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GIS-BASED ANALYSIS FOR ASSESSING LANDSLIDE AND DROUGHT HAZARD IN THE CORRIDOR OF MT. MERAPI AND MT. MERBABU NATIONAL PARK, INDONESIA

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Abstract: *A corridor is an area located between two or more protected areas that are important to support the sustainability of the protected areas. This study is aimed at assessing landslide and drought hazard in the corridor area between Mt. Merapi National Park (MMNP) and Mt. Merbabu National Park (MMbNP) as a part of the corridor management strategy. The corridor area of MMNP and MMbNP comprises four sub-districts in Central Java Province, namely, Sawangan, Selo, Ampel, and Cepogo. A spatial analysis of ArcGIS 10.1 software was used to assess landslide hazard map and the Thornthwaite & Mather Water Balance approach was used to assess drought hazard map. The results have shown that three villages in Cepogo Sub-district and all villages in Selo Sub-district are highly prone to landslide hazard. Furthermore, two villages in Cepogo Sub-district and four villages in Selo Sub-district are prone to drought hazard. This study suggests that these villages should initiate a program called conservation village model based on disaster mitigation for mitigating future landslide and drought disasters.*

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1. INTRODUCTION

The 5th World Congress on National Parks in Durban, South Africa in 2003 under the theme Benefits Beyond Boundaries recommended that the principle of collaborative management between public bodies and local communities become a new model in the management of national parks (IUCN, 2005). A manifestation of this new paradigm is the arrangement of the buffer zone of protected areas. Conceptually, a buffer zone aims to enhance the conservation values of the buffered area (regulation of Indonesian Government No.68 of 1998). A buffer zone that connects two or more protected areas is known as a corridor area (Beier & Noss, 1998; Indrawan et al., 2012).

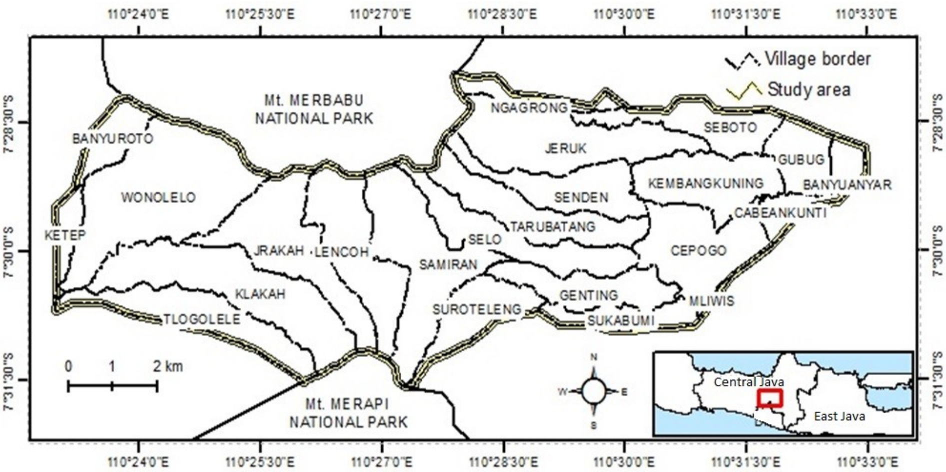
Corridor area can be production forests and plantations, and even cultivated lands owned by communities, which, if it is designed properly, will be a valuable conservation tool (Beier & Noss, 1998). Management of corridor area so far focused on its function as the expansion of protected areas to connect between biomes (Joshi et al., 2013; Wangchuk, 2007). Numerous studies had been done to explain the function of the corridor area as wildlife migration path especially those with a broad range of habitat (Douglas-Hamilton et al., 2005; Joshi et al., 2011; Silveira et al., 2014). However, the presence of people who live in the corridor can be a threat to the survival of wildlife migration process (Kushwaha & Hazarika, 2004). The expansion of settlements and cultivation of seasonal crops became the most influential factor to disturb the existence of the corridor (Joshi et al., 2011). One of the efforts to preserve the corridor area is through spatial planning and land management of it.

