RIVERBED VARIATION AS INFLUENCED BY NATURAL AND HUMAN-INTERFERED PHENOMENA OF GENDOL RIVER, MT. MERAPI AREA, INDONESIA

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ABSTRACT

Rivers that originated from Mt. Merapi have a significant role as conveyance channels to migrate the sediment produced by volcanic activities. Depending upon the number of sediment volume accumulated at the upstream of the rivers, as well as the rainfall trigger, the rivers may experience debris flow occurrence which in some extent produces significant destructive power. The accumulation of sediment in the upper part of the rivers depends on the volcanic activity of Mt. Merapi, and unfortunately, its direction is unpredictable. The migration of sediment from the upstream towards downstream rivers is dominated by two mechanisms, i.e. through natural flow employing bed load transports and debris flows, as well as flow and through human-related activities by sand mining activities. This paper evaluates the riverbed variation due to the migration of sediment due to both natural phenomena such as debris flow occurrences triggered by the heavy rainfall and the human-interfered phenomena such as sand mining. The sediment control structure of GE-D5 at Gendol River and rainfall station of ARR Kaliadem were selected objects of observation. Study on the topographical change during the period of 23 October 2019 through 22 January 2020 as affected by the rainfall and the sand mining activity was then carried out. The riverbed variations were analyzed through the photogrammetry method at two different conditions, i.e. at the beginning of the rainy season and the middle of the rainy season. The discrepancy of results of the formation of new storage at near upstream of GE-D5 is presented and discussed. Moreover, the results of the evaluation contribute the highlight on how to carry out the proper sediment mining management at upstream of GE-D5 of Gendol River.

Keywords: Riverbed, sediment, migration, natural, human interfere

1. INTRODUCTION

Mt. Merapi is one of the most active volcanoes in Indonesia. Mt. Merapi is located on the border of Central Java and Yogyakarta Provinces and is also the meeting point of the boundaries of four regencies namely Sleman, Magelang, Boyolali and Klaten Regency. The eruption of Mt. Merapi has several cycles, namely a small cycle of 2-3 years and a large cycle of 10-15 years (DGWR, 2007). The big eruption of Mt. Merapi occurred in 2010, starting on the 25th, 26th, and 29th of October 2010, followed by a larger eruption that occurred on 3rd November 2010. In 2010 the eruption generated about 140 million m^3 of sediment at the peak of Mt. Merapi (DGWR, 2007). The eruption that occurred in 2010 released a relatively large amount of material, consisting of ash, sand, gravel as well as boulders. Besides, the aforesaid eruption also produced lava and pyroclastic flows. The eruption in 2010 has resulted in various damages and losses, but, on the other hand, the eruption also provided benefits to the communities around Mt. Merapi in the form of soil fertility and material availability to meet development needs. There are nine main rivers that flow from the peak of Mt. Merapi. These include Pabelan, Blongkeng, Batang, Krasak, Boyong, Kuning, Opak, Gendol, and Woro Rivers. The river system showing the location of Gendol River, sediment control structure of GE-D5 and rainfall station of ARR Kaliadem is shown in Figure 1, whereas the damage and loss is shown in Table 1.

