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RESEARCH PAPER

DEVELOPMENT AND EVALUATION OF THE WEBGIS APPLICATION TO SUPPORT VOLCANIC HAZARD MITIGATION IN THE SOUTHERN FLANK OF MERAPI VOLCANO, SLEMAN REGENCY, YOGYAKARTA PROVINCE, INDONESIA

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ABSTRACT. Merapi Volcano is one of the active volcanoes in Indonesia, which is located in the Central Java and Yogyakarta Province. The eruption of Merapi Volcano is a threat to people living on the slopes of Merapi, especially on its densely-populated southern flank. The purpose of this study was to build a webGIS to support volcanic hazard mitigation regarding Merapi Volcano and evaluate the webGIS system for determining the community's perception. This research was the first to produce a product that is used by government agencies related to volcanic disaster mitigation. webGIS development was carried out using an open source platform. System evaluation was carried out using usability testing. The samples were obtained using systematic the random sampling method of respondents who lived in the villages on the southern flank of Merapi volcano. webGIS was built using LeafletJS and QGIS, combined with spatial data about the evacuation locations, health facilities, evacuation routes, government offices, educational facilities and worship facilities, with a basemap obtained from Openstreet Map and Google Satellite. WebGIS was equipped with a database query feature to make it easier for users to find geographical information. The usability testing results showed that as many as 83% of the respondents were very satisfied with the appearance and information of webGIS, while as many as 82% were very satisfied with the navigation offered via the webGIS display.

KEYWORDS: WebGIS, mitigation, volcanic eruption

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INTRODUCTION

Indonesia is located in a ring of fire zone, with the characteristics of an archipelago, which is an area where the world's active tectonic plates meet; namely, the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate (De Bélizal et al. 2012, Wulan et al. 2021). Due to tectonic plate activity, Indonesia has more than 18,000 islands and 127 active volcanoes located along the tectonic faults (Solikhin et al. 2012). Merapi Volcano is one of the most active volcanoes in Indonesia (Hariyono 2018), with the potential to erupt and make an impact on society (Yudistira et al. 2020).

In the 21st century, the most intense eruption to date occurred on October 26, 2010, peaking on November 6, 2010. This eruption led to 275 deaths, 576 people being hospitalized, and 287,131 people becoming refugees, with a calculated loss of Rp 4.23 trillion (280 million USD) (Surono et al. 2012). Merapi Volcano might erupt at any time, posing a huge threat, especially to those living on its southern flank (Jousset et al. 2013). Information on the efforts made to mitigate the results of Merapi Volcano erupting needs to be gathered and disseminated to the public. One way to do this is through the development of a Geography Information System (GIS) for Merapi Volcano disaster mitigation (Sukatja et al. 2014).

Various studies on the provision of eruption disaster information systems have been carried out, such as the research on building a Spatial Data Infrastructure (SDI) for disaster mitigation in Kali Putih, Magelang Regency, which shows the importance of this information regarding the eruption disaster mitigation policies in Magelang Regency

(Permatasari et al. 2020). In addition, the modelling of volcanic eruptions is also important as an early warning system for the communities living on and around Merapi Volcano (Cobar et al. 2016, Santoso et al. 2021). Various efforts to implement Geographic Information Systems (GIS) to mitigate eruption disaster have aimed to improve the disaster management and mitigation efforts. The 3D building model, combined with a webGIS system, creates a Web-based 3D GIS system that can improve the mitigation efforts by additionally considering 3D buildings in regard to the threats of tsunamis and floods. The integrated analysis and visualization capabilities enable the decision makes freely to design scenarios and make evacuation decisions (Hong & Tsai 2022). A WebGIS-based three-dimensional (3D) approach is also applicable for real-time monitoring and to serve as an early-warning system regarding geological disasters. The real time results act as an early warning system when they are received by the sensors in the disaster zone. The system is an effective disaster prediction model, and can successfully realize real-time monitoring and early-warnings about geological disasters (Yang et al. 2015). WebGIS can also fulfil many functions to provide decision support for local disaster prevention and mitigation. In a landslide information system for Lanzhou city, China, a webGIS system faciliates storage and management, query and retrieval, warning and analysis, and web publishing, to support the decision-making based on landslide disaster information (Zhishan et al. 2012).

