Results and Discussions

Description Area

This research was conducted in Gintung Sub-Watershed. Geographically, Gintung Sub-Watershed (Figure 2) is located on the zone 49 S between UTM coordinate of 393800 E until 400000 E and 9147000 N until 9153000 N or geographies coordinate of $7^0$67'00" South Latitude until $7^0$71'00" South Latitude and $110^0$04'30" East Longitude until $110^0$09'00" East Longitude. Total area of Gintung Sub-Watershed is 1,452.68 ha.

Gintung Sub-Watershed is an area regularly suffered by landslide. Rough topography of the study area tends to result high potential of landslide susceptibility. There is 70% of this area has $>20^o$ of slope steepness. This steep slopes associate with lithic soil that directly contact to impermeable andesitic breccias as a parent rock (Figure 3). Moreover, this area has thick layer of soil (3 to 4 meters sometimes up to 6 meters) characterized by residual soil and high permeable of colluviums. Consequently, all of these characteristics become favorable factors leading to landslides.

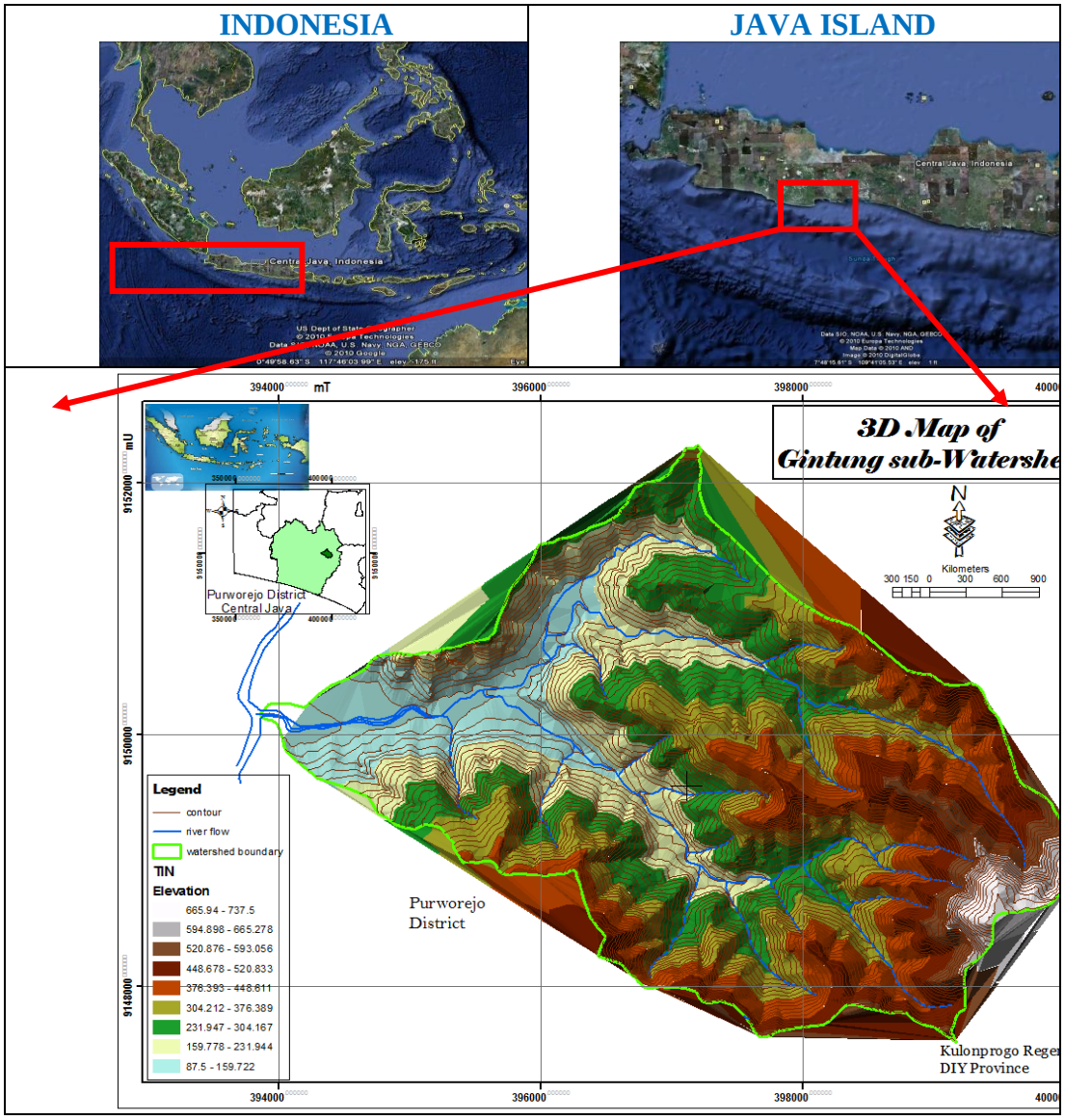

Figure 2 Gintung Sub-Watershed Location

Soil is one of passive controlling factors to landslide. Soil types covered in Gintung Sub-Watershed are classified into three classes. This classification is based on FAO classification. Those soil types in Gintung Sub-Watershed are Complex of red-yellow Latosol, old brown Latosol and Latosol; Association of red-brown Latosol, and old brown Latosol; and Complex of old brown Latosol, red brown Latosol and Latosol.

Latosol is a kind of developed soil. Latosol has *Fe* (Ferro) richness. The *Fe* proved that this kind of soil is derived from volcanic material development, which is old andesitic formation. Besides, the weathering of old material make the soil has high acid material. The *Fe* means that this soil has acid characteristic. The acid characteristic showed that this soil has intensive