Agricultural Recovery Action for Area Affected by 2010 Merapi Volcano Eruption, Indonesia

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Abstract
Remote sensing and GIS approaches are used for inventory of agricultural land affected by 2010 Merapi volcano eruption. The work was executed to support the area arrangement and recovery efforts of farmland in areas hit by material from volcano eruption in 2010. Satellite imageries were used to explore the behavior of Merapi volcano, particularly the sprawl of material eruption, damages of agricultural land and other type of landuse. Furthermore, laboratory analysis for material eruption, i.e. volcanic ash, sandy lava flow were conducted, then be used as a basic source to support the post recovery efforts of agricultural land. Recovery effort can be split up into region of: (1) the upper slope further down to the stream river which directly hit by spinning cloud of super heated gases and molten lava and (2) sloping areas buried by volcanic ash material and mud flow. Selected crops having fast rate of growth favored its rapid regeneration after being scorched by hot gas clouds erupting from crater is a beneficial adaptation while facing volcanic disaster.

1. Introduction

Merapi stratovolcano, with a height of 2965 m above sea level is a very active volcano with period of eruption between 3-6 years and 9-12 years for a major eruption (BNPB, 2010). It is located at about 30 km to the north of Jogyakarta town, Central Java Indonesia. The Merapi Volcano has had more than 81 historical eruptions since the 16th century (Voight et al., 2000) and is known as the most dangerous volcano, with a history of deadly eruption, in Indonesia. It has erupted many times during the last century (1872, 1883, 1906, 1930, 1954, 1957, 1992, and 1998) (Gertisser and Keller, 2003) and in 2006 (Sutikno et al., 2007 and Charbonnier and Gertisser, 2008,). Merapi strato volcano latest eruption occurred on 26 October to 30 November 2010, with peak eruption on 15 November, 2010, was categorized as: central vent eruption, explosive eruption, pyroclastic flows, and lava dome extrusion, caused 24 fatalities, massive damage (land, property, infrastructure), mudflows (lahars), and more than 1300 people were evacuated (Global volcanism Program, 2011 and GMU, 2011,). The volume of all materials erupted was estimated to be 150 x 10^6 m^3, the eruption covered an area of about 3,438 ha. A huge new material resource was made available, which has benefits for soil rejuvenation. In the long term material eruption has a positive impact such as profitable to increase soil fertility, rich stock for building material etc. (Bahagiarti, 2010 and Anda and Sarwani, 2012). In general, soil resources in Merapi Volcano and its vicinity areas, vary greatly, which is determined by slope, bed rock, and climate. In the upper slope region, soil are typically dominated by Andisols and Alfisols which are formed from volcanic material, that is generally rich in organic material, so that the fertility of the soil quite well. On the middle, lower slope and plane region Inceptisol is most common soil, formed from materials that were weathered volcanic, so that the lower fertility than Andisols and Alfisols (Agency for Agricultural Research and Development, 2006 and 2011). Type of landuse the slope of Merapi volcano when viewed from the crest of volcano consists of: forest, shrubs, tree crops/plantations are dominated by annual crops and fruit crops, dry land agriculture (annual crops), grass,/bare soil, paddy field (irrigated and rainfed) and settlements. (ICALRD, 2008). Remote sensing and GIS technologies which have the ability to grab information quickly, has been widely used to assess post disaster areas (Verstapen, 1983 and Rejaie and Shinozuka, 2004). This study aims to conduct inventory of the landuse and land cover damage by the 2010 Merapi volcano eruption, to support recovery efforts and management of the region damaged by the eruption, particularly in the agricultural sector.

