An Example of Karst Features Identification Using High-Resolution Aerial Photograph for Environmental Management at Pindul Cave Area, Gunung Sewu Karst, Indonesia

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Abstract. Karst area poses distinctive landform features on its surface such as karst hills, cave entrances, sinking streams, and doline. Identification of surface karst features in detail will greatly help understand the hydrogeological system of an area. However, the availability of open-source high-resolution spatial data is scarce. This study aims to identify karst features in the Pindul Cave Karst Area is part of the Gunungsewu Geopark Area using a multirotor unmanned aerial vehicle. Identification of surface karst features solely based on orthomosaic images is challenging. The use of a digital elevation model for more detailed topographic expression is necessary. The digital terrain model is more reliable for karst feature identification compared to the digital surface model. In the small study area, dense vegetation cover often leads to misinterpretation of karst features, while the digital terrain model provides stronger topographic expression.

Keywords: UAV · Karst · Gunungsewu · DEM

1 Introduction

Topographic data are an essential source of information for various studies, especially earth science. The use of digital elevation data for geomorphological studies has increased due to the availability of open-source terrain data such as SRTM, ALOS PALSAR, ASTER, etc. [1, 2]. Digital elevation data are powerful for morphometric and morphology analysis because they store quantitative parameters that allow better spatial analysis [3]. From the digital elevation model, various terrain information such as slope, aspects, and landform classification can be retrieved at a local or regional level [4, 5].

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In Indonesia, the Geospatial Information Agency (Badan Informasi Geospatial) provides a national digital elevation model (DEMNAS) for almost the whole country through their portal (https://tanahair.indonesia.go.id/demnas/#/). The availability of elevation data with medium to high spatial resolution plays an essential role in land and environmental analysis, including in the karst area. Karst is a distinctive landform characterized by particular features such as caves and extensive underground water systems that developed on soluble rocks [6, 7]. The identification of karst features, especially surface features could be done by interpreting the morphology using a digital elevation model. However, in such a small-scale research area, the data available with sufficient spatial resolution digital elevation model is often scarce. The developments of Unmanned Aerial Vehicles (UAVs) in recent few years have helped scientists to provide high-resolution DEM for vulnerable environment studies, including karst areas [8, 9] UAV-derived DEM data allow more detailed terrain analysis and accurate feature identification on karst terrain that cannot be done using open-source DEM data [10].

Identification of karst geomorphological features in detail will greatly help understand the hydrogeological system of an area [11, 12]. This will facilitate the next survey stages such as cave mapping studies, flow connectivity, defining the karst drainage basin, as well as a complete description of the hydrogeological system of an area [13–16]. With the availability of detailed data related to geomorphological features in an area, surveys and subsequent research activities will be very fast and easy compared to terrestrial surveys by relying on small-scale topographic maps [17, 18]. Based on this, studies related to mapping geomorphological features are very important. This study aims to identify the karst features using high-resolution aerial photographs generated from the UAV. This study is expected to contribute to the next study in karst areas, especially in tropical karst areas such as Indonesia which has karst features that are generally small in size.

2 Methods

The research location is in the Pindul Cave Karst Area which is part of the Gunungsewu Geopark Area. The Gunungsewu karst is established as UNESCO global geopark with more than 30 geo-sites scattered in three regencies: Gunungkidul, Wonogiri, and Pacitan. There are some cave sites situated in Gunungkidul Regency such as Pindul Cave, Kalisuci Cave, Jomblang Cave, Cokro Cave, and Ngingrong Cave, with Pindul Cave as the most visited by tourists among others. Pindul Cave is located in the Wonosari Basin and consists of Miocene limestone from the Wonosari and Kepek Formations. The Pindul Cave karst system is characterized by a 300 m-long cave passage and a 15.44 km^2 catchment area with some cave entrances in the area [19, 20] (Fig. 1). This research aims to identify karst features using detailed UAV-DEM in Pindul Cave Area, Gunungkidul, Special Region of Yogyakarta, Indonesia.

