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Rapid and low cost ground displacement mapping using UAV photogrammetry

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ABSTRACT

Ground displacement mapping has become a crucial issue for landslide hazards assessment. Unmanned Aerial Vehicle (UAV) offers many advantages in mapping applications. The objective of this study is to analyze ground displacement by UAV. This study utilizes UAV DJI 4 Pro for the landslide area in conservational forest Semarang, Indonesia. The study area for mapping is 12 ha, divided into 8 points. Three Control Points 2 × 2 meters were applied. Aerial photographs were taken during the rainy season, August 21st, 2021 and March 30th, 2022. Agisoft software was used to obtain the point cloud and Cloud Compare was used to estimate the landslide surface area. The final results show there are 2 point areas occur ground displacements. In the first location, the landslide surface area is 3420 m^2, with the depth of landslide 19 m. The ground displacement occurs in 79.4 m western. The second location landslide surface area is 3576 m^2, with the depth of landslide 4 m. The ground displacement occurs in 60.3 m to the west. This study concludes that UAV is applicable in photogrammetry to analyze ground displacement. The procedures in this study can be used for monitoring a landslide area with rapid results and a low-cost budget.

1. Introduction

The occurrence of disasters in recent years has increased frequently, causing casualties, destructing human property, and affecting socio-economic growth. The assessment of disasters has begun to perform disaster mitigation in order to diminish the losses (Li et al., 2021). Indonesia as one of the countries densely populated has a complex and diverse topography. Even though Indonesia is known for its soil fertility, it is prone to disasters, including geological disasters. Among the geological disasters in Indonesia is a landslide, a down-slope movement of soil and rock. Landslide is one of the most ruinous disasters in the world. In 2021, according to statistics from the National Board for Disaster Management of Indonesia, there were 633 landslide occurrences in Indonesia. There were 676 deaths, 8.6 million people suffered from the situation and socioeconomic losses exceeded 22 trillion(Badan Nasional Penanggulangan Bencana (BNPB), 2021).

Among the triggering factors of landslides are precipitation, human activities, river overflow, earthquakes, volcanic eruptions, and slopes undercut (Skilodimou et al., 2018; L. Chen et al., 2020; Martino et al., 2022). A landslide is a complex nature formation process. In the prevention and assessment of the hazards, documentation of slope sliding is needed to inform the critical displacement (Montanarella et al., 2013). The estimation of ground displacement in an area prone to landslides is hence, important to understand how the landslide develops (Makabayi et al., 2021; Zugić et al., 2018). Displacement mapping and monitoring over a large area of the unstable slopes have become a critical issue to prevent and assess the hazards.

The need for spatially distributed information has arisen with the use of remote sensing. Diverse remote sensing techniques, including space born (Kang et al., 2017; Qi et al., 2017; Yang et al., 2017), optical.

(Golovko et al., 2017; T. Chen et al., 2017), airborne, ground-based, and terrestrial (Luo et al., 2017) are considered effective to obtain spatially distributed information for a landslide (Zhao and Lu, 2018). Remote sensing's main advantage is able to obtain spatial data continuously with centimeter precision. However, aerial and satellite remote sensing is difficult to be extracted in an accurate manner, especially

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when the location is complex, with various kinds of vertical and horizontal objects such as buildings and trees. Thus, a platform that can carry out a horizontal and vertical spatial observation to form a coordinated observation is needed. Sort of costs is encountered in the former remote sensing, i.e. set-up costs, field survey, images acquisition, and time spent on field data analysis, in which 40–72% of the total costs are spent on set-up costs including hardware and software for habitat mapping. The ball-park figures of the costs for the remote sensing mapping in an area of 150 km^2 in the coarse area could spend £33,020, with the time taken 97 days, while for the fine area costs £57,620 with time taken 117 days (Green et al., 2000). The use of remote sensing data collection from manned aircraft can give accuracy in the range of 84–86% (Naz and Bowling, 2008). Meanwhile, satellite remote sensing has drawbacks such as time-consuming problems, that still challenging to acquire quality imagery for a short period (Zhang and Kerle, 2008).

