Lahar at Kali Konto after the 2014 Eruption of Kelud Volcano, East Java: Impacts and Risk

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Abstract

5 days after Kelud Volcano eruption 2014 in 13 February 2014, lahar was occurs in several river in slope of Kelud Volcano. Rainfall with intensity 40 mm/hour mobilized pyroclastic material from upper part of Kelud Volcano to the channel during 3,5 hour. The aims of this paper are (1) to study of geomorphic impact of lahar related with damage and (2) to study future risk due to the potential of lahar source material and lahar repose.

We use merged data from primary data as well as secondary. Geomorphology impact of lahar was identified using integration of remote sensing, GIS approach, and fieldwork checking. Interviews as well statistically data from villages were used in order to determine their perception to the risk of lahar.

Morphogenic processes such as riverbank erosion, channel widening and riverbed down cutting takes an important role in generating the impact of lahar in Kali Konto. Lahar in medial and distal area was affected more largely than lahar in proximal area. This impacted in river widening and buried crop field inside of the channel. People along this river must be prepared due to huge potential of lahar and their vulnerability.

Key Words: **Lahar, Kelud, Geomorphic impacts, Risk**

1. Introduction

Kelud Volcano (1731 masl) is one of hazardous volcano in Indonesia (Kusumadinata, 1972; Pratomo, 1992; Bourdier et al., 1997) that located in East Java in a row with Kawi-Butak, Anjasmoro Mountain, and Arjuno-Welirang Volcano (Fig. 1). Kelud Volcano has explosive eruption type that followed with pyroclastic density currents (PDC's), tephra fall, and syn or post eruptive lahar (Zen and Hadikusumo, 1965; Sudradjat, 1991; Bourdieret al., 1997a,b; Thouret et al., 1998; Cronin et al., 2000; Lavigne and Thouret, 2000, 2002). After 1300 AC, Kelud Volcano was erupted about 30 times (Hageman (1867), Houwink (1901), Kemmerling (1921), Van Padang (1951), Hadikusumo (1967), Kusumadinata (1979), dan Pratomo (1992)) with total more than 15.000 fatalities during or after eruption period (De Belizal et al., 2012).

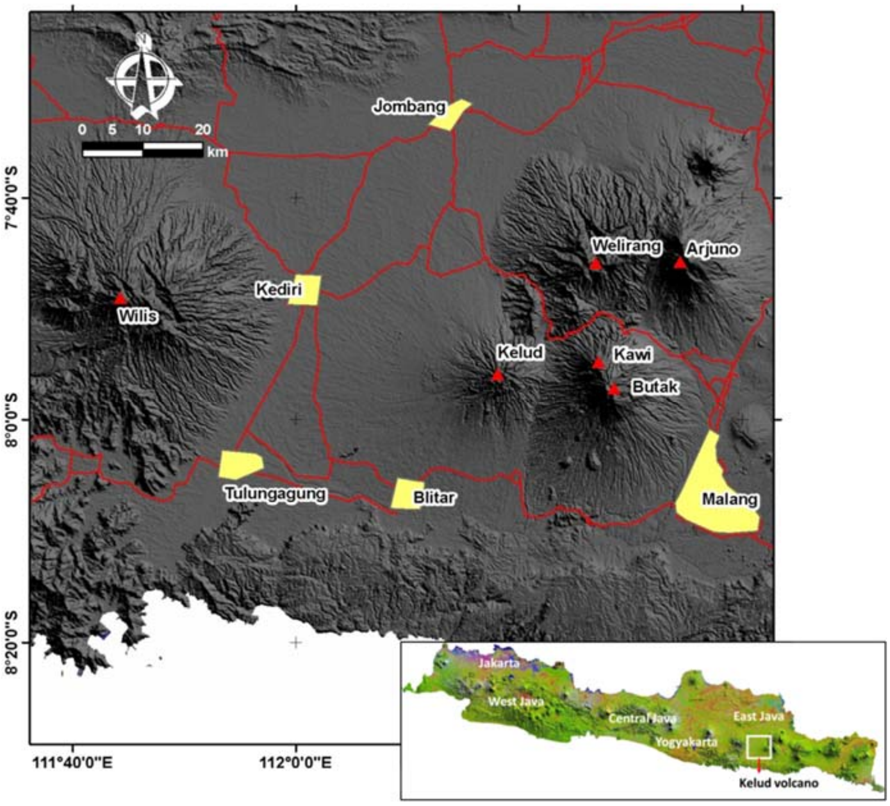

Figure 1. Location and morphological overview around of Kelud Volcano

Lahar in Kelud Volcano is one hazardous phenomena during and after eruption period in addition primary hazards (Bourdier et al., 1997a,b; Thouret et al., 1998; Cronin et al., 2000; Lavigne and Thouret, 2000, 2002). Lahar is still threatened about 160.000 peoples in Kediri, Tulungagung, and Blitar (Thouret et al., 1998; Jeffrey et al., 1998). Lahar more destructive than primary hazards (Blong, 1984), with high velocity (($< 10–10^7$ m^3s^{-1}), can covered large area (> 100 km), and have a longer period of destructive events (Pierson, 1998; Yokohama, 1999; Mayor et al., 2000). 10 rivers located under Kelud Volcano was experienced by lahar since 1000 AC (Table 1) (Thouret et al., 1998). Lahars in Kelud Volcano can generate risk for people living along the river channel. Kelud Volcano noted its own history with lahar spreading up to 131 km^2 (Rodolfo, 1999)and more than 5160 was killed (Thouret, et.al, 1998). This is because the explosive eruption characteristics and outburst of crater lake.

