E3S Web of Conferences 447, 01015 (2023) https://doi.org/10.1051/e3sconf/202344701015
The 15th AIWEST-DR 2023

Tsunami Risk Assessment on Public Facilities in Southern Part of Bantul Regency, Yogyakarta

Acintya Nurmaya[1,*], *Pranoto* Suryo Herbanu[1], *Ratri* Ma'rifatun Nisaa'[2], *Azmiyatul* 'Arifati[3], *Randy* Alihusni Wardana[4], *Sahid*[5], *Reosa* Andika Firmansyah[6], and *Fatah* Yogo Yudhanti[7]

[1]Department of Disaster Management, Politeknik Akbara, Jl. Sumbing Raya, Mojosongo, Jebres, Surakarta 57127
[2]Research Center for Ecology and Ethnobiology, National Research and Innovation Agency, Jl. Raya Jakarta-Bogor KM. 46, Cibinong, Bogor 16911
[3]Department of Land and Spatial Planning Sleman, Jl. Magelang No.10, Bangun Rejo, Tridadi, Sleman, Sleman Regency, Special Region of Yogyakarta 55511
[4]Blue Seed Indonesia, Jalan Poros Maros - Makassar KM.25, Taraoda, Turikale 90511, Kab. Maros, Sulawesi Selatan, Indonesia
[5]Department of Infrastructure Technology and Regional Development, Institut Teknologi Sumatera, Jl. Terusan Ryacudu, Way Huwi, Kec. Jati Agung, Kabupaten Lampung Selatan, Lampung 35365
[6]Department of Environmental Engineering, Akademi Teknik Tirta Wiyata, Jl. Duku I No 54 Perumahan Korpri ABRI Kramat Selatan
[7]Regional Agency for Disaster Management of Bantul Regency, Jl. KH. Wachid Hasyim, Sumuran, Palbapang, Bantul, D.I. Yogyakarta 55714.

Abstract. The southern part of Java Island is susceptible to tsunamis as its role as a subduction zone between Indo-Australian and Eurasian plates. On July 17, 2006, a tsunami struck Java's south coast triggered by an earthquake and affected more than 300 km of shoreline, as well as claimed more than 730 casualties. It is important to assess the risk in the southern part of Java. This research aims to analyze tsunami risk assessments on public facilities in the southern part of Bantul Regency, Yogyakarta. The Tsunami hazard map was created by using tsunami modeling from BMKG. Public facilities footprint such as health facilities, religious facilities and school were derived from data provided by Open Street Map (OSM). The Papathoma Tsunami Vulnerability Assessment (PTVA) model, specifically developed to estimate the relative vulnerability of buildings to tsunami hazards, is used to generate a building vulnerability map. A geographic information system (GIS) was utilized to calculate and visualize the hazard, vulnerability, and risk map. A total of 394 buildings were analyzed with the results that public facilities in three sub-districts, namely Srandakan, Sanden and Kretek, had varying levels of building vulnerability ranging from minor, moderate, average and high with RVI values ranging from 1.5 to 3.4. Additionally, tsunami risk assessment of public facilities indicates that buildings within Bantul Regency are categorized as having very high, high, moderate, or low levels of building risk.

1 Introduction

The southern coast of Java Island is highly susceptible to tsunamis triggered by earthquakes [1,2]. Earthquakes stemming from the interaction between the Indian-Australian oceanic crust and the Eurasian continental crust have the potential to generate tsunami waves exceeding 30 meters in height [3]. This poses a significant threat to the residents of Java's southern coast, impacting their lives, properties, economy, and environment [4,5].

The significant loss of life and destruction of property caused by the tsunami underscores the importance of having a comprehensive system for monitoring and evaluating hazards [5]. On July 17, 2006, an earthquake-triggered tsunami hit the south coast of Java, impacting over 300 km of shoreline and resulting in over 730 casualties [1,6]. One of the upcoming challenges will be enhancing tsunami risk assessment and modeling techniques. Mardiatno [4] introduced the calculation of the future tsunami risk potential in the Pangandaran coastal area due to the growth of tourism, which can lead to a higher concentration of the element at risk especially for building development. Furthermore, the tsunami inundation map can be developed by using high-resolution spatial data [7] and Probabilistic Tsunami Hazard Assessment (PTHA) [3].