The WebGIS platform also successfully applied the system to several recent, large magnitude earthquakes. The generated deformation map shows a good agreement when compared to the data based on real earthquakes. WebGIS can act as a database of real earthquake data collected by the community and becomes a voluntary geographic information platform for collecting disaster data for rescue and model validation (Zhao et al. 2020). GIS and WebGIS have been widely used in various scientific fields. GIS also works as a tool for various environmental studies, disasters and hazards and tourism promotion (Warsini et al. 2016, Kusmiyarti et al. 2018; Permatasari et al. 2020; Trigunasih & Wiguna 2020; Permatasari et al. 2021; Sardiana et al. 2021; Suherningtyas et al. 2021; Talib et al. 2021; Wiguna 2021; Muslih et al. 2022; Sukraini et al. 2022). According to interview results with the Agency at Regency level, namely, Planning, Research and Development Agency and Disaster Mitigation Agency of Sleman Regency, the Sleman Regency Government does not have an information system specifically related to the mitigation of a Merapi Volcano eruption, while the national government's webGIS is not detailed and specific about the Merapi volcano eruption, so it is very important to develop and implement one. This research was the first research conducted with aim to build an information system for the mitigation of the eruption of Merapi Volcano. The information system can be implemented in the community and is expected to reduce risk and increase awareness of the community at the southern slopes of Merapi Volcano. The results of this study were expected to provide policy input to the government and stakeholders in efforts to mitigate the disaster of the eruption of Merapi Volcano in an integrated and sustainable manner.

MATERIALS AND METHODS

This research was conducted on the southern flank of Merapi Volcano, which is administratively located in Sleman Regency, especially in Turi, Pakem, Cangkringan, Tempel, Sleman, Ngaglik and Ngemplak Districts, Yogyakarta Province, Indonesia. Fig. 1 shows the research area.

The application's development in this study was divided into four stages; namely, 1) the initiation of the system, 2) the analysis of the system, 3) the system design, and 4) the implementation of the system (Whitten 2007). The system development was carried out using leafletJS and QGIS software. The data for webGIS were collected from local government agencies in Sleman Regency. The data analysis was divided into three steps; namely, (1) data identification, (2) data collection and (3) data entry into webGIS.

