Coastal hazards mapping using high-resolution UAV image and DEM. A Case study in Siung Beach, Gunungkidul, Indonesia

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Abstract. The southern coast of Gunungkidul, which is adjacent to the subduction zone, is prone to various coastal hazards. The increasing number of visitors to the beach leads to more exposure and increases the risks. This study aims to determine the coastal hazards in Siung Beach, Gunungkidul, Yogyakarta. A high-resolution aerial image and DEM were acquired using a low-cost Unmanned Aerial Vehicle. The acquired images were processed using Structure from Motion (SfM) photogrammetry to generate an orthomosaic image with 5cm spatial resolution. A worst-case tsunami hazard scenario (12 m) was executed using raster filtering on the generated UAV-DEM. Based on the tsunami inundation model, most of the buildings are affected by the worst-case tsunami scenario. According to orthomosaic interpretation, rip current hazard is also spotted on the eastern part of the beach. The rip current is considered a channel rip, a stationary rip current affected by the bathymetric condition. Potential rockfall due to slope instability might be occurred on the southern part of the beach, as a former enormous mass movement can be delineated from the orthomosaic image. Siung Beach is formed by the combination of volcanic origin and karst process, resulting in undulating topography. Due to various coastal hazards in Siung beach, disaster management planning should be established to reduce the risks.

Keywords: Coast, Unmanned Aerial Vehicle, Hazard, Tsunami, Coastal Typologies

1. Introduction
Gunungkidul Regency is well known for its tourism sector, especially marine-related tourism. Gunungkidul Regency has the longest coastline in the Special Region of Yogyakarta, with a length of 87.12 km. The condition of the coast of Gunungkidul, which is in the south of Java Island, causes the
area to be exposed to several potential disasters [1]. The various disaster threats include tsunamis, rockfalls, rip currents, high waves, droughts. Tsunami is one of the biggest threats on the southern coast of Java Island [2]. Near-field tsunamis can cause enormous damage and losses, such as damage to buildings, infrastructure, and even fatalities. However, according to the number of cases, rip current accidents contribute to the area's highest fatalities. For the last three years, marine-related accidents have led to more than 25 fatalities affected mainly by rip current [3], [4]. Tsunamis and rip currents pose the biggest threats to coastal areas all over the world. In terms of the number of marine accidents, rip currents statistically occur more frequently than the tsunami event [5], [6].

Most of the coastal hazard researches in Gunungkidul regency has been focused in the middle part of the area, extended from Baron Beach to Pok Tunggal [7]–[10]. Some beaches located in that extended area are more famous than others because of ease of accessibility and proximity. In contrast, beaches that are separated kilometers away to the west and east from the centers get less concern related to coastal hazards. The coastal susceptibility to hazard will be influenced by the physical characteristic of the coastal area. The coastal zone is a transition zone between land and sea, and divided into different typologies [11]. The Coastal hazard susceptibility varies by coastal typology. Although most of the area was formed in a large limestone formation and karst zones, Gunungkidul boasts a variety of coastline typologies.

Using Indonesian topography (Rupa Bumi Indonesia) data with a medium-scale resolution for localized coastal hazard modeling is insufficient. This problem can be solved by deploying Unmanned Aerial Vehicles (UAVs) to collect high-resolution aerial photographs. UAVs are also appropriate for topographic mapping in relatively narrow areas, in addition to giving up-to-date information at a low cost. UAV photogrammetry can produce high-spatial resolution aerial photos and detailed Digital Elevation Models (DEM) for coastal hazard modeling. UAV-based topographic mapping is regarded as a practical, low-cost, and accurate method to provide high-resolution aerial photography and digital elevation model data [12]. This study aimed to identify the coastal hazards susceptibility along the coast of Siung Beach, Gunungkidul, using UAV data.

