Landslide Susceptibility Assessment using Heuristic Statistically Method in Kayangan Catchment Kulon Progo Yogyakarta-Indonesia

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Abstract
This research applied the heuristic-statistic modelling to explore landslide susceptibility map of the Kayangan Catchment in Kulon Progo, Yogyakarta. The objectives of this research were to study geomorphological situation and to evaluate landslide susceptibility area in Kayangan Catchment. Bivariate statistic based on weights of evidence was applied to evaluate the relationship between active landslide and various controlling factors of landslide. Thematic map representing various controlling factors of landslide was generated by field check and GIS techniques. The result of weights of evidence on each controlling factor of landslide was evaluated with geomorphological situation of the study area to confirm the heuristic assumptions. Geomorphology photo interpretation accompanied by ground check was applied to figure out the geomorphological situation of Kayangan catchment. All of thematic maps have been weighted based on weights of evidence and geomorphological condition into landslide susceptibility map. The results of this research showed that geomorphological situation of Kayangan catchment can be divided into three zones. There were northern zone, middle zone and south-east zone. The northern zone was dominated by denudation processes in which intensive weathering, erosion, and mass wasting occurred. The middle zone consisted of structural landform embodied by resistance volcanic breccias. The south-east zone was dominated by fluvial landform. The distribution of landslide had been matched with geomorphological zone of Kayangan Catchment. The largest number of landslide occurrences was found in the northern zone. Moreover, the landslide susceptibility and landslide typology had been also matched with geomorphological zone of Kayangan catchment. The success rates analysis was applied to evaluate accuracy of landslide susceptibility map. It showed that the accuracy of heuristic-statistic model attained 85%.

1. Introduction

1.1Problematic Background

Landslides have created several damages in the last decades. Many people were killed and many buildings were destroyed by landslide over the last five years. Volcanological Survey of Indonesia (2005) estimated that the material loss up to 800 billion IDR and 1 million casualties per year are due to the landslide. Kayangan Catchment is located in Kulon Progo and Purworejo Regency. According to Volcanological Survey Indonesia (2005), the hilly areas of Kulon Progo and Purworejo can be categorized as medium-high landslide susceptible zone. Dipo (2002) estimated that the material loss due to the occurrences of landslide in Kulon Progo during 2001 to 2002 was roughly 2 billion IDR. Landslide map can be one of tool to figure out the potential location of landslide and can be applied for landslide risk evaluation (Guzzetti, 2005). Geomorphological approach focuses on landform, material, and geomorphic processes can be applied for landslide hazard and landslide susceptibility mapping (Sutikno, 1994). Landslide analysis can be represented by landslide susceptibility map based on geomorphological concept "the past and present are the keys to the future (Carrara et al., 1995 and Huabin et al., 2006). In this research, Geographic Information System based on heuristic-statistic was tried to map the landslide susceptibility in Kayangan Catchment Kulon Progo Regency Yogyakarta. The objectives of this research were to study geomorphological condition and to evaluate landslide susceptibility characteristics in various area representing different geomorphological conditions.

1.2 Description of Study Area

Kayangan Catchment is located in Kulon Progo Regency Yogyakarta Special Province. The study area lies between latitude 7°41'24" to 7°48' (S) and longitude 110°07'12" to 110°13'48" (E) (Figure 1).

The geological condition in Kayangan Catchment is rather complex. Some major faults can be found in the middle part of Kayangan Catchment. Kayangan Catchment consists of Jonggrangan Formation (conglomerate, tuffaceous marl and calcareous sandstone, limestone and coralline limestone); Nanggulan Formation (sandstone with intercalated of lignite, sandy marl, claystone with limonite concretion, intercalations of marl and limestone, sandstone, and tuff); Sentolo Formation (limestone and marly sandstone); old andesit; colluviums; and alluvium (Rahardjo et al., 1995). Most of Kayangan Catchment consists of steep hilly slopes especially in the northern part and in the middle part. Landslide usually occurs in the month of November to April during rainy season in Kayangan Catchment. On December 2007, 29 landslides occurred in Kebonharjo Village with various extents. The precipitation is presumed as the main triggering factor that cause landslide in the Kayangan Catchment area.

