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NUMERICAL SIMULATION FOR TSUNAMI CAUSED BY DEBRIS AVALANCHE IN LAKE NICARAGUA

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ABSTRACT

This study performs the numerical simulation for the tsunami caused by the debris avalanche in Lake Nicaragua based on past events that occurred in the surroundings of Mombacho Volcano and the analysis of future scenarios of the debris avalanche in Conception Volcano. We used the Yanagisawa code for tsunami simulations and obtained arrival time and tsunami height. The model considered the volume, speed, distance, and width of the debris avalanche. We used the bathymetry and topography from the Nicaraguan Institute of Territorial Studies (INETER) for the simulation. A total of five simulations were modeled considering one simulation for Past Event and four simulations for Scenario Event. For these simulations, two directions of the debris avalanche in Conception Volcano, northeast and southwest, and two volumes such as maximum and minimum were considered. The worst impact was found in Rivas city when modeling the debris avalanche in the southwest direction with the maximum case in Conception Volcano. The arrival time of the tsunami was 10 minutes to the city, and the amplitude of the wave was from 4 m to 5.5 m. This case can be taken as an example to work on a tsunami disaster mitigation and evacuation plans.

Keywords: Tsunami in the lake, debris avalanche, Lake Nicaragua, volume, speed.

1. INTRODUCTION

A volcanic tsunami is rarely observed but is commonly known to be violent and destructive (Nishimura and Satake, 1993). The volcanic process could generate debris avalanche. A Debris avalanche occurs when part of the flank of volcanoes collapse in volcanic islands at underwater or on land. As Nicaragua has very large lakes existed, a historical record of tsunamis occurred in the two lakes. In historical documents, we can find the evidence of the volcanic activity in Nicaragua near the shore of both Lake Managua and Lake Nicaragua, which were likely to have caused a tsunami in the lakes. In Nicaragua, there is also the evidence of volcanos collapse; for instance, in Mombacho Volcano, two huge debris avalanches were generated, both with an extension of 10 km deposit. An of the debris avalanche of this volcano entered into the water of the Lake Nicaragua and formed a small islet “Las Isletas of Granada” this event provoked a tsunami, but there is no a record of this event. In Conception volcano, an event could occur with the same magnitude or higher magnitude at any time. The objective of this study is to assess the tsunami hazard in the lakes of Nicaragua based on past events occurred in the surroundings of Mombacho Volcano and the analysis of future scenarios of debris avalanche in Conception Volcano.

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2. DATA

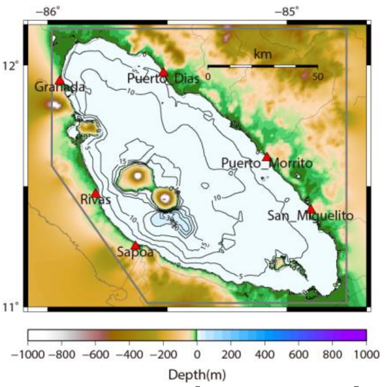


Figure 1. Bathymetry grid data used for tsunami simulations. Red triangles show output points for calculated tsunami

The bathymetry was used in this work we obtained from INETER. The bathymetry of Lake Nicaragua was prepared by Swain (1976) and INETER (1992). Both data were combined to obtain a good bathymetry resolution. Then, the topography of Mombacho Volcano was obtained from Shuttle Radar Topography Mission (SRTM) (NASA, 2019). Data of 1 arc-second (30-m resolution) was used in the 3D model with a 1:200 000 scales. Other calculation was made with Google Earth.

The displacement of debris avalanche speed was approached, using two historical events Mount St Helens volcanic eruption occurred in May 1980 in Washington, USA(Voight,1981) and Oshima-Oshima volcanic eruption occurred in August 1741 in Hokkaido, Japan (Satake and Kato, 2001).