In contrast to that of the other types of region, spatial planning of a corridor area has rarely got attention (Pouzols & Moilanen, 2014). Moreover, McRae et al., (2012) stated that there is a lack of spatial planning in a corridor area that focuses on protecting biological diversity in all levels (genetic, species, and landscapes). One of the obstacles is less of understanding between protected area managers and regional governments (Anshari, 2006). In addition, people who live in corridor area are also lack of understanding about other functions of protected area, especially as a water and soil regulator to prevent natural disasters (Qutni, 2004).

The aspects of disaster vulnerability in the corridor management strategy are still new and challenging. We believe that putting the element of disaster management in corridor areas is one of the solutions to reach an understanding between protected area managers, local communities, and local governments. Issues on disaster mitigation are more attractive than biodiversity protection so that it may gain more support from local community and local government. In addition, it is obligatory for local governments to protect communities from future disaster as stated in the Indonesia Law No. 24 of 2007 on Disaster Management.

This study aims to analyze the two potential hazards in the corridor area of Mt. Merapi National Park (MMNP) and Mt. Merbabu National Park (MMbNP), namely landslides and drought. The corridor area of MMNP and MMbNP comprises administratively the Sawangan sub-district (Magelang district), Selo sub-district, Cepogo sub-district and Ampel sub-district (Boyolali district) (see Figure 1). According to INFRONT (2008), these research areas are classified landslides prone caused by non-conservative tillage practice on the land use management. Moreover, agricultural productivity in the research sites is threatened to decrease due to hydrometeorological conditions (Putri, 2008). The results of this study will be useful as an advice for the conservation manager and local government to manage the corridor area based on disaster mitigation of landslides and drought hazard.

Figure 1. Map of the study area (Geospatial Information Agency of Indonesia, 2015)



2. DATA AND METHODS

2.1 Research Material

All the materials used in the study were obtained from various sources, both institutional and public domains. The institutional data was acquired by examining the data and reports from relevant institutions, while the public domain data was acquired by online access from the web page of the data provider. Table 1 describes the materials used in this study.

Table 1. Research material (authors, 2015)

Name	Scale/resolution	Source
Administration map **Land Use Map** **Altitude Map** **Slope Map**	1:25.000	Indonesia Topographic Map NLP: 1408-244, 1408-333, 1408-522, 1408-611; Geospatial Information Agency
Canopy Density Map	15 meter	Citra ASTER VNIR on 07 August 2009
Rainfall data	Monthly, 1997 – 2007	Selo rain station, Cepogo rain station, Sawangan rain station and Ampel rain station
Air temperature data	Monthly, 1997 – 2007	Mt Merapi observation station, Center for Volcanology and Geological Hazard Mitigation (PVMBG)
Soil Map	1:50,000	Boyolali Development Planning Agency (Bappeda)

Note:
1. The slope map is obtained by analyzing the Digital Elevation Model (DEM) map from the contour map of Indonesia Topographic map
2. Canopy density map is obtained by analyzing the Normalized Difference Vegetation Index (NDVI) image of ASTER VNIR and classified into 3 classes: high (NDVI ≥ 0.6), moderate (0.2 ≤ NDVI < 0.6) and low (NDVI < 0.2)
3. We performed all spatial analysis using ArcGIS 10.1 software.

2.2 Landslide Hazard Analysis

Landslide hazard analysis was conducted by the spatial analysis of the factors that influence the occurrence of landslides in the area of research, namely: slope, land use, soil depth, soil type and rainfall. Selection of these factors was based on field observations, previous studies from Marhaento & Sudibyakto (2007), Subekti & Hadmoko (2013), and interviews with the local communities. Subsequently, all these factors were given a score for each class according to the level of importance on landslide occurrences (see Table 2). We used overlay analysis using ArcGIS 10.1 software to combine all spatial information. The sum of scores from each class of each land unit was then used to determine the landslides hazard level. The results of the final score were proportionally classified into 5 classes, namely Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH).

