Tsunami Preparedness in Indonesia: The WAVES Initiative

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Abstract

The Indonesia archipelago is highly vulnerable to earthquakes and tsunamis. The WAVES initiative uses experts in geology, engineering, communications, public health, and geology in a multi-disciplinary, cross-cultural effort to better understand and communicate risk to federal and local government agencies, schools, businesses, and communities. Efforts include logging trenches dug on coastal plains to prospect for historical tsunami deposits, developing localized inundation maps, conducting social surveys on perceptions of tsunami threat and efficacy, creating and delivering educational sessions including the “20/20/20 principle” to schools and communities, identifying localized safe zones out of the inundation zone and within a timely walking distance, conducting tsunami evacuation drills, mapping evacuation signs, conducting interviews, and working with local and federal government officials and schools to create evacuation plans. This paper details our research findings and corresponding educational intervention.

Keywords: Tsunami, Indonesia, Natural Hazards, Education, Mitigation

Introduction

Natural Hazards in Indonesia

Geophysical hazards in the Indonesian archipelago arise from its unique geological setting at the collisional junction of three of Earth’s largest tectonic plates. Most of Indonesia is on the southeast edge of the Eurasian Plate, which is surrounded by convergent plate boundaries. The Indo-Australian Plate converges from the south and the Pacific Plate from the east. The rapid convergent motion of these plates is buffered by the episodic release of pent-up energy in the form of volcanic eruptions, earthquakes, and associated tsunamis and landslides (Harris and Major, 2017). Indonesia is the fourth most populous country in the world at over 272 million people (Badan Pusat Statistik, 2022). The Indonesian population has more than quadrupled since the 1950s and is rapidly increasing (Our World in Data, 2022). Even relatively minor natural hazards over the last few decades have resulted in greater numbers of fatalities than those of the past.

Tsunamis in Indonesia have occurred once every four years on average over the past 430 years (Latief, Puspito, and Imamura, 2000). The temporal distribution of the seismic events over the past 100 years indicates a 20-30 year alternating cycle of frequent seismic activity followed by seismic quiescence (Harris and Major, 2017). The last period of quiescence began during the mid-1980s and came to an end in 2004 when the Great Sumatra earthquake triggered the deadliest natural disaster in the 21st century. The 9.2 magnitude earthquake was the third largest ever recorded and was caused by the rupture of a gigantic segment of the boundary between the Asian and Australian plates off the northwest coast of Sumatra and Andaman Islands. The earthquake itself caused several buildings to collapse and killed hundreds of people. The plate rupture occurred at an ocean depth of more than 3,000 meters. A massive amount of water was displaced, producing the largest earthquake-generated tsunami in recorded history. The tsunami killed more than 283,000 people; the majority were in Indonesia (Lay et al., 2005). There had not been any earthquakes larger than magnitude 8.5 globally for 39 years prior to this event (USGS, 2022).

Three months after the Great Sumatra Earthquake, the plate boundary segment immediately to the south ruptured, producing a magnitude 8.7 earthquake and large tsunami that claimed thousands of lives. This event was followed in 2006 by a magnitude 6.3 earthquake near Yogyakarta that killed around 6,000 persons and displaced nearly half a million more. This event was nearly identical to what is found in historical records and was forecast to reoccur in central Java (Harris and Prasetyadi, 2002). Two months after the seismic disaster in Yogyakarta, a magnitude 7.7 earthquake struck south of the city, but offshore, which generated a tsunami that killed hundreds of people. In 2007, a magnitude 7.5 earthquake struck near Jakarta, a megacity with a population of about 13,000 people per square kilometer (Martinez and Masron, 2020). Two months later, a series of earthquakes (magnitudes 8.5, 7.9 and 7.1) struck the southwest coast of Sumatra causing more fatalities. In 2008, three aftershocks between magnitude 7.0-7.5 caused fatalities. In 2009, there were four destructive earthquakes between magnitude 7.0-7.9 that accounted for more than 2,500 fatalities in Sumatra. In 2010, three more earthquakes between magnitude 7.2-7.9 caused hundreds of fatalities, including the 2010 Mentawai tsunami. A few hours before the 7.9 event, Merapi, a volcano in central Java, exploded with an intensity unseen since 1870. At least 200 fatalities resulted. Fortunately, close to 350,000 people were evacuated immediately before the eruption. In 2012, a magnitude 8.6 earthquake struck off the coast of northern Sumatra and was followed two hours later by a magnitude 8.2 earthquake near the same location. Additional fatalities from earthquakes occurred each year from 2013-2017.

A host of disasters occurred in various parts of Indonesia in 2018, all striking in densely populated areas. Five strong earthquakes struck Lombok killing over 500 people and displacing over 4 million inhabitants. In September, a magnitude 7.5 earthquake struck the Palu area of western Sulawesi. The earthquake generated hundreds of landslides, several of which occurred under the sea and caused destructive tsunamis. Massive mudflows associated with liquefaction demolished large areas of the city. Over 5,000 people died. In December, the partial collapse of Krakatoa volcano into the Sunda Strait generated a ‘silent’ tsunami that crashed into coastal communities, killing over 400 people. A paper in 2012 warned of the likelihood of this event (Terry and Goff, 2012). From 2019 to 2021, an additional 17 earthquakes have caused fatalities in Indonesia including four events >7.0 magnitude and one event in Sulawesi that caused over 100 fatalities in 2021 (USGS, 2022).

Tsunami disaster mitigation research in Indonesia began in earnest in North Sumatra and elsewhere *after* the 2004 Great Sumatra Earthquake. Since then, tsunamis have occurred in Indonesia in Nias in 2005, Java in 2006, Mentawai in 2010, and Sulawesi in 2018. Indonesia has around 54,720 kilometers of coastline, much of which is vulnerable to earthquake-triggered tsunamis (Embassy of Indonesia, 2022). More destruction is likely to occur before the seismic mega-cluster ends. Increased earthquake and tsunami mitigation measures are needed to reverse the growing loss of life and property.

Current Tsunami Mitigation Efforts

Since the 2004 Indian Ocean tsunami, efforts to describe and analyze what can be learned from past tsunamis and how to prepare for the future have increased around the world (Jain, Virmani, and Abraham, 2021; Repetto, Cordón, and Bronfman, 2022; Dhellemmes et al., 2021; Chen, Lindell, and Wang 2021; Rasyif et al., 2020; Sun, 2020; Wegscheider et al., 2011). Current tsunami mitigation efforts include Early Warning Systems, structural measures, construction of Temporary Evacuation Shelters (TES), and community education including identifying tsunami evacuation zones, evacuation planning, and tsunami evacuation drills.

