Drone Application for Generating a High Precision Orthophoto to Support Village Boundary and Land Use Mapping in Indonesia

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Abstract
Many existing village maps in Indonesia are available without spatial references, including in Pandanrejo village in Kaligesing Sub-district, Purworejo District, Central Java. To date, the available village map of the Pandanrejo is sketches map which potentially overlaps with the area of adjacent villages. In this study, we used a commercial drone DJI Phantom 4 for generating a high precision orthophoto to create the exact boundaries and land use information of the Pandanrejo village. The drone captured the aerial images from an altitude of approximately 100 m and automatically take an image every 3 seconds giving an overlap of each image around 70% of each pair of neighboring images. By this mission plan, the drone collected of about 1,312 aerial photographs. In order to obtain better geo-referencing results, eleven Ground Control Points (GCPs) distributed over the study area were obtained by GNSS geodetic tools. Furthermore, the Structure from Motion (SfM) algorithm was used to generate point clouds, digital surface models, and digital orthophoto model. These processes were carried out by using Agisoft PhotoScan software completing 10 steps in the workflow starting from adding drone images to the software to building orthomosaic as a basis for a digital orthophoto model. We then analyzed the errors of the resulted orthophoto map by comparing between the ratio of village boundary length to the total village area from drone mapping and terrestrial mapping using GNSS geodetic. The results showed that the drone mapping has successfully produced the village boundary map of the Pandanrejo village (i.e. a boundary length 7,473.2 m and an area 2.18 km^2) that is comparable with the result of terrestrial area mapping corrected by GNSS geodetic. In addition, the drone has also successfully mapped the village land use with a total accuracy of 100% accurate. With these results, we suggest drone technology as an alternative method besides a traditional terrestrial method to create a definite village boundary and land use map to support the implementation of Indonesia Law No. 6 of 2014.

1. Introduction

In recent years, applications of drone technology have been widely adopted in many fields, particularly in the field of digital cartography for large scale map production (e.g. topographic map). Traditionally, large scale maps are produced from the aerial photograph acquired using the large format aerial camera or high resolution satellite sensors (e.g. QuickBird, IKONOS, WorldView). However, the cost of acquiring the aerial photograph is very costly and thus need to be planned properly (Ahmad, 2011), while high resolution satellite images cannot be easily accessible mainly due to financial constraints (Liu et al., 2018). In addition, the temporal resolutions of both sensors are limited by the availability of aircraft platform and the orbit of satellites (Koeva et al., 2018). Considering the cost and temporal resolution constraint, ideally, large format aerial photographs and high resolution satellite imageries are used for mapping large area to make more efficient. For a small area, these methods are economically not suitable (Ventura et al., 2016). According to Matese et al., (2015), the drone platform appears to be the most cost effective solution for the data acquisition on small fields that cost of about €300/Hectare compared to that from aircraft (around €440/Hectare) and satellite (€500/Hectare). However, the drone platform appears to be the least economic when the acquisition area is large (> 50 Ha). For this reason, combination between small format digital camera and drone platform are widely used to produce large scale map over a small study area. According to Liu et al. (2018), drone has many advantages over conventional platform because its flexibility in various terrain conditions, low-cost with high precision and reliable results that can save manpower and material costs.

Ramadhani et al., (2018) argue that drone technology is a promising tool that could support cadastral boundary data acquisition for a country like Indonesia. Since commenced land registration in 1960, 45% of the area in Indonesia still requires land registration (Silalahi et al., 2016). Drones offer extremely high resolution orthographically rectified imagery that can be compared with the feature on the ground that may represent the boundary. Furthermore, by producing a digital orthophoto map, that is an image obtained by vertical parallel projection of a surface and has the geometric accuracy, the drone technology is able to end boundary disputes between two or more parties (Radjawali et al., 2017, Ramadhani et al., 2018 and Fetai et al., 2019).

In this article, we aim to employ drone for generating a high precision orthophoto to support village boundary and land use mapping in Indonesia. According to Indonesia Law No. 6 of 2014, villages are considered as a unit of community that has boundaries with the authority to regulate and manage the affairs of government, interests of the local communities based on the community's initiatives. Implicitly stated in the Law, village map with a definite boundary is important to determine the village area authority. Furthermore, village maps are then used as a benchmark in making other maps such as district boundary maps to provincial boundary maps. For a frontier area, village boundaries will be used as a basis for states borders and therefore making an accurate village boundary is very essential.