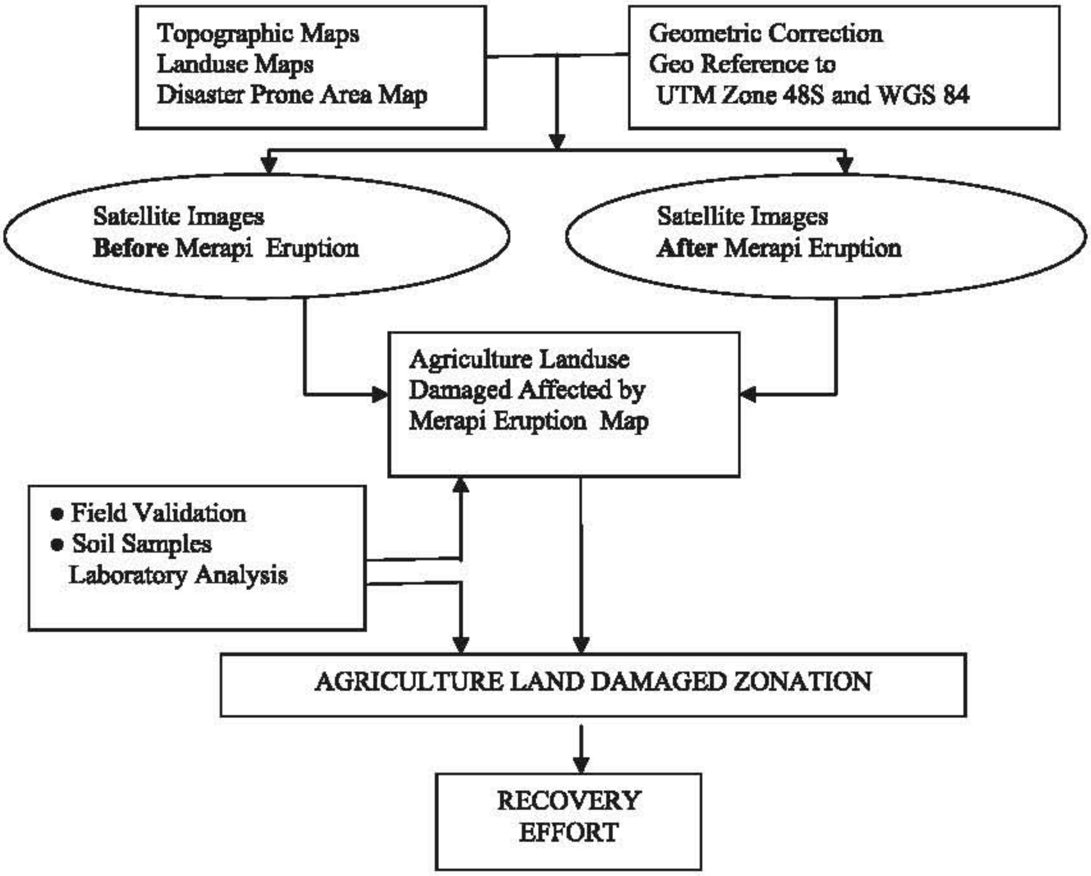

Figure 1: Scheme of the spatial data analysis to design agricultural recovery effort for damaged areas affected by 2010 Merapi volcano eruption

2. Materials and Method

Images and maps of Merapi were obtained from various sources, including: (1) Satellite imageries of Merapi volcano with acquisition date before eruption and after eruption. Satellite images with acquisition date before eruption are used: Landsat ETM acquisition dated on 17th March 2009, and 4th May 2009, Satellite images after eruption in 2010: Landsat ETM image acquisition dated on 19th February 2011 and 12th May 201, and SPOT-5 acquisition dated on 12th November 2010; (2) Indonesian Topographical Maps at scale of 1: 25.000, especially the eruption affected area published by Bakosurtanal. (3) Disaster Prone Area Map of Merapi Volcano, published by Badan Nasional Penanggulangan Bencana-BNPB (National Disaster Management Agency) dated on 19th November 2010. To get more detail information related to Merapi volcano, therefore the image is cropped to around Merapi region as shown in Figure 2 The optical sensors loaded on the platform of satellite, i.e Landsat TM-7 and SPOT-5 could provide information of land surface condition, which varied according to the growth of crops, type of land use and according to level of damaging agricultural land caused by Merapi volcano eruption. In tropical humid region, however, it has a constraint in acquiring promptly temporal data, where the percentage of occurrence of coverage by cloud is very high. Combination or analysis of multi temporal data is a key to overcome the limitation of acquiring data without effect of cloud cover. Landsat TM and SPOT are optical sensor satellite remote sensing data, with spatial resolution applicable to producing map of 1:50.000 scale, which might cover the whole area of study site more than several times without cloud. In this study, all the collected data were still covered with scattered cloud with the ratio of about 10%. In order to remove the part of cloud cover and shadow of cloud, first each scene was classified by ISODATA method and cloud affected areas were marked.

