Disaster mitigation on lands affected by landslides in Banjarnegara Regency

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Abstract. Landslide mitigation on potentially-affected lands is one of the crucial efforts in Banjarnegara Regency. Such effort, however, must comply with the existing environmental and land use conditions. This research aimed to determine the landslide susceptibility level and landslide mitigation on the affected land. A descriptive quantitative method was used to determine landslide susceptibility, and a survey method was used to determine its condition. Landslide susceptibility was examined using an overlay analysis of the major factors: slope, texture fault, regolith, and geology. The analysis results show that the levels of landslide susceptibility of the research location consisted of: not prone (19.21%), slightly prone (4.95%), moderate (6.92%), prone (29.20%), and very prone (39.72%). It also predicted that 335,940 people (36.80%) lived in highly and very-highly vulnerable areas. Based on the results, mitigation is targeted on three groups of land, including water bodies (269.57 ha), vegetated area (69,946.98 ha), and non-vegetated area (3,506.25 ha). Both physical and social mitigation actions are thus required. Physical mitigation includes slope protection (terracing, vetiver system, slope-protection structures, ground fractures covering), water management (manual horizontal drainage, drainage channel), vegetation management (multi-stratum canopy, root morphology, and plant biomass), whereas social mitigation involves community management by promoting public awareness and vigilance against disasters, and the active role of both community and stakeholders.

1. Introduction
Landslide disaster mitigation requires information on the level of vulnerability of a particular area [1] and is very important in disaster risk management [2]. The level of vulnerability will determine a more precise and accurate action in the disaster mitigation process. Banjarnegara is among the areas that often experience landslides due to its geological and meteorological conditions [3]. Many landslides have been recorded in this regency, which have been disastrous and causing casualties.

Recent mitigation actions to avoid casualties primarily refer to the standard guidelines for disaster mitigation [4]. Land-use based mitigation actions are considered effective to facilitate the needs of the vulnerable area. In addition, land-use changes are also a major concern. It potentially affects erosion and landslides [5] and indirectly affects the resilience of land to climate change [6].

Land use is one of the physical conditions that potentially affect the characteristics of disaster [7]. It is one of the contributing factors in landslides [2]; [8]. In addition, land-use change is a factor that can increase the occurrence of landslides [9]. This mitigation must follow the existing environmental and land use conditions. The factors that cause landslide can be categorized into major factors (slope, fault, soil texture, regolith, and geology), minor factors (slope shape, soil aggregation, permeability,
drainage, and soil structure), and triggers (natural and artificial) [10]. The purpose of this research was to determine the level of landslide susceptibility based on the major factors that cause landslides, and mitigation actions on the affected land in Banjarnegara Regency.

2. Methods

2.1. Location

The research was conducted in Banjarnegara Regency, Central Java, Indonesia, with the coordinates between 7°12′ - 7°3′ S and 109°20′ - 109°45′ E. Banjarnegara Regency has a tropical climate with rainfall rate of 4923 mm/year. The topographic conditions are dominated by 31,410.08 ha (29.36%) of steep slope; 25,493.21 ha (23.83%) of flat land; 23,363.96 ha (21.84%) of moderate slope; 16,297.50 ha (15.23%) of extremely steep slope; and 10,406.24 ha (9.73%) of low slope. The land in Banjarnegara comprises mostly latosols (70,868.29 ha or 66.25%), while other soil types consists of alluviums, andosols, grumusols, organosols, and lithosols. Latosol is very prone to landslides because it expands easily and causes fractures.

2.2. Materials and tools

The materials included the RBI map published by Indonesian Geospatial Information Agency (BIG; Badan Informasi Geospasial) with a scale of 1:25,000 (for land slope, land administration, and land use) and a soil map published by the Indonesian Soil Research Institute (Balittanah; Balai Penelitian Tanah) with a scale of 1:100,000 (for the depth and texture of regolith). Data obtained from field observation was also used to reassure the materials obtained. Other materials included geological maps, the 500-meter buffer on fault maps for the limitation of the affected area, and the Statistics Bureau (BPS) of Banjarnegara Regency for the 2019 population data. The tools utilized were ArcGIS 10.1, Microsoft Word, and Microsoft Excel.