Many existing village maps in Indonesia are available without spatial references (e.g. map coordinates), includes in Pandanrejo village in Kaligesing Sub-district, Purworejo District, Central Java. To date, there is no cadastral map available in the Pandanrejo village. The only available village map of the Pandanrejo is sketches map which is potentially overlap with the area of adjacent villages. In this study, we collected aerial photographs of Pandanrejo village using a commercial drone DJI Phantom 4 that is widely available in the market. Furthermore, the Structure from Motion (SfM) algorithm was executed by using Agisoft PhotoScan software. We then analyzed the accuracy of the resulted orthophoto map by comparing the results with the ground measurement using GNSS geodetic. Although this study applied readily available software and method, the drone application we provide in this research is urgently needed for many developing countries in particular for Indonesia. We expect that the result of this study will encourage the regional authorities to adopt the used method. The structure of the paper is as follows. Section 2 presents a description of the study area and the methods in data acquisition, image processing and orthophoto production, and accuracy assessment. Section 3 describes the results and discussion of the key findings. Finally, conclusions are addressed in Section 4.

2. Materials and Methods

2.1 Study Area

This research is conducted in Pandanrejo village in Kaligesing Sub-district, Purworejo District, Central Java. Administratively, the study area includes two sub village namely Pendem dan Klepu with a total area of approximately 3.2 km² according to official village government data. Pandanrejo village is located in zone 49S in the Universal Transverse Mercator (UTM) system, laid between 402,400 meters East and 404,400 meters East, and 9,145,400 meters North and 9,147,100 meters North. The elevation of Kaligesing sub district ranges from 250 m to 800 m, with mostly occupied by slope more than 15%. Figure 1 shows the administrative map of the study area including the flying path of the drone. To support this study, a meso-scale topographic map (RBI map) containing information related to elevation, roads and houses was made available by the Geospatial Information Agency of Indonesia at 1:25,000 scale. This topographic map was used as basis information of village boundary and land use of the study area. In addition, Landsat 8 image of the study area (path 120, row 65) that are made available by the United States Geological Survey (USGS) archives was used for reconnaissance visit to the study area.

2.2 Data Acquisition

The drone surveys were carried out using a DJI Phantom 4 quad-copter system fitted with default DJI 4 camera (i.e. Sony Exmor R Model IMX117: 7.81 mm CMOS sensor, 4000 × 3000 12 Megapixel) with an f/2.8 lens and a 94° field of view (see Figure 2). For this research, the aerial images were captured by drone from an altitude of approximately 100 m. With this altitude, the resulted images have an approximate ground footprint of 130 × 180 m with a spatial resolution of around 7 cm (Hardy et al., 2017). We set the camera to take an image every 3 seconds with an overlap of each image between 60 and 70% of each pair of neighbouring images. We used the Pix4Dcapture software to design a flight plan over the study area. A total of 1,312 geotagged nadir images were captured. A total of 6 flight times was carried out due to DJI's battery life that only supports for flight time of about 25 minutes per flight.

2.3 Image Processing

Image processing in this research were aimed to create a digital orthophoto map. We used Structure from Motion (SfM) algorithm that was executed under Agisoft PhotoScan software environment. We completed 10 steps in the workflow such as add images, align images, place markers and input marker coordinates, optimize camera alignment, set bounding box, build dense point cloud, build mesh, build texture, build Digital Elevation Model (DEM), and then build orthomosaic.