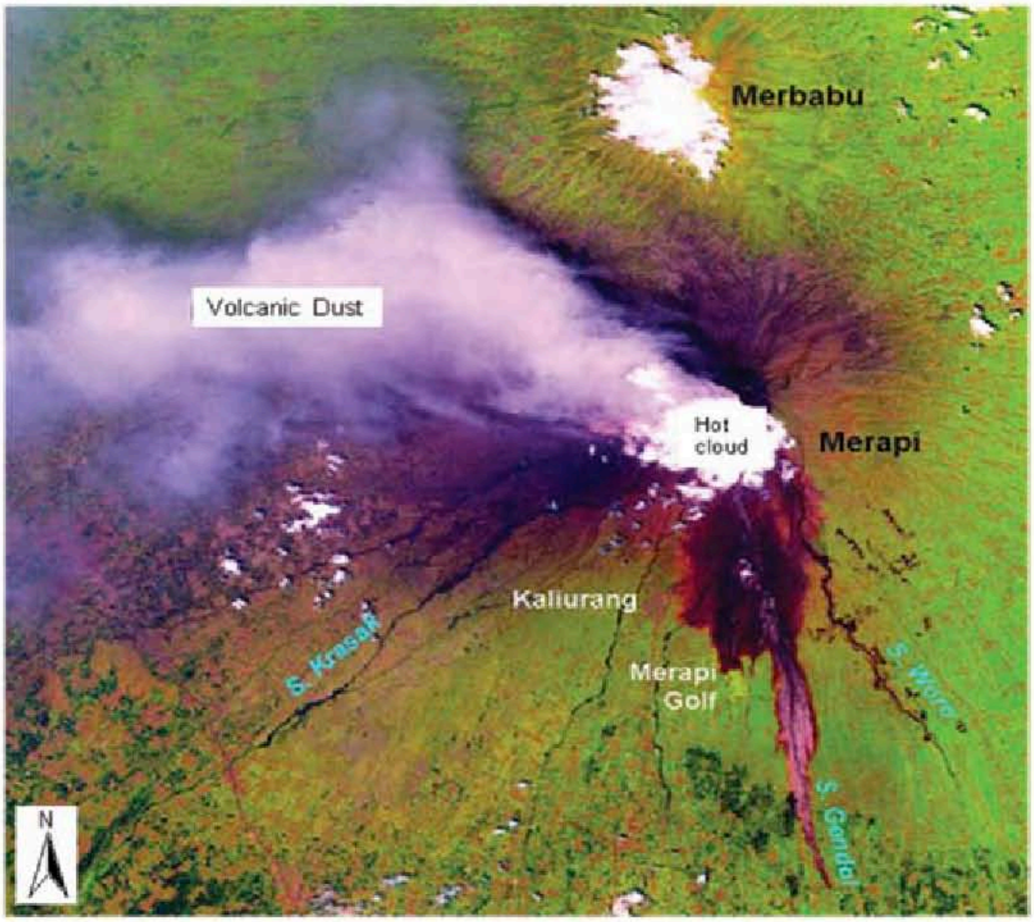

Figure 2: SPOT-5 (acq.date Nopember 12, 2010) depicted spatial distribution of 2010 Merapi volcano eruption, spining clouds of super heated gases, lava flow of pyroclastic avalanches, flow down along Gendol river

