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Optimizing Subnational Warning Mechanisms: Community and Practitioner Perspectives on the 2018 Anak Krakatau-Induced Tsunami in Pandeglang, Indonesia

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Abstract

To help optimize the tsunami warning system in Indonesia, particularly concerning non-seismically inducted tsunamis and at the subnational level, this study employs a qualitative methodology to draw lessons from the Anak Krakatau-induced tsunami on December 22, 2018. A total of 37 community members and 35 government officials in Pandeglang Regency and at the national level participated in in-depth interviews and focus group discussions. Participants emphasized bureaucratic mismatches and delays, underlining the urgent need for clearer national-subnational communication. The study presents concrete and actionable recommendations for refining warning reception, decision-making, legitimization processes and warning dissemination. Proposed changes such as diversifying information sources and localizing tsunami siren control aim to empower local entities and expedite responses, overall increasing community preparedness for future tsunami threats. By contrasting the experiences and recommendations of affected communities, local government and national-level actors, the study makes a case for improving warning systems based on the past experience and recommendations of the first concerned and first impacted.

Keywords: early warning system; non-seismically induced tsunami; local knowledge; Anak Krakatau volcano; InaTEWS.

Introduction

Tsunamis rank among the most destructive disasters, causing immense loss of life, natural, economic and other forms of damage. The Indonesia Tsunami Early Warning System (InaTEWS), instituted after the cataclysmic 2004 Indian Ocean tsunami and operating since 2008, was a major milestone to help prevent tsunami hazards from turning into disasters (BMKG, 2010; Spahn et al., 2014). However, constructing an effective warning system is a constant and intricate social process (Kelman and Glantz, 2014). It involves challenges such as bureaucratic hurdles and resource constraints, which are especially pronounced at the subnational level (Comfort et al., 2010). On the one hand, bureaucratic challenges often manifest as long procedural delays, inter-departmental communication gaps and a lack of streamlined decision-making processes. Administrative bottlenecks can critically delay the dissemination of timely warnings, sometimes leading to suboptimal disaster response (Rahayu et al., 2020). On the other hand, resource constraints encompass not only financial limitations but also shortages in trained staff, technology and infrastructural support. Such constraints can hamper comprehensive hazard monitoring, accurate detection, and efficient forecasting (United Nations International Strategy for Disaster Reduction - UNISDR, 2006).

Crucially, a human-centered and locally tailored warning system development approach is vital: one that not only addresses the potential disconnections between warning system components and actors (Garcia & Fearnley, 2012), but also one that adapts warning strategies based on past disaster experiences and recommendations as voiced by the first impacted. Community members often possess unique and context-specific understanding of

their environments and associated risks. Gaillard & Mercer (2013) argue that incorporating their knowledge into warning system design and operation can provide invaluable insights for risk communication strategies. In addition, Lauterjung et al. (2010) highlight the importance of including the perspectives of national-level institutions in developing effective tsunami warning systems. They advocate for a collaborative synergy between various agencies and actors.

In line with this literature, the present study contrasts the experiences and recommendations of affected communities, local government and national-level actors in the context of the 2018 Anak Krakatau-induced tsunami. By meticulously analyzing their perspectives, we seek to identify pivotal areas for enhancement that would enable more effective and efficient responses to future tsunami threats. The 2018 Anak Krakatau-induced tsunami revealed certain inadequacies in InaTEWS, especially its incapability to detect non-seismically induced tsunamis and inadequate readiness at the subnational level (Titov, 2021; Walter et al., 2019).

Methods

This study employed a qualitative approach. It combined a review of Pandeglang-specific literature related to historical disasters and existing policies and reports related to preparedness with primary data collected in the Pandeglang Regency between February and March 2023. Geographical focus was on communities in the Labuan district, as mapped in Figure 1. According to the National Disaster Management Agency (BNPB) (2018), Farahdita & Siagian (2020), and Solihuddin et al. (2020), Labuan district experienced significant impacts from the tsunami in terms of human casualties, damage to infrastructure and environment, and economic disruption. Before fieldwork, ethical approval was obtained from the National Research and Innovation Agency (BRIN). All data collected during the study was stored securely and any identifying information removed to maintain the anonymity of research participants.

This study utilized two distinct sampling techniques tailored to the unique characteristics and accessibility of our target groups, which are listed in Table 1. For the community group, snowball sampling allowed to reach a total of 37 individuals from the Labuan District, ultimately featuring residents, including survivors, from the villages of Teluk, Cibenda and Sukarame; members in both managing and volunteer functions from the Pandeglang disaster risk reduction forum and representatives of disaster preparedness village communities and Balawista (*Badan Penyelamat Wisata Tirta*) lifeguard members. By tapping into a network of few initial contacts, this method ensured a broader reach and the inclusion of varied community perspectives and actors considered relevant by their community peers. As visible from Table 1, gender balance remains a drawback. Meanwhile, purposive sampling was employed to reach the 35 research participants constituting the government group. This decision was driven by our intent to capture specific, knowledgeable representatives from relevant governmental bodies and agencies: officials from village and district offices in Labuan, the Local Disaster Management Agency (BPBD) of Pandeglang, staff from the Anak Krakatau volcano monitoring post, and Jakarta-based delegates from the BNPB and BMKG.

Table 1. Research Participant Overview.

