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Tsunami Awareness and Evacuation Behaviour during the 2018 Sulawesi Earthquake Tsunami

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Abstract:

On 28 September 2018 significant tsunami waves, which are considered to have been generated by submarine landslides, struck the shorelines of Central Sulawesi, Indonesia. One month after the event, the authors conducted a questionnaire survey of the affected areas (Donggala Regency and Palu City) to collect information on the evacuation behaviour and tsunami awareness of local residents. In the present study, in addition to summarising the overall trend of the survey results using descriptive statistics, a chi-squared test was applied to analyse the significance of the relationship between tsunami awareness and evacuation behaviour and the demographic characteristics of respondents. The analysis of the results demonstrates that although the respondents generally have a high level of tsunami awareness, younger people and Donggala Regency residents have an overall lower understanding of the phenomenon. It was also found that 82.5% of the population evacuated after witnessing others evacuating during the event. As there was no official warning to residents before the arrival of the tsunami, this social trigger played a significant role in prompting evacuation and decreasing the number of casualties. The present study also revealed that many people faced congestion while evacuating (especially in Palu City). This highlights the need to introduce additional tsunami disaster mitigation strategies to ensure that all residents can swiftly evacuate during such incidents.

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Keywords: Tsunami; Evacuation; Palu; Awareness; Preparedness; Statistical Analysis

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1. Introduction

1.1 Background

Tsunamis can cause widespread damage to coastal areas, as illustrated by the *2004 Indian Ocean Tsunami* and *2011 Tohoku Earthquake and Tsunami*. For the case of the *2011 Tohoku Earthquake and Tsunami* there were almost 16,000 casualties (National Police Agency of Japan 2019), and one of the important lessons from such events is that evacuation is the most effective way to protect lives (Shibayama et al. 2013).

To increase the number of people who can successfully evacuate during a future tsunami event, it is important to learn from the experience of evacuees during past tsunami events. Lindell and Prater (2010) recommend that post-disaster impact surveys should be conducted to collect information regarding the evacuation experience of residents, which have actually been investigated by a number of researchers in the past through questionnaire/interview surveys and analysis (e.g., Esteban et al. 2016; Takabatake et al. 2018a; Kang et al. 2007; Kajimoto et al. 2016). For instance, after the *2004 Indian Ocean Tsunami*, Iemura et al. (2006) conducted a questionnaire survey of the people affected in Banda Aceh, Indonesia and found that the majority of the respondents (94%) were unaware that a tsunami could occur after severe ground shaking. Gregg et al. (2006) investigated how those affected in Thailand had responded to natural signs of the *2004 Indian Ocean Tsunami* (e.g., ground shaking from earthquakes, sea-level changes, wave forms, sounds). According to these authors, although most of the 669 respondents had noticed some natural sign of the tsunami, many people did not evacuate before the first wave arrived. Lindell et al. (2015) analysed the responses of 262 residents during the *2009 American Samoa Tsunami* and indicated that 43% expected that the earthquake could cause a tsunami, and 15% obtained some sort of initial information about it from TV/radio broadcasts.

A number of questionnaire surveys were also conducted following the *2011 Tohoku Earthquake and Tsunami*. The Japanese government (e.g. Ministry of Land, Infrastructure and Transportation (MLIT), 2013; Cabinet Office of Japan, 2012) collected data on the evacuation behaviour of more than 10,000 individuals. In terms of triggers for evacuation, 46% of respondents relied on ground shaking, 28% on tsunami warnings, 27% on warnings from people around them, 22% on a warning from family members and 18% on screams of ‘tsunami’ from other people (these are the top five most frequently cited responses; note that respondents were allowed multiple answers). The data also revealed that around 60% of the respondents expected a tsunami after the earthquake, and more than half of the evacuees used vehicles to evacuate. Yun and Hamada (2012, 2015) compared the evacuation behaviour of survivors and

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non-survivors during the event and showed that starting time for evacuation was significantly different between them.

Although the majority of tsunamis are generated by the vertical displacement of the seafloor due to an earthquake, significant tsunamis are also known to have occurred as a result of subaerial and/or submarine landslides. Nevertheless, almost all past research on tsunami awareness and evacuation has focused on co-seismic tsunami events. One exception is Takabatake et al. (2019a), who conducted a questionnaire survey amongst Indonesian people that were affected by the *2018 Sunda Strait Tsunami*, which was caused by a subaerial landslide (more specifically, the collapse of a volcano, Anak Krakatau). The *1964 Alaska Good Friday Earthquake* generated submarine earthquake tsunamis that affected some coastal areas of Alaska (e.g. Seward, Valdez and Whitter), in addition to also generating co-seismic tsunamis. According to the survey reports (e.g. Lander 1996; Lemke 1967; Grantz et al. 1964), many residents witnessed that the tsunami waves generated by submarine landslides arrived to the coast within a few minutes of the initial ground shaking. Although no questionnaire surveys were conducted to analyse the evacuation behaviour of the affected people, Wood et al. (2014) showed that the location where the highest number of fatalities were recorded corresponds to that where the longest evacuation times are required.

Evacuation from submarine landslide tsunamis appears to be more challenging than that from co-seismic tsunamis. As shown in past submarine landslide tsunami events (*1964 Alaska Earthquake Tsunami*, *2018 Sulawesi Earthquake and Tsunami*, as will be explained in the next subsection), such tsunamis are likely to hit coastal areas immediately after the earthquake. To successfully evacuate, people are thus required to have a higher level of awareness and preparedness and initiate evacuation immediately after the earthquake, without expecting to receive tsunami warnings (Wood and Peter 2015). It is thus crucial to analyse the actual evacuation behaviour during submarine landslide tsunami events and derive lessons that can help to decrease the number of fatalities in the future.

1.2 2018 Sulawesi Earthquake and Tsunami

An earthquake with a moment magnitude (Mw) of 7.5 struck Donggala Regency in Central Sulawesi, Indonesia, at around 18:02 local time (UTC + 8 h) on 28 September 2018. According to the United States Geological Survey (USGS), the estimated epicentre of the earthquake was situated at 0.256° S and 119.846° E, at a depth of 20.0 km (USGS, 2018). Following the initial tremor, significant tsunami waves struck Palu City, a city that lies in a narrow bay of the island (**Fig. 1**), destroying low-lying houses and buildings near the shore. The tsunami also hit settlements in Donggala Regency, which is located north of Palu City. As of January 2019, the

National Disaster Management Authority (BNPB) of Indonesia reported that the death toll caused by both the earthquake and tsunami reached 4,340, with 667 missing, 10,679 injured and around 200,000 people still being displaced.

The earthquake took place along a strike-slip fault, which are generally not considered to be able to generate significant tsunamis. Thus, after the event many international teams, including the authors of the present study, conducted field surveys to attempt to clarify the tsunami generation mechanism, measure the run-up and inundation heights, and observe the damage to coastal communities (e.g. Arikawa et al., 2018; Muhari et al., 2018; Omira et al., 2019; Robertson et al., 2019; Mikami et al., 2019; Stolle et al., 2019). **Figure 1** presents the locations of the surveys conducted by the authors, showing that tsunami heights of above 4 m were recorded inside the bay, and below 4 m near its mouth. In **Figure 1**, tsunami heights are above the tide level at the time of the estimated tsunami arrival time (see Mikami et al. 2019), and the tidal range is around 2 m. Severe damage was concentrated within 200 m from the shoreline. Through the results of observations and computer simulations many authors (e.g., Heidarzadeh et al, 2018; Arikawa et al., 2018; Omira et al., 2019; Takagi et al., 2019; Sasa and Takagawa, 2018) concluded that the event was most likely to have been generated by submarine landslides, and there is evidence that many of them occurred inside the bay after the earthquake. In fact, a pilot who took off from the airport in Palu City just before the earthquake recorded a video showing unusual waves being generated on the west side of the bay, which quickly propagated (Takagi et al., 2019).