The aerial photograph data was collected using a quadcopter-type unmanned aerial vehicle DJI Mavic 2 zooms. This multirotor UAV is equipped with 1/2.3" CMOS camera (24–48 mm focal length) that is mounted to a 3-axis gimbal to stabilize the camera movement. The autonomous flight control is run by drone deploy software and onboard flight control system that allow the UAV to fly on autopilot mode. The data acquisition was conducted on July 2nd, 2022 as a beyond visual line of sight operation (BVLOS).

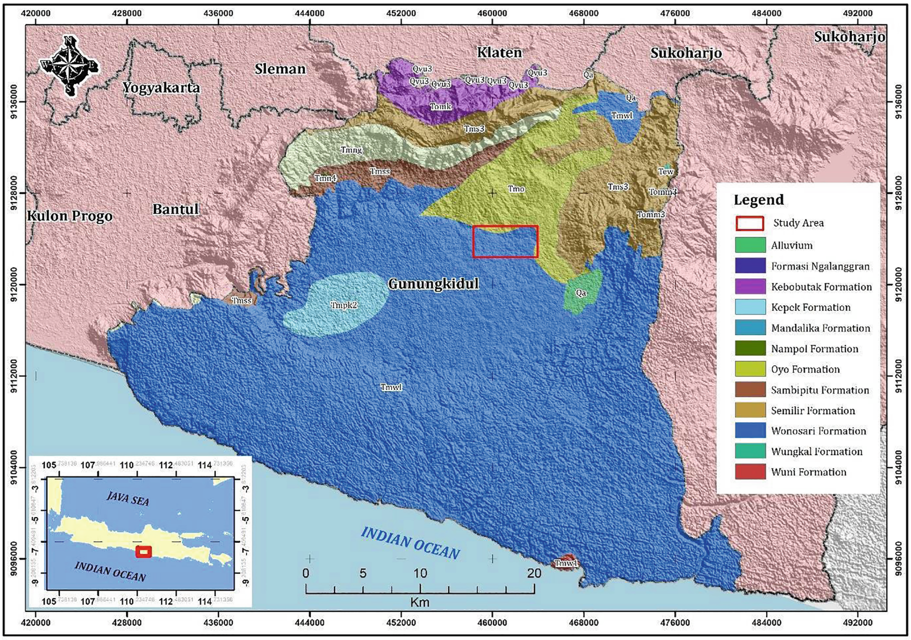

Fig. 1. Geological map of the study area [21]

The UAV deployed at 120 m above ground level with 75% front overlap, 65% side overlap, and 10 m/s flight speed. Two flight mission was done with area coverage of 43 ha and 37 ha respectively. The first flight mission successfully acquired 202 images while the second mission captured 213 images. The data processing was done using a computer with Intel core i7 2.50 GHz CPUs, and 16 GB of RAM. Orthomosaic image and DEM generation was performed using the photogrammetry software Agisoft Metashape. The step of generating orthomosaic images from the raw data includes several steps that produce 3D point clouds, 3D meshes, DSM, and Orthophoto. The first step of photogrammetry computing started with photo alignment based on camera locations and camera parameters. This process resulted in the generation of point clouds from overlapping images with a rough 3D perspective of the area. The next step is the dense point cloud calculation. This step was done using medium quality with unclassified dense points. The results from Digital Surface Model (DSM) data were then processed using PCI Geomatica 2015 software for land cover filtering and Digital Terrain Model (DTM) generation. The land cover was removed using a set of combination between terrain filter and bump removal. This process was done by delineating the land covers using polygons and applying the terrain filter in the selected polygons.

3 Result and Discussion

3.1 Orthomosaic Image

The study area is divided into two different locations that are adjacent. The first location is focused on the passage of Pindul Cave, with the extent of the flight mission covering the input and output of Pindul Cave, while the second location is focused on Kedung-buntung Cave. Based on the Structure from Motion (SfM) processing using Agisoft, the Orthomosaic image results have a Ground Sample Distance of four centimeters. While the digital elevation model spatial resolution is 20 cm.

