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Morphological Changes due to Anthropogenic Interferences in Gendol River Valley, Merapi Volcano

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Abstract. This research aims to identify the morphological changes in Gendol river, Merapi volcano. After the eruption 2010, Gendol river filled up by pyroclastic materials, then utilized as mining area. As the volcanic materials are abundance in Gendol river, sand mining activities are dominant, causing antrophogenic interferences that changes the morphology of Gendol valley. In this study, the morphological changes is measured by terrestrial survey, aerial mapping, and materials analysis through petrographic and granulometric analysis. Aerial mapping was conducted in February and August 2019 in order to identify the dynamic changes during 6 months of observation. Vertical changes is found in the active mining zone, in western-side of research area, while horizontal changes was found in eastern-side. The comparison of widening and narrowing valley is 13:1 due to horizontal changes. Result of petrographic analysis shows that three different sampling locations originated from similar provenance, which is undissected arc provenance but may differ in period of sedimentation. Grain material found in research are categorized as suitable material for mining with the 0.733 mm grain size. However, the mining activities should be aware of material availability to minimize the riverbank failure.

Keywords: anthropogenic, morphology, river valley, volcano.

Abstrak. Penelitian ini bertujuan untuk mengetahui perubahan morfologi suatu penggal sungai oleh aktivitas antropogenik. Lokasi penelitian berada di Sungai Gendol yang merupakan sungai pada lereng Gunungapi Merapi. Sungai Gendol setelah erupsi tahun 2010 banyak dimanfaatkan sebagai lokasi akrif tambang batu dan pasir. Kegiatan ini merupakan salah satu aktivitas antropogenik yang dapat menyebabkan perubahan morfologi. Perubahan morfologi diteliti melalui pengukuran terestrial, pengambilan foto udara, dan analisis material melalui analisis petrografi dan granulometri. Foto udara dilakukan pada duakali pengukuran, yaitu pada bulan Februari dan Agustus 2019. Hasil perbandingan foto udara dan DTM menunjukkan hasil bahwa lembah sungai yang diteliti mengalami perubahan horisontal dan vertikal. Perubahan vertical banyak terjadi dibagian yang aktif tambang, yaitu pada bagian barat sisi lembah, sedangkan perubahan secara horizontal banyak ditemukan pada sisi timur lembah. Perbandingan antara pelebaran dan penyempitan lembah di lokasi kajian adalah 13:1. Hasil analisis petrografi di tiga lokasi yang berbeda pada segmen lembah di lokasi kajian memunjukkan bahwa material berasal dari provenan yang sama, yaitu *undissected arc*. Tipe material berupa pasiran dengan ukuran 0,73 pada wilayah kajian termasuk kedalam ukuran pasir yang baik untuk kategori tambang. Namun apabila ketersediaan pasir mulai defisit, maka efek berupa longsor tebing sungai dapat terjadi.

Kata kunci: antropogenik, morfologi, gunungapi, lembah sungai.

1. Introduction

Merapi volcano, which is located on the border of Central Java Province and Yogyakarta Special Region, is one of the most active stratovolcanoes in Indonesia (Hadmoko *et al.*, 2018; Surono *et al.*, 2012; Thouret *et al.*, 2000). According to MAGMA 2019 (Multi-Platform Application for Geohazard Mitigation and Assessment in Indonesia), the activities of Merapi are currently at the second level, as a new dome is continuously growing and frequently collapsing. Generally, the volcano erupts on average with period every -4 years, in the form of a gravitational dome collapse (Voight *et al.*, 2000; Lavigne, 2004). The last explosive eruption occurred in 2010 on a Volcanic Explosivity Index (VEI) scale of 4, and was one of the largest eruptions in the last 100 years (Surono *et al.*, 2012). The amount of material produced from the eruption of the Merapi volcano in 2010 was estimated to be 36x10 m^3 (Charbonnier *et al.*, 2013; Komorowski *et al.*, 2013). The pyroclastic material was deposited in at least 13 rivers originating from the mountain.