Then the value of all indices changed into -1 for the affected area. Calculated maximum value 3 indices among all Landsat data represented the characteristics of variation of land cover condition at the pixel, which would be used for discriminating land use (Uchida, 2009). Digital satellite data (Landsat TM and SPOT-5) were georeferenced to UTM zone 48 South WGS 84 and clipped out with administrative boundary related to damaged areas affected by Merapi volcano eruption. All of bands were used on the separability evaluation of the spectral signatures. Smaller than 1 ha size of salt and pepper noises were removed with contiguity analysis. With the help of training data sets collected on the ground, manual (visual) interpretation, which is the conventional but well-established procedure for aerial photo interpretation, was practiced to carry out agricultural land use characterization. Time series landuse and land cover changes before eruption and after eruption were generated using remote sensing techniques, i.e Earth resources (ER) Mapper software, to assess agriculture land and settlements damaged and its infrastructures caused by Merapi volcanic eruption. The most recent images were validated by ground truthing conducted in December, 2010; February, 2011 and July, 2011, to gather geo-referenced information on existing landuses and agricultural damage. For the classification, maximum likelihood supervised classifier was used and refined by hybrid knowledge-based approach (Akbar et al., 2000 and Singh et al., 2001) to reach at least 80% assessment accuracy. Ground truth and field validation were conducted to verify the initial landuse satellite image classification and were corrected and matched with actual condition. Ground truth and field validation included (a) examine the relationship between "spectral reflectance performance of the image" with actual condition on the ground surface, especially regarding the kinds/types of land use or land cover, relief/ topography, and wetness/water availability of

Merapi volcano eruption affected area; (b) soil and material eruption samples collection for physical and chemical laboratory analysis, then used as a basic support for the recovery efforts of agricultural land. Field validations, soil and material eruption samples were selected by cross sectional transects stretching from the upper slope of Merapi volcano towards the lower slopes damaged affected areas, or by random observations depending on the type and intensity of eruption. Scheme of the spatial data analysis to design agricultural recovery effort is presented in Figure 1. Study of natural disaster such as volcano eruption, are needed to deliver real time or nearly real time information to help rescuers or engineers during emergency response. In this study, action on recovery and rehabilitation as well as management of region of agricultural land area affected by the eruption, based on type of material eruption and farm level land management were studied.

3. Results and Discussion

3.1 The 2010 Eruption and Volcanic Hazard Zoning

The event of 2010 Merapi volcano eruption, was also capable to change the landscape, destroying farmland and the surrounding settlements, hoards of several hamlets due to spinning clouds of super heated gases, and lava flow of pyroclastic avalanches. One of the most feared aspects of Merapi volcano, and something that is characteristics of this type of volcano, is the eruption not just of magma but of spinning clouds of super heated gases (called "wedus gembel" in Javanese and "awan panas" in Indonesian and "nuee ardente" in the international literature). These clouds descend the slopes at speeds of 200-300 km/hour, bear temperatures of 200-300°C, and present a far greater threat to life and limb than the much slower moving rivers of melten lava. Lava flows (Walkers, 1973) associated with strato volcanoes often emerge in the lower parts of the volcanic cones, and accompanying glowing clouds may be particularly dangerous (Fisher, 1980). Spatial distribution of 2010 Merapi Volcano Eruption and its damaged affected areas presented in Figure 3 Villagers on the slopes of Merapi commonly speak, indeed of only two volcanic hazards: these heated gases, and mudflow (the mixtures of ash sandy material and water) called lahar dingin that also can descend the slope at great, destructive speed (Verstappen H.Th, 1963 and Sparks, 1981). The wind direction at the time of eruption is an important element in their distribution. Hot pyroclastic flows and cold volcanic mud flows (lahar) are mostly concentrated in valleys and ravines. The longest distance ever travelled pyroclastic material with super heat gases recorded 13 km (1972 eruption) and 14 km at along Gendol river (2010 eruption). The ill-famed mudflows endangering the west and southwest slopes of the Merapi volcano, central Java, Indonesia. Even now, volcanic disaster ranks high among natural hazards in countries where actives volcanoes occurs in densely populated areas. The assessment of these hazards then becomes a major issue in environmental management with the aim of preventing or mitigating the disastrous effects of volcanic eruption (Michael D.R., and Hudayana B, 2008). The proper assessment of time and magnitude of the eruption, particularly when evacuation of the population from endangered areas is primarily needed. Evacuation should be effectuated timely, but on the other hand, not too early, unnecessarily or in the wrong areas. Figure 3 offers a broad view of volcanic hazard zoning of the Merapi volcano, central Java. This map in Indonesia is called "Peta Kawasan Rawan Bencana-KRB/ Disaster prone areas". Volcanic hazard map of the Merapi volcano, Central Java showing a closed/restricted in which various pyroclastic flows, glowing cloud risk is always present and directly hit by volcanic eruption, indicated as zone 3 (KRB-3). Two further hazard classes as KRB-2 and KRB-1 are stretch along the major ravines of river radiating from the top area of the volcano and relates to volcanic mud flows. Since they traverse the densely populated lower slopes of the volcano, the danger is concentrated there. The most active mudflows in the last decades, occurs in the South West slope of Merapi volcano where settlements and bridges in particular along the road Magelang – Jogyakarta, are affected. Volcanic Hazard Zone-3 or KRB-3 is situated at a radius of less than 5 km from the central eruption (crater of the Merapi volcano). Zone-2 or KRB-2 is the region situated at a radius of 5 to10 km from the central eruption and Zone-1 or KRB-1 is the region situated at a radius of 10-15 km from the central eruption. Zone I or KRB-1 has less or no agricultural land damaged directly by Merapi volcano eruption, however KRB-1 was not described in this paper. The volume of eruptive material in 2010 at the upper slope was estimated 150×10^6 m^3. Heavy rainfall at the upper slope of Merapi, could trigger flash flood mixed with mud flow (mostly loose sandy material eruption). Debris mudflow down the slope progressively increasing water content with high speed laminar or turbulent motion, can reach a distance of 20 km from the upper slope. These mud flow down along the ravine of rivers at the western and southern slope of Merapi volcano, such as: Putih River, Krasak River, Boyong river, Kuning river, Pabelan river and