3. THEORY AND METHODOLOGY

3.1. Order of analysis

To assess the tsunami hazard in Lake Nicaragua based on past events occurred in the surroundings of Mombacho Volcano and the analysis of future scenarios of the debris avalanche in Conception Volcano, we will conduct the following studies: 1. Characterize the debris avalanche of Mombacho Volcano "Past Event" and calculate the total volume of the debris avalanche and the volume that gendered the Granada islets deposit. 2. Determine the direction of possible debris avalanche in Conception Volcano "Scenario Events." 3. Create two cases of the tsunami by debris avalanche based on the volume calculated in Past Event. 4. Perform a tsunami simulation in Past Event and four tsunami simulations in Scenario Events.

3.2. Simulation of tsunami

Tsunami simulation is based on or supported by the non-linear long wave theory. This study deals with the Yanagisawa code, which was modified and integrated equations for the simulation of tsunamis generated by debris avalanche of the subaerial type.

3.2.1. Equations for tsunami modeling

The code developed by Yanagisawa (2019), which includes the source of a tsunami caused by a landslide or debris avalanche also governing equations are based on the non-linear long wave theory. Nonlinear long-wave equations with Manning bottom friction term with the spherical coordinate system are Eqs. (1) -(3) as follows:

$$\frac{\partial \eta}{\partial t}+\frac{1}{R\cos\theta}\left[\frac{\partial M}{\partial \lambda}+\frac{\partial}{\partial \theta}(N\cos\theta)\right]=0 \tag{1}$$

$$\frac{\partial M}{\partial t}+\frac{gD}{R\cos\theta}\frac{\partial \eta}{\partial \lambda}+\frac{1}{R\cos\theta\partial\lambda}\frac{\partial}{\partial \lambda}\left(\frac{M^2}{D}\right)+\frac{1}{R\cos\theta}\frac{\partial}{\partial \theta}\left(\cos\theta\frac{MN}{D}\right)+\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}=0 \tag{2}$$

$$\frac{\partial N}{\partial t}+\frac{gD}{R\cos\theta}\frac{\partial \eta}{\partial \theta}+\frac{1}{R\cos\theta}\frac{\partial}{\partial \theta}\left(\cos\theta\frac{N^2}{D}\right)+\frac{1}{R\cos\theta}\frac{\partial}{\partial \lambda}\left(\frac{MN}{D}\right)+\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}=0 \tag{3}$$

where λ and θ are latitude and longitude respectively, η is water level, M and N are the discharge fluxes in the λ and θ directions, R is the radius of the earth, t is time, g is gravitational acceleration, and h is water depth. D is the total depth $=(h+\eta)$, η is Manning's coefficient, M and N are the discharge fluxes in the directions x and y.

3.2.2. Equations in case of input by line flow in a semi-elliptical shape modified by Yanagisawa

The important parameter is the assumption of the geometric form of the avalanche. In this study, we assumed a semi-elliptical geometric shape of debris avalanche (Figure 2). Input boundary is the line where the material of the debris avalanche starts entering into and displacing water. V is the volume of the semi-elliptical shape in cubic meters of landmass that enters into water, which is calculated by Eq. (4).

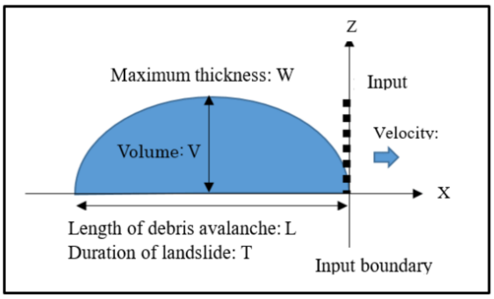


Figure 2. The draw of line flow in a semi-elliptical shape modified by Yanagisawa.

$$V = \frac{\pi}{2} LDW (m^3) \tag{4}$$

where L is the longitude of displacement of the debris avalanche, W is the width of the debris avalanche. The velocity U of the total event is calculated by Eq. (5):

$$U = \frac{L}{T}(m/s) \tag{5}$$

3.3.Source scenarios for tsunami

In order to obtain the variables, a workflow of five stages was proposed. In the first stage, the volume of Past Event was estimated. This information lets stage (2) provide inputs for the building of Scenario Event based on Past Event. Then, this information was validated in stage (3). The information acquired in the previous stages was useful for the tsunami simulation scenarios for Scenario Events in stage (4). Finally, the information obtained by the simulation of both events created the synthetic tsunami waveform.