One of the rivers on Merapi volcano that was filled with pyroclastic materials from the 2010 eruption was Gendol river valley. Pyroclastic flows, as the primary danger from the eruption of the volcano in 2010, distributed materials up to a maximum distance of ~15 km upstream from Gendol. The large amount of pyroclastic materials that were deposited upstream of Gendol were a major source of potential lahar or volcanic debris flooding, which can naturally cause changes in river morphology (Laavigne, 2004). 282 events of lahar floods after the 2010 eruption were recorded during the first (2010-2011) and second rainy season (2011-2012) (De Bélizal *et al.*, 2013). There have been many lahar flood events that have caused morphological river changes in Gendol valley by riverbank erosion, river channel expansion, and riverbed down cutting (river basin erosion/vertical erosion). Currently, Gendol river valley is extensively used for sand and stone mining activities, which have involved use of heavy equipment since 2011. After the eruption that occurred in 2010, there was no significant supply of lahar in the area, so it can be predicted that there has been a significant change in the morphology of the river valley in the last ten years. Mining activities can change landforms, such as changes to river channels, river embankments and ecological functions. Another example that can be clearly observed is terracing, a result of cut and fill from mining activities (Tarolli and Ellis, 2017). Mining activities can change the morphology of slopes, thereby accelerating the process of erosion and landslides (Mihai *et al.*, 2013).

Monitoring of morphological changes is one of the important studies in geomorphological process analysis. It is also an interesting area of study when associated with anthropogenic activities, such as mining. In this case, Gendol river valley was selected as a research location to analyze the morphological changes due to anthropogenic interference. For comparison, the existence of relatively natural river segments on the southern slopes of Merapi volcano can be used as a control to observe the effect of human activity on changes in the morphology of river valleys. An effective method that is often used to produce topographic data for morphological monitoring is UAV/aerial mapping (Cook, 2017; Darmawan *et al.*, 2018a,b; Zorn *et al.*, 2019). This is due to the ability of UAV to produce photos with a resolution of 5 cm and DTM/DSM with a resolution of 10 cm. This resolution is very suitable for use in riverbank landscape analysis (Hadmoko *et al.*, 2018). The results of research into the evaluation and effectiveness of UAV in detecting geomorphic changes indicates that UAV can produce data that can be used to analyze geomorphic changes up to the channel scale (Cook, 2017; Darmawan *et al.*, 2018a). However, morphological changes in vegetated areas will be more difficult to observe. UAV for morphological changes will be efficient if the vegetation around the study site is very sparse or short (Rusnak *et al.*, 2018; Watanabe and Kawahara, 2016).

2. Research Method

2.1. UAV Photogrammetry Data Acquisition

The research area was located in the upstream river segment of the Gendol river, Cangkringan District, Sleman Regency, DI. Yogyakarta (Figure 1). The area is classified as distal facies of Merapi volcano (Wacano and Puspitasari, 2016). Morphological changes in the river segment were observed through UAV aerial photo mapping and terrestrial survey. The UAV aerial image data acquisition was performed from two flights in February and August 2019. The UAV flew ~100 m above the Gendol river and took aerial images that overlapped 80% of each other. The overlapping UAV aerial images then were used to construct a 3D model of Gendol river using the Structure from Motion method. For geo-reference purposes, we relied on a GPS camera that automatically acquired during flight mission.

2.2. UAV Data Processing

The aerial photos for the study were obtained using a UAV quadcopter device, equipped with a 12 megapixel camera and three axis stabilization in order to reduce photo disturbances. The device was also equipped with a GLONASS sensor so that the photos were automatically given coordinate references (Andaru and Santosa, 2017). The photos were processed using Agisoft Photoscan. This software is efficient and has the ability to reconstruct 3D data. Data processing starts by aligning the photos, which is useful for determining the relative position between them, meaning the overlapping photos will have pixel values represented in the dense cloud. To generate DEM, the data were previously processed by building mesh and texture in order to produce a point cloud, which was then interpolated into DEM (Goncalves and Henriques, 2015). The results of the aerial mapping were orthomosaic photos and DTM, which were used to calculate morphological changes vertically and horizontally (Figure 2).

