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TSUNAMI EVACUATION IN THE PACIFIC AND CARIBBEAN COAST OF COLOMBIA

E. Mas[(1)], B. Adriano[(2)], R. Sanchez[(3)], O. Murao [(4)], S. Koshimura [(5)]

[(1)] Assistant Professor, International Research Institute of Disaster Science, Tohoku University, mas@irides.tohoku.ac.jp
[(2)] Post-doctoral Researcher, International Research Institute of Disaster Science, Tohoku University, adriano@irides.tohoku.ac.jp
[(3)] Researcher, Dirección General Marítima (DIMAR), Colombia, rsanchez@dimar.mil.co
[(4)] Professor, International Research Institute of Disaster Science, Tohoku University, murao@irides.tohoku.ac.jp
[(5)] Professor, International Research Institute of Disaster Science, Tohoku University, koshimura@irides.tohoku.ac.jp

Abstract

Colombia is located at the north edge of South America bordering with Panama and with coastline in the Caribe and the Pacific Ocean. Due to historical earthquake events in these regions, it is expected that Colombian coastal areas possess a significant tsunami risk. Previous studies suggest that the Caribbean coast of Colombia presents low risk of tsunami, since no significant tsunami heights were obtained to clearly classify the coastal area of Colombia as a high tsunami prone area. Within the activities of the project "Application of State of the Art Technologies to Strengthen Research and Response to Seismic, Volcanic and Tsunami Events, and Enhance Risk Management in Colombia" (JST-JICA SATREPS), this paper presents a preliminary analysis of the evacuation at a tsunami prone area in Colombia. The target area for case study is Tumaco Island, a port city and second largest populated area in the Pacific coast of Colombia. Here we introduce evacuation simulation technology as an example of tools for human loss estimation and tsunami disaster management support. Approximately 40% of the population may reach haven within the 20min window for evacuation under current data and assumptions used in the model. Future improvement of population and urban data will be incorporated to grasp a clear image of the possible tsunami impact in this area.

Keywords: tsunami evacuation; agent based simulation; Tumaco; Colombia

1. Introduction

Colombia is located at the north edge of South America, bordering with Panama. It has coastlines in the Caribbean and Pacific Oceans. Here, several earthquakes occurred in the past. In particular, the Pacific Ocean side of Colombia is a clear subduction zone area where historical events triggered tsunamis and damaged coastal communities. Conversely, studies suggest that the Caribbean coast of Colombia presents a low risk of tsunami. For instance, [8], presented two events as the most probable and threatening for Colombian coast. The analysis of tsunami risk in the Caribbean coast of Colombia considered seismic sources from the North of Panama (Mw=8.0) and the Antillas Menores (Mw=8.5), however, no significant tsunami threat was observed in simulations to clearly classify these as high tsunami prone areas.

The Pacific coast of Colombia has been extensively studied for tsunami risk. In particular, the Nariño region and the populated areas of Tumaco and surroundings (Fig.1). Here, four major events are known for their earthquake and tsunami impact in the area (1906 (Mw=8.8), 1942 (Mw=7.8), 1958 (Mw=7.6) and 1979 (Mw=8.2)). Out of these, the largest event recorded has been the 1906 with at least 500 casualties in the coast of Colombia. It caused liquefaction and washed away small islands and sand dunes in front of the Tumaco Island. The tsunami risk of Tumaco area has been assessed before by several studies [1, 2, 4, 5, 6, 9, 15, 16] and most of them agreed on the complexity of the tsunami risk at Tumaco Island due to its highly exposed and low lying territory added to the overpopulated urban area.

Since 2014 a new initiative for research collaboration between Colombia and Japan institutes and universities has given special attention to the multiple disaster risks for Colombia. The SATREPS program, Science and Technology Research Partnership for Sustainable Development; funded by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA), aims to strengthen the capacities on disaster risk reduction and promotes joint research. Thus, this study is contained within the SATREPS framework and its project "Application of the State of the Art Technologies to Strengthen Research and Responses to Seismic, Volcanic and Tsunami Events, and Enhance Risk Management in Colombia". Here, current and future activities are presented from a starting project with five years of research collaboration ahead.