Scenario Events was defined as two likely areas where the debris avalanche may occur in shore of Conception Volcano. The first Tsunami simulation of Scenario Event (northeast direction) the second Tsunami simulation of Scenario Event (southwest direction). In order to simulate two scenarios, two cases for Scenario Events were considered: (1) a debris avalanche in the flank of Conception Volcano (Medium case) and (2) a debris avalanche that enters into the Lake Nicaragua (Maximum Case).

4. RESULTS

We calculated the tsunami generation in Lake Nicaragua for the debris avalanche caused by the Past Event in Mombacho Volcano and Scenario Events in Conception Volcano.

4.1. Past Event

4.1.1. Reconstruction of bathymetry and topography before the Past Even

Currently, the bathymetry of Lake Nicaragua shows the area of deposit in the lake that originated Las Isletas. The area of this zone was removed in order to create a new bathymetry and topography so as to reconstruct the wave generated in the Past Event

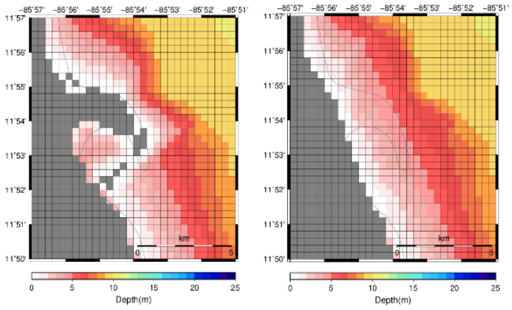


Figure 3. (Left) Present bathymetry and topography grid data around Granada. (Right) Reconstructed grid data assuming the lakefront and water depth before the Past Event. Gray grid points show the land area.

Table 1. Debris avalanche parameters used for two-case tsunami simulations.

Parameters	**Medium case**	**Maximum case**
Volume (V)	0.2632 km^3	0.4078 km^3
Length (L)	~7 km	~11 km
Duration time (T)	100 s	157 s
Width (W)	~7 km (20 grid points)	~7 km (20 grid points)

Table 1 shows the parameters obtained in the calculation for the geometric form of the debris avalanche. We used a total time of 5 hours in the tsunami modeling for both events.

4.1.2. Tsunami simulation of Past Event

The bathymetry and topography created for this specific event were explained before and used for this tsunami modeling combined with the data of Table 1.

The results of numerical simulation showed that the area of the largest impact was Granada city (Table 2). The arrival time of the tsunami was 3 minutes to the city, and the amplitude of the tsunami was 0.98 m and 1.45 m in the Medium case and Maximum case, respectively. Then, the second impact was in Puerto Diaz, which is located at 34 kilometers away from the source, after 67 minutes from the occurrence of the event with a maximum amplitude of 1 m in the Medium case and after 65 minutes of the event with a maximum amplitude of 1.17 m in the Maximum case (Figure 4).

Table 2. Tsunami arrival time and maximum amplitude from the calculated waveforms for the Past Events in Mombacho Volcano.

Name of place	Distance (km) from source	Arrival time (min)		Maximum amplitude (m)	
		Medium case	Maximum case	Medium case	Maximum case
Sapoa	76	129	127	0.15	0.19
Rivas	49	86	85	0.24	0.32
Granada	7	3	3	0.98	1.45
Puerto Diaz	34	67	65	1.00	1.17
Puerto Morrito	97	164	162	0.14	0.17
San Miguelito	125	208	205	0.16	0.20

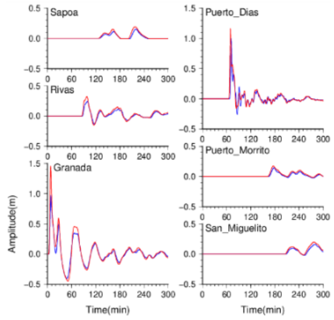


Figure 4 Blue lines and red lines indicate the calculated waveforms for the Medium case and Maximum case, respectively.