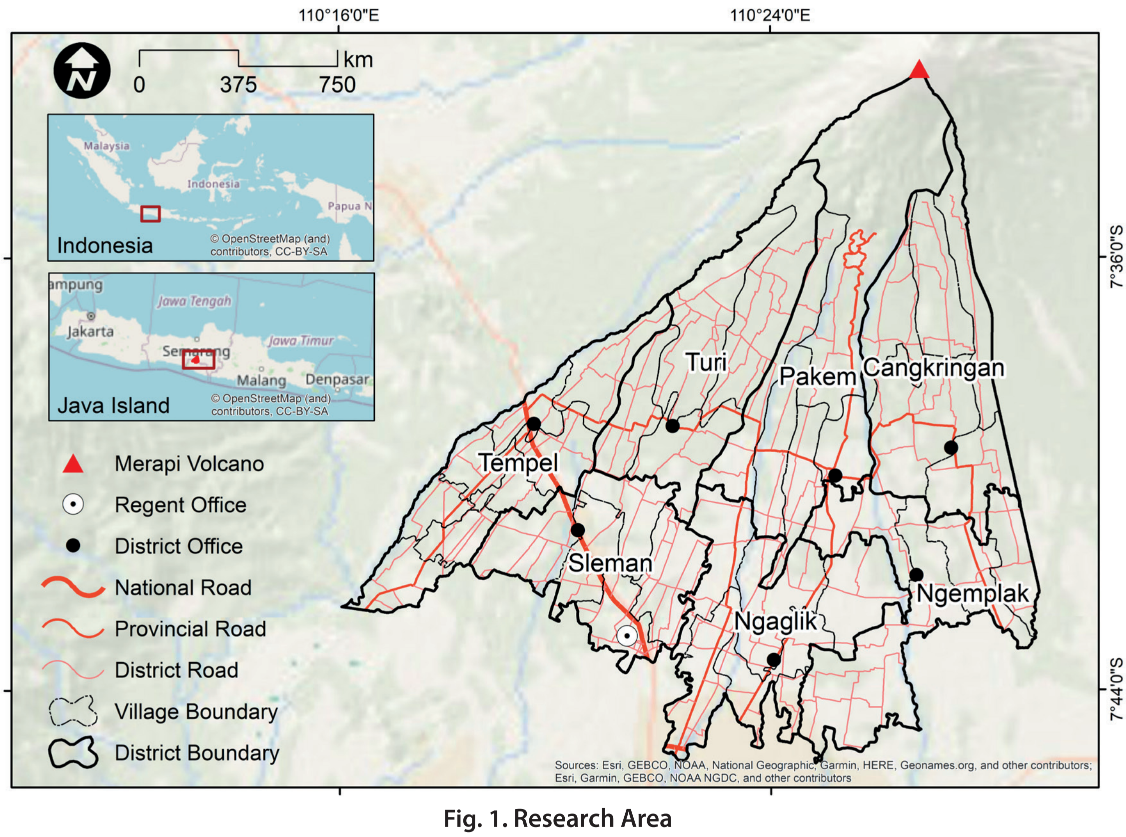

Fig. 1. Research Area

The webGIS was designed using QGIS and libraries from LeafletJS. LeafletJS is an open source JavaScript library that is widely used to build Web-based mapping applications. It supports most mobile and desktop platforms, as well as HTML5 and CSS3, and is used by many web-based mapping site applications (Edler & Vetter 2019).

The webGIS System workflow starts when the user logs in. Entering the system will call up OpenStreetmap and Google Satellite along with thematic data; namely, evacuation routes, river networks and Sabo dam locations, refuge locations, evacuation routes, educational facilities, religious facilities, public facilities, health facilities and government offices. The user can then access the map online. Fig. 2. shows the research flowchart and steps of the application development.

The application development was followed by system evaluation using usability testing (Hertzum 2020). Usability testing was applied by asking the respondents to use the system. The key elements to this technique is the use of traditional testing concepts and techniques such as scenario based testing to measure productivity and learnability of the subject. The assumption of using usability testing is by constructing test cases or tasks to measure the learnability of the application, the developer has a way to measure the quality of both the test and the software. (Mueller et al. 2009). However, evaluation of personalisation system remains a challenge due to thelack of understanding of what factors affect user satisfaction with a personalization system (Anand & Mobasher 2005, Kamarudin et al. 2017). The limitation in using this questionnaire is that it only collects data on display, navigation, and the information, which is an issue in usability testing. The sample for the usability testing were identified by applying random sampling to the inhabitants of the research area. Table 1 shows the questions related to the usability testing.

The respondents were asked to display the main page and map, select a map, display spatial data and select the nearest evacuation point, select an evacuation route, and navigate to the evacuation location. After using the system, the respondents were invited to answer questions related to the usability of the system, using a scale from 1 to 5. A score of 1 indicates dissatisfaction or that the system is not performing very well, while a score of 5 indicates very high satisfaction. The questions covered aspects of the system's display, the ease of navigation, and the completeness of the information displayed.

