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Strengthening Policy Support for Tsunami Disaster Risk Reduction through Effective Science and Risk Communication

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Abstract

This policy brief highlights the need to strengthen tsunami disaster risk reduction (DRR) in developing countries through improved science and risk communication. Despite their potentially devastating impacts, tsunamis are often deprioritized amid competing development concerns. Case studies from Philippine municipalities reveal challenges in adopting science, technology, and innovation (STI) solutions for tsunami DRR. Key barriers include low risk perception, inconsistent risk assessment rooted on fragmented knowledge management and limited technical and fiscal capacities. The interplay among trust, expertise, and power further complicates prioritization of the tsunami risk. The brief recommends enhancing local leaders' accountability, improving risk assessments, and tailoring science and risk communication to local needs to better integrate tsunami DRR into local development strategies.

Pressing Need for Tsunami Risk Reduction

Tsunamis are rare but devastating, often arriving with little to no warning and leaving communities only minutes to evacuate. This hazard poses a significant threat to both populations and economies worldwide. Densely populated Asian countries have the highest number of people living in tsunami-prone areas (Løvholt et al., 2014), while Small Island Developing States (SIDS) face greater relative economic vulnerability (Løvholt et al., 2012). Without efforts to reduce this risk, tsunamis can cause massive casualties, widespread destruction, and a long-term economic and social disruption.

The 2004 Indian Ocean Tsunami and the 2011 Great East Japan Earthquake and Tsunami (GEJET) serve as reminders of what happens when preparedness falls short. The 2004 tsunami, one of the deadliest in history, struck without a well-established early warning system, leading to over 230,000 deaths across multiple countries (Supassri et al., 2012). In response, international warning centers were established to improve detection and communication. The 2011 GEJET, despite advanced monitoring systems, revealed the importance of worst-case scenario planning, emphasizing the need for well-planned evacuation routes, designated shelters, and resilient infrastructure (Mochizuki & Komendatova, 2017).

However, we cannot wait for another disaster to trigger action. Preparedness efforts must be sustained, and governments must bridge the gap between global policies and local implementation. To this end, IOC-UNESCO established the Ocean Decade Tsunami Programme in support of the UN Decade of Ocean Science for Sustainable Development (2021-2030), aiming to make 100% of at-risk communities "tsunami ready." This initiative also contributes to the broader objective of achieving Sustainable Development Goal 14— "Conserve and sustainably use the oceans, seas, and marine resources for sustainable development." As the timeline for these frameworks draws to a close, accelerating integration into local disaster risk reduction (DRR) strategies is crucial. The best time to address the tsunami threat was yesterday. The second-best time is today—but current actions remain insufficient.

Tsunami as a Low-Priority Risk

Science, technology, and innovation (STI) have the potential to significantly advance tsunami DRR. For instance, Japan has explored innovative solutions such as self-powered movable seawalls (Takagi et al., 2023) and GPS-based tsunami warning systems (Kanai et al., 2021). In the Philippines, local scientists have made notable progress in risk and impact assessment through tools like the Tsunami Simulation (TsuSim) module in the Rapid Earthquake Damage Assessment System (REDAS) software, as well as publicly accessible web platforms such as HazardHunterPH for hazard assessment and GeoAnalyticsPH for risk assessment.

Yet, the adoption of STI for tsunami DRR in policy and practice remains inconsistent. The challenge is not a lack of knowledge or tools, but rather the failure to integrate tsunami risk into broader DRR and development agendas. This issue is especially evident in

developing nations, where governments face competing priorities due to resources and budget constraints.

In the Philippines, a 2019–2021 stocktaking initiative[1] by the Department of Science and Technology - Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS) revealed concerning results. Out of the 104 at-risk cities and municipalities who responded, 65 utilized tsunami hazard maps to identify tsunami-prone areas but only 30 conducted periodic risk assessments. Moreover, 25 respondents have established standard operating procedures for early warnings but only 18 had specific tsunami response plans. These findings highlight a general lack of appreciation of the risk of tsunami even among high-risk communities.

Furthermore, when the actual spending of local DRR funds was compared with the stocktaking results, it was found that high DRR fund spending does not correlate well with the presence of tsunami DRR efforts (see Figure 1).

Figure 1. *Statistical test of the relationship between DRR fund spending and tsunami DRR efforts shows no significant correlation*.