Table 2. Scores of each landslides triggering factor in the study area (Marhaento & Sudibyakto, 2007; Subekti & Hadmoko, 2013)

Factor	Class	Score
Land use **HD : High Density (NDVI ≥ 0.6)** **MD: Medium Density (0.2 ≤ NDVI < 0.6)** **LD : Low Density (NDVI < 0.2)**	HD Mixed-plantation, MD Mixed-plantation	10
	Pasture and Shrub	20
	LD Mixed-plantation	30
	Settlements, Rice Field	40
	Moor	50
Mean annual rainfall (mm)	< 2000	10
	2000 - < 2500	20
	2500 - < 3000	30
	≥ 3000	40
Slope class (%)	0 < 8	10
	8 – < 15	20
	15 – < 25	30
	25 – < 45	40
	≥ 45	50
Soil depth (cm)	< 90	10
	90 – < 150	20
	150 – < 300	30
	≥ 300	40
Soil Type	Grey andosol complex and litosols, brown andosols, brown latosols	30
	Grey regosol complex and latosols, litosols, brown litosols	40

2.3 Drought Hazard Analysis

Drought hazard analysis was carried out by measuring the water balance and aridity index using the Thornthwaite and Matter Water Balance (TMWB) method (Thornthwaite & Mather, 1957). Aridity index is a ratio between soil moisture deficiency and water demand for potential evapotranspiration to occur. The analysis calculates water balance in monthly basis and averages it in annual basis. There are three possible water balance conditions. First, a balance condition occurs when soil moisture meets water demand for potential evapotranspiration. Second, a surplus condition occurs when soil moisture exceeds evapotranspiration needs and then contributes to runoff. Third, a deficit condition occurs when soil moisture is not sufficient for fulfil evapotranspiration demand.

TMWB aridity index (AI) is calculated using the following equation:

$$AI = \frac{100 * D}{N};$$

where the water deficiency D is calculated as the sum of the monthly differences between precipitation and potential evapotranspiration for those months when the normal precipitation is less than the normal evapotranspiration; and N stands for the sum of monthly values of potential evapotranspiration for the deficient months. Based on the results of AI calculation and considering the agro-climate zones according to

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Oldeman, we determined the drought hazard level based on the criteria on Table 3. We performed AI calculation in each Land Mapping Unit (LMU) that is formed by soil type map and elevation map. We note that drought hazard analysis in the present study continued the work of Putri (2008).

Table 3. Criteria for drought hazard classes (Thornthwaite & Mather, 1957)

No.	Hazard Class	Criteria
1.	Not Risk (NR)	Ia < 16,7 %
2.	Risk (R)	16,7 % < Ia < 33,3 %
3.	Highly Risk (HR)	Ia ≥ 33,3 %

Three parameters are required to calculate D and N, namely monthly air temperature average, monthly rainfall and storage capacity. Storage capacity parameter is determined by soil-texture and root-depth. In order to give an insight about the procedure to calculate the AI, steps to determine AI are as follows:

1. Calculate monthly mean temperature (T)
2. Calculate heat index value (i) monthly for each month, according to the formula $i = \left[\frac{T}{5}\right]^{1,514}$
3. Calculate annual heat index (*I)* and constant values (*a*) with the formula:
   $$I = \sum_{j=1}^{12} ij$$
   $a = (675.10^{-9} * I^3) - (771.10^{-7} * I^2) + (1792.10^{-5} * I) + 0.49239$
4. Calculate mean monthly potential evapotranspiration (PET) (mm / month), with the formula PET = $1.6\ (I * T * 10)^a$
5. Determine latitude correction factor (f) according to site study, which in the present study is at latitude 7^0 so that the value of f is:

7^0S	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
f	1.07	0.96	1.04	1.00	1.02	0.98	1.02	1.03	1.00	1.05	1.04	1.07

6. Calculate corrected value of potential evapotranspiration (ET) (mm / month), with the formula ET = PET * f
7. Calculate monthly rainfall data (P)
8. Calculate difference between rainfall and potential evapotranspiration in monthly basis (P - ET)
9. Calculate potential accumulation of water lost (APWL). If the result of the calculation no.8 is positive, then the value APWL is zero, whereas if the result of the calculation no.8 is negative, then APWL is calculated based on accumulative of negative values until reach positive.
10. Calculate storage capacity (Sto) that taking into account soil texture and root-depth.
11. Calculate soil water consumption (St)
    St is in optimum condition when APWL is positive. If APWL is negative, St is calculated using the formula:
    $St = Sto * e^{APWL / Sto}$
    e = 2, 718
12. Calculate change in soil moisture (Δ St) in monthly basis.
    Change in soil moisture (mm / month) is the difference between usage of soil moisture in a month with usage of soil moisture in a previous month
    $St\ \Delta = St_i - St_{i-1}$
13. Calculate the actual evapotranspiration (EA) in wet months (P > ET) with the formula EA = ET, while in dry months (P <ET) we use formula, EA = P + |-Δ St |
14. Calculate water deficiency (D)
    Water deficiency is calculated in months when P < ET using formula D = ET – EA.