The use of Unmanned Aerial Systems after 2015 has created a sharp increase in application, including in acquiring geospatial data (Khanal et al., 2020). The continuous development of technology has progressed UAV (Unmanned Aerial Vehicle)-based remote sensing that can obtain spatial information in a timely manner. The use of UAVs for photogrammetry and remote sensing is opening interest in surface modeling and monitoring (Travelletti et al., 2012; Ruzgiene et al., 2015). Besides, it is considered reliable for cm-level resolution and costs a few hundred euros (Colomina and Molina, 2014), as the previous means technique airborne or ground-based LiDAR sensors are reviewed as very expensively (Rossi et al., 2018; Wang et al., 2021). The photogrammetry and remote sensing using UAV make a possibility to repeat measurement surveys at time intervals in order to analyze the changes happening in an area. To date, UAVs are equipped with an optical camera to carry out digital aerial photogrammetry. By using UAV, the topographic surveys are now possible by the combined simple RGB aerial images to exploit digital photogrammetry. The use of UAVs have been applied to landslide monitoring to analyze the volume of eroded slope material and material accumulation (Eker et al., 2018), analyze the surface deformation

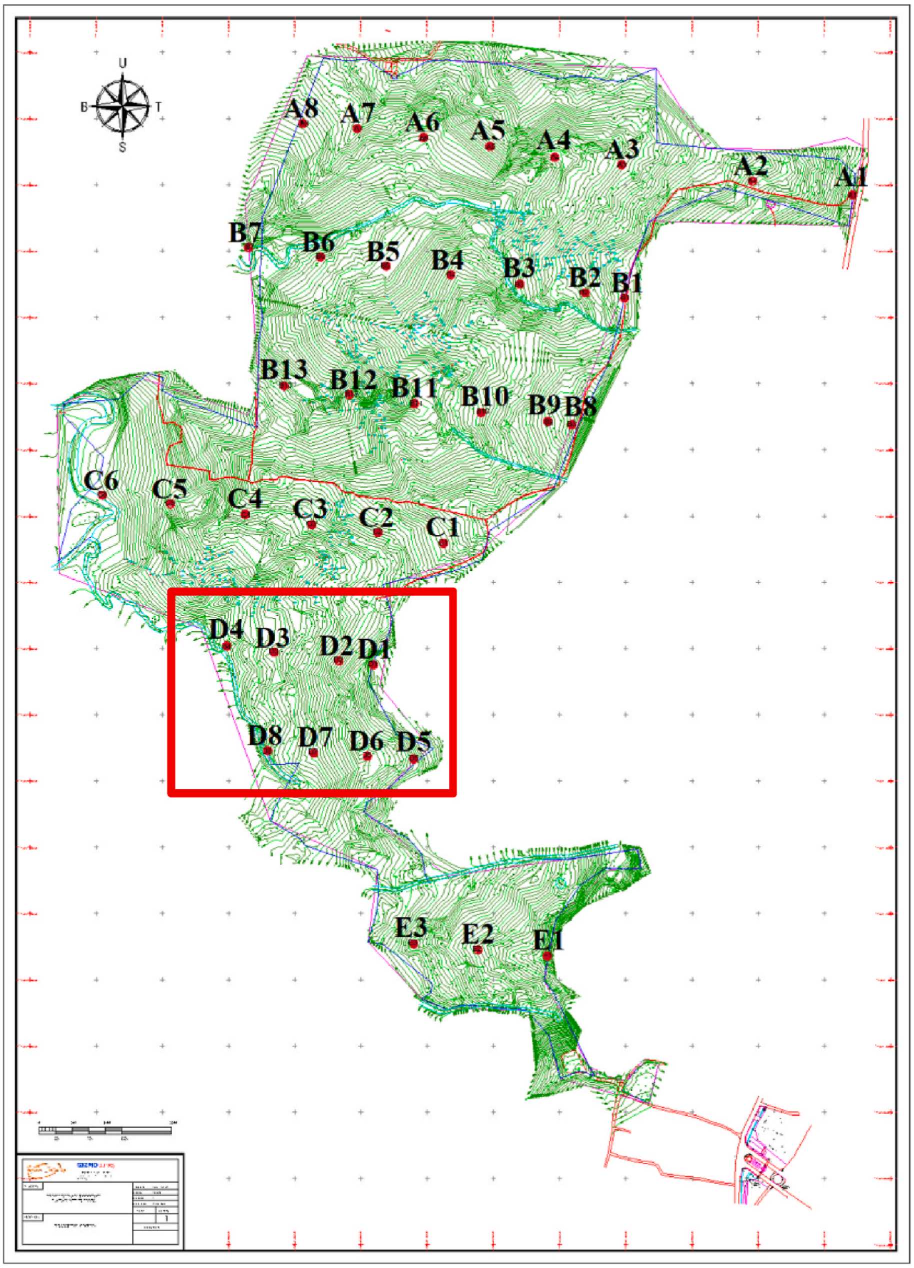

Fig. 1. The location of the study area.