Table 1. History of lahar event in river under Kelud Volcano

Date	Type of Lahar		River	Maximum Extent (km)	Trigger Processes	Casualties
	Syn-Eruptive	Post-eruptive				
1334	*	?	?	?	Lake Outburst	?
1586	*	?	?	?	Lake Outburst	> 10000
11-14 October 1826	*	?	Semut, Gedog, Lekso, Siwalan, Bedali, Putih	?	Lake Outburst	Any
16-17 May 1848	*	*	Konto, Putih, Lekso, Siwalan, Brantas	24-27	Crater wall collapse, Lake Outburst	22
31 January 1864	*	*		24-27	Lake Outpuring, Pyroclastic flow	Any
29 January 1875	No eruption	*	Bladak	?	Crater wall collapse, Lake Outpuring	Any
22-23 May 1901	*	*	Ngobo-Pulo	27	Lake outburst, Pyroclastic flow, pyroclastic surge and fall,	Any
20 May 1919	*	*	All rivers	27-37,5	Lake outburst, Pyroclastic flow, pyroclastic surge and fall	5110
31 August 1951	*	*	All rivers	6,5-12	Lake outburst, Pyroclastic flow, pyroclastic surge and fall	Any
24-Apr-66	*	*	Bladak, Senut, Putih, Ngobo-Pulo, Konto, Mangli, Sumberagung, Konto, Petungkobong, Gedog	7; 18,5-21; 24-29,5	Lake outburst, Pyroclastic flow, pyroclastic surge and fall	211
February-March 1990		*	Konto, Mangli, Abab, Bladak, Gedog, Petukobong, Sumberagung, etc	7-37,5	Lake outburst, Pyroclastic flow, pyroclastic surge and fall	
2007		*	?	?	?	?
2014		*	Konto; Bladak	?	?	?

Source: Thouret et al., 1998.

On 13 February 2014 after 1,5 hour of the danger level of volcanic activity announced by government, at 22:50 (local time) the Plinian eruption took place. Ash fell in the region in all direction of the vent. The 2014 eruption was made high of eruption column that reach until ~25 km and distributed almost in a half of Java

Island. After 2014 eruption, about 50 x 10^6 m^3 material was deposited on the upper slope of Kelud Volcano. This material will remobilization by rainfalls and generate lahar along the river under Kelud Volcano. In 18 February 2014, first lahar after Kelud eruption 2014 was occurred in several rivers (Kali Ngobo, Mangli (Kediri), Kali Bladak (Blitar), and Kali Konto (Kediri-Malang). Kali Konto (Fig. 2) is one of river that located in northern part of Kelud Volcano that repeatedly experience of lahar events. Historically in recent 100 years, Kali Konto was affected due to lahar in 1919, 1951, 1966, 1990, and 2007. Lahar events at Kali Konto was evidenced by the construction of physical mitigation infrastructure such as dyke in Blaru village and SABO DAM along the river channel.

Study of lahar after 2014 eruption related with disaster risk reduction must be updated. The issues are lahar hazard can become more frequent and more widespread due to large material still exist in upper part of Kali Konto. This paper focus in two issues, (1) lahars led to several impacts on river channels on the slope of the volcano, creating lahar corridors which damaged houses, agricultural land, and irrigation located along the Kali Konto. (2) People around Kali Konto more vulnerable due to repetition of lahar in wet season and risk assessment needs to be done due to future lahar potential.

2. Methods

To fulfill our objectives, we used methodology by mixing primary data taken from the field and also by remote sensing; and secondary data obtained from local government:

(1) Geomorphology impact was identified using integration of remote sensing, GIS approach, and fieldwork checking. Lahar corridors was identified by compare two satellite imagery from Quckbird 2009 and Formosat 2014. Both of images were analyzed and compare to delineate lahar corridor in upstream, mid-stream, and downstream along the Kali Konto.

(2) Field investigation of the Kali Konto during March-August 2014. Field analysis involved: (a) ground-truthing areas of the Kali Putih to verify

remotely-sensed findings, (b) mapping lahar deposit thickness with point measurements in proximal, medial, and distal site (Fig. 2), (d) categorizing, mapping, and classifying the level of damage house, agricultural land, and infrastructure resulting from lahar activity.

(3) Interviews with local people will be done in order to determine their perception to the risk of lahar. Semi-structured questionnaire will be conducted for these training areas. Interviews were conducted with village chief and the key person in each village in the study area. This step also used combination of interview using questioner and secondary data from PODES (Potensi Desa) and KDA (Kecamatam Dalam Angka).