Despite progress in Early Warning Systems (EWS) (Safri et al, 2020; Harig et al., 2020) several studies have found the systems insufficient to warn individuals in the event of a tsunami. A recent study in Indonesia found a lack of operational communication networks to relay warnings to those who are vulnerable (known as ‘the last mile’ problem) (Rahayu et al. 2020). Another study in Aceh Indonesia found a lack of community engagement in EWS (Sufri et al. 2020). Since the implementation of Indonesia’s EWS in 2006 there have been six tsunamis, yet those at risk were often not warned in time to evacuate. Either the warning was not received until after the tsunami struck, the warning was terminated early and people returned to low ground only to be hit with a second wave, or the warning underestimated the tsunami hazard (Suppasri, 2015). A combination of challenges is responsible for the failure of these technology-based early warning systems including the short distance between where the tsunami forms and the coastlines they impact. Most tsunamis are generated by earthquakes along the subduction interface of convergent plate boundaries surrounding Indonesia. For example, the Sumatra and Java Trenches are only 200-300 km offshore. In deep water, tsunamis travel at speeds of 600 km/hr, which means that there is only 20-30 minutes from the time the tsunami forms until it arrives. Additionally, EWS are not always properly maintained. This suggests recognition of natural warning signs and immediate self-evacuation is timelier and more beneficial than waiting on a siren prior to evacuating (Hall et al. 2017).

Natural tsunami barriers such as coral reefs and mangrove forests have been depleted due to tourism, shrimp farms, and foreign wood export (Niman, 2010; Barbier, 2006). Structural disaster mitigation measures include building vegetative barriers to absorb some of the energy of the tsunami waves (Danielsen, 2005; Muhari et al., 2012). The identification of tall sturdy buildings for evacuation or construction of Temporary Evacuation Shelters (TES) in low-lying areas is needed (Kemal 2020; Nakaseko et al., 2008; Hein, 2014). TES resemble parking garages with wide staircases for climbing and an open roof designed to hold a large number of people above the water. Establishing trust in these structures has been problematic, particularly in Aceh where lack of local input is perceived as government control (Spahn et al. 2010). Another important structural measure is placement of tsunami evacuation signs. These signs are now common occurrences in coastal communities in Indonesia prone to tsunamis. Although signage directs individuals where to go in the event of a tsunami, they do not state under what circumstances to evacuate (e.g., after observation of a natural warning sign such as an earthquake or receding ocean), nor do they communicate the urgency of evacuation immediately after an earthquake (Hall et al. 2017).

Geohazard education and implementation of disaster mitigation strategies are needed to reverse the growing losses to natural disasters. Health communication research suggests creating high-threat (susceptibility and severity) and high-efficacy (self-efficacy and response efficacy) messages will be most effective in encouraging behavior change (Witte and Allen 2000). Messages related to tsunami threat may include communicating information about risk through tsunami modeling and identification of inundation zones. Efficacy components may focus on educating those at risk to recognize natural tsunami warning signs and to immediately self-evacuate to high ground rather than waiting for a siren which can cause deadly delays. Another efficacy component includes identifying safe locations that can be reached by foot in a timely manner. Furthermore, tsunami evacuation drills increase efficacy by allowing communities or individuals in at-risk areas to practice evacuation behavior before a disaster occurs (Hein, 2014; Nakaya et al., 2018; Sun and Yamori, 2018). In 2017, the United Nations Development Programme set out to increase tsunami awareness for school children in 18 countries of Asia and the Pacific. From 2017-2018 over 61,000 students, teachers, and administrators in 115 schools participated in evacuation drills (United Nations Development Programme, 2019).

WAVES Initiative

The WAVES research consortium involves multi-disciplinary researchers and students from government agencies and universities in Indonesia and the United States. The mission of WAVES is to assess and communicate risk of natural hazards and implement risk reduction strategies. The Indonesian government has adopted the 20-20-20 principle for tsunami risk reduction, which was developed by WAVES. Generally, if ground shaking from an earthquake lasts more than 20 seconds, nearby coastal communities have around 20 minutes to evacuate to 20 meters elevation for safety (Hall et al. 2017). Although there are many exceptions to the rule, such as tsunamis caused by landslides or volcanic eruptions, the 20-20-20 rule empowers those in harm's way to self-evacuate in a majority of the regions in Indonesia threatened by tsunami hazards. WAVES collaborates with local government leaders and natural disaster mitigators. Community-based activities include natural hazards education, including earthquake and tsunami evacuation drills. WAVES includes PhD’s and government leaders in geology, engineering, communication, public health, and geography. The geology and engineering team focuses on assessing natural hazard risk, such as earthquakes and tsunamis. Estimates of seismic ground motion and tsunami inundation from historical and geological records provide a way to make numerical models of previous and likely major earthquake and tsunami events. The public health team focuses on community assessments to determine perceptions of tsunami risk and behavioral intentions. The team uses this information to develop key messages and tsunami preparedness campaigns. The geography team identifies safe evacuation areas out of the inundation zone, conducts tsunami evacuation drills, and discusses evacuation plans with government officials. All fields work together to better understand local perceptions related to tsunamis and provide educational sessions to communities and schools in at-risk coastal areas.

Methodology

Geological and Geophysical Research Methods

Using the principle that the past is the key to the present we query historical and geological records of past earthquake and tsunami events to identify areas most at risk. These methods involve logging trenches dug on coastal plains to prospect for tsunami deposits. We have discovered that many coastal cities are partially built on these deposits from previous tsunamis. Age analysis of the deposits provides a chronology of tsunamis that reaches back thousands of years. We also analyze historical accounts of earthquake and tsunami events that provide more detail about the impact of these events when they happen again (Harris and Major, 2016).

With these data we construct numerical models that reconstruct many pre-instrumental earthquake events to determine the likely source, magnitude and recurrence intervals. The time difference between when the earthquake occurs and when the tsunami arrives at several different locations provides a method of tracing where the tsunami was generated. The height of the waves provides a way to estimate the earthquake magnitude. We are able to reconstruct these events using Bayesian statistical models and machine learning that aid in developing tsunami inundation maps that inform coastal zoning plans and evacuation drills.