Correlations

			ActualSpent	DRRInitiative
Spearman's rho	ActualSpent	Correlation Coefficient	1.000	.150
		Sig. (2-tailed)	.	.167
		N	86	86
	DRRInitiative	Correlation Coefficient	.150	1.000
		Sig. (2-tailed)	.167	.
		N	86	86

Data source: Local Disaster Risk Reduction and Management Fund (LDRRMF) utilization published by the Department of the Interior and Local Government's Full Disclosure Policy Portal (https://fdpp.dilg.gov.ph/fdpp/report)

This implies that even with high DRR spending, it is unsure whether resources were directed towards addressing the tsunami risk. Often, resources are directed toward more frequent hazards such as typhoons and flooding, leaving tsunami DRR underfunded and deprioritized.

Bridging this gap requires a stronger science-policy interface—one that ensures tsunami risk information is effectively translated into policies that align with local governance priorities. This policy brief examines the challenges of adopting STI solutions for tsunami DRR using case studies from the Philippines. It argues for the importance of improving science and risk communication with local decision-makers to address these gaps, especially in nations with similar socioeconomic and political situations.

Case Studies of Tsunami-Prone Municipalities in the Philippines

DOST-PHIVOLCS conducted a study examining four municipalities in the Philippines. The cases were selected to illustrate the diverse contexts influencing tsunami DRR at the local level, considering both risk levels and tsunami DRR performance based on the DOST-PHIVOLCS stocktaking.

Lingayen, a first-class municipality, faces high tsunami risk. GeoAnalyticsPH estimates that 80% of its population—82,384 residents—would be affected in a worst-case tsunami scenario. The municipality's flat central plain facing Lingayen Gulf may create a funnelling effect, amplifying tsunami waves, and allowing water to enter the Agno River, which bounds the municipality to the west. However, there are no recorded historical tsunami occurrences in Lingayen. Based on the Cities and Municipalities Competitiveness Index (CMCI)[2] of the Department of Trade and Industry (Philippines), Lingayen ranks as the 29th most resilient municipality among first- and second-class municipalities, with strong implementation of annual drills and early warning systems. Likewise, based on the stocktaking survey by DOST-PHIVOLCS, Lingayen met 40 out of 57 indicators for tsunami DRR.

Palimbang, a second-class municipality in southern Philippines, has experienced two tsunami events: the 1976 Magnitude 8.1 Moro Gulf Earthquake and Tsunami and the 2002 Magnitude 6.8 Palimbang Earthquake and Tsunami. In a worst-case scenario, 31,235 residents—or 34.54% of the population—are exposed to tsunami. Palimbang's coastline is flat, with many coastal settlements contributing to its high vulnerability. Although the municipality has a permanent local disaster risk reduction and management office

[1] Based on the Framework for Future Goals and Performance Monitoring of Tsunami Risk Reduction, Hazard Warning, and Mitigation laid out by the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System

[2] The 2021 data from the Cities and Municipalities Competitiveness Index (https://cmci.dti.gov.ph/) was considered given that the survey on tsunami DRR initiatives conducted by DOST-PHIVOLCS spanned 2019 to 2021.

(LDRRMO) and 24/7 operations center, its CMCI resilience ranking is 462nd among first- and second-class municipalities. The municipality also failed to report any tsunami DRR initiatives during the DOST-PHIVOLCS survey.

General Nakar, a first-class municipality, has low tsunami risk. Only 188 residents—1% of its population—are expected to be affected in a worst-case scenario, with two health facilities potentially inundated. The municipality has no recorded historical tsunami events. Despite the low risk, General Nakar satisfied 38 out of the 57 indicators for tsunami DRR by DOST-PHIVOLCS, although they were ranked by the CMCI only as the 151st most resilient municipality among first- and second-class municipalities.

Quinapondan, a fifth-class municipality, also faces low tsunami risk. An estimated 446 residents—3% of its population—are at risk. The municipality has no recorded tsunami events. Quinapondan ranks 198th in the CMCI resilience index for fifth- and sixth-class municipalities, with low scores in DRR planning and risk assessment. Correspondingly, they only satisfied 19 out of the 57 tsunami DRR indicators by DOST-PHIVOLCS.

This diverse selection of municipalities provides insights into the complex relationship between tsunami risk levels, local governance capacity, and the integration of STI solutions in DRR strategies. The following section presents the key results and lessons learned from each case.

Key Challenges Identified

Local perception of tsunami risk as low

Public perception of tsunami risk can be low even in high-risk areas (Alam, 2016; Cerase et al., 2019; Couling, 2014; Crawford et al., 2019). The case studies reveal that even local disaster managers may perceive the tsunami risk as lower than what is indicated by technical risk assessments.

