TSUNAMI SIMULATION AND HAZARD ASSESSMENT ALONG THE COASTS OF FIJI

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ABSTRACT

This study was aimed to assess the tsunami hazard around the coastline of Fiji, in terms of the tsunami heights and tsunami arrival times. Eleven hypothetical source models were considered along the Tonga Trench of which six had Mw 8.0 and five had Mw 8.5. The five source earthquakes considered for the Vanuatu Trench had Mw of 8.0. The fault parameters were determined considering the worst case scenario using Papazacho's scaling law while the tsunami propagation was computed numerically using the TUNAMI- N2 code.

The expected travel time of tsunami from the Tonga trench is about 63 minutes for an earthquake source of Mw 8.0 and 56 minutes for a source of Mw 8.5. Tsunami high risk areas from any tsunami source along the Tonga Trench were identified to be the Lau Islands, Pacific Harbor and the Vanua Levu coastlines particularly Udu and Natewa Bay. The earliest tsunami arrival time from the New Hebrides Trench is 91 minutes. Tsunami high risk areas were identified to be the coasts of Malolo Lailai in the Mamanuca Group, Yalobi in the Yasawa Islands, Vunisea Kadavu, Pacific Harbor and the coral coast of Viti Levu particularly Korotogo and Natadola.

Generally it can be inferred that a major reason of the relatively high tsunami height is that some of these coastlines are within range of maximum directivity of the tsunami, thus, there is little scattering of tsunami energy. In addition, reflection and refraction phenomenon taking place amplifies the tsunami heights at some of these locations.

Keywords: Tsunami simulation, Tsunami hazard, Tsunami height, Tsunami arrival time.

1. INTRODUCTION

The nature and severity of tsunami disasters are determined by the conditions related to the attacking tsunami and the attacked region. The basic parameter of a tsunami is its height; therefore, if a height of a tsunami attacking a region can be estimated then it is possible to infer how large a tsunami attack will be and how much damage will occur in that region. As for the region, its basic parameters are its distance from the coast, height above sea level, coastal disaster prevention facilities and buildings (breakwaters, tsunami control forests, construction type and density) and the state of human activities (sleeping, working, etc) (Murata et al., 2010).

Fiji is located in the southwest Pacific Ocean at the midpoint of the opposing potential tsunami sources, the Tonga Trench and New Hebrides Trench (Gill 1976), therefore is particularly vulnerable to tsunamis. In understanding the tsunami hazard and its causes the more we are able to enhance our preparation in reducing the tsunami vulnerability thus reducing the tsunami risks in Fiji. The main purpose of this study is to assess tsunami threat around the coastlines of Fiji in terms of tsunami heights and arrival times.

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2. METHODOLOGY

2.1 Fault Parameters

The worst case scenario was considered for maximum risk analysis; therefore the dip of the fault was set as 45º, rake as 90º and the depth as 0km (Depth of top edge of the fault). The strikes of the faults are calculated from the trench alignment at each source location. The longitude and the latitude of these source point locations represent the location of the top edge corner of the fault. The length, width and slip amount of the fault are calculated using the scaling law by Papazachos et al (2004).Tables 1 and 2 show all the fault parameters of the source earthquakes from both the Tonga and New Hebrides Trench. Figures 1 to 3 illustrates the fault areas of the different sources from the Tonga and New Hebrides Trenches.

Table 1. Fault Parameters of the eleven tsunami sources with M_w 8 and 8.5 from the Tonga Trench.