Assessing the risk associated with public facilities as an element at risk is essential. In the event of a disaster, public facilities serve as locations for tsunami evacuation [8] and collection points or shelters [9,10]. Public facilities are also utilized as temporary, vertical and final evacuation places [11]. It is imperative to undertake a range of measures to mitigate these risks and effectively reduce the level of risks posed by the tsunami disaster through public facilities. Therefore, this study aims to assess tsunami risk on public facilities in the southern part of Bantul Regency, Yogyakarta.

*Corresponding author: acintyan@gmail.com

2 Method

2.1 Research location

The research was carried out in the Bantul Regency, located in the Special Region of Yogyakarta, Indonesia, encompassing three sub-districts: Srandakan, Sanden, and Kretek (see Figure 1). These sub-districts are situated in a region prone to tsunamis, as they directly face the Indian Ocean and have implemented the Tsunami Early Warning System [12]. The combined population of Srandakan, Sanden, and Kretek sub-districts is 30,631, 33,968, and 30,317, respectively. These areas boast significant tourism potential, particularly due to their beautiful beaches. Notably, Kretek sub-district stands out for its unique landscapes, featuring stunning sand dunes.

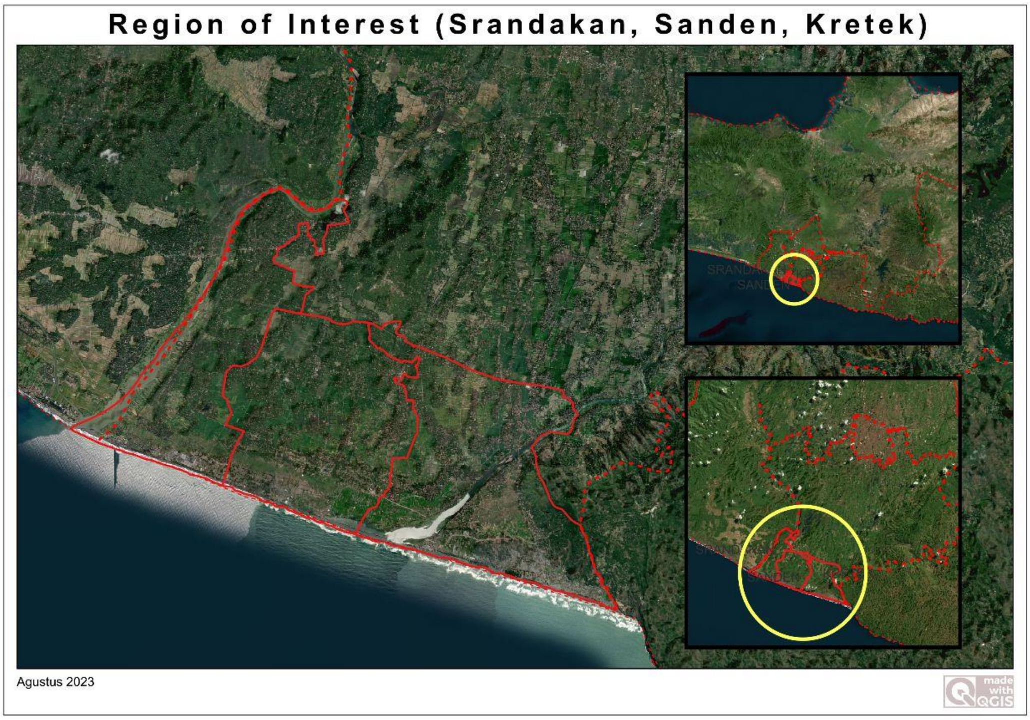

Fig. 1. Research Location

2.2 Data collection

The tsunami hazard map in the southern region of Bantul was obtained from the Indonesian Meteorological, Climatological, and Geophysical Agency. This map is generated by modeling a tsunami resulting from an earthquake with a potential maximum magnitude of Mw8.8 [11]. Additionally, the building footprints were derived from data provided by Open Street Map (OSM). Our research focuses on three specific types of public facilities: schools, health facilities, and religious establishments. To gather building characteristics, we conducted on-site surveys supplemented by Google Satellite and Google Street View analyses.

