Chapter

The Risk of Tsunamis in Mexico

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Abstract

The paper reviews the risk of tsunamis in Mexico. It is highlighted that the Pacific coast of the country forms part of the so called "Ring of fire". Overall, the risk of tsunami that has the potentiality to affect communities along the Pacific coast of the country are twofold: a). Local tsunami; i.e., those triggered by earthquakes originating from the "Cocos", "Rivera" and the "North American" plates (high risk); and b) the remote tsunamis, those generated elsewhere (e.g, Alaska, Japan, Chile) (low risk). Further, a preliminary model for a "tsunami early warning" system for the case of Mexico is put forward.

Keywords: tsunami, earthquake, Mexico, tsunami early warning

1. Introduction

A *tsunami* has been defined as "a series of travelling waves of extremely long length and period, usually generated by disturbances associated with earthquake occurring below or near the ocean floor … Volcanic eruptions, submarine landslides, and coastal rock falls can also generate tsunamis, as can a large meteorite impacting the ocean" [1]. Also, tsunamis may be regarded as low frequency events but with high impacts in terms of human/infrastructure/economic losses. Their power of destruction has been more than evident in recent years [2–11]. It is believed that from the time period between 1998 and 2017, the losses inflicted by tsunami disasters were a total of US$280 billion and 251,770 causalities, in damages [7]. Moreover, the authors argue that the impact from this period has been 100 times higher than during the time period 1978–1997.

Following the 2004 tsunami in the Indian Ocean, there has been a large amount of literature published on several topics associated with tsunami science. For example, research has been conducted on the physics of tsunami waves [12], tsunami's impact and characteristics [1–3, 11, 13], tsunami early warning systems [14, 15], tsunami risk assessment [10, 11, 16], geology's perspective [17–19], to mention a few.

Recent tsunamis have highlighted the need for an effective early warning system. An early warning is defined as "the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid or reduce their risk and prepare for effective response" [20]. Moreover, the United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR) argues that an "effective early warning system" should include the following four key elements: "the knowledge of risks", "the technical monitoring and warning service", "dissemination & communication of meaningful warnings to those at risk", and "the public awareness and preparedness to react to warnings" [20, 21].

The objective of the paper is to highlight the tsunami risk in Mexico. The data presented in the paper are based on previous studies on tsunamis in the country [15, 22]. Further, a preliminary "tsunami early warning" system which aims at integrating, for example, the four key elements proposed by the UNISDR [20] for the case of Mexico is presented.

2. The risk of tsunamis in Mexico

The "Pacific ring of fire" belt covers a vast area of highly active tectonic plate boundaries where most of the earthquakes originate and active volcanoes (**Figure 1**). It is believed that three quarters of all the volcanoes in the world are in the ring [23].

Further, the "Ring of fire" runs through several countries, such as Canada, USA, Russia, Chile, Peru, Guatemala, New Zealand, Japan, Indonesia, Philippines, Mexico.

Regarding the tsunami risk in Mexico, studies based on tsunami historical data showed that there are two zones of tsunami threat: local (i.e., generation of tsunamis) and remote (i.e., arrival of tsunamis) (**Figure 2**) [15, 22]. The authors defined these two zones by considering the nature of the faulting and tectonic plate interaction. In the subsequent subsection each of these will be addressed.

2.1 Local tsunami risk

According to [15, 22] at the west of the "Rivera plate" and along the "Middle America trench," the "Cocos plate" subduction beneath the "North American plate" at rates of 2.5 to 7.7 cm/year (**Figure 2**). Given the fact, that large earthquakes occur in this region; therefore, the zone has been regarded as a generator of tsunamis (**Table 1** and **Figure 3**).

According to historical data, the generated tsunamis that produced the highest wave heights were those that occurred in 1925 (7–11 m), 1932 (9–10 m), 1995 (2.9–5.10 m), 1985 (1–3 m). For example, the 1985 earthquake of M8.0 of magnitude generated a tsunami that affected several communities in this zone. It is believed that a key infrastructure port was affected with waves of 2.5 m and flooded the area about 500 m inland [15]. Also, several tourist resorts were affected by the tsunami; for example, waves for up to 2.5 m high were observed in Playa Azul [15].

Interestingly, a day after the main earthquake, a M7.5 aftershock hit the zone; it is thought the generated tsunami affected a local fishing community with waves ranging from 2 to 3 m high [15].

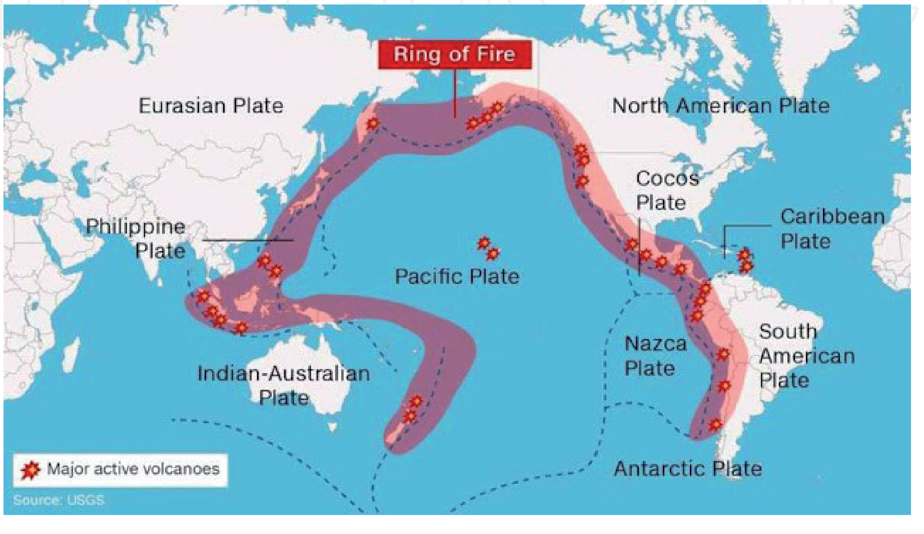

Figure 1.
The "Ring of fire" [23].

