Landslide Susceptibility Zone using Frequency Ratio Method in Karangkobar Catchment, Merawu Watershed, Banjarnegara District, Central Java Province

V Y G Radjah*, H Suryatmojo1 and Ngadisih2

1Faculty of Forestry, Gadjah Mada University, Yogyakarta, 55281, Indonesia
2Faculty of Agriculture and Technology, Gadjah Mada University, Yogyakarta, 55281, Indonesia

*Corresponding author : yudharadjah@gmail.com

Abstract. Karangkobar catchment is located in the upstream area of Merawu watershed, classified as one of the most critical watershed in Indonesia. Land use change from forested area to agricultural land has changed the hydrological process in the catchment. A huge landslide disaster has occurred at the end of 2014 and causing 95 people deaths. It is important to have a landslide susceptibility map for disaster risk mitigation in this area. The purpose of this study is to apply the frequency ratio method to analysis the landslide susceptibility in Karangkobar catchment. Actual landslide data is obtained from the results of field survey. Frequency ratio method is used to assess the landslide susceptibility using 70% of total landslides data while 30% is used for model validation. The results show that the highest FR value is found in the distance from the road at range of 0-25 m, distance from the river at range of 100-125 m, flat curvature and garden land use. The broad percentage of low landslide susceptibility is 38%, moderate susceptibility is 48% and high susceptibility is 14%. The results of validation for landslide susceptibility showed that the resulting susceptibility model is very effective for assessing the landslide susceptibility.

1. Introduction
Landslide is the one of the most natural hazard that very difficult to predicted cause the majority triggering factor is the nature itself. Human intervention like cutting slope, building road on steep slope and agriculture activity made this situation even more critical. In this catchment landslide disaster has occurred at the end of 2014 and causing 95 people deaths caused by heavy rains that occurred for 2 days, which resulted the soil being saturated with water and the constituent rocks were old volcanic deposits so that the solum or soil layer was quite thick and weathered. In addition, the slope in the area is less than 60% and the top of the hill landslides are planted with seasonal crops with non-dense crops causing the soil to become loose and easily carried by water [1]. It is important to have a landslide susceptibility map for disaster risk mitigation in this area. The first step before mitigation developed in evaluating landslide event is generate the landslide susceptibility map [2]. Landslide susceptibility map will give an information of susceptibility levels and landslide distribution which is very useful to help make decision for mitigation plan according to susceptibility levels.

To assessed landslide susceptibility, there are two approaches that can be used. First, direct approach is a qualitative method depends on experiences of expert and subjectively [3, 2]. Second, indirect
approach (heuristic, analysis of inventories, statistical modelling, process based). Heuristic, is a method that used rank or weight to assessed susceptibility which is gave by expert, in term all of instability factor should have known before [3]. Analysis of inventories, trying to predicted landslide event in the future according to landslide event from the past [4, 5]. Process based, applied to analyzed or studied a specific kinds of landslide such as, shallow landslide, debris flow and others. Statistical modelling used to describe relationship between instability factors and past distribution of a landslide or slope failure [6] and giving a quantitatively result which is more suitable for assessing landslide event [3], some statistical modelling have been applied such as, Logistic regression method, Artificial Neural Networks and Frequency Ratio. At the previous year In Indonesia, landslide susceptibility assesment using logistic regression method and artificial neural network have been applied and done by [7] and heuristic approach done by [8].

The purpose of this study is to applied the frequency ratio method to analyzed the landslide susceptibility in Karangkobar catchment. The frequency ratio is the ratio of the where landslides occurred in the total study area and also the ratio of the probabilities of a landslide occurrence to a non-occurrence for a given attribute. The more the FR is greater than unity, the stronger the relationship between landslide occurrence and the given parameter’s attribute. On the contrary, the lower the value of FR than unity means the lesser the relationship between landslide occurrence and the given parameter’s attribute [2]. Some researcher such as [9, 10, 11] has been applied Frequency ratio to assessed landslide susceptibility. The result of this study will gave an information about landslide susceptibility zone which is very useful to determine mitigation plan that should be developed.