2.3 Tsunami vulnerability assessment

The Papathoma Tsunami Vulnerability Assessment (PTVA) model is specifically designed to estimate the relative vulnerability of buildings to tsunami hazards. For our research, we utilized the revised PTVA-4 version, developed by Dall'Osso et al. [13]. The PTVA-4 was chosen for its comprehensive consideration of various parameters in determining the relative vulnerability of each building, as illustrated in Figure 2. The model calculates a numerical index for each building, known as the Relative Vulnerability Index (RVI), which ranges from 1 (minor) to 5 (very high) [14,15]. This index serves as a vital tool in assessing the potential impact of tsunamis on different buildings.

2.4 Risk assessment of public facility buildings

The risk map of public facility buildings is derived from the combination of hazard and vulnerability maps, as following formula.

$$Risk = Hazard * Vulnerability \qquad (1)$$

The hazard and vulnerability maps are reclassified on a scale of 1 to 4 for the hazard map and 1 to 4 for the vulnerability map. The hazard and vulnerability maps are then overlaid using the raster calculator tool in GIS software. The risk map is classified into four classes: low, moderate, high, and very high.

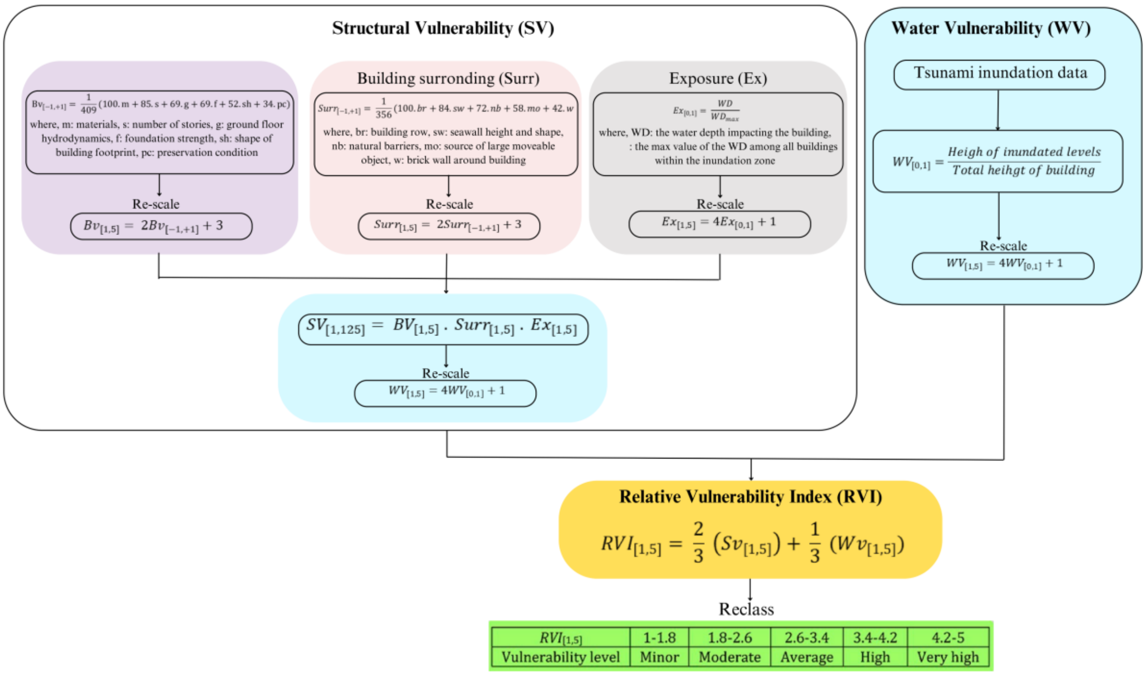

Fig. 2. PTVA-4 Model framework [13]