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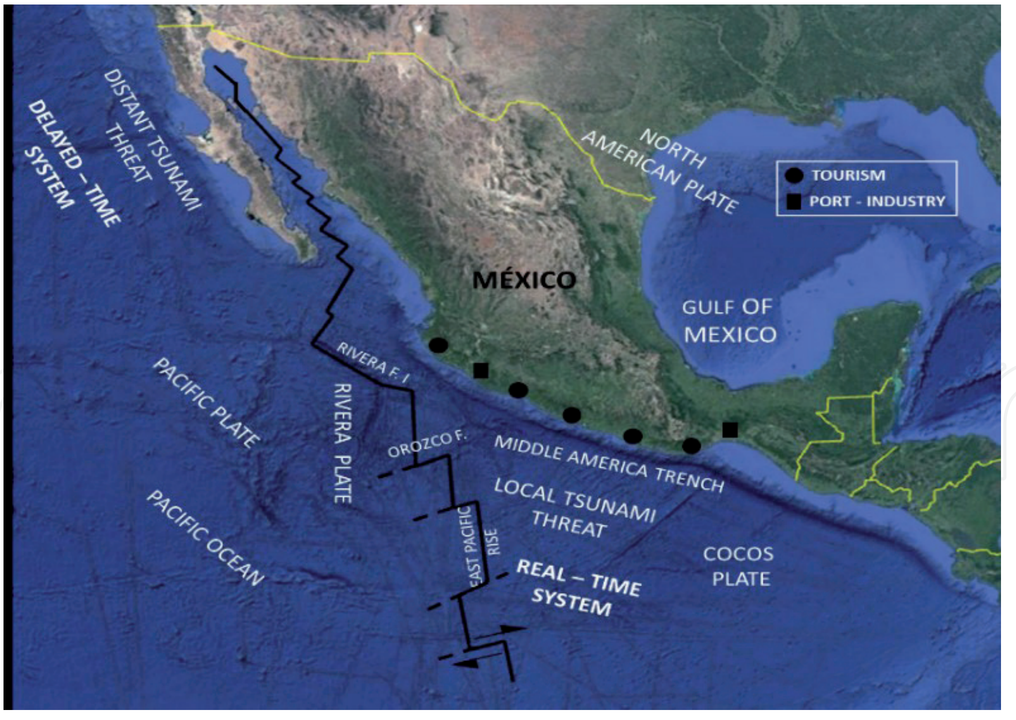

Figure 2.
Mexico's local & remote tsunami threat [15, 22].

Year	Region	Magnitude	Tsunami (places hit, Mexico)	Max. height waves (m)
1732	Guerrero	—	Acapulco	4.0
1754	Guerrero	—	Acapulco	5.0
1787	Guerrero	>8.0	Acapulco	3–8
1787	Oaxaca	—	Juquila Pochutla	4.0 4.0
1820	Guerrero	7.6	Acapulco	4.0
1852	B. C.	—	Río Colorado	3.0
1907	Guerrero	7.6	Acapulco	2.0
1925	Guerrero	7.0	Zihuatanejo	7.0–11.0
1932	Jalisco	8.2	Manzanillo San Pedrito	2.0 3.0
1932	Jalisco	7.8	Manzanillo	1.0
1932	Jalisco	6.9	Cuyutlán	9.0–10.0
1948	Nayarit	6.9	Islas Marias	2.0–5.0
1957	Guerrero	7.8	Acapulco	2.6
1973	Colima	7.6	Manzanillo	1.1
1978	Oaxaca	7.6	Puerto Escondido	1.5
1979	Guerrero		Acapulco	1.3
1985	Michoacán	8.1	Lázaro Cardenas Ixtapa Zihuatanejo Playa Azul Acapulco Manzanillo	2.5 3.0 2.5 1.1 1.0
1985	Michoacan	7.8	Acapulco Zihuatanejo	1.2 2.5

Year	Region	Magnitude	Tsunami (places hit, Mexico)	Max. height waves (m)
1995	Colima	8.1	Boca de Iguanas	5.10
			Barra de Navidad	5.10
			San Mateo	4.90
			Melaque	4.50
			Cuastecomate	4.40
			El Tecuán	3.80
			Punta Careyes	3.50
			Chamela	3.20
			Pérula	3.40
			Punta Chalacatepec	2.90
2003	Colima	7.8	Manzanillo	1.22
2017	Chiapas	8.1	Salina Cruz	1.10

Table 1.
Local tsunamis-only those with wave height > 1.0 m are shown [22].

