INTRODUCTION

The land is one of the primary resources in the concept of environmental sustainability, and the use pattern determines the quality of carrying capacity of the agroecosystems. Land use patterns in the Mount Merapi region have provided a balanced environmental quality to agricultural production. The abundance of biological resources found in Merapi slopes has served as a substantial capital resulting in insufficient local food availability. The eruption that occurred in 2010 caused the decline of land quality and changed the land use pattern in the southern regions. This study evaluated and determined the land use planning in disaster-prone areas affected by the Mount Merapi eruption. This research was conducted from August 2018 to March 2019 in Kepuharjo village, Cangkringan, Sleman, Special Region of Yogyakarta. This study was performed by using observational methods through data collection, such as physiographic areas, volcanic materials depth, rock distribution, and soil characteristics. Prone zoning and area planning was determined using a descriptive-spatial method to produce an appropriate model for the new land use. The results revealed the difference in land suitability in the distance interval of 8 km from the mountain peak. A region located less than 8 km from the peak was predicted to be suitable for the community forest and fodder grass cultivation and could function as a conservation area. In contrast, the region located within ≥ 8 km was found to be suitable for dry land farming of food crops using alley cropping systems. Additionally, an integrated sustainable farming system should be promoted and implemented for increasing the sustainability of soil and crop productivity.

ABSTRACT

The eruption of Mount Merapi in 2010 caused the decline of land quality and changed the land use pattern in the southern regions. This study evaluated and determined the land use planning in disaster-prone areas affected by the Mount Merapi eruption. This research was conducted from August 2018 to March 2019 in Kepuharjo village, Cangkringan, Sleman, Special Region of Yogyakarta. This study was performed by using observational methods through data collection, such as physiographic areas, volcanic materials depth, rock distribution, and soil characteristics. Prone zoning and area planning was determined using a descriptive-spatial method to produce an appropriate model for the new land use. The results revealed the difference in land suitability in the distance interval of 8 km from the mountain peak. A region located less than 8 km from the peak was predicted to be suitable for the community forest and fodder grass cultivation and could function as a conservation area. In contrast, the region located within ≥ 8 km was found to be suitable for dry land farming of food crops using alley cropping systems. Additionally, an integrated sustainable farming system should be promoted and implemented for increasing the sustainability of soil and crop productivity.

ARTICLE INFO

Keywords:
Farming system
Land-use models
Land use planning
Mount Merapi

Article History:
Received: July 29, 2020
Accepted: December 13, 2020

*Corresponding author:
E-mail: goenb@yahoo.com

Land Use Planning for Disaster-Prone Areas in Southern Region of Mount Merapi
Gunawan Budiyanto
Department of Agrotechnology Faculty of Agriculture Universitas Muhammadiyah Yogyakarta Indonesia

ISSN: 0126-0537 Accredited First Grade by Ministry of Research, Technology and Higher Education of The Republic of Indonesia, Decree No: 30/E/KPT/2018

Cite this as: Budiyanto, G. (2021). Land use planning for disaster-prone areas in Southern Region of Mount Merapi. AGRIVITA Journal of Agricultural Science, 43(1), 1–12. https://doi.org/10.17503/agrivita.v1i1.2774
disaster-prone area (level I) with a radius of more than 15 km. Areas located within 5 km from the peak experiencing frequent contact with nuées ardentes, lava flow, and incandescent lava are considered level III. The eruption would damage this area and degrade the land potency, including its capacity to facilitate plant growth. Disaster-prone area level II are areas within a radius of 6-10 km from the peak that are potentially affected by nuées ardentes and lava flow. Areas in this level suffer higher land damage due to the sedimentation of volcanic ash found in several centimeters of the topsoil, thus resulting in poor fertility and low plant productivity. Disaster-prone area level I is defined as areas located more than 15 km from the peak affected by the expansion of nuées ardentes. This level I area is commonly surrounded by several rivers, such as the Krasak River, Boyong River, Yellow River, Opak River, and Gendol River. Land in these watershed areas was potentially damaged due to the flowing volcanic materials containing mud, sand, and rock. Deposit of volcanic materials caused by the eruption in 2010 could reach 10-30 cm (Suriadikarta et al., 2010), but it could enter more than 30 cm in the soil basin, thus covering the upstream area of Gendol River. Elevated temperatures due to this deposit could also reduce the land potency, thereby threatening food security and raising community dependence on food supply from other regions.

