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Unmanned Aerial Vehicles for geospatial mapping of damage assessment: A study case of the 2021 Mw 6.2 Mamuju-Majene, Indonesia, earthquake during the coronavirus disease 2019 (COVID-19) pandemic

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ABSTRACT

There is an increase in Unmanned Aerial Vehicles (UAV) after disasters to assess impacts, including damage and losses worldwide in poorer and more prosperous countries. In Indonesia, there is a substantial increase in the use of UAVs to assess post-disaster damages. Unfortunately, there is still a lack of documentation on the lessons on the effectiveness and efficiency of UAVs in post-disaster mappings from Indonesia. This case study research offers lessons and insights from the uses of UAVs to fly above the affected areas of the 2021 Mamuju-Majene earthquake that caused severe damage to buildings in the Mamuju and Majene regencies in the West Sulawesi Province, Indonesia. First, we used a fixed-wing UAV to fly above Simboro district and Mamuju district, and two multirotor UAVs to fly above Simboro district, Mamuju district, Tapalang district and Malunda district. Our result of 2D-UAV maps on the north coast of Simboro district and Mamuju district have been used by the Indonesian National Board for Disaster Management (BNPB) for assessment on search and rescue (SAR) and recovery planning in the field.

1. Introduction

The use of drones or Unmanned Aerial Vehicles (UAVs) in emergencies and post-disaster situations can be divided into several categories. Among many, at least five usages can be identified: assessment of situational awareness that informs search and rescue operation; assessing loss and damage; response operation that focuses on disaster waste management; the need to establish spatial data recovery needs assessments; some even envision massive handling of humanitarian logistics and emergency package deliveries (Daud et al., 2022; Recchiuto and Sgorbissa, 2018).

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Disaster management authorities and international humanitarian actors continue to use UAVs to generate visual data in the aftermath of disasters to estimate initial impacts, such as the potential spatial distribution of damages to buildings and infrastructure (e.g. Atmaca et al., 2020; Bayraktar et al., 2014; Bayraktar et al., 2015; Günaydin et al., 2021). In the context of earthquakes as primary hazards, flying over UAVs will be useful to get aerial views of potential secondary events such as liquefaction and landslides that might block access to incoming responders, and the identification of other secondary risks.

The promise of the UAVs technology in disaster context includes efficiency and effectiveness in data collection in that traditional assessment could not outbid the merits of drones. "The sky is the limit is a general expression of its potential applicability within disaster response communities. It can immediately pinpoint road access for local responders."

There is an increase in UAV after disasters to assess impacts, including damage and losses worldwide in poorer and more prosperous countries. In Indonesia, there is a substantial increase in the use of UAVs to assess post-disaster damages. Unfortunately, there is still a lack of documentation on the lessons and efficiency of UAVs in post-disaster mappings from Indonesia.

The objective of this explorative research includes identifying lessons and insights from the case of the uses of UAVs to fly above the affected areas of the 2021 Mamuju-Majene earthquake that caused severe damage to buildings in the Mamuju and Majene regencies in the West Sulawesi Province, Indonesia. We used a fixed-wing UAV to fly above Simboro district, Mamuju district, and two multirotor UAVs to fly above Simboro district, Mamuju district, Tapalang district and Malunda district. Our results of 2D-UAV maps on the north coast of Simboro district and Mamuju district have been used by the Indonesian National Board for Disaster Management (BNPB) to assess the field’s search and rescue (SAR) and recovery planning.

2. Case study context: the 2021 Mw 6.2 Mamuju-Majene earthquake Earthquake

Sulawesi is located in a complex tectonic region where destructive earthquakes are frequent, at least during the last decade (i.e. Heidarzadeh et al., 2019; Gunawan et al., 2020; Natawidjaja et al., 2021; Gunawan, 2021). One of those earthquakes was the Mamuju-Majene earthquake in West Sulawesi (Gunawan et al., 2021). The Mamuju-Majene Earthquake occurred in a sequence, with the foreshock occurring on Thursday January 14, 2021, at 14:35 (local time, GMT+8) with a magnitude of 5.9 at a depth of 12.3 km (Supendi et al., 2021). Twelve hours after the foreshock, a mainshock occurred in the early morning of Friday January 15, 2021, at 02:28 (local time, GMT+8). Limited only ~5 km from the foreshock, the mainshock occurred at a depth of 19.9 km with a magnitude of 6.2. Analyzing the fault source of the earthquake using Global Positioning System (GPS) data in Sulawesi, a previous study found that the mainshock occurred along the Mamuju fault (Gunawan et al., 2021). Fig. 1 is a map of the region impacted by the 2021 Mamuju-Majene earthquake.