weathering process. This situation tends to make the soil prone to landslide. Otherwise, Lithosol is a kind of soil that have *lithic* characteristic. *Lithic* means that soil is directly contacted to parent rocks. This type of soil only has C-horizon. The direct contact between soil and parent rocks enable to create clay layer. The clay layer leads to make slip plane. Landslide is mostly occurred due to the slip plane.

Figure 3 Steep Slope with Lithic Soil

Land use has a crucial role to landslide events. Land use is a physical factor that is induced by human action. Unsuitable land use applied could aggravate slope instability in areas. Besides, land use has tight relation to a run-off and an infiltration rate that is indirectly control landslide. Densely vegetated used is better to control surface water flow over open vegetated. Thus, land use could have a great affecting to the stability of slope.

Gintung Sub-Watershed has five main types of land use. Types of land use existed in the study area consist of bush, garden, paddy field, settlement, and dryland agriculture. Among those five land uses, garden is the most dominated land use in the study area. Almost the entire area of Gintung Sub-Watershed is covered by garden. There is 68% of Gintung Sub-Watershed covered by garden (Figure 4).

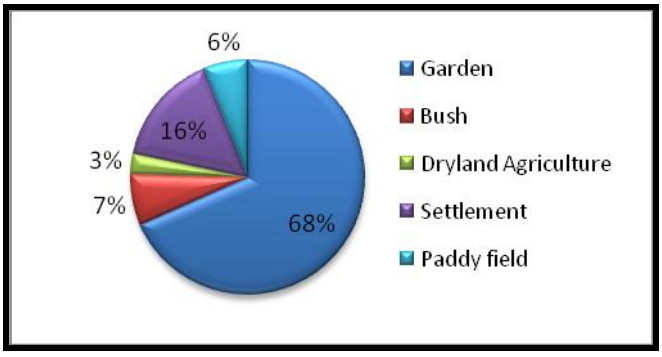

Figure 4 Percentage of Land Use in Gintung Sub-Watershed

Garden is one of land uses which use a land for planting some crops surrounds a house yard. However, as long as the crops are planting surround a yard could be called as a garden. The kinds of vegetation usually use in the garden type are coffee, banana, teak, a kinds of perennial crop. Since garden has monoculture systems, the harvest time of a crop is uniform. Once the crop is harvested, soil will be opened. The open soil on the slightly steep-to-steep slope could trigger a destabilized of slope. Thus, landslide easily occurs.