(Wang et al., 2021; Erenoglu et al., 2014; Lin et al., 2015), determine the speed of the landslide (Yaprak et al., 2018), characterize landslide and mapping (Casagli et al., 2017).

In this work, a UAV DJI Phantom 4 Pro with an embedded camera conducted photogrammetric data acquisition in an area prone to landslide in Gunungpati, Semarang city, Indonesia. The aim of this work is to analyze ground displacement by a landslide area, depth of a landslide, and direction of a landslide using aerial photogrammetry UAV with rapid and low-cost advantages.

2. Method

2.1. Study location

The study location is at a slope of Gunung Ledek, specifically in Taman UNNES, Gunungpati, Semarang city. Gunungpati is one of the sub-districts in Semarang city that is prone to landslides. Fig. 1 shows the sketch of the area in Taman UNNES divided into A1 to E3. The area of study location is at 8 points (D1 – D8) with the specific coordinate 7° 2′ 30.81'' S 110° 23′ 4.08'' E (D1) to 7° 2′ 35.02'' S 110° 22′ 58.87'' E (D8). The reason behind these point areas is the slope in D1-D8 is the strongest i.e. D1-D4 21.2% and D5 – D8 18.4%, compared to A1-A8 16%; B1-B7, B8-B13 17%; C1-C6 17%, E1-E3 18.4%. All of the areas from A1 to E3 is categorized as a steep slope (Canada.ca, 2013), but the strongest slope is at points D1-D8. The type of soil in those areas is dominated by clay (D1-D4) and sandy clay (D5-D8). The type of soil and the coordinates of the location are shown in Table 1. The area is about 12 ha.

Table 1
The type of soil in study site.

Depth (m)	The type of soil
D1	
0–9.38	Clay and sandy clay
9,38–15.9	Loose clay
15.9–39.8	Sandy clay
D2	
0–5.58	Clay and sandy clay
5.58–10.2	Loose clay and clay
10.2–43.9	Clay
D3	
0–1.08	Clay
1.08–2	Loose clay
2–41.4	Clay
D4	
0–1.74	Clay and sandy clay
1.74–7.71	Clay
7.71–44.1	Clay
D5	
0–4.84	Clay
4.84–6.8	Loose clay
6.8–42.5	Clay
D6	
0–1.8	Clay and sandy clay
1.8–3.49	Loose clay
3.49–55.9	Clay and clayey sand
D7	
0–2.36	Clay and sandy clay
2.36–2.65	Loose clay
2.65–40.7	Clay
D8	
0–1.49	Clay and sandy clay
1.49–3.11	Loose clay
3.11–4.09	Clay
8.94–39.8	Loose clay

2.2. Materials and methods

The UAV system adopts DJI Phantom Pro 4. It is embedded with 1-inch CMOS sensor camera, with effective pixels of 20M. This type of UAV can have a flight time of 30 min(DJI Phantom, 2017). The software used for processing the image captured by UAV is open source software, Agisoft, and Cloud Compare. Agisoft software was used to obtain the point cloud. The Cloud Compare software was used to estimate the landslide surface area. The image data were processed using Personal Computer (PC) Windows 10 Pro-64-bit, RAM 16 GB, VGA NVIDIA GT730.

2.3. The image acquisition

The process of image acquisition using the DJI Phantom 4 Pro UAV is shown in Fig. 2.

The height of the flight was set to 60 m. The process of the flight plan was set to 3 times of acquisition, with 12 min time, for each. This method was performed to get better pixels of images, rather than taking all areas of 12 ha at one time.

In the data acquisition, GCP (Ground Control Point) 2 m × 2m were used, as many as 3 units (see Fig. 3). The black and white GCPs were placed onto 3 points of the study area in low, intermediate, and high points. The use of GCPs is important to improve the accuracy of the mapping (Park and Yeom, 2022), because the GCPs function as a real measurement to calibrate the image acquisition from UAV. If the measurement from the image acquisition of UAV is closed to the real measurement of the GCP, means that the data is reliable and the UAV can be used for the photogrammetry instrument.