3 Results and Discussion

3.1 Tsunami hazard scenario

The tsunami hazard map used as the basis for the scenario in this paper resulted from tsunami modeling conducted by BMKG in 2022. The model was derived from an 8.8 Mw megathrust earthquake predicted to occur off the south coast of Daerah Istimewa Yogyakarta. Such an earthquake could potentially generate a tsunami with a maximum height of 18-22 meters and an estimated arrival time of 37-41 minutes in three sub-districts within Bantul Regency : Srandakan, Sanden, and Kretek [11]. If compared to the surrounding regencies, such as Kulonprogo and Gunungkidul Regency, there is no difference in the height level of tsunami in those three regencies. However, there is a slight difference in arrival time between those regions which might be caused by the slight difference in modelling input parameters, such as bathymetry, topography, administrative boundaries, and land cover data. Tsunami is predicted to arrive 1-2 minutes faster on the south coast of Bantul.

3.2 Building vulnerability on public facilities

A total of 394 public facility buildings were analyzed, comprising 337 school buildings, 7 healthcare facilities, and 50 religious facilities. Among these, schools had the highest number of buildings, with 179 elementary schools, 85 middle schools, and 73 high schools, including both public and private institutions. The healthcare facilities consisted of community health centers (Puskesmas) and privately managed clinics. Additionally, all religious facilities were places of worship for muslims, including mosques and mushola.

Relative vulnerability index (RVI), a non-dimentional score, is used to descibe the relative vulnerability level of a building [13]. The RVI scores are classified based on [14,15] classification. A majority (58%) of public facility buildings fall under the category of moderate vulnerability (Figure 3). In addition, the study location has four classes of building vulnerability to tsunamis: minor (RVI 1 – 1.8), moderate (RVI 1.8 – 2.6), average (RVI 2.6 – 3.4), and high (3.4 – 4.2) (Figure 2).

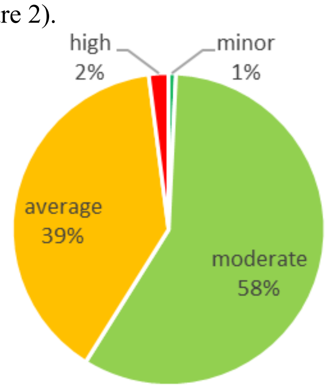

Fig. 3. The percentage of building vuleravility assessment

Table 1. Building vulnerability assessment

Public facilities	Vulnerability level				Total building
	Minor (RVI < 1.8)	Moderate (RVI 1.8 - 2.6)	Average (RVI 2.6 - 3.4)	High (RVI > 3.4)	
Health facility	1	5	1	0	7
Religious facility	0	43	7	0	50
School	2	181	146	8	337
Total Building	**3**	**229**	**154**	**8**	**394**