The first step of karst feature identification is started with a visual interpretation of orthomosaic results. In the first location (Pindul passage), the surface karst features that were recognizable were the input and output of the Pindul Cave passage. The water bodies at the input and output are visible from the aerial photographs. Manual delineation was done on the identified water bodies, with the size of the detected object being 441.62 square meters for cave input, and 403.13 square meters for the output respectively. The distance between the two objects was 197.425 m measured using a straight line with NE-NW direction. This passage is classified as a linear passage that is controlled by a local structural setting [19]. The interpretation of karst features and the orthomosaic results is depicted in Fig. 2.

Adjacent to the first location, another water body was identified by visual interpretation. A similar opening with a water body presumed to be underground river output

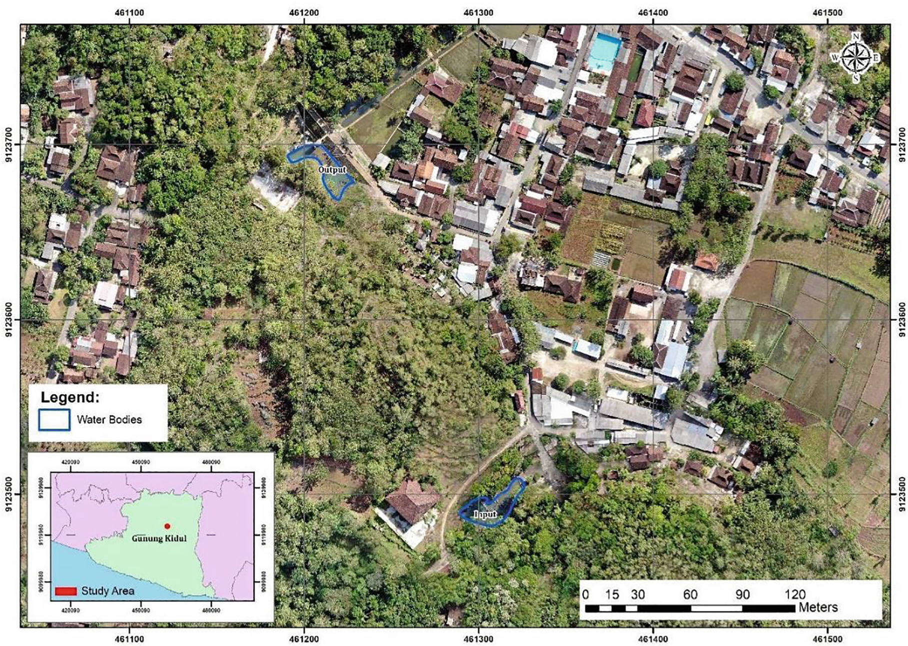

Fig. 2. Result of surface karst features at Pindul Cave Passage using the Orthomosaic image.