The image acquisition was performed in the interval of the rainy season, i.e. August 21st’ 2021, and March 30th’ 2022. This is one of the factors of landslides, which is rainfall.

2.4. Geographic information system (GIS)

After the data were obtained, the following process is the GIS process. The process was performed using Agisoft and Cloud Compare can be seen in Fig. 4.

The filtering of the image quality is purposed to delete the images with bad quality such as blurred images, or overlapped images. This is to ensure that the images to align are qualified so can acquire a good 3D model.

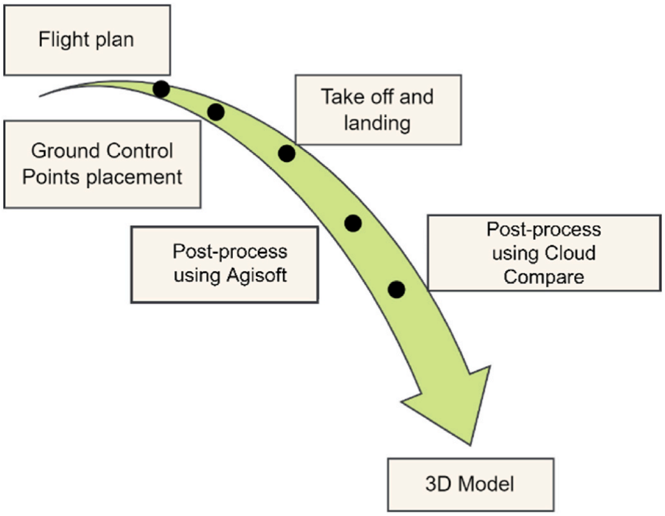

Fig. 2. The block diagram of the image acquisition.

Fig. 3. Ground control points.

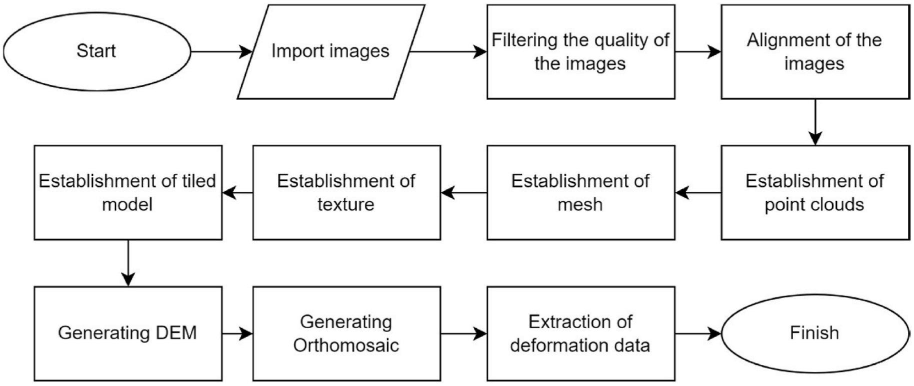

Fig. 4. The GIS process of acquired images from UAV.

3. Results and discussion

3.1. Accuracy information

This work used 3 GCPs (Ground Control Points). This number meets the minimum amount of ground control points (GCPs) which is three (Oniga et al., 2018). The color of GCP is black and white, it is intended to recognize the high contrast patterns easier. The accuracy of information of images captured by UAV is compared to GCP. Fig. 5 shows the length of a GCP from a UAV image. A line was drawn from the corner to corner in a row to measure the length of the GCP image acquisition by UAV. The result of the GCP image length is 2.01 m, and the actual length of the GCP is 2 m.

The accuracy is measured using equation (1)

$$\text{Accuracy} = 100\% - \text{Error Rate}$$

Fig. 5. The accuracy of the image from UAV acquisition with GCP.

$$\text{Accuracy} = 100\% - \left\{ \frac{(\text{GCP by UAV} - \text{GCP by real})}{\text{GCP by real}} \text{ x } 100\% \right\} \tag{1}$$

$$\text{Accuracy} = 100\% - \left\{ \frac{(2.01 - 2)}{2} \text{ x } 100\% \right\}$$

$$\text{Accuracy} = 99.5\%$$

Referring to the results of GCP by UAV 2.01 m, and actual GCP 2 m, so the accuracy is 99.5%. This result indicates that the use of the UAV is reliable for 3D mapping. Because for land classification, the accuracy of a minimum of 85% can be considered reliable land cover classification (Anderson et al., 1976).