Participant type	Female	Male	Interview Participant	FGD Participant
Residents without disaster-related community responsibilities	4	16	1	19
Community Disaster Preparedness Group members		3	1	3
Balawista members		9	2	9
Pandeglang DRR Forum members	4		1	4
Private Sector member working at the Tanjung Lesung resort		1	1	
Village Government officials (Teluk, Sukrame)	4	10	1	14
District Government officials (Labuan, Carita)	1	7	1	7
BPBD Pandeglang		8	7	1
PVMBG – Anak Krakatau Watch Post		1	1	
BMKG – Centre for Earthquake and Tsunami		3		3
BNPB – Directorate of Early Warning		1	1	
TOTAL: **72 participants**	13	59		

The first author conducted fieldwork between November 2022 and February 2023. He first explored the recollections of the community members and Pandeglang government staff concerning the December 22, 2018, tsunami. This allowed us to understand what the tsunami revealed in terms of warning procedures and preparedness, with the warning chain and decision-making process emerging as particularly relevant. Subsequent data collection focused on these same themes, gathering the perspectives of both the community and government members. Qualitative analysis was carried out using the atlas.ti software. Braun & Clarke's (2013) six-phase thematic analysis method allowed to familiarize with the data, generate initial codes, searching for themes, reviewing, defining and naming them, and finally, reporting. Throughout this process, data triangulation was utilized to cross-validate emergent themes between the community and government groups. This step was instrumental in enhancing the study's validity, ensuring that themes were not only internally consistent within groups but also coherent across them. It also allowed to pinpoint perception and prioritization differences between the various groups. Ultimately, primary data findings were combined with a review of the relevant policy and academic literature to provide recommendations on how to better integrate local knowledge, needs and capacities into Pandeglang tsunami warning chain.

Figure 1. Study locus (in green) in Pandeglang Regency. (Source: Authors).

Results

Analysis of the interviews, FGDs and grey literature points towards three main themes which would contribute to a more effective tsunami warning system for Pandeglang Regency: allocate more space for natural warning signs, addressing gaps to the warning system setup in Pandeglang, and tailor warning mechanism to local specificities, in particular the risk of non-seismically induced tsunamis.

Local Knowledge on Natural Warning Signs

During the interviews and FGDs held with community and local government members in Pandeglang, discussion on the December 2018 tsunami often focused on the natural warning signs concerning both the volcanic eruption and the impending tsunami.

Community narratives highlighted unique felt experiences associated with the 2018 eruption of Anak Krakatau. The community members had been accustomed to the frequent seismic activities of the volcano since childhood. However, the intensity and duration of the natural signs were distinct on the day of the 2018 eruption. For instance, one participant described a deviation from the norm: "…unusual, the vibration felt stronger and longer, lasting for around two minutes". Moreover, one participant from Teluk village government said that "the vibrations were more pronounced in the mountainous regions," indicating a geographical variance in the perception of these warning signs, which were felt particularly strongly by those residing in elevated or mountainous terrains. Witness accounts pointed to audible and visual signs. The explosion sound from the volcano, as one participant noted, was distinguishable from other natural sounds such as thunder and occurred irrespective of weather conditions. Observations of physical changes in the volcano were also reported. One participant recounted "…it was before *maghrib* (evening prayer), I saw the volcano spew fire sparks frequently and a plume of black smoke rising straight up," signaling its increased activity.

Later on, community members observed distinct natural signs relating to the tsunami onset. One significant indicator was the appearance of long white foam formation in the sea, reminiscent of a swimming duck as described by a FGD participant. Another resident recounted witnessing the seawater splash twice unexpectedly, followed by a tall spread of foam towards the sea that many initially mistook for clouds due to its height. Several

FDG testimonies highlighted a 'white screen-like formation in the sea'. The bright full moon accompanied by clear skies and calm weather enhanced the visibility of these signs, as further supported in a study by (Takabatake et al., 2019). "It was beautiful night; the full moon illuminated the ocean, and we could see the stars," one participant recalled. An unusual wind preceding the tsunami waves further intensified the evening's peculiar atmosphere.

When asked why they had not acted following these signs, research participants referred how, in the moment itself, the signs felt as 'ordinary' and frequently happening. The signs' distinct nature only became clear in hindsight, this was described by several community members as 'newly acquired local knowledge'.

The community's inherent understanding of these signs highlights the need to incorporate this knowledge into the existing warning systems, particularly for non-seismically induced tsunamis.

Warning system setup in Pandeglang and gaps in facing non-tectonic tsunamis

A draft document prepared by BPBD Pandeglang (2015) details the InaTEWS protocol in Pandeglang District. It outlines the delegation of evacuation decision making from the Regent to the Executive Head of BPBD Pandeglang. However, the delegation of evacuation decision-making to the Executive Head of BPBD Pandeglang, as outlined in the draft, is not straightforward. Because the draft has remained unratified since 2015 and the leadership of both the Regency and BPBD Pandeglang has changed over time, the protocol to evacuate requires (re)confirmation from the current Regent.

The 2018 tsunami highlighted the lack of timely post-event information dissemination, linked to the absence of early tsunami detection and consequent official warning from the TEWS. The immediate aftermath was marked by a palpable absence of clarifying information neither from the national and local government. An interview with a Balawista lifeguard emphasized the gravity of this delay. He recalled an argument with the Governor of Banten who remained reluctant to make a public announcement until receiving confirmation from BMKG, the authoritative agency for tsunami or high wave information. This hesitance starkly contrasted with the urgent pleas from several Balawista personnel, who had directly witnessed the tsunami's devastation, advocating for swift public communication. The Governor's response was "[n]o, if this is a tsunami, it should come from the BMKG—we should wait!". This underscored the critical need for government agencies to swiftly relay accurate post-event information.

As conveyed in their interview statements and as aligned with their mandate a stipulated in Presidential Regulation 93/2019, the Pandeglang BPBD primarily identifies itself as a conduit for warning services, as shown in Figure 2. Their main responsibilities are centered around the acquisition and distribution of data, alerts, and instructions from national and provincial entities. Additionally, they are tasked with disseminating information about disaster-prone areas, facilitating communication and education, and providing a 24/7 warning dissemination service.

The Pusdalops PB officials shared how they operate continuously, using the Warning Receiver System developed by BMKG, to monitor and receive warnings from the InaTEWS. Per procedure, as detailed in Pandeglang tsunami early warning system draft document (Kabupaten Pandeglang, 2015), they have to answer two critical questions following the receipt of a warning bulletin from BMKG: (1) 'does the earthquake have the potential to trigger a tsunami in the Pandeglang region' and (2) 'which areas within Pandeglang require evacuation'. However, according to a high-ranking Pusdalops PB official, "in reality, Pusdalops PB personnel often face challenges in conducting intricate analysis pertaining to earthquake information and tsunami early warnings." As a routine, they either pass on the information to the Executive Head of BPBD or disseminate (i.e., forward) the warning information via social media.