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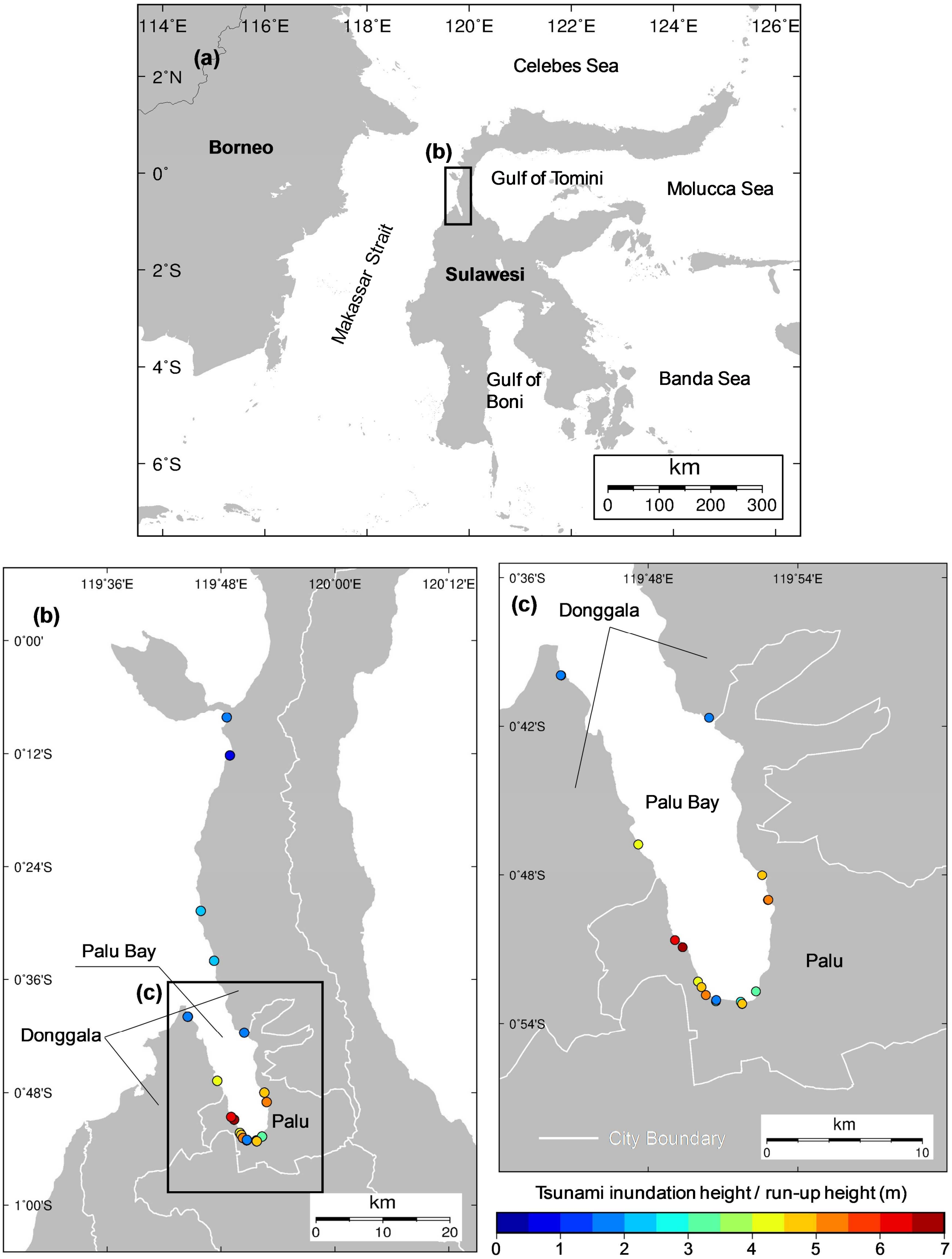

Fig. 1 Distribution of the tsunami heights measured along the coastline in Palu and Donggala (data from Mikami et al., 2019). Tsunami heights are above the tidal level at the estimated time of tsunami arrival. White lines show city boundaries.

During the event, immediately after the initial earthquake (at 18:02 local time) the BMKG issued a tsunami warning showing possible wave heights of 0.5 to 3 m for coastal areas, including Sulawesi Island (the warning was subsequently lifted at 18:39 local time). However, a newspaper article (Suroyo and Ungku, 2018) reported that residents neither received text alerts nor heard sirens during the disaster (which may have been due to the damage that power transmission lines suffered as a consequence of the earthquake). According to Takagi et al. (2019) and Carvajal et al. (2019), the tsunamis reached coastal areas within several minutes after the ground shaking.

1.3 Objectives

As explained earlier, although there is a need to investigate the actual evacuation behaviour that takes place during a submarine landslide tsunami, to the authors' knowledge, no research has been conducted using questionnaire surveys. To address this gap in the literature, the authors conducted a questionnaire survey in Palu City and Donggala Regency a month after the event, and gathered basic information about tsunami awareness, preparedness and the evacuation behaviour of coastal residents in each community. The primary aims of the present study are thus to characterise the tsunami awareness and evacuation behaviour of individuals during the *2018 Sulawesi Tsunami*, to examine the relationships between these variables and basic demographic information (such as age or gender) , and to derive lessons to improve the resilience of coastal communities that could suffer from submarine landslide tsunamis in the future.

2. Methodology

A field survey was conducted approximately one month after the tsunami, between the 27th and 31st of October 2018, concentrating on the coastline of Palu City and Donggala Regency. A questionnaire survey was administered by four native Indonesian speakers to individuals living in the residential areas of Palu and Donggala. More specifically, during the field survey, the authors drove along a road that runs parallel to the coastline of the bay, stopping whenever they saw a group of local residents, moment at which the enumerators got off the vehicle and administered the questionnaire survey. A total of 200 questionnaire sheets were used, as this number would give a confidence interval of 10%[1]. The original questionnaire survey was

[1] Given the population of the area, and the expectation that there was the possibility that some respondents might choose not to complete the questionnaire survey, the authors printed 200 questionnaires (though only n=166 would be needed to ensure a confidence interval of 10%). It should be noted that this assumes that there was a

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drafted in English, following the same basic format as the questionnaire surveys distributed in Chile and Indonesia in earlier research (see Esteban et al. 2013) and translated into Bahasa Indonesia.

It took approximately 5 to 10 minutes to complete the questionnaire survey, which consisted of 24 questions that were divided into 9 sections: demographics, awareness of tsunamis before the disaster, information about the tsunami, behaviour during the earthquake, whether the respondent evacuated or not, behaviour of those who evacuated, behaviour of those who did not evacuate, and awareness after the disaster (see Table 1). Some of the questions allowed only one response, though others allowed multiple responses. In the present study, if more than 20% of the questions were not properly answered (i.e., a questionnaire sheet had more than 5 incomplete responses), the sheet was assumed to be incomplete. It should be noted that this threshold of 20% is determined based on the authors own judgement and could be considered too strict. As a result, 197 questionnaires were considered valid out of 200 (valid rate: 98.5%).

In addition to summarising the results using descriptive statistics, a chi-squared test was used to analyse the significance of the relationship between tsunami awareness and evacuation behaviour and the demographic characteristics of respondents, including gender, age and location. To make comparisons easier, when investigating age differences the authors grouped the ages of 10–29 and termed them as the “young population”, 30–49 as the “middle-aged population” and 50–79 as the “old population”, and then analysed the differences between these groups. It should be noted that the authors indeed asked questions to those that were younger than 18 years, which were included in the 10-29 age group. The chi-squared tests were conducted using SPSS® software, version 25.