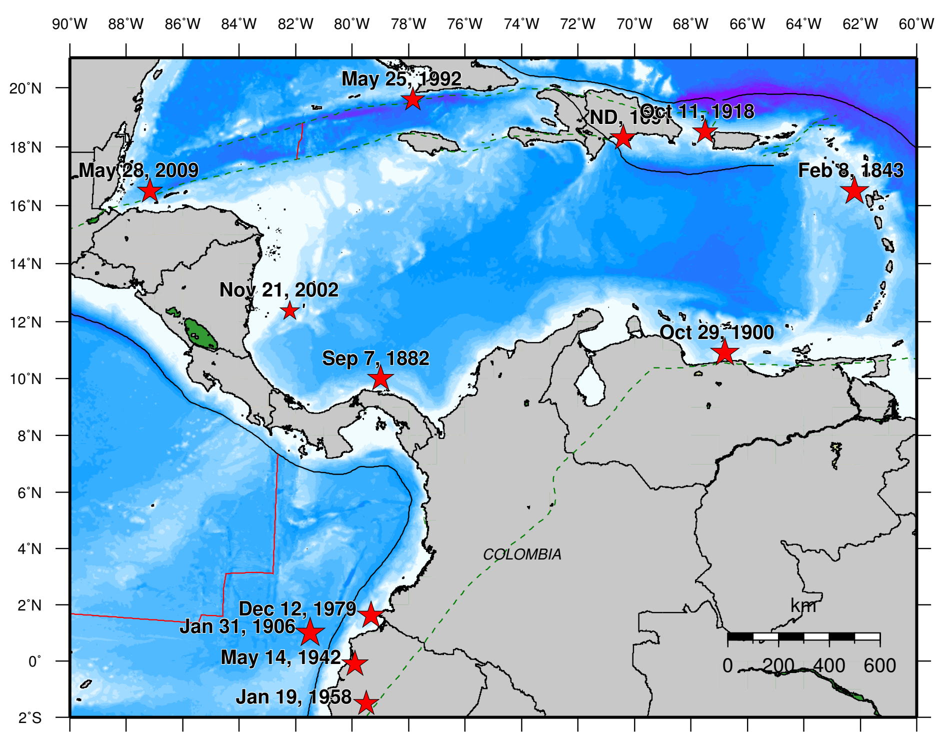

Fig. 1 – Colombia major events in the Caribe and Pacific. Tumaco is located next to the 1979 event.

2. Earthquake and tsunami risk

2.1 Caribbean coast

Large earthquakes had occurred in the past in the Caribbean Sea. A summary of these events has been reported elsewhere [8], herewith some are detailed in Table 1 and shown in Fig. 1.

Table 1 – Significant earthquakes in the Caribbean Sea

Date	Mag	Lat.	Long.
ND, 1691	7.7	18.30	-70.40
Sep 7, 1882	7.9	10.00	-79.00
Feb 8, 1843	8.3	16.50	-62.20
Oct 29, 1900	8.3	10.90	-66.80

Date	Mag	Lat.	Long.
Oct 11, 1918	7.5	18.50	-67.50
May 25, 1992	7.1	19.60	-77.86
Nov 21, 2002	5.8	12.37	-82.22
May 28, 2009	7.3	16.50	-87.17

The analysis of tsunami risk from these and other expected sources was conducted by [8] and resulted on tsunami heights of 0.8 to 1.0 m in the worst case for the northern areas of the continental Colombian coast. Tsunami arrival time was estimated as 40 min. The study also recommends further detailed analysis for areas like San Andres Island, Providencia and Cartagena. Therefore, some of these areas were proposed for future tsunami simulation and tsunami risk assessment by the research group of the SATREPS project with respect to the Caribbean side of Colombia. Results of these activities will be reported in the future.

2.2 Pacific Coast

During the last century four major events occurred (1906, 1942, 1958, 1979) in the Pacific coast of Colombia and close to the Tumaco area. These events are detailed in Table 2 and shown in Fig. 1.

Table 2 – Significant earthquakes in the Pacific Sea

Date	Mag	Lat.	Long.
Jan 31, 1906	8.8	1.00	-81.50
May 14, 1942	7.8	-0.10	-79.90
Jan 19, 1958	7.6	-1.50	-79.50
Dec 12, 1979	8.2	-1.68	-79.36

Due to these events the Tumaco area, in the Nariño coast, was classified as a highly seismic and tsunami risk zone by Colombian governmental institutes (i.e. INGEOMINAS, DIMAR) [6]. The events shown in Table 2 have been assessed by previous studies [9, 17, 18] and a brief summary of their contents and conclusions is as follows:

a. The tsunami events of 1906 and 1979 occurred during low tide, thus, lower impact was observed compared to the expected inundation if high tide was present.
b. The level of tide in Tumaco may change up to 4 m, thus, the extent of the impact from a tsunami during low tide is significantly lower in comparison to the impact produced by a tsunami that may occur during high tide. In particular, during low tides, the inter-tidal zones act as damper areas for tsunami inundation.