Kepuharjo Village, located in Cangkringan District, Sleman Regency, is considered a disaster-prone area level III and II. This village is bordered by MMNP (to the north), Wukirsari Village (to the south), Umbulharjo Village (to the west), and Glagahharjo Village (to the east). This village consists of eight sub-villages, namely Kaliadem, Jambu, Petung, Kopeng, Batur, Pagerjurang, Kepuh, and Manggong (Fig. 1). Several sub-villages in Kepuharjo are considered disaster-prone area level III since these areas confer high resilience in anticipating the post-eruption hazard caused by the eruption in 2010 (Rahman, Nurhasanah, & Nugroho, 2016). Therefore, this condition serves as a potential social capital required to design the land use planning in the southern region of Mount Merapi. Since 1960, Mount Merapi has erupted more than eight times, and its eruption cycle ranges between 4 to 6 years. The pyroclastic flow caused by the eruption in 2006 had reached the Gendol River up to 7 km (Iguchi, Ishihara, Surono, & Hendrasto, 2011; Kadavi, Lee, & Lee, 2017).

Fig. 1. Map of Kepuharjo village, Cangkringan district, Sleman regency

Remarks: Source: https://cangkringankec.slemankab.go.id/wp-content/uploads/2017/08/kepuharjo.jpg
Although Mount Merapi’s eruptions always cause disturbance and threat to the surrounding areas, especially land use of agricultural practices. In the long term, the eruption of Mount Merapi can provide the potential fertility for improving land quality, due to the supply of mineral content in the eruption material. In the short term, the eruption of Mount Merapi has a negative impact that can cause land damage and threaten human safety. Based on these rationales, land use patterns in the southern region of Mount Merapi are recommended to be redesigned based on the hazard vulnerability created by the eruption cycle.

MATERIALS AND METHODS

This study was conducted from August 2018 to March 2019 in Kepuharjo village, Cakringan District, Sleman Regency, Special Region of Yogyakarta, which is the southern area of Mount Merapi, as shown in Fig. 1. A survey was performed to observe the area’s physiographic conditions, soil properties, and the indigenous plants grown after the 2010 eruption. Data collected were categorized into primary data and secondary data. Primary data consists of the data from field observation (physiographic conditions such as slope, depth of pyroclastic deposits, rock distribution, indigenous plants, and land status) and laboratory work analyzing the soil properties (particle density, bulk density, soil porosity, C-organic content, and soil pH). Secondary data was collected from the information on the physical condition of the eruption-affected region and its level of disaster-proneness.

The determination of the location of the observation and soil sampling was carried out using a purposive method based on the topography and slope of the land. Soil samples were collected at several sample points in each sub-village from 30 cm depth and were determined based on the homogeneity conditions of the topography, land area, and soil surface micro-relief. Soil samples were taken in a composite manner to obtain soil samples that could represent each soil condition in each sub-village. Soil samples from each sub-village were prepared in air-dried condition and filtered with a size of 2.0 mm for laboratory analysis of some soil characteristics.

These data were analyzed descriptively and spatially. Descriptive analysis was conducted to provide an overview, explanation, and relationship between one observation phenomenon with another phenomenon based on facts and information obtained in the field. Suryana (2010) stated that descriptive analysis aims to make a systematic, factual, and actual description of the population’s facts and characteristics. Spatial analysis is an analysis technique based on field conditions data presented in the form of several maps (geomorphological patterns, topographic pattern, the change of land use pattern, zoning determination, and plan of spatial patterns). Spatial analysis was carried out by overlaying two maps of several observed parameters (topographic pattern, micro-relief of the soil surface, and soil characteristic) so that a buffer-image was obtained based on the equations of points, lines, and polygons of an area (Kunarso et al., 2019; Rachmah, Rengkung, & Lahuamendu, 2018). The results of the study using descriptive-spatial methods were used as the basis for selecting new land-use models.

RESULTS AND DISCUSSION

The Merapi eruption in 2010 had significantly contributed to the destruction of the surrounding land resources due to the deposit of volcanic materials, such as rock, sand, and ash. Table 1 shows that deposits of volcanic materials and rock varied in all sub-villages observed. According to the sliding distance from the center of the sub-villages’ eruption, three sub-villages revealed more extensive rock distribution and thicker deposits of volcanic materials, namely Kaliadem, Jambu, and Petung (Table 1). It indicated that the closer the sub-village distance to the center of the eruption, the bigger the destruction resulted. Table 1 also conferred that Kaliadem and Jambu were the most threatened regions as their proximity allowed the earliest distribution of volcanic materials during an eruption occurring in the thickest after effect deposits. Considering the thickness of pyroclastic materials, depth of ash sedimentation, and high rock distribution, Kaliadem and Jambu sub-villages had experienced a significant decline in soil fertility, thus becoming less favorable for agricultural farming. The presence of these pyroclastic materials had fixed the soil nutrient, making it unavailable for plant uptake.
Based on observations of the slope of the land, as shown in Table 1, Kepuharjo village has four sub-village groups with a slope of more than 15% (Kaliadem, Jambu, Petung, and Kopeng) and below 15% (Batur, Pagerjurang, Kepuh, and Manggong). According to Zhang et al. (2015) under various land surface conditions, an increase in land slope causes increased soil erosion. Based on this, the four sub-villages in Kepuharjo village (Kaliadem, Jambu, Petung, and Kopeng) have enormous erosion potential than the other four sub-villages which have a slope of under 15%. Based on the Universal Soil Loss Equation (USLE), many factors affect soil erosion (rain erosivity, soil erodibility, slope length, and slope level, land cover, and soil conservation). Budiyanto, Aini, & Setyawan (2019) stated that the slope length and slope level of the land are topographic factors that affect soil erodibility and proportionally directly affect erosion. Based on this, the sub-village, which has a slope of more than 15%, needs to get mechanical conservation treatment (terracing) and organic conservation (regulation of cropping patterns and systems).