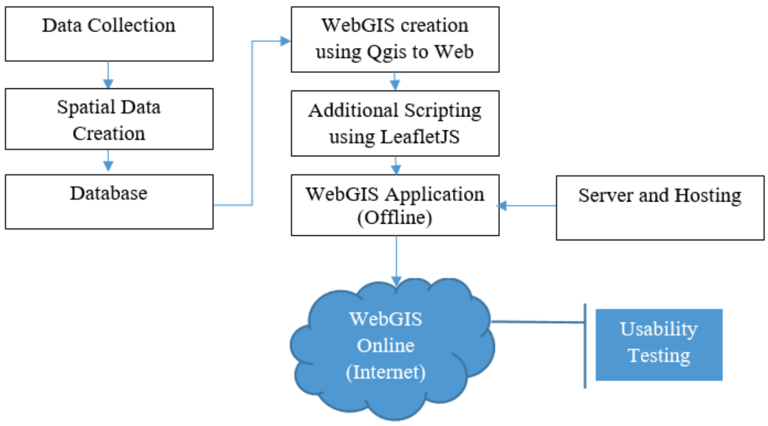

Fig. 2. Steps of the Application Development

Table 1. Questions related to the Usability Testing

No	Questions	Score					% Respondents
		1	2	3	4	5	
	Display (100 respondents)						100%
1	Is the display on the system easy to understand?						
2	Are the colors, layout, and text on the system easy to see and attractive?						
3	Are the image symbols on the system easy to understand?						
	Navigation (100 respondents)						100%
4	Are the pages on the system easy to navigate?						
5	Is the system easy to read?						
6	Are the features in the system easy to use/operate?						
7	Are the menus and displays on the system easy to remember?						
	Information (100 respondents)						100%
8	Is the information on the system easy to use/understand?						
9	Do the specifications on the system meet your needs?						
10	Is the information in the spatial data easy to see/understand?						

Note: Score: 1) Very Not Satisfied, 2) Not Satisfied, 3) Average, 4) Satisfied, 5) Very Satisfied

The method employed to determine the sample was systematic random sampling, which is appropriate for use in area- or region-based research, and involves identifying samples based on a grid system (De Souza & Koizumi 2020). The total number of samples in this study was 100 respondents, aimed to adapt to the large population (Memon et al. 2020). An overview of the sampling technique is shown in Fig. 3.

RESULTS AND DISCUSSION

The webGIS on mitigation of Merapi Volcano eruption was designed to be easily accessible to and used by both the government and public to search, locate and visualize geospatial data related to disaster mitigation regarding a potential eruption of Merapi Volcano. WebGIS was also intended to increase the readiness of the government of Sleman Regency to mitigate the effects of a Merapi Volcano eruption. The data displayed on webGIS were supplied by the Center for Research and Development of Geological Disaster Technology (BPPTKG), the Planning, Research and Development Agency of Sleman Regency, Sleman Regency Health Agency, the Sabo Department of the Ministry of Public Works and Public Housing and the Serayu Opak River Basin Center of the Ministry of Public Works and Public Housing. The available data were relatively comprehensive, ranging from administrative data and basic data (such as road networks, rivers, village government offices, educational facilities and religious facilities). The data were in ESRI shapefile format with UTM coordinates. The only drawback was that the data lack of metadata, so only limited information can be extracted. The thematic data obtained from local governments include spatial data on the disaster-prone areas around Merapi Volcano, the evacuation locations, and the health service locations, plus Sabo dam distribution data and evacuation routes data. Table 2 shows the data displayed on webGIS.