1. Landslide Density

A number of landslides in a specified mapping unit of a certain area are called landslide density. The density of landslides is calculated through the pixel number of each

variable. The total number of landslide distribution from 5 period data is 64 points. Those points just have 0.8867 ha for the entire area of Gintung Sub-Watershed. This total area of landslide is very narrow since not all of the landslide points have huge wide of area (Figure 5). The whole area of Gintung Sub-Watershed is about 1,452.68 ha. Therefore, the overall landslide density in the study area is 6.11 m^2/ha. For detail explanation, the density of landslides on each variable was shown in Table 3.

Table 3. Density of Landslides on each variable

Factors of Parameter	Class Code	Class Name	Number of Pixels	Number of Landslides Pixel	Landslide Density Area (per millage)
LANDSLIDE	0	No slide			
	1	Slide			
LAND USE	1	Paddy field	5042	151	29.95
	2	Dryland agriculture	284	4	14.08
	3	Bush	3484	103	29.56
	4	Settlement	5694	451	79.21
	5	Garden	50081	1641	32.77

There are two types of density measured in the study area such as the number density and the area density of landslide. The number density of landslide is obtained by dividing of landslide number and the wide of area for each variable class. While, the area density is reached by dividing of pixel number showing landslide and number of pixel for each variable class. The trend of landslide in an area could be gained by comparing the number density and the area density of landslide for each variable class. Consequently, the trend of landslide for each land use type was shown in Figure 5.

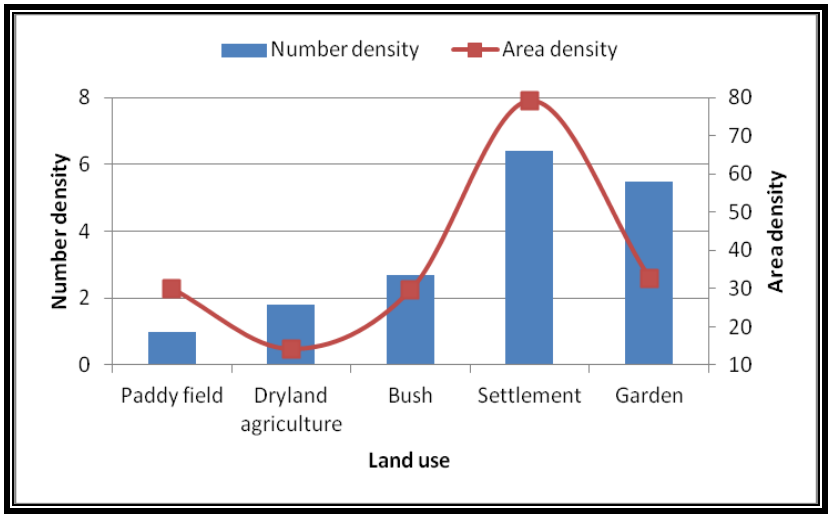

Figure 5 Landslide Density of Land Use

The graphic clearly describes that the highest of number density and area density of landslide is on settlement, 6.41 number/km^2 and 79.21 millage (Figure 5). Landslide on the

settlement area usually occurs along the road network (Figure 6). There is a lot of cutting slope for road construction, which is not suitable to the slope characteristic. This situation could aggravate slope failures, especially settlement on the steep relief. The steep slope area is easy to create prone slope stability. Therefore, steep slope enable to make landslide more intensive.

Figure 6. Landslide due to Cutting Slope for Road

The biggest number of landslide occurred on the garden, 45 points (Figure 7). Garden as the most dominated land uses should be developed by appropriate conservation strategy to keep the stability of slopes. Otherwise, the steep slope is easily to produce landslide prone area. The large area of garden makes its density of landslide is less dense than settlement.

Regarding to the cultivated land, paddy field has higher area density of landslide than dry land agriculture and bush have. This condition is caused by paddy field has greater wide area and wider landslide areas over dry land agriculture and bush. However, number density of landslide on paddy field is lower than the others. Therefore, based on this situation, it could be stated that the amount of landslides in particular variable class has not yet showed the wide area of landslide.