The Agency for Meteorology, Climatology, and Geophysics of Indonesia (BMKG) reported that the recorded maximum intensity was VI (https://www.bmkg.go.id/seismologi-teknik/ulasan-guncangan-tanah.bmkg?p=ulasan-guncangan-tanah-akibat-gempa-mamuju-sulawesi-barat-15-januari-2021&tag=ulasan-guncangan-tanah&lang=ID, accessed on March 10, 2022). Several critical and public facilities were severely damaged, such as the West Sulawesi Governor's building, Regional Public Hospital, and Mitra Manakarra Hospital. An Accelerometer station of BMKG located 400 m from the Governor's building recorded a peak ground acceleration (PGA) of 150.7 gals (https://www.bmkg.go.id/berita/?p=laporan-survei-gempabumi-merusak-mamuju-majene-15-januari-2021-2&lang=ID&tag=gempabumi, accessed on March 10, 2022).

The 2021 Mamuju-Majene earthquake caused severe damage to several buildings. Furthermore, landslides blocked several roads after the mainshock, severely limiting access into the impact region. This assessment aimed to geospatially map the damage to buildings in Mamuju regency and Majene regency following the devastating earthquake. In order to give a clear view of the earthquake's impact on buildings, we used UAVs to fly above the Mamuju regency and Majene regency for our analysis. We also discuss the constraints of conducting UAVs during the coronavirus (COVID-19) pandemic.

3. Field data collection and Methods

Our team departed on Saturday January 16, 2021, from Jakarta to Mamuju regency via Makassar, South Sulawesi Province. In Mamuju, we coordinated with the Muhammadiyah Disaster Management Center (MDMC), the Indonesian National Board for Disaster Management (BNPB) and other volunteers in the attempt to conduct areal mapping using UAV. For the aerial mapping to support rapid assessment, the team used a fixed-wing UAV and two multirotor UAVs (DJI Phantom 4 and DJI Mavic 2). During our field survey, our field team's presence has also been informed and coordinated with the Volunteer Desk of BNPB.

On January 18, 2021, we planned for our first UAV flight in the Simboro district and Mamuju district using the fixed-wing UAV (Fig. 2a). On this day, the flight was planned to cover a total area of ~40 km (Fig. 2b). Our team conducted no UAV flight the next day because authorities permitted no UAV flights. No UAVs were allowed to fly throughout the airspace of the city of Mamuju within a 5.6 km radius of the West Sulawesi Governor's Office or 15 km from the airport due to VIPV activities. The UAV flights were continued on 20–January 21, 2021. The flight on the January 20, 2021 covered Mamuju district and Simboro district. The flight above Mamuju district covered an area of ~28 km (Fig. 2c), and a ~41 km area was covered over Simboro district (Fig. 2d). Thus, the flight on 20 January covered a total area of ~69 km. The final UAV flight was done on January 21, 2021, a continuation of the previous flight that covered ~41 km of Mamuju district (Fig. 2e) and ~34 km of Simboro district (Fig. 2f).

Other UAV flights were conducted in the Simboro district, Mamuju district, Tapalang district and Malunda district. For these particular regions, multirotor UAVs were used to identify the damage done to buildings. Fig. 3 shows where the multirotor UAVs were used in the field.
4. Results and discussion

4.1. Earthquake impact damage to buildings

We present our 2D-UAV map on the north coast of Simboro district and Mamuju district obtained from the fixed-wing survey from 18 to January 21, 2021 in Fig. 4. BNPB used the results to inform the assessment of search and rescue (SAR) in the field and early recovery planning. Our field observation in the Simboro and Mamuju districts showed that critical infrastructure, such as the West Sulawesi Governor's Office, was completely destroyed (Fig. 5). Other critical infrastructure in the Mamuju regency, i.e. Regional Public Hospital and Mitra Manakarra Hospital, were also heavily damaged (Fig. 6).

The aerial data suggested a pattern of damage caused mainly by three possibilities. First, the buildings' lower base shear strength was far below the actual seismic loads as the design was based on the old seismic hazard data, including the old seismic zonation of Sulawesi. Irsyam et al. (2020) showed that the peak ground acceleration (PGA) values of West Sulawesi on the 2010 Indonesian Seismic Hazard Map were much lower than that on the 2017 Indonesian Seismic Hazard Map (Indonesian National Center for Earthquake Studies, 2017). Second, there is likely inadequate and improper detailing (e.g. critical zones in the reinforced concrete frames – e.g. beam-column joint) do not anticipate higher seismic loads and do not comply with the National Standards of building design (e.g. code for designing earthquake-resistant buildings in Indonesia SNI 1726:2002, SNI 1726:2012, and SNI 1726:2019). There is often a long delay in adopting such Building standards in Eastern Indonesia, including West Sulawesi. Third, some forms of irregularity in the buildings, such as setback irregularities, structural asymmetric, and incline columns, may increase the risk of seismic forces compromising the collapsed structures.