2. Methodology

Generally, this research can be divided into three steps. There are geomorphology mapping, landslide inventory mapping, and landslide susceptibility mapping. All of the steps were generated by GIS techniques. The GIS was carried out using PC-based software ILWIS 3.4.

2.1 Geomorphology and Landslide Inventory Mapping

Geomorphology map was resulted from the aerial photograph interpretation accompanied by extensive fieldworks in order to figure out the geomorphological condition of Kayangan Catchment. Aerial photograph interpretation was used as an initial phase in geomorphological mapping dealing with detection, recognition, and identification of geomorphological features. It involved analysis of drainage pattern, lineament recognition, and analysis of landforms. A topographic map and geological map were also used in order to analyze the morphological and geological condition in the study area. Analytical approach focusing on morphology, morphogenetic, morphochronology, and morphoarrangement was used to delineate landform unit (Demek and Embleton, 1978; Verstappen, 1983 and Sartohadi, 1997). Field observation has also been carried out in order to verify the result from previous stage. In Indonesia, the active and historical events of landslides are not well documented. Local governments posed unreliable record of landslide occurrences. Due to the lack of data, it is critical to conduct the ground check in order to provide the data inventory of landslide. In this research, 131 landslides occurred during period of 2000 to 2007 have been successfully identified and mapped through extensive fieldworks.

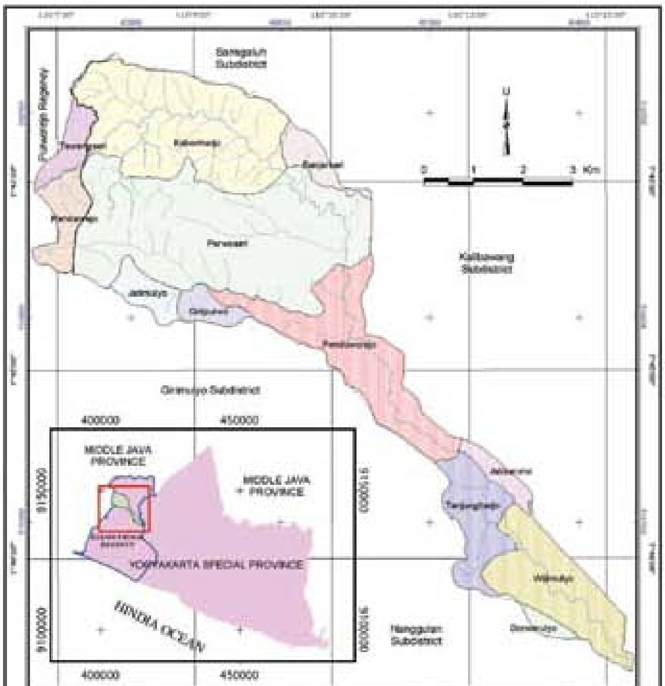

Figure1: Location of Kayangan Catchment with Main River in Kulon Progo Regency

2.2 Landslide Susceptibility Mapping

Heuristic-statistic method was used to evaluate landslide susceptibility in Kayangan Catchment. According to Ruff and Czurda (2007), quantitative method focusing on mechanical parameter is difficult to be used in wide area, whilst qualitative method tends to be subjective and strongly depend on the experts. It is therefore necessary to use quantitative and qualitative methods in order to bridge the gap between them. Statistical landslide analysis used in this research was bivariate statistic method based on weights of evidence. The application of weights of evidence method in landslide analysis can be applied through comparing the landslide density in each controlling factor and the landslide density in the whole area (Westen et al., 2003; Suzen and Doyuran, 2004; Dahal et al., 2007 and Neuhauser and Terhorst, 2007). The analysis of weights of evidence method based on the following equations:

$$Wi^{+} = \ln \frac{P\{B_i \mid S\}}{P\{B_i \mid \overline{Si}\}}$$

Equation 1

$$Wi^{-} = \ln \frac{P\{\overline{B_i} \mid S\}}{P\{\overline{B_i} \mid \overline{Si}\}}$$