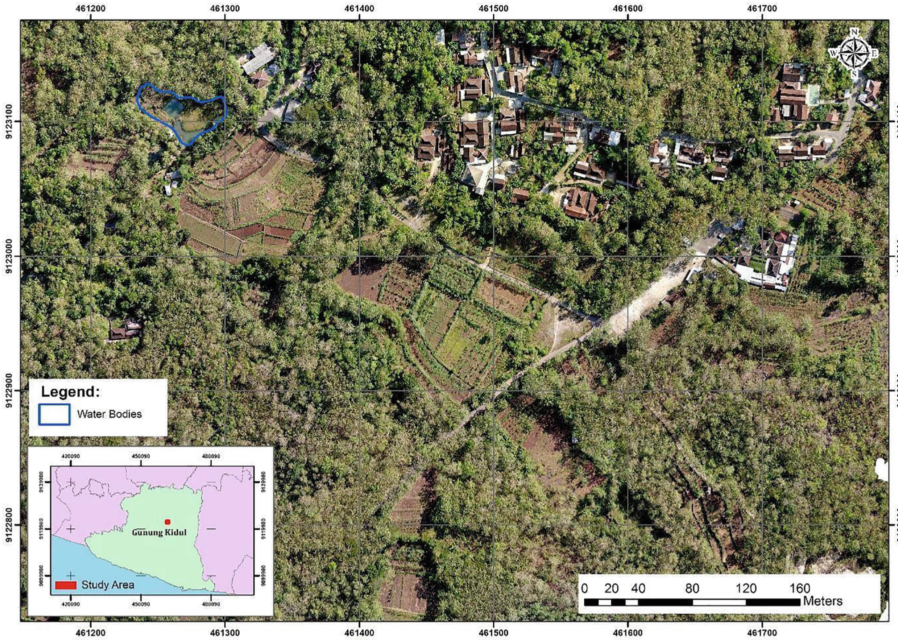

Fig. 3. Interpretation result of surface karst features at Kalibuntung sinking stream using the Orthomosaic image.

was identified based on its color and shape. However, relying on visual interpretation techniques is limited to some extent without enough experience [22]. Validated with the field survey, the water body that was identified as cave output based on its shape, color, and association, it is found that the object was a sinking stream. The disadvantage of visual interpretation is the sense of direction is weak, so we are not able to tell whether the object was cave input (sinking stream) or cave output without a field validation. The object that is identified was known as Kalibuntung sinking stream. The interpretation of Kalibuntung and the orthomosaic results of the second location is shown in Fig. 3.

3.2 Digital Elevation Model

Identification of karst features solely based on visual interpretation is difficult. Shaded relief from the digital elevation model can help visual interpretation of feature identification [13]. Digital Elevation Model was created using the dense cloud results from photo alignment. This digital elevation model represents the surface elevation of the area (digital surface model/ DSM). The digital surface model's spatial resolution is 20 cm. Based on the DSM data, several features have appeared which were initially quite difficult to identify from interpretation. Figure 4 shows a very clear depression at the inlet and outlet of Pindul Cave which is the main tourist attraction at the study site. Figure 5 clearly shows some of the more complex features, such as Suruh Cave (Karst Window), Sioyot Cave Entrance, Ngancar Spring and Ngancar Cave (Karst Window), Kedungbuntung Sinking Stream, and the depression in Tanding Cave which is an artificial cave.

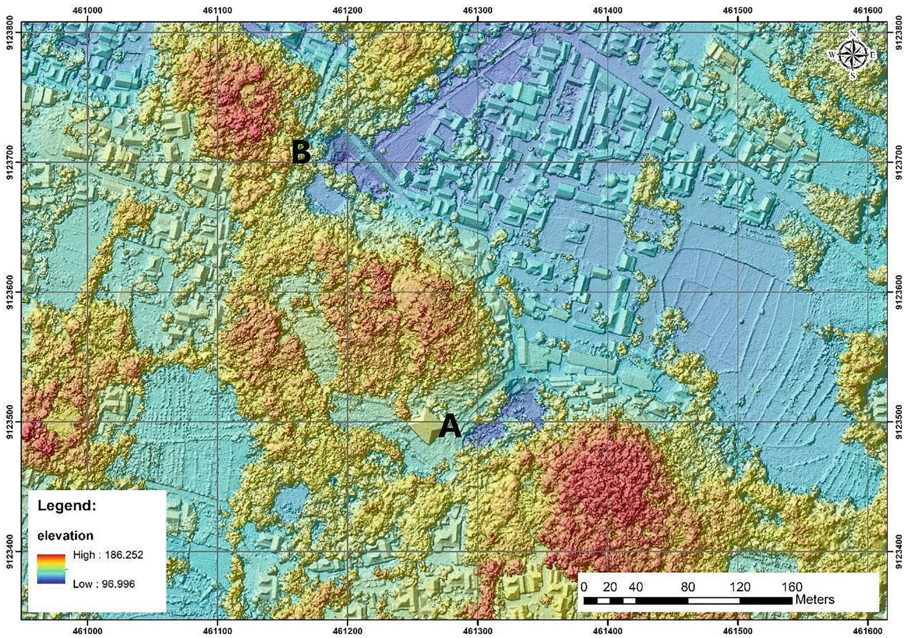

Fig. 4. Digital Surface model of Pindul Cave Passage; A) Input and B) output appear as low elevation area compared to surrounding.