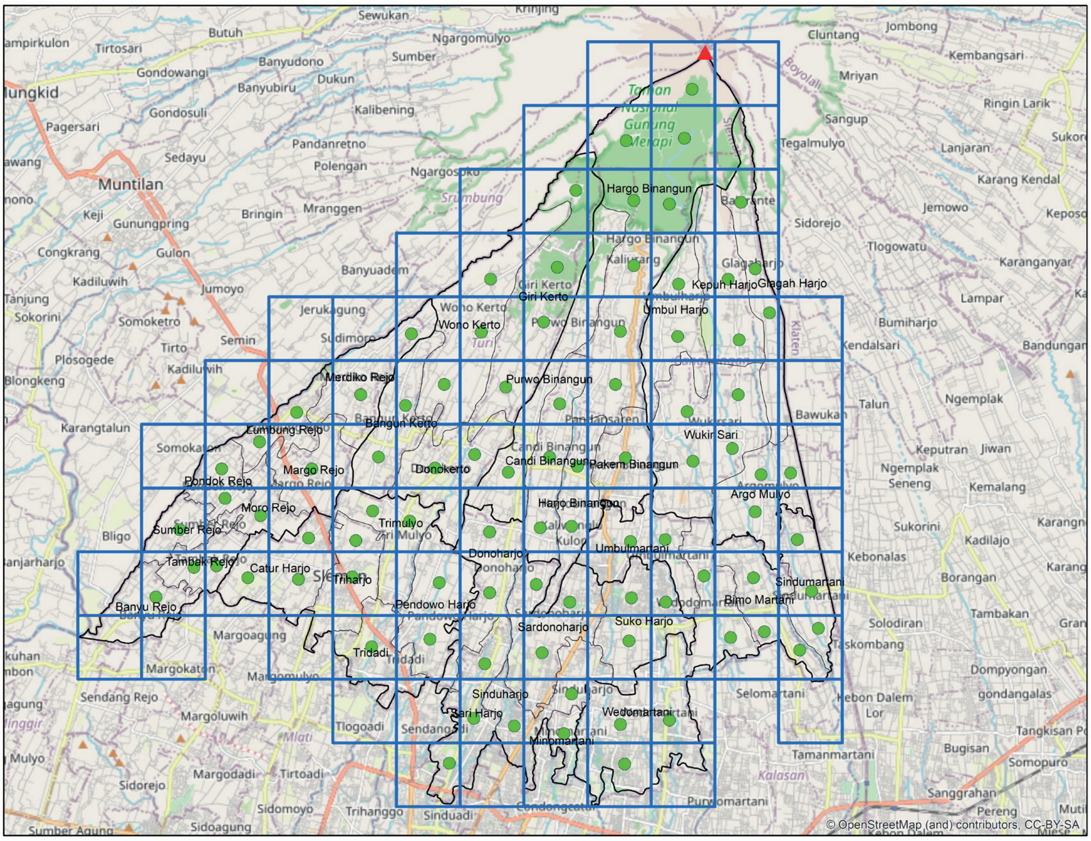

Fig. 3. Grid of the sample location

Table 2. Spatial Data on WebGIS

NNo	Government Agency	Data	Coordinate	Data Type
11	Center for Research and Development of Geological Disaster Technology (BPPTKG)	• Spatial data on the disaster-prone areas around Merapi Volcano	UTM Zone 49S	ESRI Shapefile
2	Planning, Research and Development Agency of Sleman Regency	• Spatial data on the administrative area of Sleman Regency • Spatial data on the road network • Spatial data on the river network • Spatial data on the religious facilities • Spatial data on the educational facilities	UTM Zone 49S	ESRI Shapefile
33	Sleman Regency Health Agency	• Spatial data on the health service locations	UTM Zone 49S	ESRI Shapefile
44	Sabo Department of the Ministry of Public Works and Public Housing	• Sabo dam distribution data	UTM Zone 49S	ESRI Shapefile
65	Serayu Opak River Basin Center, Ministry of Public Works and Public Housing	• Evacuation route spatial data • Village government office spatial data • Spatial data on the evacuation locations	UTM Zone 49S	ESRI Shapefile

The webGIS was equipped with a database query function to allow users to access data which were then displayed in the form of pop-up information. The webGIS also has a dynamic data display. Users can easily select the data from the legend menu to be displayed. Several types of data were also categorized based on colors and symbols to make it easier for users to understand the distribution of the locations; for example, the information on evacuation points was divided into three categories: gathering points, temporary shelter and permanent shelters. The gathering point is used as an initial evacuation place. The Village and District boundary also make it easier for users to identify their location; for example, the initial meeting point is located in Hargobinangun Village, Pakem District, while the temporary shelter point at the Hargobinangun Village Office and the permanent shelter is located in Kledok, Pakem District. By using this information system, the public can be educated, because of the completeness of the information, ease of access and navigation, and attractive display, and it can be accessed at any time. WebGIS, which is available to government agencies in Sleman Regency, can be accessed at http://wigunagis.42web.io/MitigasiMerapi.html#11/-7.6489/110.3752. Fig. 4 shows the display on webGIS on mitigation of Merapi Volcano eruption.