Mechanical conservation with the application of terraces on sloping land is an effective way to reduce the length of slopes and slope levels. The dimensions of the terraces vary according to the geographical diversity of the landscape, according to the height, width, and length values in relation to the slope angles and slope lengths (Kovář, Bačinová, Loula, & Fedorova, 2016). The efficiency of terraces can be improved by applying tillage practices that do not damage the soil, applying plant lines in the direction of contour lines that can reduce the water flow rate, and the maintenance of ground cover crops. Putra, Triyatno, Syarief, & Hermon (2018) stated that bench terraces, cover-crop planting, crop rotation, and mulch utilization could reduce erosion rates in upstream watersheds.

Organic conservation can be done by arranging spacing and mixed cropping patterns between annual crops and annual crops (agroforestry). This mixed cropping system was applied considering that the four sub-villages had the most severe forest damage during the 2010 eruption, even though it is part of the upstream area of Mount Merapi that functions as a water harvester. The application of agroforestry with mixed cropping patterns of forest plants and seasonal plants has ecological advantages so that it can accelerate the process of vegetation succession and restore biological stability and biodiversity. Consistent with the statement of Elevitch, Mazaroli, & Ragone (2018) that agroforestry is known as a holistic food production system, which can provide environmental, economic, and social benefits. In comparison, Udawatta, Rankoth, & Jose (2019) add information that the integration of agroforestry can improve the biodiversity of agricultural land. Field observations also indicate that mountain ash deposits can form impermeable layers that are difficult for rainwater to penetrate (Fig. 2), thereby reducing the infiltration of water into the soil. The application of mixed cropping patterns in the area can increase water infiltration and reduce the flow rate of water on the soil’s surface so that the erosion of pyroclastic material erosion can decrease.

Merapi is the most active volcano in Indonesia. Saepuloh, Aisyah, & Urai (2015) stated that the activity of Mount Merapi is characterized by small eruptions with periodicity ranging from one to five years. The eruption of the last century was marked

| Sub-villages | Slope (%) | Thickness of volcanic materials (cm) | Rock distribution(%) |
|--------------|-----------|-------------------------------------|----------------------|
| Kaliadem     | 20        | 15 – 32                             | 70                   |
| Jambu        | 25        | 15 – 30                             | 55                   |
| Petung       | 18        | 12 – 26                             | 40                   |
| Kopeng       | 20        | 10 – 18                             | 18                   |
| Batur        | 15        | 5 – 10                              | 18                   |
| Pagerjurang  | 15        | 3 – 8                               | 22                   |
| Kepuh        | 10        | 3 – 7                               | 12                   |
| Manggong     | 15        | 2 – 4                               | 8                    |
by the growth of effusive lava domes and collapsed to produce a “Merapi type” pyroclastic flow. However, the characteristics of the Merapi eruption changed in November 2010. Iguchi, Ishihara, Surono, & Hendrasto (2011) reported the occurrence of 33 times the flow of pyroclastic materials recorded from October 26th to 30th, 2010. The more significant impact caused by this 2010 eruption was the morphological change of the Merapi peak marked by the collapse of the crater cliff (locally known as geger boyo). Before the collapse occurred, this crater cliff played a role in protecting several areas in the surrounding headwaters connecting to Gendol River (located in Kepuharjo Village). This collapse led to the opening upstream of Gendol River, hence enabling the volcanic materials to flow down. Therefore, as a consequence of this collapse, Kepuharjo Village became the area experiencing the most severe damage due to the eruption.

Along with the accumulation of volcanic materials, the Merapi eruption contributed to an extreme change of soil properties in the affected areas. The deposit of pyroclastic materials in each sub-village observed had shaped different soil characteristics, as presented in Table 2. Soil particle density and bulk density are the basic properties of soil physics related to soil porosity. The distribution of soil pores affects soil moisture and aeration. As shown in Table 2, Merapi’s pyroclastic materials had increased the soil porosity, particularly in the regions located close to the mountain peak. This increasing soil porosity led to lower bulk density and lower water holding capacity (Table 2). This condition was also in line with Tanveera, Kanth, Tali, & Naikoo (2016) as the bulk density of soil is higher, the porosity is lower, and subsequently, the water holding capacity of the soil is also low.