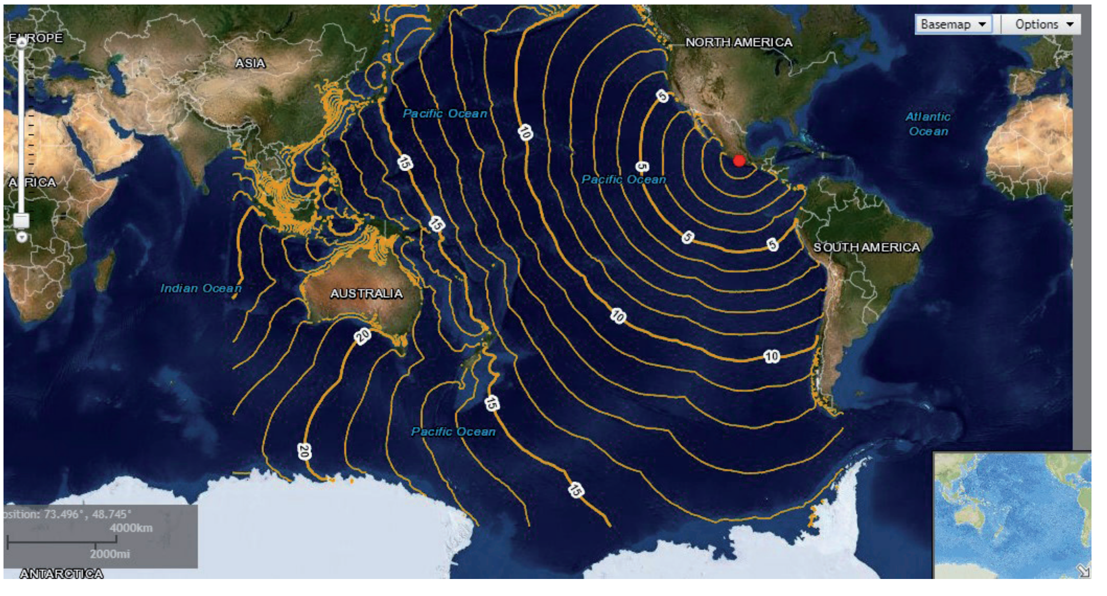

Figure 3.
Local tsunamis in the pacific coast of Mexico [24].

More recently, it has been found that instrumentally based assessments of "tsunamigenic" possibility of subduction zones in the Pacific coast have underestimated the frequency and magnitude of great earthquakes and tsunamis [25]. The authors argue that geological evidence shows that in fact great tsunamis (and earthquakes) have occurred in the subduction zone in the past, i.e., the stretch of the coasts of Guerrero and Oaxaca, the southern region of Mexico.

For example, it has been found evidence of two sand tsunami deposits, 1.5 km inland of the coast [25]. Further, it is believed that an earthquake of M8.6 of magnitude occurred in 1787 and produced a giant tsunami that flooded up to 6 km inland. The second tsunami (less documented) occurred in the year 1537. More importantly, the authors conclude that great tsunamis have occurred in the Pacific coast of the country.

On the other hand, it should be highlighted that another geographical region that is not mentioned in the official reports (e.g., in Ref. [22]) in relation to the potential tsunami source is that related to those originating in the Caribbean Sea (**Figure 4**). It is believed that geological events such as volcanoes and earthquakes

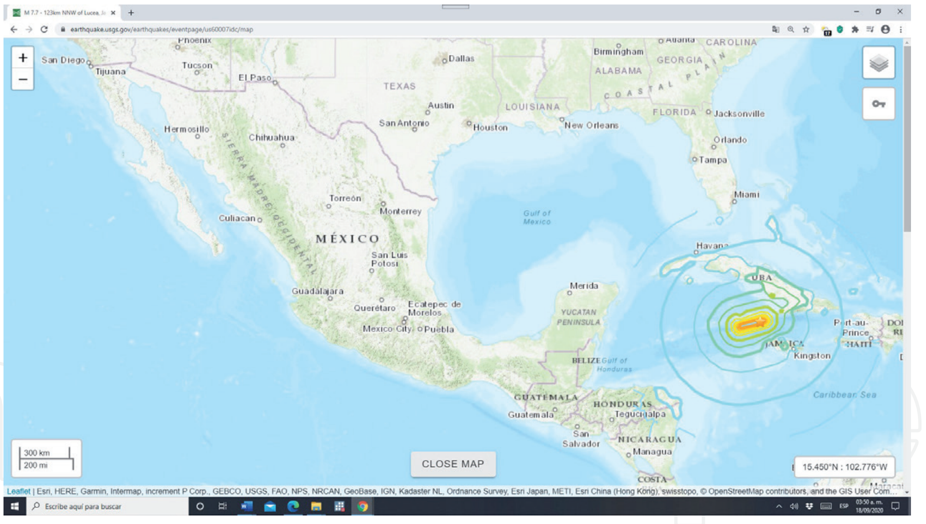

Figure 4.
The 123 km of Lucea, Jamaica earthquake in 2020 [26].

are common and therefore the region is geological active [27]. Further, the authors argue that historical data has shown that there has been the occurrence of "tele-tsunamis," tectonic tsunamis, landslide tsunamis, and volcanic tsunamis in the region [27], p. 60.

That is, there has been twenty-seven "verified tsunamis" and "nine are considered to be very likely true tsunamis" of a total of 97 reported waves that might be tsunamis in the Caribbean region [27]. Moreover, it is believed that one of the deadliest and most recent tsunamis that hit communities in Dominican Republic, Haiti, and Puerto Rico occurred in 1946; the tsunami killed 1790 people [27], p. 84.

More recently, this threat became more apparent with the occurrence of a strong earthquake in the region (**Figure 4**). That is, on 28 January 2020, an earthquake of M7.7 of magnitude (with a depth of 1o km) hit between the Cayman Islands and Jamaica and Cuba [26]. It is believed that the tremors were felt as far away as Miami, US. However, no causalities have been reported.

