Dynamics of Lahar Material Deposition Post 2014 Kelud Eruption of Bladak River

S Bachri¹, L Y Irawan¹, R Wirawan¹, A E Nurjanah¹, I W N Tyas¹, S Utaya¹, Sumarmi¹

¹Departement of Geography, State University of Malang, Jl. Semarang 5, Malang 65145, Indonesia

Abstract. Kelud volcano eruption on February 2014 has a tremendous impact on several around volcanic prone areas. Bladak catchment on the west flank of Kelud Volcano is the most affected area post-eruption in 2014. This area covered by pyroclastic material and lahar. Lahar is the most potential hazard in the study area. Lahar hazard in Bladak river has long records not only from the current eruption but also from several past eruptions. The dynamics of lahar material deposition necessary needed to study in order to understand the physical characteristics of lahar. Field survey and GIS was used to gain information about lahar deposition characteristics. The results showed there were two different factors on lahar deposits behavior: 1) natural geomorphologic process and, 2) human-induced on river environment. The natural process shows that lahar on Bladak has different materials from the lithofacies analysis. Human activities on the river have a positive impact on normalizing the flow of the Bladak river to reduce the danger of lahar floods.

1. Introduction
Kelud volcano last eruption on February 13, 2014, resulted in changes in the body Volcano Kelud. Central eruption type followed by the destruction of lahar dome from an effusive eruption in 2007[11]. The direct impact of 2014 eruption is the pyroclastic materials such as bomb, gravel, sand, and volcanic ash. These materials are widely distributed in Kelud Volcano Disaster Prone Area.

Lahar is a pyroclastic material that is composed of volcanic ash and rock fragments that flows as a result of mingling with the rain [1]. The term lahar comes from the Javanese language to describe the flow of volcanic sediment carried by flowing water [2]. The scientific lahar definition is explained by (Smith and Fritz, 1989 in Hadmoko, et al, 2015) as a rapidly flowing material, lahar material is a mixture of pyroclastic material with water. Comparison of pyroclastic solids with water ranging from 60-75% in solid form while the remaining 40-25% is water. The driving factors of lahars related to rainfall are the intensity and the total amount as well as the duration of the rainfall. In addition, other factors that induce lahar are (1) slope and channel gradient, (2) volume and thickness of the source deposits, (3) physical characteristic of pyroclastic deposits including permeability, pore pressure and grain size, and (4) vegetation cover [3].

Lahar flood in Bladak occurs during and after an eruption when the unconsolidated volcanic debris remobilized by rain. Lahar flow in Kelud have several characteristics which differed according to its significant sedimentologic differences: (1) early, massive deposits are coarse, poorly sorted, slightly
cohesive and commonly inversely graded, (2) abundant, very poorly sorted deposits include non-cohesive, clast-supported, inversely graded beds and ungraded, finer-grained and cohesive matrix-supported beds, (3) fine-grained, poorly sorted and ungraded deposits are interpreted as recording late hyper-concentrated streamflows, and (4) ungraded, crudely stratified deposits emplaced by flows and behaviors occur within only 10 km of the source [4]. Lahar in Bladak are induced by heavy rainfall (30 - 70 mm) periodically during the storm from December to March and fed by abundant loose and water-saturated sediments eroded from steep slopes.

The prediction of transported lahar in Bladak river is an important study along with lahar floods. The dynamics of sedimentation of lahar material can be observed from changes in river morphology. In this case is the morphological changes of Bladak. Preparation of information on changes in river morphology is essential in studying the hazards and risks of lahar floods.

2. Study Area
This research is situated in Bladak river which lays as one of the rivers with the upstream located on the volcanic peak of Kelud volcano. Bladak is geographically located between 9113664 mN – 9123058 mN and 619099 mE – 643515 mE. The river is approximate length 19 km which administratively is part of Kabupaten Blitar, which small part of the upstream in the volcanic peak is included in Kabupaten Kediri. Its river has an elongated shape, which is highly related to the dynamic of its peak discharge. The flow rate resulted by the elongated shaped river is lower compared to the one resulted by the rounded shaped river. It is due to the longer time needed for the streamflow to be concentrated in the control point, thus affected the rate and volume of runoff. Bladak located in a relatively flat area in the downstream. In Fig. 1 shows the study area map that pointed out the situation of Bladak river.

