Tsunami preparedness and environmental vulnerability analysis in Kukup Beach, Gunungkidul, Indonesia

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Abstract. The coastal area of Gunungkidul Regency directly faces the subduction zone in the Indian Ocean that includes one of the nine seismic gaps in Indonesia. This location has a history, and the possibility, of tsunamis with a large magnitude. This study aimed to analyze the community preparedness and the environmental vulnerability to tsunami hazard in Kukup Beach, Gunungkidul Regency. The preparedness was measured from the presence of early warning installations, information boards about hazards on site, publicly displayed maps of the area, self-rescue facilities in case of disasters, and education related to tsunami risk reduction. Meanwhile, the environmental vulnerability was determined by the presence of evacuation instructions, evacuation access, resources for evacuation, the condition of evacuation route, topographical characteristics, and emergency-related environmental conditions. All of these data were acquired from in-depth interviews and field observation on related environmental conditions. The results of the analysis indicated that the level of community preparedness in the study area was high, accompanied by the low environmental vulnerability.

1. Introduction
Tsuni is a disaster with a massive and widespread devastating impact [1, 2, 3]. Since the 2004 tsunami in Aceh, the attention to this disaster has increased dramatically [4]. This condition is visible not only in the growing number of people who are aware of it but also in the increasing number of scientific and popular writing in various forms of publication. The 2004 tsunami event also leads to the establishment of the National Disaster Management Agency (Badan Nasional Penanggulangan Bencana–BNPB) and an act on disaster management, which was realized in 2007 (Act No. 24/2007).

Part of Indonesia that has a high susceptibility to tsunami disaster is the coastal areas facing the subduction zone on the south of Java Island [5, 6]. This subduction zone is formed by the meeting of the Eurasian Plate and the Indo-Australian Plate [7]. The mass of the Indo-Australian Plate has a lighter density that makes it move under the Eurasian Plate, which has a higher density. The active collision of the two plates causes a frequent occurrence of earthquakes. Several events of earthquakes cause plate deformation and trigger tsunamis [8].

Earthquakes in the southern Java Island are known to have caused nine tsunamis since 1926 [9, 10, 11]. The last incident occurred in 2006 and caused considerable damage at Pangandaran Beach, West Java [12, 13]. The southern part of Central Java Province and the Special Region of Yogyakarta is one
of the nine seismic gaps in Indonesia [3, 14, 15]. This area is predicted to experience a potential earthquake with a large magnitude and possible tsunami disaster [16, 17].

Disaster risk reduction in coastal area is part of coastal area management [18, 19]. This management has to view a coastal area as at least four entities, namely [20]:

1) as a geographical area where natural terrestrial and marine processes interact;
2) as a center of economic activity that utilizes regional coastal and marine resources;
3) as a sociocultural entity with specific traditions and values; and
4) as an institutional entity with territorial boundaries.

Coastal area management, therefore, cannot accentuate one entity only. The Canadian International Development Agency [21] explains that the main problem leading to a failed coastal area management is the exclusion of social aspect, particularly regarding the local community involvement. This problem is strongly related to disaster management efforts in coastal areas where social element is part of disaster risk analysis [22, 23, 24]. The social aspects of a disaster are associated with community preparedness and vulnerability [25,26].

This study aimed to analyze the level of community preparedness and environmental vulnerability to the tsunami disaster in Kukup Beach, Gunungkidul Regency. This region is one of many areas are prone to tsunamis because the coastal typology is mainly marine deposition coast [3, 27]. Moreover, the land utilized primarily for shops and settlements occupies flat cockpit karst (karst alluvial plain), which increases the risk of tsunami disaster [10].