The earthquake prompted the issuing of tsunami warnings by the Pacific Tsunami Warning Center (PTWC) [28]. The PTWC's warning was: "hazardous tsunami waves are possible; it is thought the warning was for communities living along the coasts located within 300 km from the epicentre; i.e., those include coasts of the following countries: the Caiman Islands, Jamaica, Belize, Cuba, Honduras, and Mexico (i.e., the Caribbean coast of the Yucatan Peninsula, **Figure 4**). The tsunami warning was lifted off after a few hours.

Overall, it may be argued that a potential threat of tsunamis come from the Caribbean Sea, although it may be regarded as extremely low (i.e., there has not been any data of tsunamis hitting the Caribbean coast of the Yucatan Peninsula); however, tsunamis are unpredictable and communities, governments should always be prepared for the unthinkable, because as usual, this is what happens (see Section 3 for further details about this).

2.2 Remote tsunami risk

It is believed that on the Northwest of the "Rivera plate" (**Figure 2**), along the Gulf of California where the Pacific Plate slides north with respect to the North American plate, generation of tsunamis in this zone is unlikely [15, 22]. This is

Date	Region	Magnitude	Tsunami (places hit, Mexico)	Max. height waves (m)
1952	Kamchatka, USSR	8.3	La Paz, BCS	0.5
			Salina Cruz	1.2
1957	Aleutian Islands	8.3	Ensenada, B.C.	1.0
1960	Chile	8.5	Ensenada, B.C.	2.5
			La Paz, B.C.S.	1.5
			Mazatlán	1.1
			Acapulco	1.9
			Salina Cruz	1.6
1960	Peru	6.8	Acapulco	0.10
1963	Kuril, Islands, USSR	8.1	Acapulco	<1.0
			Salina Cruz	
			Mazatlan	
			La Paz, B.C.S.	
1964	Alaska	8.4	Ensenada, B.C.	2.4
			Manzanillo	1.2
			Acapulco	1.1
			Salina Cruz	0.8
1968	Japan	8.0	Ensenada, B.C.	<1.0
			Manzanillo	
			Acapulco	
1975	Hawaii	7.2	Ensenada, B.C.	<1.0
			Manzanillo	
			Puerto Vallarta	
			Acapulco	
1976	Kermadec Islands	7.3	San Lucas, B.C.S.	<1.0
			Puerto Vallarta	
			Manzanillo	
			Acapulco	
1995	Chile	7.8	Cabo San Lucas	<1.0
2004	Indonesia	9.0	Manzanillo	1.22
			Lazaro Cardenas	0.24
			Zihuatanejo	0.60
2010	Chile	8.8–9.0	Manzanillo	0.32
			Cabo San Lucas	0.36
			Acapulco	0.62
2011	Japan	9.0	Ensenada, B.C.	0.70
			Huatulco	0.70
			Puerto Angel	0.29
			Acapulco	0.72
2018	Indonesia	7.5	—	—
2018	Indonesia	AK Vulcano tsunami	—	—

Table 2.
Remote tsunamis- historical data taken from [22] except for the last two tsunamis that occurred in 2018.

consistent with historical data (**Table 2**); it can be seen that data on "small" and "moderate" tsunamis generated by remote sources; for example, the two most recent 2010 Chile and the 2011 tsunamis (**Figure 5**) where the maximum wave heights registered were < 1.0 m. However, it is worth mentioning that the historical data showed that there were two tsunamis that registered the height of waves up to 2.4 and 2.5 m; that is, those generated in Chile (1960) and Alaska (1964), respectively (**Table 2**).

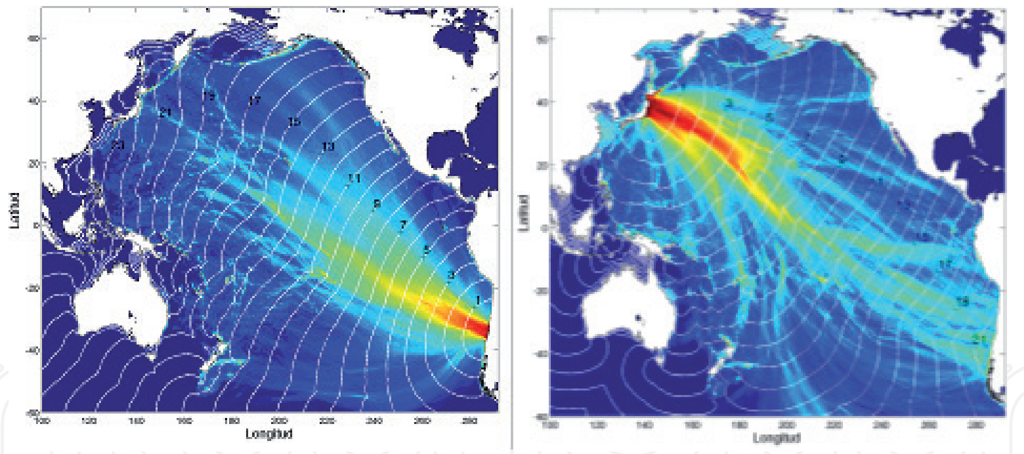

Figure 5.
The 2010 Chile tsunami (left) and the 2011 tsunami in Japan (right) [29].

3. A Mexican tsunami early warning system

As mentioned in previous sections, tsunamis (and earthquakes) are unpredictable and can happen any time. Therefore, there is a need for an effective tsunami early warning system (TEWS). A system which should include not only the technical aspect but also the human issue. This section presents a preliminary model for such a system.