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Table 1 List of questions asked to local residents in the affected area.

Category	Question
Demographics	Gender
	Age
	Occupation
	Location
Tsunami awareness before the disaster	Q.1 Did you think that a tsunami was a real danger for you?
	Q.2 Did you receive enough information about tsunami hazards by the authorities?

normal population and that the sampling was random, though given the opportunistic nature of the survey these are not perfect assumptions.

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	Q.3 Did you think that you could evacuate in the event of a tsunami?
	Q.4 Have you joined evacuation drills for tsunamis in the last 5 years?
Information about the tsunami	Q.5 From where did you get information about the tsunami?
	Q.6 Was the information useful?
	Q.7 Did you get an evacuation order?
Earthquake event & Awareness of cascading hazards	Q.8 Did you experience the earthquake on 28 September 2018?
	Q.9 What types of phenomena were you afraid of during the earthquake?
Evacuation	Q.10 What did you do when you knew about the tsunami attack?
	Q.11 Did you evacuate?
For those who did evacuate	Q.12 What made you decide to evacuate?
	Q.13 How did you evacuate?
	Q.14 How many minutes did it take for you to reach the evacuation area?
	Q.15 Where did you evacuate to?
	Q.16 Was there any difficulty in evacuating?
For those who did not evacuate	Q.17 Why didn’t you evacuate?
Post Disaster	Q.18 Did you feel imminent fear about another tsunami after the attack?
	Q.19 When did you feel it was safe to go back to your house?
	Q.20 If face a similar situation once again, would you evacuate?

3. Results

3.1 Demographics

A summary of the respondents’ demographics characteristics is presented in **Table 2**, showing that the proportion of males and females was similar. The most common age groups were 30–39 (27%), 40–49 (22%) and 20–29 (22%). As the damage to the coastal area was more severe in Palu City (compared with Donggala) and this was the bigger population centre, the authors spent more time there resulting in a higher percentage of respondents from this location. The two main occupations of respondents included being a housewife (35%) or working in the fishery sector (25%), which is not surprising as Palu City and Donggala Regency are coastal cities and fishing activities are common.

Table 2 Summary of demographics. Percentages may not add up to 100% due to rounding.

Category	Percentage (N)

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Gender	Male	49% (97)
	Female	50% (98)
	No response	1% (2)
Age Group	10-19	8% (16)
	20-29	22% (43)
	30-39	27% (53)
	40-49	22% (44)
	50-59	12% (24)
	60-69	6% (12)
	70-79	2% (4)
	No response	1% (1)
Place of residence	Palu	64% (125)
	Donggala	36% (71)
	No response	1% (1)
Occupation	Fisheries	25% (50)
	Office	5% (10)
	Transportation	2% (4)
	Agriculture or livestock	4% (7)
	Retired	2% (4)
	Unemployed	5% (9)
	Housewife	35% (69)
	Student	8% (15)
	Others	13% (25)
	No response	2% (4)

3.2 Tsunami awareness before the disaster

At the start of the questionnaire respondents were asked whether they thought that a tsunami posed a danger to them, with 100% of the responses being affirmative, which would indicate a high level of tsunami awareness in the area. However, **Fig. 2** reveals that more than 50% of the respondents indicated that not enough information about tsunami hazards had been provided by authorities before the event. In fact, to the authors knowledge (one of the authors of the present study is a resident in Palu and actually experienced this disaster), there was no education at schools about tsunamis in the study area. A significant correlation exists between the evaluation of the tsunami information and the demographic profile of the respondents. For instance, whereas more than 50% of the male respondents did not have any opinions regarding the adequacy of the information about a tsunami, a higher percentage of female respondents (71%)

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had opinions (as either sufficient or insufficient, with the majority feeling the latter). Moreover, none of the respondents in the old population group responded that the information provided by the authorities had been satisfactory. Interestingly, a clear difference in the percentage of people who did not know whether the information had been satisfactory exists between the two locations, with 18% of the respondents in Palu City and 87% in Donggala Regency feeling this way.

A significant correlation was also found between the confidence in being able to evacuate and the demographic profile of the respondent. Male respondents and those in Donggala Regency reported being more confident in being able to evacuate from a tsunami (see **Fig. 3**). The reason why respondents in Donggala Regency were more confident could be explained by its relatively hilly terrain, which would allow people to easily evacuate (Mikami et al., 2019). Regarding age, while one could expect younger respondents to be more confident to be able to evacuate, the opposite was true, with older respondents appearing more secure in this respect. This could be related to their experiences and knowledge about tsunamis, though more detailed research would be needed to prove whether this is true.

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Figure 4 indicates how over 95% of the respondents had never participated in tsunami evacuation drills or had access to any drill. Those who had participated were mostly below 50 years of age, though in this case none of the answers were statistically significant. To the authors' knowledge, as no tsunami evacuation drills were ever conducted in the study area (at elementary schools the government only conducts earthquake evacuation drills), those who had participated might have done so at other locations in Indonesia.

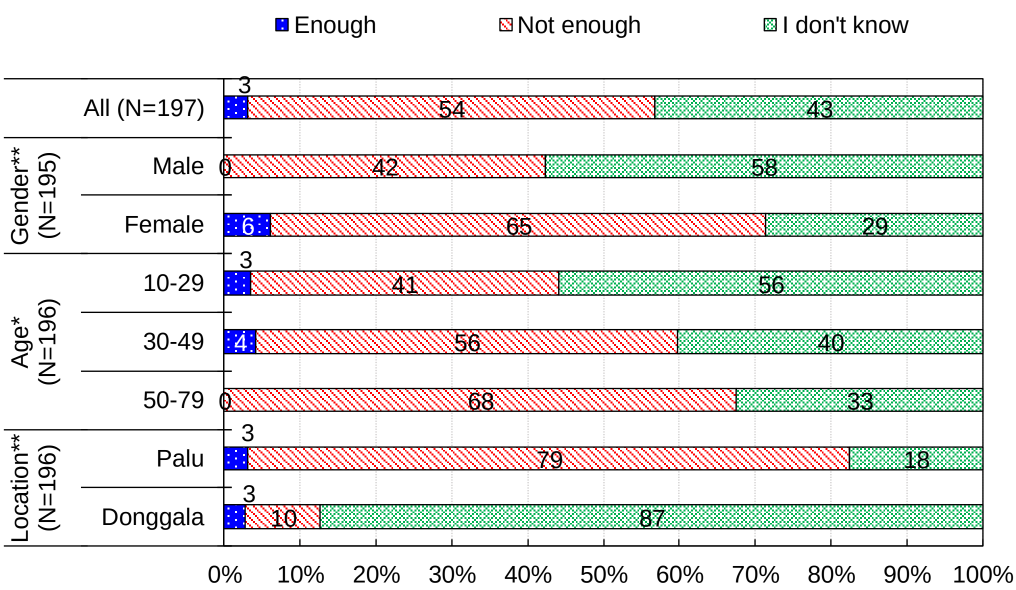

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Fig. 2 Distribution of responses regarding whether respondents thought that they had been sufficiently informed about tsunami hazards by authorities. Percentages may not add up to 100% because of rounding. ** p < 0.01. * p < 0.05.