2. Methods
The data required for preparedness assessment consisted of the presence of the presence of early warning installations, information boards about hazards on site, publicly displayed maps of the area, self-rescue facilities in case of disasters, and education related to tsunami risk reduction. Meanwhile, the environmental vulnerability was measured with the presence of evacuation instructions, evacuation access, resources for evacuation, the condition of evacuation route, topographical characteristics, and emergency-related environmental conditions. These data were obtained from field observations and in-depth interviews with community leaders, angler communities, search and rescue (SAR) officers, groups of traders and tourists. The evaluation and planning of evacuation route used the topographic map of the study area and field survey, which focused on the access in the study area.

3. Results and Discussion
3.1. Community Preparedness for Tsunamis
The communities in Kukup Beach are sufficiently prepared for tsunamis. They are provided with frequent knowledge dissemination and simulation organized by the Regional Disaster Management Agency (Badan Penanggulangan Bencana Daerah–BPBD) of Gunungkidul Regency every twenty days. This government intervention significantly increases the knowledge of the public about tsunamis. The adequate preparedness also appears in the large quantity of media informing both communities and tourists about tsunamis, for instance, tsunami susceptibility maps posted on the walls of food stalls (Figure 1), maps displayed in strategic locations (Figure 2), information boards providing the characteristics of coastal region (Figure 3), and evacuation route signs (Figure 4).
Figure 1. An Information Board Plastered on the Wall of a Food Stall Displaying Tsunami Susceptibility Map

Figure 2. A Board of Tsunami Susceptibility Map Installed on the Side of the Main Road in Kukup Beach
Figure 3. A Noticeboard Displaying the Characteristics of Kukup Beach, Installed on an Open Space for a Better Visibility

Figure 4. Tsunami Evacuation Route Signs on the Main Road in Kukup Beach
3.2. The Environmental Vulnerability to Tsunami Hazards

Even though the local community is highly aware of tsunamis, the study area still has a low environmental vulnerability. This situation is evident from the assembly points that are located very far from the beach, the narrow road for evacuation, the absence of evacuation route to the nearest hills, hill cutting for stalls and lodgings development, and the poor layout of the stalls. The assembly point is on Kukup-Baron Road, which is far from the study area (about 1 km). The road leading to it has different paths located on a karst alluvial plain, which is dangerous because tsunamis will propagate when passing through this landform. The narrow paths likely complicate the evacuation process when a tsunami occurs (Figure 5). Hill cutting for the construction of shops and lodgings not only makes the hills covered with buildings but also destroys the access road to the hilltop. It also creates a very steep and vertical slope (Figure 6). Moreover, traders and visitors will have difficulty to evacuate during emergency cases because the shops and the food stalls in Kukup Beach are built with narrow exits (Figure 7).

![Figure 5](image1.png)

**Figure 5.** The Narrow Path and Stairways that May Complicate Evacuation Process During Tsunamis

![Figure 6](image2.png)

**Figure 6.** Hill Cutting Creating a Vertical Slope and Destroying Access to the Hilltop
Figure 7. The Layout of the Shops Including a Narrow Exit that Potentially Complicates Evacuation Process during Tsunami Events

3.3. Recommendations for Assembly Points and Evacuation Routes

The analyses of topographic and morphological conditions and tsunami heights in the past, along with the results of the field survey, formulated several potential locations for assembly points. The new assembly points were identified considering the shortcomings of the current ones, namely the very long distance of the first assembly point from the beach, the evacuation routes on long karst alluvial plain and a congestion-prone road, and minimal space for the assembly point. The proposed assembly points are located on the hilltop in the study area with a minimum height of 25 meters. The locations of the recommended assembly points and evacuation routes are presented in Figures 8, 9, and 10.

Figure 8. Potential Hills for Assembly Points in the Study Area Based on Heights and Locations
Figure 9. One of the Hills on the East of Kukup Beach That Can Function as an Assembly Point with Good Accessibility

Figure 10. Map Containing the Recommended Assembly Points and the Construction of New Evacuation Routes

3.4. Institutional Strengthening and Community Capacity Building to Tsunami Disaster
The results of the interviews showed the significant roles of the local people and the government agencies in building community capacity to deal with tsunamis in the study area. The simulation of tsunami events is performed at least every two months. Nevertheless, better simulations are needed to improve any shortcomings that may prevent effective evacuation and emergency response. The flaws include the assembly points that are located too far according to the authors’ observation and, as mentioned by the local people during the interviews, the simulations that have never reached the assembly points.