In particular, it considers the Pacific and the Caribbean coasts of Mexico (Section 2). However, only those aspects associated with the "structural-organisation" of the proposed model will be discussed in some detail (i.e., the five interrelated subsystems associated with systems 1–5 and its channels of communication as shown in **Figure 6**). The proposed model is based on previous research on issues related to safety and disaster management systems [30–32].

In the context of this case study, the overall function of systems 2–5 (MTEW-SMU) is to establish the key tsunami safety policies aiming at maintaining tsunami risk within an acceptable range; this implies allocating the necessary resources, for example, to build response capabilities at national and community levels.

System 1, on the other hand, embraces the following three subsystems: TNZO (Tsunami Northern Zone Operations), TSZO (Tsunami Southern Zone Operations), and TCZO (Tsunami Caribbean Zone Operations) with their associated management units (TNZ-SMU, TSZ-SMU & TCZ-SMU). These three operations of system 1 were considered given the fact that the risk of tsunamis comes from local and remote tsunami sources as mentioned in Section 2.

Further, it is important to highlight that one of the key functions within the MTEW-SMU is that related to System 2, which is associated with what it is called here MTEW-CC (Mexican Tsunami Early Warning-Coordination Centre); its key function is the monitoring, detection of a tsunami through the following coordination centres: TSZ-CC (Tsunami Southern Zone-Coordination Centre), TNZ-CC (Tsunami Northern Zone Coordination Centre), and TCZ-CC (Tsunami Caribbean Zone Coordination Centre), as shown in **Figure 6**. The process of the flow of key information and decision making process is briefly described in **Table 3**; **Table 4**, on the other hand, presents some of the key actors involved in the existing system when compared with the features of the model.

In general, communities living in active seismic areas and along coastal regions are vulnerable to tsunamis. These natural hazards are not that common and unpredictable, but powerful and with devastating consequences to those communities in

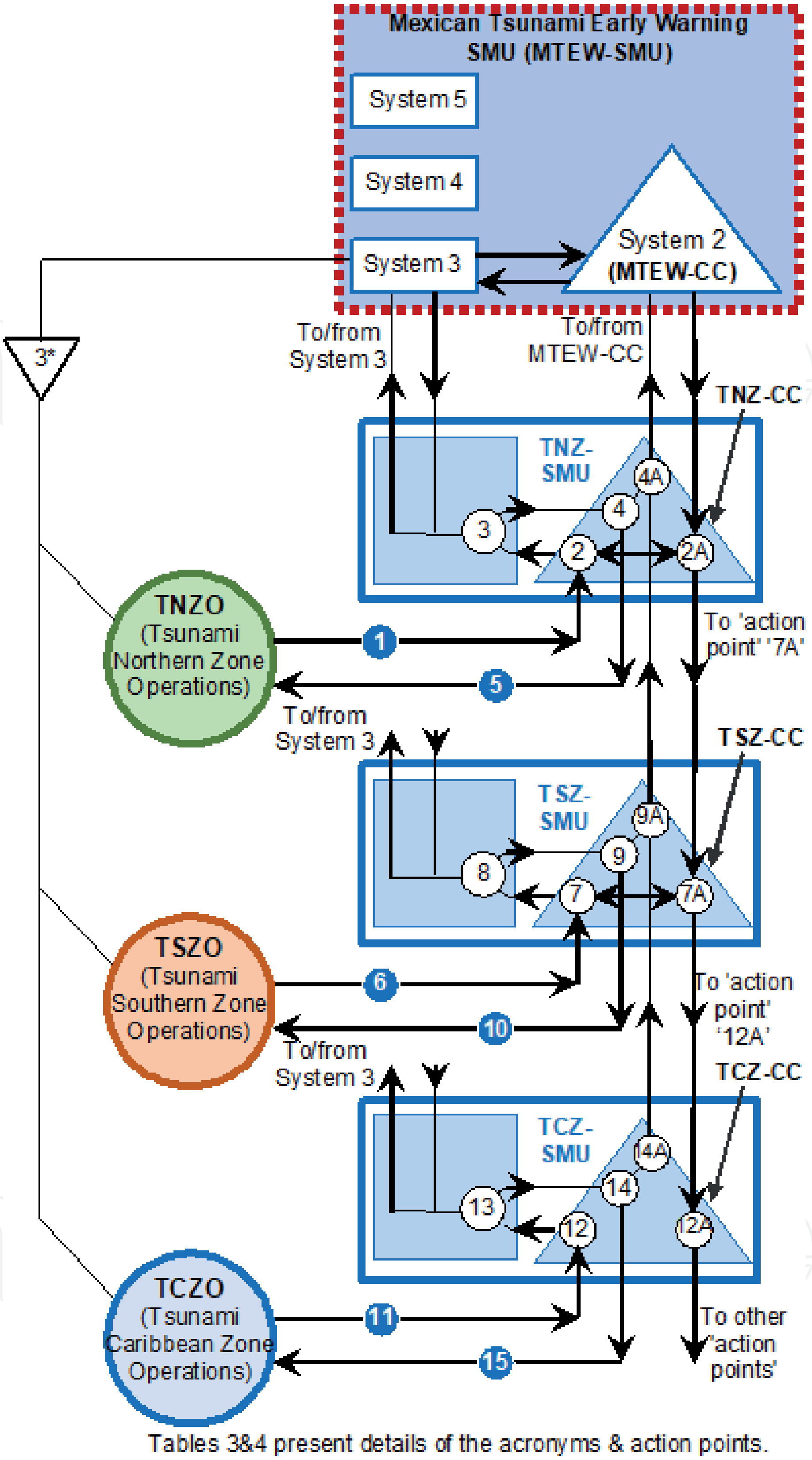

Figure 6.
A Mexican tsunami early warning system (MTEWS).

their path. It is believed that tsunamis are the deadliest in terms of the proportion of people being killed [34].