Fig. 2. Dense and water-impermeable layer sedimented in the soil surface created by the precipitated volcanic ash
The flow of high-temperature volcanic materials, particularly *nuées ardentes*, diminished the organic matter content in the soil, thus leading to poor C-organic content (Table 2). Compared to these sub-villages presented in Table 2, several regions located more than 8 km (Batur, Pagerjurang, Kepuh, and Manggong) were found to have higher C-organic content. However, these eruption-affected sub-villages did not significantly change the soil pH (Table 2). The measurements of soil acidity level indicate that land in Kepuharjo village has a pH between 5.8-6.2 or around neutral pH, hence making it possible to be used for food crop farming. According to Soti, Jayachandran, Koptur, & Volin (2015), soil pH level ranging from 5.5-6.5 is the pH of the soil solution that is most suitable for the process of nutrient absorption, growth, and development of biomass. A significant change was also found on the soil surface as the precipitated volcanic ash made the soil surface denser and formed puddles when penetrated by water (Fig. 2). Pujiasmanto (2011) stated that one of the characteristics of the ash of Mount Merapi is that it easily hardens at the surface of the ground, making it difficult to penetrate water. Similar results were confirmed by Ildjudin, Erfandi, & Sutono (2012) and Suriaidikarta et al. (2010) mentioning that volcanic ash’s physical properties enabled the formation of highly dense and water-impermeable sediment in the soil surface.

The Center for Volcanology and Geological Disaster Mitigation of Indonesia categorized disaster-prone areas based on the level of possible vulnerability towards the eruption of Mount Merapi. Three sub-villages (Kaliadem, Jambu, and Petung) in Kepuharjo Village were categorized as disaster-prone level III. In comparison, the other five sub-villages (Kopeng, Batur, Pagerjurang, Kepuh, and Manggong) were considered as disaster-prone level II. Anticipating the possibility of the upcoming eruption, the government decided to relocate the villagers in Kepuharjo Village to several new settlement points, such as the Batur sub-village and around the Merapi Golf area. The regions categorized as disaster-prone level III were no longer inhabited due to its vulnerability and are now being converted into forest areas. However, this land conversion was strongly opposed by the residents as they remained fully dependent on fodder grass for animal feed that was commonly obtained in the forest area. As most of the lands in these areas have been certified, local residents wished to own their land. Therefore, residents preferred that their former residential areas be converted into the community forest, making it more accessible for the residents to harvest fodder grass.

Considering the history of the Merapi eruption in 2010, planning of land-use development in Kepuharjo Village was based on the level of disaster-proneness and vulnerability. According to this parameter, Kepuharjo Village was divided into two zones, namely within a radius of less than and more than 8 km from the mountain peak. The first zone of disaster-proneness within a radius of less than 8 km consists of Kaliadem, Jambu, Petung, and Kopeng, and the second zone of disaster-proneness is located within a radius of more than 8 km consists of Batur, Pagerjurang, Kepuh, and Manggong (Fig. 3).

### Table 2. Soil properties found in several sub-villages affected by the Merapi eruption

| Sub-villages | Particle Density (g/cm³) | Bulk Density (g/cm³) | Soil Porosity (%) | Content of C-organic (%) | pH  |
|--------------|------------------------|----------------------|-------------------|-------------------------|-----|
| Kaliadem     | 2.85                   | 1.39                 | 51.2              | 0.76                    | 6.1 |
| Jambu        | 2.57                   | 1.32                 | 48.6              | 0.88                    | 6.2 |
| Petung       | 2.75                   | 1.42                 | 48.4              | 0.78                    | 6.0 |
| Kopeng       | 2.85                   | 1.40                 | 50.8              | 0.82                    | 6.2 |
| Batur        | 2.65                   | 1.48                 | 44.2              | 1.10                    | 5.8 |
| Pagerjurang  | 2.66                   | 1.52                 | 42.8              | 1.12                    | 6.2 |
| Kepuh        | 2.81                   | 1.55                 | 44.8              | 0.98                    | 6.2 |
| Manggong     | 2.98                   | 1.53                 | 48.6              | 1.04                    | 5.9 |
Fig. 3. The division of the area in the southern region of Merapi is based on the 2010 eruption