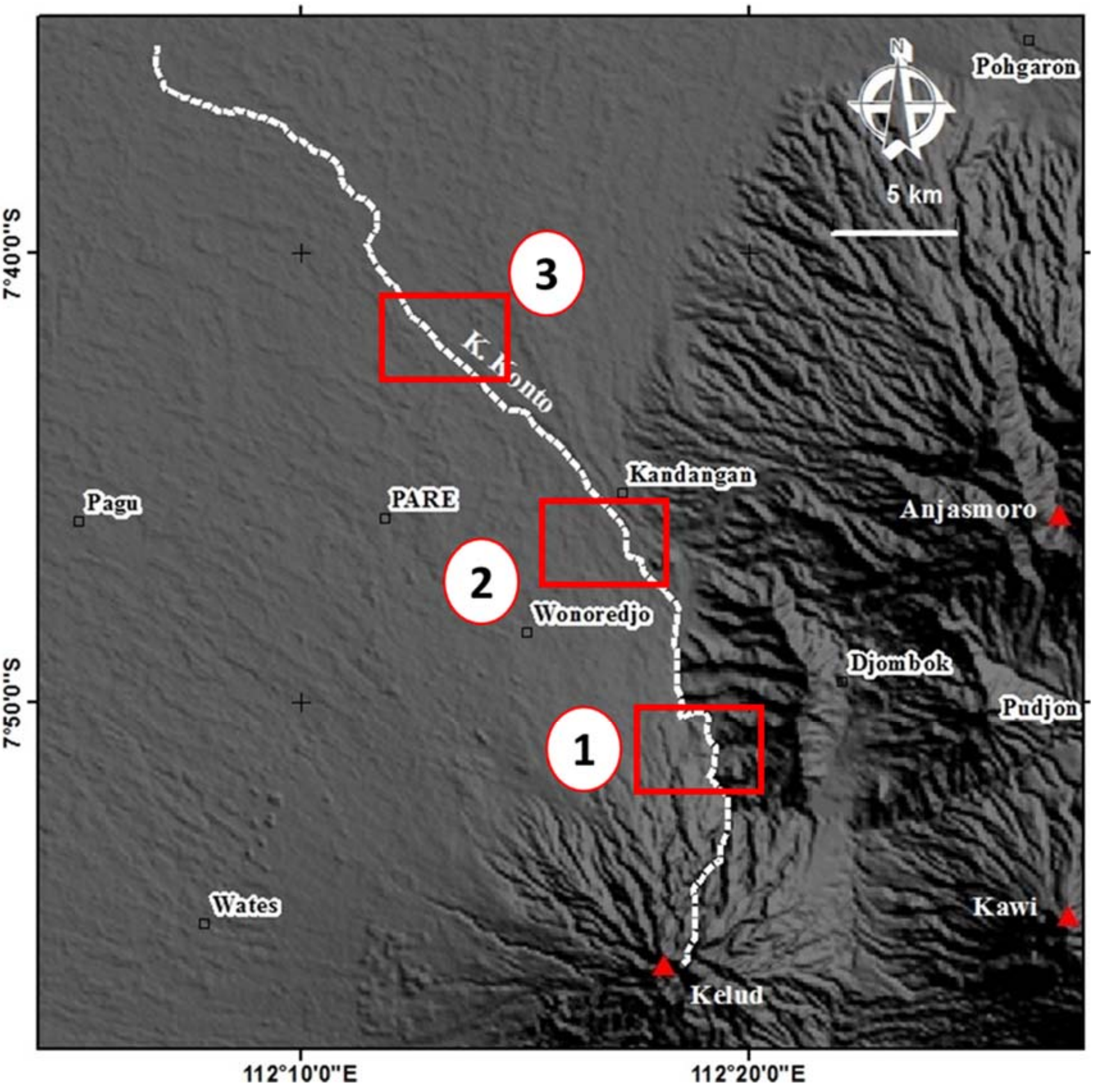

Figure 2. Location Kali Konto in northern slope of Kelud Volcano and observation site in proximal (1), medial (2), and distal (3) area (red box).

3. Results and Discussion

3.1. February 18th, 2014 lahar at Kali Konto

Kali Konto has main river as far as 47 km. This headwater from Kelud Volcano, Mount Lokak, and Mount Leksongo (that located in eastern part of Kali Konto). Headwater of Kali Konto also from Selorejo Reservoir in Ngantang, Malang. Lahar in Kali Konto occurs 5 days after peak phase of the Kelud Volcano eruption (13 February 2014). This lahar triggered by 40 mm/hour rainfall during 3,5 hour. There was remobilized pyroclastic material from upperpart of Kelud Volcano. There are any three factor that can explain why first lahar preferentially occurs in Kali Konto. (1) Higher hourly rainfall in 18 February 2014 during lahar event period (04.00 – 07.30 PM at local time) at northern and western slope of Kelud Volcano. (2) Large fallout tephrawhich was deposited on the west, east, and north slopes of Kelud, due to thedominant wind direction during the eruption. Tephra fall with large grain-size (ϕ 2-17 cm) was deposited in northern and eastern slope. This tephra fall was damaged several villages (such as Pagersari, Pandansari, and Banturejo Villages), in in eastern slope of Kelud Volcano. (3) Existence of drainage system in Konto watershed with deserve morphometric and the presence of erodible material along river channel.