c. Tsunami hazard assessment was conducted for the area of San Andres de Tumaco in Colombia. The scenario used was the 1979 earthquake, which reported significant damage in the area.
d. About the simulations; bathymetry data of 15m was used in calculations. As a result, the arrival time of tsunami was estimated on 18 to 20 min. for the Tumaco Island.
e. Sanchez and Puentes [18] compared tsunami hazard maps of 2004 and 2012 published by the local government (Fig. 3). He found that in 2004, 84% of the island was inundated based on estimations, while in 2012, 96% of it was considered as inundated area. In addition, for extreme scenarios without natural barriers the complete area of Tumaco Island would be inundated.
f. For expected scenarios of tsunami, in Tumaco Island, the estimated tsunami height is 1 to 3 m to the west and 0.8 to 2.0 m to the east of the island. Only a small portion on the south of the island remained dry, whereas the rest of the island was inundated over 1m depth.
g. The extent of inundation in Tumaco bay is, among others, influenced by the position of the seismic source with respect to the entrance of the bay.
h. The Colombian National Program for Prevention of Tsunami considers as one of its components the necessity to develop, maintain and utilize mangrove areas as mitigation measures in the Pacific coast [14].

Finally, from the literature reviewed on tsunami risk, at the Pacific and Caribbean coast of Colombia, it is clear that a significant risk is present and recognized for the Pacific coast in the Tumaco Island. Therefore, the tsunami risk assessment of this area is evaluated through tsunami evacuation.

3. The study area

Tumaco is located in the Nariño department by the Pacific Ocean. It is a port city near the border of Colombia and Ecuador. It is the second largest populated area in the Pacific coast of Colombia. Tumaco is home to more than 100,000 inhabitants within the urban area and nearly 90,000 in the rural areas (Fig. 2).

Fig. 2 –Aerial view of Tumaco city.
Photo: Williton Fernandez, Apr 18, 2016 (Wikimedia Commons)

4. Tsunami evacuation

Whereas in countries like Japan, structural measures can be applied in multiple areas in the coast, near Tumaco the coastal dynamics and continuous environmental changes, due to erosion and deposition of sands and the human activities related to deforestation of mangrove, adds complexity to the disaster risk management. In many countries it is common that evacuation drills are organized by authorities to train the population and its first responders. However, oversetting the conditions for a safe and smooth evacuation drill may incur on drawing unreal scenarios and end up with optimistic conclusions about the level of preparedness in the city. For example, in Tumaco, it has been found that law strictly prohibits vehicles to be used during the day and hours of the evacuation drill. This measure contributes to the order, safety and smoothness of the drill, however it does not portraits the real situation of the city during a common day, a day when tsunami may occur and people decide to evacuate by vehicle.

The evacuation problem for Tumaco Island is particularly complex due to its high exposure; low lying area and lack of elevated structures with proven earthquake and tsunami resistant characteristics. Based on the studies discussed in previous sections, the tsunami run up is expected to reach as much as 3m, leaving a dry portion in the south for possible evacuation gathering. It is a challenge to design a safe evacuation for approximately 100,000 people distributed throughout the island with only a small portion of territory for gathering such as the southern area of “Calle del Comercio” (Fig. 3). However, as a preliminary assessment and to kick off the discussion and application of evacuation models to assess the feasibility of evacuation and find out mitigation measures to promote a safer evacuation in Tumaco, in the next section a test case of simulation is presented.