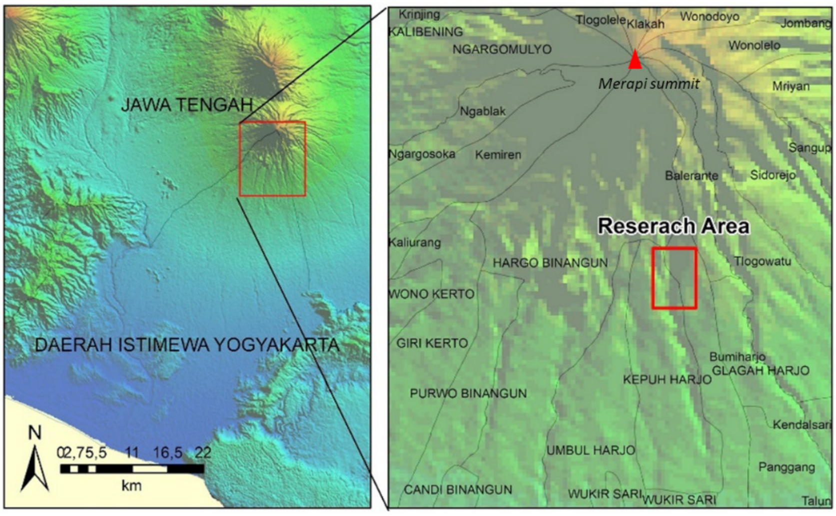

Figure 1. Research location upstream of Gendol River valley, approximately 5 km from the Merapi volcano summit.

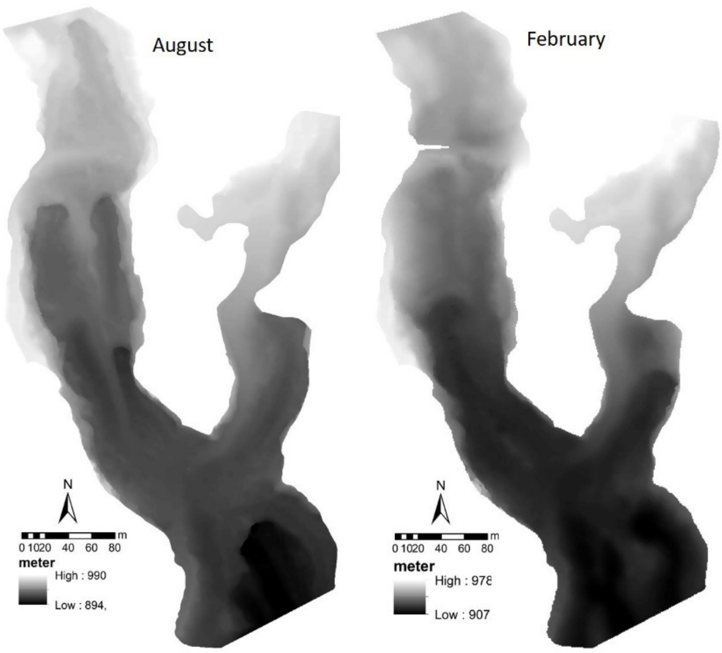

Figure 2. Comparison of DTM records from February and August in the research area.

2.3. Terrestrial Laser Scanning

Terrestrial laser scanning data acquisition was conducted using a Forestry 550 Laser Rangefinder. This is a powerful device for measuring horizontal distance and height difference. Measurements were made by dividing the river profile into multiple selected points based on the morphological details in the river segments. The Gendol river segment was divided into seven points, which were then interpolated to generate a detailed river profile. Each point had three types of data: coordinate reference, horizontal distance and height difference. The laser rangefinder method was also used by Scott *et al.* (2016) to generate a river bed profile; especially when combined with the RTK-GNSS method, it will produce very detailed data, even in a 3D model. In this study, we did not use the RTK-GNSS method because 3D data could be obtained from the aerial photos.

2.4. Petrographic Data Analysis

To support the morphological changes, information on the pyroclastic materials in the Gendol river segment was obtained by sampling some of the pyroclastic materials. There were three different sample locations of the materials: two in the affected mining area and one in a former mining area. To discover more about the differences in the materials, petrographic analysis was conducted to determine the origin of three pyroclastic material samples. Granulometric analysis was also performed to determine the grain-size characteristics in each sample of pyroclastic material, such as texture and sediment type.