In photogrammetry applications, such as for land surveying and construction, Ground Control Points (GCPs) are proven greatly increase the accuracy of 3D information results such as a point cloud, 3D mesh, orthomosaic or Digital Elevation Model (DEM). Three GCPs are enough for photogrammetry, as the exceeding GCPs can be a time-consuming process in either field or computation (Oniga et al., 2018). However, the UAV specifications such as its camera's focal length, flight altitude, camera orientation, and image quality also influence (Gindraux et al., 2017; Harwin and Lucieer, 2012).

3.2. Deformation data

The deformation data presents the information about the Digital Elevation Model and orthomosaic form of the image acquisition. Figs. 6 and 7 shows the orthomosaic and DEM of the data acquisition on August 21st' 2021 and March 30th' 2022. They show a significant growth of grass in the first and second surveys. The orthophoto and DEM carry out their comparison. The DEM provides the information on the geomorphological change in the study area which informs the occurrence of landslides. In the interval of seven months of data acquisition, the differences apparently shown by the images are the landslide occurred. The comparison between the first and second data acquisition highlights appreciable displacement with two scarp areas.

3.3. Landslide information

The process used Agisoft and Cloud Compare software. The occurrence of landslides is shown in Figs. 8 and 9. Fig. 8 shows the landslide that occurred in points D2 and D7, processed by using Agisoft. The figure shows that the ground displacement in the D2 area is 79.4 m, in the western direction. Meanwhile, in the D7 area, the ground displacement occurred 60.3 m in also western direction.

The result of processing using Cloud Compare obtained the landslide surface area as shown in Fig. 9. The figure shows that the landslide surface area of D2 is 3420 m^2 and the landslide surface area of D7 is 3576 m^2.

Determining the depth of displacement is seen from the orthomosaic difference values of the peak and valley. Fig. 10 shows the orthomosaic to analyze the depth of landslide/ground displacement. For D2, the depth of the displacement is 19 m from 111.2 subtracted by 92.2 and for D7, the depth of displacement is 4 m from 82.4 subtracted by 78.4.

The aim of this work was to analyze ground displacement by landslide area, depth of a landslide, and direction of a landslide using UAV. The UAV adopted in this work is a DJI Phantom 4 Pro embedded with a camera 20M pixel to detect and monitor the movement of the slopes from its image capture. By performing the method in this work, one advantage pointed out is the repeatability of surveys in a relatively short time with high resolution and high accuracy. The displacement that occurred in the study area is 79.4 m and 60.3 m. These numbers are due to the image acquisition from August to March that including the rainy season in Indonesia which ranges from October–April, as rainfall does influence the occurrence of landslides (Feranie et al., 2021). According to the Varnes classification landslide type, the number of 79.4 m and 60.3 m are close to the moderate velocity scale landslide which is 13 m/month (Hungr et al., 2014). Even so, the response to this type of landslide velocity requires evacuation.

Formerly, land mapping was performed by analyzing aerial photographs. There were only two choices to do the mapping, i.e. obtain existing photography or contract new photography. For a better result, it should be contracted new photography. But the consequence is that the method is much more time-consuming. The processes in the method are trial delineations, the field survey, creating category definition and descriptive keys, and evaluating the accuracy. The interpretation of photography should include trained and trainable aerial photo interpreters who have three or five years of experience with aerial photography. Besides, this method also should include base maps and the evaluation of accuracy. In the field study, the interpreter should also judge which land needs additional study and interpretation. The problem goes on they interpret the colors transparencies of pink half and a red half which the best way to interpret is to have those printed in a custom lab in order to obtain a consistent tone of the colors. However, this traditional method has time and cost constraints to conduct an on-site investigation which is spend a lot of manpower and resources, but inefficient (Baker et al., 1979)

The data were processed using Personal Computer Intel® Core™ i3-10105F CPU @3.70 GHz (8 CPUs), 16 GB RAM, VGA NVIDIA GT730 to obtain point-cloud for about 2.5 h to process 50 images from 12 ha area in each first and second data acquisition. The process includes image matching, alignment, and point-cloud densification. Some of the results in the data acquisition contain doubled photos because the UAV run based on a timer, not based on the distance. So, when the UAV passed the corner area of the flight path, there are some photos doubled. Therefore, there is a process of refinement by doubled photo removal. Compared to the proposed method, this is more effective in cost and time. Table 2 shows the cost needed for the proposed method. The operational cost of this method is $2150. This cost is worth the advantages of UAV-based landslide mapping such as its rapid and repeatable survey at various time intervals and much cheaper than traditional photogrammetry and LiDAR. The process of data acquisition used a personal computer workstation.