2.3. Data analysis

The identification of landslide-prone areas was made by assessing the vulnerability of land to landslides [10]. The method was overlay-mapping by overlapping several major factors of slope (S), texture (T), fault (F), regolith (R), and geology (G). Landslide disaster assessment used scoring and weighting (Table 1). The overlapping of these parameters was grouped into five classes using the natural breaks classification method, as shown in Table 2.

| No | Parameter/weight | Classification | Category | Scoring |
|----|-----------------|----------------|----------|---------|
| 1  | Slope 0.415     | 0–8%           | Flat     | 1       |
|    |                 | 8–15%          | Low slope| 2       |
|    |                 | 15–25%         | Moderate | 3       |
|    |                 | 25–45%         | Steep slope| 4       |
|    |                 | > 45%          | Extremely| 5       |
| 2  | Soil texture 0.136 | Very rough | Low | 1 |
|    |                 | Coarse         | Slightly low| 2       |
|    |                 | Medium         | Moderate | 3       |
|    |                 | Smooth         | Slightly high| 4       |
|    |                 | Very smooth    | High | 5       |
| 3  | Fault 0.172     | No fault       | Low | 1       |
|    |                 | Fault          | High | 5       |
| 4  | Regolith 0.121  | < 1            | Low | 1       |
|    |                 | 1–2            | Slightly low| 2       |
|    |                 | 2–3            | Moderate | 3       |
|    |                 | 3–5            | Slightly high| 4       |
Table 2. The weighting of landslide hazard classification

| No | Parameter/weight | Classification       | Category     | Scoring |
|----|------------------|----------------------|--------------|---------|
| 5  | Geology          | > 5                  | High         | 5       |
| 0.157 | Alluvial plain | Chalk                | Slightly low | 2       |
|     | Granite          | Slightly high        |              | 4       |
|     | Sediment         | Basalt-Clay shale    | high         | 5       |

Source: [10]

An analysis of landslide-affected lands was done based on SNI 7645:2010 concerning Land Cover Classification [11]. The classification divides land use into three groups, namely water (freshwater and swamps), vegetated areas (agricultural and non-agricultural), and non-vegetated areas (built-up land). Agricultural areas include rice fields, moor, and plantations, while non-agricultural areas are forests, shrubs, and grasses. Finally, built-up areas include buildings and settlements.

3. Result and discussion

3.1. Landslide susceptibility level

Based on the analysis results, Banjarnegara Regency has a high landslide risk. According to the major factors of landslide assessment, the susceptibility level of the Banjarnegara Regency is presented in Figure 1.

Figure 1. Landslide hazard map in Banjarnegara Regency

3.2. Lands affected by landslides based on land use

The analysis and calculation of the population were done based on the data derived from the Statistics Bureau of Banjarnegara Regency in 2019 [12]. A total of 335,940 (36.80%) Banjarnegara residents lived in settlements with a high risk of landslides. Based on the land use classification, 73,722.77 ha or 68.92% of the total area are prone and very prone to landslide. Meanwhile, the affected land consisted of water bodies (fresh water and swamp) with an area of 269.57 ha, vegetated area (agricultural and non-agricultural) with a total of 60,677.33 ha, and non-vegetated areas (built-up land) with an area of 355,405.36 ha.
non-agricultural) with an area of 69,946.98 ha, and non-vegetated area (built-up land) with an area of 3,506.25 ha. The largest land uses identified in the landslide-affected areas include settlement (3,504.82 ha), rain-fed rice field (3,364 ha), and forest (3,203.38 ha) (Table 3).

3.3. Landslide mitigation

3.3.1. Slope management
Slope is the topography of the Earth's surface with a certain tilt angle, which can cause unstable conditions [13]. Therefore, slope management is the most critical effort in landslide mitigation aimed to stabilize any slopes. Steep slopes, particularly, potentially trigger landslides [9]. Therefore, such slopes require serious management through proper actions. Slope mitigation actions include the Vetiver system, terracing, the construction of slope-protection structures, and the closure of soil fractures at the end of the dry season.

Vetiver is a plant that can be used for slope stabilization to directly and effectively reduce landslides [14]. Vetiver is a fast-growing plant that can increase soil cohesion to 119.6% and soil internal friction factor to 81.96% [15]. In addition, with specific systems and configurations, vetiver can help improve soil aggregation to protect slopes.