Gendol river. Flash flood of mudflow capable to change the landscape, destroying farmland and the surrounding settlements, hoards of several hamlets from the stream nearby. Based on analysis, the pair of satellite images before and after eruption, followed by field validation, the eruption covered an area of about 3,438.5 ha mostly agricultural land. Damaged areas buried by material eruption in the region of Volcanic Hazard Zone-3 (KRB-3) as amount of 3,115.4 ha including Yogyakarta and Central Java province are 1,486.4 ha and 1,629 ha, respectively, (as of as August 2011). Damaged areas buried by material eruption in the KRB-2 area as about 323.1 ha, including Yogyakarta Province and Central Java province are 82.1 ha and 241 ha, respectively. Type of farmland damaged by Merapi volcano eruption are: mixed tree crops, plantation, paddy field and food crops dry land, and settlement as about of 1,592.8 ha in KRB3 and as about of 272.2 ha in KRB-2. Other type of land cover/landuse affected area such as forest, shrubs and bushes, bare land estimated at about 1,3114 ha. Type of landuse/land cover damaged by 2010 Merapi volcano presented in Table 1 and its distribution presented in Figure 3.

3.2 Effect of Material Eruption to Soil Characteristics

Material volcanic of Merapi eruption, buried agricultural land, occurred several times during the event of volcano eruption. Thickness of buried volcanic ash mostly influenced by wind direction and the distant from the central eruption. Buried of material volcanic (dominated by ash material) has accumulated 5 to 25 cm thick from the ground surface, however, the effort of mixing with original topsoil underneath should be implemented by farmers for growing agricultural crops. This ash layer if not immediately treated by mixing with the original soil layer will harden forming a pan layer as a waterproof layer. Farming land close to river mainly at Gendol river (14 km along down stream Gendol river, for about 100- 500 m wide from the bank of river) mostly buried by debris avalanches and mudflow with thickness varied from 30 cm to 350 cm.