Regions located within a radius of less than 8 km are now functioning as a community forest. This function facilitates the improvement of water systems and the environment and enables the cultivation of fodder grass as livestock feed. The availability of this grass should be maintained to support the resident farming business that mostly focused on dairy farming, and commonly this species of grass cultivated in this first zone of disaster-prone. This grass is namely Kolonjono grass (*Panicum muticum*) and local fodder grass (*Pennisetum purpureum*) (Fig. 4). This livestock feed is supplemented with organic fertilizer or manure originated from dairy farming waste. According to Sutomo, Hobbs, & Cramer (2015), the abundance of some invasive species, such as *Imperata cylindrica*, *Brachiaria* spp., and *Eupatorium* spp. played an essential role in the vegetative succession of Mount Merapi, supporting the land regeneration in the eruption-affected regions. Moreover, the selection of the best-fit local grass species was reported to be associated with the success of land recovery in the Merapi region (Utami, Purwanto, & Marwasta, 2018). The use of pre-existing grass is considered as a more accessible solution through the fertilization of primary plant nutrients. Revegetation efforts of areas affected by volcanic eruptions, Fiantis, Ginting, Gusnidar, Nelson, & Minasny (2019) stated that nitrogen supply to pioneer plants was hypothesized as the key to replanting in areas affected by volcanic ash. Concerning local wisdom possessed by farmers in reclaiming land affected by volcanic eruptions, Ishaq et al. (2020) reported that the practice of farmers in reclaiming land after the eruption of Mount Kelud was carried out by mixing volcanic ash with mineral soil underneath by hoeing and adding organic fertilizer (chicken manure or crop residues) and inorganic fertilizers (urea or NPK). In addition, Wardoyo & Santoso (2016) had proven that the use of organic matter as a nitrogen fertilizer improved the growth of *Canavalia virosa* and *Flemingia congesta* cultivated in the sandy ash soil of Mount Merapi.
Agroforestry is a form of land use that is in the forest area for annual crops. Agroforestry is a form of forest management that can increase land productivity and provide ecological benefits, especially biodiversity quality. Suprayogo et al. (2020) stated that agroforestry systems with high crown density permanent litter cover can maintain high infiltration rates and can positively impact hydrological function. Agroforestry-based land use development in surrounding MMNP consisted of home gardens, dry fields, and village lands (Suryanto, Hamzah, Mohamed, & Alias, 2011). Soewandita & Sudiana (2014) stated that forest land for heterogeneous forests and homogeneous plantations are suitable for the area of Mount Merapi with a high level of disaster. The agroforestry system between forest plants and animal feed grass is appropriate for the Mount Merapi area with a moderate level of disaster. Based on the grass productivity found in the agroforestry system, grass cultivation in each area has low and high production. It was considering that grass cultivation is one of the main jobs performed by residents, especially those working with dairy farming as their primary economic resource. This dairy farming also provides manure that plays a critical role in providing nutrients and improving soil's ability to store water.

Mount Merapi National Park (MMNP) has been established in 2004 as a conservation area that mainly functions conserving the microclimate quality, hydrology cycle, and agroecosystem in the surrounding regions of Mount Merapi. However, the volcanic eruption that occurred in 2010 had completely changed the existing vegetation structure. This extreme change restricted the forest capacity in the process of rainwater catchment. To restore this vital function, Rahayu et al. (2014) recommended planting pyroclastic sediment-tolerant plants in the area of MMNP. Syahbudin, Meinata, Arifriana, & Wiyono (2020) reported that seven years after Mount Merapi’s eruption, the banks of the Gendol river in Cangkringan District had undergrowth consisting of plants, shrubs, grasses, and seedlings and tree saplings. Dewi et al. (2015) also reported several forest plants that successfully survived during the Merapi eruption, namely pine (Pinus merkusii), jackfruit (Artocarpus heterophyllus), and melinjo (Gnetum gnemon). The survival of these plants might be associated with the canopy characteristics, roots, and stems that allow a promising capacity for the rehabilitation and conservation of water catchment areas, particularly in the Mount Merapi slope. Besides these plants, many species of Acacia decurrens were widely found in the MMNP complex at nearly all growth stages (Haryadi, Sunarto, & Sugiyarto, 2019). Moreover, Sunardi, Sulistijorini, & Setyawati (2017) also reported that A. decurrens was dominantly grown in Cangkringan District. This indigenous species is known for its rapid growth, particularly in regions conferring high temperatures. Therefore, this species is highly suggested to be cultivated, especially in disaster-prone area level III, as it would stimulate the regeneration of the ecosystem service in these highly vulnerable regions. Along with A. decurrens, Panicum muticum or Pennisetum...
purpureum (fodder grass) were also reported to be capable plant species grown as the primary vegetation in Merapi slope. The utilization of the regions located within a radius of less than 8 km from the Mount Merapi peak as community forest was aimed at preventing erosion and volcanic material avalanches as the slope of these regions range from 15 to 30%. The recommended land use for this kind of condition was the alley cropping system combining the forest plants and fodder grass on its terrace part (Fig. 5a).