In 1919, lahar in Kali Konto travelled long distancesdownvalley up to 27±37km (Thouret et al., 1998). In 1990, several *SABO DAM* and sediment traps have been constructed in thevalley channels of Kali Konto and they reduced the travel distance of lahar to 10 km for debris flows and 27 km for hyperconcentrated and stream flow. And nowadays, lahar after 2014 eruption has caused disruption in transportation due to closure of the bridge in Kandangan (25 km from summit) (Damarwulan Bridge; connecting Kediri and Malang) and Badas (37 km from summit) (Badas Bridge; connecting Kediri and Jombang). Lahar in Kali Konto also damaged Siman reservoir (13 km from summit) and has threatened the irrigation system in Siman, Besowo, and Brumbung Village. In eastern part of Kelud Volcano, lahar covered Selorejo

Reservoir with ~2,8 million m^3 material from lahar in Kali Sambong (first river network of Kali Konto). Lahar run out distance in Kali Konto exceed 40 km for hyperconcentrated lahar and stream flow and 23 km of debris flow.

Recording of lahar motion show the characteristic of lahar such as peak discharge and velocity. Lahar was recorded in two locations, in Damarwulan Bridge and in Blaru Village. Due to the limitations of recording equipment and methods, we only gets recording several time of lahar events by courtesy of the local people. However, we could study about lahar velocity in two observatory locations, Lahar at Damarwulan Bridge started at 04.17 PM (at local time). At Blaru village lahar recorded with velocity ~2-7 m/s. Lahar discharge recorded reaches 420 m^3/s in Blaru village. This lahar close similar with lahar in 28 February 2011 and 14 March 2011 in Kali Gendol, Merapi Volcano (peak discharge 540 m^3/s and 410 m^3/s) (De Belizal et al., 2013). This difference is lahar at Kali Konto has more small grain size material than lahar at Kali Gendol.

3.2. Geomorphic impacts of lahar in Kali Konto related damages

Lahar in Kali Konto occurs no more than a week after eruption phase. Nearly 25 km^2 area was affected due to lahar in Kali Kanto. River channel also were affected bylahar and by their morphogenic processes: riverbank erosion, channelwidening and riverbed downcutting.This processes takes an important role in generating the impact of lahar in Kali Konto. Impact of lahar that generated by lahar and geomorphic processes was observed in three locations (Fig.2) that represent three zone (proximal, medial, and distal area). This locations are Mendalan (represent proximal Fig, 2.1), Damarwulan, Kandangan (medial Fig.2.2), and Blaru, Badas (distal Fig. 2.3).

Proximal part (in Mendalan) of the Kali Konto experienced some changes as a result of lahar on 18 February 2014. Lahar was caused river widening which threatens settlement and crop field on the riverbank (Fig.3). Before the 2014 eruption, the proximal part of the Kali Konto at Mendalan was a small channel between 1.5 m and 2 m deep and 5-10 m wide. After first lahar in Kali Konto created 75-100 m wide corridors and the channel fully by lahar material.It expanded with crop field in eastward and westward of river channel. 42 houses, road network, and hydroelectricity building near the river (50-150 m) potentially damaged on the future lahar due to the pattern of river widening and lahar over flow or avulsion. The depth of the laharreached 0,3 m to 1,2 m and damaged2,3 ha crop field (Fig. 4). Crop field was buried by lahar with majority fine sand up to pebbles material.