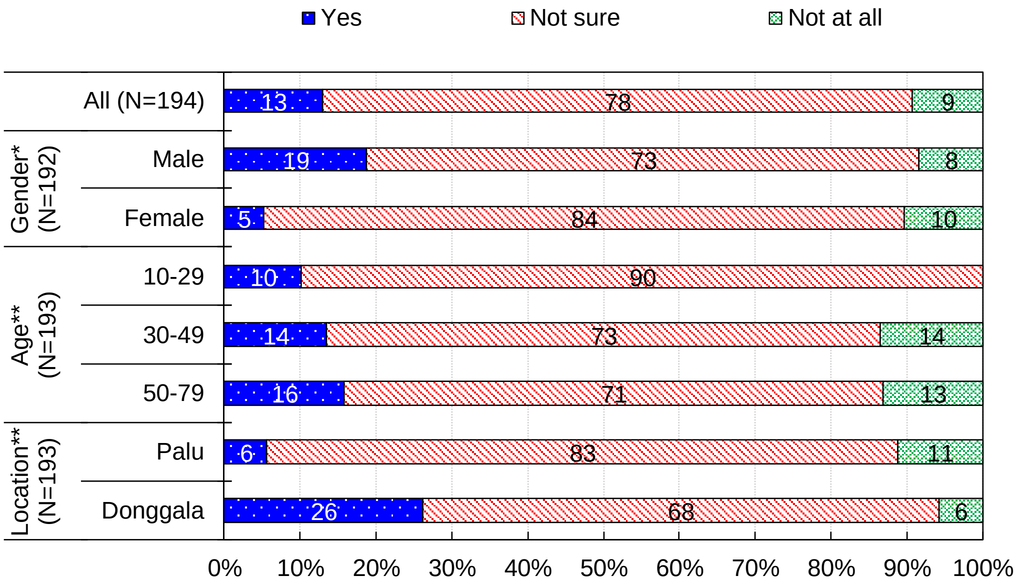

Fig. 3 Distribution of responses regarding whether respondents thought that they could evacuate in the event of a tsunami. Percentages may not add up to 100% due to rounding. ** p < 0.01. * p < 0.05.

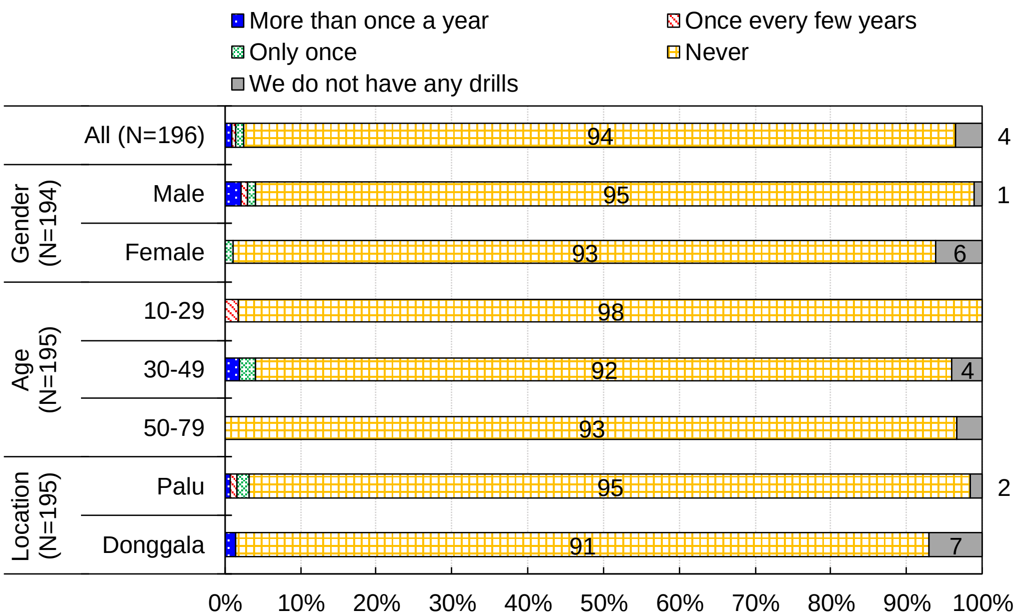

Fig. 4 Distribution of responses regarding whether respondents had joined tsunami evacuation drills in the past 5 years. Percentages may not add up to 100% due to rounding.

3.2 Information about the tsunami

A summary of the sources of information on the tsunami is presented in **Table 3**. Contrary to the observations in other coastal disasters (e.g. the *2013 Typhoon Haiyan* in the Philippines (Esteban et al., 2016), the *2018 Typhoon Jebi* in Japan (Takabatake et al., 2018a) and the *2009 Samoa Tsunami in Samoa* (Lindell et al., 2015)), fewer people received information from the media (e.g. TV, radio or Internet) during the event. The results also indicate that few respondents obtained information from public speakers, confirming that tsunami sirens indeed failed to provide any warning (an electricity blackout happened to the whole Palu and Donggala, as some towers of electricity transmission were broken). Instead, most respondents received information through face-to-face communication with neighbours (46%) and family members (22%), or by making their own deductions (after feeling the earthquake: 42%; after seeing or hearing the state of the sea: 19%). Male, older, and Donggala Regency respondents mostly received information from others, whereas many female, younger and Palu City respondents relied on their own deductions. In fact, significant statistical relationships exist between the likelihood of citing ‘neighbour’ and ‘own assumptions after feeling an earthquake’ as information sources and two of the demographics (gender and location).

More than 90% of the respondents indicated that the information obtained was useful or extremely useful (**Fig. 5**). Significant relationships were obtained between the age and location demographic variable, with younger and Donggala Regency respondents giving a lower evaluation to the quality of the information obtained.

Figure 6 indicates that a high percentage of respondents received an evacuation order. However, as explained previously, although an evacuation order was issued by authorities immediately after the earthquake (BMKG, 2018), the information was not widely disseminated (due to the malfunction of the tsunami sirens). Thus, the evacuation order that they received would likely have been the one given to them by others (e.g. neighbours, or family members). Significant relationships were not found between this question and any of the demographic variables.

Table 3 Sources of information about the tsunami (multiple-choice allowed). ** $p < 0.01$. * $p < 0.05$.

Answer options	All	Gender (N=195)	Age (N=196)	Location (N=196)

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	(N=197)	Male	Female	10-29	30-49	50-79	Palu	Donggala
TV, Radio	10%	12%	6%	7%	10%	13%	6%	17%
Loudspeaker car	1%	1%	0%	0%	1%	0%	0%	1%
Area loudspeaker	0%	0%	0%	0%	0%	0%	0%	0%
Internet	1%	0%	1%	0%	1%	0%	0%	1%
Family, relatives	22%	26%	17%	15%	21%	33%	19%	27%
Neighbors	46%	62%**	30%**	48%	46%	40%	34%**	68%**
Police and/or firefighter	1%	0%	0%	2%	0%	0%	0%	1%
Deduced by themselves (after feeling earthquake)	42%	30%**	54%**	42%	42%	40%	53%**	23%**
Deduced by themselves (after seeing or hearing the sea)	19%	12%*	27%*	22%	20%	15%	22%	13%

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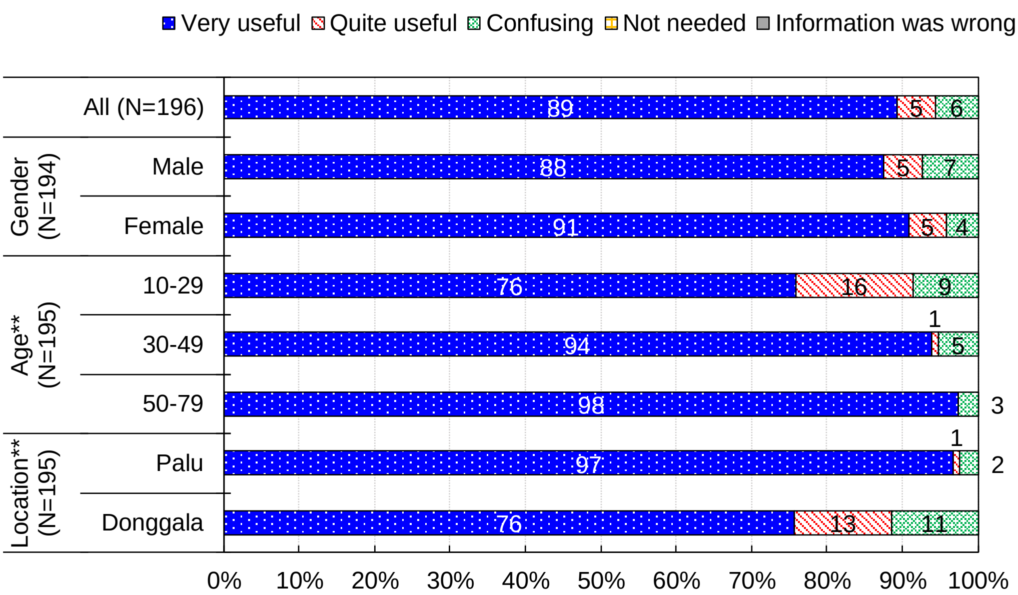

Fig. 5 Distribution of responses regarding whether the information respondents obtained about the tsunami was useful. Percentages may not add up to 100% due to rounding. ** p <0.01. * p < 0.05.