The detection of the Kedungbuntung Sinking Stream very clearly shows the ability of DEM-UAV to provide data on allogenic rivers that recharge groundwater in the karst area. This result will make it easier to map the karst buffer area which is part of the allogenic river catchment area.

Although the DSM data is quite good in describing small karst features, the characteristics of tropical karst areas with dense vegetation often lead to misinterpretation because it does not appear that the karst depression is completely or even completely covered by vegetation. However, processing DSM data into DTM was able to overcome this problem (Fig. 6 and Fig. 7). DTM also shows a clearer surface morphology, so that it can be used to better identify positive and negative morphological forms in the study area. The results of the analysis of surface morphology using DTM show that the surface morphology of the karst area at the study site has differences from the Gunungsewu Karst Area in general. The shape of the karst hills in the Gunungsewu Karst Area is generally in the form of a conical hill or some experts call it a hemispherical shape or like steamed buns. It appears that at the study site the positive morphological form seems to indicate hills with large sizes with many small peaks. This shows that karst hill development is less intensive than the Gunungsewu Karst Area in the south Gunungkidul District. However, this study shows that the subsurface part of the study site has developed cave systems and underground rivers as indicated by the number of surface depressions, karst windows, cave entrances, sinking streams, and springs or resurgence of underground rivers.

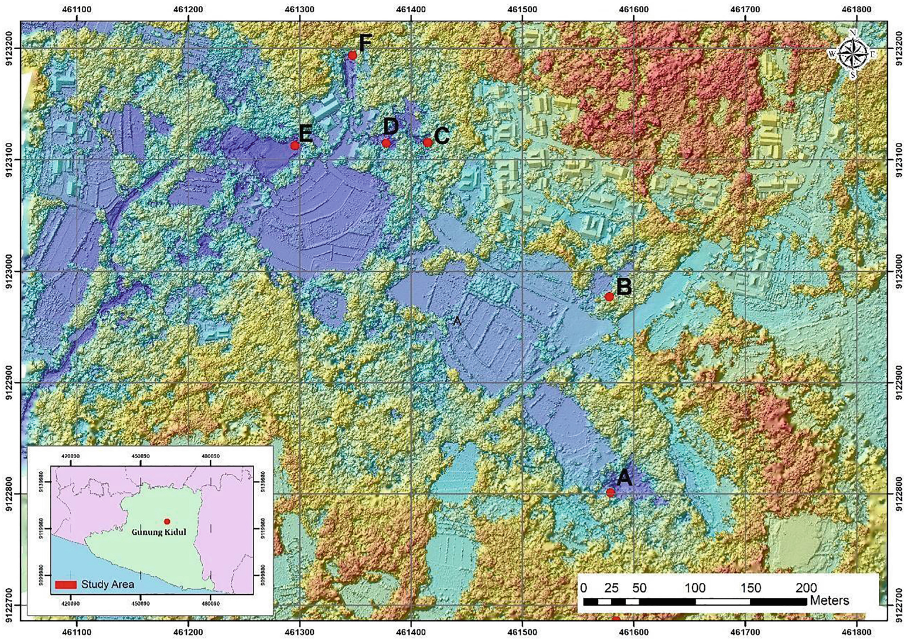

Fig. 5. Digital surface model of Kedungbuntung cave complex; A) Suruh Cave, B) Sioyot Cave, C) Ngancar Spring, D) Ngancar Cave, E) Kalibuntung Sinking Stream, F) Tanding Cave