Equation 2

where, P= probability, ln= natural log, Bi = presence of a potential landslide controlling factor, *Bi* = absence of a potential landslide controlling factor, *S* = presence of a landslide, and *Si* = absence of a landslide, Wi^{+} = indicates that the predictable variable controlling factor of landslide is present at the landslide locations and show the positive correlation between the presence of the predictable variable and the landslides, and Wi^{-} indicates the absence of the predictable variable controlling factor of landslide and shows the level of negative correlation (Westen et al., 2003 and Dahal et al., 2007). Bivariate statistic based on weights of evidence method was used in this research to evaluate each controlling factor of landslide. It is applied based on the basic assumption that each controlling factor of landslide is not related each other. Thematic maps representing controlling factor of landslide were generated by GIS techniques to obtain the weights of evidence. The presuming controlling factors that related to landslide were road, landform, relief, slope, river, and land use. The existing landslide distribution was compared to the presuming controlling factors of landslide separately. It was applied to evaluate the relationship of each predictable variable controlling factor of landslide towards landslide occurrences. In ILWIS 3.4 software package, the analysis can be written on a formula based on the equation (1) and (2) as follows:

$$\ln \quad Wi = \ln \frac{\{Densclas\}}{\{Densmap\}} = \ln \frac{\dfrac{Npix(Si)}{Npix(Ni)}}{\dfrac{\Sigma\, Npix(Si)}{\Sigma\, Npix(Ni)}}$$

Equation 3

where, Wi = the weight given to a certain factor of landslide, Densclas = the landslide density within the factor of landslide, Densmap = the landslide density within the entire map, Npix(Si) = number of pixels which contain landslides in a certain factor of landslide, and Npix(Ni) = total number of pixels in a certain factor of landslide (Westen, 1997). The result of weights of evidence on each factor related to landslide was evaluated with geomorphological analysis of the study area to confirm the heuristic assumptions. Each of thematic maps representing various factor of landslide has been weighted based on heuristic assumption into landslide susceptibility map based on the following equations:

$$I_{factor} = I_1 \times I_2$$

Equation 4

$$\text{Susceptibility index} = I_{landform} + I_{slope} + I_{relief} + I_{\textit{buffer} \text{ to road}} + I_{\textit{buffer} \text{ to river}} + I_{landuse}$$

Equation 5

where, I_1 is the Index of the layer and I_2 is the index of the group (Ruff and Czurda, 2007).

3. Result and Discussion

3.1 Geomorphology and Landslide in Kayangan Catchment

Geomorphic processes tend to change the earth surface configuration. Weathering, erosion, and landslide were the most intensive geomorphic processes in Kayangan Catchment. The geologic condition of Kayangan Catchment caused intensive weathering processes, even though it had spatially and temporally differentiated. The differentiation was caused by different geomorphology processes in Kayangan Catchment. There are 21 landform units recognized in Kayangan Catchment. Geomorphologically, Kayangan Catchment can be divided into three zones. There were northern part zone, middle part zone and south-east part zone (Figure 2). The northern part zone was dominated by denudation process in which weathering, erosion, and mass wasting occurred very intensive. The middle part zone consisted of structural landform which was formed by resistance volcanic breccias. The south-east part zone was dominated by fluvial landform. Landslide occurrences were distributed based on geomorphological zone. The most intensive landslide occurrences were found in the northern part zone.