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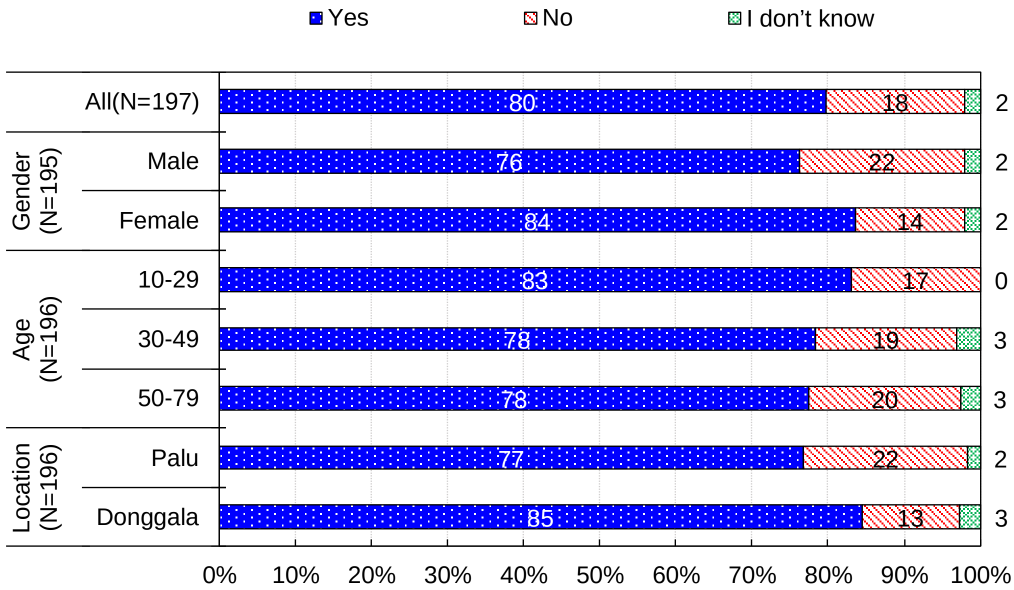

Fig. 6 Distribution of responses regarding whether respondents had received an evacuation order. It should be noted that the evacuation order in this case would not be an official one, but rather an unofficial one from neighbors or family members. Percentages may not add up to 100% due to rounding.

3.3 Awareness of cascading hazards

All respondents confirmed that they felt the earthquake on 28 September 2018. Respondents were asked what phenomena they thought would take place after the ground shaking, in order to clarify their overall disaster awareness and what the percentage of people who had anticipated a tsunami. Generally, people who anticipated a tsunami attack after the ground shaking should start evacuation earlier than others. However, there are many cascading hazards that can occur after an earthquake, and in the present study the authors focused on five of these. Indeed, it appears that the intense shaking caused fear of potential types of associated disasters, with respondents indicating that these included a tsunami (83%), house/building collapse (53%), landslides (12%), liquefaction (9%) and fire (1%) (see **Table 4**). It should be noted that multiple choice was allowed in this question. The difference between the most cited response for Palu City (tsunami, 97%) and Donggala Regency respondents (house or building collapse, 65%) may indicate a significant disparity in tsunami-likelihood awareness between the two locations.

Table 4 Phenomena that respondents were afraid of during the event (multiple-choice allowed). ** $p < 0.01$. * $p < 0.05$.

Answer options	All (N=197)	Gender (N=195)		Age (N=196)			Location (N=196)	
		Male	Female	10-29	30-49	50-79	Palu	Donggala

House / building collapse	53%	64%**	42%**	46%	57%	55%	46%*	65%*
Tsunami	83%	80%	86%	64%**	93%**	85%**	97%**	59%**
Liquefaction	9%	9%	8%	7%	12%	5%	9%	10%
Fire	1%	0%	1%	0%	1%	0%	0%	1%
Landslides	12%	13%	11%	15%	11%	10%	10%	16%

3.4 Evacuation

Table 5 shows the actions taken by respondents when they became aware about the tsunami attack. Most respondents (95%) indicated that they prepared to evacuate, 16% contacted families or neighbours, 6% collected further information and 2% just waited. No respondent mentioned going to the sea after knowing about the tsunami attack.

Table 5 Actions taken by the respondents when they knew about the tsunami attack (multiple-choice allowed). ** p <0.01. * p < 0.05.

Answer options	All (N=197)	Gender (N=195)		Age (N=196)			Location (N=196)	
		Male	Female	10-29	30-49	50-79	Palu	Donggala
Just waited	2%	2%	2%	3%	1%	3%	1%	4%
Prepared to evacuate	95%	92%	98%	93%	97%	93%	98%*	90%*
Collected further information	6%	7%	5%	14%**	4%**	0%**	2%**	14%**
Contacted family or neighbors	16%	25%**	8%**	22%	12%	15%	14%	21%
Went to the sea	0%	0%	0%	0%	0%	0%	0%	0%

Almost all of the respondents answered that they evacuated (only one respondent did not evacuate, as he was out of the risk area). The respondents' reasons for evacuation (evacuation trigger) are presented in **Table 6**, with nearly 50% indicating feeling the ground shaking, around 10% mentioning one or more environmental signals of a tsunami (e.g., 12% noticing an unusual behaviour of the sea surface, 7% hearing loud sounds from the sea, 6% directly observing the seawater approaching land and 7% being caught by the tsunami waves). However, the most frequently cited reason for evacuation is that they saw someone else evacuating (83%), demonstrating that this social trigger worked well, and decreased the number of residents caught by the flooding. No respondent cited the evacuation warning from local authorities as the reason for starting to evacuate, further confirming the poor dissemination of the official evacuation

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warning in the study area before the tsunami arrived.

The “feeling the ground motion” trigger correlated significantly with age and location. Older people and Palu City residents started evacuating after feeling the ground shaking, whereas younger people and Donggala Regency residents did so after seeing someone else evacuating. The rapid evacuation of Palu City residents after feeling the earthquake could be explained by their high level of awareness of tsunami as a cascading effect of an earthquake (see **Table 4**).

Figure 7 shows different modes of evacuation. It is possible to observe that only 1% of the respondents evacuated by car, which is clearly different from the evacuation behaviour observed during the *2011 Tohoku Earthquake and Tsunami* (in which around 50% of the evacuees used their car for evacuation). In the present event, the vast majority of people evacuated by foot, regardless of their demographic background. While part of this could be explained by the relative low car ownership in the area, the use of motorbikes is more widespread, though few reported to use this mode of transportation. The reason for this appears to be that immediately after the earthquake there were many people running and walking on the road, and thus due to this congestion evacuees could not use cars/motorcycles (one of the authors of the present study is a survivor from the tsunami, and actually witnessed severe congestion on the road leading to higher ground soon after the earthquake). There is also the possibility that many of the residents knew where to evacuate to in the event of a tsunami, and the distance from their position to this safe location was short, which meant they did not need to use a vehicle.