2. Study Area
The re-opening of tourism sectors after the covid-19 pandemic led to the outburst of beach visits. The higher the number of beach visitors, the more people are exposed to coastal hazards. This study was conducted in Siung Beach, Tepus Sub-District, Gunungkidul Regency, Special Region of Yogyakarta (Fig.1). Geographically, Siung Beach located located at UTM 49L 465107 mE and 9095589 mS. Siung Beach is formed by volcanic-origin and karst terrain.
3. Methods
3.1. Data Acquisition
The primary data used in this study is a high-resolution Digital Elevation Model (DEM) obtained through aerial photography. The aerial photography was carried out using an Unmanned Aerial Vehicle (UAV) with a multirotor type, the DJI Mavic Pro. The aerial photo data was collected using the official manual-pilot software of DJI. Manual control is preferred instead of autonomous due to the high wind velocity during data acquisition. The DJI Mavic Pro carried a camera with 35 mm focal length, 12.35 MP camera resolution, and 1/2.3" (CMOS) sensor. The drone deployed to 182 m above ground level and captured 291 images.

The captured image was then processed using Agisoft Photoscan software to generate an orthomosaic image and Digital Elevation Model using Structure from Motion (SfM) approach. A photograph with orthogonal projection was created by combining many photos with central projection. Structure from Motion (SfM) processing was used from the moving camera platform to detect stationary objects on the ground from overlapping images of the study area [13]. Manual flight paths have been arranged in such a way as to obtain sufficient overlap and sidelap. The camera coordinates and automatic point detection were used to align all of the photos from each location. The set of photos from each site produced scattered point clouds, forming dense point clouds and 3D structures, respectively, by the SfM technique [14]. The flight route and the camera position are depicted in Fig. 2.
3.2. Tsunami inundation model
The tsunami inundation model in Siung Beach was executed using a raster calculator in ArcGIS 10.2. The tsunami height scenario was computed using the Digital Elevation Model (DEM) based on the worst scenario on the southern coast of Java. According to the current study, seismic gaps off Java's southern coast have the potential to generate a Mw 8.8 earthquake with a 400-year return period. Tsunamis of this scale will exceed 12 meters in height in some spots along the southern coast of Java [15]. Therefore, in this study, the inundation area was determined using a tsunami height scenario of 12 meters. The extent of the floodplain reflects the susceptibility of the area to a tsunami. Raster filtering was performed to select pixels with a value of 12 meters or less in the DEM. The flooded area was filtered using the SpatialAnalyst tool in ArcGIS 10.2. We used the Map Algebra Tool's raster calculator to perform a binary selection of pixels with a value of 12 meters or less. We then reclassified the selected rasters to form an independent dataset classified as flooding pixels. After the flooded pixels were selected with the given values, the raster was converted to polygons. Another filtering process was performed to remove polygons that are not connected to the coastline using the Select by Location command [16].

4. Results and discussion
In this study, the UAV generated an orthomosaic image with a ground sample distance (GSD) of 5.4 cm/pixel from an average altitude of 180 m. This accuracy certainly provided very detailed elevation data for DEM extraction. A high-resolution DEM is required to model the tsunami inundation in a small area instead of using terrain data from the DEMNAS. The DEM reconstruction obtained from optical orthophoto can support high-precision measurements [17]. Figure 3 shows the Ortho-mosaic and DEM SfM process from of the Agisoft Metashape software.
A high-resolution digital elevation model was needed to generate an accurate and reliable tsunami hazard model. The maximum horizontal and vertical ranges of tsunami models have been studied for years, but challenges remain because tsunami hazard modeling requires high-resolution bathymetric and topographical data [18]. In this study, the digital elevation model generated from UAV photogrammetry has an average spatial resolution of 43.7 cm and a point density of 52.4 points/m². UAV-derived DEMs can record rough terrain features that ground surveys cannot measure. The DEM generated from SfM processing is Digital Surface Model (DSM). DSM results clearly show the details of topographical morphology and land cover at Drini Beach. However, the tsunami inundation model executed in DSM is unreliable since most of the landcover elevation diminished the extent of the inundated area. Therefore, the DSM must be converted to Digital Terrain Model (DTM) to provide barren land representing the topographic condition. The conversion from DSM to DTM was executed using PCI Geomatica 2015 software through DEM Filtering. This study used terrain filtering and bumps remover to remove the land cover elevation data. The result of DSM-DTM Conversion using PCI Geomatica is depicted in Figure 4.
Figure 4. Digital Surface Model results from Structure from Motion processing (a) and Digital Terrain Model result from PCI Geomatica.