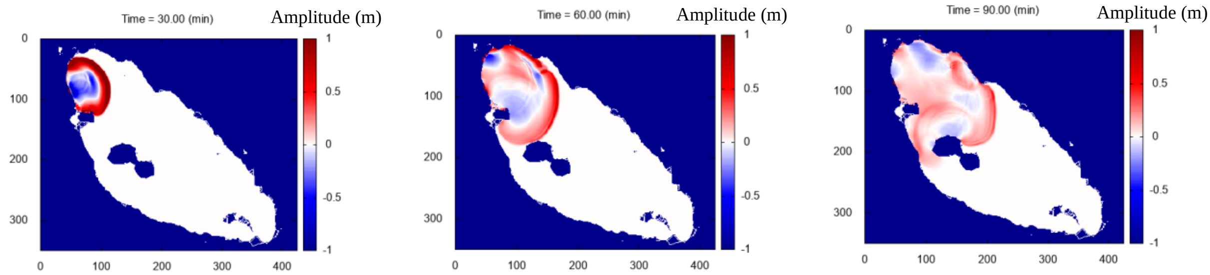


Figure 5. Snapshots of tsunami propagation from the debris avalanche model (Maximum case) for the Past Event in Mombacho Volcano.

4.2. Scenario Events

We used the bathymetry and topography given by INETER to create the tsunami modeling in both directions of northeast and southwest, combined with the data of Table 1. In Figure 6 we can see the input volume vectors of the width (W) of the debris avalanche for the Maximum case for, Scenario Event (Northeast direction) and Scenario Event (Southwest direction).

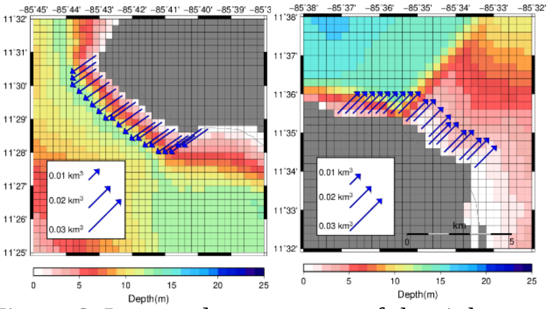


Figure 6. Input volume vectors of the right: northeast-direction and left: southwest-direction for Maximum case for the Scenario Events in Conception Volcano.

4.2.1. Scenario Event (Northeast direction).

The results of numerical simulation showed the area of the largest impact, which could be Puerto Diaz in this case (Table 3). The arrival time of the tsunami was 57 minutes and 56 minutes to the port, and the amplitude of the tsunami was 1.20 m and 1.40 m for the Medium case and Maximum case, respectively. Then, the second largest impact could be in Granada, which is located at 52 kilometers away from the source after 81 minutes from the occurrence of the event with a maximum amplitude of 0.48 m in the Medium case, and after 80 minutes of the event and a maximum amplitude of 1.40 m in the Maximum case (Figure 7).

Table 3. Tsunami arrival time and maximum amplitude from the calculated waveforms for the Scenario Event (northeast direction)

Name of place	Distance (km) from source	Arrival time (min)		Maximum amplitude (m)	
		Medium case	Maximum case	Medium case	Maximum case
Sapoa	27	38	37	0.54	0.72
Rivas	11	10	10	4.09	5.61
Granada	57	96	96	0.13	0.18
Puerto Diaz	55	86	85	0.19	0.25
Puerto Morrito	70	127	126	0.17	0.24
San Miguelito	88	149	148	0.18	0.24

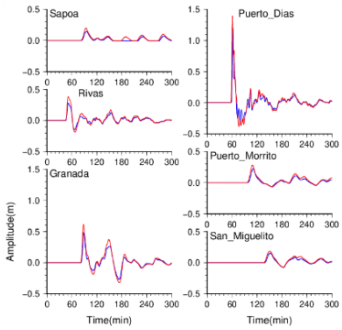


Figure 7 Blue lines and red lines indicate the calculated waveforms for the Medium case and Maximum case, respectively.