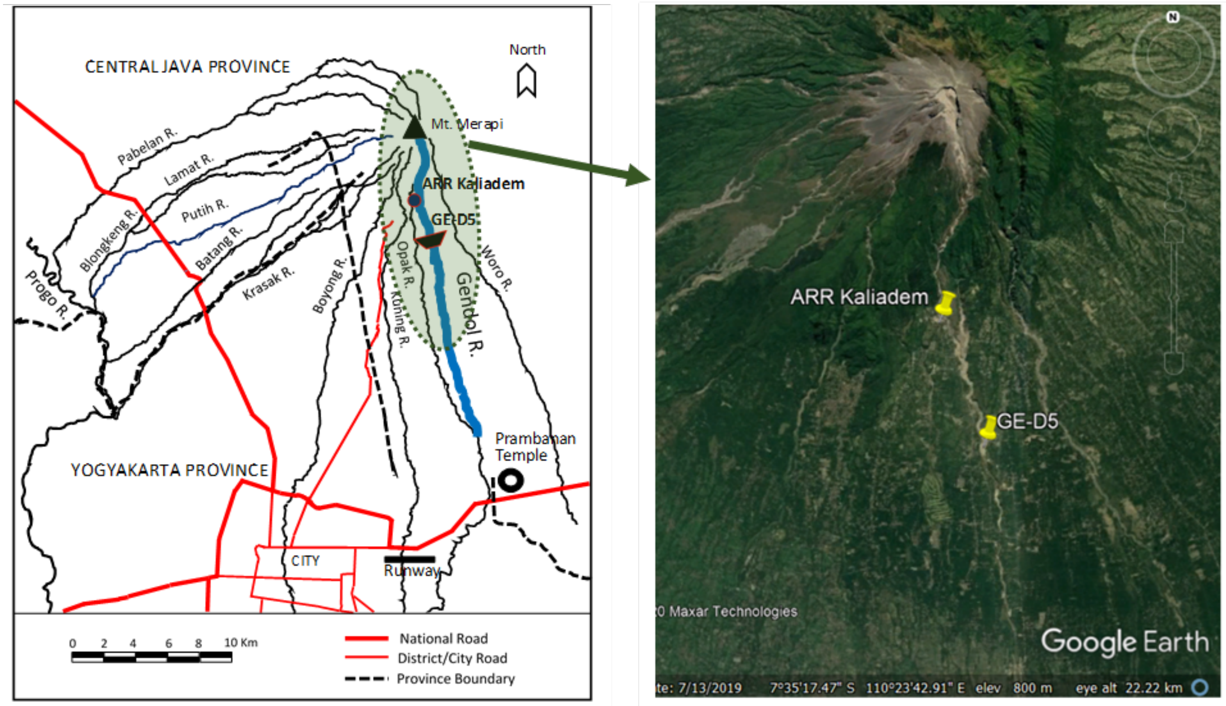


Figure 1. Rivers in Mt. Merapi area and location of Gendol River, GE-D5 and ARR kaliadem.

Table 1. Damage and loss due to 2010 Mt. Merapi eruption.

TYPE	DAMAGE	MAIN HAZARD
Fatality	386	Pyroclastic
Evacuee	399,400 at maximum	Pyroclastic
Asset	3,300 houses	Pyroclastic
Irrigation Facility	32 locations	Debris
Bridge	14 locations	Debris
Sabo Dam	77 locations	Debris
Innundation	6.9 million m^2	Debris
Lost (IDR)	4.23 trillion	Both hazards

Source: BPBD Sleman Regency, 2010

Mt. Merapi eruption in 2010 with a scale of Volcanic Explosivity Index (VEI) 4 had an impact on several aspects, one of which was the change in river morphology of Gendol River (Dipayana, 2013). Changes in river morphology can be caused by the results of the erosion and sedimentation processes of pyroclastic and lava flows. This process can be accelerated by mining activities. Such eruption was considered huge since the history of the eruptions. After the eruption, the rivers may experience dynamic river bed variation due to both debris flow occurrences and sand mining activities. Figure 2 shows the scale of Mt. Merapi eruptions compared to world volcano eruptions. In many cases of eruptions, the volcano produced two types of disasters that are known as primary and secondary disasters. The 2010 eruption was reckoned as a huge disaster that brought about the primary disaster such as ashfall, ballistics, and lava flow. Many rivers and surrounding villages were affected by the lava flows. The lava flow had reached 16 km downstream of Gendol River, the longest ever distance over the history of lava flow occurrences since 1930. The primary disaster of ashfall had also affected the aviation activity to a degree that the international airport of Yogyakarta could not be operated within a week to avoid possible aviation disaster. The 2010 eruption was not only huge but also unique in terms of eruptions that took place two times, i.e. on 26 October 2010 and 3 November 2010.