Concerning warning communication devices, the Pandeglang tsunami early warning system draft document (Kabupaten Pandeglang, 2015) and interviews revealed that the local BPBD office does not control the tsunami sirens. The two installed sirens, managed by the provincial BPBD office and the BMKG office in Jakarta, moreover have a limited reach along the 307 km coastline of the Pandeglang Regency. This leads to convoluted warning chains through which the entire coastal population cannot be reached. Although the Pusdalops PB warns through WhatsApp, radio communication, and telephone, community members indicated that for them, sirens were the most efficient and direct warning device, especially for tsunamis that occur without preceding earthquake tremors.

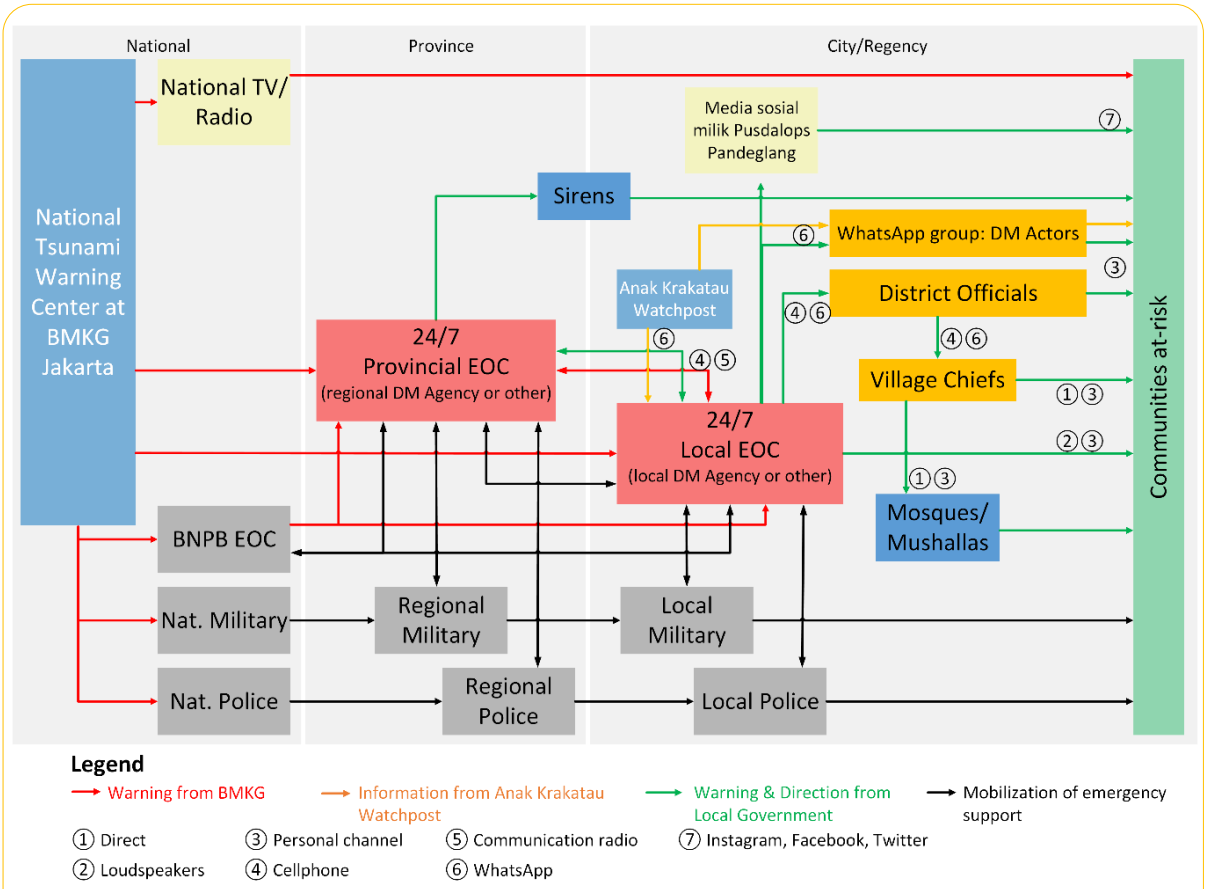

Figure 2. Tsunami warning chain in Pandeglang. (Source: modified from BMKG, 2013 based on participant interviews).

Optimizing the InaTEWS taking into account local specificities

Interviews and FGDs brought forward 29 main recommendations which can be categorized into 14 categories. The Sankey diagram on Figure 3 shows how often each recommendation was cited by which participant type, differentiating between the community and government group. The recommendation categories were clustered into three broader thematic groups which are now presented in more detail: (1) accurate and fast warning system, (2) better policy arrangements, and (3) capacity building.