2. Location of The Study Area
Study area is located in karangkobar catchment area, Merawu watershed, Karangkobar District, Banjarnegara District, Central Java Province. The Study started at march until october 2018. Figure 1 show the location of study area.
3. Landslide Inventory

In this section, landslide data collection is carried out using GPS at easily accessible locations, due to the limitations of tools, costs and time during the research activities. There are 45 landslide occurrence has been collected during landslide survey. 36 landslide classified as translational type and 9 rotational landslide type. Landslide type classified based on [12]. All of these landslide data is the actual landslide data from the survey results without any additional data from other agencies. Landslide location illustrated by points feature. Figure 2 shown the result landslide inventory in study area.
4. Material and Methods

Parameter used in this study are land use, curvature, distance to road, distance to drainage, elevation, slope, soil texture and permeability. The 1:25,000 scale topographic maps used to derivating elevation, curvature, slope. All of these parameter are converted from vector to raster datasets in ArcGIS 10.4 platform with pixel size 12,5x12,5 m. Land unit maps from overlaying land use map and toposoquence are used as the basis for soil sampling for permeability and texture tests. To running the model, landslide data will be divided into two parts (modelling and validation). 70% landslide data will include in analysis and the rest 30% will include in validation process. Elevation maps (Figure 3) will classified into 5 classes based on natural break analysis based on ArcGIS 10.4. Distance from road (Figure 4) and distance from river (Figure 5) were classified within 25 m interval based on euclidean distance in platform ArcGIS 10.4. Soil permeability map (Figure 6) are classified into 4 classes (moderate to low, very low, low and moderate), soil texture map (Figure 7) are classified into 3 classes (silt loam, loam and sandy loam), before being inserted into the map, soil samples were analyzed in the laboratory. Land use map (Figure 8) are classified into 4 classes (Cropland, settlement, rice fields, field not irrigated). Curvature maps such as planform (Figure 9) and profile curvature (Figure 10) were classified into the 3 classes (convex, flat and concave) and Slope map (Figure 11) was classified into 5 classes.

After all these parameters are generated, the next step is to analyzed the frequency ratio. The frequency ratio is the ratio of the where landslides occurred in the total study area and also the ratio of the probabilities of a landslide occurrence to a non-occurrence for a given attribute. The more the FR is greater than unity, the stronger the relationship between landslide occurrence and the given parameter’s attribute. On the contrary, the lower the value of FR than unity means the lesser the relationship between landslide occurrence and the given parameter’s attribute [9]. Frequency Ratio formula can be seen on Eq.1.
\[
F_{ri} = \frac{N_{\text{pix}(S_i)} / N_{\text{pix}(N_i)}}{\sum N_{\text{pix}(S_i)} / \sum N_{\text{pix}(N_i)}}
\]

(1)

Where, \( N_{\text{pix}(S_i)} \) is amount of pixel that contains landslide event in class (i), \( N_{\text{pix}(N_i)} \) is sum of whole pixel amount in class (i), \( \sum N_{\text{pix}(S_i)} \) is the sum of total pixel that contains landslide event, \( \sum N_{\text{pix}(N_i)} \) is the sum of total pixel of whole area.

Figure 3. Elevation map.
Figure 4. Distance from road map.

Figure 5. Distance from river map.
Figure 6. Soil permeability map.

Figure 7. Soil texture map.
Figure 8. Land use map.

Figure 9. Planform curvature map.
Figure 10. Profile Curvature.

Figure 11. Slope Map.
5. Result and Discussion

In this analysis, 32 (70%) landslide data are used to modelling process and 13 (30%) landslide data are used to validated process. Table 1. shown the result frequency analysis in this catchment area. Most landslides occured at elevation of 875-1035 masl (meter at sea level). In this catchment, the percentage of land use area at elevation of 875-978 masl is 17% (cropland, field not irrigated, rice fields, settlements) and elevations of 978-1,036 masl is 32% (field not irrigated, settlements, cropland). Based on the field conditions, concluded that the amount of human activity in cultivated land will increase the potential for landslides, especially that land is in steep slope. Human activities such as changing the shape of slopes or patterns of land use, mining, agricultural activities on steep slopes, excavating and cutting slopes for the construction of buildings, roads and mining cause changes to slopes, clogging surface drainage and loading slopes further increasing susceptibility to landslide [13].

Analysis of the distance from the river, most landslides occur at a distance of 100-125 m, 0-50 m and >200 m. The FR values are respectively 1.96; 1.33; 1.05; 1.03. Landslides in this area occurred due to erosion at the cliffs by river water which causes the lower slope constituent materials to detach and reduced slope stability. The distance from the river can affected slope stability, because the movement of water on the slope and erosion is more common in the area near the river [14] and saturate the material at the bottom of the slope resulting in instability [15]. [16] stated that, the erosion of the riverbed at the lower of the slope causes the slope to become larger and the height of the slope to increase, consequently the slope becomes unstable.