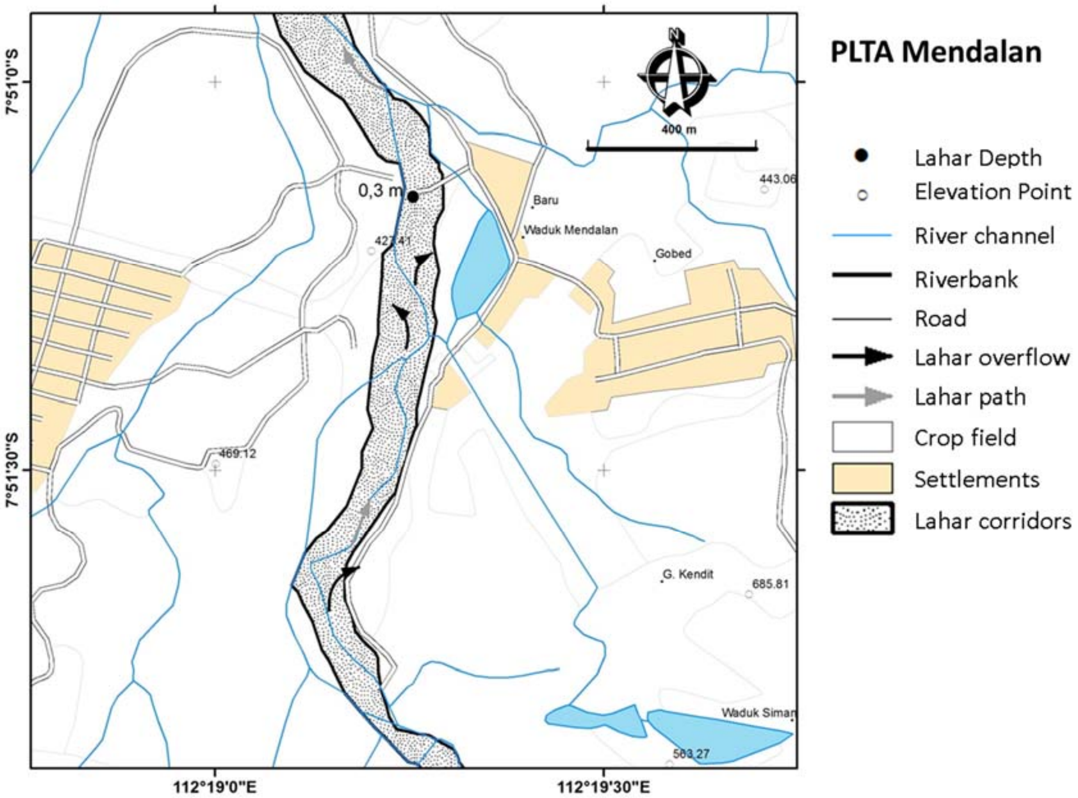

Figure 3. Formation of lahar corridors on the proximal slopeat Mendalan site

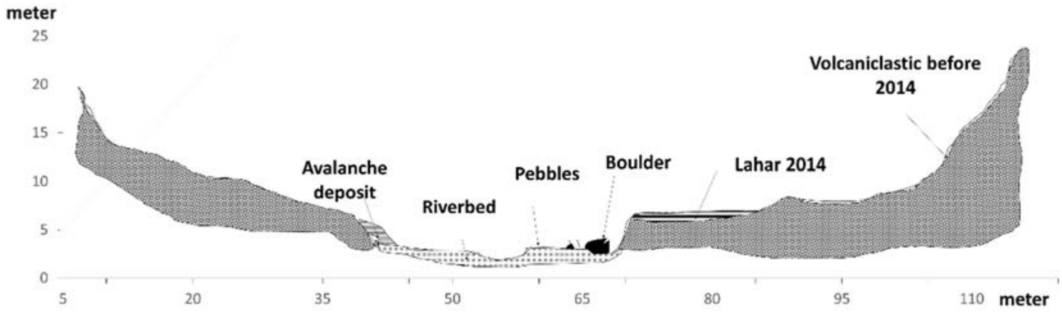

Figure 4. Cross-sectional condition on the proximal slope at Mendalan site

Contrary with proximal slope, the medial slope of Kali Konto in Damarwulan, Kandangan more widespread than proximal slope. Impact of lahar in Damarwulan indicated by 6 houses and 1 mosque that located in the river bank was buried by lahar (Fig.6). This houses are illegal house due to land owned by irrigation division of Public Work Department. This lahar potentially damage the settlement that located 30 m near the maximum lahar corridors. Lahar created ~60 meter wide corridors in eastward of river (before SABO DAM) and ~40 meter eastward and westward (after SABO DAM) (Fig.5). A part ofthe Damarwulan village was built on a 2-3 m high volcaniclastic terraceoverlooking the riverbed, and buried by 2014 lahar. The 0,5 – 1,5 meter lahar deposited in riverbank which very fine to pebble dominated (Fig. 7). The large impact in this site was caused by the morphological condition that located in the knick point.