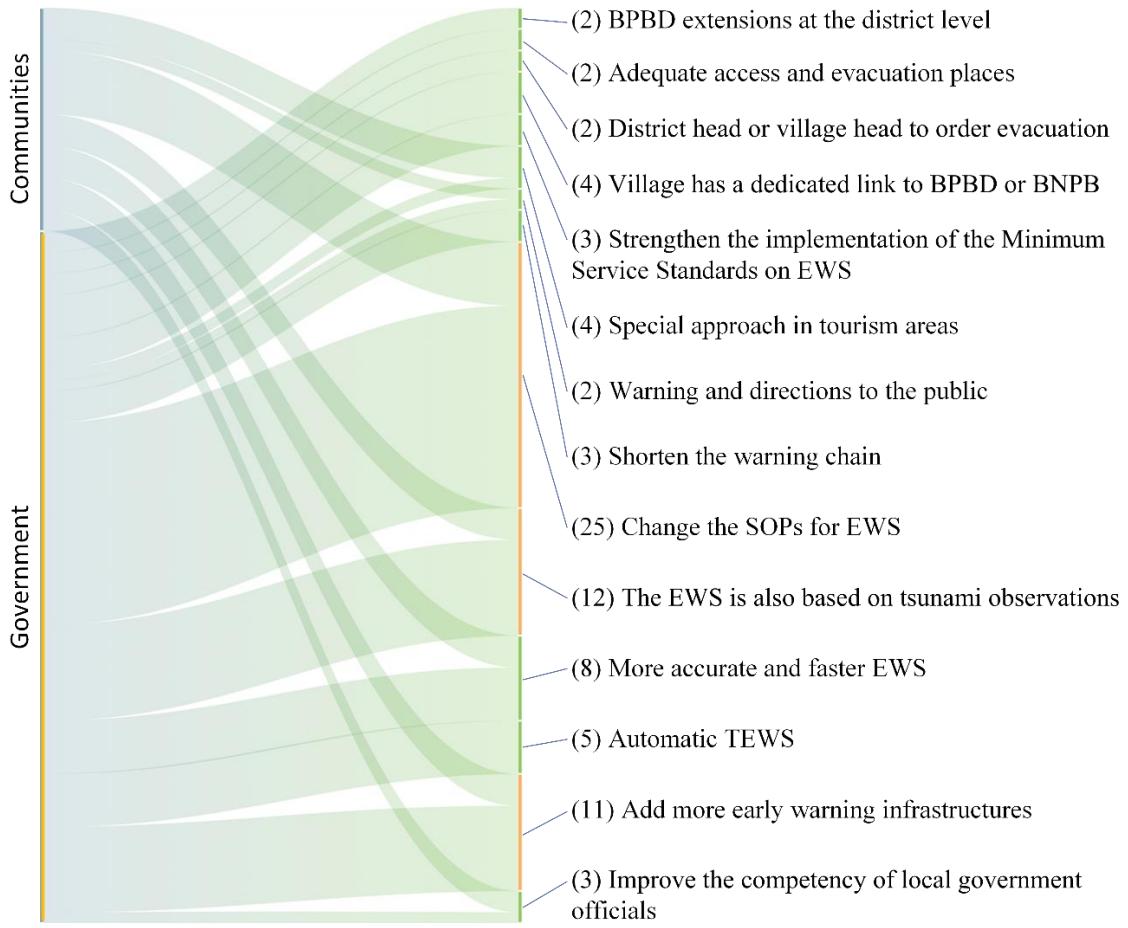

Figure 3. Sankey diagram of what the participants recommend to improve tsunami early warning services in Pandeglang (Source: Authors, 2023).

Accurate and Fast Warning System

In Labuan, all 37 community research participants agreed that accurate and timely tsunami warnings are essential in the face of multiple tsunami sources: earthquakes, Anak Krakatau eruptions, and submarine landslides. In slight contrast, participants from BNPB and BMKG emphasized the need for an early warning system that monitors tectonic earthquakes, Anak Krakatau volcanic activity, and sea surface changes to differentiate between tsunamis and high waves.

Based on the local government and community statements, the study recommends improving warning accuracy by granting district and village authorities as well as Disaster Risk Reduction Forum (DRR Forum) and Balawista access to data from sea level monitoring sensors, including the Inexpensive Device for Sea Level measurement (IDSL) and Closed-Circuit Television (CCTV) cameras installed in the Anak Krakatau complex. The Anak Krakatau Volcano Observation Post and BRIN should consider opening access to their sensor data for Pusdalops PB BPBD Pandeglang. This will ensure local governments have access to necessary data and information, even if the volcano and sea level monitoring systems are not yet optimally integrated into InaTEWS. An automatic early warning system based on sensor data has been found to potentially minimize misinformation and slow government response by activating sirens as a single command for evacuation. Additionally, the findings emphasize the importance of empowering local actors, such as fishers and Balawista personnel, to report or confirm potential

tsunamis based on natural signs or direct observations. This approach ensures that the community is not solely reliant on unprepared systems or insufficient personnel competence.

As long as the InaTEWS cannot integrate data from volcano monitoring and other anomalies that can potentially generate non-seismic tsunamis, local governments must have mechanisms to respond to these risks. While advanced analysis, such as differentiating between tsunami waves or wind-driven large waves requires specialized knowledge, there are simpler observational techniques that local units can adopt. Units operating 24/7, such as BPBD's Pusdalops, the local military office (Komando Rayon Militer/Koramil), local police office (Polisi Sektor/Polsek) in each district, and even coastal star-rated hotels, can be provided with access to monitor the data collected by sensors. These local units can undertake straightforward monitoring of Anak Krakatau's rapid morphological changes and the sea surface using CCTVs from both the Anak Krakatau observation post and those installed on IDSLs. However, to enhance accuracy and response times, it is crucial that these personnel receive foundational training from the equipment-owning agency.

In each village, the Pandeglang Regency government could rely on mosques and mushallas to relay tsunami warnings. Each mosque and mushallas must have outdoor loudspeakers which can be modified to enable remote activation from Pusdalops PB BPBD Pandeglang, sending siren tones and/or verbal announcements such as evacuation instructions or other important messages. This dissemination model has been tested in places such as Padang City, Bantul, Cilacap, and Kebumen (Usdianto et al., 2010).

The BNPB participant envisioned the potential of the Mass Notification Alert method, which is in use in countries like Japan and the United States. Through this method, mobile phones in at-risk areas continuously sound and display warning messages and guidance from the government. This approach could trigger early action from communities at risk, thereby reducing reliance solely on expensive tsunami sirens for procurement and operational purposes. These findings collectively underscore the need for multi-faceted, community-based solutions to improve the accuracy and speed of tsunami warnings in Pandeglang.