![Figure 1. Location of Study Area Showing Bladak River in Kelud Volcano Area](image)

3. Methodology
This research objective to examine the dynamics of lahar material deposition in Bladak river after the eruption of Kelud in 2014. The dynamics of lahar material deposition are analyzed through the morphological changes of the river. Lahar material in the river flow triggered by the occurrence of rain
in upstream Bladak is located on the peak of Kelud volcano. Changes in river morphology are measured by changes in width and depth of the river. This research was conducted in several stages including 1) pre-field survey (collecting secondary data to calculate basin morphology and rainfall data); 2) field survey (primary data collection in the field); 3) post-field survey (classification, analysis, and modeling of river basin morphological changes). In addition to using tools and materials to obtain descriptions of lahar deposition sites, measurements were made at some point location/sample locations. The calculation of lahar deposits in Bladak river is based on pyroclastic material inputs located in the river.

3.1. Input Data

This research uses an approach between actual measurement result (post-eruption) with the result of the extraction of dem data (before eruption). The result of the comparison is then compared with stream flow morphology condition with secondary data of maximum daily rainfall.

3.1.1 Slope

The slope represents a plane of ground surface connecting a higher soil surface to a lower soil surface [5]. The size of a slope can be expressed by its slope. The slope can be classified based on the resulting relief units[6].

![Figure 2. Slope Map of Bladak River](image)

3.1.2. Rainfall Data

Rainfall data used for 4 periods (2014, 2015, 2016, and 2017) and it is from 4 rainfall station. Maximum rainfall is used with the assumption of the occurrence of movement of material flow occurs every rain occurs. The determination of mean daily rainfall of each region is determined by an isohyet interpolation technique. Isohyet interpolation techniques are particularly suitable for hilly areas and have irregular topography [7].
3.1.3 Litofacies Analysis

Litofacies is a stratigraphic recording of sedimentary rocks exhibiting certain physical, chemical and biological characteristics that are different from the rocks above, below or by distribution [8]. Litofacies analysis is used to determine the depth and depth characteristics of erupted material in 2014. Litofacies analysis is illustrated by field identification sketch.

3.2. Research Process

3.2.1. DEM Extraction

The Digital Elevation Model is considered a vital and vast spatial information provider by several terrestrial applications. DEM is a digital model used for hydrological applications, geomorphology, geology and disaster risk mitigation [9].

The purpose of observation of morphological conditions of the river before the eruption of Gunungapi Kelud in 2014. Also-Palsar DEM data with 12.5 x 12.5 m spatial resolution dated July 24, 2009. DEMO data for the extraction of river cross-profile data commonly fed by volcanic materials before there was an eruption.

3.2.2. Field Survey

Field Survey conducted to obtain actual data that occurred in the field. Data taken from the field include the post-eruption Bladak River profiling data of 2014 and the result of lithofacies analysis of material deposits resulting from eruptions. Location survey conducted in priority on sabo dam 1 and 2 along the flow of the river Bladak with the assumption that the dam is a lot of lahar sediment erupted results 2014 which is still accommodated.

3.2.3. Processing Data

The data collected and then processed into several stages. Stages of DEM data extraction are done to obtain the river profiling data and slope. Stages of extraction are done by using GIS software. The result of collected data is then done overlay process to know the condition of the field before happened erupt. The modeling is done by adding daily maximum daily rainfall data to know the flow power that
is capable of removing the eruption material from the top of the volcano which then accumulates in sabo dam 1 and 2. The survey results become a reference for us to see the dynamics of the material deposits that occur after the eruption in terms of profiling of rivers and visible lithofacies.

