Participatory Mapping of Tsunami Evacuation Routes (Case Study of Karangbenda Village Cilacap Regency)

W Sabani1,2, Juhadi1 and E Trihatmoko1
1Geography Department, Faculty of Social Science, Universitas Negeri Semarang, Semarang 50229, Indonesia
2e-mail: wahyusabani@students.unnes.ac.id

Abstract. Indonesia is one of the countries with a high tsunami risk, in this case the community plays an important role in disaster management, one of which can be done through the preparation of a tsunami evacuation route map which can be done through participatory mapping. This research was conducted in Karangbenda Village, Adipala District, Cilacap Regency, the purpose of this study was to determine how the skills of the community in determining tsunami evacuation routes were compared with the criteria for evacuation locations and effective evacuation routes and to test the effectiveness of tsunami evacuation routes prepared by the community. Data collection in this study was carried out through focus group discussions (FGD) and field surveys. The results show that the community can arrange a tsunami evacuation route properly, the evacuation route consists of the evacuation location and evacuation route, the designated evacuation location is in accordance with the evacuation location criteria and the evacuation route is in accordance with the route obtained through network analysis. The effectiveness level of the tsunami evacuation route was 98.82% and there were some people who were unable to reach the evacuation location within the specified time, totaling 36 people who were in the area of Dusun Congot to be precise in RT 02 / RW 02 because of the long distance from the evacuation location.

Keyword: Participatory Mapping, Disaster Mitigation, Network Analysis.

1. Introduction
Indonesian territory is influenced by the movement of the Eurasian, Australian and Pacific tectonic plates [1] thus making Indonesia often experience tsunami disasters [2], most of the tsunami cases in Indonesia were caused by earthquakes and the rest were due to volcanic eruptions and landslides [3]. Compared to other disasters, the number of incidents of tsunami disasters is relatively low, but the impact is very destructive and causes high casualties. [4], One of the causes of this is the waves of sea water coming quickly, in some cases the tsunami disaster in Indonesia only left a limited time for evacuation, which was about 10-30 minutes after the earthquake
occurred. [5], so the community had to evacuate in less than 30 minutes [6]. Responding to this risk, the Indonesian government developed a tsunami early warning system known as InaTEWS (Indonesia Tsunami Early Warning System) which was inaugurated on 11 November 2008 which provides early warning at the national level and is one of the 3 providers of early information for the Indian Ocean region together with Australia and India [7].

Even though an early warning system has been built, in reality, the tsunami disaster management efforts in Indonesia still have weaknesses, one of which is the absence of any evacuation instructions resulting in congestion. field of geographic information systems [8], This condition is also influenced by the low level of disaster literacy in Indonesian community [9]. With the high risk posed, the community must be aware of the threat of a tsunami disaster, one of which is by knowing the correct tsunami evacuation route to reduce the risk when a tsunami occurs. [10]. For the community to know the evacuation route for their area, it is necessary to involve the community to play an active role in determining the tsunami evacuation route through participatory mapping of the tsunami disaster evacuation route.

Participatory mapping is a way for community to interact to create and communicate knowledge, experiences, and aspirations about the world on a map [11]. Participatory mapping in this study uses a participatory rural appraisal approach which is intended to provide flexibility for the community to determine tsunami evacuation routes for their communities, participatory mapping can integrate local knowledge and scientific knowledge which is the result of top-down and bottom-up approaches that enable disaster risk assessment in an area, identify local potential and scientific strategies for disaster risk reduction, and integrate these strategies into comprehensive action plans [12]. The purpose of this study was to determine how the skills of the community in determining tsunami evacuation routes were prepared through participatory mapping, then the evacuation routes determined by the community were compared with the criteria for the evacuation location and the shortest evacuation route, and to analyze the effectiveness of tsunami evacuation routes that had been prepared by the community.

2. Methods
The study is done in the village karangbenda, kecamatan adipala, kabupaten cilacap located at 109º 9’ 42,26” E – 109º 11’ 29,49” E and 7º 39’ 52,94” S – 7º 41’ 34,5” S. This village is one of the villages directly facing the Indian Ocean so that Karangbenda Village has a high risk of a tsunami disaster. This is based on the tsunami risk map published by GITEWS (German-Indonesia Cooperation for Tsunami Early Warning System) as shown in the Figure 1.
Figure 1. Research sites