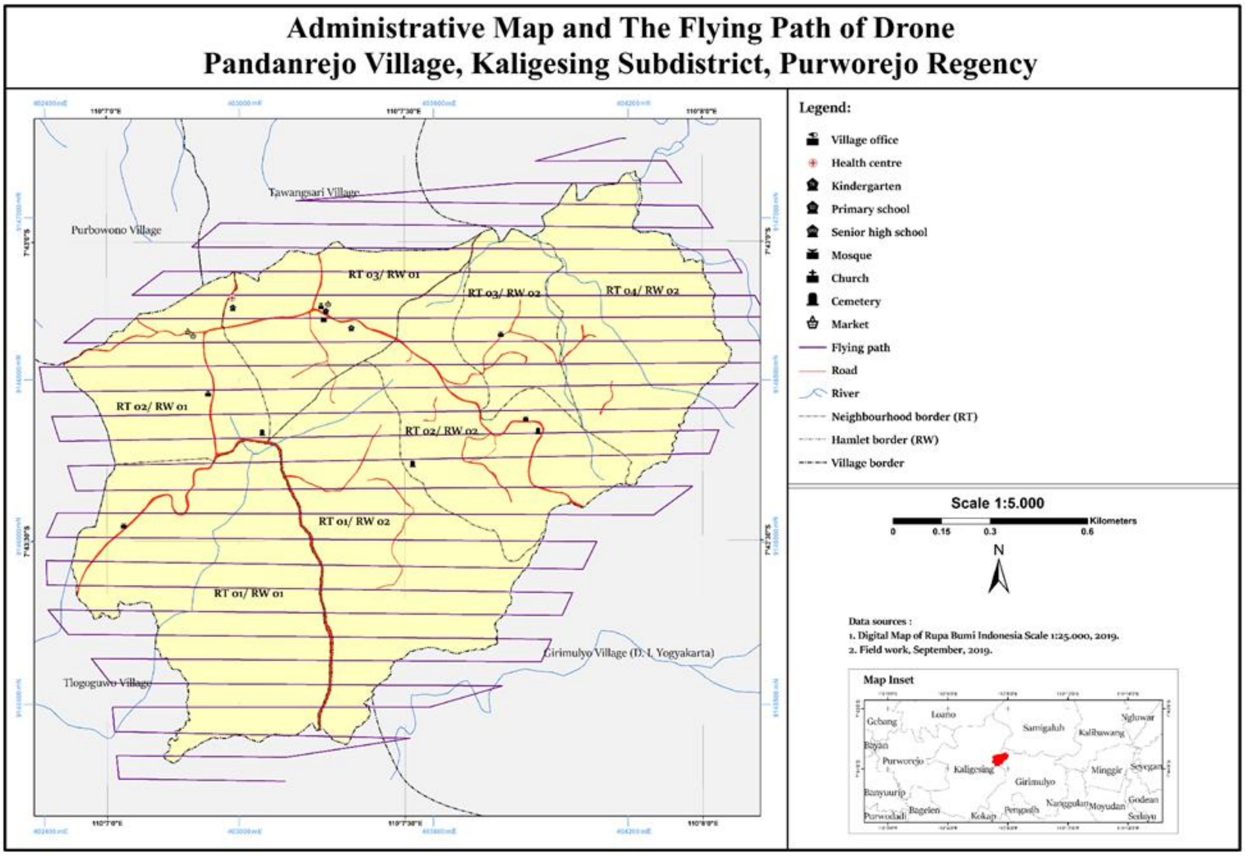
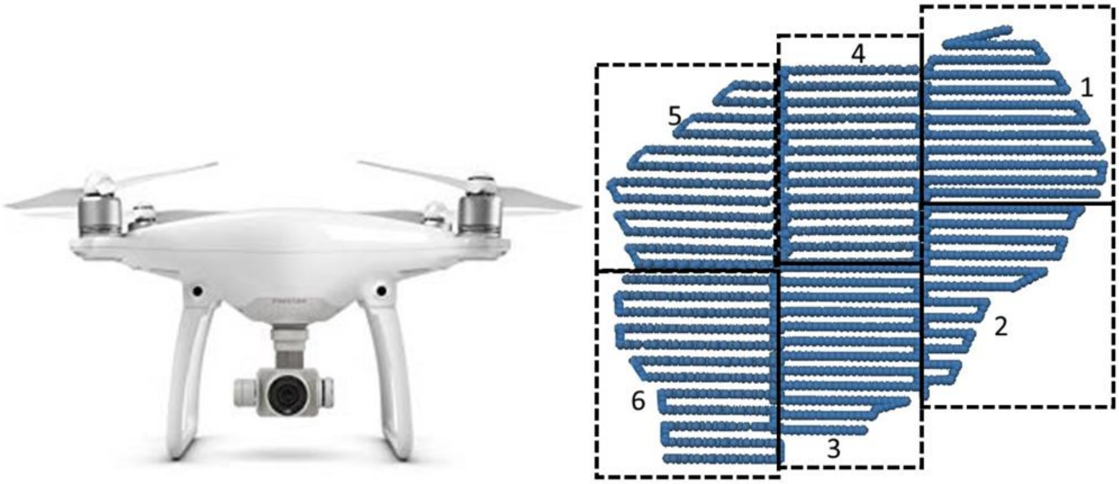