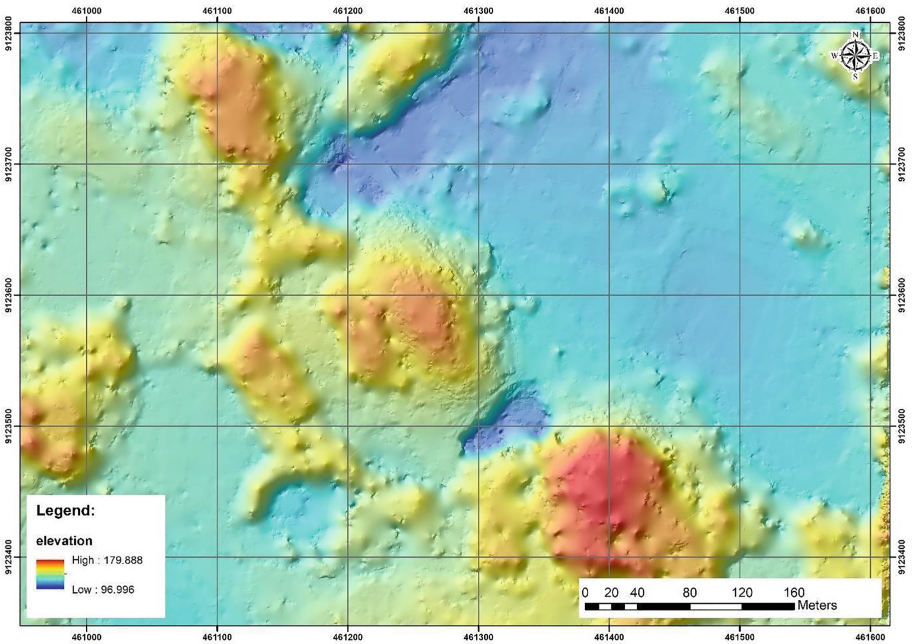

Fig. 6. Digital terain model of pindul cave passage

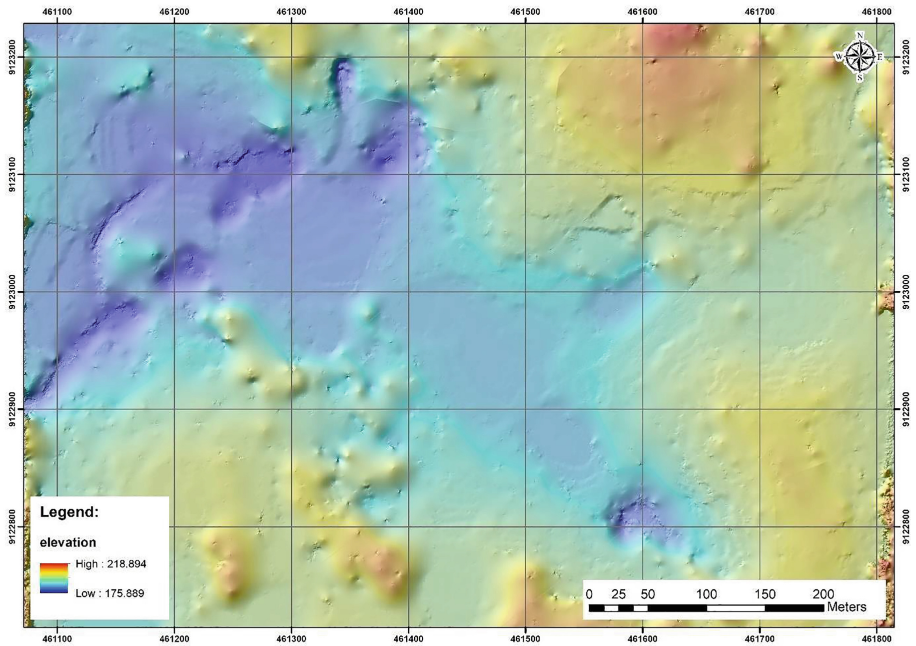

Fig. 7. Digital Terrain Model of Kedungbuntung Cave Complex

3.3 The Progress and the Challenges for the Future Research

The results of this study have shown that the DEM-UAV can be used to identify features in small karst areas, such as those found in tropical karst areas such as Gunungsewu. The results of the study can be followed up by surveying the cave system, connectivity testing by mapping cave passages and tracer tests, as well as defining karst drainage basins in both allogenic and autogenic recharge areas. The definition of a good hydrogeological system will greatly support the better management of the Pindul Cave karst area in the future.