In Palimbang, for example, disaster managers acknowledge high exposure—80% of the population resides along the coast, and 26 of its 40 barangays are coastal. However, tsunami ranks only third in risk prioritization, as managers perceive its probability to be low compared to flooding. Moreover, DOST-PHIVOLCS' hazard maps indicate a worst-case scenario of a 9-meter tsunami, yet local officials expect waves only 1 meter high like what they have previously experienced.

Several factors influence perceptions of low tsunami risk. While some literature suggests that direct experience can heighten tsunami risk perception, the case studies showed that this is not always the case. Palimbang experienced the 1976 Moro Gulf Earthquake and Tsunami and the tsunami following the 2002 Palimbang Earthquake, yet their perception of tsunami risk remains low. Quinapondan, which experienced the storm surge during Typhoon Yolanda in 2013 with moderate impacts, shares Palimbang's low tsunami risk perception. In both cases, past experiences were perceived as less severe than expected, potentially leading to underestimation of future risks. This underscores the role of near-miss experiences in shaping risk perception (Tinsley et al., 2012).

Without direct tsunami experience, proxy experience of other devastating hazards and media messaging can help heighten perceptions of tsunami risk. Lingayen and General Nakar, with no direct tsunami experience, exhibit higher risk perception due to past devastation experienced from storm surges. In these areas, the extensive reporting on the 2011 GEJET also heightened awareness of the tsunami's destructive potential.

Religious and socio-cultural beliefs can also influence tsunami risk perception. However, fatalistic interpretations of religious beliefs were observed only in Palimbang, where some view disasters as inevitable acts of God, reducing perceived urgency for preparedness. Aksa (2020) notes that fatalism often stems from a misinterpretation of Islamic teachings, which emphasize preparedness rather than passive acceptance.

Individual heuristics also shape perceptions. Risk is often judged by recalling similar events, leading to biases (Mochizuki & Komendatova, 2017). In Lingayen, General Nakar, and Quinapondan, tsunami probability was perceived as low due to the absence of recent events. Paradoxically, despite experiencing two tsunamis, Palimbang still perceives the likelihood of another as low, misinterpreting recurrence as reducing future risk rather than indicating an ongoing hazard.

These findings highlight the need for improved science communication to address misconceptions about tsunami probabilities and recurrence. This is especially important because scientific understanding and risk perception also influence the result of risk assessments.

Incomplete and inconsistent risk assessments

Risk perception plays a crucial role in shaping how local disaster managers conduct risk assessments. In Lingayen, engagement with scientific data fosters a proactive stance, whereas in Palimbang and Quinapondan, past experiences and intuitive heuristics influence decision-making. While experiential knowledge is valuable, it can lead to the underestimation of low-frequency but high-impact hazards like tsunamis.

Accurately estimating risk is essential, yet the case studies reveal two distinct approaches to risk assessment. One focuses primarily on hazard probability and severity, while the other incorporates capacities and vulnerabilities. Among the municipalities studied, only Lingayen explicitly integrates these factors, whereas Palimbang, General Nakar, and Quinapondan adhere to the contingency planning framework (Office of Civil Defense, 2020), which prioritizes the likelihood of hazard occurrence and its immediate impacts. This inconsistency raises concerns about the effectiveness and uniformity of risk assessment frameworks across local governments.

Another major gap is the absence of systematic uncertainty evaluation. While Lingayen and General Nakar acknowledge the unpredictability of hazards, these uncertainties are not fully integrated into the documentation of their risk assessments. Similarly, risk tolerability assessments remain largely unaddressed, with General Nakar being the exception. In Palimbang and Quinapondan, tsunami risk is deprioritized high despite exposure, mainly due to the absence of structured tolerability thresholds. Without clear definitions of acceptable risk, preparedness efforts may be inconsistent and reactive rather than proactive.

Addressing these gaps requires strengthening the understanding of tsunami science, risk science, and the role of STI in risk assessments. A deeper grasp of tsunami generation, propagation, inundation, impacts, and uncertainties would help local governments move beyond reliance on historical accounts and adopt science-based risk assessments. Before conducting risk assessments, efforts must be in place so that local disaster managers understand that risk also encompasses vulnerabilities, adaptive capacities, uncertainty, and tolerability, enabling a more comprehensive and actionable DRR strategy. STI products like readily available hazard maps, tsunami modeling tools, and risk and impact assessment applications must also be promoted as tools that can simplify the risk assessment process. Beyond technical improvements, science communication must bridge the gap between scientific knowledge and local information and knowledge (LIK). Scientific insights should not replace LIK but rather enhance it, ensuring that risk assessments are both technically sound and grounded in local realities.