The methods we use to assess risk of earthquakes and tsunamis are varied. For example, we employ a method known as Vs30 to determine the way the upper 30 meters of Earth’s surface will respond during an earthquake. The method involves striking a metal plate with a sledge to produce shock waves recorded by multiple sensors to determine how fast these waves move through the ground. If the shock waves move slowly the site is prone to amplification of seismic waves and much more damage than other areas, even if these sites are far away from the epicenter. From our measurements we have mapped out many densely populated areas with low Vs30 values. These maps are essential for urban planning and earthquake zoning. We have also used ground penetrating radar and high-resolution drone surveys to map out the extent of tsunami deposits we discovered. As a result, we have discovered several areas previously inundated by tsunamis where the extent of inundation is estimated and used in inundation maps (Harris et al., in press).

Social Survey

We conducted social surveys to inform the development of our educational interventions. The pencil/paper survey was delivered in Indonesian and contained several categories of questions: (1) demographic (e.g., sex, island of residence), (2) earthquake and tsunami risk and efficacy perceptions on a 1-5 Likert scale from *strongly disagree* to *strongly agree*, (3) personal warning preferences, and (4) behavioral intentions. The survey was validated in previous research (Hall et al. 2017). The surveys were conducted in coastal schools (N=50) in Java, Bali, Lombok, and Sumba. Schools were identified by leaders in Indonesia's regional governmental disaster management agency 'Badan Penanggulangan Bencana Daerah' (BPBD). Adolescents aged 12-18 (N=2,386) individually filled out surveys in class. We used Pearson's Chi-square to compare the sampling distribution of sex across islands and no significant differences were found at $p<0.5$. Descriptive statistics were used to analyze the number and percentage for each response by island and in total. We calculated the means and standard deviations for earthquake and tsunami susceptibility and efficacy perceptions for each island. Welch's ANOVA was used to determine differences in perceptions of threat and efficacy across the four islands. Significant findings were probed with the post hoc Games-Howell test. We used independent t-tests to determine whether there were significant differences in threat and efficacy perceptions by sex. We also used a step-wise logistic regression to determine the associations of additional demographic variables, tsunami information sources, and prior hazard experience with tsunami threat and efficacy perceptions; however, these are reported in another paper and will not be discussed here (Hall et al., in Press).

Educational Intervention

The researchers, BPBD officials, and students from Indonesia and the United States developed and delivered an approximately one-hour long educational presentation that included lecture, images, videos, maps, stories, songs, games, and movement. The educational intervention included key messages based on previous survey results. The main intent of the presentation was to stress the tsunami vulnerability of coastal Indonesia based on historical evidence, to encourage the use of the 20-20-20 guidelines, to stress the importance of immediate self-evacuation instead of waiting for a siren or government warning, and to identify an evacuation plan. Most of our presentations were given in schools, but we also presented to communities, factories, and officials in government, disaster preparedness, and tourism. We conducted evacuation drills for each school that desired. This consisted of a 20-second earthquake drop/cover/hold followed by practicing a walking route to a safe high ground out of the inundation zone identified in our previous tsunami mapping. In every drill we were able to evacuate all students to safety in less than 20 minutes. Before and after our educational intervention, we conducted informal interviews about tsunami perceptions and evacuation intentions with government officials, teachers and school administrators, community members, and students. While these interviews were not intended to serve as formal research findings, they provide additional directions for future research on religious, economic, and political factors related to tsunami mitigation. We also followed existing evacuation signs and discussed current community evacuation plans with community leaders.

Results

Geology Results

The most significant results of our geological and geophysical research have been the discovery of geological and historical records of earthquakes and tsunamis and using these data in developing risk assessments for densely populated regions of Indonesia. We compiled and translated historical accounts of earthquake and tsunami events of Indonesia (Harris and Major, 2016) to reconstruct several natural disasters in the past that claimed many lives. Reconstructing the 1852 Banda Sea earthquake provided a way to test a new code we developed that uses Bayesian statistical methods to predict the location, geometry and size of the earthquake from anecdotal accounts (Ringer et al., 2021). These results provide a way to incorporate historical accounts into seismic risk assessments and therefore extend the record of earthquakes and tsunamis much further back in time than instrumental records of earthquakes (<80 years). Since most fault zones have earthquake recurrence intervals of hundreds to thousands of years, we now have a way to estimate where and how large these events were and then how much strain energy has since accumulated on various fault zones.

One of the most important geological discoveries is the common occurrence of boulder ridges on the south coast of Java and other islands adjacent to the eastern Sunda subduction zone. This subduction zone is interpreted as incapable of producing mega-thrust earthquakes and large tsunamis due to the lack of instrumental records and historical accounts of earthquakes > 7.9 (Newcomb and McCann, 1987). However, we discovered sparsely preserved layers of sand from tsunamis with ages of 500 and 1000 years before present and well preserved imbricated boulder ridges that were most likely formed by tsunamis (Harris et al., in press). The ages and extent of these tsunami deposits indicate that the eastern Sunda subduction zone is capable of producing megathrust earthquakes and giant tsunamis. This discovery changes the earthquake and tsunami risk assessment for the densely populated coastal cities in this region.

Social Survey Results

Participants (N=2,386) resided in Java (N=649), Bali (N=388), Lombok (N=432), and Sumba (N=917). Our independent t-tests for sex indicated significant differences in perceptions of earthquake susceptibility, tsunami susceptibility, and tsunami efficacy. Females (M=3.53, SD=1.13) had a significantly higher mean for perceptions of earthquake susceptibility compared to males (M=3.37, SD=1.27); t(1881.99)=-3.07, SE=.05, p=.00. Females (M=3.30, SD =1.21) also had a significantly higher mean for perceptions of tsunami susceptibility compared to males (M= 3.11, SD = 1.35); t(1875.54)=-3.44, SE=.06, p=.00. However, males had a significantly higher mean perception of tsunami efficacy (M=3.37, SD =1.22) compared to females (M= 3.22, SD = 1.15), t(1936.06) = 3.00, SE=.05, p=.00. Java had a significantly higher mean perceived susceptibility for both earthquakes (M=3.81) and tsunamis (M=3.91) compared to other islands. Mean perceptions of both earthquakes (M=3.05) and tsunamis (M=2.69) were significantly lower in Sumba.