In contrast, the regions located within a radius of more than 8 km showed a lower slope (<15%) and thinner layers of volcanic materials deposition (<10 cm). Even the sedimented sand and ash in these areas were the potential to be further processed using a hoe. Compared to the regions with higher slopes, these regions were possible to be further utilized for food crops farming with dryland cropping patterns (Fig. 5b) as well as animal feed businesses. However, its utilization should be supported by primary tillage and add manure or organic fertilizer. Due to the sedimented volcanic materials, deep and thorough tillage was required to attain the original soil layer previously covered by the volcanic materials (Fig. 6). In line with this recommendation, Utami, Purwanto, & Marwasta (2018) mentioned that deep tillage of 20 cm was suggested to discard the sedimented volcanic materials in a thickness of more than 10 cm.

Based on the slope condition for each sub-village (Table 1), this study suggested using alley cropping systems to combine the annual and food crops with being intensively cultivated, especially in the land with less than 15% slope. Combining 25% of annual crops with 75% of food crops in the alley cropping was considered the most suitable land use planning to be developed in several regions affected by the Merapi eruption. This model offered several advantages, as follows: (1) reduced risk of run-off, (2) prevented the deposition of pyroclastic materials transported through erosion, (3) improved the nutrient use efficiency, (4) sequestered the carbon, and (5) increased the biodiversity. Agroforestry-based land use was considered a holistic food production system that provided various benefits to the environment, society, and economy of the local community (Elevitch, Mazaroli, & Ragone, 2018). Additionally, the use of alley cropping systems could also develop an economically, environmentally, and socially sustainable farming system (Xu, Bi, Gao, & Yun, 2019).

Fig. 5. Comparison of land use model designated for the southern regions in Merapi slope with high (a) and low (b) slopes
CONCLUSION

Based on the above discussion, this paper contributed the significant finding that the land use in the southern region of Mount Merapi was categorized into two types of regions; (1) region within a radius of less than 8 km from the peak was recommended to function as a conservation area consisting of a community forest, and fodder grass farming, and (2) the regions located within a radius of 8 km or more could be used for agricultural practices. Besides that, integrated dryland farming systems (alley cropping system, conservation tillage, mix cropping) combined with the annual crops should be promoted and adopted for managing and increasing soil and crop productivity in sustainable ways.

ACKNOWLEDGEMENT

The authors would like to acknowledge local government for permitting the use of location and the Head of Soil and Plant Nutrition Laboratory Universitas Muhammadiyah Yogyakarta for providing material and equipment.

REFERENCES

Budiyanto, G., Aini, L. N., & Setyawan, H. (2019). Landscape planning of tobacco plantation based on erosion potential in Eastern Region of Mount Sindoro Temanggung. In IOP Conference Series: Earth and Environmental Science (p. 012072). IOP Publishing. https://doi.org/10.1088/1755-1315/393/1/012072

Dewi, W. S., Budiastuti, M. S., Sumarno, Nawawi, N. F., Christa, B., & Komariah. (2015). Hydrological performance of pine tree, melinjo and jackfruit for rehabilitation of catchment area of slope of Mt. Merapi, Indonesia after 2010 eruption. Journal of Environment and Earth Science, 5(8), 173–179. Retrieved from https://www.iiste.org/Journals/index.php/JEES/article/view/22038

Elevitch, C. R., Mazaroli, N. D., & Ragone, D. (2018). Agroforestry standards for regenerative agriculture. Sustainability (Switzerland), 10, 3337. https://doi.org/10.3390/su10093337

Fiantis, D., Ginting, F. I., Gusnidar, Nelson, M., & Minasny, B. (2019). Volcanic ash, insecurity for the people but securing fertile soil for the future. Sustainability (Switzerland), 11(11), 3072. https://doi.org/10.3390/su11113072

Haryadi, Sunarto, & Sugiyanto. (2019). Vegetation analysis of the secondary forest area of Mount Merapi National Park. Jurnal Biodjati, 4(1), 50–57. https://doi.org/10.15575/biodjati.v4i1.4239

Idjudin, A. A., Erfandi, M. D., & Sutono. (2012). Teknologi peningkatan produktivitas lahan endapan volkanik pasca erupsi Gunung Merapi. Jurnal Sumberdaya Lahan, 6(1), 33–44. Retrieved from http://ejurnal.litbang.pertanian.go.id/index.php/jsl/article/view/6300

Iguchi, M., Ishihara, K., Surono, & Hendrasto, M. (2011). Learn from 2010 eruptions at Merapi and Sinabung volcanoes in Indonesia. Annual Report of Disaster Prevention Research Institute, Kyoto University, 54B, 185–194. Retrieved from https://www.dpri.kyoto-u.ac.jp/enpo/no54/ronbunB/a54b0p22.pdf
Gunawan Budiyanto: Planning for Disaster-Prone Areas in Southern Region of Mount Merapi