Importance of knowledge management

Effective risk assessment is further supported by knowledge management which encompasses knowledge generation and integration from multiple disciplines and sources (Weichselgartner and Pigeon, 2015). Knowledge management enables disaster managers to synthesize scientific research, local knowledge, and community narratives, avoiding bias and strengthening risk assessments. Without robust knowledge management systems, risks can be misunderstood, leading to inaction. This issue is particularly concerning for tsunamis, given their complexity, ambiguity, and uncertainty, which require diverse data and information sets.

Lingayen exemplifies good knowledge management practice by leveraging a mix of direct and indirect information sources—information gained from training, Geographic Information System (GIS) mapping, hazard simulations, and external expert collaboration (e.g., DOST-PHIVOLCS, JICA). These efforts support an informed, structured understanding of tsunami risk. In contrast, Quinapondan faces challenges in maintaining updated hazard maps, highlighting the need for continuous verification and integration of new data to enhance risk assessments.

The cases underscore that the effective use of scientific products, such as hazard maps, depends not just on their availability and quality but on the existence of a good knowledge management system at the local level. Strengthening knowledge management systems is therefore essential for adapting STI to enhance tsunami DRR. This need is further highlighted by Oktari et al. (2020), who found that most knowledge management research focuses on flood disasters, with only 2 out of 72 reviewed studies addressing tsunamis.

Limited technical and fiscal capacities

Effective knowledge management in DRR depends on various factors, including organizational structure, culture, technology, human resources, and policy priorities (Magnier-Watanabe & Senoo, 2009; Omar Sharifuddin Syed-Ikhsan & Rowland, 2004). Furthermore, technical expertise is particularly critical. In Lingayen and General Nakar, local disaster managers have the capacity to compile, update, and analyze

hazard maps using GIS tools, enabling data-driven risk assessments. In contrast, while Palimbang's disaster officer has GIS capabilities, risk interpretation is often shaped by the personal experience and informal networks not just of the organization but of the local disaster risk reduction and management council (LDRRM Council) who essentially approves DRR strategies. Quinapondan, meanwhile, relies on external technical experts for their climate and disaster risk assessments.

A key challenge, however, is the cyclical nature of risk assessment and investment. Without a clear understanding of tsunami risk, local governments may not prioritize investments in tsunami DRR. At the same time, the lack of investment leads to limited technical capacity, which further hinders accurate risk assessments. Breaking this cycle requires an initial effort to help local stakeholders understand their risks, even before they have the full technical capability to conduct their own assessments. By strengthening access to expert-driven assessments and fostering engagement with scientific agencies, local governments can recognize the urgency of investing in DRR. Over time, as investments are made, they can build the internal capacity needed for independent and sustained risk assessment efforts.

For example, in resource-constrained municipalities like Palimbang, local governments prioritize pressing development needs, such as infrastructure, agriculture, and ecotourism. With these competing priorities, tsunami DRR must be framed not as a competing expense but as a necessary foundation for sustainable development. Strategic policy support and targeted investments in knowledge-building initiatives can help local governments integrate tsunami risk considerations into their broader development plans.

Interplay of trust, expertise, and power dynamics

Different forms of power—structural, ideological, economic, decision-making, and non-decision-making—interact to shape how tsunami risk is addressed in the four case study municipalities. National agencies like the Department of the Interior and Local Government and the Office of Civil Defense (OCD) exert structural power through incentive programs such as Gawad KALASAG[3] and Seal of Good Local Governance[4], influencing the local priorities in DRR. In brief, these recognition bodies require local governments to address the top 2 hazards in the locality. However, how local disaster managers navigate this influence varies. High-performing municipalities like Lingayen and General Nakar effectively balance national directives with localized decision-making, ensuring their risk reduction strategies remain contextually relevant. Conversely, Palimbang and Quinapondan show a stronger reliance on national frameworks, which can sometimes limit their ability to move beyond the top 2 hazards and address low-ranking hazards like tsunami.