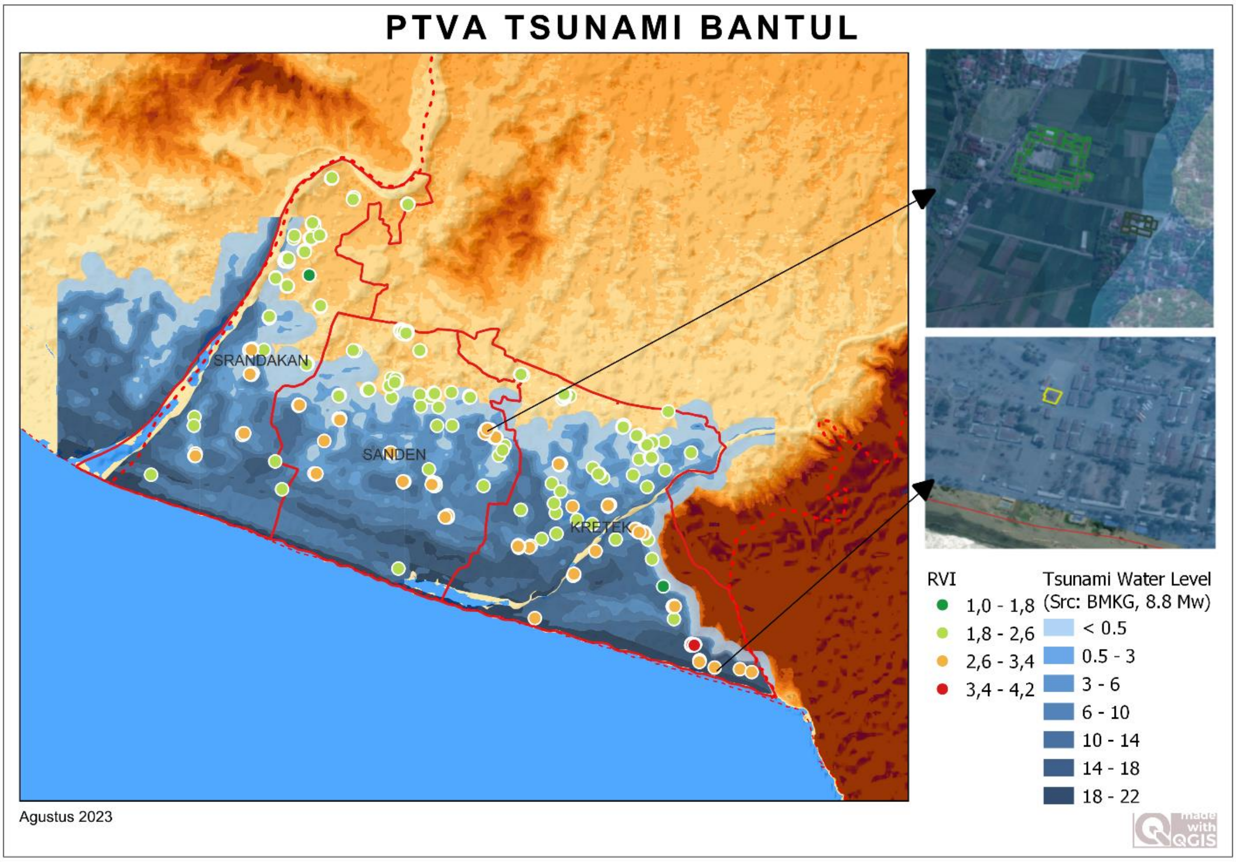

Fig. 4. The map of building vulnerability assessment based on PTVA-4 in Bantul Regency

Table 1 presents the vulnerability assessment of buildings within various public facilities. Among health facilities, there are a total of 7 buildings : 1 minor, 5 moderate, and 1 average in vulnerability. Religious facilities are categorized into 43 buildings with moderate vulnerability and 7 buildings with an average vulnerability. On the other hand, educational facilities have the highest building count, totaling 337. These buildings in educational facilities are further classified as 2 minor, 181 moderate, 146 average, and 8 high vulnerability buildings.

Building characteristics according to the PTVA-4 model vary across public facilities. Educational facilities, like schools, exhibit specific characteristics, including lengthened rectangular or complex-shaped buildings, brick or mansory material, single storey, and brick walls around the building with a height of 0–20% of the water depth. In contrast, religious facilities have their unique traits, featuring a 50% open plan for the ground floor hydrodynamics, and a squared building footprint. On the other hand, health facilities stand out with multiple storeys and reinforced concrete materials, providing enhanced structural strength.

Schools frequently serve as evacuation sites or tsunami shelters within public facilities [10]. Based on data from BMKG [11], there are several places that are used as temporary evacuation places if a tsunami occurs in Bantul Regency, Koripan Elementary School, Rojoniten Elementary School, and Tegalsari Elementary School. The three schools are categorized as having "average" building vulnerability, indicated by an RVI value of 2.8, making them highly suitable for temporary evacuation centers. The PTVA-4 model has also been applied in the coastal area of Batuhiu, Pangandaran Regency [16]. In this area, both school buildings and mosques are classified under the medium vulnerability, exhibiting RVI values ranging from 2.42 to 3.8.