S.E.	Mw	Depth (km)	Dip (º)	Rake (º)	Strike (º)	L (km)	W (km)	Slip (m)	Max. Up. (m)	Max. Sub. (m)	Lat. (º)	Lon. (º)
A1	8	0	45	90	210	162.2	70.79	2.14	1.23	-0.59	-23	185.4
B1	8	0	45	90	205	162.2	70.79	2.14	1.23	-0.59	-21	186.4
C1	8	0	45	90	200	162.2	70.79	2.14	1.23	-0.59	-19	187.14
D1	8	0	45	90	190	162.2	70.79	2.14	1.23	-0.59	-17	187.66
E1	8	0	45	90	160	162.2	70.79	2.14	1.23	-0.59	-15	187.36
F1	8	0	45	90	113	162.2	70.79	2.14	1.23	-0.59	-14.28	185.37
A2	8.5	0	45	90	210	305.49	101.16	4.47	2.55	-1.25	-23	185.4
B2	8.5	0	45	90	205	305.49	101.16	4.47	2.56	-1.25	-21	186.4
C2	8.5	0	45	90	200	305.49	101.16	4.47	2.56	-1.25	-19	187.14
D2	8.5	0	45	90	193	305.49	101.16	4.47	2.56	-1.25	-16.5	187.9
E2	8.5	0	45	90	113	305.49	101.16	4.47	2.56	-1.25	-14.28	185.37

S.E.; Scenario Earthquake, Max. Up. ; Maximum Uplift, Max. Sub. ; Maximum Subsidence,
Lat.; Latitude and Lon. ; Longitude.

Table 2. Fault Parameters of the five tsunami sources with M_w 8 from the New Hebrides Trench.

S.E.	Mw	Depth (km)	Dip (º)	Rake (º)	Strike (º)	L (km)	W (km)	Slip (m)	Max. Up. (m)	Max. Sub. (m)	Lat. (º)	Lon. (º)
VA1	8	0	45	90	302	162.2	70.79	2.14	1.23	-0.59	-23	171
VA2	8	0	45	90	323	162.2	70.79	2.14	1.23	-0.59	-22	169.5
VA3	8	0	45	90	329	162.2	70.79	2.14	1.23	-0.59	-20.5	168.52
VA4	8	0	45	90	347	162.2	70.79	2.14	1.23	-0.59	-19	167.74
VA5	8	0	45	90	344	162.2	70.79	2.14	1.23	-0.59	-17.25	167.51

2.2 Tsunami Simulation

The TUNAMI-N2 code (Tohoku University Numerical Analysis Model for Investigation- Near field Tsunami Number 2 code) was used for modeling propagation of tsunami towards the coast of Fiji from the proposed tsunami sources along the Tonga and New Hebrides Trenches.

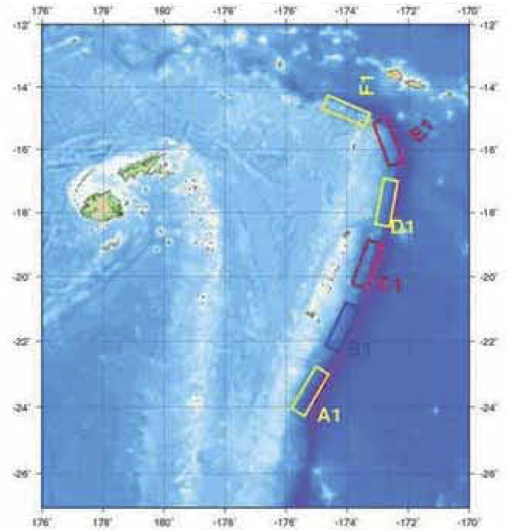

Figure 1. Fault area of the M_w 8 sources along the Tonga Trench.

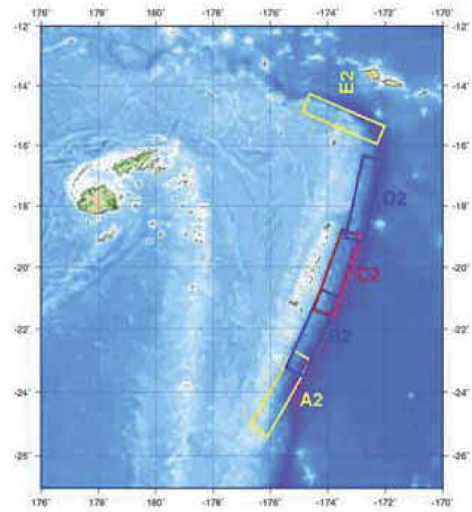

Figure 2. Fault area of the M_w 8.5 sources along the Tonga Trench.