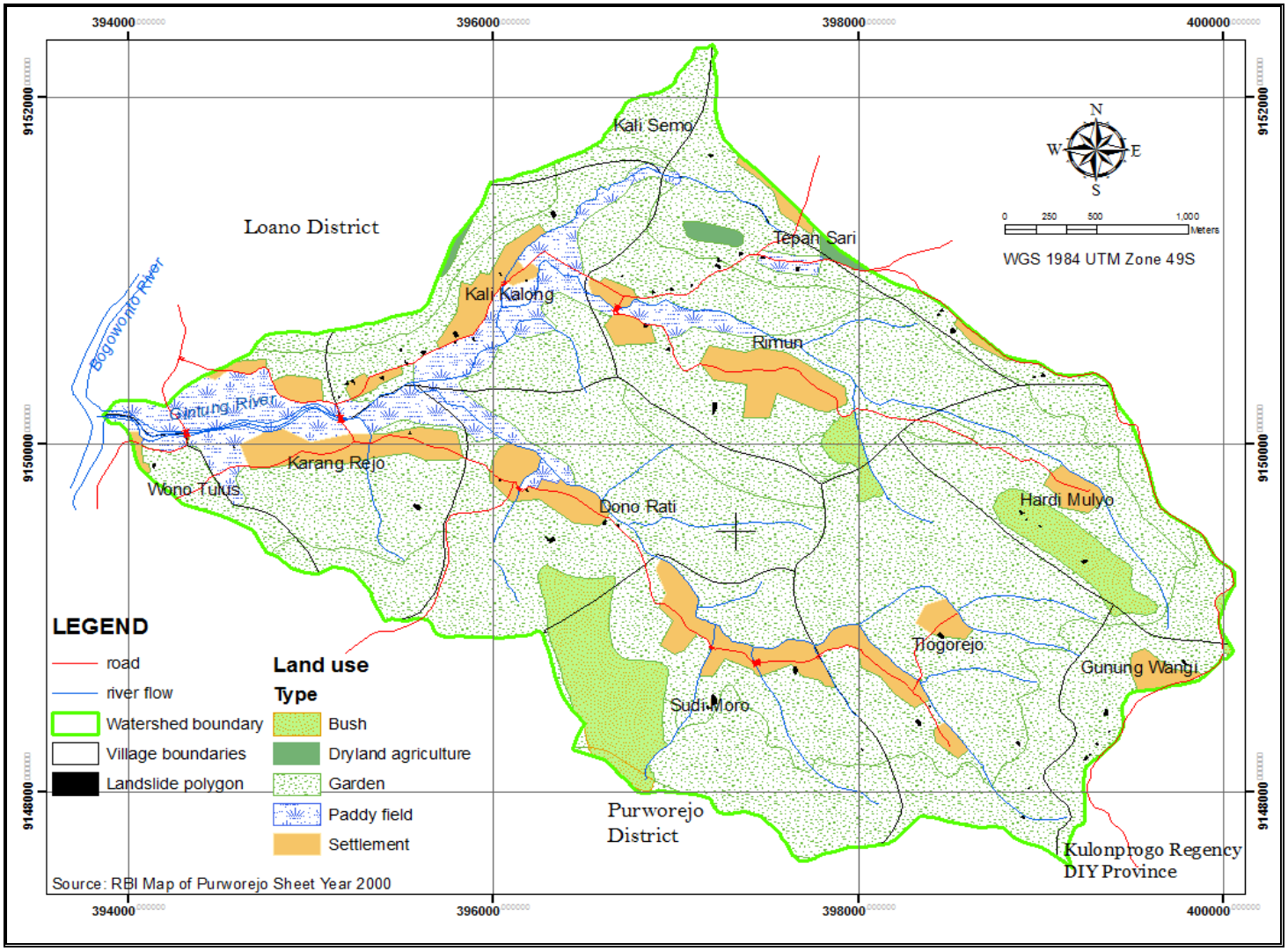

Figure 7 Landslide area distribution on each land use type

2. Soil Conservation Strategy

Proposed land use is a strategy to conserve soil from landslide impact. It is conducted by giving recommendations through put appropriate land uses. The recommendation, in this case, is based on landslide occurrences in Gintung Sub-Watershed. Inappropriate land uses tends to cause destabilized of soil. Therefore, a number of landslide events could be worse if land use activities do not fit with soil capability.