4.2.2. Scenario Event (Southwest direction).

The result of numerical simulation showed that the most affected area would be Rivas city, which is located11 kilometers from the source (Table 4). The arrival time of the tsunami was 10 minutes to the city, and the amplitude of the tsunami was 4.09 m and 5.61 m for the Medium case and Maximum case, respectively. Then, the second largest impact could be in Sapoa, which is located at 27 kilometers away from the source after 38 minutes from the occurrence of the event with a maximum amplitude of 0.54 m in the Medium case, and then 37 minutes after the event with a maximum amplitude of 0.72 m in the Maximum case(Figure 8).

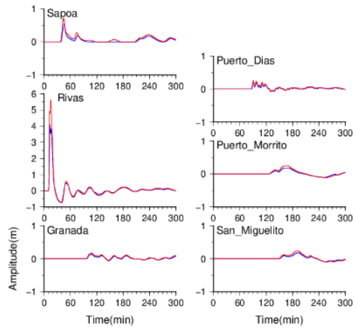
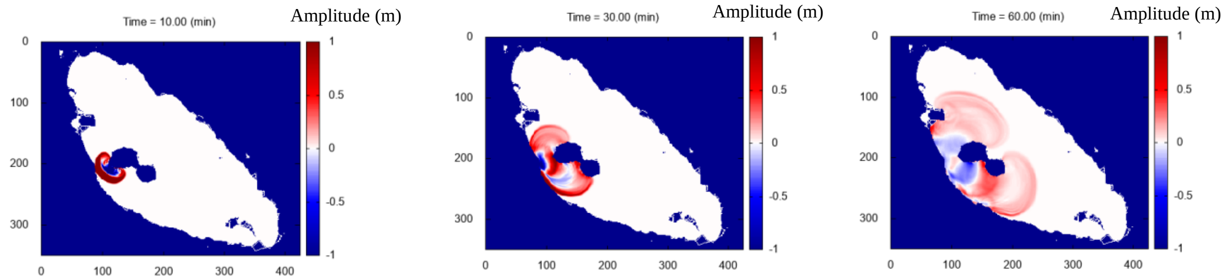


Figure 8 Blue lines and red lines indicate the calculated waveforms for the Medium case and Maximum case, respectively.

Table 4. Tsunami arrival time and amplitude from the calculated waveforms for the scenario events (southwest direction)

Name of place	Distance (km) from source	Arrival time (min)		Maximum amplitude (m)	
		Medium case	Maximum case	Medium case	Maximum case
Sapoa	--	83	82	0.15	0.20
Rivas	23	45	44	0.28	0.38
Granada	52	81	80	0.48	0.62
Puerto Diaz	63	57	56	1.20	1.40
Puerto Morrito	57	98	96	0.23	0.28
San Miguelito	80	138	136	0.15	0.18

Figure 9. Snapshots of tsunami propagation from the southwest-direction debris avalanche model (Maximum case) for the Scenario Event.



5. CONCLUSIONS

Past Event. The results of numerical simulation show the area of the larges impact was in Granada city. The arrival time of the tsunami was 3 minutes to the city, and the amplitude of the tsunami was 0.98 m and 1.45 m for Medium case and Maximum case, respectively. Then, the second impact was in Puerto Diaz. These areas were the most vulnerable and were possibly affected by this event in the past.

Scenario Event (Northeast direction). The result of numerical simulation shows that the area most be affected will be Puerto Diaz. The arrival time of the tsunami could be 57 minutes and 56 minutes to the Port and the amplitude of the tsunami will 1.20 m and 1.40 m for Medium case and Maximum case, respectively.

Scenario Event (Southwest direction). The result of numerical simulation shows that the area most be affected will be Rivas city. The arrival time of the tsunami could be 10 minutes to the city and the amplitude of the tsunami will 4.09 m and 5.61 m for Medium case and Maximum case, respectively.

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