

Topographic data acquisition in tsunami-prone coastal area using Unmanned Aerial Vehicle (UAV)

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Abstract. The southern coastal area of Java Island is one of the nine seismic gaps prone to tsunamis. The entire coastline in one of the regencies, Gunungkidul, is exposed to the subduction zone in the Indian Ocean. Also, the growing tourism industries in the regency increase its vulnerability, which places most of its areas at high risk of tsunamis. The same case applies to Kukup, i.e., one of the most well-known beaches in Gunungkidul. Structurally shaped cliffs that surround it experience intensive wave erosion process, but it has very minimum access for evacuation routes. Since tsunami modeling is a very advanced analysis, it requires an accurate topographic data. Therefore, the research aimed to generate the topographic data of Kukup Beach as the baseline in tsunami risk reduction analysis and disaster management. It used aerial photograph data, which was acquired using Unmanned Aerial Vehicle (UAV). The results showed that the aerial photographs captured by drone had accurate elevation and spatial resolution. Therefore, they are applicable for tsunami modeling and disaster management.

1. Introduction

The logical consequences of the meeting of three tectonic plates in Indonesia are, for instance, high susceptibility to earthquakes and tsunamis [8][12][19]. The meeting forms a subduction zone along the plate boundaries. With its active movement, the surrounding areas are highly vulnerable to earthquakes [6][10][18]. Moreover, when an earthquake is followed by plate deformation, it potentially develops into a tsunami [3][5].

Tsunami is one of many disasters that have enormous impact [2][7]. In Indonesia, it is associated with earthquakes that alter the submarine plates [5]. Earthquake is the leading cause of most tsunamis in Indonesia. Around 90.5% tsunami events in Indonesia were caused by earthquakes, while the remaining 8.6% and 1% were, respectively, preceded by volcanic eruptions and underwater landslides. From the tsunami in 2000 BC until the one in 2005, there were 253 events, which were the third highest occurrences after Japan (444 events) and the United States (287 events) [15]. Nevertheless, regarding death toll, the tsunamis in Indonesia are the most destructive in the world [18]. The highest casualties were during the 2004 tsunami in Nangroe Aceh Darussalam, i.e., 250.000 deaths.

The southern coastal area in Java Island is one of the most vulnerable locations to tsunami [1][9][12][14][17]. Tsunamis have struck this area for several times, i.e., in 1818, 1840, 1859, 1904, 1921, 1925, 1957, 1994 and 2006 [4][16]. Therefore, studies on hazard, vulnerability, and risk assessment as well as disaster preparedness and management for tsunamis in this area are crucial.

One of the obstacles in tsunami susceptibility and hazard analysis is the availability of high-resolution topographic data. Moreover, not every remote sensing image with high spatial resolution is available and applicable for risk analysis and mitigation planning. However, this issue can be overcome by, for instance, acquiring remote sensing images using Unmanned Aerial Vehicle (UAV).



Aside from providing the latest information at a relatively low cost, UAV produces remote sensing image with high spatial resolution and detailed Digital Elevation Model (DEM).

The coastal area in Gunungkidul Regency contributes IDR 7.1 billion per year to the local revenue, which is one of the highest incomes outside of tax revenue. The tourism sector also has a strategic role in improving the economic condition of the local people and increasing by the year [20]. On the other hand, the coastal area directly faces the open sea where the subduction zone of tectonic plates exists. Moreover, the subduction zone in the south of the Special Region of Yogyakarta is located in the seismic gaps (figure 1) in which earthquakes and tsunamis with large magnitude potentially develop [13].