Plantation sector, which is addressed on the current spatial planning, has been widely cultivated surround the study area. The plantation is developed by gardening activity. Garden has similar meaning with horticulture, which means cultivating a plant (Anon, 1960; Notohadinegoro, 2006) as long as the land is located around the house. Garden is specific with perennial crops. Cocoa, coffee, coconut, durian, banana, and mango are kinds of crops mostly found in the study area.

The strategy to propose the land uses should be adjusted with the physical characteristics of particular area. The changing in proposed land uses is occurred for other uses except settlement. There is no chance to alter settlement into other uses although it is located on the high susceptible area. This exceptional is related to the social-historical aspect of the people surround this. Thus, the only solution for this condition is settlement limitation in conservation area. It means that the existing settlements are allowed to live in that area but without more expansion of it.

The fact is most of cultivated areas in Gintung Sub-Watershed located on landslide prone area. As the consequence, some areas are not suitable for garden uses. Growth of garden, which is not considering characteristics of an area, would give a potential to create new landslide prone area. Garden, as the most dominated land use in the study area, should be reduced and be changed into another suitable land uses. Proposed land uses were formulated to accomplish it as shown on Figure 8.

Some gardens, which are located in a lower slope, would be better if it is changed into dry land agriculture. Dry land agriculture is a kind of cultivated sector which is usually applied in dry land condition (Notohadiprawiro, 2006) located away from the house yard. Dry land condition means that the agriculture does not really need irrigation. Dry land agriculture is usually planted by seasonal crops with "tumpang sari" system. "Tumpang sari" system means that there are several of crops planted in a cultivated land. For instance, cornfield could be combined with other crops such as peanut, vegetable, or leguminous. This system is useful to protect the land from crop failure since seasonal crops are very vulnerable to pests. Moreover, the combination plant could keep the water balance in a land. Thus, this system could help to protect slope failure in an area.

The proposed land use should be appropriated with the characteristics of slope condition. More attention of proposing land uses should be put on the upper slope of hill. Greater slope area tends to produce more gravitational force. Adding mass that exceeds capability of land could destabilize the soils. Soil surface would be slope down easily. Rimun village and Donorati village could be a good example for this situation. Those villages are categorized into high landslide risk area. Any human intervention had to be restricted in this area. The changing of land use from garden into conservative forest would be wise chosen. Conservative forest is a forest area with a specific characteristic that has main function as a preservation of animal and plant diversity and ecosystem (Napitu, 2007). The conservation uses are helpful in order to keep stability of the slope.

In the middle slope of hill, garden is the appropriate land use. Slightly steep slope has no problem with the garden uses. However, dense garden also could add the slope mass. Combining the garden density with shrub and bush is needed in this case. Bush is the lowest species of plant compared with other plant such as tree and shrub (Kusminingrum, 2007). However, shrub means short woody plant with a fairly stiff branch and strong enough to carry on parts of plant (Djuwita, 2007). The idea of putting bush and shrub in is related to the soil

water balance. The existence of bush and shrub could control the infiltration and run off process. Well-cycle of water balance could protect the insecure soil against landslide. Therefore, unify some uses could be a pretty good strategy to propose land uses for Rimun village and Donorati village.

The other use, paddy field is really fixed to be planted in a flat up to undulating area. The paddy field has a specific characteristic to be flooded for all day long. However, this situation is able to cause saturated soil. Therefore, paddy field, which is planted in a slope area, should be followed by a proper management. Otherwise, it could diminish soil retaining then it tends to trigger landslides.

To the end, the strategy to conserve the soil has to be considered in Gintung Sub-Watershed. The strategy should be collaborated with proposed land use in order to develop better further spatial planning.