Table 1: Type of Landuse/ Land cover Damaged Affected by 2010 Merapi Volcano Eruption

Material Eruption/ Landuse/ Land cover	Volcanic Hazard zone-3 (ha)		Volcanic Hazard Zone-2 (ha)		Total Area Damaged (ha)
	Yogyakarta	Central Java	Yogyakarta	Central Java	
Pyroclastic and lava flow					
Forest	90.8	6.6	-	-	97.4
Plantation	353.9	11.7	-	-	365.6
Settlements	81.9	-	-	-	81.9
Mixed Tree crops	200.1	392	1	-	593.1
Shrubs and Bushes	310.7	390.4	3	-	704.1
Bare lands	92.9	177.3	-	-	270.2
Paddy filed	33.4	8.9	-	-	42.3
Dry land/food crops	199.8	392	-	-	591.8
River Plain	40.3	48	-	-	88.3
Sub Total -1	1,403.8	1,426.9	4	-	2,834.7
Debris and Mudflow					
Forest	14.2	4.2	-	-	18.4
Plantation	6.3	23.4	5.9	11.7	47.3
Settlements	1.5	5.9	1.9	1	10.3
Mixed Tree crops	3.5	4.9	8.4	19	35.8
Shrubs and Bushes	21	84.7	16.6	18.5	140.8
Bare lands	1	38.1	5.5	34.9	79.5
Paddy filed	31.5	11.1	31.4	83	157
Dry land/food crops	3.6	1.8	8.4	18.3	32.1
River Plain	-	28	-	54.6	82.6
Sub Total-2	82.6	202.1	78.1	241	603.8
GRAND TOTAL	1,486.4	1,629	82.1	241	3,438.5

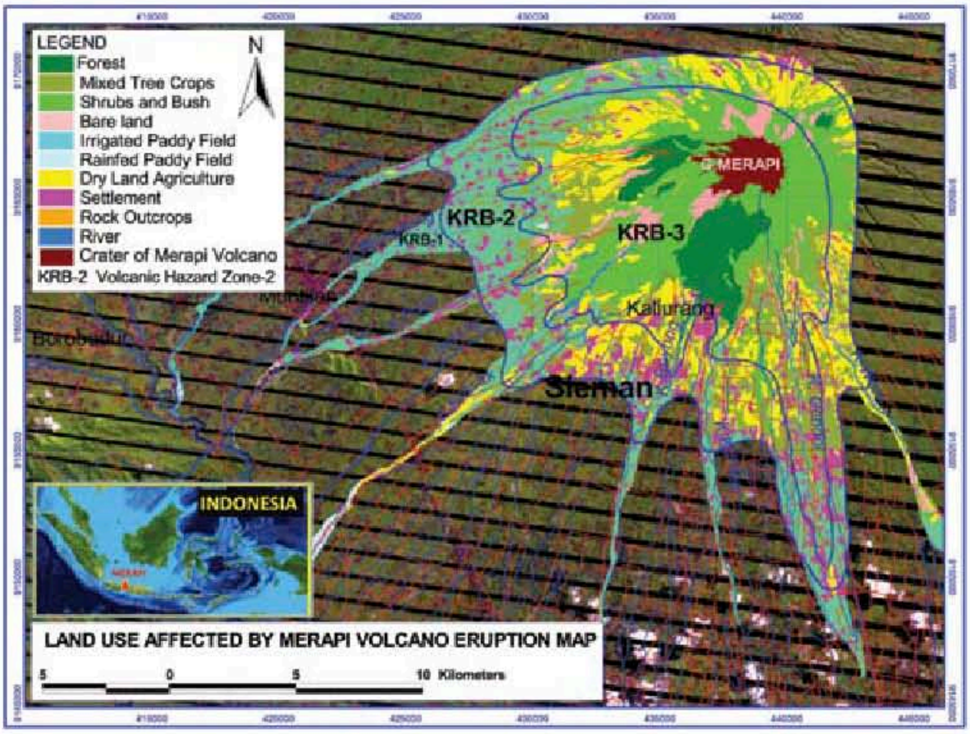

Figure 3: Landuse damaged affected by 2010 merapi volcano eruption, in Jogyakarta and Central Java Provinces, Indonesia