Table 1 shows mean perceptions of earthquake susceptibility, tsunami susceptibility, and tsunami efficacy for the four islands. There were significant differences in perceptions of earthquake susceptibility at the *p*=.05 level between the islands [F(3, 1145.93) = 56.27, *p*=.00]. Post hoc comparisons indicated no significant difference (*p*=.99) in mean perceptions of earthquake susceptibility between Bali and Lombok. However, mean perception of susceptibility to earthquake was significantly higher in Java compared to Bali (*p*=.00, SE=.06, 95%CI=.09, .38), Lombok (*p*=.01, SE=.07, 95%CI=.03, .40) and Sumba (*p*=.00, SE=.06, 95%CI=.61,.92). Mean perceptions of earthquake susceptibility were significantly higher in Bali compared to Sumba (*p*=.00, SE=.06, 95%CI=.37, .69). Mean perceptions of earthquake susceptibility were significantly higher in Lombok compared to Sumba (*p*=.00, SE=.07, 95%CI=.37, .74). We also found significant differences in perceptions of tsunami susceptibility [F(3, 1141.29) = 127.91, *p*=.00]. Post hoc comparisons again showed no significant differences between Bali and Lombok (*p*=.96) while showing significant differences between all other islands at the *p*<.05 level. Mean perceptions of tsunami susceptibility were significantly higher in Java compared to Bali (*p*=.00, SE=.06, 95%CI=.54, .86), Lombok (*p*=.00, SE=.07, 95%CI=.48, .85), and Sumba (*p*=.00 SE=.06, 95%CI=1.1, 1.4). Mean perceptions of tsunami susceptibility were significantly higher in Bali compared to Sumba (*p*=.00, SE=.06, 95%CI=.36, .68) They were also significantly higher in Lombok compared to Sumba (*p*=.00, SE=.07, 95%CI=.37, .74). There were significant differences in perceptions of efficacy in the event of a tsunami [F(3, 1132.78) = 11.75, p=00]. Post hoc comparisons showed no significant differences between Bali and Lombok (*p*=.47) or Bali and Sumba (*p*=.58). Mean perceptions of efficacy were significantly higher in Java compared to Bali (*p*=.00, SE=.06, 95%CI=.11, .44), Lombok (*p*=.00, SE=.07, 95%CI=.20, .56), and Sumba (*p*=.01, SE=.06, 95%CI=.03, .35). They were also significantly higher in Sumba compared to Lombok (*p*=.04, SE=.07, 95%CI=.01, .37).

Table 1. Perceptions of Earthquake and Tsunami Threat and Efficacy on Four Islands

Variable	**Java** M (SD)	**Bali** M (SD)	**Lombok** M (SD)	**Sumba** M (SD)	**Sig.**
Sus. Quake	3.81 (.98)	3.58 (.82)	3.60 (1.17)	3.05 (1.37)	.00*
Sus. Tsunami	3.91 (1.11)	3.21 (.88)	3.25 (1.17)	2.69 (1.33)	.00*
Eff. Tsunami	3.47 (1.08)	3.20 (.94)	3.09 (1.12)	3.28 (1.35)	.00*

[a]ANOVA results; asterisks indicate there was a significant difference between two or more message groups at *p*<.05.

Slightly fewer than half of our total survey participants either *agreed* or *strongly agreed* that they are susceptible to a tsunami. Participants who *agreed* or *strongly agreed* they were susceptible to a tsunami varied substantially depending on location: Java (77.2%), Lombok (49.3%), Bali

(37.6%), and Sumba (35.9%). 31.8% of total survey participants *disagreed* or *strongly disagreed* they are susceptible to a tsunami. More than a quarter of survey participants in Lombok and more than half in Sumba *disagreed* or *strongly disagreed* that they are susceptible to a tsunami. Fewer than half of total participants (48.5%) *agreed* or *strongly agreed* they would be able to save themselves in the event of a tsunami. Over half of participants in Java (57.2%) and Sumba (52.9%) *agreed* or *strongly agreed* they would be able to save themselves in the event of a tsunami. This was only true for about one-third of participants in Bali (36.9%) and Lombok (36.4%). Many participants *disagreed* or *strongly disagreed* that they would be able to save themselves in Java (21.3%), Bali (21.4%), Lombok (31.9%), and Sumba (33.9%).

Table 2 shows cross-tabulation results for perception of tsunami risk and efficacy perceptions, preferred warning preferences, and behavioral intentions. The overall preferred warning preference of participants was a siren followed by tv and then natural warning signs. 76.7% of participants in Java reported that they would evacuate after observing natural warning signs compared to 58.8% in Sumba. The most common overall evacuation intention circumstance was an order or alert from the authorities although the percentage was higher in Java (84.7%) compared to all other islands (62-67%). Uphill evacuation was the most common evacuation intention location followed by inland, and then climbing the stairs to a tall building. 93.4% of participants in Java reported they would evacuate uphill compared to only 65.7% in Bali. 48.7% of participants in Bali reported they would climb the stairs of a tall building, compared to 26-29% of participants on other islands.

Table 2. Perceptions of Earthquake and Tsunami Risk and Efficacy, Warning Preferences, and Behavioral Intentions

Question (N, %)	Java (N=649)	Bali (N=388)	Lombok (N=423)	Sumba (N-917)	Total (N=2,386)
Earthquake Susceptibility					
Str. Disagree	30: 4.6%	10: 2.6%	39: 9.0%	183: 20.0%	262: 11.0%
Disagree	45: 6.9%	14: 3.6%	35: 8.1%	155: 17.0%	249: 10.4%
Neutral	65: 10.0%	141: 36.3%	74: 17.1%	131: 14.3%	411: 17.2%
Agree	382: 58.9%	181: 46.6%	192: 44.4%	314: 34.2%	1069: 44.8%
Str. Agree	124: 19.1%	38: 9.8%	90: 20.8%	126: 13.7%	378: 15.8%
No Answer	3: 0.5%	4: 0.3%	2: 0.5%	8: 0.9%	17: 0.7%
Tsunami Susceptibility					
Str. Disagree	39: 6.0%	15: 3.9%	46: 10.6%	212: 23.1%	312: 13.7%
Disagree	46: 7.1%	53: 13.7%	65: 15.0%	268: 29.2%	432: 18.1%
Neutral	58: 8.9%	171: 44.1%	103: 23.8%	102: 11.1%	434: 18.2%
Agree	294: 45.3%	128: 33.0%	164: 38.0%	245: 26.7%	831: 34.8%
Str. Agree	207: 31.9%	18: 4.6%	49: 11.3%	84: 9.2%	358: 15.0%