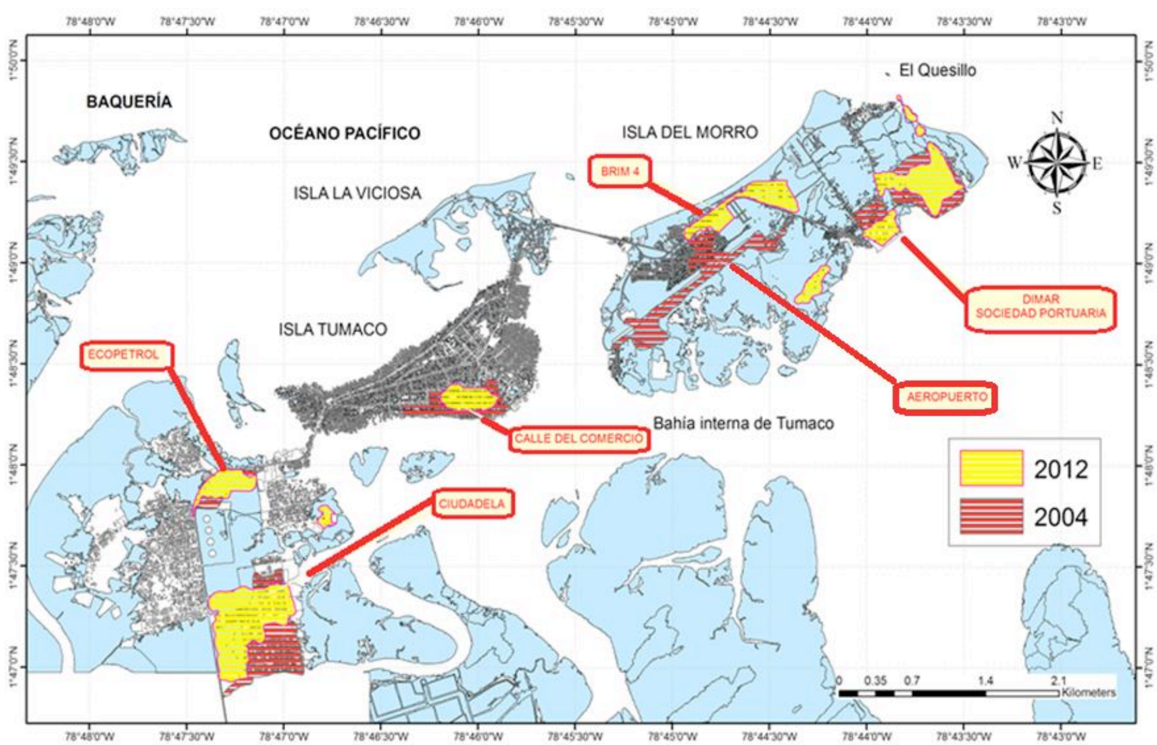

Fig. 3 –Analysis of two Hazard Maps from 2004 and 2012. Notice that the available area for evacuation has been reduced in the Tumaco Island. (Sector Calle del Comercio). Source: Sanchez, R.

5. Evacuation Simulation

We used the model developed by [12, 13]. The model uses the agent-based approach and GIS data together with the outputs of tsunami simulation obtained from the TUNAMI model [10]. According to numerical simulations and previous studies we set the arrival time of tsunami to 20min. As a first trial we allowed the whole population to gather in the high ground area despite the availability or constraint of space. This is not to replicate a real evacuation, but to investigate the number of people who can reach the area in the given time. A follow up issue is to evaluate the capacity and space for all of these people in the safe area. Moreover, this analysis is to discover the number of population who may not reach the safe area so new strategies can be dimension according to these numbers.

The area set for study and a snapshot of the model is shown in Fig. 4. These are the general objectives of this test case:

a. To introduce the evacuation simulation for human loss estimation and tsunami disaster management.
b. To estimate, from a randomly spatial distribution of population, the time needed for evacuation – age and number of people was taken from census data, however location of people is unknown, thus the randomness.
c. To quantify the number of people able to get to the safe area, the area needed to sheltered them and the number of people that remain in risk areas.

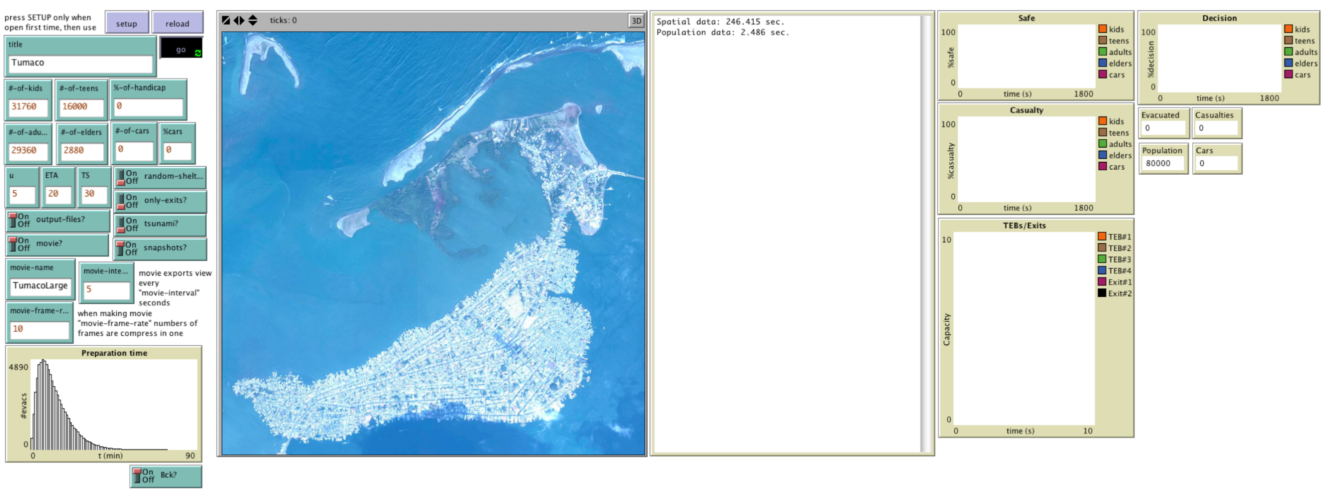

Fig. 4 –Model of agent based evacuation and study area of Tumaco Island.