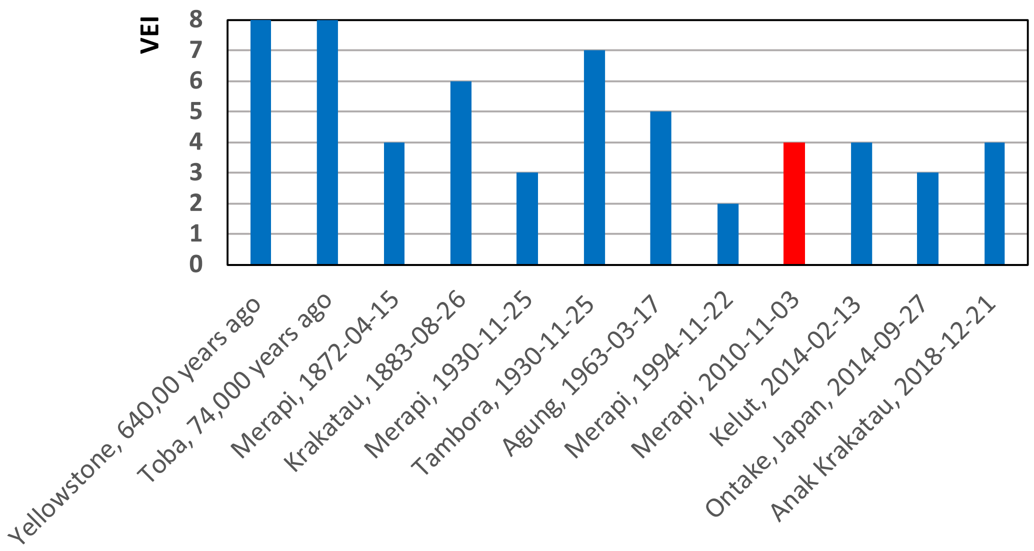
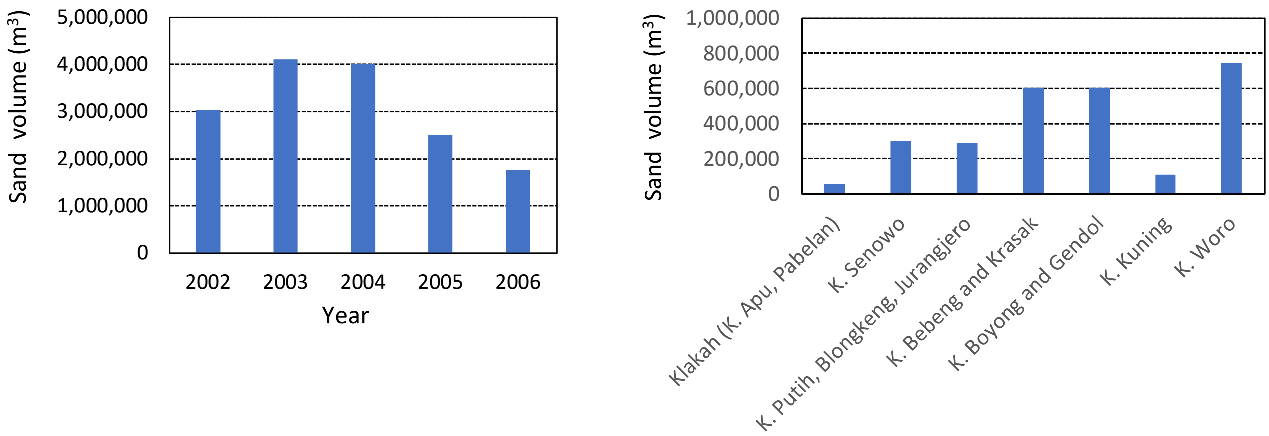


Figure 2. Scale of 2010 Mt. Merapi eruption and comparison with other world volcanic eruptions

As it was mentioned, Mt. Merapi frequently produces disasters, however, the volcano also contributes the land fertility and source of sediment. The utilization of sediment originating from the volcano has been lasting for a long time, along with the dynamics of sediment supply from the upstream area. The amount of sediment in the rivers in the Mt. Merapi region is strongly influenced by the activity of volcano and the hydrological conditions (mainly triggered by the rainfall) in the volcano area.