3. Results and Discussion

The morphological changes were analyzed for vertical and horizontal differences. Vertical changes were analyzed by calculating DTM before (February) and after (August). The results of the calculation show that most river valley were relatively stable, as shown in Figure 3A. This means that anthropogenic (mining) activities had not changed much vertically. This was because such activities occurring in the Gendol river valley were only located at a few points, not along the river valley segment. Some areas which remained stable were used as road or dump trucks. In addition, the horizontal changes calculated from February to August show that most of the river valley remained constant or had changed little during the 6 months of observation (Figure 3B). Only a few areas were dramatically changed by mining activities, located in the eastern part of the river segment. The spatial variation in vertical and horizontal changes are shown in Figure 3.

Apparently 86% of the Gendol river valley remained stable or constant, while 13% had widened, and 1% narrowed. These values show that the ratio between widening and narrowing of the valley was 13:1. This means that mining activities are far more extensive in some areas compared to river sedimentation or accumulation (Figure 4A). The narrowing of the valley indicates an accumulation process which may have been caused by anthropogenic factors, such as remaining piles of mining materials. In addition, the values also suggest that within the period of 6 months, anthropogenic activities changed the morphology of the river by up to 14% horizontally in the Gendol river segment. Terrestrial measurement of river valley dynamics in the profile A-J using a laser range finder shows the differences between active and inactive mining (Figure 4B).

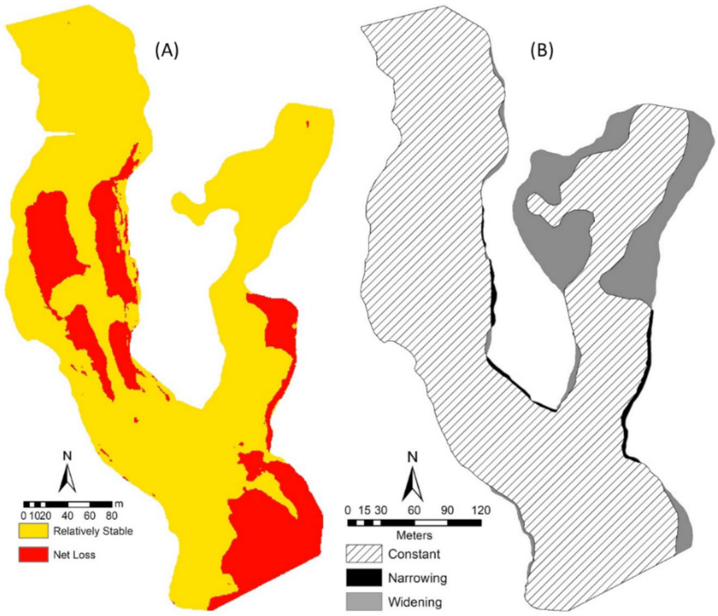

Figure 3. (A) Vertical morphodynamics in the research area calculated from DTM comparison and (B) Horizontal morphodynamics calculated from different valley delineations from February to August.

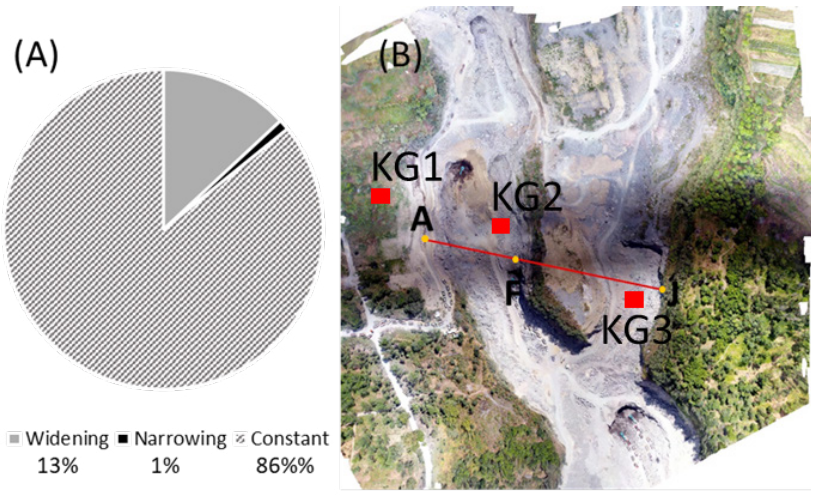

Figure 4. (A) Percentage of horizontal morphodynamics in the research area; the ratio of widening to narrowing of the valley is 13:1. (B) Profile A-J in the research area measured in detail using a laser range finder, and material sampling location.