Following the 2004 tsunami in the Indian Ocean, the need for a tsunami warning system (TWS) was more than evident; however, it may be argued that the existing TWS may be deficient in dealing with the mitigation of impacts of such events; moreover, there are still regions worldwide without such systems.

"Action points"	Description
"1", "6", "11"	Flow of data on key variables monitored by MTEW-CC through TNZ-CC, TSZ-CC, TCZ-CC (e.g., earthquakes, pressure sensors, tide gauges, etc.). It should also be mentioned that this information is provided by the SSN (National Seismological Service), USGS, the PTWC (Pacific Tsunami Warning Centre), see **Table 4**.
"2&2A", "7&7A"	If a strong earthquake occurs, for example, within TNZO (Tsunami Northern Zone Operations), then in "2", the tsunami risk is assessed, if the key variable not withing the acceptable criteria (e.g., a tsunami), then it issues the tsunami warning to "2A", which in turn issues the warning to the TSZ-CC, even if the risk is low (Section 2), through the "action point" "7A". In the model, the TCZ-CC also receives the warning, although in the context of this scenario, it is not necessary to warn communities within TCZO (Tsunami Caribbean Zone Operations) to take some protective actions for obvious reasons. Nevertheless, the key decision-makers within this zone are on alert.
"3&4", "8&9", "13&14"	"Actions points" "3&4" plan and devise measures to respond to the tsunami emergency, e.g., design of risk maps, plans to conduct drills, evacuation plans; etc. All of these aiming at better prepare the vulnerable communities within TNZO. "Action point" "3" also issues the tsunami warning to MTEW-SMU (i.e., to System 3). In the same vein, "action points" "8&9" and "13&14" perform similar functions into their respective coordination centres (i.e., TSZ-CC & TCZ-CC), see **Figure 6** and **Table 4**.
"4A", "9A", "14″	Following the scenario herein, "4A" communicates the protective measures taken (e.g., evacuation) to the MTEW-CC, which in turn may devise further actions given its synergistic view of the total system through system 3, as shown in **Figure 6**. The same rationale applies to "9A" and "14" within their respective coordination centres.
"5", "6", "15″	"Action point" "5" issues the tsunami warning to the affected communities within this zone (e.g. B.C, B.C.S., Sinaloa, Manzanillo, etc.). Further, it implements all the protective measures to mitigate the impact of the tsunami in the coastal areas, e.g., evacuation to safe areas, etc. Moreover, it also implements plans to relocate the affected people to safe areas if necessary. Similarly, as in "5", "6" issues the tsunami warning to the affected communities within this zone (e.g. Acapulco, Oaxaca, Manzanillo, Zihuatanejo, etc.). "Action point" "15", issues the warning to the communities vulnerable to tsunamis within this zone (e.g. Cancun, etc.), see **Figure 6**.

Table 3.
*Description of the key action points of the model in **Figure 6**.*

Recent tsunami disasters have highlighted some of these deficiencies; for example, in the case of the 2010 tsunami in Chile, the entity in charge of issuing a tsunami warning failed to do so [5], p. 30 (see "action point" "2"& "7" in **Figure 6** and **Table 3**). The failure to perform this action contributed to fatalities in the coastal communities. More recently, the 28 September Sulawesi tsunami and the 24 December Anak Krakatau (AK) volcano tsunami, both in Indonesia, illustrate deficiencies in TWS too. In the former case, the tsunami warning was issued but the warning was lifted over thirty minutes [4]. However, the city of Palu, located in a narrow bay, was hit hard with waves reaching six metres of height; why were not they warned? the head of the BMKG (Indonesia Agency for Meteorology, Climatology and Geophysics) argued that "we have no observation data at Palu…", "If we had a tide gauge or proper data in Palu, of course it would have been better" [4]. The tsunami (and earthquake) killed over 2000 people [2]. Finally, regarding the AK volcano tsunami, it is thought that there was not a tsunami warning system for the case of volcano-induced tsunamis; however, the tsunami killed 437 people [3].

It may be argued that a TWS should not be only concerned with the technical infrastructure systems (e.g., tidal gauge, network of buoys, etc.), but also the organisational and human components. Further, it may be argued that the most

Some of the key features of the model		**Examples of what perform some of the functions of the existing system (left & Figure 6)**	
System	Key Components	SMU ("square boxes")	Operations ('circles')
Systems 2–5	MTEW-SMU ("Mexican Tsunami Early Warning-SMU")	1. Secretariat of the Navy (SEMAR) manages the Tsunami Warning Centre (CAT); the monitoring, detection, and forecasting centre [33]. 2. Receives information from the SSN (National Seismological Service), 3. Receives the input from the PTWC. 4. Receives the input from the USGS. 5. Other (e.g. CICESE, etc. [15, 22])	-
	MTEW-CC ("Mexican Tsunami Early Warning Coordination Centre")	Warning coordination centres within the CAT.	-
System 1	TNZ-SMU ("Tsunami Northern Zone- SMU")	Same as with 1,2 & 5 above, and local/regional decision-makers, e.g., civil protection, etc.	—
	TNZO ("Tsunami Northern Zone Operations")		Local communities living in the zone, including tourists & those working in touristic resorts, such as 'Los Cabos', etc.
	TNZ-CC ("Tsunami Northern Zone-Coordination Centre)	Same as with 1,2 & 5 above, and local/regional decision-makers, e.g., civil protection, etc.	-
System 1	TSZ-SMU ("Tsunami Southern Zone- SMU")	Same as with 1,2 & 5 above, and local/regional decision-makers, e.g., civil protection, etc.	-
	TSZO ("Tsunami Southern Zone Operations")		Local communities living in the zone, including tourists & those working in touristic resorts, such as 'Puerto Vallarta', 'Acapulco', 'Huatulco', etc.
	TNZ-CC ("Tsunami Southern Zone-Coordination Centre)	Same as with 1,2 & 5 above, and local/regional decision-makers, e.g., civil protection, etc.	-