Table 6 Reasons why respondents decided to evacuate (multiple-choice allowed). ** $p < 0.01$. * $p < 0.05$.

Answer options	All (N=194)	Gender (N=192)		Age (N=193)			Location (N=193)	
		Male	Female	10-29	30-49	50-79	Palu	Donggala
Feeling the ground motion	50%	51%	48%	31%**	60%**	55%**	59%**	33%**
Seeing unusual behavior of the sea surface	12%	10%	14%	5%	13%	18%	15%*	6%*
Hearing a loud sound from the sea	7%	5%	8%	3%	10%	5%	11%**	0%**
Being caught by sea water	7%	9%	5%	0%**	13%**	5%**	8%	6%
Seeing someone evacuating	83%	91%**	74%**	86%*	86%*	68%*	74%**	97%**
Hearing someone calling for evacuation	4%	3%	5%	0%*	6%*	5%*	6%	1%
Receiving a message from the authorities through TV, radio, sirens, etc.	0%	0%	0%	0%	0%	0%	0%	0%

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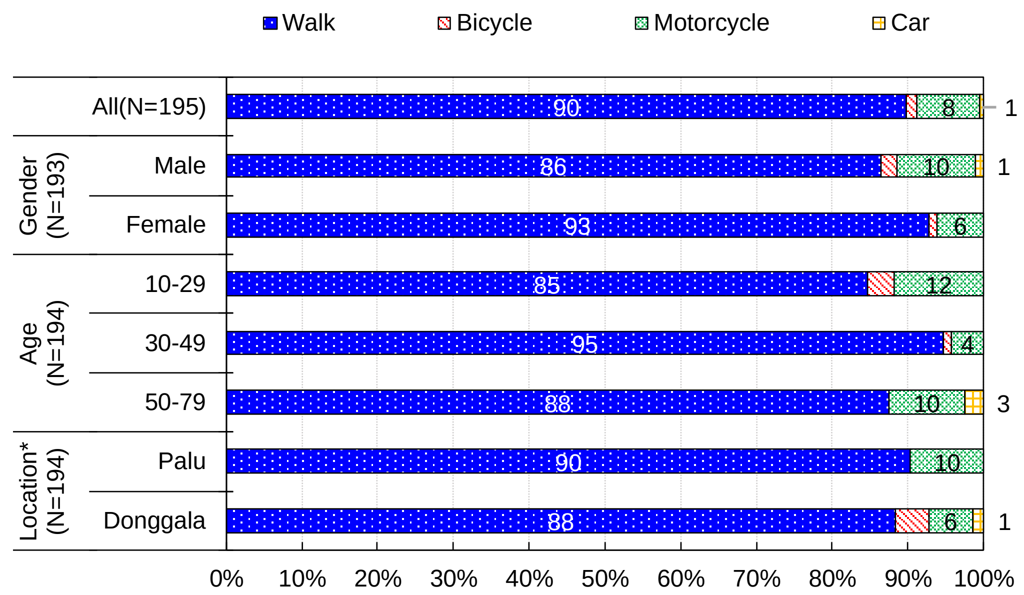

Fig. 7 Distribution of responses regarding how respondents evacuated. Percentages may not add up to 100% due to rounding. ** $p < 0.01$. * $p < 0.05$.

The time taken by respondents to reach the evacuation area (see **Fig. 8**) varied from 0–5 min (24%), 5–10 min (36%), 15–30 min (20%) and more than 30 min (21%). As expected, respondents in good physical shape (i.e., male, younger) took less time to reach a safe place. For instance, over 40% of the respondents aged 10–29 reached the evacuation area within 5 min, whereas only 10% of those aged 50–79 was able to do the same. A higher percentage of people in Donggala Regency finished evacuation within 5 min, and this is explained by its relatively hilly terrain, allowing people to easily reach a safe place (Mikami et al., 2019). This hypothesis is supported by data in **Fig. 9,** which shows the evacuation destination of the respondents. A higher percentage of those in Donggala Regency (68%) indicated that they evacuated to nearby high ground.

Regarding the difficulties encountered during the evacuation (**Table 7**), 63% of the respondents indicated congestion in the roads leading to a safe place (corroborating earlier explanations about the mode of evacuation). Although there was not a clear influence of gender in this reporting, other demographic characteristics showed strong correlations. Particularly, a significantly higher percentage of people in Palu City (75%) experienced congestion on the roads while evacuating, compared with those in Donggala Regency (39%), which can be easily explained by the higher population density in the area. Many respondents in Donggala Regency also indicated that they faced difficulty with deciding what to take with them, particularly amongst the younger respondents.

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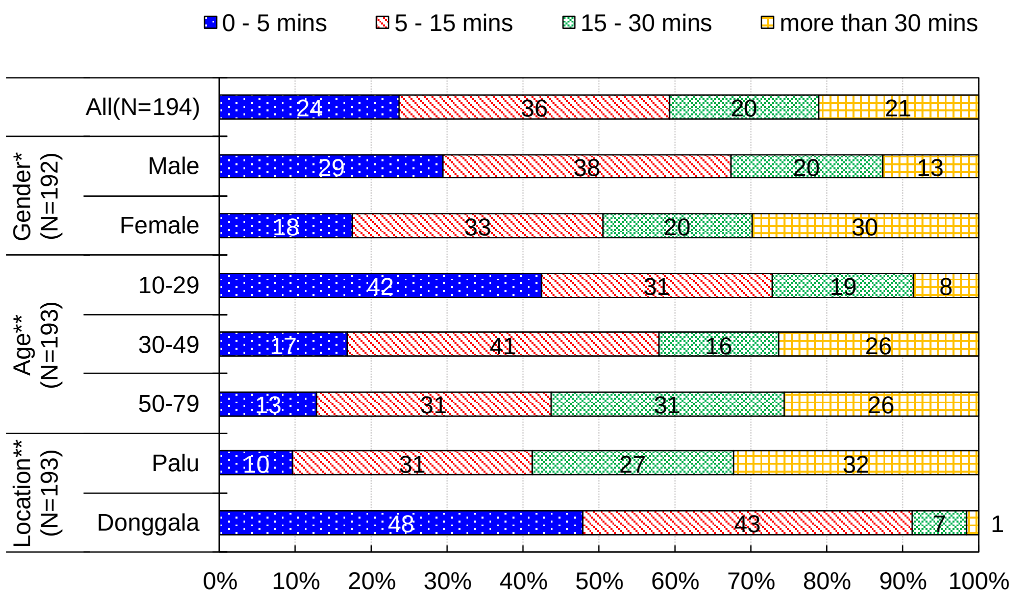

Fig. 8 Distribution of responses regarding how many minutes respondents took to reach a safe place. Percentages may not add up to 100% due to rounding. ** p < 0.01. * p < 0.05.