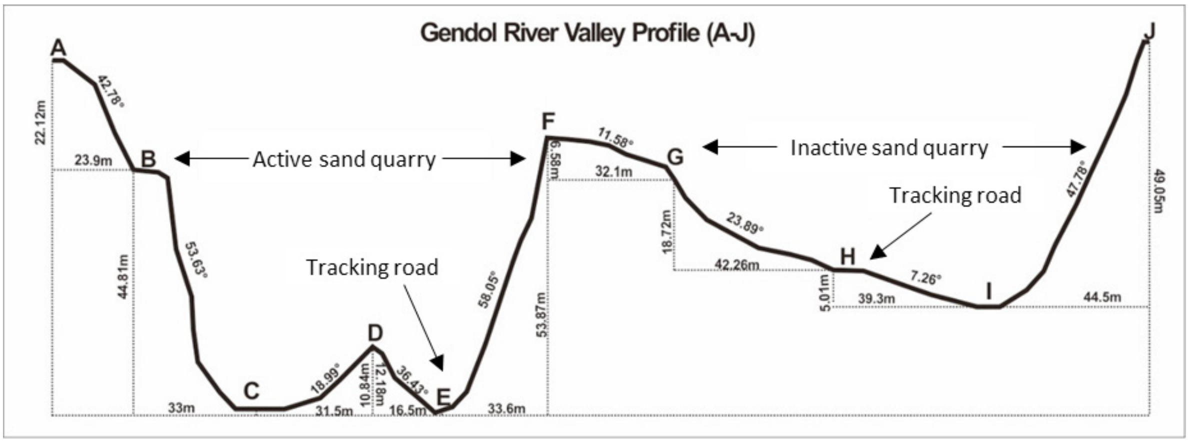

Figure 5. Detail of valley morphometry in Gendol river valley. Measured in segment A-J, which emphasizes the comparison between active and inactive mining areas.

River valley profile analysis was performed to find the morphological details of the river segment morphometry. Terrestrial surveys using a laser range finder were used to calculate the morphometrical aspects. The results from the field measurement were then used to produce a detailed profile sketch, as shown in Figure 5. In this profile, it can be seen that the active area of sand mining has a U-shaped valley morphology (A-F segment), whereas in the inactive mining valley area the morphology tends to be V-shaped (G-J segment). Generally, in the upstream area, the river has a V-shaped river valley morphology due to natural processes, but in the Gendol river segment it is U-shaped (A-F segment). The valley depth differences between active and inactive mining area re quite marked. The active mining valley area is 18 m deeper than the inactive area. This indicates that the extensive sand mining activities have changed the morphology of the valley dramatically. Another process that can also cause dramatic changes in river morphology is the occurrence of lahars (Lavigne *et al.*, 2007; De Bélizal *et al.*, 2013).

To analyze how strong the anthropogenic interference is in changing the morphology, petrographic analysis was also performed to predict the source surface materials. Petrographic analysis shows different results between former mining area, location that are still actively mined, and locations that are not actively mined (former, active and inactive mining). Lithic and feldspar minerals were contained in each sample, while not all the samples contained quartz, amphibole and pyroxene minerals (Table 1). The volume of lithic fragments ranged from 40-60%, which shows that the sand was formed from the detachment of other materials that existed before. The KG 1 sample was taken from a former mining site, so the material in this location is the result of previous material that had experienced weathering. Both KG 2 and KG 3 samples contained quartz. Quartz is a mineral in sand which can be used as an indicator to determine whether the sand is suitable for mining material or not (Wacano, 2014). This also shows why material around the KG 1 sample location is no longer mined. However, only the KG 3 sample contained pyroxene. This may indicate that the material deposited in surrounding KG 3 is more basaltic than KG 2 and KG 1.

Table 1. Minerals content of sampled materials, analyzed using the CPL and XPL method.