The interview results also depicted the community’s excellent knowledge of tsunami. Many information boards describe a variety of issues associated with this hazard. However, the locations of the current assembly points are not functional regarding accessibility, distance, and size. Moreover, the evacuation routes do not exist. Vehicles for evacuation and emergency response system for victims are not available. Besides, the SAR branch office and watchtower are located at Baron Beach, which is about 2 km from Kukup Beach.

4. Conclusions
The analysis results showed a high level of community preparedness and low environmental vulnerability. The community is sufficiently prepared for tsunamis, as evidenced by the presence of early warning system, routine training, and simulation, and information boards about susceptibility to tsunamis. Even though there are no SAR branch office and watchtower on Kukup Beach, there are SAR officers present in the study area. The low environmental vulnerability is caused by the far distance of the assembly point, the narrow and complicated evacuation routes, and difficult vertical evacuation due to hill cutting.

Acknowledgment
This research is part of a larger study entitled “The Integration of Unmanned Aerial Vehicle (UAV) Technology and GIS for Disaster Risk Detection in the Coastal Area of Gunungkidul Regency”, which receives funding from the Indonesian Ministry of Research, Technology and Higher Education under the scheme of Primary Higher Education Research Grant (Penelitian Unggulan Perguruan Tinggi-PUPT) 2018. Authors would like to express their gratitude for the financial support and assistance during the research.

References
[1] Bryant E 2008 Tsunami: The Underrated Hazard (Second Edition). (Chichester: Praxis Publishing).
[2] Triatmadja R 2010. Tsunami: Kejadian, Penjalaran, Daya Rusak dan Mitigasinya. (Yogyakarta: Gadjah Mada University Press).
[3] Marfai M A and Cahyadi A 2012 Kerentanan Wilayah Kepesisiran terhadap Tsunami di Yogyakarta, Analisis Regional dan Local Site Effect. Jurnal Spatial, 10(2) : 1-6.
[4] Subandono D and Budiman 2008 Hidup Akrab dengan Gempa dan Tsunami. (Bogor: Penerbit Buku Ilmiah Populer).
[5] Marfai M A Cahyadi A and Anggraini D N 2013 Tipologi, Dinamika dan Potensi Bencana di Pesisir Kawasan Karst Kabupaten Gunungkidul. Forum Geografi, 27(2) : 147 – 158.
[6] Marfai M A Sekaranom A B and Cahyadi A 2015 Profile of Notches in the Baron Coastal Area-Indonesia. Arabian Journal of Geoscience, 8(1) : 307-314.
[7] Verstappen H 2000 Outline of The Geomorphology of Indonesia. (Enschede: ITC).
[8] Liu Z Y C and Harris R A 2013 Discovery of Possible Mega-thrust Earthquake Along the Seram Trough from Records of 1629 Tsunami in Eastern Indonesian Region. Natural Hazards, Springer. DOI 10.1007/s11069-013-0597-y.
[9] Dewi R S and Dลบahrı 2009 Bencana Tsunami Parangtritis. In Sunarto, Marfai, M.A. and Mardiatno D (eds), Penaksiran Multirisiko Bencana di Wilayah Kepesisiran Parangtritis. Yogyakarta: Pusat Studi Bencana (PSBA) Universitas Gadjah Mada.
[10] Cahyadi A Afianita I Gamayanti P and Fauziyah S 2012 Evaluasi Tata Ruang Pesisir Sadeng Gunungkidul: Perspektif Pengurangan Risiko Bencana. Presented in Seminar Nasional Sustainable Culture, Architecture and Nature ke-3 Tahun 2012. Program Studi Arsitektur Fakultas Teknik Universitas Atma Jaya Yogyakarta, 15 May 2012.