Better Policy Arrangements to Accommodate Non-seismically induced Tsunamis

The communities' lack of understanding regarding the potential of tsunami caused by other factors than tectonic earthquakes can lead to confusion in the warning process, inadequate response to warnings, and evacuation efforts. Referring to the Indonesian Disaster Management Law UU 24/2007, every effort in disaster management must be based on a disaster risk assessment. Therefore, policy development for disaster management, specifically for the tsunami early warning system, needs to start with a disaster risk assessment. The Pandeglang Regency disaster risk assessment document has expired since 2018. It needs to be updated or created new by adding threat scenarios of tsunamis induced by Anak Krakatau eruption and submarine landslides.

The new disaster risk assessment document becomes the basis for calculating the fulfillment of the Minimum Service Standards for disaster sub-sectors, as regulated in the Ministry of Home Affairs regulation 101/2018. The calculation to fulfill the minimum service standard then becomes the basis for formulating disaster management strategies and plans and becomes a basis for development planning and multi-stakeholder cooperations. According to an interview with BPBD Pandeglang official, the Pandeglang Regency received assistance from BNPB to conduct a disaster risk assessment and contingency plan for tsunami in 2023. This underscores the will for more attention towards non-seismically induced tsunamis and would make Pandeglang the first Regency in Indonesia to consider multi-sourced tsunami threats in their disaster management and tsunami early warning system specifically.

The areas exposed to tsunami hazards are tourist destinations, one of the leading sectors in Pandeglang Regency. Thus, the Pandeglang government must embrace tsunami preparedness efforts in its future tourism development plans. The approach taken by the Province of Bali in building preparedness in the tourism sector could serve as an example. For instance, members of the Bali Hotels Association prepare their hotels as temporary evacuation sites. Hotels will receive a 'Tsunami Ready' certificate if they meet checklist criteria from the Tsunami Ready Toolbox (Kesper, 2009), created specifically for the tourism industry in collaboration with the Ministry of Culture and Tourism in 2009.

The findings showed that the decision-making process and warning dissemination, as outlined in the draft Book III of the Pandeglang tsunami early warning system (Kabupaten Pandeglang, 2015), were seen as complex and lengthy by the BPBD research participants, even though they were never implemented as such. The current official process requires the analysis of warnings to be conveyed to the Executive Head of Pandeglang BPBD, and if approved, Pusdalops PB will follow up. However, if the Head cannot be contacted, the warning process is interrupted at Pusdalops PB. To minimize dependence and encourage accountability, it is suggested that the delegation of authority be given directly to Pusdalops PB for legitimizing the direction, ensuring that warnings do not depend on a single person. A modified warning chains to the draft Book III of the Pandeglang tsunami early warning system (Kabupaten Pandeglang, 2015) is proposed. The modification includes mechanisms for receiving data and information to monitor non-seismic-generated tsunamis, with data and information coming from the Anak Krakatau Volcano Observation Post, IDSL devices, and community reports.

Capacity Building

Changing public perception following the 2018 tsunami can serve as a modality to intensify preparedness efforts. Disaster management actors in Pandeglang need to formulate risk communication strategies and create awareness raising materials based on the characteristics of the area and its community.

Preparedness materials on tsunami in Labuan or Pandeglang must specifically highlight Anak Krakatau volcano as a potential trigger for tsunami events, emphasizing its unique characteristics compared to typical seismic-induced tsunamis. Drawing inspiration from other regions with volcanogenic tsunami threats, such as the Santorini island in Greece (Nomikou et al., 2016) or the Taal volcano in the Philippines (Pakoksung et al., 2021), the content could incorporate visual representations, historical data, and natural signs as warning indicators specific to volcanic eruptions leading to tsunami. Collaborating closely with BNPB, BMKG, PVMBG, and BRIN, the Pandeglang government, via BPBD, should create a tailored tsunami preparedness template focused on potential eruptions from Anak Krakatau. Subsequent initiatives could involve training and engaging non-government actors such as the DRR Forum, Taruna Siaga Bencana, the Balawista and community-based disaster risk reduction programs like Kampung Siaga Bencana, Desa Tangguh Bencana, and Siaga Bencana Berbasis Masyarakat.

All research participants agreed on the importance of capacity building for local government officials in Pandeglang Regency. They are perceived as still lacking sufficient political commitment to disaster management. It is crucial to prioritize the technical abilities of personnel, especially those in Pusdalops PB, for the successful implementation of early warning standard operating procedures (Error! Reference source not found.). Regular practice of each stage of the procedures for different emergency scenarios should involve BMKG, the Anak Krakatau Watchpost, and BRIN as providers of early warning data. All Pusdalops PB personnel must be able to understand the data and information they receive. There is room for improvement there, for instance concerning the warning bulletins I to IV from BMKG, information on the status and condition of Anak Krakatau as received from the Watchpost and sea level data and its anomalies as received from BRIN.

Discussion

The 2018 tsunami events in Palu and Sunda Strait highlighted the limitations and vulnerabilities of the existing InaTEWS, particularly in addressing non-tectonic tsunamigenic events like mid-sea volcanic eruptions and underwater landslides. Moreover, the initiatives taken by the Indonesian government after 2018, such as the installation of additional equipment around Anak Krakatau, making it the most equipped tsunami warning system in Indonesia (Husrin et al., 2021; Muhari et al., 2019), were commendable.

This study illuminated the inadequacies in the current system through the lens of community and local government experience. The community-based disaster risk management guideline emphasizes the critical aspects of accessible, official, prompt, and coherent warning information (MPBI, 2014). Yet, during the 2018 tsunami, the research participants' experiences suggested a deviation from these ideals. Collecting and analyzing their recommendations as part of our study, it is worth noting the large extent to which their recommendations coincide with existing literature and other countries' experience.