The FR value of distance from road 0-25 m is 5.64 and this value is the highest FR value. The lowest FR value occurs at a distance of 75-150 m and >200 m. In this catchment the slope cutting activities for road and agricultural development necessary are often occurred, this activity can result slope become unstable and increasing potential for landslides event. Almost all landslide events recorded during the study occurred along the edge of the roads. Slope cutting activities will result in increased slope steepness and landslide events [17].

On 25-45% slope has a high probability of landslides with a frequency value of 1.47, while the slope of 15-25% has the lowest probability of landslide events with a FR value of 0.15. In this area, 34% of the area is dominated by a slope of 25-45%. in addition, many people built agricultural areas on that land which increased the potential for landslides. [18] stated that generally landslide-prone areas are areas with high average rainfall (> 2,500 mm / year), steep slope (> 40%), and or vulnerable areas earthquake.

Medium permeability has the highest FR value of 1.18 while slow permeability has the lowest FR value of 0. When the infiltration of rainwater meets lower permeability (more waterproof), the penetration speed will be inhibited. Although land with good permeability is having the ability to escape water, it does not mean that the area could avoid from landslides. However, if there is clay or a permeable layer, it will be a contributing factor to landslides. This event may occured when the water infiltrated into the soil is held up by the clay layer. The characteristics of clay rocks will shranked if it is dry and expanded when it is wet. The expand-shrink of this layer causes the soil’s adhesion decrease and becomes a slipping place. This condition is stated by [16].

Silt loam soil texture has the highest FR value of 1.02 and the lowest FR value is found in sandy loam soil texture with FR value is 0. As stated by [16] that slope failure also often occurs when the slope consists of crumb soil (soil residual) above the bedrock layer whose position is relatively parallel to the slope surface. Silt loam soil has a crumb structure, so it is easy to become instability.

Cropland land use has a high probability of landslides frequency ratio of 1.59 while the lowest FR value is found in the use of paddy fields with an FR value of 0. People in this catchment are mostly gardening on sloping land which is not ideal for farming, and the catchment area is dominated by a slope of 25-45% with 39% of garden land making this area quite potential for landslides. In addition to natural factors, land use patterns also play an important role in triggering landslide event. deforestation, tree planting that is too heavy with tight distance, mining, cutting slopes, for roads, settlements, is a land use pattern found in landslide areas [17].
In planform curvature, the highest FR value is found in flat land with FR value of 1.73 while the lowest is in convex landforms with FR value of 0.94. The curvature profile of the FR value is highest in flat land forms while the FR value is 1.59 while the lowest FR is in convex landforms with a FR value of 0.35. Many factors, such as geological and hydrological conditions, topography, climate and weather changes affect slope stability which results in Landslide. Natural causes that disturb the slope, for example, heavy rain or not but occur in the long term, the presence of soft layers and others. Causes related to human activities, for example: excavation at the foot of the slope, construction on the slope surface and others [16].

| Parameter                        | Σ Landslide Pixel | % Landslide Pixel | % class area | FR  |
|----------------------------------|-------------------|-------------------|--------------|-----|
| Elevation (masl)                 |                   |                   |              |     |
| 874.9 - 978.2                    | 7                 | 21,875            | 16,331       | 1.34|
| 978.2 - 1035.6                   | 13                | 40,625            | 32,682       | 1.24|
| 1035.6 - 1101.2                  | 7                 | 21,875            | 18,464       | 1.18|
| 1101.2 - 1165.1                  | 1                 | 3,125             | 15,187       | 0.21|
| 1165.1 – 1293                    | 4                 | 12,5              | 17,336       | 0.72|
| Distance from river (m)          |                   |                   |              |     |
| 0-25                             | 10                | 31,25             | 23,561       | 1.33|
| 25-50                            | 6                 | 18,75             | 17,791       | 1.05|
| 50-75                            | 5                 | 15,625            | 17,018       | 0.92|
| 75-100                           | 3                 | 9,375             | 13,46        | 0.7 |
| 100-125                          | 7                 | 21,875            | 11,142       | 1.96|
| 125-150                          | 0                 | 0                 | 6,636        | 0   |
| 150-175                          | 0                 | 0                 | 4,942        | 0   |
| 175-200                          | 0                 | 0                 | 2,408        | 0   |
| >200                             | 1                 | 3,125             | 3,042        | 1.03|
| Distance from road (m)           |                   |                   |              |     |
| 0-25                             | 27                | 84,375            | 14,949       | 5.64|
| 25-50                            | 3                 | 9,375             | 10,645       | 0.88|
| 50-75                            | 1                 | 3,125             | 10,188       | 0.31|
| 75-100                           | 0                 | 0                 | 8,923        | 0   |
| 100-125                          | 0                 | 0                 | 8,446        | 0   |
| 125-150                          | 0                 | 0                 | 6,559        | 0   |
| 150-175                          | 1                 | 3,125             | 6,667        | 0.47|
| >200                             | 0                 | 0                 | 33,622       | 0   |
| Slope (%)                        |                   |                   |              |     |
| 0-8 (flat)                       | 5                 | 15,625            | 17,176       | 0.91|
| 8-15 (slightly tilted)           | 5                 | 15,625            | 13,84        | 1.13|
| 15-25 (tilted)                   | 1                 | 3,125             | 20,935       | 0.15|
| 25-45 (steep)                    | 16                | 50                | 34,017       | 1.47|
| >45 (very steep)                 | 5                 | 15,625            | 14,032       | 1.11|
| Permeability                     |                   |                   |              |     |
| Moderate to low                  | 11                | 34,375            | 30,400       | 1.13|