Although it has shown encouraging results in studies in the Pindul Cave Karst Area, in the future the challenge of mapping in a wider area is still difficult to do. Mapping a very large area is needed to cover the entire karst area so that the geomorphological and hydrogeological characteristics of the karst area can be described as a whole. Currently, UAVs still have relatively narrow mapping capabilities, although several UAVs with the fixed wing type have shown quite wide results in the mapping area. However, in mapping karst areas that have a large area such as the Gunungsewu Karst Area, data acquisition using UAVs still requires enormous effort, time, and cost.

4 Conclusion

The aerial photograph using the multirotor unmanned aerial vehicle in this study has a spatial resolution of four centimeters while the digital elevation model was 20 cm. This study shows that surface small karst features in the study area can be identified by the orthomosaic image results. Several objects such as cave entrances, karst windows, karst depression (doline), sinking streams, and karst hills can be identified well. Shaded relief from the digital elevation model can help the visual nterpretation of feature identification. In a small study area, the digital terrain model shows a more distinct topographic impression compared to the digital surface model.

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References

1. C. Huggel, D. Schneider, P. J. Miranda, H. Delgado Granados, and A. Kääb, "Evaluation of ASTER and SRTM DEM data for lahar modeling: A case study on lahars from Popocatépetl Volcano, Mexico," *J. Volcanol. Geotherm. Res.*, vol. 170, no. 1–2, pp. 99–110, 2008, doi: https://doi.org/10.1016/j.jvolgeores.2007.09.005.
2. T. K. Saha *et al.*, "How far spatial resolution affects the ensemble machine learning based flood susceptibility prediction in data sparse region," *J. Environ. Manage.*, vol. 297, no. July, p. 113344, 2021, doi: https://doi.org/10.1016/j.jenvman.2021.113344.
3. G. P. B. Garcia and C. H. Grohmann, "DEM-based geomorphological mapping and landforms characterization of a tropical karst environment in southeastern Brazil," *J. South Am. Earth Sci.*, vol. 93, no. August 2018, pp. 14–22, 2019, doi: https://doi.org/10.1016/j.jsames.2019.04.013.
4. G. A. Tang and F. Li, "Landform classification of the loess plateau based on slope spectrum from grid dems," *Lect. Notes Geoinf. Cartogr.*, vol. 0, no. 199049, pp. 107–124, 2008, doi: https://doi.org/10.1007/978-3-540-77800-4_6.
5. Liu, "DEM-based analysis of local relief," *Lect. Notes Geoinf. Cartogr.*, vol. 0, no. 199049, pp. 177–192, 2008, doi: https://doi.org/10.1007/978-3-540-77800-4_10.
6. D. Ford and P. Williams, *Karst Hydrogeology and Geomorphology*. West Sussex: John Wilwy and Sons, 2007.
7. W. B. White, "Karst hydrology: recent developments and open questions," vol. 65, no. 0013, pp. 85–105, 2002.
8. H. Fatchurohman, A. Cahyadi, and T. H. Purwanto, "Worst-Case tsunami inundation modeling using high-resolution UAV-DEM in various coastal typologies, case study Gunungkidul coastal area," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 986, no. 1, p. 012027, 2022, doi: https://doi.org/10.1088/1755-1315/986/1/012027.
9. J. Rotnicka, M. Dłużewski, M. Dąbski, M. Rodzewicz, W. Włodarski, and A. Zmarz, "Accuracy of the UAV-Based DEM of Beach–Foredune Topography in Relation to Selected Morphometric Variables, Land Cover, and Multitemporal Sediment Budget," *Estuaries and Coasts*, vol. 43, no. 8, pp. 1939–1955, 2020, doi: https://doi.org/10.1007/s12237-020-00752-x.
10. O. L. Silva, F. H. R. Bezerra, R. P. Maia, and C. L. Cazarin, "Karst landforms revealed at various scales using LiDAR and UAV in semi-arid Brazil: Consideration on karstification processes and methodological constraints," *Geomorphology*, vol. 295, pp. 611–630, 2017, doi: https://doi.org/10.1016/j.geomorph.2017.07.025.
11. E. Haryono and M. Day, "Landform Differentiation Within The Gunung Kidul Kegelkarst, Java, Indonesia," *J. Cave Karst Stud.*, vol. 66, no. 2, pp. 62–69, 2004.