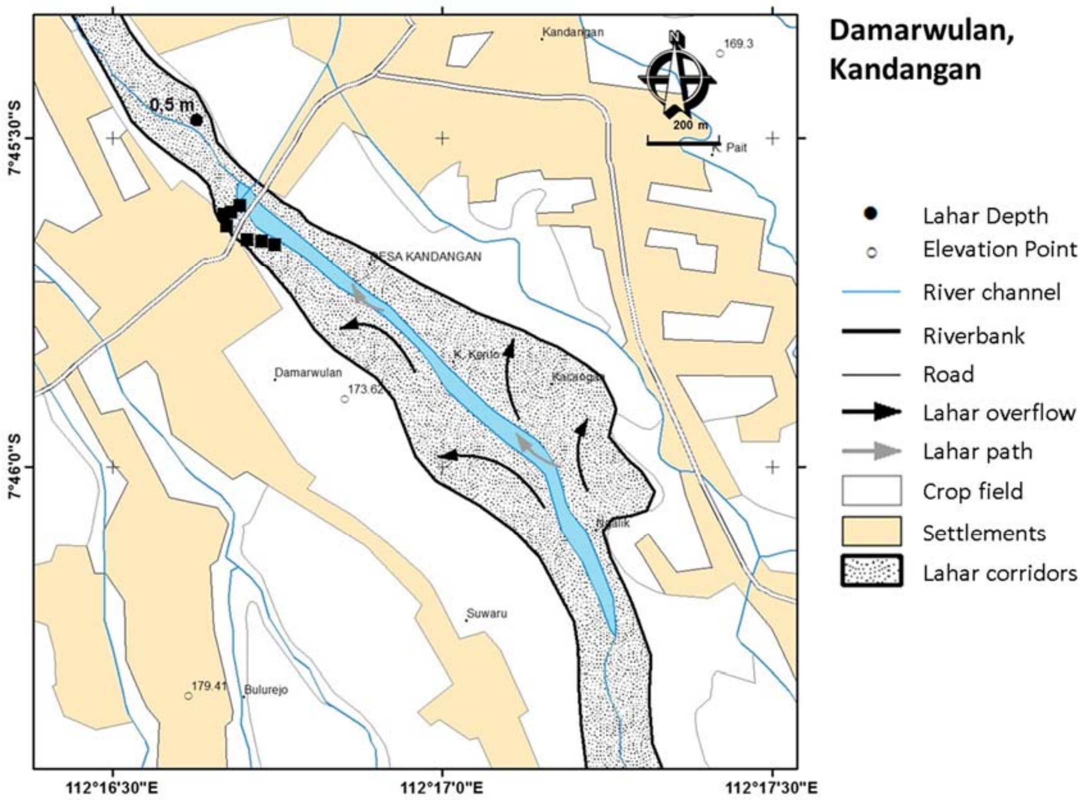

Figure 5. Formation of lahar corridors on the medial slope at Damarwulan site

Impact lahar in distal area showed in Blaru village that located 35 km from summit. Morphologically, this area located in gentle-flat slope. Historically, lahar more frequently has impacted in this location. It was evidenced of human made levee as far as 300 m from river side. Lahar caused river widening from 5 meter to ~ 25 meter. Lahar corridors was exceed 300 meter in both of river side and buried crop field inside levee (Fig. 8). Crop land was buried with lahar thickness 0,5 – 1 meter. Lahar deposit in Blaru different with lahar material in proximal and medial slope. Lahar overflow in the distal slope was bounded by artificial levee. The artificial levee built after lahar event 1919 to protect settlement and crop field in the vicinity. Lahar resulted aggradation in riverbed with fine-very fine sand material and it taken by mining activity (Fig. 9).

Figure 6. (a) The houses and mosque that damage due to lahar and (b) crop field located in eastward of river channel covered by lahar