The webGIS was expected to be implemented to increase the level of public awareness about a potential Merapi Volcano eruption. Through usability testing, a total score of 81% (satisfied to very satisfied) for the display criteria, a total score of 81.8% (satisfied to very satisfied) for the navigation criteria and 83.3 % for the information criteria (satisfied to very satisfied). Only 16% to 19% of the respondents has a very not satisfied, not satisfied and average responds. Overall, the respondents were satisfied and very satisfied with webGIS as a way to mitigate the effects of a potential Merapi Volcano eruption. Table 3 shows the total scores for the usability testing.

The respondents also offered suggestions about how webGIS might be improved. They suggested adding a contact person from among the government or volunteers, adding a history of the eruptions of Merapi Volcano and the importance of webGIS developing into a mobile application. These suggestions and inputs were very helpful with regard to further webGIS development. The visualization and data displayed show the potential of web GIS to increase the awareness of the risk of Merapi Volcano erupting and facilitate the planning process by increasing the stakeholders' awareness about the importance of mitigating volcanic eruption risks, including an analysis of safe eruption areas, as well as the potential for evacuation shelter, evacuation routes and the selection of sustainable scenarios to minimize fatalities. However, some potential improvements remain, and the availability and quality of the data on the evacuation sites and evacuation routes must be updated regularly. The webGIS should be updated by developing participatory mapping through citizen and stakeholder engagement.

The webGIS has often been applied in the field of disasters. One example of using webGIS technology for disaster mitigation is urban flood mitigation (Palla & Gnecco 2021). This research concerns the implementation