On January 25, 2021, our team conducted a field survey to identify the damage to masonry buildings in Tampalang village, Tapalang district (Fig. 7). This field survey serves as a validation of the aerial mapping from UAVs. We found that the masonry walls of these buildings were destroyed, suggesting that the confinement from the surrounding joint elements of the structure was inadequate. We also found that the space between vertical and horizontal joints of the structural elements was more than 3 m in many cases. In addition, there are barely any reinforcements around openings in the walls, which amplifies the vulnerability of the overall
buildings. The roofs of the buildings were also collapsed, indicating that the supporting elements, such as roof frames, were not adequately designed. Bracing elements seemed to be missing in the roof frames or rafters. Furthermore, the perimeter columns of the mosque were also destroyed. The presence of arched walls between perimeter columns shortens the column height. As a result, shear demand becomes excessive, causing the shear failure of the columns. This phenomenon is called the “short column mechanism”.

Our field survey found a liquefaction phenomenon in the Tajimane and Taan villages in the Tapalang district. In those two villages, mudflow and dry wells were observed (Fig. 8). These were caused by a layer of sand from the bottom of the well rising along with groundwater in the well due to the earthquake tremors. When the tremors were over, the water came back down, but the fine sand soil could not go, so it clogged the mouth of the well, drying the well. Digging through this clogging sand can allow the water to return. A small secondary earthquake might trigger this event if the groundwater level is shallow because the soil layer will have already liquefied during the main earthquake.

On January 26, 2021, in addition to the site visit to damaged buildings, our team conducted UAV flights in Kayuangin village, Malunda district, Majene regency (Fig. 9). This region is located ~10 km to the west of the epicentre. In this region, more buildings were destroyed than in Tampalang village. If our observations in Tampalang village suggest that the earthquake damaged only some sections of the buildings and the majority of those buildings remained standing, then in Kayuangin village, the majority of the buildings collapsed entirely.

By January 28, 2021, we compiled our field survey on damaged buildings, as shown in Table 1. BNPB cited the data in their field report to inform the stakeholders at sub-national (district and provinces) and national levels. The report covered six sub-districts in the Mamuju regency (Bonehau, Kalukku, Mamuju, Simboro, Tapalang and West Tapalang) and two districts in Majene (Malunda, Ulundu) were reported on. Damage to buildings was categorized into three types, i.e. minor damage, moderate damage and severe damage. According to the regulation by the Head Of National Disaster Management Agency No. 8, 2011 (https://bnpb.go.id/uploads/migration/pubs/28.pdf, accessed on March 13, 2022), damage to buildings is categorized into three types, i.e. minor, moderate, and severe. A severe damage status is when a building completely collapses, or most of its internal structures are damaged by more than 50%. One example of severe damage we found was at a dam, where most of the walls and floors were broken, most of the embankments were broken, and the waterline did not work. Moderate damage is a criterion that results in a small part of the structure being damaged by up to 50% and the supporting components being damaged, but the building remains standing. Some examples of moderate damage include a small part of the main structure of a building being damaged, most of the floodgates and other supporting components is damaged, and the waterline being cut off. Finally, minor damage refers to the cracking of some structural components
Fig. 3. Location of the field investigation on damaged buildings due to the 2021 Mamuju-Majene earthquake in West Sulawesi province using multirotor UAV.

Fig. 4. 2D map obtained from UAV used by BNPB to support assessment on SAR and recovery planning in the region.
by up to 15%, but the building remains standing and can continue to be used. Minor damage would refer to cracks in stucco walls, a small part of the floodgates and other supporting components being damaged, and irrigation canals still being used.

For the six districts in the Mamuju regency, we compiled a damage report on buildings with minor damage (5,526), moderate damage (3,843), and severe damage (2,054). Between those six districts, Mamuju received the most severe damage to its buildings. Meanwhile, for the two districts in the Majene regency, we compiled a damage report on buildings with minor damage (1,177), moderate damage (1,140), and severe damage (1,782). Although the total number of damaged buildings for each district is significant in the Mamuju district, the most considerable heavy damage to buildings is in the Malunda district, Majene regency. Apart from the poor quality of the building structure, the earthquake rupture (Gunawan et al., 2021) located near the Malunda district (Fig. 1), is most likely the cause of the severe damage to buildings in this district.

4.2. Managing emergencies and damage assessment during Coronavirus disease 2019 (COVID-19) pandemic

The earthquake occurred during the coronavirus (COVID-19) pandemic. Since January 21, 2021, the West Sulawesi Volunteer Desk has provided Antigen Rapid Swab services for volunteers who have joined and registered at the Volunteer Desk for free. The swab officer is from the National Zakat Agency, and they can serve 100 people daily, with a service time of 15:00 to 18:00 local time.