The DSM-DTM conversion shows considerable differences in terms of the topographical condition. The study area landuse is dominated by agricultural area and bushes. The vegetation and other land covers will block the inundation model, so the affected area will not be determined accurately. Therefore, it is necessary to remove the land cover in order to get the best results. Some examples from the DSM and DTM cross-section elevation are expressed in Figure 5.

Figure 5. Cross sections indicate the difference between DSM (red line) and DTM (blue line).

The DEM conversion plays a significant role in the accuracy of the tsunami inundation model and landform delineation. We executed two different inundation models using DSM and DTM, showing significant differences. The area extent inundated by the tsunami is approximately 4.61 hectares calculated from the shoreline using the DSM. In contrast, the tsunami model using DTM inundates more than 5.59 hectares of the area. The land cover, primarily buildings, and vegetation, are the main obstacle for the model. During the tsunami evacuation, the most crucial action is to escape to the higher ground [19]. The elevation data conversion from DSM to DTM is necessary to determine terrain elevation to select the safe place since most land covers in the hazard area are semi-permanent buildings and vegetation. Without converting the DSM to DTM, the selection of tsunami shelters might be biased. The difference between tsunami inundation using DSM and DTM is expressed in Figure 6.
Figure 6. The difference between the tsunami inundation model generated from DSM (a) and DTM (b) at Siung Beach.

Siung Beach is situated in the west of Wediombo Beach. Based on Shepard’s classification [11], Wediombo beach is classified as a primary coast because of its volcanic origin from Wuni Formation. The eastern part of Siung Beach is formed by the same volcanic rocks derived from Wuni Formation, which is breccia [20]. The terrain composed of volcanic rocks formed steep topography and natural obstacle for tsunami run-up. The inundated model mainly affects the relatively flat terrain occupied by houses, food stalls, motels, and parking areas. Therefore, vertical tsunami evacuation is recommended to be performed in this topographical condition [21]. The primary purpose of tsunami vertical evacuation is to save lives, placing the affected community to higher ground and evacuating to safe places afterward [22].

We also determine another coastal hazard using the aerial image: rip current. A rip current often appears as a free foam area in the surf zone [23]. The absence of breakers indicates a deeper bathymetry that forms rip current [24]. A narrow gap between the reef flat can be observed from the aerial image and indicate a stationary rip current channel. Most channel rips are associated with sand substrates between the coral reef flats in the bottom. This type of rip current is commonly referred to as a reef rip current [25]. This type of rip current is persistent and stationary, proven from a series of google satellite images showing the gap between reef flats with no breakers (figure 7). This type of rip current is stationary and persistent, with a specific time occurrence controlled by the tides. Therefore, the mitigation for an accident can be performed by the safeguards by directly prohibiting the swimmers or using markers in the hazard area [26].
5. Conclusion

According to the megathrust earthquake scenario, the worst tsunami scenario was set at 12 meters tsunami height. Based on the model, the extent of the affected area is mostly located in the flat terrain. The volcanic origin rocks derived from the Wuni Formation in the east formed hilly topography that significantly reduced tsunami spread. However, with most facilities inundated, the tsunami evacuation scenario must be carefully planned. We suggest prioritized vertical evacuation instead of horizontal. Another hazard, the rip current, is indicated to be persistent and stationary because of the control of bathymetry. This type of rip current is relatively easy to recognize and can be avoided to minimize the fatalities of coastal accidents.

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