**Figure 4. Research process**

The research flow diagram illustrates the steps - steps performed in this study. Primary data is actual data obtained from the results of the survey field. The data will provide information related to lahar flow conditions in the black river post-eruption 2014. Secondary data is data used to reference lahar flow conditions prior to the eruption of 2014. The two information is combined to create the latest information about the dynamics of the erupted lahar flow that occurred now.

**4. Result and Discussion**

The process of dynamics of lahar sedimentation in the Bladak River can be identified through the field survey, measurement and by being combined with the interpretation of satellite imagery. The dynamics of lahar sedimentation in Bladak are influenced by natural processes and by human-induced. The natural processes include the flow of erupted material carried by the flow of water and the collapse of material on the sides of the river. While human activities that affect the morphological changes in the Bladak River are caused by mining activities. In the discussion of this paper explained about the natural processes that affect the morphology of the River Bladak along with the dynamics of the deposition of lahar material after the eruption of Kelud Volcano in 2014.
4.1. The natural process in the dynamics of lahar deposition

Movement and displacement of lahar caused by the force of gravity and the flow of water/transport by the rain. Research location has a hilly relief condition with sloping to steep slopes. This condition is very influential in the dynamic process of pyroclastic material deposits. The process of transporting and deposition of materials is the main process found in the Upper Bladak River. The process can be shown in figure 5.

Figure 5. a) Lahar Flow on UpperBladak; b) Lahar Materials Deposits

Lahar material can be divided into two different material forms, pyroclastic material in the size of stone, crust, gravel, sand, and volcanic ash, while other materials in the form of ruins of the river body. Both the erupted pyroclastic material and the debris have loose properties. This condition is caused by a very steep slope, so the force of gravity will make the sediment material collapse down from the upper to the middle slope. Material crashes vary from random grains to Figure 5a.

The deposition of the erupted lahar material is characterized by a high particle concentration level of Figure 3b. Lahar deposits are deposited rapidly in turbulent currents along the volcanic slopes or river valleys [10]. Lahar flow that occurs at the location of the study is a small-scale lahar flow. This condition means that the lahar on the upper part of the Bladak River is the initial phase of the lantern flow process, see figure 6.

Figure 6. Lahar Depositions on Bladak Channel
Lahar flow along of the Bladak River channel and is directly above the pyroclastic deposit that fills the inside of the Bladak River channel. It can be identified from the thickness of lahar deposits in the study area that less than 1 meter. Further, lahar flow can be trigger factor of river valleys collapse. This may occur due to the interaction between rock fragments in the event of a turbulent flow of lahar causing vibrations that can disrupt the stability of the material on the low cliff.

The eruption precipitate material may undergo a process of change of position and shape in particular. These position and shape changes are included in the depositional process. The depositional process is influenced by a combination of several causal factors, namely the force of gravity, the flow of water, and the morphometry of the source channel of the material is derived. The gravitational force will directly make the grains of pyroclastic material falling down the slope. The items are then rearranged vertically on top of the slope surface.

These natural geomorphological processes take place continuously at a relatively slow rate of the process so that the pyroclastic precipitate compaction process can occur despite exogenous processes acting on the precipitate. This is evident in the massive and compact structure of the pyroclastic precipitate surface at the study site. The massive structure is formed from the process of cementation of volcanic silica containing silicates. The silicate content will actually harden when in contact with air and rainwater. Compaction process will occur faster when the pyroclastic material still has a high temperature.

4.2. Human influence in the dynamics of deposition of lahar

The pyroclastic flow deposits are widely used for mining activities. The current mine aims to enlarge the capacity of the Bladak River flow when subsequent eruptions occur so that the flow of the Bladak River can accommodate pyroclastic flows in subsequent eruptions. However, not all areas are feasible and suitable for mining activities. In addition to the quality of individual mine material that varies according to the type and nature of its pyroclastic deposits, mining activities carried out in areas where mining is not allowed will damage the river's own environment. One location that should not be done mining is the upstream location of the Bladak River.