No Answer	5: 0.8%	3: 0.8%	5: 1.2%	6: 0.7%	19: 0.7%
Tsunami Efficacy					
Str. Disagree	29: 4.5%	13: 3.4%	29: 6.7%	114: 12.4%	185: 7.8%
Disagree	109: 16.8%	70: 18.0%	109: 25.2%	197: 21.5%	485: 20.3%
Neutral	135: 20.8%	157: 40.5%	131: 30.3%	111: 12.1%	534: 22.4%
Agree	270: 41.6%	114: 29.4%	107: 24.8%	289: 31.5%	780: 32.7%
Str. Agree	101: 15.6%	29: 7.5%	50: 11.6%	196: 21.4%	376:15.8%
No Answer	5: 0.8%	5: 1.3%	6: 0.7%	10: 0.01%	26: 1.1%
Warning Preferences					
Local leader	49: 7.6%	37: 9.5%	70: 16.2%	76: 8.3%	232: 9.7%
Cell phone	67: 10.3%	65: 16.8%	76: 17.6%	121: 13.2%	329: 13.8%
Radio	78: 12.0%	48: 12.4%	76: 17.6%	195: 21.3%	397: 16.6%
Siren	262: 40.4%	189: 48.7%	109: 25.2%	69: 7.5%	985: 41.3%
Nat. Warning	135: 20.8%	127: 32.7%	149: 34.5%	300: 32.7%	711: 29.8%
TV	170: 26.2%	85: 21.9%	156: 36.1%	372: 40.6%	783: 32.8%
Other	31: 4.8%	6: 1.5%	16: 3.7%	35: 3.8%	88: 3.7%
Evacuation Circumstances					
Alert from authority	550: 84.7%	256: 66.0%	290: 67.1%	575: 62.7%	1671: 70.0%
Family/Friend	283: 43.6%	87: 22.4%	116: 26.9%	266: 29.0%	752: 31.5%
Others Evacuating	481: 74.1%	94: 24.2%	124: 28.7%	271: 29.6%	970: 40.7%
Natural Signs	498: 76.7%	239: 61.6%	278: 64.4%	539: 58.8%	1554: 65.1%
Would not evacuate	24: 3.7%	5: 1.3%	10: 2.3%	31: 3.4%	70: 2.9%
Evacuation Intentions					
Climb building	189: 29.1%	189: 48.7%	113: 26.2%	267: 29.1%	758: 31.8%
Go up hill/mountain	606: 93.4%	255: 65.7%	331: 76.6%	765: 83.4%	1957: 82.0%
Go toward ocean	17: 2.6%	11: 2.8%	10: 2.3%	23: 2.5%	61: 2.6%
Go inland	563: 86.7%	208: 53.6%	264: 61.1%	477: 52.0%	1512: 63.3%
Stay in house	12: 1.8%	6: 1.5%	8: 1.9%	18: 2.0%	44: 1.8%
Other	71: 10.9%	13: 3.4%	65: 15.0%	64: 7.0%	213: 8.9%

*Select all that apply question results in over 100% when responses are totaled.

Results of Geographical Survey

This section outlines findings outside the survey results, considering various additional aspects of preparedness island by island.

All three cities that we surveyed in Java (Pelabuhan Ratu, Pangandaran, Pacitan) had mapped evacuation routes and identified gathering places. Along these routes, posted orange signs with a large rolling wave and a person running up a hill pointed the way (see *Figure 1*). In Pelabuhan Ratu the signs also included information listing the name of the evacuation destinations (park, hospital, government building etc.) and the distance, usually less than 1.5 kilometers.

Figure 1. Evacuation signs in Pelabuhan Ratu. All photos by Chad Emmett.

Interviews with many local leaders demonstrated a fear that they would be shamed if they called for an evacuation and no tsunami occurred. This included the head of the Indonesian Hotel and Restaurant Association (PHRI) for the Sukabumi regency, Dadang Hendar, and the village chief of Cimaja who said: “If there is a twenty second earthquake and we evacuate, but there is no tsunami, then we have evacuated for nothing.” There is still confusion as to who is actually in charge of educating and preparing people for tsunami mitigation and sounding the alarm. The head of PHRI was in favor of identifying and marking evacuation routes and having hotels inform each guest about evacuation procedures but noted that this was the “duty of the country and not the duty of the hotels.” There was a perception that interest in tsunami awareness wanes over the years as memories of past tsunamis fade. The village chief of Cimaja mentioned that they had held a practice evacuation five years ago. He related that since there had not been a tsunami, people lost interest in continuing to hold evacuation drills. The principal of the Pacitan Middle School 3 stated that his school had never held an evacuation drill. The fact that his school in the center of the coastal plain was 3-5 kilometers from any high ground made holding an evacuation drill most challenging due to time and distance. The principal stated that he assumed that tsunamis would happen at night when the children were in their own homes. He also believed that the police would drive through town with a siren telling people to evacuate.

The town of Pacitan with its surrounding villages was perhaps the best prepared. It was often women volunteers who were most involved and effective in the day-to-day tsunami mitigation efforts. They commented that their involvement was due in part their motherly instincts of wanting to help and save others. The village of Kembang in southeastern Pacitan was one of the first municipalities that the BPBD worked with in 2013 to help with tsunami preparedness. Large signs in the village show inundation areas, evacuation routes, and safe gathering places (see *Figure*

2). Additionally, the village widened and paved a path through rice paddies for easier evacuation and built two evacuation stairways up steep wooded hillsides to safe higher ground.

Figure 2. Directional sign along the evacuation route.

We were invited to host six evacuation drills in Pelabuhan Ratu. Reasons for not holding practice drills cited by school administrators included time constraints, unsafe evacuation routes due to heavy traffic, midday heat, and drills recently held or drills already scheduled for a future date. The drills that were held provided an excellent learning experience and in some cases drew attention to problems. We held our first evacuation drill in the village of Cidadap. It was a hot, humid and sunny midday. This proved to be our first introduction to the fact that adults are less inclined to participate in the heat. Cidadap had no evacuation signs or marked evacuation routes. The village leaders offered to drive us to the designated gathering point, but it was a circuitous route and defeated the purpose of empowering people to save themselves, preferably without relying on cars that can get stuck in traffic and in this case took them closer to the more vulnerable coast before heading inland to the hills. When asked, the children knew which way to go. To practice we used our phones to set a timer and identity our elevation and then set out with 50 children and one father walking through the village, across the rice fields--walking on foot wide banks between the flooded fields, through another cluster of houses and then climbing up a tree covered hillside to a safe elevation (see *Figure 3*). It took 15 minutes to get to safety.

Figure 3. Evacuation drill in Cidadap.