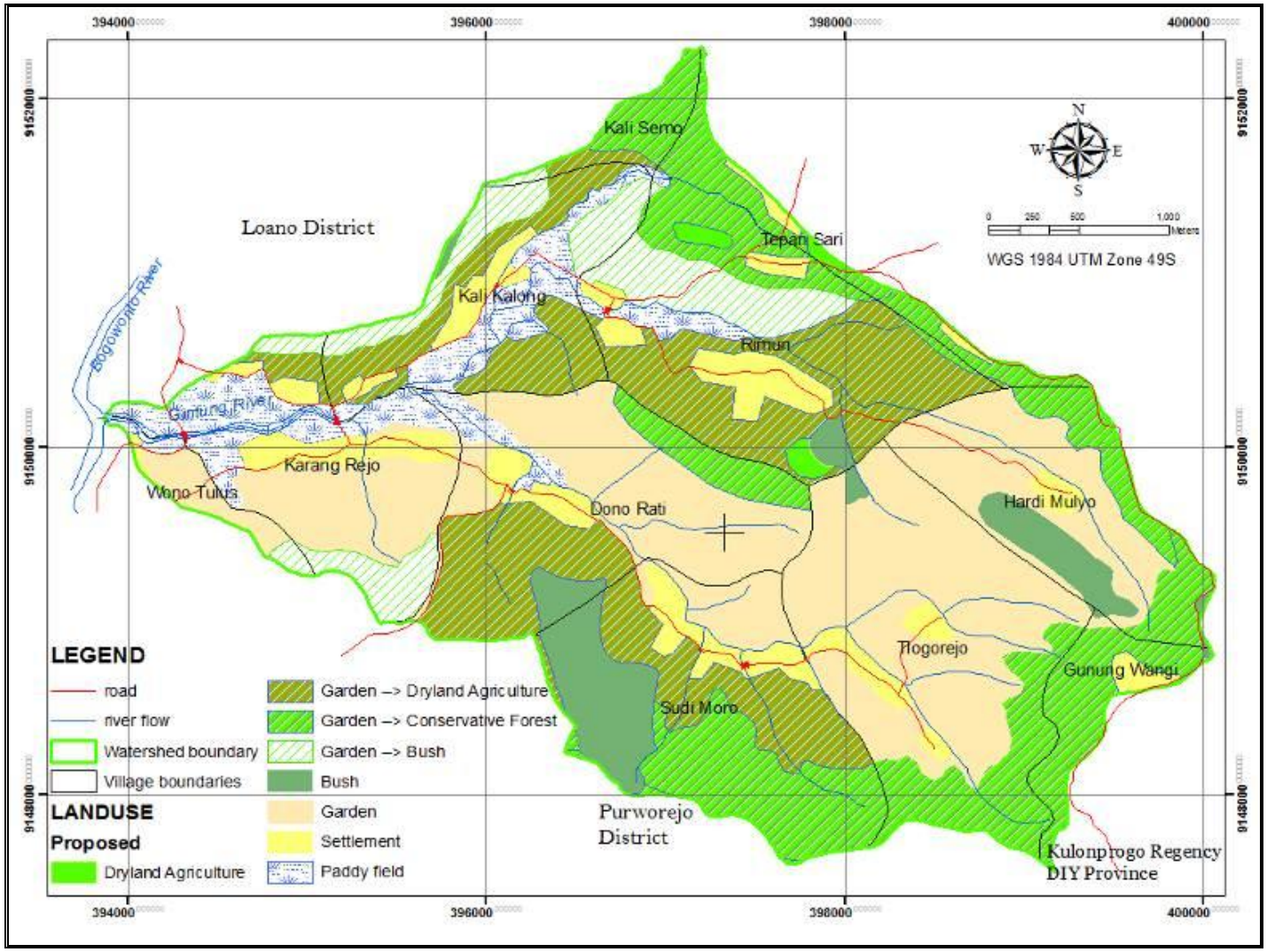

Figure 8 Proposed land uses for Gintung Sub-Watershed

Conclusion

Gintung sub-Watershed is one of landslide prone areas in Central Java Province. That inappropriate land uses tends to cause destabilized of soil. a number of landslide events could be worse if land use activities do not fit with soil capability. The biggest number of landslide events is occurred on mixed garden. Open soil on the slightly steep-to-steep slope could trigger a destabilized of slope.

Appropriate land use planning becomes one of soil conservation strategies from landslide impact. The changing in proposed land uses is occurred for other uses except settlement. The strategy to propose the land uses should be adjusted with the physical characteristics of particular area. Some gardens located in a lower slope should be changed into dryland agriculture, especially tumpangsari technique. In the upper slope of hilly, garden should be changed into conservative forest. In the middle slope of hilly, garden would be appropriate if it combines with shrub and bush. In addition, paddy field is appropiate to be planted in a flat up to undulating area.

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