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Some of the key features of the model		**Examples of what perform some of the functions of the existing system (left & Figure 6)**	
System 1	TSZ-SMU ("Tsunami Caribbean Zone- SMU")	Same as with 1,2 & 5 above, and local/ regional decision-makers, e.g., civil protection, etc.	-
	TCZO ("Tsunami Caribbean Zone Operations")		Local communities living in the zone, including tourists & those working in touristic resorts, such as 'Cancun', 'Playa del Carmen'.
	TNZ-CC ("Tsunami Caribbean Zone- Coordination Centre)	Same as with 1,2 & 5 above, and local/ regional decision-makers, e.g., civil protection, etc.	-

Table 4.
*Examples of the key players that perform some of the functions of the system in place when compared with the model (**Figure 6**).*

difficult aspect is the human factor; there is a need to better understand human behaviour during these events, so that make these communities less vulnerable and resilient to tsunamis. In other words, there is a need for an effective tsunami early warning system able to consider all these components in a coherent manner, such as the system being proposed herein and elsewhere. Further, these systems should be "people-centred" [21, 35].

4. Conclusions

The paper has presented the risk of tsunamis in Mexico. The approach has been a review of existing literature on historical data of tsunami occurrence in Mexico. The literature survey showed that the tsunami threat comes from local and remote zones. Overall, the review showed that the highest tsunami risk comes from tsunamis induced by earthquakes occurring in the Southern zone of the country (i.e., local zone). The paper has also put forward a preliminary model of a TEWS (Tsunami Early Warning System) for the case of Mexico. However, it needs further research to design the whole networks of the flows of information not only for the case of tsunamis, but also for the case of earthquake early warning "people-centred" systems.

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Conflict of interest

The author declares that he has no competing interests.

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References

[1] UNESCO/IOC (United Nations Educational, Scientific and Cultural Organization/Intergovernmental Oceanographic Commission)., 2013. Tsunami Glossary. Revised Edition 2013. IOC Technical series, 85. UNESCO, Paris (IOC/2008/TS/85rev).

[2] Widiyanto, W., Santoso, P.B., Hsiao, S.C., Imananta, R.T., 2019. Post-event field survey of 28 Septemeber Sulawesi earthquake and tsunami. Nat. Hazards Earth Syst. Sci., 19, 2781-2794.

[3] Muhari, A., Heidarzadeh, M., Susmoro, H., Nugroho, H.D., Kriswati, E., Supartoyo, Wijanarto, A.B., Imamura, F., Arikawa, T., 2019. The December 2018 Anak Krakatau Volcano Tsunami as inferred from post-tsunami field survey and spectral analysis. Pure Appl. Geophys. 176, 5219-5233.

[4] BBC. 2018. Indonesia earthquake and the tsunami: How warning system failed the victims. Available at: https://www.bbc.com/news/world-asia-45663054 (Accessed date: 24/12/2019).

[5] Valenzuela, I.B., Camus, P.M., 2012. Chile pre y post catástrofe: algunas claves para aproximarse a los desafíos de reconstrucción. In: Brain y Mora (ed). Emergencia y reconstruccion: El antes y después del terremoto y tsunami del 27 F en Chile. Fundacion Mapfre y Pontificia Universidad Católica de Chile. Chile.

[6] Fakhrul-Razi, A., Ridwan-Wong. M.M., Mat-Said, A. 2020. Consequences of the 2004 Indian Ocean Tsunami in Malaysia. Safety Science, 121, 619-631.

[7] Imamura, F., Penmellen-Boret, S., Suppasri, A., Muhari, A. 2019. Recent occurrences of serious tsunami damage and the future challengues of tsunami disaster risk reduction. Progress in Disaster Science, 1, 100009.

[8] Moreno, J., Lara, A., Torres, M. 2019. Community resilience in response to the 2010 tsunami in Chile: The survival of a small-scale fishing community. International Journal of Disaster Risk Reduction, 33, 376-384.

[9] Paula Dunbar, Heather McCullough, George Mungov , Jesse Varner & Kelly Stroker. (2011) 2011 Tohoku earthquake and tsunami data available from the National Oceanic and Atmospheric Administration/National Geophysical Data Center, Geomatics, Natural Hazards and Risk, 2:4, 305-323, DOI: 10.1080/19475705.2011.632443

[10] Leon-Canales, J., Vicuña del Río, M., Gubler, A. 2019. Increasing tsunami risk through intensive urban densification in metropolitan areas: A longitudinal analysis in Viña del Mar, Chile. International Journal of Disaster Risk Reduction, 41, 101312.

[11] Li, Z., Yu, H., Chen, X., Zhang, G., Ma, D. 2019. Tsunami-induced traffic evacuation strategy optimization. Transportation Research Part D, vol.77, 535-559.

[12] Robke, B.R., Vott, A. 2017. The tsunami phenomenon. Progress in Oceanography, 159, 296-322.