The confusions relating to the December 22, 2018 tsunami once more highlight the importance of reliable and coherent information from authoritative sources. Uncertainty can lead to confusion and delays in response, ultimately putting more lives at risk. Timely and accurate early warning systems have been identified as critical factors in reducing the loss of life and property during tsunamis and other disasters triggered by natural hazards (Bernard et al., 2010; Papathoma-Köhle & Dominey-Howes, 2018). Without clear information from authoritative sources, decision-making processes can become hindered, potentially leading to inadequate emergency response and increased vulnerability of affected communities (Comfort et al., 2004; McEntire, 2012). Effective communication and coordination between actors, including local government, emergency responders, and the affected population, are essential for efficient disaster management (Drabek & McEntire, 2003; Quarantelli, 1999). The lack of clear information during the Sunda Strait tsunami emphasizes the need for improved communication channels and collaboration between authoritative sources, local government, and emergency responders. Implementing comprehensive early warning systems and providing appropriate training and resources to local authorities can help minimize confusion and ensure prompt, coordinated responses during emergencies, ultimately reducing the impact of disasters on communities (Cutter et al., 2003; Suryadi et al., 2021; Tierney, 2012).

Understanding the signs or semiotics of an approaching hazard can greatly assist in reducing the disaster risk and impacts. For Hall et al. (2017),increasing awareness and knowledge among communities about the signs or natural warnings of a disaster should even be the main objective in tsunami disaster mitigation efforts. In line with this, several countries such as Australia, the United States, and Japan promote public awareness by introducing natural signs of tsunamis through various media, including signposts installed on beaches and brochures distributed to tourists at information centers (Australian Government, n.d.; The Caribbean Disaster Emergency Management Agency, 2010).

As a system serving all tsunami-risk areas in Indonesia, even though variously implemented regionally, the InaTEWS is still top-down and lacks consideration of the specific needs or characteristics of the community. The top-down approach means that government and other responsible authorities will control and manage information and actions taken during a tsunami. This approach conveys early warning information from the central level to the regional level and at-risk communities. Although this can ensure centralized decision-making and faster response (Post et al. 2009), it does not consider local community specificities. The research findings indicate that although the Indonesian Presidential Regulation 93/2019 mandates the regional government through BPBD to coordinate actions taken by the community to save lives, this role has not been effectively carried out by BPBD Pandeglang.

In addition, Kabupaten Pandeglang only has two tsunami sirens controlled by the Provincial BPBD and integrated with BMKG. This number is insufficient to cover the entire coastal area at risk of tsunami in Pandeglang, which has the longest coastal line in Banten Province. This practical situation leaves the Kabupaten Pandeglang government without a formal warning dissemination mode that is used and/or integrated with InaTEWS. In this context, aligning the warning dissemination process with the cultural beliefs, customs, and practices community members associate with specific risks requires careful consideration of the methods to be employed to warn and guide the population. This perspective aligns with Christian et al. (2020) and Gaillard & Mercer (2013), who argue that enhancing the effectiveness of warning systems necessitates a deeper understanding of local communities' knowledge and beliefs.

A proposal for improved local warning mechanisms

Previous studies have shown that the tsunami warning system often exhibits bureaucratic tendencies and hesitation when it comes to making quick decisions. This is due to various factors. Firstly, the bureaucratic nature of governments is characterized by complex administrative structures, multiple levels of decision-making, and lengthy procedures; this factor can hinder the agility and responsiveness required in tsunami early warning (Lassa, 2018; Sakalasuriya et al., 2020). Secondly, government officials may face pressure and scrutiny in times of crisis, and the potential consequences of issuing a false alarm or unnecessary evacuation can have significant social, economic, and political ramifications (Bonadonna et al., 2021). Therefore, they may adopt a cautious approach to avoid making hasty decisions without adequate information or consensus among relevant actors.

Building on these insights, this study proposes detailed modifications which might help address the aforementioned challenges. Overall, our emphasis is on shortening the warning chains, as endorsed by Rahayu et al. (2020) to enhance agility and responsiveness. Shortening the warning chain involves streamlining decision-making processes and empowering local authorities to make swift and informed decisions during tsunami events. By reducing the layers of approval and delegating authority to lower levels, governments can respond more effectively to early warning information.

The first proposed adjustment, as visualized in Figure 5, pertains to the procedure for receiving warnings. Recognizing the limitations of relying solely on the BMKG for tectonic-induced tsunami threats, the authors suggest incorporating other sources of information into the process. These include warnings from the Anak Krakatau Observation Post, IDSL monitoring data, and direct reports from the public. This broader range of information inputs is expected to enhance the system's ability to detect potential tsunamis, including non-seismically induced ones.

Secondly, as illustrated in Figure 6, the authors recommend a significant shift in the decision-making and legitimization procedure. Specifically, the proposal includes the elimination of the legitimization process, a step currently adding unnecessary complexity and reducing the precious time available for community response. The intention is to expedite the warning chain and empower swift action during emergencies.

Lastly, relating to the warning dissemination procedure, depicted in Figure 7, the authors suggest a revision in the control over the tsunami sirens. Currently under the authority of the Provincial BPBD and integrated with BMKG, this centralization limits the local responsiveness in emergencies. The authors propose transferring control of the sirens to the BPBD Pandeglang or, at the very least, granting them access to their activation. Such decentralization of control aims to strengthen local disaster management capacities and improve community preparedness in the face of future tsunamis as noted by Tanesab (2020).