This research was conducted in July 2019, primary data in this study were obtained through focus group discussions (FGD) and field surveys, while secondary data was obtained from related institutions, namely the Geospatial Information Agency (BIG). The population in this study were the people of Karangbenda Village, the samples were determined using a purposive sampling technique, namely the Karangbenda Village Government, Karangtaruna, PKK, and Community-Based Disaster Preparedness Groups (SIBAT). The series of research activities are described in the following table:

| No. | Activity                                             | Date              |
|-----|------------------------------------------------------|-------------------|
| 1   | Introducing mapping ideas                           | July 4-6, 2019    |
| 2   | Mapping training for the community (mapping team)    | July 10, 2019     |
| 3   | Field survey                                        | Juli, 12-22 2019  |
| 4   | focus group discussion (FGD) determination of tsunami evacuation routes | July 23, 2019 |
| 5   | Make the final map                                  | July 23, 2019     |
| 7   | focus group discussion (FGD) for map validation      | July 30, 2019     |

The FGD process is intended to discuss tsunami evacuation routes where the evacuation movement includes at least the destination or location of the evacuation, route of travel, and evacuation mode [13]. The variables in this study are the suitability of the evacuation route and the effectiveness of the evacuation route. The
suitability of the evacuation route consists of the suitability of the tsunami evacuation location and the tsunami evacuation route, in this case, the evacuation routes prepared by the community are compared with the evacuation location criteria shown in Table 2 as follows:

| Criteria        | Parameter                                                                 |
|-----------------|---------------------------------------------------------------------------|
| Distance to River| Not in the tsunami-affected area based on the tsunami model               |
| Distance to beach| Not in the tsunami-affected area based on the tsunami model               |
| Elevation       | Not in the tsunami-affected area based on the tsunami model               |
| Slope           | Less than 20°                                                             |
| Extensive       | Adequate to accommodate the number of refugees assuming the need for refugee space, namely 1 m$^2$.|

Sources: [6], [7]

Whereas for the evacuation route compared to the shortest evacuation route obtained using geographic information system (GIS) technology, the geographic information system in recent years has grown to become increasingly important with its varied uses, especially for evacuation [16]. The information system technology used in this research is network analysis, namely the route function in the ArcGIS application which uses the Dijkstra algorithm to determine the best route from one point to another based on travel time. [17]. Then to test the effectiveness level of the tsunami evacuation route using network analysis, namely the service area function. The service area is an analysis to determine the area that can be served by a location in the road network [18]. Service area analysis in this study is used to model the evacuation time with 5-minute intervals, tsunami early warning takes 5 minutes. [19], then the tsunami evacuation route is considered safe if it does not exceed 5 - 25 minutes after the tsunami occurs. Assuming the speed for a tsunami evacuation is 1 meter/second [20], then used modeling the maximum distance from the evacuation site, namely 1,400 meters.

3. Result and Discussion

The determination of the tsunami evacuation route was accommodated in the FGD activity on July 23, 2019, which took place at the Karangbenda Village Hall. This activity was attended by community components consisting of the Village Government, PKK, Karangtaruna, SIBAT, and involved related agencies, namely BPBD Cilacap Regency and PMI Cilacap Regency. The results of the FGDs are the tsunami evacuation locations for each neighborhood (RT) that shown in Table 2.
Figure 2. Focus Group Discussion on Determining Tsunami Evacuation Route in Karangbenda Village

Table 3. The location for the Evacuation of Karangbenda Village agreed by the community Through the Activities of Focus Group Discussion

| Dusun     | RT  | Evacuation Location | Dusun     | RT  | Evacuation Location       |
|-----------|-----|---------------------|-----------|-----|---------------------------|
| Karangbenda | 01  | Sumur Windu         | Babukan   | 01  | Selok Hill (Bridge 1)     |
|           | 02  | Sumur Windu         |           | 02  | Selok Hill (Bridge 1)     |
|           | 03  | Gili Jaran          |           | 03  | Selok Hill (Bridge 1)     |
|           | 04  | Gili Jaran          |           | 04  | Selok Hill (Bridge 1)     |
|           | 05  | Sumur Windu         | Sodong    | 01  | Mandara Giri Temple courtyard |
| Congot    | 01  | Gili Jaran          |           | 02  | Mandara Giri Temple courtyard |
|           | 02  | Gili Jaran          |           | 03  | Mandara Giri Temple courtyard |
|           | 03  | Gili Jaran          |           | 04  | Mandara Giri Temple courtyard |
|           | 04  | SD 1 Karangbenda    |           |     |                           |
|           | 05  | SD 1 Karangbenda    |           |     |                           |

Then the evacuation location is compared with the indicators and parameters of the tsunami evacuation location as follows:

Table 4. Suitability of the Evacuation Location Determined by the Community with Evacuation Location Criteria

| Evacuation Location | Distance to River (m) | Distance to Beach (m) | Elevatio n (m) | Slope (°) | Capacity (1 m²/person) | Capacity (0.25 m²/person) | Number of Refugees (jiwa) | Information |
|---------------------|-----------------------|------------------------|----------------|----------|-------------------------|---------------------------|---------------------------|-------------|
| Gili Jaran          | 520                   | 1.628                  | 16.8           | 1        | 972                     | 3.890                     | 930                       | suitable    |
| Sumur Windu         | 636                   | 1.687                  | 19.1           | 2        | 3.126                   | 12.507                    | 594                       | suitable    |
| SD N Karangbenda 1  | 997                   | 1.654                  | 11             | 4        | 298                     | 1.195                     | 320                       | suitable    |
| Mandara Giri Temple courtyard | 1.453         | 1.324                  | 15             | 8        | 6.053                   | 24.213                    | 1.751                     | suitable    |
| Bridge 1            | 1.320                 | 1.300                  | 34.3           | 9        | 475                     | 1.901                     | 739                       | suitable    |
The table above shows that the tsunami evacuation location determined by the community is following the tsunami evacuation location criteria. The community has also determined an evacuation route that is described in paper media, the route is then compared with the results of the analysis of the shortest route to the evacuation location obtained through the route function in the network analysis which is shown in Figure 3 as follows:

![Figure 3. Sketches of Tsunami Evacuation Routes Prepared by Communities (a) and Evacuation Route Map obtained through network analysis (b)](image)

The image above shows the same evacuation route which shows the same result which shows that the community can determine the evacuation route well. Then for the analysis of the effectiveness level of the tsunami evacuation route is shown in Figure 4. From Figure 4 it can be seen that the number of people who can evacuate with the following evacuation time:

| Total Population Based on Evacuation Time Intervals | Number | Evacuation Time | Accumulated Population by Time of Evacuation | Effectivity |
|---------------------------------------------------|--------|-----------------|---------------------------------------------|-------------|
| 0 - 5                                             | 226 person | 5 minutes       | 226 person                                  | 7.41 %      |
| 5 - 10                                            | 778 person | 10 minutes      | 1.004 person                                | 32.91 %     |
| 10 – 15                                           | 1.417 person | 15 minutes     | 2.421 person                                | 79.35 %     |
| 15 – 20                                           | 439 person | 20 minutes      | 2.860 person                                | 93.74 %     |
| 20 – 25                                           | 155 person | 25 minutes      | 3.015 person                                | 98.82 %     |
| > 25                                              | 36 person | > 25 minutes    | 3.051 person                                | 100 %       |

From the data above, it can be seen that the effectiveness level of the tsunami evacuation route in a period of 25 minutes is 98.82% where there are some people who cannot reach the evacuation location within the specified period of time totaling 36 people, which are known to be in the area of Dusun Congot precisely in RT 02 / RW 02.
Figure 4. Tsunami Evacuation Route Map from Karangbenda Village Network Analysis

From the results above, it can be seen that participatory mapping activities through FGD activities can be an effective method for extracting information from village communities, information stored in community mental maps can be written in the form of informative maps, besides that FGD activities can be a forum to bring stakeholders together in the community, this is the government and local communities, so that disaster management policies do not only focus on top-down policies, as explained by Gaillard et. al [21] that participatory mapping can also be used to integrate the capacities of people of different castes, government, scientists, and community organizations in disaster risk reduction.

4. Conclusion
The conclusion obtained from this research is that the people of Karangbenda Village can develop a good tsunami evacuation route, seen from its suitability with the criteria for the evacuation location and evacuation route using network analysis. The evacuation route that has been agreed upon by the community has an effective level of 98.82%, this is obtained through service area analysis, although there are people who cannot go through the tsunami evacuation route within the specified time.

Acknowledgement
The author gives thanks to the people of Karangbenda Village who have been willing to play an active role in research activities and also to the Cilacap Regency BPBD and Cilacap Regency PMI for their cooperation in preparing the evacuation route map for Karangbenda Village.
Reference

[1] A. Hartoko, M. Helmi, M. Sukarno, and Hariyadi, “Spatial Tsunami Wave Modelling for the South Java Coastal Area, Indonesia,” *Int. J. Geomate*, vol. 11, pp. 2455–2460, Jan. 2016.

[2] Juhadi and M. Herlina, *Pendidikan Literasi Mitigasi Bencana Di Sekolah*. Kudus: Parist Penerbit, 2019.

[3] H. Latief, N. Puspito, and F. Imamura, “Tsunami Catalog and Zones in Indonesia,” *J. Nat. Disaster Sci.*, vol. 22, pp. 25–43, Jan. 2000.