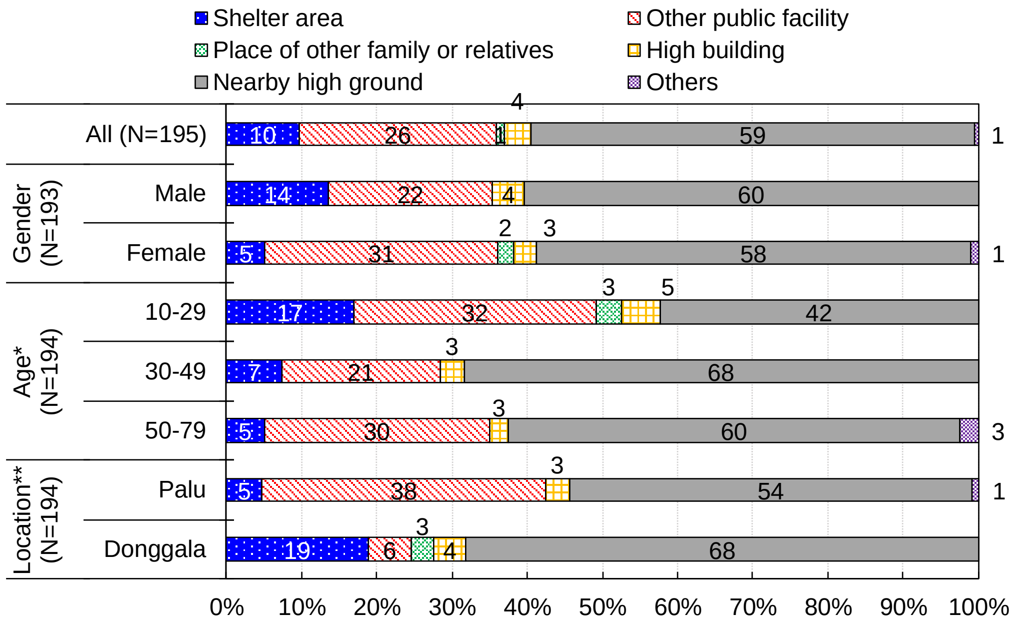

Fig. 9 Distribution of responses regarding where respondents evacuated to. Percentages may not add up to 100% due to rounding. ** p < 0.01. * p < 0.05.

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Table 7 Difficulties that the respondents faced while evacuating (multiple-choice allowed). ** p < 0.01. * p < 0.05.

Answer options	All (N=186)	Gender (N=184)		Age (N=185)			Location (N=185)	
		Male	Female	10-29	30-49	50-79	Palu	Donggala
I didn't know what to bring	20%	24%	15%	35%**	16%**	8%**	5%**	48%**
I had to look for relatives	22%	28%	17%	15%	25%	27%	26%	14%
There were too many people on the way to safety	62%	56%	70%	44%**	70%**	68%**	75%**	39%**
I didn't know where to go	7%	9%	4%	0%**	11%**	5%**	9%*	2%*

3.5 Post disaster

Almost all respondents (99%) indicated that they remained frightened after the event. **Figure 10** displays the time when residents felt it was safe to return home, with more than 50% only doing so after a week or more. A news article (Shelley et al. 2018) reported that for the case of this disaster it was difficult to quickly deliver aid, due to the difficulty in accessing the affected areas. That delay and the challenge to obtain fresh water and food could have influenced the mental state of respondents, and help to explain why it took so long for them to return. Statistically significant correlations were found for all three demographic variables, with male, younger and Donggala Regency respondents likely needing less time to feel safe to return home. Finally, all (100%) of the respondents confirmed they would evacuate if a similar situation occurred in the future, which was not surprising.

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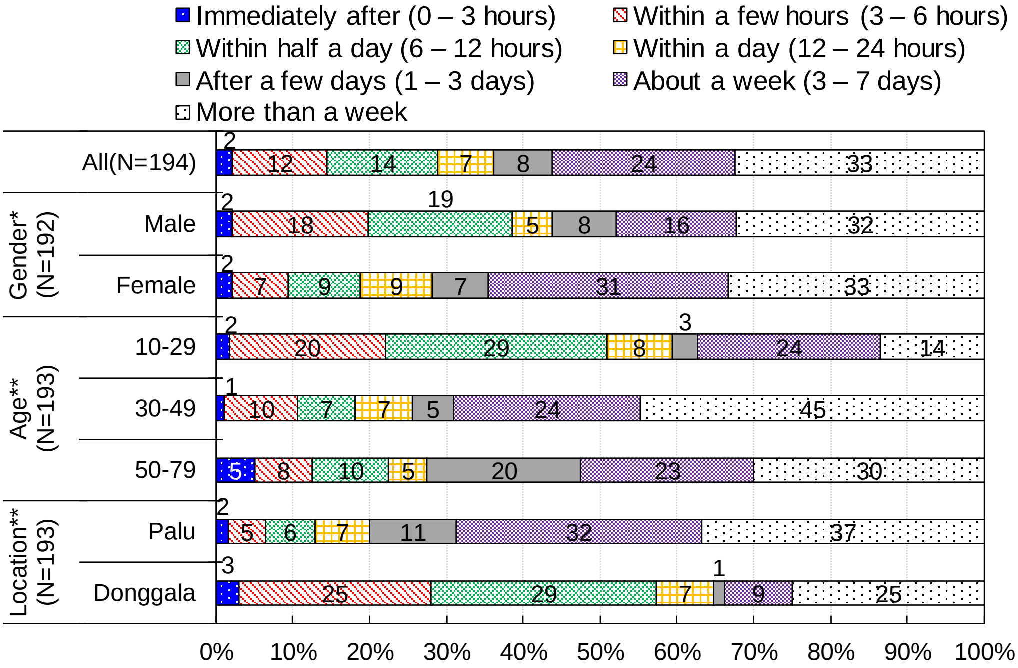

Fig. 10 Distribution of respondents regarding the time when they felt safe to go back to house. ** p < 0.01. * p < 0.05.

4. Discussion

The tsunami that affected Palu City and Donggala Regency originated from, and was amplified by, multiple submarine landslides. Takagi et al. (2019) and Mikami et al. (2019) interviewed several survivors who witnessed tsunami waves and reported that at least three waves, with the third being the largest, arrived at Palu City. Videos taken by survivors also revealed that the three waves reached Palu City within 10 min of the earthquake (Takagi et al. (2019) also confirmed the arrival time of the tsunami waves using a numerical simulation). This indicates that residents had barely a minute to start to evacuate from the coastline after the initial earthquake (though this first wave was quite limited in height). As previously discussed, official tsunami warnings failed to reach most residents. Likewise, challenging evacuation requirements (in terms of the short arrival time of tsunami) were observed during the *1964 Alaska Earthquake Tsunami*, which also resulted from submarine landslides. It is thus worthwhile to derive some lessons that could be helpful to decrease the damage and casualties from future submarine landslide tsunamis, by comparing the tsunami awareness and evacuation behaviour analysed in the present study with those of other coastal disasters in the past.

4.1 Tsunami Awareness

A questionnaire survey conducted amongst the people affected by the *2004 Indian Ocean*

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Tsunami revealed that many lacked enough knowledge about tsunamis and were unable to link a severe earthquake with the likelihood of a tsunami. In fact, Kurita et al. (2007) show that more than 70% of the respondents in Indonesia at the time were ignorant about what tsunamis were. Iemura et al. (2006) also indicate that more than 90% of the respondents in Banda Ache, Indonesia, were unaware of the risks associated with a major earthquake. Evidently, the level of tsunami awareness increased significantly after that amongst the population of Indonesia, as all respondents in the present study knew the dangers of tsunami, and 83% anticipated that a tsunami could take place following an earthquake. Such high levels of awareness that a tsunami could follow an earthquake have also been highlighted in the other places at risk (Lindell et al., 2015; Esteban et al., 2015), though the percentage of respondents answering this (83%) exceeds that (55%) reported for the *2011 Tohoku Earthquake and Tsunami* (Cabinet Office of Japan, 2012). Considering that few respondents in the present study felt that the information provided by the authorities had been enough (and many had not participated in evacuation drills), the high level of awareness could be the result of oral transmission of prior events to new generations, TV footage and associated media coverage (including the extreme devastation caused by events like the *2004 Indian Ocean Tsunami* or the *2011 Tohoku Earthquake and Tsunami*) rather than official efforts to disseminate information about tsunami hazards.