Terracing is another effort to reduce the slope length so that the slope is not too steep. Terracing is designed to reduce the slope angle in order to minimize potential landslides [13]. The construction of slope-protection structures, such as wire gabions and soil nailing, are standard techniques. Soil nailing is frequently used as a slope protection and slope stability method [16]; [17], and it has a similar function with wire gabions [18]; [19]. In addition, the closure of soil fractures, especially on slopes, can prevent rainwater infiltration, reduce soil saturation, and increase slope stability. This action is undertaken at the end of the dry season or before the rainy season.

3.3.2. Water management
Water management is critical in landslide mitigation. Water management includes the construction of manual horizontal drainage and drainage channels. The construction of horizontal water channels can reduce water saturation and stabilize the slopes [17]. In addition, the construction of structured waterways can hinder water flow, optimize the flow system, and reduce stagnant water[20].

3.3.3. Vegetation management
Vegetation is essential in landslide mitigation [21]. Vegetation management focuses on selecting functional and eligible types of plants to be planted in landslide-prone areas. Planting and structuring with a multi-strata canopy system can reduce slope loads. Plants with light canopies at the top of the slope, plants with strong roots on the lower slope, and plant biomass that should not load the slope are among the features. This multi-strata canopy can protect the slopes from direct rainwater infiltration into the soil [21]. In this context, the root morphology is the root shape; the roots' tensile strengths will affect soil cohesion and be placed systematically along the slope [22].

3.3.4. Community empowerment management
The concept of community-based mitigation in the community will optimize the use of local natural resources and the role of community organizations by increasing the community and stakeholders' participation in monitoring and promoting awareness of landslide hazards, which can reduce their impacts [23].
| No | Districts     | The potential affected area (Ha) | Water bodies | Vegetated areas | Non-vegetated areas |
|----|--------------|----------------------------------|--------------|-----------------|---------------------|
|    |              |                                  |              |                 |                     |
|    |              | Fresh water | Swamp | Rice Fields | Rain-fed Rice fields | Forest | Fields | Moor | Bush | Grass | Building | Settlement |
| 1  | Banjarmangu  |            |       |            |               | 21.76  | 897.05 | 1.41 | 306.73 | 1,632.46 | 347.15 | 202.67 | 0.22 | 296.96 |
| 2  | Banjarnegara |            |       |            |               | 7.88   | 248.21 |     |         | 1,555.68 | 118.86 | 70.16  | 3.53 | 239.40 |
| 3  | Batur        |            |       |            |               | 4.17   | 0.08   | 26.31 | 135.94 | 2,078.97 | 591.51 | 22.19  | 0.25 | 59.25  |
| 4  | Bawang       |            |       |            |               | 11.17  | 112.82 | 52.59 | 68.75  | 864.03   | 1,112.86 | 82.96  | 58.60 | 160.86 |
| 5  | Kalibening   |            |       |            |               | 26.11  | 212.35 | 21.06 | 380.74 | 1,768.88 | 4,080.80 | 359.57 | 23.68 | 198.65 |
| 6  | Karangkobar  |            |       |            |               | 9.81   | 359.44 |     |         | 1,119.65 | 1,443.19 | 98.32  | 60.01 | 143.96 |
| 7  | Madukara     |            |       |            |               | 18.34  | 84.47  | 58.76 | 2,265.64 | 51.26    | 27.73   |       | 195.05 |
| 8  | Mandiraja    |            |       |            |               | 12.66  | 8.94   | 47.59 | 64.28  | 899.40   | 740.07   | 33.11  | 20.39 | 101.61 |
| 9  | Pagetan      |            |       |            |               | 5.73   | 19.63  | 807.33 | 1,316.89 | 907.31   | 1,135.84 | 4.70   | 0.14  | 173.96 |
| 10 | Pandamanum   |            |       |            |               | 16.52  | 856.91 | 1002.80 | 1,360.70 | 1,120.25 | 655.79   | 45.77  | 0.45  | 126.83 |
| 11 | Pegedongan   |            |       |            |               | 37.06  | 233.25 | 31.55 | 114.34 | 3,704.38 | 1,399.91 | 339.83 |       | 363.39 |
| 12 | Pejawaran    |            |       |            |               | 43.57  | 435.77 | 219.34 | 4,066.72 | 157.70   |         | 0.24   | 233.13 |
| 13 | Punggelen    |            |       |            |               | 34.47  | 171.00 | 601.89 | 2,518.00 | 2,131.13 | 835.03   |       | 392.27 |
| 14 | Purwonegoro  |            |       |            |               | 15.43  | 52.52  | 1.53  | 19.07  | 933.34   | 2,545.57 | 158.50 | 6.61  | 114.48 |
| 15 | Purworejo Klampok |    |       |            |               | 3.43   | 368.10 | 28.36 | 24.28  |          |          |       | 26.31  |
| 16 | Rakit        |            |       |            |               | 16.21  | 91.81  | 7.64  | 165.45 | 147.97   | 143.33   |       | 52.61  |
| 17 | Sigaluh      |            |       |            |               | 6.94   | 66.53  | 139.73 | 2,631.65 | 172.66   | 166.99   | 0.16   | 151.16 |
| 18 | Susukan      |            |       |            |               | 0.54   | 17.19  | 13.16 | 1,933.12 | 133.62   | 128.99   |       | 186.13 |
| 19 | Wanadadi     |            |       |            |               | 20.22  | 65.23  | 0.08  | 472.11 | 67.98    | 9.36     | 29.93  | 0.07  | 87.48  |
| 20 | Wanayasa     |            |       |            |               | 4.47   | 169.78 | 257.26 | 969.46  | 3,606.73 | 1,934.52 | 1.81   | 0.43  | 201.31 |
|    | Total        |            |       |            |               | 269.49 | 0.08   | 2,810.22 | 3,364.00 | 3,203.38 | 26,834.22 | 26,301.37 | 7,156.18 | 277.61 | 1.43  | 3,504.82 |