Table 2. Potensial Tsunami Risk identification to public facilities

Sub-district	**Risk category**				**Total Building**
	Low	**Moderate**	**High**	**Very High**	
Srandakan	82	8	25	0	**125**
Sanden	77	13	64	0	**115**
Kretek	50	12	55	8	**125**
Total Building	**209**	**33**	**144**	**8**	**394**

3.3 Risk assessment

A GIS-based method utilizing spatial overlay analysis is employed to identify risk classes of public facility buildings while considering the potential tsunami hazard classes with relative vulnerability index (RVI) values. The risk assessment is conducted systematically, commencing with the identification of potential tsunami hazards based on wave height scenarios and distribution. The vulnerability of public facility buildings is analyzed using the PTVA-4 method. The identification of tsunami hazard potential distribution across three sub-districts is based on simulations of worst-case earthquake scenarios with an 8.8 Mw magnitude. It is well-known that the southern region of Java Island, particularly the studied area, holds significant earthquake potential due to the presence of a megathrust zone [17,18]. The earthquake hazard potential in the southern part of Java Island, especially in the studied area, falls into the category of shallow water earthquakes with depths ≤ 60 km [11]. The results of the worst-case scenario simulation indicate that the maximum tsunami wave height along the coastline reaches 22 meters. Overall, the simulation results reveal 7 hazard classes: <0.5 m, 0.5 – 3, 3 – 6, 6 – 10, 10 – 14, 14 – 18, 18 – 22 (Figure 4). Information regarding tsunami wave height and its distribution is employed as input in the PTVA-4 analysis for each building to obtain relative vulnerability index (RVI) values. Furthermore, this study illustrates that the tsunami's height presents varying risks, as depicted in the scenarios categorized as very high, high, moderate, and low building risks (see on Figure 5).