A total of 100,000 agents were simulated and classified by age following the census data reported in the 2008-2019 Tumaco Territorial Planning report [2]. Pedestrian evacuation was simulated to evaluate the capacity of the area. Vehicles were not included in the simulation. In addition, evacuee intention is limited to the safe area in the south and no evacuee intends to cross the island through one of the two bridges located to the north and south ends of the island.

In this case, no tsunami inundation was included in the simulation, instead, we set as stop condition of simulation, the estimated arrival time of tsunami. Thus, at 20 min of estimated tsunami arrival time, the condition of evacuation and location of population is evaluated. The number of safe people is considered as the number of agents that had reached one of the three street intersections within the high ground area. The expected human loss is considered as the number of agents still on the way, since those agents would be trapped by the tsunami inundation immediately after the 20min.

5.2 Simulation results and discussion

The area modeled has approximately 1,700,000 m^2, and the areas over the 2m, where tsunami inundation is minimum, correspond to 130,000 m^2, this is approximately 8% of the total area. According to humanitarian standards for shelters, an initial minimum floor area of 3.5 m^2 per person is necessary. Thus, the areas with minimum inundation may shelter approximately 37,000 people following humanitarian standards. Simulation results showed that approximately 40% of the population may reach the safe area within the time available, while the remaining 60% is still on its way to the high ground. Apparently the high ground areas can accommodate the current population that may arrive within the 20min time window. However, still 60% of the population remain highly at risk of being trapped by the tsunami. Consequently, using evacuation simulation in a simple case study, the main issues for a successful evacuation in Tumaco Island have been clarified here. Provided the evacuation is performed within the area and not towards other island or the continent, capacity and reachability are major problems in this area.

Possible solutions to this issues are multiple and need to be implemented together. For instance, the possibility of vertical evacuation to structures even out of the high ground will allow to allocate larger population and distribute the spatiality of the evacuation process. Some structures that may contribute to evacuation in a highly urbanized and consolidated area, where new structures cannot be build, have been reported elsewhere [19]. Muhari et al. (2012) proposed the use of pedestrian bridges at intersection where tsunami flow is reduced due to hydrodynamic conditions. In addition, promoting a faster evacuation would increase the amount of population reaching high ground or safe haven within the time available. In Tumaco, motorcycles are probably the most common mean of transportation. The 2011 Tohoku tsunami is an example of the risk of evacuation on vehicles, while the 2004 Indian Ocean tsunami and 2009 tsunami warning in Padang, Indonesia are examples of congestion during evacuation while using motorcycles. There is a risk of using this mean in Tumaco, however to certain degree it might be useful to accelerate the evacuation of some vulnerable population. It is a task for evacuation simulation to assess these options and grasp the advantages and disadvantages of each mitigation measure.

6. Conclusions

In this paper we have succinctly described the tsunami risk in Colombia and the evacuation issues at the Island of Tumaco in the Pacific coast. The assessment of the risk and evacuation in the coasts of Colombia are part of the ongoing activities within the framework of a JST-JICA-SATREPS Japan-Colombia joint research project. Here, we have briefly shown the tsunami risk in the Colombian coast and the complex issue of evacuation planning for the Tumaco Island. In addition, a tool of tsunami evacuation was presented to aid the analysis of the evacuation feasibility. In the future multiple alternatives and scenarios are planned to be tested within the evacuation simulation to find a suitable solution to the evacuation process in Tumaco. The topographic conditions of the Tumaco Island have the capacity of sheltering approximately 37,000 people in high ground. In addition to this, vertical evacuation structures are needed and an adequately distribution of safe areas through the island may help on the evacuation process. From simulation, at most 40% of the population reached high ground within the 20min available, this is nearly 40,000 people. Apparently those can be sheltered in the available high ground. Still the remaining 60% of population persist to be a challenge for the evacuation planning in this area. Our future activities within this collaboration project are focused on this challenge.

7. Acknowledgements

We acknowledge the collaboration of DIMAR from Colombia within the framework of the JST-JICA-SATREPS project Application of State of the Art Technologies to Strengthen Research and Response to Seismic, Volcanic and Tsunami Events, and Enhance Risk Management in Colombia.

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