The hydro-environment complexity arises in the form that too much sediment in the river may bring about the insufficient capacity of the river to store the sediment inflow, however, less sediment may cause riverbed degradation. The continuous degradation would further bring about the instability of the sediment control structures. The volume of sediment that has been resulted from sand mining activity during the few years before the 2010 eruption was found to be very significant (see Figure 3). It is seen from Figure 3 a) that during 2002 thru 2006, sand mining activity varied considerably with the maximum and minimum volume that took place in 2003 and 2006 respectively. The 2006 eruption has made the activity decreased significantly because the sand miners considered their safety from pyroclastic (lava and lahar) flow disaster. Survey on sand mining activity as a part of Study on Institution and Community Development (DGWR, 2010) showed the condition of sand mining activity on several rivers at the Mt. Merapi area and the approximation of 2007 sand mining volume as shown in Figure 3 b). The total sand mining volume at the Mt. Merapi area as shown in Figure 3 b) is approximated to be 2,711,320 m^3, much larger than it was in 2006 (1,762,000 m^3). Additionally, the approximated 2007 sand mining volume at Gendol and Boyong River was found to be 600,000 m^3, this was about 22% of the total sand mining activity that took place in the whole area of Mt. Merapi. Indeed, the fluctuation of pyroclastic material availability seems to be very important for predicting any business related to sand mining.



a). Total at Mt. Merapi area

b). Total at some rivers in 2007

Figure 3. Sand mining volume at Mt. Merapi area (DGWR, 2010).

2. TOPOGRAPHICAL CONDITION AND SAND MINING ACTIVITY AT NEAR UPSREAM OF GE-D5 OF GENDOL RIVER

The Unmanned Aerial Vehicle (UAV) platforms were a valuable source of data for inspection, surveillance, mapping and 3D modeling issues (Remondino et al., 2011 and Nex, et al., 2014). The UAVs have been a low-cost alternative to the classical manned aerial photogrammetry. Rotary or fixed-wing UAVs, capable of performing the photogrammetric data acquisition with amateur or SLR digital cameras, can fly in manual, semi-automated and autonomous modes (Shikada, et al., 2011). The latest developments of UAV image processing methods for photogrammetric applications have been reported, including mapping and 3D modeling issues. The UAV or unmanned aircraft is a flying machine with remote control by a pilot or by an autopilot. Two types of UAV have been widely used, i.e. the wing type and the rotary typed (further known as drone). Drone technology has been used in various countries not only for taking aerial photographs or videos but also used in the remote sensing process (Ren, et al., 2019). For making Digital Elevation Model (DEM) maps or topographic maps, the use of drones using cameras is still not widely used, which is commonly used in mapping are drones equipped with Light Detection and Ranging (LIDAR) and Terrestrial Laser Scanning (TLS). The technique used in making DEM maps using drone cameras is called photogrammetry (see Figure 4). With this technique, the properties of the geometry of an object obtained from many images can be known. These images must be overlapped with one another in the same section of the image. The wider the overlapping area, the more accurate the results obtained. Drone technology can be used to make technical maps both from Digital Surface Model (DSM) maps, Digital Terrain Model (DTM) maps, and the final result in the form of contours with high accuracy.

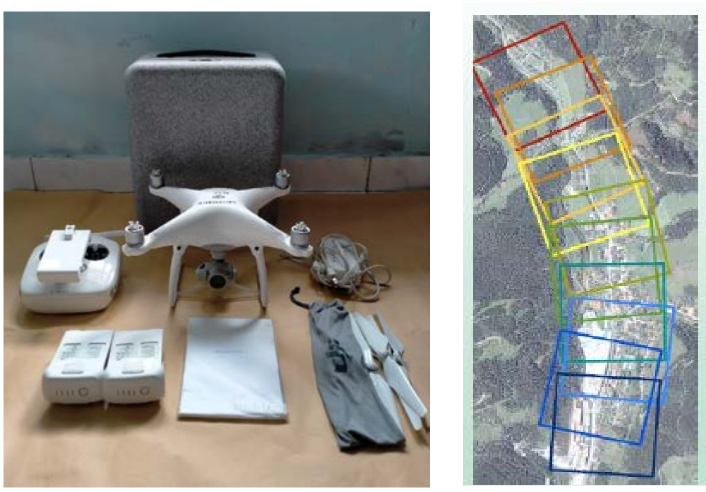


Figure 4. Drone and over-lapping/side-lapping techniques of photo aerial mapping.