In order to prevent the transmission and potential spread of COVID-19 in the refugee camps, the Ministry of Social Affairs has provided nine tents that use COVID-19 barriers and ventilation systems. The tents are intended for vulnerable groups: seniors, residents
Fig. 6. Damage to the two hospitals in the Mamuju district: (a) Mitra Manakarra Hospital, and (b) Regional Public Hospital. Photograph taken by authors.

Fig. 7. Damaged buildings in Tampalang village, Tapalang regency, which was surveyed on January 25, 2021. Photograph taken by authors.
Fig. 8. Observed liquefaction phenomenon in the Tajimane and Taan villages. Photograph taken by authors.

Fig. 9. Damaged buildings in Kayuangin village, Malunda district, Majene regency, which was surveyed on January 26, 2021. Photograph taken by authors.

| No. | Location of the district | Minor Damage ± | Moderate Damage ± | Severe Damage ± | Total ± |
|-----|--------------------------|----------------|-------------------|----------------|--------|
| Mamuju regency | 1. Bonehau | 75 | 12 | 0 | 87 |
| | 2. Kalukku | 207 | 347 | 26 | 580 |
| | 3. Mamuju | 1.923 | 1.961 | 1.244 | 5.128 |
| | 4. Simboro | 2.046 | 862 | 313 | 3.221 |
| | 5. Tapalang | 1.230 | 633 | 439 | 2.302 |
| | 6. West Tapalang | 45 | 28 | 32 | 105 |
| Cumulative No. | 5.526 | 3.843 | 2.054 | 11.423 |
| Majene regency | 7. Malunda | 746 | 673 | 1.308 | 2.727 |
| | 8. Ulumanda | 431 | 467 | 474 | 1.372 |
| Cumulative No. | 1.177 | 1.140 | 1.782 | 4.099 |

Table 1
Damage buildings in Mamuju regency as of January 28, 2021 at 06.00 (local time, GMT +8).

with comorbid diseases, pregnant women, breastfeeding mothers, people with disabilities, toddlers and children. This tent is located at Manakarra Stadium in the Mamuju district (Fig. 10).

We found that the application of health protocols in several refugee locations is not supported by the proper number of temporary shelters for human settlement. In our survey, we found up to 20 families in one tent. If we multiply that by four people, assuming a
family consists of two parents and two children, it would mean that up to 80 people lived in one tent. Furthermore, sanitation facilities were limited, as was the availability of clean water. In addition, internally displaced persons (IDPs) lack awareness of the COVID-19 pandemic. We found that most IDPs were not wearing masks, although masks were being handed out at the camp. In this case, applying health protocols in the communities was difficult.

The West Sulawesi Health Office reported an increase of COVID-19 patients up to 100% after the earthquake, suggesting that health protocols were not implemented during the earthquake's aftermath. On January 23, 2021, there were 143 cases of COVID-19 in the earthquake-affected area, with 130 people in Mamuju regency and 13 in Majene regency. Most of them were IDPs. On January 25, 2021, 5197 people tested positive for COVID-19, including evacuees, volunteers and government officers.

5. Conclusions

We have conducted a thorough field investigation on the damage to buildings by the 2021 Mamuju-Majene earthquake in the West Sulawesi Province. We used a UAV to map the region geospatially. We found that:

- In Kayuangin village, Malunda district, Majene regency, located ~10 km west of the epicentre, there were more destroyed buildings than in Tampalang village. Also, significant numbers of severely damaged buildings were found in Malunda district, Majene regency, most likely due to its proximity to the earthquake epicentre. In addition, the liquefaction phenomenon was also evident in the Tajimane and Taan villages in the Tapatlang district.
• Heavily damaged buildings due to the inadequate confinement from the surrounding tie elements, the sparse distance between vertical and horizontal tie elements, and unprovided tie elements around openings in the walls.

• Health protocols during the COVID-19 pandemic in several refugee locations were not followed. IDPs could not access the proper number of temporary shelters and could not easily access sanitation or clean water. Furthermore, the lack of self-awareness by the IDPs during the COVID-19 pandemic, as shown by the lack of mask-wearing, increased COVID-19 patients by 100% after the earthquake.

Ethical statement

All ethical practices have been followed in relation to the development, writing, and publication of the article.

CRediT authorship contribution statement

Nuraini Rahma Hanifa: Conceptualization, Formal analysis, Writing – original draft, Resources; Endra Gunawan: Conceptualization, Formal analysis, Writing – original draft, review and editing, Resources, Visualization; Septian FirmanSyah: Field Investigation; Lutfi Faizal: Formal analysis; Dyah Ayu Retnowati: Visualization; Giovanni Cynthia Pradipita: Visualization; Iswandi Imran: Formal analysis, Resources; Jonatan A. Lassa: Writing –review and editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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