The utilization of UAV is essential in aerial image surveys to obtain 3-dimension-modeling with high accuracy of the orthophoto. Because recently, orthophoto products as the results of photogrammetry have

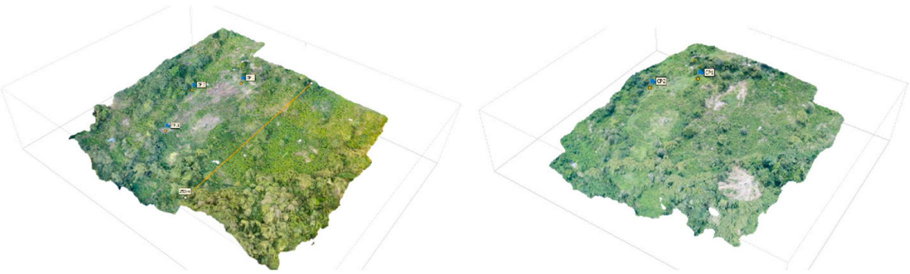

Fig. 6. The first survey on August 2021 (left) and the second survey on March 2022 (right).

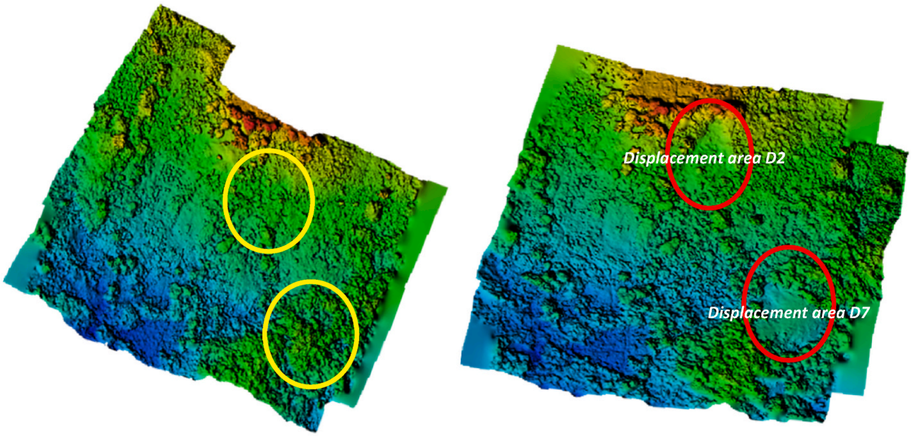

Fig. 7. Digital Elevation Model (left) and orthomosaic (right) of March 30th, 2022.

Fig. 8. Landslide information occurrence 79.4 m in the D2 area (left) and D7 (right), refer to Fig. 2 of study area.

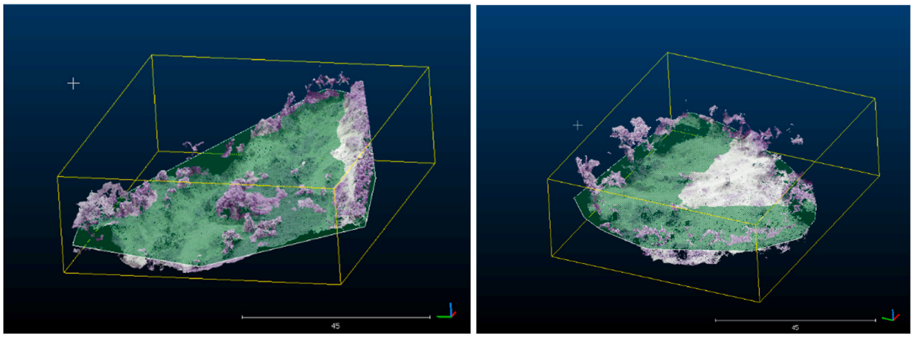

Fig. 9. The landslide surface area of D2 (left) and D7 (right).

become the standard measurement in survey mapping methods, even di developed countries, as orthophoto decides the image representation and information (Muneza et al., 2015).