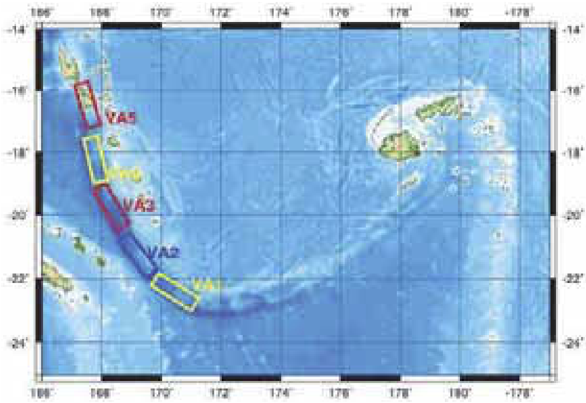

Figure 3. Fault area of the M_w 8 sources along the Tonga Trench.

The computation region used for all scenarios along the Tonga Trench extends from 176ºW to 190ºE and from -27ºS to -12ºS, with grid points equal to 840 and 900 points along the longitude and latitude, respectively. The computation region used for all scenarios along the New Hebrides Trench extends from 166ºW to 185ºE and from -25ºS to -14ºS, with grid points equal to 1020 and 660 points along the longitude and latitude, respectively. From the 1 arc-minute GEBCO bathymetry data, the computational domain of 1 minute grid spacing is derived for each of the computation region. For the initial condition, static deformation of the seafloor (Okada, 1985) was calculated using the parameters of the source models.
The integration time step Δt is equal to 3.0 s, computational time is equal to 3 hours, number of time steps for computational time is 3600, the grid interval Δx is 1749.2847 m, Δy is 1844.6793 m and the maximum depth is 10568.437 m. This is for the tsunami simulation from the Tonga Trench.

As for the tsunami simulation from the New Hebrides trench, the integration time step Δt is equal to 3.0 s, computational time is equal to 4 hours, number of time steps for computational time is 4800, the grid interval Δx is 1749.2846 m, Δy is 1844.6793 m and the maximum depth is 7198.1133 m. With both, the integration time step of 3.0 s, the condition of CFL's stability is satisfied because the value of Δt is less than the quotient between Δx and $\sqrt{2gd}$ which is equal to 3.84 for the Tonga Trench simulation region and 4.66 for the New Hebrides Trench region. Snapshots are taken in the interval of 1 minute.

3. RESULTS AND DISCUSSION

3.1 Maximum Tsunami Heights

Figure 4 shows the clarification of the different regions mentioned in the discussion of results.

3.1.1 Maximum Tsunami Heights for M_w 8 earthquakes along the Tonga Trench

From Figure 5, source A1 generated the highest tsunami height of 0.7m at the coast of Onoilau (TG1), Vatoa (TG2), Ogea (TG3) and Waciwaci, Lakeba (TG9). Sources B1, C1 produce the highest tsunami heights of 1.2 m at the same coast of Lakeba (TG9). Similarly at the same coast the highest tsunami wave of 1.0 m was calculated for source E1. Source D1 generated the maximum tsunami heights of 1.1 m at the coast of Yacata (TG13) whereas source F1 generated 0.9 m wave height both at the coast of Ogea (TG3) and Lakeba (TG9). Most of these coastlines recording tsunami heights of 0.5 m and higher are within the Lau islands (Region A).

At the coasts of Udu (TG36) and Natewa Bay (TG38) tsunami heights larger than 0.5 m were estimated even though these locations are far away from the sources. This is due to the refraction and reflection effect. For Mw 8.0 sources, the tsunami high risk areas were identified to be the Lau Islands (Region A), Udu (TG36) and Cicia in Natewa (TG38) in Region C (See Figure 4).