Figure 1: Administrative map of the study area including the flying path of the drone



(a) (b)

Figure 2: Drone DJI Phantom 4 used for the study (a) and the flight mission (b)

Add images are a process to enter the 2D images from drone to the software. We skipped camera position calibration process, but we carried out lens calibration by using Agisoft Lens v1.3.3 software. Image alignment is a process to find matching points between overlapping images, estimates camera position for each image, and then builds sparse point cloud model. In this alignment procedure, we set the accuracy in high position with key point limit of 40,000 and tie point limit of 4,000 as recommended by Agisoft (2018). Place markers and input marker coordinates were used to optimize camera positions and orientation data, which allows for better model georeferencing results. In this step, we used eleven of Ground Control Points (GCP) determined by GNSS geodetic tools. Bounding box was used to define the reconstruction area of interest which is resizable and rotatable. In addition, bounding box can also be used to remove erroneous points in the sparse point cloud and to restrict areas for further processing (Agisoft, 2018).

We manually aligned the bounding box and manually removed only a few of erroneous points. Furthermore, based on the estimated camera positions, the depth information for each camera was calculated, and then was combined into a single dense point cloud. The next step was generating polygonal mesh model based on the dense cloud data and building texture. We created Digital Elevation Model (DEM) based on the dense point cloud and then generated the orthomosaic. From the resulted orthomosaic, we delineated the Pandanrejo village boundary by head-up digitizing procedure under ArcGIS v.10.4 environment, assisted by prior village boundary map that was resulted by ground tracking using *Maverick Pro* apps from android mobile. Figure 3 shows the schematic diagram of the orthomosaic production through the workflow of Agisoft PhotoScan software environment.

2.4 Accuracy Assessment

The error assessment in this research was carried out using the ratio of total length to area, where we compared the difference between the ratio of total length of village boundaries to village area resulted from drone mapping and the ratio of total length of village boundaries to village area resulted from terrestrial mapping using Maverick Pro that was corrected by GNSS geodetic tools.

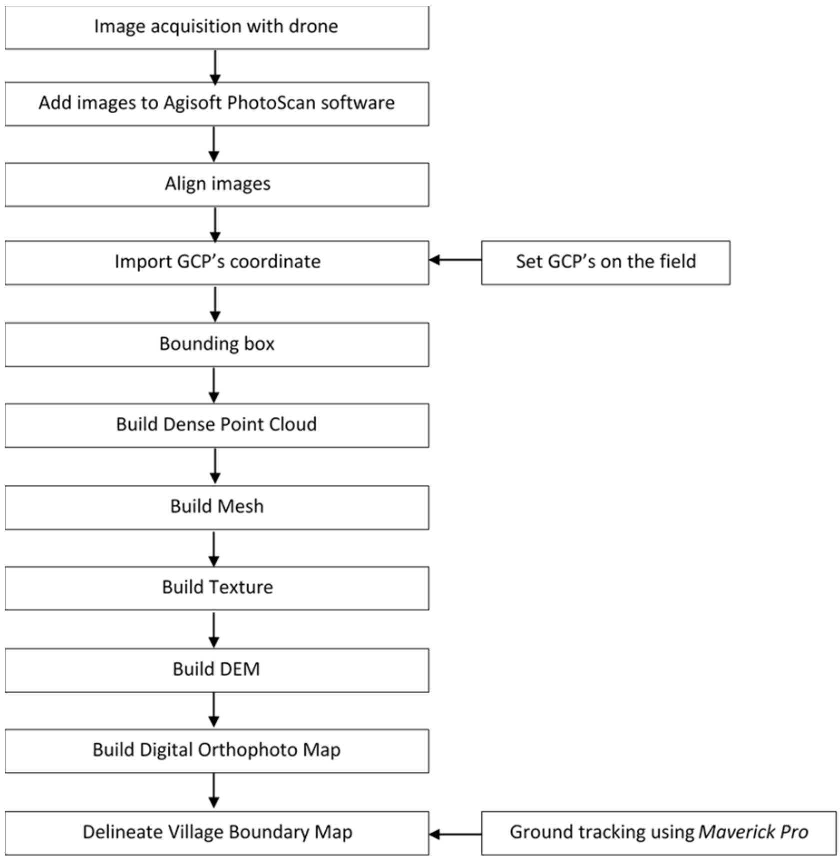


Figure 3: Workflow to produce the orthomosaic under Agisoft PhotoScan software environment