Today, there is also supporting software to process aerial photogrammetries such as Agisoft and Cloud Computing. There is software to process aerial photogrammetries such as Agisoft Photoscan, and Pix4D. Agisoft is more excellent than Pix4D in quantitative analysis based on points and distance measurement and qualitative analysis by the quality of processing phases (Rani and Rusli, 2018). The process allows the filter of the images such as the shaded area which can lead to creating holes in the model. Important information about landslides such as ground displacement, depth, direction, and landslide surface area can be acquired with the use of UAV and processed with GIS-based software such as Agisoft.

4. Conclusion

This work presented the method for photogrammetry intended to map and monitor landslides through UAVs. Three GCPs were used as calibration as well as to improve the accuracy of measurement. The accuracy of the method is 99.5% from the comparison of image acquisition from UAV and real measurement of the GCPs. Post-processing of

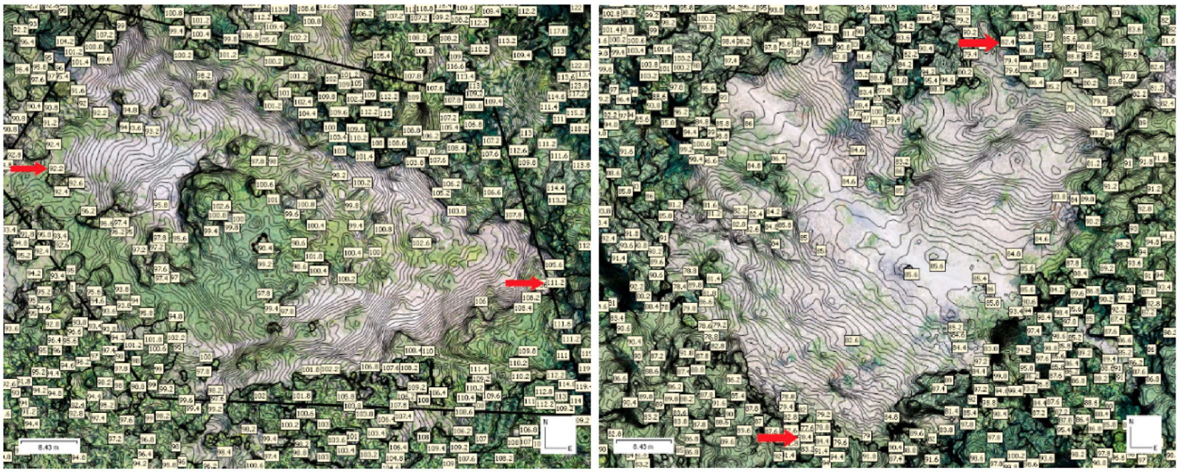

Fig. 10. Ground displacement depth using orthomosaic (the values shown by red arrows). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
The cost for operational mapping using UAV.

Item	Cost ($)
DJI Phantom 4 Pro	1500
Personal Computer (PC) Windows 10 Pro 64-bit, RAM 16 GB, VGA NVIDIA GT730	650

the image acquisition utilized Agisoft and Cloud Compare. These enable obtaining ground displacement, the depth, the direction of the landslide as well as the surface area incurred by the landslide. The UAV survey has proven a rapid and low-cost for mapping and monitoring a land surface, specifically for mitigating disaster such as landslides. Future work which takes drone surveys into account will need to be undertaken with a sort of processing software such as Pix4D, Drone Deploy, Bentley ContextCapture, and 3Dsurvey to reconstruct land displacement and evaluate each of its advantages and disadvantages. Because each software has different features which resulted in different accuracy.

Authorship contributions

Muhammad Mukhlisin: Supervision, Project administration, Validation.

Hany Windri Astuti: Conceptualization, Data curation, Software.

Rini Kusumawardani: Investigation, Resources.

Eni Dwi Wardihani: Writing – Reviewing and Editing.

Bambang Supriyo: Visualization, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Muhammad Mukhlisin reports financial support was provided by Ministry of Education Culture Research and Technology.

Data availability

No data was used for the research described in the article.

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