In Cisolok, the Junior High School is located across the coastal road from the beach and is very vulnerable. The village had never held a practice drill, but the school had held its first tsunami simulation practice two years earlier. For that event, students ran up the hill, 300 meters in 3 minutes, to pre-designated areas for each class. Administrators were happy to do it again. After a morning of presentations, more than 600 eighth and ninth graders left the school yard via a back gate and walked 300 meters up the hill to a safe elevation of 40 meters (see *Figure 4*). Then the first in line all sat down on the side of one lane road while waiting for the rest to arrive. Within 10 minutes all of the students were at a safe elevation. Afterwards, the physical education teacher observed that "it would be good to have evacuation practices every year at school."

Figure 4. Evacuation drill in Cisolok.

The easiest and most convenient evacuation drill we held was in the center of Pangandaran. All the elementary school children had to do was walk 50 meters to the end of the street, climb over a median planter in the center of the city's main street and then go to the second floor (the women's prayer section) of the main mosque which is a designated tsunami gathering place. Since the 2006 tsunami, Pangandaran has held annual evacuation drills so the children at this school knew exactly where to go. While the second floor was high enough to provide protection during the 2006 tsunami, it would not have survived an Aceh strength tsunami. An encouraging development in Pangandaran is the recent opening of a Temporary Evacuation Shelter (TES) closer to the coast.

During the 2006 tsunami the small village of Masawah (located right on the coast and about 30 kilometers west of Pangandaran) lost 47 residents to the wave. Most were at work or at home and had not evacuated because they had not been taught that even a low intensity earthquake could be a sign of a tsunami. There was no warning from the government or local leaders either. To ensure that more people survive the next tsunami, the village erected a memorial made of an actual fishing boat that was broken in two by the tsunami as a reminder of what could happen again and as an incentive to be prepared for the next natural disaster. In the village elementary school about 40 students participated in our evacuation drill. They first sought shelter under their desks while the earth "shook" then they ran through the village and up a steep hill via a cement stairway (installed after the last tsunami) to safety (see *Figure 5*). It took only a matter of minutes. The children knew exactly where to go and the cement stairway made it easy for everyone to easily ascend what could be a muddy, slippery mess during the rainy season.

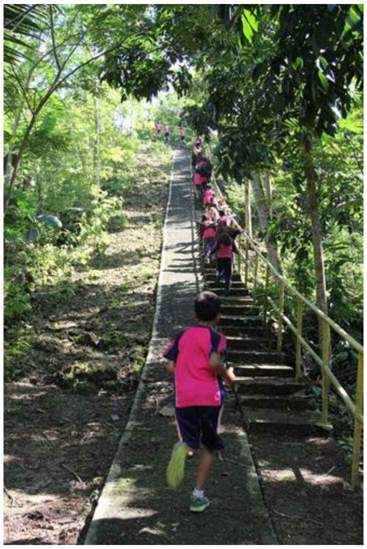

Figure 5. Evacuation drill in Masawah.

The village of Sidomulyo to the east of Pacitan had recently been awarded the provincial (East Java) prize for "self-reliance" because of its grassroots efforts to be prepared and trained for disasters. Practice evacuations were regularly held. At the start of our evacuation drill, children took off out the front gate on a predetermined and marked evacuation route. After about 200 meters inland the students knew to cross over a drainage ditch (a bottleneck in the evacuation route) on a log. Here the local leaders had the students stop, saying they had gone far enough. Of concern to our team was the fact that an elevation of 20 meters had not yet been reached. Further inspection of the rest of the route revealed that beyond the grove of trees the route ended at the base of a long and tall rock cliff. This thirty meter high rock face could be surmounted by agile adults and older youth, but it would be nearly impossible for the elementary school children to scale to a safe elevation. Later, back at the school when asked about this problem, local officials readily noted that they were very aware of this problem and that previous evacuation plans had called for building some sort of steps up the side of the cliff, but they were held back by inadequate funding. Also planned, but pending funding is adding a gate to the inland side of the school yard so that evacuees don't have to exit via the seaward front gate of the school yard.

Bali not only had tsunami warning signs, marked evacuation routes, and designated gathering points, but also had monthly evacuation drills, a workable EWS, published brochures with tsunami evacuation information and maps of inundation zones, and a certification program that identified Tsunami-Ready hotels. Ida Bagus Purna Sideman, the executive director of the Indonesian Hotel and Restaurant Association, noted that it was only after the 2004 Indian Ocean tsunami that Bali began to be aware of tsunami danger. Since then, there have been ongoing efforts to properly ensure that local Balinese and visiting tourists are more aware of and better prepared for tsunamis. Tsunami mitigation efforts in Bali's thriving hotel industry got their start in October of 2013 when the Asia-Pacific Economic Cooperation (APEC) forum held its 25th annual gathering in Bali. In preparation for the meeting, embassies of the participating countries requested that local police conduct security inspections of event hotels. The initial security concerns focused primarily on terrorism; however, while making their inspections, the police happened upon a Tsunami Ready Certificate in a major hotel in Nusa Dua—an Indonesia based company that advises, trains, and certifies hotels and other tourism related businesses on tsunami preparedness. The certificate was passed on to the local Tourism Board which questioned its validity. This prompted a discussion between the BPBD, Red Cross, Bali Tourism Board, and police about the merits and possibility of having the government issue such a certificate. Eventually the BPBD was tasked with making inspections and issuing Natural Disaster Ready Certificates which seems to have superseded the work of Tsunami Ready. Requirements for the government issued certificate include a safe assembly point, access (with direction signs) to the assembly point, and stored water and food at the assembly point. In addition, some hotels chose to have drills to train staff members about how to evacuate guests to the assembly point. When drills are held, the guests are given advance warning and participation is optional. Some hotels have reported that guests are in favor of these drills because it assures them that the hotel is a safe and ready place to be staying. Between 2013-2017, only forty of the thousands of hotels in Bali were awarded the Natural Disaster Ready Certificate. Most of the tsunami ready hotels are larger chain hotels that require such safety measures. According to Sideman, this means that 'the government has not given full attention to this matter.' Of the thousands of hotels in Bali, 260 are classified as star (1-5 star) hotels, 1,500 as non-star hotels, and 1,750 as homestays. The cheaper homestays and non-star hotels seldom have any type of disaster readiness. It is generally the high end hotels that express interest in becoming certified. Sideman notes that if tourism-dependent Bali is perceived as 'not being safe, then tourism will fail.' To facilitate preparedness, he suggests improved coordination between the Bali Tourism Board (which includes the Hotel association), the Tour Guide Association (HPI) and the Association of Recreational Parks (PUTRI).