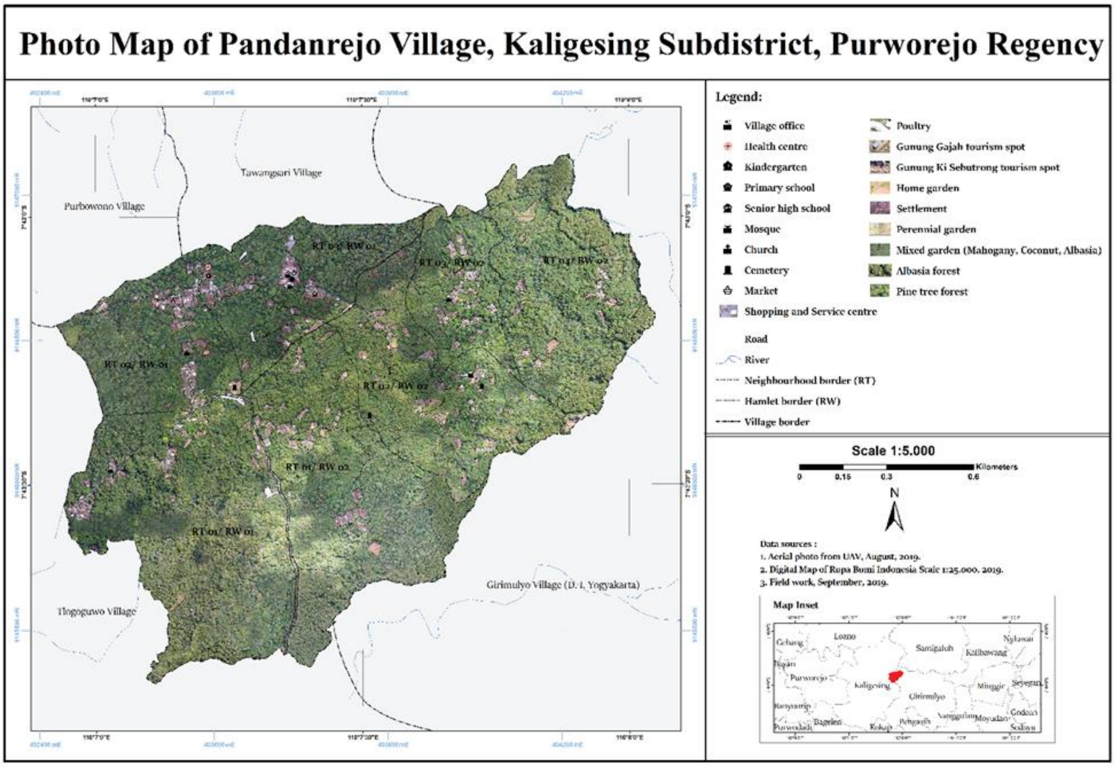


Figure 4: Orthophoto map of the study area including resulted village, Rukun Warga (RW) and Rukun Tetangga (RT) boundaries