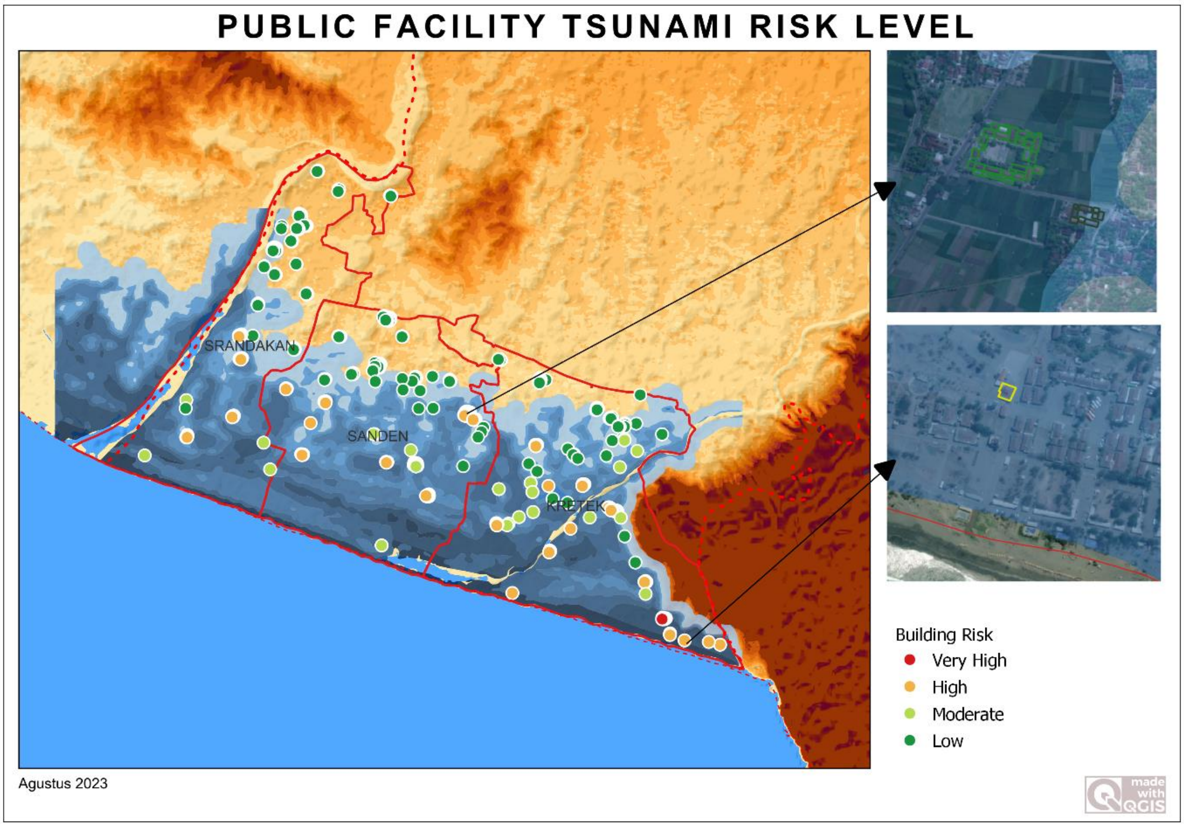

Fig. 5. Risk level of public facilitiy buildings

The risk assessment results provide an in-depth overview of the potential risks associated with each individual building in the event of a tsunami disaster. The classification of risk classes yields six risk categories, ranging from low to very high risk (Table 2). Based on the risk assessment outcomes, it is evident that in the Srandakan sub-district, the potential risks associated with each public facility building range from the low category to the high-risk category. In contrast, in the Sanden and Kretek sub-districts, there are buildings classified as high and even very high risk. As known, the risk level classification is based on the PTVA-4 assessment, considering the hazard levels of each building. The risk assessment in this study is based on three categories of buildings: helath facility, religious facility, and schools. The analysis of risk for these three building categories reveals that the majority of school buildings have risk values ranging from low to very high risk, whereas health facility only reach the moderate risk category (Figure 6). Among the school buildings, there is 8 buildings categorized as very high risk. This illustrates that certain school based on their structure, location, neighboring structures, and vulnerability to water contact, remain highly susceptible if a tsunami hazard occurs.

Corresponding author: acintyan@gmail.com

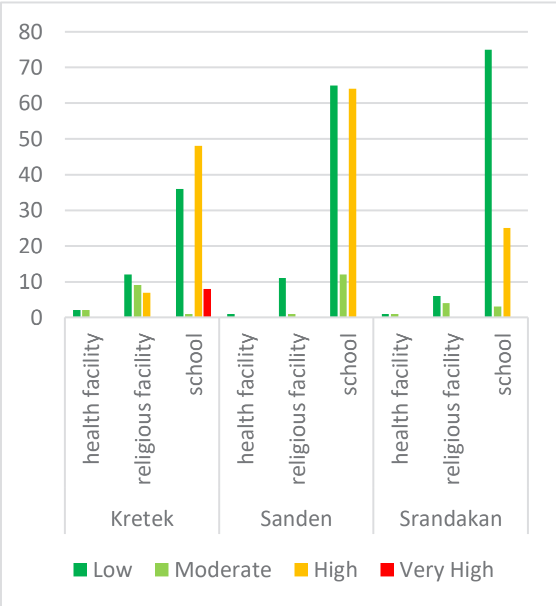

Fig. 6. Potensial tsunami risk identification to public facilities based on building categories

Understanding the potential risks associated with each type of building can greatly assist as a mitigation step to reduce the level of losses caused by disaster events. Buildings, in general, serve as potential shelters that could be chosen during a tsunami disaster. The application of criteria in building construction is crucial, particularly for structures located along coastal areas with high tsunami hazard levels. Indonesia, through government regulations, has established standards that can be used for constructing buildings. Regulations related to building codes in Indonesia have undergone improvements over the years, starting with the use of these regulations in 1970 and continuously being refined based on evaluations of building damage caused by disaster events [19]. The implementation of standard regulations such as SNI 03-1728-1989 for building construction procedures, SNI 1726-2019 for earthquake-resistant planning procedures for building and non-building structures, SNI 03-2847-1992 for minimum requirements for the use of Benton in buildings, and SNI 04-0225-2000 for general mechanisms of electrical installations in buildings are examples. Implementing these standards during the construction of a building can at least reduce the vulnerability of the structure, thus minimizing the associated risks of building damage and its consequences.