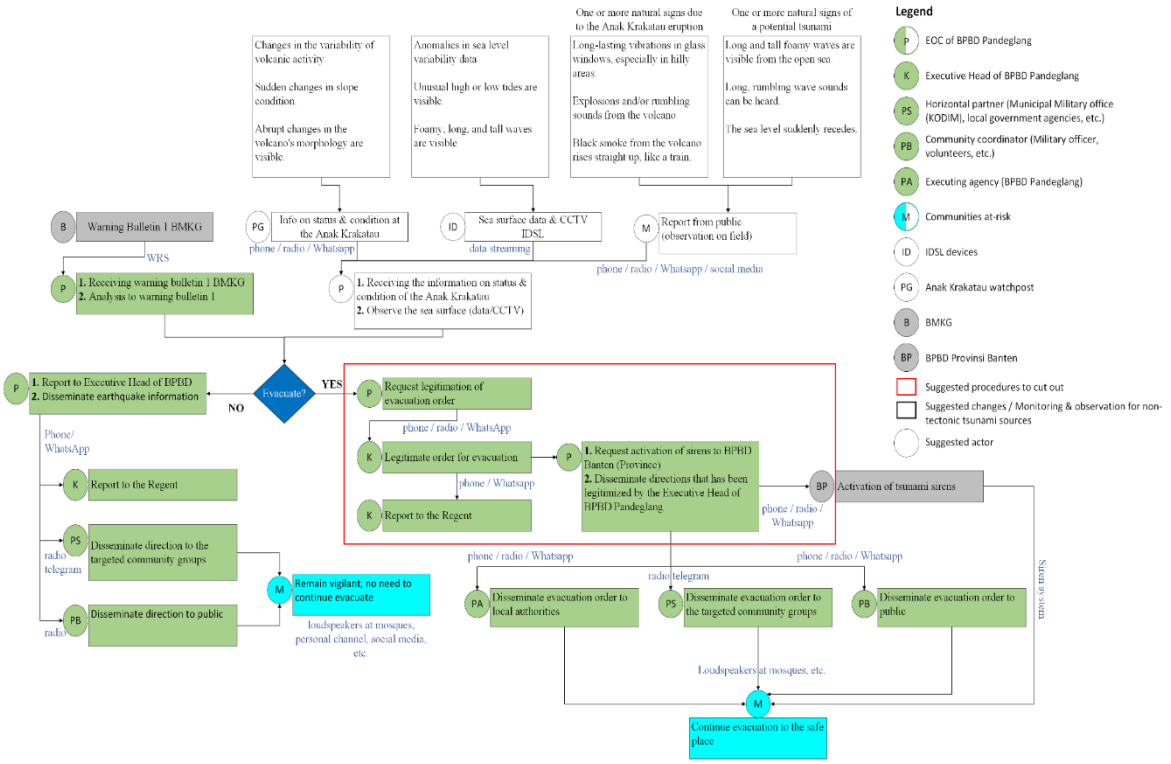

Figure 4. Modifications suggested to Pandeglang early warning SOPs. (source: Authors).

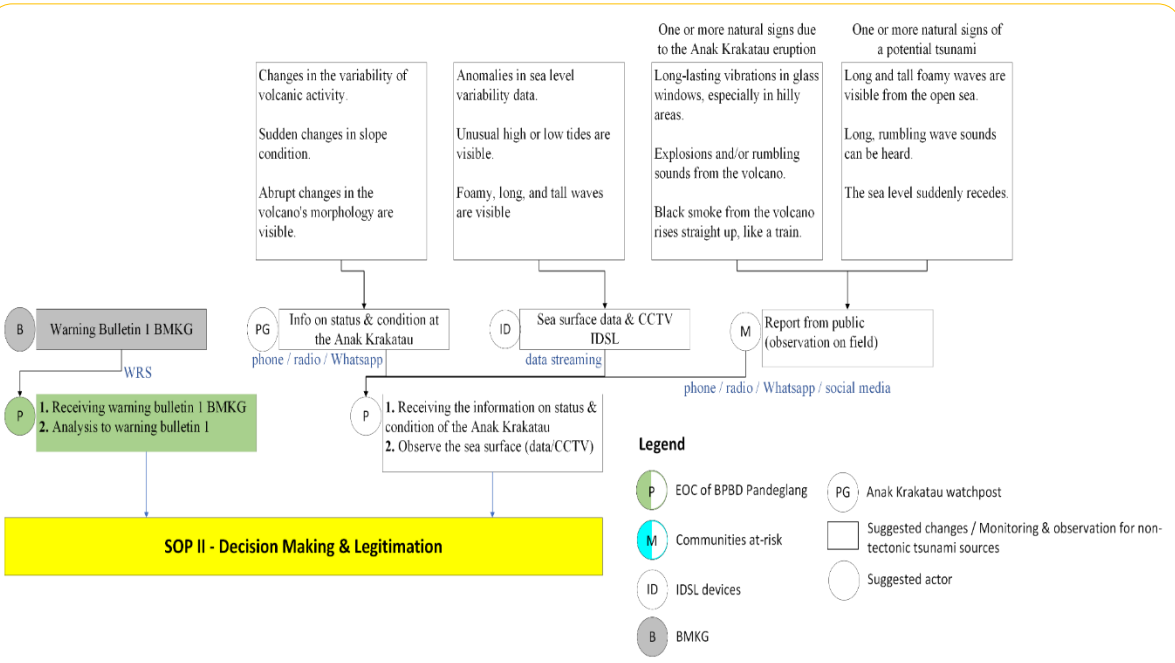

Figure 5. SOP I – Receiving warning from institutions, devices, and local communities for tectonic and non-tectonic tsunami sources. (source: Authors).