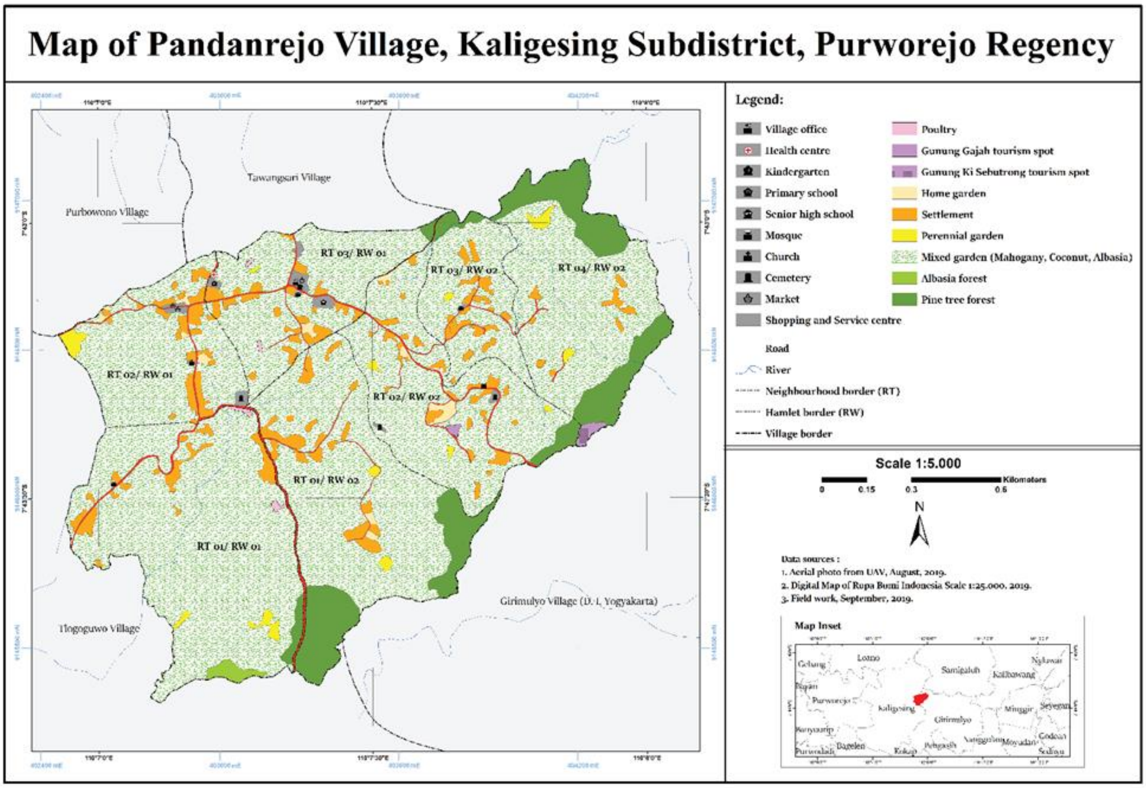


Figure 5: Land use map of the study area

In addition, a total accuracy of land use classification was measured based on the total number of correct samples divided by the total number of samples. The samples were collected along the field work of terrestrial mapping.

3. Results and Discussion

3.1 Orthophoto Map of the Study Area

Figure 4 shows the resulted orthophoto map of the study area. ArcGIS v.10.4 was used to digitize the resulted orthomosaic and produce an orthophoto map by adding legend, scale and other map elements including the boundaries of village, *Rukun Warga* (RW), and *Rukun Tetangga* (RT). *Rukun Warga* (RW) is the area division under the village, while RT is the area division under the RW, where both are not part of the state administration. The formation of RW and RT usually based on the agreement among the community themselves, thus the RW and RT's boundaries are often not based on the topographic condition. For this reason, we conducted a meeting with a small number of people including the community leaders (i.e. village leader, RW leaders, and RT leaders) of the study area. During the meeting, a laptop was used to view the orthophoto map and we asked the group to trace the village, RW and RT boundaries. For the village boundary, the delineation process was assisted by the results of ground tracking using Maverick Pro apps. It did not take a long time to have the results since the guiding features (e.g. houses, roads, paths, and trees) were clearly visible on the images. According to the group, the resulted orthophoto map has a good spatial accuracy which helped them to easily identify the object specifications. Furthermore, we added more information on the map such as the locations of village office, health center, schools, mosque, church, cemetery, and local markets. We delivered the orthophoto map in the scale of 1:5,000 as required by the village authorities so that can be printed in A1 paper size. From this orthophoto map, it was found that the area of Pandanrejo village is about 2.179.582,5 m^2 (~2.18 km^2) that is lesser than the official village government data that is of about 3.2 km^2, but relatively similar with the result of terrestrial area mapping using Maverick Pro that was corrected by GNSS geodetic tools that is of about 2.168.210,7 m^2 (2.17 km^2).

With the successful results on the village, RW and RT boundaries, we continued the work by producing the land use map of the study area. A head-up digitizing procedure was carried out to delineate each land use type within the study area. In the head-up digitizing procedure, the orthophoto map was inserted as background image under the ArcGIS v.10.4 editing tools environment. Then, by using snapping and zooming tools, the boundary of each land use detected by the image were digitized. The land use classification was determined by the same group of people as before. It resulted in nine land use classes namely poultry farm, Gunung Gajah tourism spot, Gunung Ki Sebutrong tourism spot, home garden, settlement, perennial garden, mixed garden, albazia forest, and pine tree forest. Figure 5 shows the land use map of the study area.