3. RESULTS AND DISCUSSION

3.1 Landslide Hazard Analysis

The study area has nine land use classes, the three dominant classes of which are moor with the area of 3,552.8 ha (47.6%), settlement area of 1.158,2 ha (15.5%), and high density mixed-plantation area of 868.3 ha (11,6%). The moor areas consist of vegetables such as Cabbage (*Brassica oleracea*), Prei (*Allium Porum*), Carrot (*Daucus carota*), Onion (*Allium cepa*), Jipang (*Sechium edule*), Fennel (*Pimpinela anisium*) and Beans (*Phaseolus vulgaris*). The mixed-plantation areas consist of perennial trees such as: Sengon (*Paraserianthes falcataria*), Suren (*Toona sureni*), Leucaena (*Leucaena leucocephala*), Jackfruit (*Artocarpus sp*), Gmelina (*Gmelina arborea*), Acacia (*Acacia auriculiformis*), Cinnamon (*Cinamomum* sp) and Teak (*Tectona grandis*).

Based on the Digital Elevation Model (DEM), medium slope and steep slope are dominant with the area of 2,664.2 ha (35.7%) and 1,783.5 ha (23.9%) respectively. The dominant soil type is Andosol with the area of 3,513.9 ha (47.1%) and complex Regosol and Latosol type with the area of 2,840.3 ha (38.1%). Soil with the depth of less than 90 cm and between 90-150 cm are dominant with the area of 2,632.4 ha (35.3%) and 4,823.4 ha (64.7%) respectively.

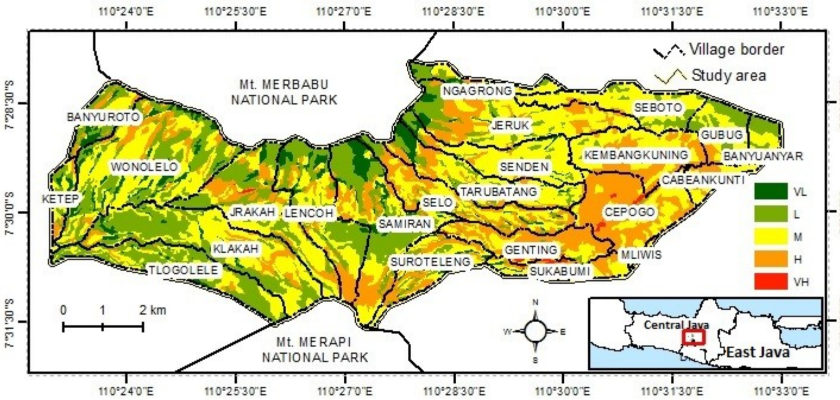
Using *Krigging* analysis in the ArcGIS software to analyze monthly rainfall data from years 1997 - 2007 of four rainfall stations, we found that 6,540.9 ha (87.7%) area has a mean annual rainfall of 2500 - 3000 mm/year and 914.9 ha (12.3%) area has a mean annual rainfall above 3.000 mm, which mainly occurred in the Cepogo sub-district. After overlaying all thematic maps and classifying the scoring results, we found that medium hazard class (M) is dominant in the study area with the area of 3,131.5 hectares (42.0%), followed by low class (L) with an area of 2,060.1 ha (27.6 %) and high class (H) with the area of 1,713.0 ha (23.0%). Table 4 shows the detail results of the hazard analysis.