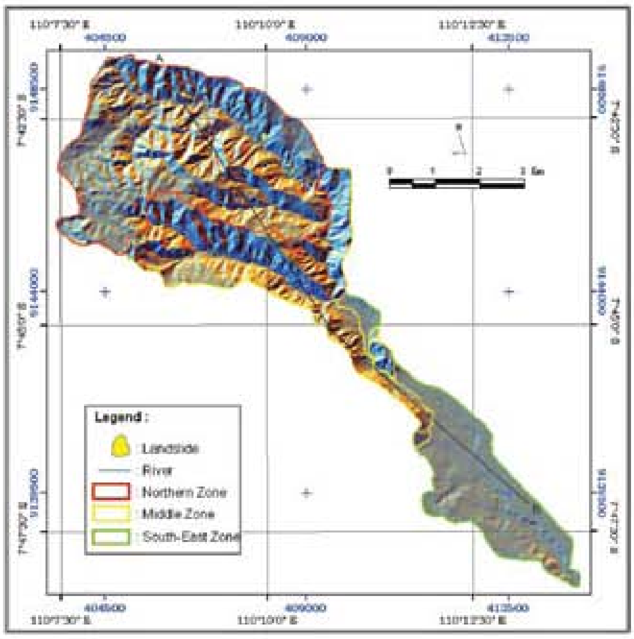

Figure 2: Geomorphological Zone of Kayangan Catchment

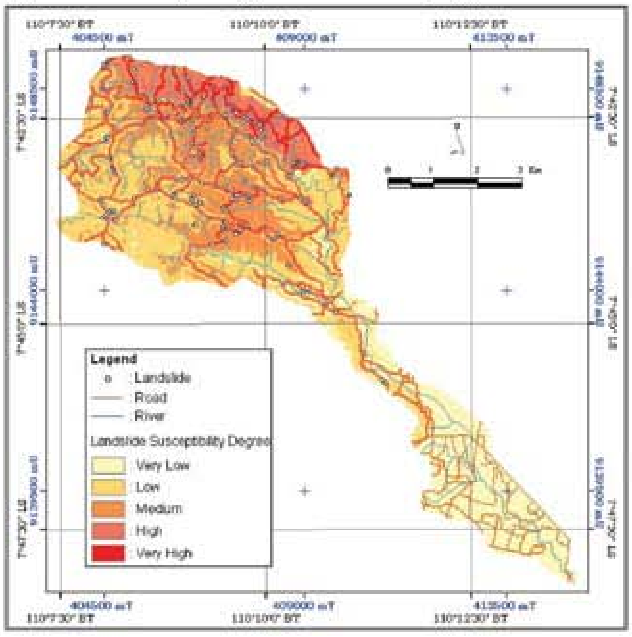

Figure 3: Landslide Susceptibility Map of Kayangan Catchment

The characteristic of the geomorphology process of Kayangan Catchment also caused different types of landslide typology. Northern zone of Kayangan Catchment consisted of 7 landform units. There are backslope of the ridge of tuffaceous andesitic breccia denudational hill; coral reef and tuffaceous andesitic breccia denudational hill complex; tuffaceous andesitic breccia denudational hill complex; coral reef, andesitic breccias denudational hill complex; the ridge of tuffaceous andesitic breccia denudational hill; gently slope of tuffaceous andesitic breccias denudational hill; and top of the ridge of denudational hill Jonggrangan Formation. Geologically, northern zone was dominated by weathered tertiary tuffaceous andesitic breccias. Due to the lithology and high intensity of precipitation, very intensive weathering processes occurred in the northern zone. The largest number of landalide was found in the northern zone of Kayangan Catchment because of high intensity of weathering and erosion. Landalide typology in the northern zone was characterized by flow. Flow could not be found in the middle and south-east zone. Flow occurred in the northern zone because of specific characteristic of northern zone. Despite the very intensive weathering and high intensity of precipitation, fundamental factor of the landslide in the northern zone was also the land use pattern. Middle zone of Kayangan Catchment was characterized by structural landform with resistance volcanic breccias and very steep slope. There were 8 landforms recognized in the middle zone of Kayangan Catchment. The landforms were steep slope of andesitic breccia structural hill; ridge of andesitic breccia structural hill; backslope of the ridge of tuffaceous marl andesitic breccias denudational hill; colluvial foot slope; top of the ridge of andesitic breccia denudational hill; ridge of andesitic breccia denudational hill; backslope of denudational hill andesitic breccia; tuffaceous andesitic breccia denudational hill. Weathering process did not work intensively because of specific lithology and geological structure. The lithology was embodied by resistance andesitic breccia. It was influenced by Kalingiwo faults and Nogosari fault. Kalingiwo fault lies from the north to the south in Kalingiwo Village and Nogosari fault lies from the north-west to the south-east in Nogosari Village. The faults can be recognized in the field by differences of rock type, topography, lineament, and seepages in the foot slope. Release joint can also be found surrounding both of the faults. During the rainy season, it made precipitation could infiltrate to the joint and crack of the resistance old andesitic breccias. Because of this process, rockfall could occur in the middle of Kayangan Catchment. South-east zone of Kayangan Catchment was characterized by plain morphology. It was dominated by fluvial processes. Due to the morphology and genesis, landslide could not be found in the south-east of Kayangan Catchment. Landform units recognized in south-east zone of Kayangan Catchment were fluvio-colluvial terraces; kayangan valley; alluvial plain; denudational of undulating slope plain of Sentolo Formation; fluvio colluvial plain of Sentolo Formation; and Terraces. Most area in the south-east zone was used as paddy field.