As explained earlier, evacuating from a submarine landslide tsunami is more difficult than doing so from a co-seismic tsunami, as existing tsunami warning systems are generally unsuitable for submarine or subaerial landslide tsunamis due to their short arrival times (Takagi et al. 2019). Thus, to minimise casualties from a similar event in the future, residents must quickly establish a link between strong ground shaking and the potential for a tsunami to arrive and start evacuation immediately by their own initiative. Although at present people in Indonesia report to have a higher level of tsunami awareness than in the past, knowledge on the risks and characteristics of submarine landslide tsunamis might not be sufficient. It is thus necessary for authorities to focus on disseminating information about submarine landslide tsunamis in potential areas at risk.

4.2 Information source and evacuation behaviour

Mass media is known to play an important role in the disseminating of disaster information, especially in cases of a slow disaster onset, such as typhoons, storm surges (Esteban et al. 2016; Takabatake et al., 2018a; Senoo et al., 2019) and far-field tsunamis (Perry, 2007). However, as the present tsunami affected coastal areas within a short time after the occurrence of the earthquake and due to the damage to the electricity supply system, only 10% of the respondents obtained information through TV or radio, which is much smaller than the 85% reported for the *2013 Typhoon Haiyan* (see Esteban et al. 2016). Rather, many respondents received information

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about the tsunami from neighbours or family members (46% and 22%, respectively), which is consistent with the findings from other near-field tsunami disaster studies (e.g., Esteban et al. 2013; Wei et al. 2017).

50% of respondents answered that they decided to evacuate due to feeling the ground shaking, which is similar to that reported in previous events (around 60% and 45% did so for the 2010 Chilean (Esteban et al. 2015) and 2011 Tohoku Earthquake and Tsunami (Cabinet Office of Japan, 2012), respectively). Given the shorter arrival time of submarine landslide tsunamis, it is necessary to increase awareness so that more people evacuate immediately after an earthquake, especially in coastal areas that are at risk of being hit by this type of tsunami event. Interestingly, although only around 15% cited 'seeing others evacuating' as the reason for evacuation during the 2011 Tohoku Earthquake and Tsunami (Cabinet Office of Japan, 2012), 83% did so for the present event, indicating that this social warning significantly helped in decreasing fatalities. Prompt evacuation should thus play a crucial role to decrease the number of fatalities from future submarine landslide tsunamis, and it is thus important to conduct further research to clarify why more people evacuated due to this social warning in the study area than in other places. Contrary to the case of the 2011 Tohoku Earthquake and Tsunami (where over 50% evacuated by car), more than 80% of respondents in this study walked to safe areas. This difference can be explained by the difference in tsunami arrival times, as the first wave arrived at Palu City within several minutes of the earthquake, which did not give respondents any alternative options (for the 2011 Tohoku Earthquake Tsunami the first wave reached many coastal areas within around 20 min – 60 min). It is also important to note that there was severe congestion on roads and many of the evacuees could not use cars. In fact, respondents faced a variety of difficulties while evacuating by foot, including congestion in roads, which was also noted in a study of the 2018 Sunda Strait Tsunami (Takabatake et al. 2019a). For the case of submarine landslide tsunamis, as residents should start evacuation immediately after the ground shaking, roads are more likely to suddenly become very crowded. It is thus necessary to consider the capacity of each road beforehand, and to develop an effective evacuation plan, including constructing, widening and maintaining new and existing evacuation routes,

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and increasing/or optimising the location of tsunami shelters. In this sense, agent-based modelling that is capable of simulating evacuation behaviour can be helpful to highlight potential problems during disaster events (Takabatake et al. 2017, 2018b, 2019b; Mostafizi et al., 2017). In addition, disaster risk managers in Palu City and Donggala Regency must seek to reduce the evacuation time for vulnerable people, as the results clearly showed that female and older people took longer to reach safe places. This can be done through multi-layer safety measures, where the locations where vulnerable groups undertake most of their daily activities is located away from the most at risk areas (such as by placing hospitals and schools on elevated ground, Esteban et al., 2015). 4.3 Difference in tsunami awareness and evacuation behaviour among different groups of people

The differences in the awareness and evacuation behaviour across individuals of different gender and age has been actively studied by a number of scholars (Huang et al., 2015; Wei et al. 2017; Bateman and Edwards 2005; Yun and Hamada, 2015). For instance, Bateman and Edwards (2005) reported a higher likelihood for females to evacuate during the 1998 Hurricane Bonnie, due to a higher overall risk perception. The present study supports the hypothesis that women anticipate better the risk that a tsunami might take place(see **Table 3**), and that they are less likely to be prompted to evacuate by others (**Table 6**). Despite the lack of significant correlations between information sources and age (**Table 3**), the results suggest a lower level of awareness and preparedness among younger than older people, with fewer anticipating a tsunami (**Table 4**), more attempting to collect information (**Table 5**), fewer starting to evacuate due to ground shaking (**Table 6**) and more being uncertain of what to bring with them (**Table 7**). The survey results also found that people in Donggala Regency were less aware of tsunami risks, with few anticipating a tsunami after the earthquake (**Table 3 and 4**), many trying to collect further information (**Table 5**), a few starting to evacuate due to severe ground shaking (**Table 6**) and many being uncertain of what to bring (**Table 7**). Although the reasons behind this are not entirely clear, Donggala Regency might have been less affected by previous tsunami events in Palu Bay, and prior generations there might have had less experience with such events (a tsunami was reported to have hit Paly Bay in 1927, see Mikami et al. 2019). Their occupations (there are many farmers in Donggala Regency) could also have had an effect on their lower level of tsunami awareness. These findings suggest the need to focus more on raising the tsunami awareness and preparedness of younger people and Donggala Regency residents in the study area.

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5. Conclusions

In the present study the authors examined the tsunami awareness and evacuation behaviour of people affected by the *2018 Sulawesi Earthquake and Tsunami*. A questionnaire survey was conducted 1 month after the event, and 197 valid answers were obtained. In addition to summarising the overall trend of the results using descriptive statistics, a chi-squared test was used to analyse the significance of the relationship between tsunami awareness and evacuation behaviour and the demographic characteristics of respondents (including gender, age and location).

The analysis of the results demonstrates a high level of tsunami awareness amongst the residents of the study area, with more than 80% anticipating a tsunami after ground shaking. Undoubtedly, the high level of tsunami awareness saved many lives, especially given the fact that the tsunami reached the study area within several minutes. One of the characteristics of submarine landslide tsunamis is this shorter arrival time, which highlights the importance of residents evacuating at-risk coastlines immediately after ground shaking using their own initiative (instead of expecting an evacuation warning). It is also necessary for local authorities to increase information dissemination activities about this type of tsunami. For the case of the study area, as the survey result indicates that younger people and Donggala Regency residents had a lower overall awareness, efforts should be made to improve their education regarding how to act during a disaster. It was also found that 83% of the population evacuated after witnessing others evacuating. As there was no official warning, this social trigger played a significant role in prompting evacuation and decreasing the number of casualties from the tsunami, indicating the importance of strengthening the relationship among people in local communities. It is also necessary to carry out further research on the influence of social behaviour on human evacuation behaviour.

The present study also revealed that many people faced congestion while evacuating (especially in Palu City). Given the shorter arrival time of tsunami, such road congestion issues could appear in other areas at risk of submarine landslide tsunamis. Even if all residents could start evacuation immediately in the future, they would still be caught by a tsunami if they failed to swiftly evacuate due to congestion. This highlights the need to introduce additional tsunami disaster mitigation strategies (formulating an effective evacuation plan, constructing sufficiently wide and paved evacuation routes, and increasing the number of sturdy evacuation buildings) to ensure that all residents can rapidly evacuate during such incidents.

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Sincerely,

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