3.2 Error Assessment

It was found that the total boundary length from drone mapping and terrestrial mapping resulted in 7,473.2 m and 7,572.5 m, respectively. This give a ratio of total length to area from drone mapping of about 0.0034 m/m^2, while the ratio of total length to area from terrestrial mapping of about 0.0035 m/ m^2. This result showed that the drone mapping has comparable result with the terrestrial mapping with GNSS geodetic. In addition, based on 60 points of randomly selected land use information, it was found that the resulted land use map from the drone mapping have 100% accurate.

3. Discussion

Application of drone technology for topographic mapping in Indonesia actually is not new. This technique has been widely used for various purposes such as post-disaster mapping, forest mapping, infrastructure mapping and many more. It gains more popularity in particular after the Indonesia government issued a regulation on the application of drone through the Ministry of Transportation Regulation No. PM 90/2015 on the Control of Unmanned Aircraft Operations Airspace Served in Indonesia. This regulation states that drones can be used for the benefit of the government in the form of state border patrols, maritime patrols, weather observation, observation of plant and animal activity in national parks, and geographical surveying and mapping (Rahakundini and Prasetya, 2016). Although the Indonesia government has opened the opportunity to use drone technology in various aims, the application of drone technology to support village boundary is still limited. According to Radjawali and Pye (2015), there are only 19% of the village in Indonesia (i.e. about 74,000 villages) have been mapped, while the rest are only indicative maps (maps which are not yet legalized), that brings consequence to overlapping boundaries with other villages or concessions that is a source of land conflict (Hanafi, 2015). In order to mitigate the potential land conflict, the Indonesia Law No. 6 of 2014 has given the legal back up for every village to conduct their own village mapping.

From the results of this study we argue that the drone technology is a promising tool to support village boundary mapping. With a small error in the ratio of total length to area from the drone mapping compared with a terrestrial method using Maverick Pro that was corrected by GNSS geodetic tools, the village boundary resulted from orthophoto map can be used to update the current indicative map as well as the village topographic map. However, in order to increase the accuracy, we suggest more works focusing on image accuracies (i.e. geometric). It should be noted that in this research we used only eleven GCPs for the camera calibration and geometric correction, while the study area is mostly occupied by moderate to steep slope. In this condition, distribution of GCP numbers is important where more GCPs will increase the accuracy of the final products (Agüera-Vega et al., 2016, Gindraux et al., 2017 and Oniga et al., 2018). Besides lack of GCPs, we expect elevation differences plays a significant contribution on the errors. It should be noted that the study area has large difference of elevation that ranges between 250 m and 800 m above mean sea level, with mostly occupied by slope more than 15%. With this condition, ideally GCPs were set on the high and low points of the study area (Madawalagama et al., 2016 and Ajayi et al., 2017). Furthermore, the worldwide available (25 meter) elevation model might serve as a cross check for the elevation model quality. In addition, conducting a good flight mission is very crucial yet often negligible. Nagendran et al., (2018) argue that flight mission setting depends on site condition, weather, and available lightings. In this study, the flight mission setting was priory determined without trial and error to find the best setting. This can be one of the cause we obtained a relatively low accuracy in particular for point and line objects. Furthermore, many elements are also important to be considered in the flight mission plan such as the flying altitude, percentage of overlapping front and side pictures as well as the speed of the aircraft while taking photos.

4. Conclusion

In this study, drone technology has been used to produce village boundary map of the Pandanrejo village in Indonesia. Through a digital image processing with the aid of Ground Control Points (GCPs), images acquired from the drone were processed to produce an orthophoto map that was used to assist the process of village boundary and land use mapping. It was found that the drone mapping resulted in the area of Pandanrejo village of about 2.179.582.5 m^2 (~2.18 km^2) with the boundary length 7,473.2 m. This result is comparable with the result of terrestrial area mapping using Maverick Pro that was corrected by GNSS geodetic. In addition, the resulted land use map from the drone mapping is 100% accurate. From these results, we concluded that the drone technology is a promising tool to support village boundary mapping in Indonesia. Furthermore, it can be an alternative method besides a traditional terrestrial method to create a definite village boundary and to update the village land use map.

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