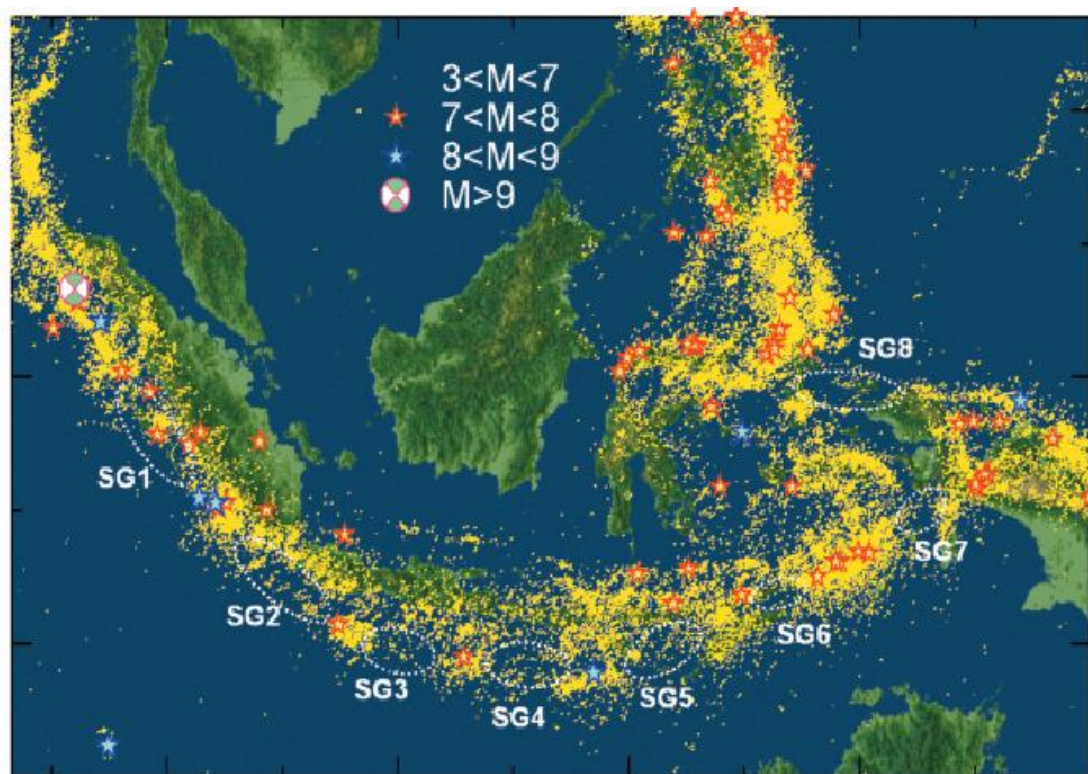


Figure 1. The location of seismic gaps (SG) in Indonesia [1].

2. Method

The aerial photography began with flight route planning and pre-mark or marker installation for the Ground Control Point (GCP). The research used two flight routes that recorded at an altitude of 300 m above the ground. There were 10 points of pre-marks distributed in the field (figure 2), which represented the topographic configuration in the study area. The coordinates were measured by geodetic GPS with Real Time Kinematic (RTK) method.

The research used a fixed-wing unmanned aerial vehicle with a Bixler airframe. The UAV had a semi automatic control, i.e., an autopilot component that directs it toward the predefined route while in the air. Therefore, the pilot controlled it during take-off and landing only. Meanwhile, the co-pilot monitored its movement and position from the Ground Control Station (GCS). The sensor was a pocket digital camera Canon Powershot A2500 with 16Mpix resolution. It was set to take photos automatically every two seconds at a shutter speed of 1/2000 to avoid blurred images.

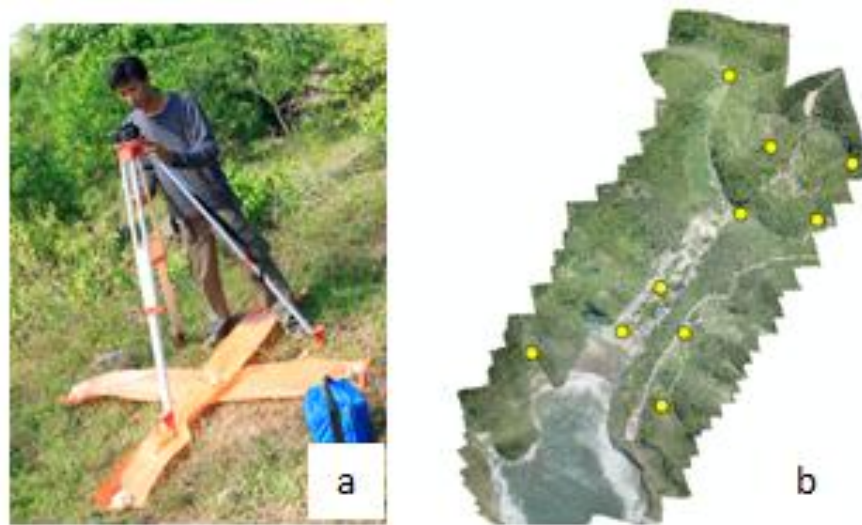


Figure 2. (a) Pre-mark Installation and Ground Control Point (GCP) Measurement Using Geodetic GPS and (b) The Distribution of GCP on the Field.

The aerial photographs were sorted to exclude widely distorted (oblique) images in further analysis. Each of the photos from this recovery was then adjusted to have equal brightness and contrast. Afterward, mosaic compilation and orthorectification were processed in Agisoft Stereoscan software. Orthorectification aims to convert the projection of aerial photos, i.e., from central to orthogonal projection, to minimize geometric distortion on them.

2.1. UAV-assisted photography for acquiring data in Kukup coastal area

UAV-assisted photography of Kukup Beach covered an area of approximately 41 ha and took one working day in the field. The type of UAV used in this research was the Bixler (figure 3a). The aerial photography started with creating a flight plan and designing the position of GCP (Figures 3b and 3c). The plan included determining the altitude of the object capture, which was 150 m above the ground. Therefore, the resolution of the aerial photos was expected to reach <10 cm. The overlaid parameters, namely, end lap and side lap, were adjusted to 80% and 50%. Then, the GCP distribution was designed as minimal as possible to see whether three ground control points could already produce elevation data (Digital Surface Model-DSM).