To determine the variation of riverbed contour due to mining activity and to estimate sediment volume that occurs in the upstream part of the GE-D5 Dam, an assessment of topographical conditions and sand mining activities were carried out. This assessment is further utilized to provide recommendations for sediment management related to sand mining operations carried out around GE-D5 Dam. The GE-D5 Dam is located at Cangkringan District, Sleman Regency. The dam is located in the Gendol watershed with the geographical position between 7º37'30"S - 7º43'0"S and 110º27'0"E - 110º29'0"E. The length of the Gendol River is about 22 km with a watershed area of 14.6 km^2. The upstream catchment area of Gendol River is part of the Opak watershed where the downstream of the Gendol River is a tributary of the Opak River. Some of the boundary conditions used in the assessment are as follows:

(a) Topographic measurements are carried out using the Unmanned Aerial Vehicle (UAV) or Drone method in areas ranging from the GE-D5 Dam upstream along two kilometers,
(b) The assessment is conducted at the beginning of the rainy season and in the middle of the rainy season.
(c) The volume of sediment from sand mining activities is obtained from secondary data and direct observation data.

Monitoring of river morphological changes due to natural processes and accelerating processes can be done with a remote sensing approach using high-resolution data. Two main activities that are considered essential as a basic requirement to describe the morphological changes they are the remote sensing and the DEM processing. The drone technology was used in identifying the morphological changes of upstream GE-D5, besides, the sediment balance was also analyzed based on the empirical formula. The topographical conditions near upstream of GE-D5 at three different times of observations are shown in Figure 5. Further monitoring on the dynamic of the topographical and the potential trigger was carried out on two different times of observation, i.e. on 23 October 2019 and 22 January 2020.

a). Before 2006 eruption

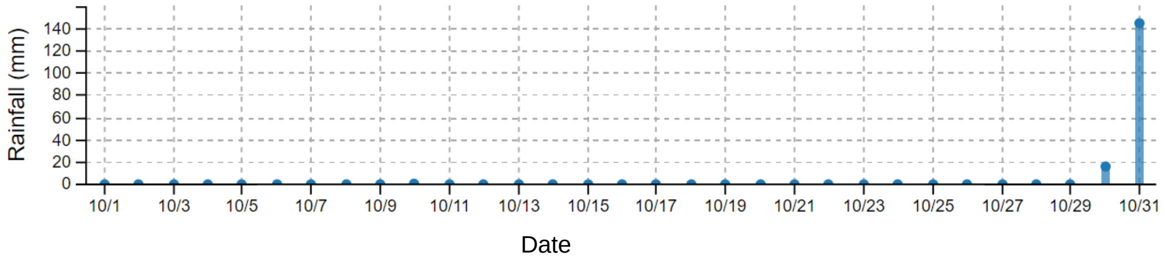
b). After 2010 eruption

c). 23 October 2019

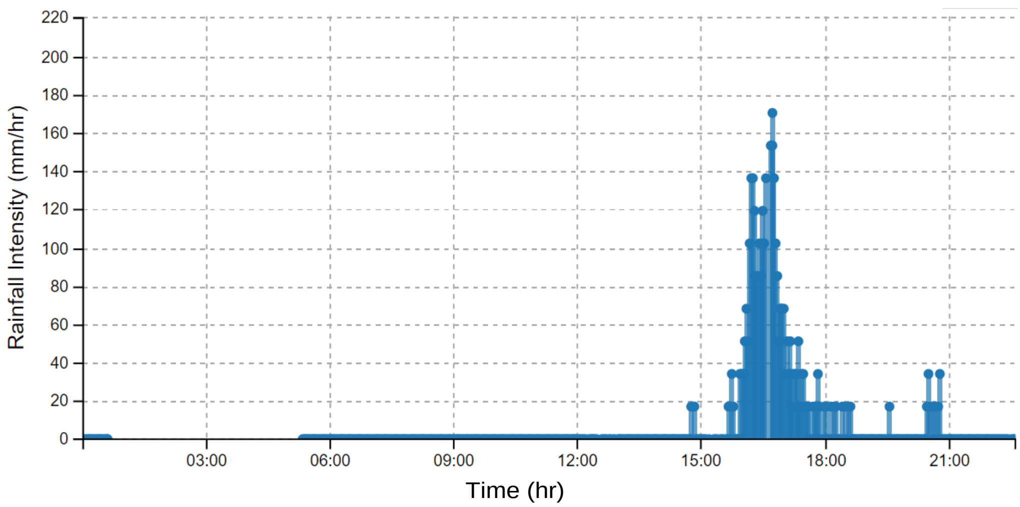
Figure 5. Topographical condition at near upstream of GE-D5