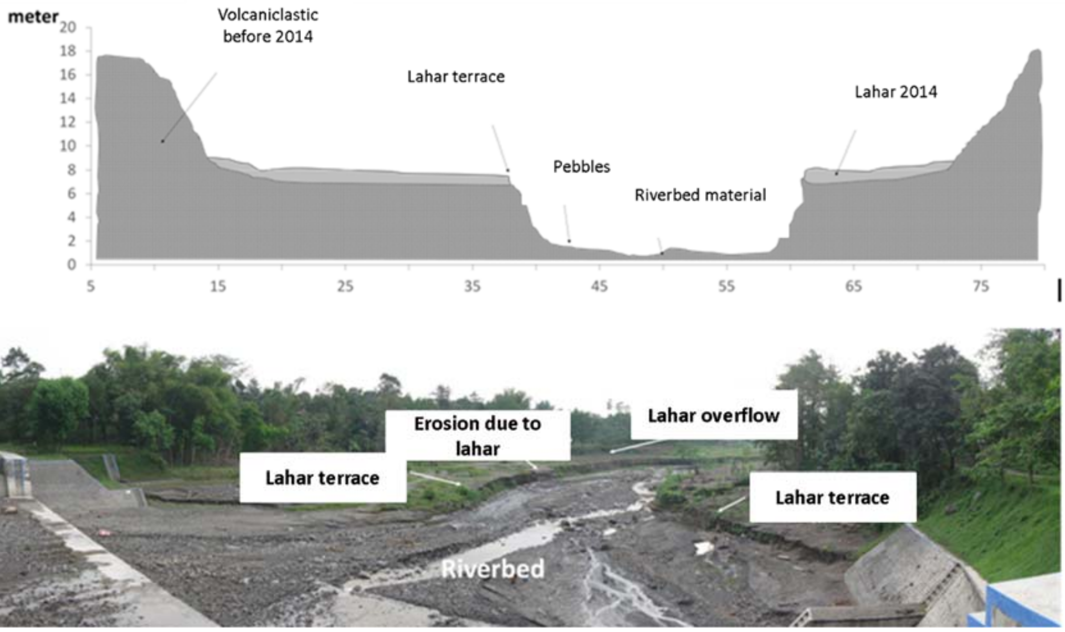

Figure 7. Cross-sectional condition on the medial slope at Kandangan site

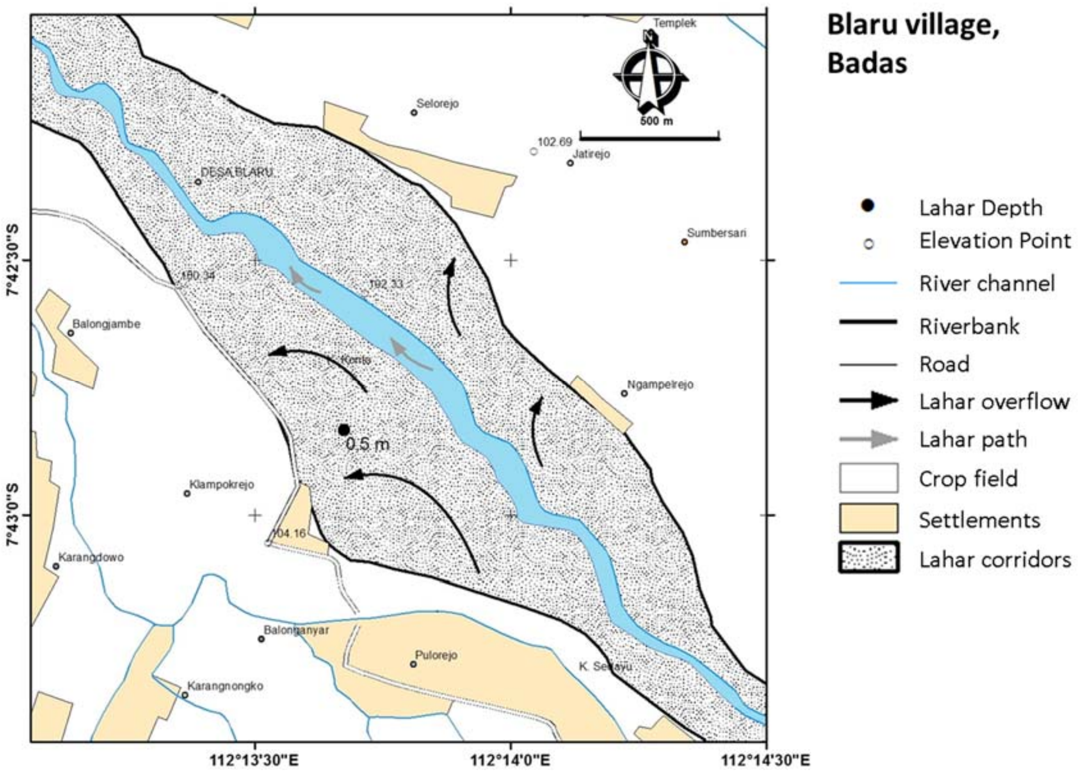

Figure 8. Formation of lahar corridors on the distal slope at Blaru site

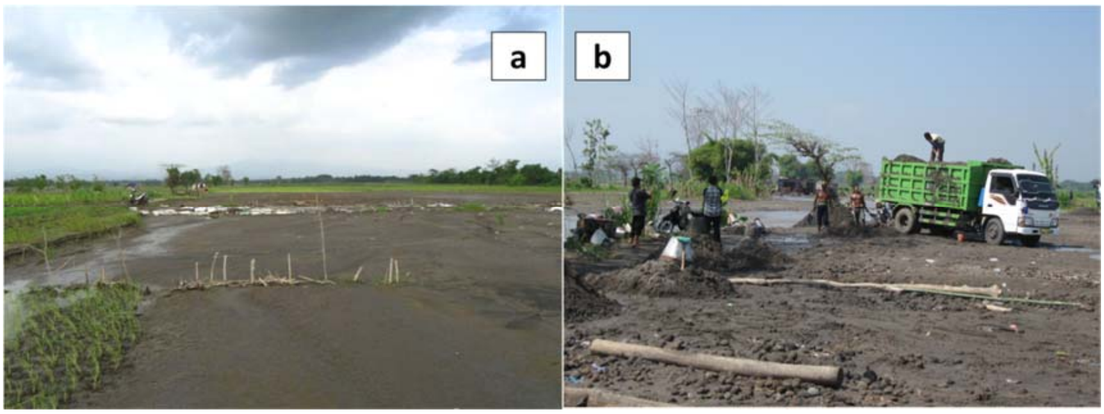

Figure 9. (a) Crop field inside the levee that buried by lahar and (b) mining activity in Kali Konto after lahar

3.3. Manage a risk for future lahar in Kali Konto

Damage by the 2014 lahar was particularly important to houses, land and infrastructures at Kali Konto. After the 2014 eruption until September 2014 lahar in Kali Konto damaged 7 building in medial and distal slope, destroyed 4 bridges and SABO DAM, and cover 3 reservoir. Lahar also buried a hundreds hectare crop land along Kali Konto (including 34 Ha crop land in Kuwik village on distal area). The damagesrelated to the main geomorphic process related to lahar in Kali Konto (riverbank widening,riverbed downcutting, avulsions and overflows). The highway passing Damarwulan Bridgewas closed1 timeby lahar during 5 hourin 18 February 2014. Whilst the road was being closed, generating traffic-jams on this road.

Associated with slightly frequent of lahar and large channel capacity, lahar did not reach settlements and did not cause a casualties. Although the eruption is finished, lahar hazards still threatencommunities along the Kali Konto, where potentially damage particularlyhigh related with this population was considered very "vulnerable" to natural hazards. Any several parameters that can be used to quantifying risk potential along Kali Konto based on village unit. There are population, area of crop field, and number of building.

Number of population distribution showed the "urbanism" type of village along Kali Konto. Main road connecting Kediri and Malang take an important role of population distribution. Several villages under this corridors has large population (Kandangan, Klampisan, and Damarwulan with number of population > 8000) than other villages (Fig. 10a). This role similar with village under corridors road network Kediri-Jombang in Blaru and Badas villages (with number of population > 8000). Large number of population led to increased potential of loss. Settlement and crop field as the example sector that resulted from human activities.