Table 1. Frequency ratio analysis.
| Very low | 5 | 15,625 | 21,857 | 0,71 |
| Low | 0 | 0 | 5,236 | 0 |
| Moderate | 16 | 50 | 42,506 | 1,18 |

**Texture**

| Silt loam | 15 | 46,875 | 45,893 | 1,02 |
| Loam | 17 | 53,125 | 53,556 | 0,99 |
| Sandy loam | 0 | 0 | 0,551 | 0 |

**Land use**

| Cropland | 20 | 62,5 | 39,426 | 1,59 |
| Settlement | 2 | 6,25 | 9,713 | 0,64 |
| Field not irrigated | 10 | 31,25 | 50,310 | 0,62 |
| Rice fields | 0 | 0 | 0,551 | 0 |

**Planiform curvature**

| Concave | 14 | 43,75 | 44,595 | 0,98 |
| Flat | 3 | 9,375 | 5,424 | 1,73 |
| Convex | 15 | 46,875 | 49,981 | 0,94 |

**Profile curvature**

| Convex | 5 | 15,625 | 44,592 | 0,35 |
| Datar | 2 | 6,25 | 3,939 | 1,59 |
| Concave | 25 | 78,125 | 51,469 | 1,52 |

*sum of total pixel is 66611*

After FR analysis, landslide hazard maps were generated using the raster calculator on ArcGIS 10.4 and divided into 3 classes low, moderate and high. The result shown 38% low landslide area, 48% moderate landslide area and 14% high landslide area. Figure 12 shown susceptibility map using frequency ratio method. Based on Figure 12. Almost all the landslide exist near road networks. This condition proved that the most influencing factor made slope become unstable is activity nearby roads such as, cutting slope or cropland area around road networks. Human activity become a trigger landslide occur in this catchment.
Figure 12. landslide susceptibility map using frequency ratio.

6. Validation of Frequency Ratio Model
Landslide Density index are used to validate model. 30 % landslide validation data will include to the analysis. Pham et al [19] used Landslide Density index to validate model which is a ratio between the percentage of landslide pixels and the percentage of class pixels in each class on landslide susceptibility map. Landslide Density (LD) shown at Table 2. From Table 2. shown the landslide event increase accordingly susceptibility levels and conclude that landslide susceptibility zone using frecuency ratio method is valid and able to predicted landslide event.

| Susceptibility | % Landslide | % Pixel Class | LD |
|----------------|-------------|---------------|----|
| Low            | 0           | 37.69         | 0.00|
| Moderate       | 15.38       | 48.02         | 0.32|
| High           | 84.62       | 14.29         | 5.92|

7. Conclusion
Landslide susceptibility zone at Karangkobar catchment has carried out using Frequency Ratio model with 9 parameter such as land use, elevation, planform and profile curvature, distance from river, distance from road, slope, soil permeability and texture. The results shown that the highest FR value is found in the distance of the region from the road at range of 0-25 m, distance from the river at range of 100-125 m, flat curvature and garden land use. The broad percentage of low landslide susceptibility is 38%. Moderate susceptibility is 48% and high susceptibility is 14%. Human activity such as cutting slope for roads and agricultural development are the most influenced factor that made slope become
unstable and affect landslide event in this catchment. The results of validation for landslide susceptibility showed that the resulting susceptibility model is very effective for assessing the landslide susceptibility.

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