Table 4. Landslide hazard classes in the study area (Data Processing, 2015)

Landslides vulnerability Class	Size (Ha)	%
Very Low (VL)	523.5	7.0
Low (L)	2,060.1	27.6
Medium (M)	3,131.5	42.0
High (H)	1,713.0	23.0
Very High (VH)	27.6	0.4
Total	7,455.8	100.0

We found that the area with high level of landslides hazard was the eastern part of Selo and all villages in the Cepogo sub-district. Apparently, high rainfall occurrence and steep slope that dominant in these areas was the main cause of the high level of landslide hazard. In addition, we also found that landslides frequently occur on along the main road that connect Selo sub-district with Cepogo sub-districts. Figure 2 shows the spatial distribution of landslide hazard in the study area.

Figure 2. Landslide hazard map of the study area (analysis, 2015)



3.2 Drought Hazard Analysis

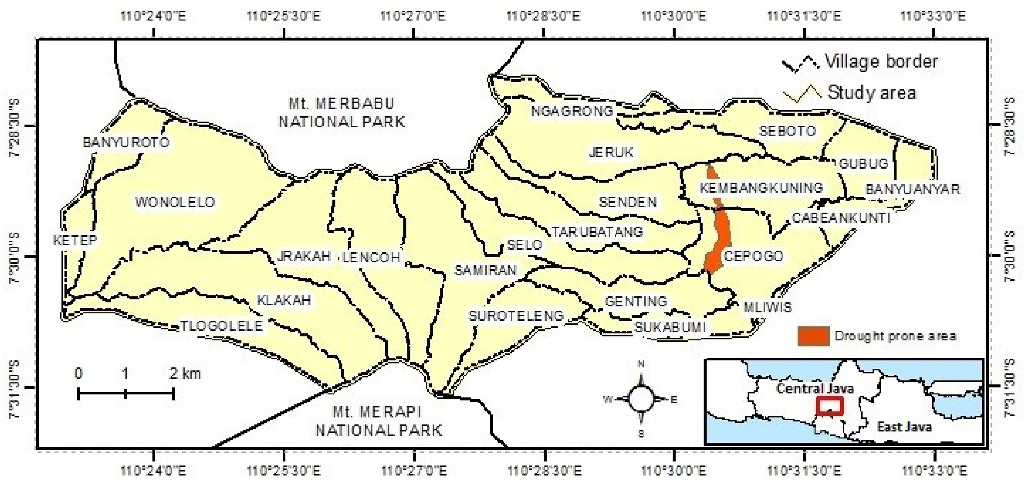
Table 5 shows the calculation of Aridity Index (AI) in each Land Mapping Unit. The results show that the entire area has AI value below 16.7%, which categorized as Not Risk (NR)—according Thornthwaite and Mather (1957). However, there are some areas that have a high value of AI, such as Cepogo village and Kembangkuning village at Cepogo sub-district, and Jeruk Village, Senden village, Tarubatang villages, and Selo villages at Selo sub-district. Figure 3 shows the spatial distribution of drought hazard in the study area.

Table 5. Aridity Index in each land mapping unit (Data Processing, 2015)

No	Land Mapping Unit	Elevation (m dpl)	AI (%)
1	Ampel_ brown andosol 1000 – 1500 m	1267	4.0
2	Ampel_ brown andosol > 1500 m	1664	3.3
3	Ampel_ grey andosol complex and lithosol >1500 m	1664	1.9
4	Ampel_ grey andosol complex and lithosol 1000 – 1500 m	1664	2.0
5	Ampel_brown latosol 1000 – 1500 m	1245	2.8
6	Cepogo_brown andosol < 1000 m	964	11.1
7	Cepogo_brown andosol coklat 1000 – 1500 m	1102	7.1
8	Cepogo_ grey complex regosol and lathosol < 1000 m	834	3.5
9	Cepogo_ grey complex regosol and lathosol 1000 – 1500 m	1085	3.9
10	Cepogo_brown Latosol < 1000 m	744	3.1
11	Cepogo_brown Latosol 1000 – 1500 m	1110	4.1
12	Cepogo_litosol coklat < 1000 m	812	3.2
13	Cepogo_brown litosol 1000 – 1500 m	1039	3.8
14	Selo_brown andosol < 1000 m	996	2.8
15	Selo_ brown andosol 1000 – 1500 m	1326	2.6
16	Selo_ brown andosol > 1500 m	1950	1.4
17	Selo_ grey andosol complex and lithosol 1000 – 1500 m	1475	1.2
18	Selo_ grey andosol complex and lithosol > 1500 m	1934	0.8
19	Selo_ grey regosol complex and latosol < 1000 m	948	2.3
20	Selo_ grey regosol complex and latosol 1000 – 1500 m	1276	1.6
21	Selo_ grey regosol complex and latosol > 1500 m	1704	1.2
22	Selo_brown latosol 1000 – 1500 m	1262	1.6
23	Selo_brown litosol < 1000 m	966	2.4
24	Selo_brown litosol 1000 – 1500 m	1032	4.4