Anthropogenic factors that affect the morphological changes of the Bladak River have been longstanding. During the mining process that has occurred many changes that occurred in the research area. The change is predominantly occurring on the inside of the Bladak River channel where the sand that once filled the river channel has now undergone significant reductions due to the mining process. The mining activities granted by this permit are generally reviewed as an attempt to normalize the basin. The normalization of the basin is intended for surface flow and improves the flow to pass similar materials in the event of future eruptions. The problem that arises is that not all pyroclastic materials start from the size of the boulder until the sand can be mined. Most of the big rocks and crags are still piled up and left behind in the river channel and on the left bank of the river. The mining process that takes place not only take the material in the body of the river but also by clamping the cliffs on the right and left side of the river and lahar material deposits of previous eruptions. This is certainly a problem that is the addition of soluble material in the flow of the Bladak River. Thus, mining activities for the purpose of normalizing the flow of the Bladak River valley to reduce the danger of lahar floods turn into environmental concerns that must be observed.

5. Conclusion

The dynamics of lahar material deposition are analyzed through the morphological changes of the river. Lahar material in the river flow triggered by the occurrence of rain in upstream Bladak. The dynamics of lahar sedimentation in Bladak are influenced by natural processes and by human-induced. The natural processes include the flow of erupted material carried by the flow of water and the collapse of material on the sides of the river. While human activities that affect the morphological changes in the Bladak River are caused by mining activities.
References

[1] Kumalawati R 2015 Pengelolaan Bencana Lahar Gunungapi Merapi, (Yogyakarta: Ombak).
[2] Hadmoko D S Dibyosaputro S and Widiyanto 2015 Banjir Lahar: Pembentukan, Proses, Dampak, dan Mitigasinya (Yogyakarta: Gadjah Mada University Press).
[3] Lavigne F and Thouret J C 2002 Sediment Transportation and Deposition by Rain-Triggered Lahars at Merapi Volcano, Central Java, Indonesia Geomorphology 49 45-69.
[4] Thouret et al 1998 Origin, characteristics, and behaviour of lahar following the 1990 eruption of Kelud volcano, eastern Java Indonesia Bull Volcanol 59 460–480.
[5] Pangemanan V G 2014 Analisis Kestabilan Lereng Dengan Metode Fellenius (Studi Kasus: Kawasan Citraland) Jurnal Sipil Statik 2(1), January 2014 (37-46) ISSN: 2337-6732.
[6] Van Zuidam R A 1983 Guide to Geomorphology Ariel Photographic Interpretation and Mapping. (ITC Enschede The Nederland)
[7] Moore J D Grayson R B and Ladson AR 1991 Digital terrain modeling: a review of hydrological, geomorphological, and biological applications. Hydrol Proc. 5 3–30
[8] Suripin 2003 Sistem Drainase Perkotaan Berkelanjutan (Penerbit ANDI,Yogyakarta)
[9] Tran T A Raghavan V Masumoto S Vinayaraj P and Yonezawa G 2014. A geomorphology based approach for digital elevation model fusion – case study in Danang City, Vietnam. Earth Surface Dynamics Disc. 2(1) 255–296. https://doi.org/10.5194/esurf-2-255-2014
[10] Aisyah N Purnamawati D I 2012 Tinjauan Dampak Banjir Lahar Kali Putih, Kabupaten Magelang Pasca Erupsi Merapi 2010 Jurnal Teknologi Technosci. 5(1) 19-30
[11] Bachri S Utaya S Nurdiansyah F D Nurjanah A E Tyas L W N Purnama D S and Adillah A A 2017 HidupSelaras Bersama GunungApi: Kajian DampakPositif Dari LetusanGunungApi Kelud Tahun 2014 Sebagai Modal Pembangunan Berkelanjutan. Proc. Seminar Nasional Geografi UMS 2017: PengelolaanSumberdaya Wilayah Berkelanjutan 3(1) 147–158