Source: Data analysis, 2021
### Table 4. Mitigation actions based on land-use

| No | Mitigation                                      | Water bodies | Vegetation area | Non-vegetation area |
|----|-------------------------------------------------|--------------|-----------------|---------------------|
|    |                                                 | Fresh water  | Rice Fields     | Moor               |
|    |                                                 | Swamp        | Irrigation      | Bush               |
|    |                                                 | Rain-fed Rice fields | Forest | Grass | Building | Settlement |
| 1  | Slope management                                |              |                 | v                  |
|    | 1.1. Vetiver system                             | v            | v                | v                  |
|    | 1.2. Terracing                                  | v            | v                | v                  |
|    | 1.3. The construction of slope protection structures | v            | v                | v                  |
|    | 1.4. The closure of soil fractures at the end of the dry season | v            | v                | v                  |
| 2  | Water management                                |              |                 | v                  |
|    | 2.1. Manual horizontal drainage                 | v            | v                | v                  |
|    | 2.2. drainage channels                          | v            | v                | v                  |
| 3  | Vegetation management                           |              |                 | v                  |
|    | 3.1. Multi-stratum canopy                       | v            | v                | v                  |
|    | 3.2. Root morphology                            | v            | v                | v                  |
|    | 3.3. Plant biomass                              | v            | v                | v                  |
| 4  | Community management                            |              |                 | v                  |
|    | 4.1. Community-based mitigation                 | v            | v                | v                  |
|    | 4.2. Community and stakeholders' participation  | v            | v                | v                  |

Source: Data analysis, 2021
Based on the discussion, landslide mitigation can be carried out according to the level of landslide susceptibility and land use. In general, landslide mitigation in water bodies (fresh water and swamp) will require water-related specific actions and community management. Similarly, landslide mitigation in vegetated areas will involve slope, water, vegetation, and community management. On the other hand, mitigation for in-built areas will require water, slope and community management. The results of the mitigation management analysis are presented in Table 4.

4. Conclusion
Based on the level of landslide susceptibility, Banjarnegara Regency can be divided into not prone (19.21%), slightly prone (4.95%), moderate (6.92%), prone (29.20%), and very prone (39.72%). Based on land use, the potentially affected area includes 269.57 ha of water bodies; 69,946.98 ha of vegetated areas; and 3,506.25 ha of non-vegetated areas. Each group requires different mitigation actions. Mitigation can be designed by considering several aspects, including slope management, water management, vegetation management, and community management.

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