3. RESULTS AND DISCUSSION

One of the objectives of this study is to estimate the sediment volume that has been withdrawn by the sand mining activity through the identification of the changes in topographical condition. The sediment volume that has been supplied by the rainfall-triggered debris flow was considered insignificant since there was no record on the debris flow occurrence within the period of the study. The rainfall occurrences that took place during the period of 23 October 2019 through 22 January 2020 is shown in Figure 6. Such occurrences are considered not significant to trigger the debris flow occurrences; therefore, no sediment had been supplied during the period under investigation. The daily rainfall during October 2009 is shown in Figure 6 a). with the highest rainfall took place on 31 October 2019 with the five minutes distribution is shown in Figure 6 b), no debris flow occurrence had been reported. The change in the topographical condition was mainly due to the sand mining activity. Previous studies on various rainfall conditions triggering debris flow occurrences in Gendol River (Fibriyantoro, 2015) showed the debris flow occurrence even with the relatively low rainfall intensities, i.e. 100 mm/hr and the daily accumulative rainfall at 119 mm (see Figure 7).



a). Rainfall depth of ARR Kaliadem in October 2019



b). Rainfall intensity of ARR Kaliadem on 31 October 2019

Figure 6. Rainfall depth and intensity of ARR Kaliadem (http://data.hydraulic.lab.cee-ugm.ac.id)

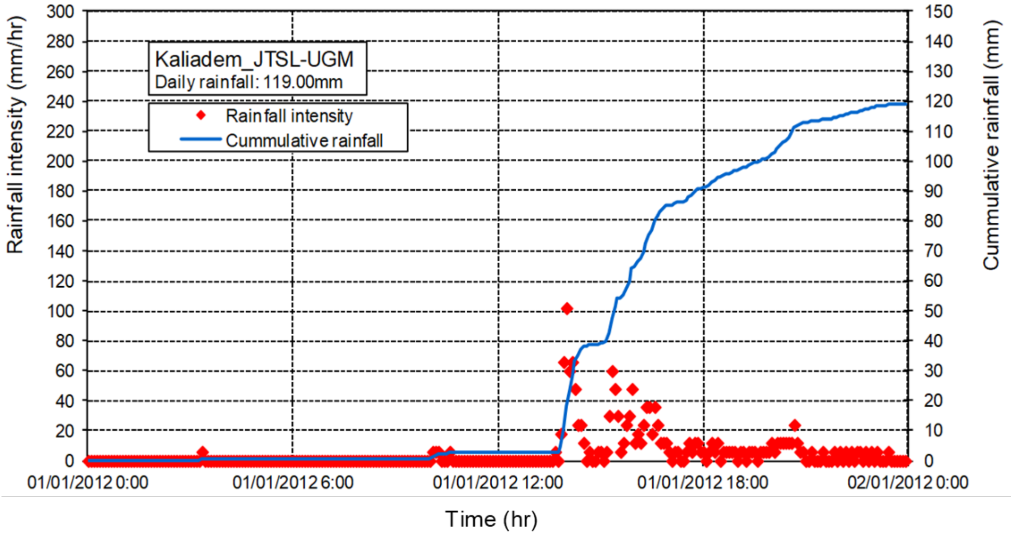
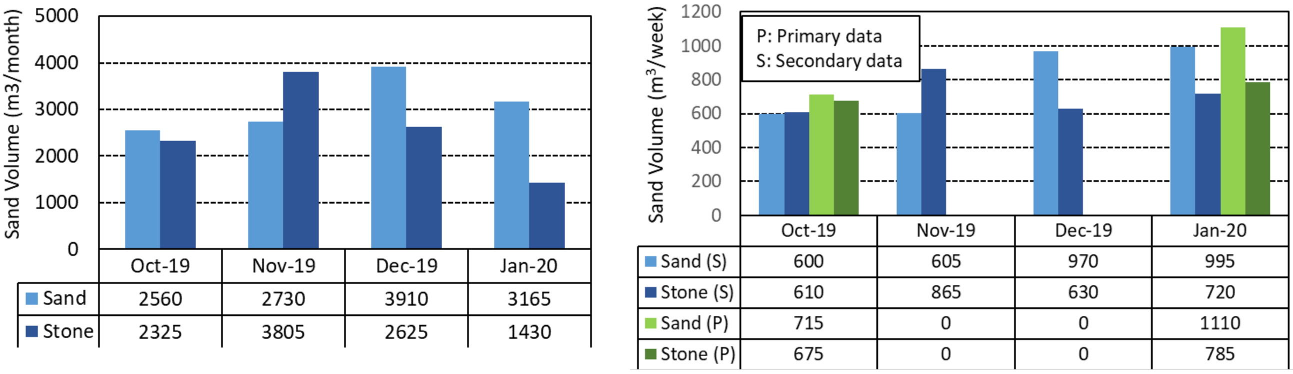