Ishaq, R. M., Saputra, D. D., Sari, R. R., Suprayogo, D., Widianto, Prayogo, C., & Hairiah, K. (2020). Turning volcanic ash into fertile soil. Farmers’ options in coffee agroforestry after the 2014 Mount Kelud eruption. AGRIVITA. Journal of Agricultural Science, 42(1), 78–91. https://doi.org/10.17503/agrivita.v42i1.2494

Kadavi, P. R., Lee, W.-J., & Lee, C.-W. (2017). Analysis of the pyroclastic flow deposits of Mount Sinabung and Merapi using landsat imagery and the artificial neural networks approach. Applied Sciences (Switzerland), 7(9), 935. https://doi.org/10.3390/app7090935

Kovář, P., Bačinová, H., Loula, J., & Fedorova, D. (2016). Use of terraces to mitigate the impacts of overland flow and erosion on a catchment. Plant, Soil and Environment, 62(4), 171–177. https://doi.org/10.17221/786/2015-PSE

Kunarsa, A., Syabana, T. A. A., Mareti, S., Azwar, F., Kharis, T., & Nuralamin. (2019). Analisis spasial tingkat kerusakan Kawasan Suaka Margasatwa Padang Sugihan Sumatera Selatan. Jurnal Penelitian Hutan Dan Konservasi Alam, 16(2), 191–207. https://doi.org/10.20886/jphka.2019.16.2.191-206

Lavigne, F., Morin, J., Mei, E. T. W., Calder, E. S., Usamah, M., & Nugroho, U. (2018). Mapping hazard zones, rapid warning communication and understanding communities: Primary ways to mitigate pyroclastic flow hazard. In C. J. Fearmley, D. K. Bird, K. Haynes, W. J. McGuire, & G. Jolly (Eds.), Observing the Volcano World (pp. 107-119). Cham: Springer. https://doi.org/10.1007/11157_2016_34

Nugraha, A. L., Haniah, Firdaus, H. S., & Haeriah, S. (2019). Analysis of risk assessment of Mount Merapi eruption in settlement area of Sleman Regency. IOP Conference Series: Earth and Environmental Science, 313, 012003. https://doi.org/10.1088/1755-1315/313/1/012003

Pujiasmanto, B. (2011). Strategi pemulihan lahan pasca erupsi gunung api (Segi agroekosistem, domestikasi tumbuhan herba untuk obat; dan action research). Journal of Rural and Development, 2(2), 85–96. Retrieved from https://jurnal.uns.ac.id/rural-and-development/article/view/23398

Putra, A., Triyatno, Syarief, A., & Hermon, D. (2018). Penilaian erosi berdasarkan metode USLE dan arahan konservasi pada DAS air dingin bagian hulu kota Padang-Sumatera Barat. Jurnal Geografi, 10(1), 1–13. https://doi.org/10.24114/jg.v10i1.7176

Rachmah, Z., Rengkung, M. M., & Lahamendu, V. (2018). Kesesuaian lahan permukiman di kawasan Kami Gunung Dua Sudara. Spasial: Perencanaan Wilayah Dan Kota, 5(1), 118–129. Retrieved from https://ejournal.unsrat.ac.id/index.php/spasial/article/view/19285

Rahayu, Ariyanto, D. P., Komariah, Hartati, S., Syamsiyah, J., & Dewi, W. S. (2014). Dampak erupsi Gunung Merapi terhadap lahan dan upaya-upaya pemulihannya. Caraka Tani: Journal of Sustainable Agriculture, 29(1), 61–72. https://doi.org/10.20961/carakatani.v29i1.13320

Rahman, M. B., Nurhasanah, I. S., & Nugroho, S. P. (2016). Community resilience: Learning from Mt Merapi eruption 2010. Procedia - Social and Behavioral Sciences, 227, 387–394. https://doi.org/10.1016/j.sbspro.2016.06.090

Rindrasih, E. (2013). The impact of environmental changes after Merapi eruption 2010 toward the image of tourism. Jurnal Nasional Pariwisata, 5(1), 6360. Retrieved from https://jurnal.ugm.ac.id/tourism_pariwisata/article/view/6360

Sadono, R., Hartono, Machfoedz, M. M., & Setiaji. (2017). Monitoring land cover changes in the disaster-prone area: A case study of Cangkringan Sub-District, the flanks of Mount Merapi, Indonesia. Forum Geografi, 31(2), 209–219. https://doi.org/10.23917/forgeo.v31i2.5324