Referring to soil samples analysis, debris and mud flow contain more than 70% sand fraction, will impact to decline its hydrological functions with low water holding capacity. Therefore, buried sandy material should be removed in order to get agricultural crops growing well. The chemical properties of volcanic material eruption (ash and sand), and original soil of Merapi volcano resulted by Soil Research Institute laboratory analysis, showed that: volcanic ash contains: silica (SiO_2) 54 percent, aluminum (Al_2O_3) 18 percent, sulfur (S) 5 percent, and chloride (Cl) 6 percent. The remaining nutrients (17 percent) consists of calcium (Ca), magnesium (Mg), potassium (K), iron (Fe) and other micro elements. The elements were very beneficial to the plant growth, especially rice and seasonal food crops, so that the stalks can stand growing up, in addition crops resistance enough to pests and diseases. Sulfur is needed for plants to initiate on generating essential in situ nutrients, while the availability of chloride is to maintain the balance of the osmotic pressure of plant cells. Referring to the chemical soil characteristics, farmers can regrow their agricultural field as soon as possible with deep ploughing, breaking out the harden ash layer and mixed with the original top soil underneath. Ash volcanic contains aluminum with silica. If the water is soluble at low pH then it causes the plant poisoning. Aluminum can be neutralized with an organic fertilizer or compost or manure with doses 50-20 tonnes per ha. Thus, improvement of irrigation facilities (repair dam/weir damaged, cleaning of irrigated channel), seeking new sources of spring water to support the guarantee of the availability of irrigation water. Planning of optimal use of the land, the proper relocation of settlements, major structures, bridges, etc., are other matters that should be guided by the results of the volcanic adverse effects with respect to irrigation, excessive sedimentation in the rivers near active volcanic cones should be included. Furthermore, implementing protective measures such as reforestation of devastated slopes, construction of check dams in ravines affected by mudflows may be applied.

3.3 Post Eruption Recovery Effort

Based on the type of material eruptions, agricultural land recovery effort and arrangement of the region can be split up into area of: (a) damaged areas were directly affected by various pyroclastic flows, glowing cloud risk is always present and directly hit by volcanic eruption. It is situated at radius less than 5 km from the crater of Merapi volcano, and belong to volcanic hazard zone-3 (KRB-3). This zone should be remained to bare land or for forest protection; (b) damaged area of Gendol river. It is situated from the peak of Merapi volcano stretched to down stream river and it vicinity areas (200-500 meter wide) along 14 km till Morangan hamlet. Debris volcanic material and former heated gases flow was also concentrated along Gendol river, pile up and destroyed agricultural land and settlement of Gendol river nearby. This zone is recommended as a green belt or buffer zone; (c) agricultural land region mostly buried by volcanic ash, thickness of ash layer deposit as about 5 to 25 cm. Commonly this region situated in 5-10 km from the center eruption at the part of west and southern slope of Merapi volcano, and belongs to volcanic hazard zone-2 (KRB-2). Land preparation for cultivation was done by applying deep ploughing to break ash pan layer then mixed with original top soil, which will improve soil characteristics. Provision of organic fertilizer/ green manure is urgent to rehabilitate soil fertility; and (d) river plain of major rivers radiating from the crest of Merapi volcano, related to debris mudflow down slope with high speed flash flood, can reach a distance of 20 km from upper slope. Rivers plain of River: Pabelan, Kuning, Putih, Krasak, Blongkeng, Woro are potentially damage prone areas caused by flash flood of debris and mudflow. Design buffer zone is the best way to conserve these river plain along the stream river. Buffer zone preparation as a green belt should be conducted at least 100 - 300 m from the bank of river. Buffer zone should be free from settlement and farming.

4. Conclusions

Satellite remote sensing and GIS technologies have ability to grab information quickly, which could be widely used to assess volcanic eruption and its impact. Volcanic hazard zoning is beneficial as a guide on post eruption recovery effort and planning of optimal use of land, proper reallocation of settlements, infrastructure rehabilitation, combating the adverse effects with respect to irrigation, and other matter related to management volcanic hazards region. The assessment of volcanic hazard becomes a major issue in environmental management with the aim of preventing and mitigating the disaster effect of volcano eruption.

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References

Abkar, A. A., Sharifi, M. A. and Mulder. N. J., 2000, Likelihood Based Image Segmentation and Classification: A Framework for the Integration of Expert Knowledge in Image Classification Procedure. *Int. J. Appl. Earth Observation and Geoinf.* 2(2); 78-86.