Given these power dynamics, it is crucial to examine who the trusted sources of information are and which type of expertise is most valued by those who hold power. Adekola (2020) identifies two primary forms of expertise—technical and experiential—that shape risk assessment. In Lingayen, technical expertise is prioritized, with the local disaster managers relying on DOST-PHIVOLCS for hazard data, adhering to OCD's risk assessment methods, and using GIS for risk visualization. The local council places high trust in the local disaster manager's technical capabilities, often approving their recommendations with minimal scrutiny. This trust, built on the local disaster manager's proactive approach and track record, enables swift decision-making. In contrast, a stronger preference for experiential expertise is observed in Palimbang and Quinapondan where community narratives and own experiences outweigh the trust in technical models of the tsunami hazard. Hence, these cases demonstrate how the interplay of trust, expertise, and power affects risk governance outcomes.

Policy Recommendations

The cases demonstrate that a more effective tsunami DRR strategy requires coordinated efforts at the global, national, and local levels. Strengthening science and risk communication, enhancing the use of STI, and addressing structural barriers to investment and decision-making are key priorities.

For the Global Community

International organizations and scientific institutions must lead in advancing tsunami science and risk communication strategies tailored to different governance contexts. Global networks should prioritize

[3]A nationwide program in the Philippines that aims recognize outstanding contributions to DRR

[4]The highest recognition given by the Department of the Interior and Local Government to local government units that exhibit good governance, including in the field of DRR

capacity development programs that support developing nations in integrating tsunami risk into DRR strategies. Maximizing and strengthening the implementation of the IOC-UNESCO Tsunami Ready Recognition Programme can help align local initiatives with global frameworks, ensuring that best practices in preparedness and response are widely adopted. At the same time, STI solutions—such as hazard mapping, early warning systems, and mitigation strategies—should be made more accessible, localized, and user-friendly to bridge the gap between scientific knowledge and on-the-ground decision-making. Additionally, funding mechanisms should be expanded to help resource-constrained municipalities develop risk-informed policies without competing against other development priorities.

For National-Level Stakeholders

At the national level, efforts must focus on reshaping how local governments perceive and respond to tsunami risks by ensuring that scientific information is accessible, relevant, and compelling. Since many LGUs deprioritize tsunami due to its perceived low probability, messaging should emphasize impact and preparedness urgency. National agencies must shift the narrative from probability alone to uncertainty and worst-case scenarios, reinforcing that uncertainty is a reason to prepare, not to delay action.

Local knowledge and survivor narratives should also be integrated into science communication efforts. Rather than replacing experiential expertise, technical insights must enhance and validate LIK to build trust in risk assessments.

Additionally, institutionalizing risk literacy training for disaster managers is critical, ensuring they understand tsunami hazards, uncertainties, and STI tools such as hazard maps and tsunami models. However, tools alone are insufficient. National agencies must actively promote their use by embedding them in local decision-making processes, simplifying data interpretation, and providing clear, actionable recommendations.

To sustain these efforts, national incentive programs should prioritize evidence-based risk assessments over compliance checklists. Performance-based incentives and DRR funding should be tied to engagement with scientific agencies and risk-informed planning. Strengthening these science and risk communication strategies will help local governments make informed, proactive decisions, leading to more effective tsunami DRR.

For Local Stakeholders

Local governments must move beyond a reliance on historical accounts and integrate scientific risk assessments into planning and decision-making. While contingency planning frameworks are useful, municipalities need to adopt a more comprehensive risk perspective that includes vulnerabilities, adaptive capacities, uncertainty, and risk tolerability thresholds. This shift requires investments in a stronger knowledge management system, where scientific data is systematically collected, understood, and applied in local policies.

Decision-makers must also recognize that uncertainty should not be a justification for inaction but rather a compelling reason to enhance preparedness. Even if the probability of a tsunami is perceived as uncertain, the potential consequences warrant proactive measures. Similarly, the occurrence of past events, even if moderate, does not guarantee that future incidents will follow the same pattern. Preparing for the understood science-based worst-case scenarios ensures that communities remain resilient regardless of the severity of future hazards.

For resource-constrained municipalities, DRR must not be framed as a competing expense but as a foundation for sustainable development. Integrating tsunami risk assessments into infrastructure, agriculture, and ecotourism planning can ensure that DRR measures align with existing local priorities rather than being treated as an isolated burden. Strengthening direct engagement with scientific agencies will help municipalities recognize the urgency of investing in DRR, even before they have the internal capacity to conduct independent assessments.

Lastly, local decision-making power must be strengthened to ensure that municipalities can adapt national directives to their specific contexts. While national frameworks provide essential guidelines, local agency and accountability must be reinforced so that tsunami risk is not deprioritized simply because it ranks lower than other hazards. By implementing these recommendations, we can move towards a reality where science, governance, and local realities work together, ultimately leading to more resilient and risk-informed communities.

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