[11] Hartoko A Helmi M Sukarno M and Hariyadi 2016 Spatial Tsunami Wave Modelling for The South Java Coastal Area, Indonesia. International Journal of Geomate, 11(25) : 2455-2460.

[12] Lavigne F Gomez C Gifo M Wassmer P Hoebreck C Mardiatno D Priyono J and Paris R 2007 Field observations of the 17 July 2006 Tsunami in Java. Natural Hazards and Earth System Sciences, 7(1) : 177–183.

[13] Okamoto T and Takenaka H 2009 Waveform inversion for slip distribution of the 2006 Java tsunami earthquake by using 2.5D finite-difference Green’s function. Earth Planets Space, 61:17-20.

[14] Adyan Ö 2008 Seismic and Tsunami Hazard Potentials in Indonesia with a special emphasis on Sumatra Island. Journal of The School of Marine Science and Technology, Tokai University, 6(3) : 19-38.

[15] Cahyadi A 2013 Kerawanan Tsunami di Wilayah Kepesisiran Kawasan Karst. Buletin Karst Gunungsewu, 2(1) : 1-5.

[16] Sunarto Marfai M A and Mardiatno D 2010 Multirisk assessment of Parangtritis Coastal Area. (Yogyakarta: Gadjah Mada University Press).

[17] Sutikno 2009 Indonesia Negeri 1001 Bencana. Presented in Seminar Sistem Informasi Kebencanaan Sebagai Sebuah Kearifan di Negeri 1001 Bencana. Environmental Geography Student Association (EGSA), Faculty of Geography, Universitas Gadjah Mada. Yogyakarta, 3-5 Desember 2009.

[18] Abelshausen B Vanwing T and Jacquet W 2015 Participatory Integrated Coastal Zone Management in Vietnam: Theory Versus Practice Case Study: Thua Thien Hue Province. Journal of Marine and Island Culture, 4 : 42–53.

[19] Bird E 2008 Coastal Geomorphology: An Introduction. (West Sussex: John Willey and Sons, Ltd).

[20] Dronkers J and de Vries I 1999 Integrated Coastal Management: The Challenge of Transdisciplinarity. Journal of Coastal Conservation, 5 : 97 – 102.

[21] CIDA 1995 Coastal Ecosystems, Environmental Screening of NGO Development Projects. (Hull, Quebec, Canada).

[22] Burkett V and Davidson M 2012 Coastal Impacts, Adaptation and Vulnerabilities. (Washington: Island Press).

[23] Cahyadi A 2013 Krisis Identitas, Putusnya Estafet Kearifan Lokal dan Peningkatan Risiko Bencana. In Marfai, M.A. and Widyastuti, M. 2013. Pengelolaan Lingkungan Zamrud Khatulistiwa. (Yogyakarta: Pintal), pp. 114 – 118.

[24] Ellis J T and Sherman D J 2015 Perspectives on Coastal and Marine Hazards and Disasters, in Shroder J F and Ellis J T (eds). 2015 Hazards and Disasters Series: Coastal and Marine Hazards, Risks and Disasters. (Amsterdam: Elsevier).

[25] Mathbor G M 1997 The Importance of Community Participation in Coastal Zone Management: a Bangladesh Perspective Community Development Journal, 32(2) : 124 – 132.

[26] Parvin G A Takahashi F and Shaw R 2008 Coastal Hazard and Community-coping Methods in Bangladesh. Journal of Coastal Conservation, 12 : 181 – 193.

[27] Marfai M.A Sunarto Khakhim N Cahyadi A Rosaji F S C Fatchurohman H and Wibowo Y A 2018 Topographic Data Acquisition in Tsunami-prone Coastal Area using Unmanned Aerial Vehicle (UAV). Earth and Environmental Science, 148. doi: 10.1088/1755-1315/148/1/012004