4 Conclusion

It is important to evaluating the risk assosiated with public facilitiy building toward tsunami disaster. Public facilities play critical roles not only for tsunami evacuation places but also for gahering point during a disaster event. Srandakan and Sanden sub-district has the potential risks associated with each public facility building that range from the low-risk category to the high-risk category. Additionally, the building in Kretek sub-districts, is classified as low and even very high risk. The potential risks can greatly assist as a mitigation to reduce the level of losses caused by tsunami. Srandakan, Sanden and Kretek sub-districts should be the priority on tsunami risk management, especially related to risk on public facilities.

References

1. S. Reese, W. J. Cousins, W. L. Power, N. G. Palmer, I. G. Tejakusuma, and S. Nugrahadi, Nat. Hazards Earth Syst. Sci. **7**, 573 (2007)
2. C. J. Ammon, H. Kanamori, T. Lay, and A. A. Velasco, Geophys. Res. Lett. **33**, L24308 (2006)
3. N. Horspool, I. Pranantyo, J. Griffin, H. Latief, D. H. Natawidjaja, W. Kongko, A. Cipta, B. Bustaman, S. D. Anugrah, and H. K. Thio, Nat. Hazards Earth Syst. Sci. **14**, 3105 (2014)
4. D. Mardiatno, M. N. Malawani, and R. M. Nisaa', Int. J. Disaster Risk Reduct. **46**, 101523 (2020)
5. M. A. Marfai, L. King, L. P. Singh, D. Mardiatno, J. Sartohadi, D. S. Hadmoko, and A. Dewi, Environ. Geol. **56**, 335 (2008)
6. F. Lavigne, C. Gomez, M. Giffo, P. Wassmer, C. Hoebreck, D. Mardiatno, J. Prioyono, and R. Paris, Nat. Hazards Earth Syst. Sci. **7**, 177 (2007)
7. Ibrahim, Syamsidik, Azmeri, M. Hasan, A. Irwansyah, and M. D. Al Farizi, Geoenvironmental Disasters **10**, 8 (2023)
8. R. Garside, D. Johnston, W. Saunders, and G. Leonard, Aust. J. Emerg. Manag. **24**, 28 (2009)
9. K. F. Doerner, W. J. Gutjahr, and P. C. Nolz, OR Spectr. **31**, 651 (2009)
10. F. Ashar, D. Amaratunga, and R. Haigh, Procedia Eng. **212**, 109 (2018)
11. BMKG, *Peta Bahaya Tsunami Daerah Istimewa Yogyakarta (Menggunakan Skenario 8,8Mw)* (Stasiun Geofisika Kelas I Sleman, Sleman, 2022)
12. BPS, *Village Potential Statistics of Bantul Regency 2018* (CV. Lunar Media Sejahtera, Bantul, 2018)
13. F. Dall'Osso, D. Dominey-Howes, C. Tarbotton, S. Summerhayes, and G. Withycombe, Nat. Hazards **83**, 1229 (2016)
14. D.-V. Batzakis, L.-M. Misthos, G. Voulgaris, K. Tsanakas, M. Andreou, I. Tsodoulos, and E. Karymbalis, J. Mar. Sci. Eng. **8**, 886 (2020)
15. N. Sathiparan, J. Build. Eng. **27**, 100952 (2020)
16. R. M. Nisaa', J. Sartohadi, and D. Mardiatno, Maj. Ilm. Globe **21**, 79 (2019)

Corresponding author: acintyan@gmail.com

17. Y. Rizal, Aswan, Y. Zaim, W. D. Santoso, N. Rochim, Daryono, S. D. Anugrah, Wijayanto, I. Gunawan, T. Yatimantoro, Hidayanti, R. H. Rahayu, and Priyobudi, IOP Conf. Ser. Earth Environ. Sci. **71**, 012001 (2017)
18. S. Widiyantoro, E. Gunawan, A. Muhari, N. Rawlinson, J. Mori, N. R. Hanifa, S. Susilo, P. Supendi, H. A. Shiddiqi, A. D. Nugraha, and H. E. Putra, Sci. Rep. **10**, 15274 (2020)
19. W. O. Nugroho, A. Sagara, and I. Imran, Structures **41**, 1092 (2022)