Some multi-story hotels in Bali are readily identified as evacuation points. Two examples of hotels in tsunami vulnerable Tanjung Benoa, which straddles a narrow peninsula with no high ground, that could be considered 'tsunami ready' are the Novotel and the Grand Aston. Corporate policies of the Novotel international hotel chain requires that its hotels in Indonesia are prepared for tsunamis. Every guest room in the hotel has a brochure with a map and information about what to do in case of a fire, earthquake, medical emergency or bomb threat. This brochure is generic and not site specific to a tsunami inundation area. Also, in each room is a very noticeable large placard on the door with an evacuation map of the hotel grounds and with detailed instructions about what to do in the event of a tsunami and other emergencies. It explains that if a guest feels a strong or long lasting earthquake there may be a tsunami. Guests are told to follow the instructions announced in the hotel and on the beach by loudspeakers and megaphones. Guests are encouraged not to panic and to move to the designated assembly places in the hotel. Once gathered at the assembly points, the hotel guests are then directed 200 meters down the street to the Grand Mirage Hotel. A sign in front of the Novotel points the direction to the taller hotel. A local elementary school has arranged to use the nearby Grand Mirage and Ion Hotels for evacuations. The Elementary school children would also follow these signs.

The tsunami ready Grand Aston Hotel in Tanjung Benoa is not identified as a public gathering place, but it does have well marked signs near the beach and pool areas and on every floor in the hotel that leads guests up to the safety of the hotel rooftop above the fourth floor (see *Figure 6*). While well marked with signs, at check in guests are not informed about the meaning and use of these signs and the emergency information posted on the doors of each room of this hotel is very generic and refers only to evacuating down and out of the building for emergencies like a fire. No mention is made to evacuate up to the rooftop in the event of a tsunami threat.

Figure 6. Tsunami evacuation sign at the pool of the Grand Aston Hotel.

The island of Lombok is often referred to as an up and coming rival to Bali. It is more laid back and less congested than Bali while still offering beautiful beaches. The two main tourist destinations are the city of Kuta on the southern coast and the Gili islands off of the northwest coast. In 1977, a relatively small tsunami came ashore in Kuta. People remember the ocean turning black, easily catching stranded fish when the water first receded only to have a second wave wash out their catch, and people climbing coconut trees for safety. There were no deaths. Little action was taken after that tsunami: no signs were posted, memorials erected or inundation levels marked. The Aceh tsunami in 2004 was different. After seeing news reports of the devastation, several families in Kuta made the decision to leave their homes on the coastal plain and build new houses on the slopes of the nearby hills. Additionally, as in most parts of Indonesia, local and national disaster mitigation agencies started to act. In 2015, the BPBD put up evacuation signs and held a tsunami simulation. Local residents were recruited and compensated (20,000 rupiah or about $2, a meal and a bottle of water) to gather on the beach and then run several hundred meters inland to the mayor's office after a siren sounded. Residents were taught that earthquakes cause tsunamis and that they should run to higher elevations for safety. Several dozen tsunami evacuation signs were posted throughout the small town. Unfortunately, the signs were posted with the simulation in mind. All of the signs in town pointed to end-of-simulation gathering points like the mayor's office, the central mosque, an elementary school and an artists' market. These gathering points were fine as a place to offer compensation and a rice lunch, but they were not in line with teaching the need to head for the hills.

When asked about the signs, some locals explained that they would go to one of the gathering points first and from there they expected that someone from the government would come with transportation to take them inland. Others were more pragmatic. When asked about the purpose and practicality of the gathering points, one father, who had built a home on the safety of the hillside, described the evacuation signs as "crazy" and noted that if they followed the signs to the gathering point "they would all die." Several merchants with evacuation signs posted nearby, also explained that they would ignore the signs and run or ride a scooter to the hills. Several government officials also mentioned that the reason the signs pointed away from the hills was that the land belonged to private developers for future resorts and they did not want people "trespassing" during evacuation drills.

While in Kuta our team held two evacuation drills. The first at Elementary School 2 showed the mixed-up futility of the signs and the reality that even school children knew that the best direction to go was up the nearby hills. The school is one of the designated gathering places so signs point first to the school and then from there the signs point to the additional gathering points further into the center of the coastal plain. When presented with the need to quickly get to an elevation of 20 meters, all of the fourth and fifth graders knew to run westward, against the signs, to the nearby hills only a few hundred meters away.

The small city of Pemenang and its port of Bangsal are the ferry departure point to the Gili Islands. In 2012 a TES was built on the outskirts of the town (see *Figure 7*). The national governmental disaster management agency (BNPB Badan Nasional Penanggulangan Bencana) made the decision to build the shelter in part to provide protection for tourists. Curiously, most tourists only pass through Pemenang en route to the Gili Islands. Additionally, there are hills to the south of town that could provide tsunami refuge. Sirens have yet to be installed.

Figure 7. Temporary Evacuation Shelter in Pemenang

Soon after being built, the local BPBD held the first and only evacuation drill to the TES in which locals were paid to participate. Locals have mixed feelings about the building. Interviews with locals indicated that many in town attribute the construction of the TES to corruption and collusion that enriched some but made no sense to most. Some feel that the Gili Islands will stop a tsunami from reaching the town thus rendering such a structure as useless. A local non-profit (Pasir Putih) led a crusade to use the building for community activities as a way of helping suspicious locals become more accepting of the building and thus more willing to use it for evacuations. In 2016 the first annual Bangsal Meggawe Festival was held at several locations around town including the TES. The festival included cultural performances, activities, cinema showings and artists in residence. Many of those artists were then recruited to decorate the TES which they renamed Taman Evakuasi Seniman (evacuation park artists) which still uses the same acronym. Upbeat murals now decorate the ramps and the top two floors of the structure. Included in the decorations are dozens of yellow ducks leading the way up the ramps; a humorous slogan encouraging people to open their umbrellas before being rolled up by the waves, and a mural of clenched fists stating, “Together we our strong.” Another mural covers the whole floor of the top level and is easily seen from the air. It depicts a person with raised arms floating on half of an avocado with the large words “I’M HERE” written to the side. When not in use for the artist festival local children use the structure to play badminton in the open atrium and for athletic training on the top floor. Sadly, the 2018 earthquake in Lombok rendered the TES unsafe and destroyed the colorful main mosque in the center of town.

The island of Sumba is unique among most of the major islands of Indonesia in that it is not volcanic. It is an uplifted slab of limestone with low lying hills and limited fertility. It sits astride the Java Trench and is as prone to earthquakes and tsunamis as the other islands along Indonesia’s southern perimeter. Sumba is also the only Christian majority island included in our survey with a mix of Protestants and Catholics. Sumba and the other eastern islands of Indonesia are less developed and less populated compared to Java and Bali. They do not receive as much access to government resources and programs.