Saepuloh, A., Aisyah, N., & Urai, M. (2015). Detecting surface structures after large eruption of Mt. Merapi in 2010 using ALOS/PALSAR data. Procedia Earth and Planetary Science, 12, 84–92. https://doi.org/10.1016/j.proeps.2015.03.042

Soewandita, H., & Sudiana, N. (2014). Analisis penggunaan dan kesesuaian lahan berdasarkan potensi bahaya letusan Gunung Merapi. Jurnal Sains Dan Teknologi Indonesia, 16(3), 8–19. https://doi.org/10.29122/jsti.v16i3.3418

Soti, P. G., Jayachandran, K., Koptur, S., & Volin, J. C. (2015). Effect of soil pH on growth, nutrient uptake, and mycorrhizal colonization in exotic invasive Lygodium microphyllum. Plant Ecology, 216, 989–998. https://doi.org/10.1007/s11278-015-0484-6

Sunardi, Sulistijorini, & Setyawati, T. (2017). Invasion of Acacia decurrens Willd. after eruption of Mount Merapi, Indonesia. Biotropia, 24(1), 35–46. https://doi.org/10.11598/btb.2017.24.1.524
Suprayogo, D., van Noordwijk M., Hairiah, K., Meilasari, N., Rabbani, A. L., Ishaq, R. M., & Widianto. (2020). Infiltration-friendly agroforestry land uses on volcanic slopes in the Rejoso Watershed, East Java, Indonesia. *Land, 9*(6), 240. https://doi.org/10.3390/land9060240

Suriadi, D. A., Abbas, A., Sutono, Erfandi, D., Santoso, E., & Kasno, A. (2010). *Identifikasi sifat kimia abu volcan, tanah dan air di lokasi dampak letusan gunung Merapi* (No. 010). *Makalah Merapi*. Bogor, ID. Retrieved from http://balittanah.litbang.pertanian.go.id/ind/dokumentasi/lainnya/Makalah Merapi 010. revisi.pdf

Suryana. (2010). *Metodologi penelitian: Metodologi penelitian model prakatis penelitian kuantitatif dan kualitatif*. Bandung, ID: Universitas Pendidikan Indonesia. Retrieved from http://file.upi.edu/Direktori/FPEB/PRODI_MANAJEMEN_FPEB/196006021986011-SURYANA/FILE__7.pdf

Sutomo, Hobbs, R. J., & Cramer, V. A. (2015). Plant community structure and composition in secondary succession following wildfire from Nuees Ardentes of mount Merapi, Indonesia. *Tropical Plant Research, 2*, 204214. Retrieved from http://lipi.go.id/publikasi/plant-community-structure-and-composition-in-secondary-succession-following-wildfire-from-nues-ardentes-of-mount-merapi-indonesia/24562

Syahbudin, A., Meintara, A., Arifiana, R., & Wiyono. (2020). Short communication: The composition of undergrowth vegetation in the Gendol Riverbank, Sleman District, Yogyakarta, Indonesia. *Biodiversitas, 21*(5), 1786-1792. https://doi.org/10.13057/biodiv/d210503

Tanveera, A., Kanth, T. A., Tali, P. A., & Naikoo, M. (2016). Relation of soil bulk density with texture, total organic matter content and porosity in the soils of Kandi Area of Kashmir Valley, India. *International Research Journal of Earth Sciences, 4*(1), 1–6. Retrieved from http://www.isca.in/Earth_SCI/Archive/v4/i1/l.ISCA-IRJES-2015-015.php

Udawatta, R. P., Rankoth, L. M., & Jose, S. (2019). Agroforestry and biodiversity. *Sustainability (Switzerland), 11*, 2879. https://doi.org/10.3390/su11102879

Utami, S. N. H., Purwanto, B. H., & Marwasta, D. (2018). Land management for agriculture after the 2010 Merapi Eruption. *Planta Tropika: Journal of Agro Science, 6*(1), 32–38. https://doi.org/10.18196/pt.2018.078.32-38

Wardoyo, S. S., & Santoso, A. Z. P. B. (2016). Environmental adaptability of *Canavalia virosa* and *Flemingia congesta* to sandy ash soil of Merapi volcano, Java. *Journal of Degraded and Mining Lands Management, 3*(4), 659–662. https://doi.org/10.15243/jdmlm.2016.034.659

Xu, H., Bi, H., Gao, L., & Yun, L. (2019). Alley cropping increases land use efficiency and economic profitability across the combination cultivation period. *Agronomy, 9*(1), 34. https://doi.org/10.22146/ijag.17299

Xiang, Z., Sheng, L., Yang, J., Chen, X.-A., Kong, L., & Wagan, B. (2015). Effects of land use and slope gradient on soil erosion in a red soil hilly watershed of Southern China. *Sustainability (Switzerland), 7*, 14300–14325. https://doi.org/10.3390/su71014309