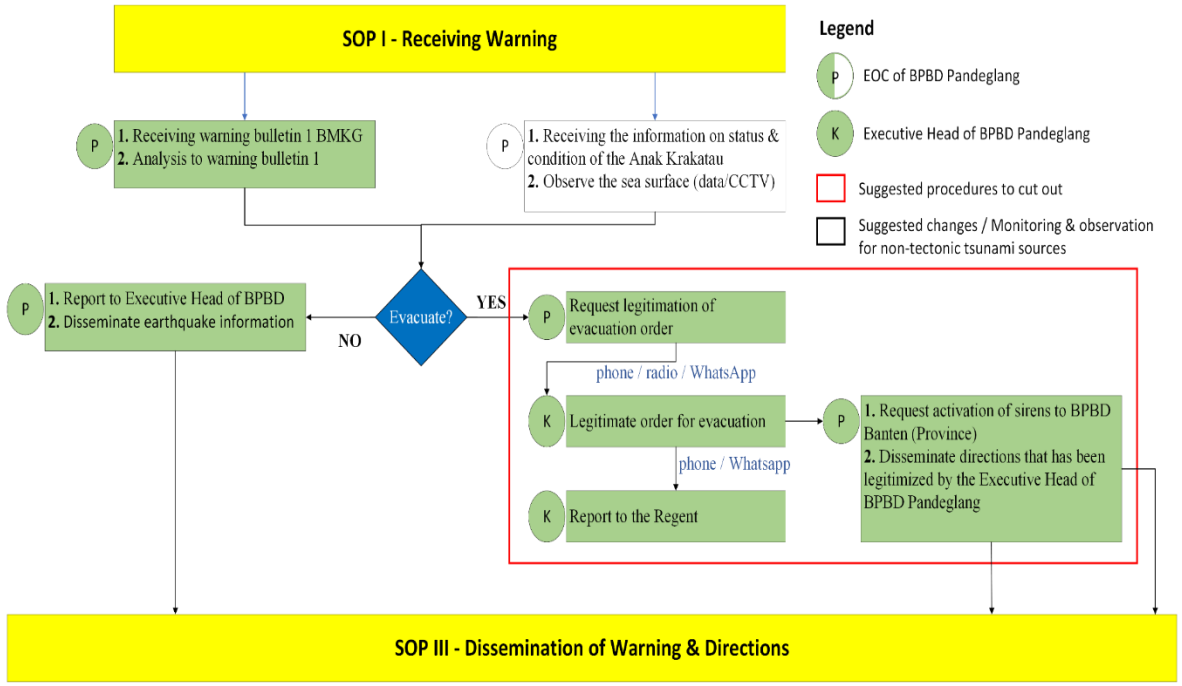

Figure 6. SOP II – Decision Making and Legitimation. (source: Authors).

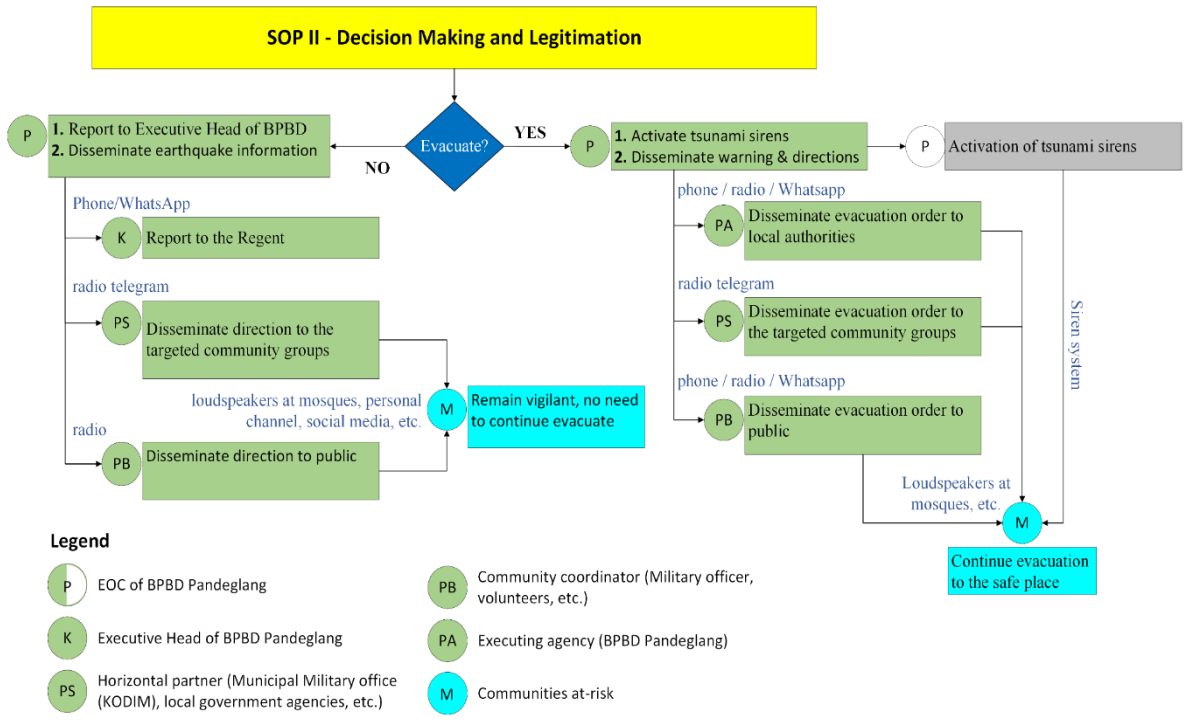

Figure 7. SOP III – Dissemination of Warning and Directions. (source: Authors).

Conclusions

This study underscores the pressing need for effective early warning systems and elucidates the essential nature of clear, prompt, and official tsunami warning delivery. The accounts provided by research participants of the December 22, 2018 Sunda Strait tsunami shed light on the palpable limitations and gaps of the InaTEWS, especially when handling non-seismically induced tsunamis. Our exploration brings to the forefront the bureaucratic challenges that government officials grapple with, including the apprehensions of social, economic, and political repercussions tied to false alarms. These apprehensions often culminate in delayed and less than optimal reactions.

Based on the insights from the community members, as well as representatives from local and national governments and disaster management agencies, we proposed concrete ways to improve the current warning chain and procedures. Diversifying sources of information, streamlining legitimization procedures, and decentralizing siren control are concrete, actionable steps grounded in the community's lived experiences and the observed shortcomings of the InaTEWS. Central to our study's conclusions is the endorsement of concise warning chains, swift decision-making, and the fortifying of local authorities' roles. The overarching aim of these suggestions is to enhance agility in responses and foster a disaster management approach more attuned to the specificities of local contexts. Taken together, the proposed changes do not only address the current system's limitations but also illuminate a path forward to a more robust, agile, and community-centric tsunami warning system.

Building on our study's central theme, future research should investigate region-specific warning strategies, considering the diverse geological, geographical, and social contexts in which tsunamis occur. By understanding the localized dynamics of potential tsunamigenic events, researchers can design targeted early warning systems that effectively communicate risk to vulnerable communities but also take into account their own knowledge and recommendations.

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