Figure 3. (a) Bixler, the UAV Used for Photography, (b) Preparation, UAV component Setting, and Ground Control Station, (c) Pre-mark Installation and Ground Control Point Measurement by Team Member During Preparation.

The personnel involved in the process of data acquisition was five people, i.e. one pilot, one co-pilot, and three crews tasked with GCP coordinate measurement using geodetic GPS. The aerial photography took one day, starting from the placement of pre-marks/markers for GCP. They were made of 30x150 cm² tarpaulins and placed crossing each other in an opened space, so they were detectable during the UAV-assisted photography. When the team installed the pre-marks, both pilot and co-pilot prepared the UAV setting, calibrated its components, and re-checked the position of the planned flight route. The communication between the GCP team and aerial photography team used handy talkies (HT) for time efficiency. When all of the markers were in position, the UAV was ready to take off and start photographing.

The aerial photography used a fixed-wing aircraft with Bixler airframe (the main body of the plane) whose main material was EPO foam. Therefore, it is easily repairable after a crash or hard landing. The Bixler had a 1.4-meter wingspan. This size is categorized as small. Nevertheless, it has the advantage of easy equipment mobilization and maneuver control. Furthermore, for aerial photography in a small area, this kind of plane is relatively economical.

The aerial photography of Kukup coastal area took approximately 2 hours for preparation, takeoff, and image capture at an altitude of 150 m, and landing. The flight was conducted twice because the coastal area was very windy, requiring the rotor to generate a great pushing energy. Since the rotor was driven by battery, the team had to execute a landing once the battery power was low. It aimed to prevent UAV from losing control due to exhausted battery capacity. After the UAV finished its photography mission and landed, the aerial photos were checked and stored in a hard disk drive. The GCP measurement took a longer time. The measurement at each point spent ± 18 minutes.

2.2. Digital orthophoto generation with aerial photos

The aerial photos acquired using UAV were processed in photogrammetric software, Agisoft Photoscan. This software processes the aerial photos to generate an orthophoto mosaic (figure 4) and the altitude data to provide Digital Surface Model (DSM). The reconstruction of the position of each photo was also visible during the data processing in the software.

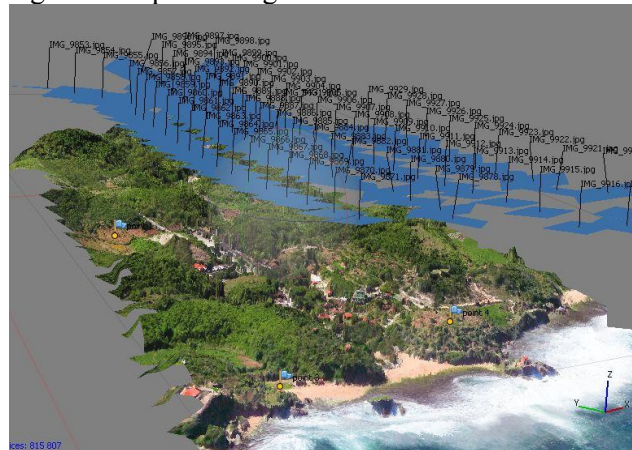


Figure 4. The reconstruction of multiple aerial photos (Orthophoto Mosaic) from the recording of Kukup coastal area.

3. Results and Discussion

The results of the aerial photography had a Ground Square Distance (GSD) of approximately 5 cm. This GSD is considered very detail for data input in large-scale mapping. The details of several objects captured and recognized from the aerial photos are presented in figure 5. They confirm that every single car, plant, and even a person in the photos are well detected.



Figure 5. (a) The visible pre-mark, (b) the recognizable distribution of tourists on a sandy beach, (c) the visible individual stand of cassava, (d) the size and type of cars identified from aerial photos, and (e) apparent road markings.

The aerial photo processing produced orthophotos with very little distortion due to the central projection of the camera. Therefore, these orthophotos could generate a mosaic with an orthogonal projection that supported an accurate mapping with minimal distortion. The orthophoto mosaic resulted in this research had a pixel size of ± 5 cm.

3.1. Digital Surface Model (DSM) generation with aerial photos

Another data acquired from photography using UAV was Digital Surface Model (DSM) with a horizontal resolution of 0.4 m. The accuracy of horizontal resolution is affected by the camera resolution, flight altitude, and focus length. Because DSM provides a higher detail than the elevation data presented in the Indonesian Topographic Map scale 1: 25,000, it is more reliable for tsunami inundation modeling. The orthophoto mosaic, DSM, and 3D reconstruction are presented in figures 6, 7, and 8, respectively. The detail of the elevation acquired from the analysis was up to 30 cm.