[4] N. Parwanto and T. Oyama, “A Statistical Analysis and Comparison of Historical Earthquake and Tsunami Disasters in Japan and Indonesia,” *Int. J. Disaster Risk Reduct.*, vol. 7, Nov. 2013.

[5] F. Imamura et al., “Tsunami Disaster Mitigation by Integrating Comprehensive Countermeasures in Padang City, Indonesia,” *J. Disaster Res.*, vol. 7, Dec. 2011.

[6] Y. Yunarto and A. Sari, “Analysis of Community Tsunami Evacuation Time: An Overview,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 118, p. 12033, Feb. 2018.

[7] S. Harig et al., “The Tsunami Scenario Database of the Indonesia Tsunami Early Warning System (InaTEWS): Evolution of the Coverage and the Involved Modeling Approaches,” *Pure Appl. Geophys.*, vol. 177, no. 3, pp. 1379–1401, 2020.

[8] D. Mardiatno, M. Malawani, D. Wacano, and D. Ahmad, “Review on Tsunami Risk Reduction in Indonesia Based on Coastal and Settlement Typology,” *Indones. J. Geogr.*, vol. 49: 2, Dec. 2017.

[9] Juhadi, M. Hernila, E. Kurniawan, and E. Tryhatmoko, “Disaster Mitigation Learning Literacy Towards Earthquake And Tsunami Based On Lamban Langgakh Local Wisdom For Student At School,” *Int. J. GEOMATE*, 2019.

[10] A. Putra and H. Mutmainah, “The Mapping of Temporary Evacuation Site (TES) and Tsunami Evacuation Route in North Pagai Island, Mentawai Islands Regency - Indonesia,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 47, p. 12020, 2016.

[11] G. Brown and M. Kytä, “Key Issues and Priorities in Participatory Mapping: Toward Integration or Increased Specialization?,” *Appl. Geogr.*, vol. 95, pp. 1–8, 2018.

[12] J. R. D. Cadag and J. C. Gaillard, “Integrating Knowledge and Actions in Disaster Risk Reduction: The Contribution of Participatory Mapping,” *Area*, vol. 44, no. 1, pp. 100–109, 2012.

[13] F. Makinoshima, F. Imamura, and Y. Oishi, “Tsunami Evacuation Processes Based on Human Behaviour in Past Earthquakes and Tsunamis: A Literature Review,” *Prog. Disaster Sci.*, vol. 7, p. 100113, 2020.

[14] M. Mück, “Tsunami Evacuation Modelling. Development and Application of A Spatial Information System Supporting Tsunami Evacuation Planning in South-West Bali,” *Inst. für Geogr.*, vol. Degree in, p. 131, 2008.
[15] R. Fernando, B. Sujatmo, and A. Hendri, “Perencanaan Tempat Evakuasi Bencana Banjir Berbasis Teknologi Sistem Informasi Geografis (SIG),” *J. Online Mhs. FT UNRI*, pp. 1–9, 2017.

[16] A. Trindade, P. Teves-Costa, and C. Catita, “A GIS-based analysis of constraints on pedestrian tsunami evacuation routes: Cascais case study (Portugal),” *Nat. Hazards*, vol. 93, no. 1, pp. 169–185, 2018.

[17] S. Ahmed, R. Ibrahim, and H. Hefny, *GIS-Based Network Analysis for the Roads Network of the Greater Cairo Area*. 2017.

[18] S. M. H. Erfani, S. Danesh, S. M. Karrabi, R. Shad, and S. Nemati, “Using applied operations research and geographical information systems to evaluate effective factors in storage service of municipal solid waste management systems,” *Waste Manag.*, vol. 79, pp. 346–355, 2018.

[19] Masturyono, T. Hardy, P. Susilanto, W. Setyonegoro, D. Ngadmanto, and M. Madlazim, “DESAIN SISTEM PENENTUAN POTENSI TSUNAMI MENGGUNAKAN: RUPTURE DURATION (Tdur), TIME DOMINAN (Td) DAN T50EX,” *Pros. BMKG*, May 2013.

[20] Sea Defence Consultan, *Pedoman Perencanaan Pengungsian Tsunami (Tsunami Refuge Planning)*. Nias: Sea Defence Consultan, 2007.

[21] J. C. Gaillard *et al.*, “Participatory 3-Dimension Mapping: A Tool for Encouraging Multi-caste Collaboration to Climate Change Adaptation and Disaster Risk Reduction,” *Appl. Geogr.*, vol. 45, no. December, pp. 158–166, 2013.