3.2 Heuristic-Statistic Analysis of Landslide

Cross map between each controlling factor with landslide inventory map was applied to evaluate each controlling factor toward landslide occurrences. Positive and negative weights would indicate the contribution of each controlling factor toward landslide. Based on the weights of evidence, it could be analyzed that sequent of predominant factor of landslide was road, landform, relief, slope, river, and land use. Positive and negative weights of each controlling factor of landslide accompanied by analysis of landslide area density and landslide point density were used to evaluate the heuristic assumption. It was also analyzed using geomorphology condition of Kayangan Catchment. Therefore, Landslide Susceptibility Index was resulted from overlaying of all thematic maps of landslide controlling factor based on equation (4) and (5). From the overlay, the minimum landslide susceptibility index was 0.28 and the maximum was 2.54. The result showed that Kayangan Catchment has five landslide susceptibility degrees. It can be divided into very low, low, medium, high, and very high, which covered 21.6%, 34.3%, 25.8%, 14.3%, and 3.9% of total area respectively. Most of high landslide susceptibility occurred in the northern-part of Kayangan Catchment (Figure 3).

Geomorphologically, the northern-part of Kayangan Catchment is dominated by denudational landform. Theoretically, the landform which is dominated by denudational landform is characterized by intensive weathering, erosion, and mass wasting or landslide.

3.3 Success Rate Model for Landslide Susceptibility Mapping

The best validation of landslide susceptibility mapping is comparing the landslide susceptibility model with landslide occurrences after the model finished (Neuhausers and Terhorst, 2007). Nevertheless, it is not possible to conduct the analysis using the method due to the lack of information about the accurate time of future potential landslide occurrences.

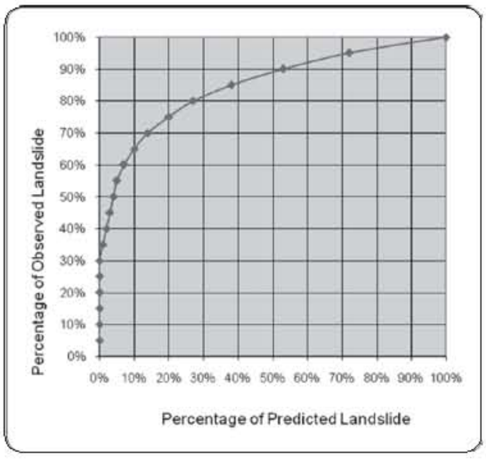

Figure 4: Success Rate of Landslide Susceptibility Map

However, landslide validation must be inserted when landslide model had been finished. Success rate analysis can be applied to measure or validate how well landslide susceptibility index predicting the landslides. Success rate showed that landslide susceptibility model of Kayangan Catchment attained 85% (Figure 4).

4. Conclusion

It was theoretically accepted that high susceptibility degree on the landslide susceptibility map occurred in the northern part of Kayangan Catchment. Geomorphologically, the northern part of Kayangan Catchment was dominated by denudation processes in which weathering, erosion, and mass wasting occurred very intensive. It indicates that GIS system especially based on heuristic-statistic method can be applied in Kayangan Catchment accurately. The landslide susceptibility map of Kayangan Catchment also indicates that GIS based on heuristic-statistic method can be applied to derive landslide susceptibility model effectively. The process of mapping is not time consuming and can also be applied directly with GIS software. GIS offers more effective and efficient tool for creating landslide susceptibility map. GIS is applicable with certain methods of landslide susceptibility mapping depend on the geomorphology and geology condition of the research area. Landslide susceptibility map would be valuable as a main tool for disaster mitigation and regional planning.

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