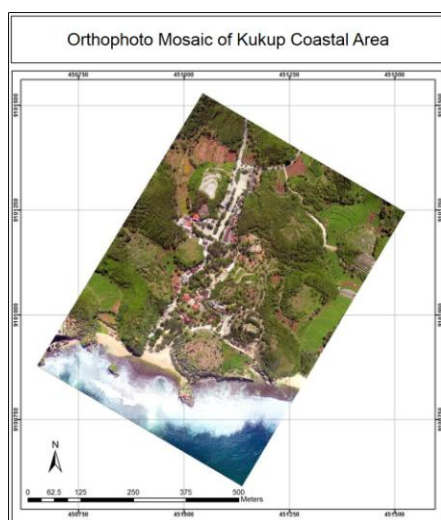


Figure 6. The orthophoto mosaic of Kukup Beach generated by UAV aerial photo processing.

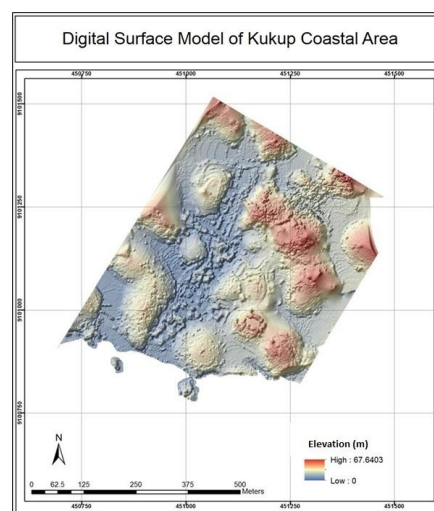


Figure 7. The Digital Surface Model (DSM) of Kukup Beach produced by UAV aerial photo processing.

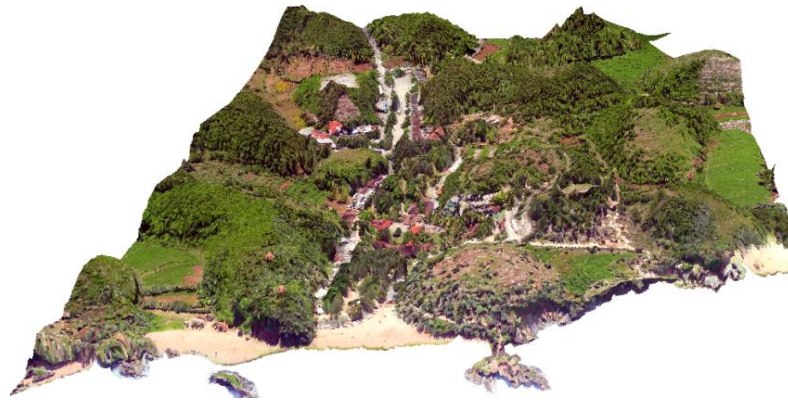


Figure 8. The 3D reconstruction of Kukup Costal Area from orthophoto mosaic and DSM produced in UAV aerial processing.

3.2. *The challenges of UAV-assisted topographic mapping for tsunami disaster management in Indonesia*

Indonesia is vastly and greatly susceptible to tsunamis. Therefore, the large-scale procurement of supporting data requires encouragements to be able to accelerate data production using priority scale. For instance, the priority scale represents the location of the seismic gap, the subsequent potential of damage and risk, and the record of tsunami events in the past. The method used in this research is applicable for supporting the acceleration of data procurement because it offers many advantages, including the ease of operation and low operational cost. Due to the main vehicle that used for acquiring the aerial photo data, UAV is relatively cheap. The risk of flying UAV for aerial mapping is also very small. Compared to the conventional photogrammetric method, UAV method is more effective especially in small mapping area. The DSM that produced from UAV data acquisition is also accurate for generate tsunami hazard modelling. The constraints of this method are the disability to covers large mapping area. The battery endurance of the UAV is limited so it takes several flight missions to cover the whole area. Strong wind and wireless interference are also limiting the flexibility of UAV mobilization.

4. Conclusion

The topographic data acquired from an unmanned aerial vehicle has an accurate spatial resolution and elevation. Therefore, it is suitable for tsunami modelling. The results of the mapping process had a spatial resolution of 0.4 m and an altitude accuracy of 30 cm, indicating a higher detail than the topographic maps that are currently available in official publications in Indonesia. However, DSM data should be supported by bathymetry data to generate more detailed model and simulation. Furthermore, due to the excellent spatial resolution, the resultant topographic data is best suited for analyses that focus on at-risk element identification, economic valuation of potential damages, spatial planning, and disaster risk reduction and management associated with tsunamis.

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