Figure 7. Rainfall intensity at Kaliadem on 1st January 2012 that causing debris flow.

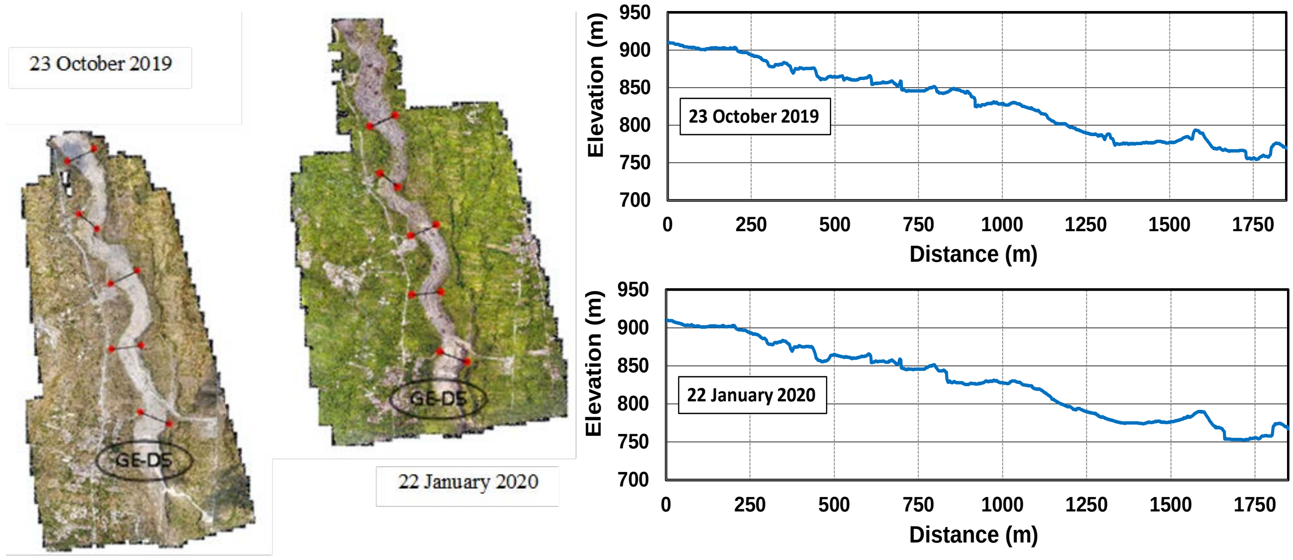
Sediment mining activities along the Gendol River are the most active mining businesses in Sleman Regency. Mining is no longer using simple tools but using mechanical tools (excavators). Through the direct observation in the field (observation points were located between the Kepuharjo and Glagaharjo hamlet), an estimate of the volume of mining was made. Other data (secondary data) were also collected from records made by the sand miners themselves. The secondary data that obtained during 4 (four) months, from October 2019 to January 2020 and its further analysis shows that sand mining activities remain very intensive, with the total amount of sand and stone production is shown in Figure 8.