Note: Land Mapping Unit consist of sub-district name, soil type and elevation class

Figure 3. Drought hazard map of the study area (Analysis, 2015)



3.3 Discussion

The new paradigm in management of protected area to emphasize collaborative management between public bodies and local communities brings consequence that the buffer zone of protected area should be managed. The importance of a buffer zone is even more when it connects more than one protected areas as a corridor area (Joshi et al., 2011). In the present study, hazard analysis is used as one component of strategy to manage the corridor area between the Mt. Merbabu National Park (MMbNP) and the Mt. Merapi National Park (MMNP). Numerous studies on the management of protected and corridor areas have focused on aspects of the protection of biodiversity (Douglas-Hamilton et al., 2005; Kushwaha & Hazarika, 2004; Marhaento & Kurnia, 2015; Silveira et al., 2014). In fact, the role of corridor area as a protector from potential disasters for its surroundings is also significant and thus requires more attention.

Landslides and land drought are two kinds of natural disasters that can disrupt productivity of land and have a major impact on socio-economic of local communities—in the study area, they are mostly farmers. We found that approximately 23% of the area has a severe impact of landslide from high to very high grade. These areas are mainly in Cepogo village, Genting village, and Sukabumi village at the Cepogo sub-district and in all villages at Selo sub-district that is adjacent with MMNP and MMbNP. The landslides frequently occur in along the main road connecting Selo sub-district with Cepogo sub-districts. It shows that the cutting slope, which is often performed in the road-construction process, is as important factor in the landslide occurences. Marhaento & Sudibyakto (2007), Priyono (2008), Subekti & Hadmoko (2013), and Nirwansyah et al. (2015) also delivered the high contribution of cutting slopes in the landslide.

Using Thornthwaite-Mather Water Balance (TWMB) method, we found that all areas have an Aridity Index (AI) value below 16.7%, or it includes in Not Risk criteria. It indicates that the water balance in the corridor area is sufficient to support crop productivity (Thornthwaite & Mather, 1957). However, some areas have a quite high AI value close to 16.7%, i.e. Cepogo village and Kembangkuning village at Cepogo sub-district and Jeruk village, Senden village, Tarubatang villages, and Selo villages at Selo sub-district.

The areas detected to be prone to future landslides and drought would then become a prime target in the management strategy of MMbNP and MMNP corridor area. We suggest the scheme of Rural Conservation (DK) according to Regulation of The Forestry Minister No.P-16 / Menhut-II / 2011 be implemented on villages with high level of hazards. Furthermore, these selected villages should be designated as *Model Desa Konservasi Berbasis Mitigasi Bencana* or Rural Conservation Model Based on Disaster Mitigation Effort (MDK-BMB). The selected villages in this scheme are pointed as a model to apply strategy on community empowerment with full respect to soil and land conservation tillage and disaster mitigation.

4. CONCLUSION

The results showed that several villages in the corridor area of Mt. Merapi National Park (MMNP) and Mt. Merbabu National Park (MMbNP) are prone to landslides and drought. The villages are Cepogo, Genting, and Sukabumi villages at Cepogo sub-district and all villages at Selo sub-district that are located adjacent to the area of MMNP and MMbNP. The villages that are prone to drought hazard are Cepogo village and Kembangkuning village at Cepogo sub-district and Jeruk Village, Senden village, Tarubatang village, and Selo village at Selo sub-district. We suggest these villages to be included in the national program called Rural Conservation Model Based on Disaster Mitigation Effort (MDK-BMB), the implementation of which should be collaborative between the local governments and the conservation area managers.

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