Mineral	KG 1 (%)	KG 2 (%)	KG 3 (%)
Lithic	60	45	40
Feldspar	15	5	18
Quartz	-	5	8
Amphibole	1	2	-
Pyroxene	-	-	4

Provenance analysis of the Merapi pyroclastic samples shows that all the materials were dominated by lithic and classified as having undissected arc provenance (Figure 6). Although all the materials had the same provenance, it can be predicted that they originated from different processes. Merapi volcano is an active volcano that releases a large quantity of materials; the last time this happened was in 2010. The KG 3 sample location is one of inactive mining, so the KG 3 material is presumed to be the most recent pyroclastic material produced by the 2010 eruption. If the material source of the three samples is different, we presume that the surface materials in the active mining (KG 2) area consist of material predating the 2010 eruption. This is can be assumed that on active mining, recent material from the 2010 eruption was already drained. In addition, the KG 1 materials are the oldest ones due to their high content of lithic fragments, which indicates continued weathering.

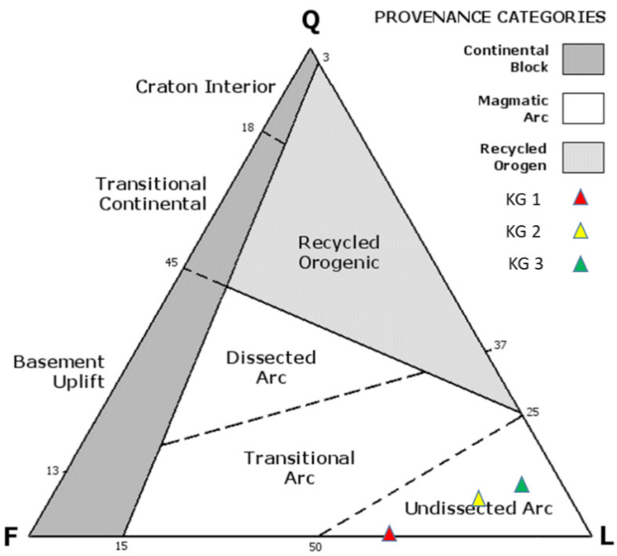

Figure 6. Provenance graph plotting three sampling materials from the Gendol river segment. (after:* Dickinson and Suzcek, 1979*).

The active mining in the studied segment was directly affected by the dynamic river morphology, as previously explained. Besides, this location is suitable for sand mining activities, especially around the KG 2 sample location. In this location, the size of the sand grains is classified as sandy materials. The textural triangle analysis from Gradisat (Blott, 2000) indicates that Gendol sand is categorized as gravelly sand. The sediment type is classified as very fine gravelly medium sand, with a grain size of 0.73 mm. In different locations in the Gendol river segment that is not actively mined, the size of the sand grains is 0.33 mm, classifying them as medium sand. This shows that mining activities prefer river segments that have a coarser sand size than a fine one. Other research found that the Gendol river sand at a radius of 2-5 km from the top of Merapi volcano is very good sand for making concrete (Lasino *et al.*, 2015). We suggest that if mining activity continues on the same scale in the research area, the sand will become deficit. The morphology of the valley will rapidly change and affect slope stability. The aerial photo in Figure 7 shows that the river valley has experienced major riverbank failure in some parts of Gendol river. Therefore, sand mining in deficit areas should be moved to other river segments which contain rich recent material and prefer to follow the local government regulation.

Figure 7. Aerial photo of riverbank failure (delineated by the red line) in some parts of the Gendol river valley. This location is close to the research area, located 200 m from point J in Figure 4.

4. Conclusion

Anthropogenic activities have significantly affected the morphological changes. In this case, vertical and horizontal changes over a six month period in the selected segment of the Gendol river valley have been triggered by mining activities. The morphological changes due to anthropogenic activities cannot be compared to catastrophe events such as lahar or PDC, which lead to greater effects on morphological changes. However, in general anthropogenic activity can lead to more rapid morphodynamic changes then natural processes such as erosion or sedimentation. This can be seen in the differences between valley shape in active and inactive quarry mining areas. In addition, aerial mapping is very useful for monitoring rapid morphodynamic changes due to anthropogenic processes. Petrographic analysis was also very useful for justifying the availability of recent material in the research location. We suggest that the recent material in active quarry mining areas of Gendol river was already been depleted. If the sand mining continues in the depleted location, riverbank failure could potentially occur because of unstable river valley slopes.

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