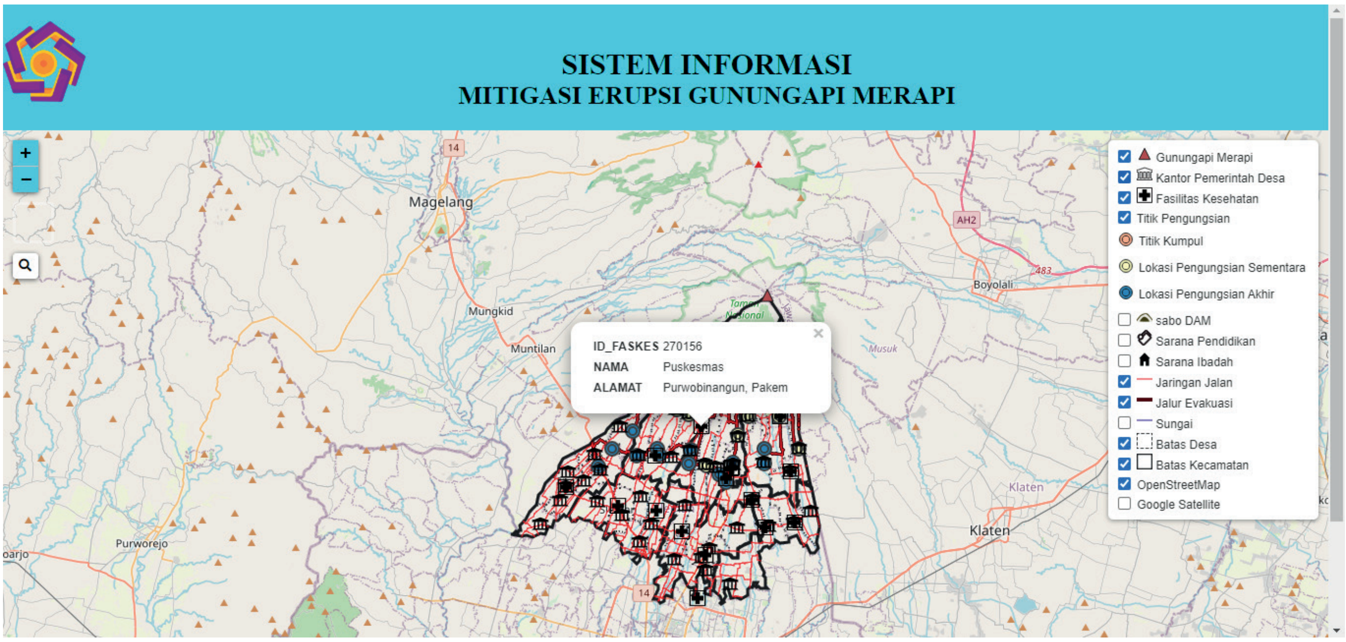

Fig. 4. WebGIS for Mitigating a Merapi Volcano Eruption

Table 3. The Total Scores for Usability Testing

No	Usability of the Website	VNS	NS	A	S	VS	Total
		1	2	3	4	5	
	Average responds (100 respondents)						
1	Display	0,33	3,67	15	39	42	100
2	Navigation	0,25	4,25	13,8	42,3	39,5	100
3	Information	0	6	10,7	37,3	46	100
	AVERAGE	0,19	4,64	13,16	39,53	42,5	100

Note: 1. VNS: Very Not Satisfied, 2. NS: Not Satisfied, 3. A: Average, 4. S: Satisfied, 5. VS: Very Satisfied of a GIS-based web to support urban flood mitigation and assessing its impact. In this web-GIS application, a special web page is implemented to provide reference studies in the field of urban flood risk mitigation for urban areas. Rocha et al. (2021) studied a multi-hazard webGIS platform for coastal regions, which provides access to a detailed database of past hazardous events, organized along several risk indicators, for the western coast of Portugal. The combination of features on the platform provides a unique repository of hazard information to support end-users in terms of both emergency and long-term risk planning actions. This implementation can be further applied and extended to other coastal zones. Li, et al. (2022) built and analysed the use of webGIS for sustainable natural disaster education for high school students. In the 21st century, webGIS brings opportunities and challenges to the whole educational field, as it is an indispensable supplementary element to improve the quality of education and teaching, so that teaching activities can be effective and students can learn meaningfully (de Lázaro Torres et al. 2017).

Although there are many differences between webGIS platforms, software, databases, processing stages, analysis, and visualisation, the use of webGIS in the field of disasters can support and accelerate the decision-making when a disaster occurs, such as the disaster response, mitigation or reconstruction and recovery activities. Geographic Information System (GIS) and webGIS technology, when applied to disaster management, can help to reduce the loss of life, property and critical infrastructure in the face of natural disasters; facilitate a vulnerability analysis, multi-natural disaster studies, evacuation plans and evacuation shelter plans; and enhance targeted disaster management scenarios, modeling and simulations. With regard to disaster mitigation, GIS can minimize the impact or number of victims of disasters through mapping disaster-prone areas, based on education or increasing public awareness of disaster-prone areas. GIS can identify priority areas in disaster mitigation and also scan the damage and extent of the disaster that has occurred.

CONCLUSION

The webGIS for Merapi Volcano Eruption Mitigation was processed using QGIS software which was published by a free hosting provider. The webGIS contains information on evacuation routes, evacuation gathering points, village government offices, health facilities, religious facilities, and lahar control building points (Sabo dams), which will provide spatial information for mitigation. Based on the results of the usability testing, a total score of 81% and 83.3% (very satisfied) was obtained for the display and system information while, for the information on navigation, a total score of 81.8% (very satisfied) was obtained. Suggestions and input from the users or respondents were considered to improve the quality of webGIS and information for the community, especially related to the south flank of Merapi Volcano.

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