In our many classroom presentations and from survey results and interviews it became evident that most inhabitants of Sumba do not think their island is susceptible to tsunamis. This stems in part from the lack of worrisome volcanoes which are constant reminders of subducting plates below and a limited awareness of the island's seismic history in which there have been 21 tsunamis in the past 388 years beginning in 1629 (an average of one tsunami every 18 years). The most recent tsunami was in 1977 and before that 1938. None of these recorded tsunamis were major. Most of them originated from earthquakes along lesser faults to the north or east. The lack of tsunamis from the south suggests that there is considerable buildup of pressure along the section of Java Trench to the south of Sumba. The lack of any heavily destructive tsunamis in the past 400 years may explain why there is a local perception that Sumba is tsunami free and may also explain why Sumba, unlike Java, seems to have no folk tales or guardian deities associated with tsunamis or the sea to serve as a reminder of past disasters. Locals commonly expressed sentiments such as "tsunamis don't come here, that happens in Aceh." Sumba is the island furthest east and away from Sumatra of all our surveyed islands.

When visiting with local BPBD officials we were told that they were allocated a small budget from the BNPB (national agency) for posting evacuation signs. The budget was based on previous reporting of natural disasters, most of which were landslides during the rainy season. Signs were therefore posted in the areas where landslides have occurred leaving coastal tsunami areas with limited signage. There was no evidence of municipalities on other islands having to choose which disasters to focus on because of limited budgets. The focus on landslides has meant that in the rural outskirts of Waingapu, some of the evacuation signs (using the standard tsunami wave) point out into the rice paddies—which provide safety from landslides instead of up onto the surrounding hills which provide safety from tsunamis.

The undulating physical geography of Waingapu makes the establishment of evacuation routes and gathering points much more problematic than most coastal towns where it was easy to see and know what was high and what was not. On one day of field work we were discouraged to observe that there were no identified evacuation routes leading from the port area to safe areas. There were also no hills within sight. There was however a gradual rise in elevation leading away from the port. At the top of the rise stood a large mosque with a second story. When we inquired at the mosque as a potential evacuation site we were told that there had never been any thought of using the mosque and that a better option would be to evacuate down the rise across a river bottom and then up another rise to the government complex to safety. That rise was also a safe place, but the distance, especially for those coming from the port was too far outside the evacuation window to individuals to reach in safety.

In Waingapu we met with about two dozen local disaster officials to share our findings. We showed a map of the city that highlighted the inundation zone (see *Figure 8*). We pointed out the few evacuation signs posts that confusingly point in opposite directions. We then recommended evacuation sites (red stars), including the mosque up the incline from the harbor, that were in safer locations than the currently identified gathering places. Laying out and marking routes to these evacuation sites and then holding evacuation drills along the routes will help the people of Waingapu to be ready for a future tsunami.

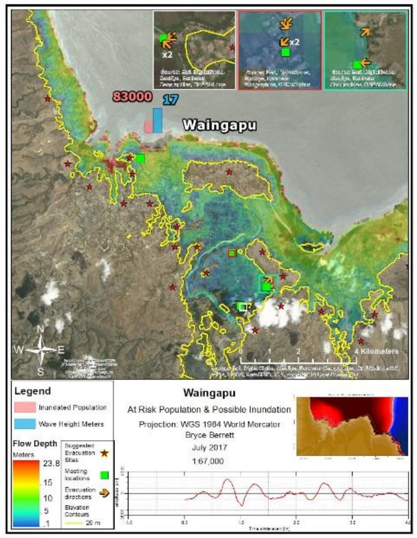

Figure 8. Waingapu inundation map by Bryce Berrett.

Conclusion

Our survey results demonstrate a great need for communicating tsunami risk and efficacy messages throughout Indonesia. Java, Bali, and Lombok tsunami susceptibility perceptions fell, on average, between *neutral* and *agree* while average tsunami susceptibility perceptions for Sumba fell between *disagree* and *neutral*. Tsunami risk and efficacy perceptions varied substantially by island suggesting the importance of needs assessments and culturally-tailored interventions when planning educational campaigns. Proximity to Aceh, funding for safer evacuation routes, lack of tall structures for evacuation, and varying terrains were shown to impact threat and efficacy perceptions depending on location and these factors must be addressed in localized initiatives.

Survey participants overall preferred to be warned by siren and TV over natural warning signs (e.g., ground shaking, receding ocean). There was also an overall preference to “order or alert from an authority” over “natural warning signs” in terms of evacuation circumstance. The history of delays, failures of EWS, and reluctance of local leaders to prompt community evacuation (since they believe they may be shamed if a tsunami does not come) necessitates a shift in attitude in terms of recognizing natural warning signs and immediately self-evacuating. This key message is included in the 20/20/20 campaign. The majority of participants said that they would evacuate uphill, followed by inland, followed by climbing the stairs of a tall building. Some of our research areas did not have hills or sufficiently tall buildings and we recommend TES are built in these areas as structural mitigation measures. Conservation of natural vegetative barriers is also important in many of the high-tourist locations where mangrove forests are cleared for tourist beaches and coral reefs are being depleted.

Since 2004, many coastal communities on the southern rim of Indonesia have made significant improvements to prepare residents for future tsunami disasters. National and local disaster mitigation agencies have installed tsunami warning systems (some of which no longer work), posted evacuation and tsunami inundation signs, identified safe gathering areas, built evacuation shelters, identified other tsunami ready evacuation structures, and conducted evacuation drills. Additionally, some locales have distributed tsunami maps showing routes and inundation zones, placed evacuation directions in hotels, and built tsunami memorials as a reminder of what has once happened and what might again happen.

In spite of these efforts there are still many who believe they live in a safe area or think that the government will be able to warn and transport them to safety in time. Efforts at all levels of governance need to continue to foster tsunami awareness.. Each new cohort of school children needs to regularly practice evacuation drills and be taught the principles of 20/20/20. Complacent adults should formulate or adjust plans so that they know how to recognize tsunami signs, where to go for safety and the time frame of how long it will take to reach a safe place. Additionally, more funding should be made available to make sure each village and city has evacuation routes and gathering places identified and appropriate signage posted to show the way. Future actions could include posting tsunami high water markers/signs along the coast, making sure that tsunami warning systems are installed and kept working, and developing rapid alert systems that are connected to increasingly common hand phones.

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