a). Monthly sand volume b). Weekly sand volume

Figure 8. Sand mining volume at near upstream of GE-D5 during October 2019 thru January 2020.

It is seen from Figure 8 a) that the total sand and stone that has been taken out from the area upstream of GE-D5 of Gendol River was approximately 22,550 m^3 from October 2019 until January 2020. The sand material was slightly (54.83%) higher than the stone material (45.27%), as sand is more marketable rather than the stone. Moreover, the weekly sand and stone mining obtained from primary data (direct observation) was slightly higher rather than obtained from the sand miners' report as shown in Figure 8 b). The photogrammetry technique by the drone utilization was also carried out to identify the morphological changes from 23 October 2019 to the 22 January 2020 condition. The results in the form of Mozaic orthorectification with selected five cross-sections provided with the long sections through the lowest riverbed elevation are presented in Figure 9.



a). Aerial view at two different conditions b). Long section at two different conditions

Figure 9. Mozaic orthorectification and long section around GE-D5 of Gendol River.

The river morphology (particularly in the form of the plan view) near upstream of GE-D5 does not indicate the significant change. It was found from the field observation that the position of the riverbanks along approximately 1,600 m upstream of GE-D5 on 22 January 2020 condition remains the same as it was on 23 October 2019. However, a significant riverbed degradation took place at the upstream of GE-D5, starting the 600 m until 1600 m upstream of GE-D5. So far, there was not any report on the debris flow (and lava flow) occurrence during October 2019 until January 2020. This means that there was not any sediment supply from upstream either triggered by heavy rainfall and/or volcanic activity. It could then be mentioned that riverbed degradation as an impact of the sand mining activity. The riverbed degradation at upstream of GE-D5 varied considerably at the degree of 5-10 m along the 600 m until 1,600 m upstream of GE-D5. In such a situation, the formation of new storage from the sand mining activity is considered positive since the possible sudden supply of sediment from upstream of GE-D5 could be detained and hence reduce potential damage at downstream infrastructures. The aforesaid new storage volume is estimated to be approximately 37,500 m^3 where any sediment supply of less than this value would not cause any overflow passing through the GE-D5. The sand mining activity might create a problem when the amount being excavated is too much that contribute potential instability of the parts (foundation, bank protection, etc.) of the GE-D5. To avoid the instability of the structure, the area at a distance of at least 500 m from upstream of GE-D5 should be left free from sand mining activity.

4. CONCLUSIONS

Until now, sand mining activities in the upstream of GE-D5 of Gendol River remain intensive that causing riverbed degradation at the degree of about 5-10 m river degradation between 23 October 2019 to 22 January 2020. During the investigation period, there was no debris flow in the river, therefore, the riverbed degradation was largely due to the sediment mining activities. The storage at near upstream of the GE-D5 of Gendol River decreased at 37,500 m^3 during the instigation period of 22 October 2019 until 23 January 2020. At the same time, sand mining activity has reached approximately 22,550 m^3. Unless there was a significant debris flow passing through the GE-D5, such a discrepancy of about 14,950 m^3 was presumably due to the under calculation of sand mining volume. Further assessment on both topographical change and sand mining volume should be carried out continuously along one year covering the dry and wet season. Similarly, to get the more accurate estimation on the sediment balance, a continuous debris flow monitoring along the river including the debris flow through GE-D5 should be carried out. Moreover, aerial mapping utilizing the UAV sound to be very useful for further suggestions on more proper sand mining activity to meet further sustainability.

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