12. M. Widyastuti, I. A. Riyanto, M. Naufal, F. Ramadhan, and N. Rahmawati, "Catchment Area Analysis of Guntur Karst Spring Gunung Kidul Regency, Java, Indonesia," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 256, no. 1, 2019, doi: https://doi.org/10.1088/1755-1315/256/1/012008.
13. N. F. Tastian, T. N. Adji, and A. Cahyadi, "Flood water hydrogeochemistry characteristics in Pindul Cave, Gunungsewu Karst Area, Indonesia," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1039, no. 1, p. 012004, 2022, doi: https://doi.org/10.1088/1755-1315/1039/1/012004.
14. M. Q. Al-Ghozali et al., "Identification of Karst Underground River Catchment Areas with Artificial Tracer Tests and Water Balance in Banteng Cave Springs (Karst Gombong Selatan, Central Java)," E3S Web Conf., vol. 325, p. 08007, 2021, doi: https://doi.org/10.1051/e3sconf/202132508007
15. A. P. Priambada et al., "Analysis of underground river network connectivity in Barat Cave, Karst Karangbolong, Central Java, using the Artificial Tracer Test Method," E3S Web Conf., vol. 325, p. 02010, 2021, doi: https://doi.org/10.1051/e3sconf/202132502010.
16. E. S. Astuti et al., "A groundwater tracing investigation to determine Kalisirah Karst Springs catchment area, Kebumen Regency, Central Java," IOP Conf. Ser. Earth Environ. Sci., vol. 451, no. 1, 2020, doi: https://doi.org/10.1088/1755-1315/451/1/012072.
17. M. A. Marfai, N. Khakim, H. Fatchurohman, and A. D. Salma, "Planning tsunami vertical evacuation routes using high-resolution UAV digital elevation model: case study in Drini Coastal Area, Java, Indonesia," Arab. J. Geosci., vol. 14, no. 19, 2021, doi: https://doi.org/10.1007/s12517-021-08357-9.
18. H. Fatchurohman and W. Handayani, "Coastal hazards mapping using high-resolution UAV image and DEM. A Case study in Siung Beach, Gunungkidul, Indonesia," IOP Conf. Ser. Earth Environ. Sci., vol. 1039, no. 1, p. 012026, 2022, doi: https://doi.org/10.1088/1755-1315/1039/1/012026.
19. A. Cahyadi, M. A. Labib, M. H. D. Sasongko, R. F. Agniy, R. Oktama, and T. N. Adji, "Karakterisasi Lorong Gua di Geosite Gua Pindul, Geopark Gunungsewu, Kabupaten Gunungkidul," Semin. Nas. Geogr. III, no. November, p. 9, 2019.
20. A. Nurkholis, T. N. Adji, E. Haryono, A. Cahyadi, and S. Suprayogi, "Time series analysis application for karst aquifer characterisation in pindul cave Karst system, Indonesia," Acta Carsologica, vol. 48, no. 1, pp. 69–84, 2019, doi: https://doi.org/10.3986/ac.v48i1.6745.
21. Surono, B.T.; Sudarno, I. and Wiryosujono, S. 1992,. Geology of the Surakarta-Giritontro Quadrangles, Java, scale 1:100,000. Bandung: Geological Research and Development Center
22. Thomas M. Lillesand, R. W. Kiefer, and J. W. Chipman, REMOTE SENSING AND IMAGE INTERPRETATION Seventh Edition, vol. 53, no. 9. 2018.