[13] Goff, J., Terry, J.P., Chagué-Goff, C., Goto, K. 2014. What is a mega-tsunami? Marine Geology, 358, 12-17.

[14] Chaturvedi, S.K. 2019. A case study of tsunami detection system and ocean wave imaging mechanism using radar. Journal of Ocean Engineering and Science, 4, 203-210.

[15] Ferraras, S.F., Sanchez, A.J., 1991. The tsunami thereat on the Mexican west coast: A historical analysis and recommendations for hazard mitigation. Natural Hazards, 4, 301-316.

[16] Jaimes, M.A., Reinoso, E., Ordaz, M., Huerta, B., Silva, R., Mendoza, E., Rodríguez, J.C. 2016. A new approach to probabilistic earthquake-induced tsunami risk assessment. Ocean & Coastal Management, 119, 68-75.

[17] Trejo-Gómez, E., Ortiz, M., Nuñez-Cornú, F.J. 2015. Source model of the Octobre 9, 1995 Jalisco-Colima Tsunami as constrained by field survey reports, and on the numerical simulation of the tsunami. Geofísica International, 54-2, 149-159.

[18] Roy, P.D., Jonathan, M.P., Consuelo-Macias, M., Sanchez, J.L., Lozano, R., Srinivasalu, S. 2012. Geological characteristics of 2011 Japan tsunami sediments deposited along the coast of southwestern Mexico. Chemie der Erde, 72,91-95.

[19] Ramirez-Herrera, M.T., Bogalo, M.F., Cerny, J., Goguitchaichvili, A., Corona, N., Machain, M.L., Edwards, A.C., Sosa, S. 2016. Historic and ancient tsunamis uncovered on the Jalisco-Colima Pacific coast, the Mexican subduction zone. Geomorphology, 259,90-104.

[20] United Nations International Strategy for Disaster Reduction (UN/ISDR), 2006. Global survey of early warning systems. UNISDR, Geneva, Switzerland.

[21] Bashir, R., 2006. Global early warning systems for natural hazards: systematic and people centred. Philosophical Transactions of the Royal Society A 364, 2167-2182.

[22] Ferraras, S.F., Dominguez-Mora, R., Gutierrez-Martinez, C.A., 2014. Tsunamis. Centro Nacional de Prevencion de Desastres (CENAPRED), Secretaria de Gobernación, Mexico.

[23] USSG. Ring of fire map. Available at: http://www.geologyin.com/2018/01/the-ring-of-fire.html#kMGfZ4P00Ue21LoI.99 (Accessed date: 24/12/2019).

[24] NOAA, 2019. Estimated tsunami travel times to coastal locations-Acapulco Mexico. National Centers for Environmental Information (NOAA). Available at: https://maps.ngdc.noaa.gov/viewers/ttt_coastal_locations/ (Accessed date: 24/12/2019).

[25] Ramirez-Herrera, M.T., Corona, N., Cerny, J., Castillo-Aja, R., Melgar, D., Lagos, M., Goguitchaichvili, A., Machain, M.L., Vasquez-Caamal, M.L., Ortuño, M., Caballero, M., Solano-Hernandez, E.A., Ruiz-Fernandez, A.C, 2020. Sand deposits reveal great earthquakes and tsunamis at Mexican Pacific Coast. Scientific Report, 10, 1145. DOI: 10.1038/s41598-020-68237-2

[26] USGS, 2020. M7.7-123 km NNW of Lucea, Jamaica. Available at: https://earthquake.usgs.gov/earthquakes/eventpage/us60007idc/executive (Accessed date: 20/04/2020).

[27] Lander, J.F., Whiteside, L.S., Lockridge, P.A., 2002. A brief history of tsunamis in the Caribbean Sea. Science of Tsunami Hazards, vol. 20(1), 57-94.

[28] PTWC. 2019. Pacific Tsunami Warning Centre. Available at: https://ptwc.weather.gov/ (Accessed date: 24/12/2019).

[29] Ortiz-Huerta, L.G., Ortiz-Figueroa, M., 2014. ¿Cómo me puedo preparar ante un Tsunami? Guía para el Maestro. SEGOB, CENAPRED, CICESE, Mexico.

[30] Santos-Reyes, J., Padilla-Perez, D., Beard, A.N., 2019. Transport infrastructure interdependency: Metro's failure propagation in the road transport system in Mexico City. Sustainability, vol. 11, 4757, 1-24. DOI:10.3390/su11174757.

[31] Santos-Reyes, J., & Beard, A.N., 2017. An analysis of the

1996 Channel tunnel fire. Journal of Rail and Rapid Transit: Proc. IMechE, Part F. vol. 231(8), 850-876. DOI:10.1177/0954409716647093.

[32] Santos-Reyes, J., & Beard, A.N., 2011. Applying the SDMS model to the analysis of the Tabasco flood disaster in Mexico. Human and Ecological Risk Assessment: An International Journal, vol. 17(3), 646-677. DOI:10.1080/10807039.2011.571099.

[33] CAT, 2020. CAT-Tsunami Warning Centre. Available at: https://digaohm.semar.gob.mx/cat/centroAlertasTsunamis.html (Accessed date: 22/05/2020).

[34] CRED, 2016. Tsunami disaster risk-Past impacts and projections. Centre for Research on the Epidemiology of Disasters (CRED), UNISDR.

[35] Santos-Reyes, 2019. How useful are earthquake early warnings? The case of the 2017 earthquakes in Mexico City. International Journal of Disaster Risk Reduction, vol. 40, 101148, 1-11.