Disaster risk management can be applied by using many elements in the surrounding environment, such as: human resources and natural resources. Human resources are can creating strength materials building that appropriate to lahar, while each person increases their capacity in order to be a resilience people in lahar. Natural resources can be managed as a mitigation plan, such as make a dike using the stones or soil along the river. The Government need to concern about disaster risk management, where there are many steps from the beginning to final plan. There are preparedness plan (included mitigation and contingency plan), during hazard occur and after hazard. It can be the activities of developing early warning system, such as *kentongan* that functioned as siren, irrigation and river maintenance. It will be a beginning to make a resilient people in lahar prone area.

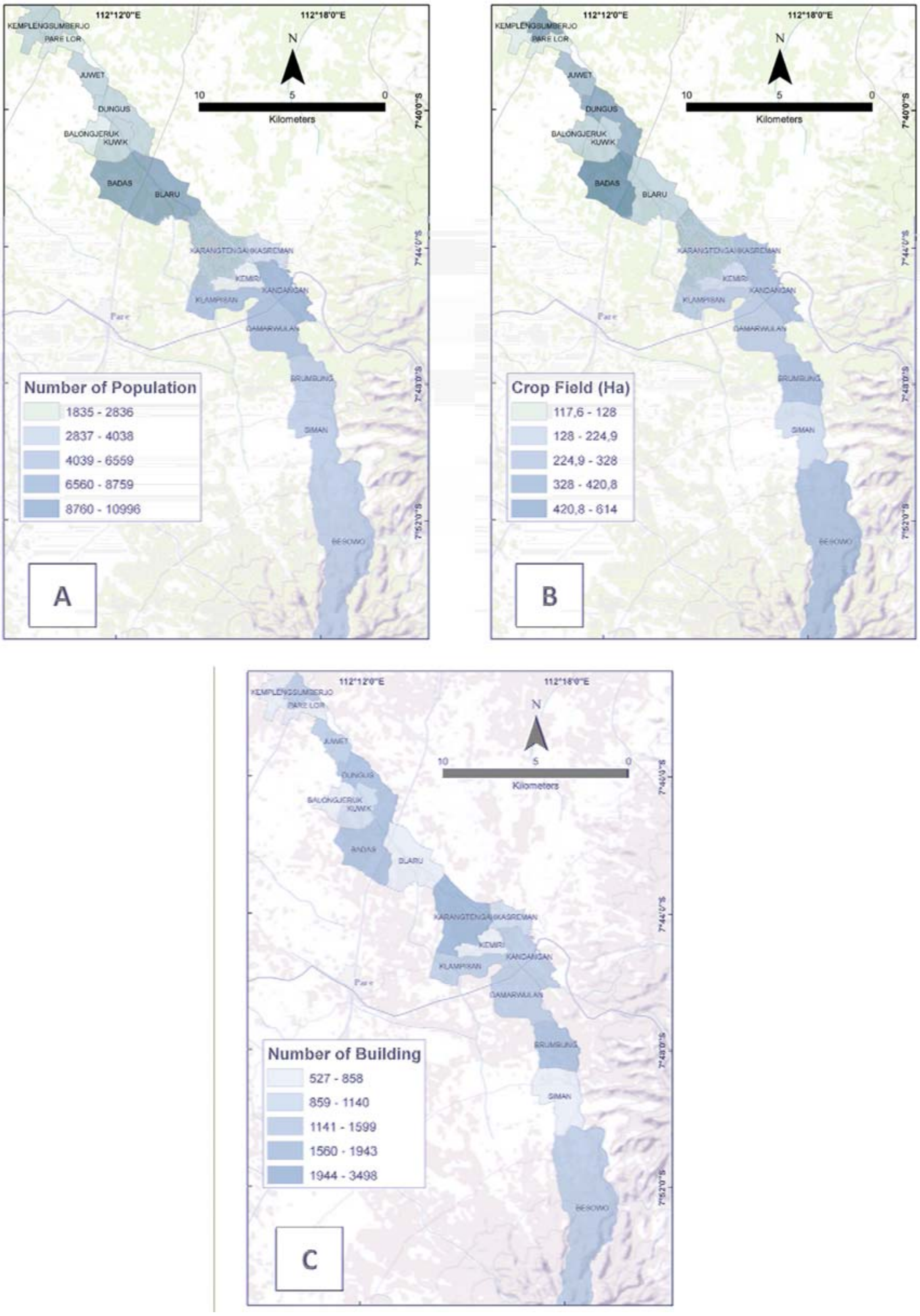

Figure 10. (a) Crop field inside the levee that buried by lahar and (b) mining activity in Kali Konto after lahar

4. Conclusion

The impact of lahar in Kali Konto is not very large due to the lahar event was only happen in once time. Different geomorphic impacts of lahar can be seen from the proximal until distal area. In the distal, lahar corridor is larger than in the medial due to gentle-flat slope condition. There are several geomorphic impacts observed from the field i.e. 1) There is no channel avulsion along the river from proximal until distal; 2) Riverbank erosion due to lahar was observed in the medial; 3) Lahar corridor in the distal was limited by human made levee.

Some notices should be considered for future lahar because of the combination of huge volcaniclastic material in proximal zone as a source material for lahar event and the coming of rainy season could occur in far distance to the distal area. People must be prepared due to repetition of lahars and the hazard map must be created to mitigate the risk.

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