Agricultural Agency for Research and Development (IAARD), 2006, Report on 2006 Merapi Volcano Eruption. Agricultural Sector Research Team. Bogor. June 2006 (un-published).

Agricultural Agency for Research and Development (IAARD), 2011, Quick Assessment on Eruption Impact of Merapi Volcano in the Agricultural Sector. *Agricultural Agency for Research and Development.* Jakarta.

Anda, M. and Muhrizal, S., 2012, Mineralogy, Chemical Composition, and Dissolution of Fresh Ash Eruption: New Potential Source of Nutrients. *Soil Sci.Soc.Am.*J.76:2012.SSSAJ: Vol. 76 Number 2 (March –April 2012).

Bahagiarti, S., 2010, Merapi Eruption and Local Wisdom. Gadjahmada University. Yogyakarta.

Center for Agricultural Land Resources Research and Development, 2008, Digital Map at scale 1:100,000 Agricultural Land Use. ICALRD, Juanda 98, Bogor. (un-published).

Charbonier, S. J. and Gertisser, R., 2008, Field Observations and Surface Characteristics of Prestine Block and Ash Flow Deposits From the 2006 Eruption of Merapi Volcano, Java-Indonesia. J.Volcanol. Geotherm.Res. 177:971-982. doi:10.1016/j.jvolgeores. 2008.07.008.

Gadjah Mada University-GMU, 2011. Proposed Spatial Planning and Settlement (RTRWP) Post-2010 Eruption of Merapi Volcano. Gadjah Mada University. Yogyakarta

Gertisser, R. and Keller, J., 2003, Temporal Variations in Magma Composition of Merapi Volcano (Central Java, Indonesia): Magmatic Cycles During the Past 2000 Years of Explosive Activity. *J. Volcanol. Geotherm. Res.* 123:1-23.doi:10.1016/s0377-0273(03)00025-8.

Global Volcanism Program, 2011. Merapi Eruptive History, Smithsonian Institute, Available on Line: http://www.volcano.si.idu/world/

Michael, D. R. and Hudayana, B., 2008, The View from the Volcano: an Appreciation of the Work of Piers Blaikie. Science Direct. *Geoforum 39* (2008): 736-746. Elsivier.

National Disaster Management Agency (BNPB), 2010, Merapi Volcano Eruption Disaster Prone Areas, 2010. BNPB, Yogyakarta, 18 November 2010.

Singh, H., Porwal, M. C., Jeganathan, C., Talukdar, G. and Roy. P. S., 2001, Vegetation Cover Mapping using Hybrid Approach in Digital Classification. *Asian Journal Geinf.* 2(2):37-46.

Sparks, R. S. J., 1981. Triggering of Volcanic Eruptions. Nature, 290 (5806), 448.

Sutikno, L., Widiyanto, S., Andri, K. and Taufik, H. P., 2007, Kingdom of Merapi Volcano: Potential of Natural Resources and its Carrying Capacity. Faculty of Geography, Gadjahmada University. Yogyakarta.

Uchida, S., 2009, Identification of Seasonal Features of Crop Planting. Proceeding of the ICALRD-JIRCAS Workshop on Enhancement of Remote Sensing and GIS Technologies for Sustainable Utilization of *Agricultural Resources in Indonesia.* Bogor, 25 June 2008, 104-120.

Verstappen, H. Th., 1963. Some Observation on Indonesian Volcanoes. Tijdschr. Kon.ned.Aardrijksk. gen., 84 (3):237-251).

Verstapen, H. Th., 1983, Applied Geomorphology: Geomorphological Surveys for Environmental Development. Elsevier Science Publishers B.V., 1983. P.O.Box 330, 1000 AH Amsterdam, the Netherlands.

Voight, B., x Consnanninea, S., Siswowidjoyo, S. and Norley, R., 2000, Historical Eruptions of Merapi Volcano, Central Java, Indonesia, 1768-1998. *J. Volcanol. Geotherm. Res.* 100:69-138. Doi:10.1016/S0377-0273(00)00134-7.