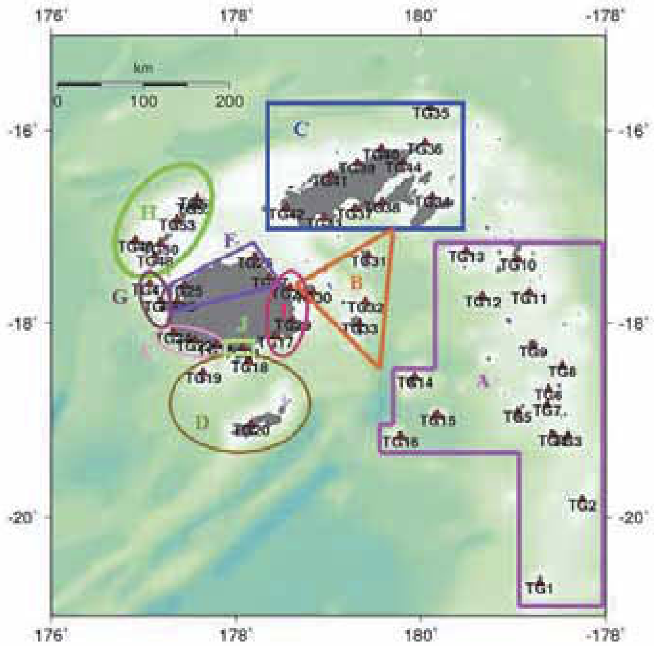

Figure 4. Locations of tide gauges as output points. Region A -Lau Islands (TG1-TG16). Region B -Lomaiviti Islands (TG30-TG33) Region C -Vanua Levu Group (TG34-TG44). Region D -Southern Islands (TG18-TG20). Region E -Coral Coast of Viti Levu (TG22-TG24). Region F -Western Side of Viti Levu (TG25-TG27). Region G -Mamanuca Group (TG45-Tg47). Region H -Yasawa Islands (TG48-TG53). Region I -Central Division of Viti Levu (TG17) TG28 & TG29). Region J -Pacific Harbor (TG21).

3.1.2 Maximum Tsunami Heights for M_w 8.5 earthquakes along the Tonga Trench

Figure 6 shows the graphed maximum tsunami heights at each of the 53 tide gauge stations from the Mw 8.5 sources along the Tonga Trench.

Sources A2 and B2 generated the maximum tsunami height of 1.9 m and 2.2 m respectively at the coast of Pacific Harbor (TG21). The directivity of the tsunami from these two sources is particularly towards this coastline. In addition the tsunami height is possibly amplified at this location because the coastline is shaped like a bay, therefore there is a concentration of tsunami energy at this coast due to repeated reflection and refraction as the tsunami propagates towards the shore. Further more, high tsunami height at Pacific Harbor is indicative of the low gradual slopes of the bathymetric profile of this bay (Vuetibau, 2007).

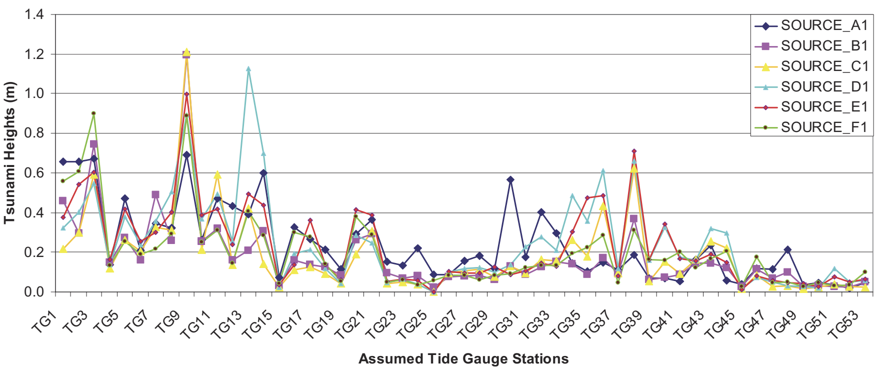

Figure 5. Maximum tsunami heights at each assumed tide gauge station for all the M_w 8. sources along the Tonga Trench.

Sources C2 and D2 generate maximum tsunami heights of 1.7 m at Ogea (TG3) and 2.1 m at Udu (TG36), respectively. Udu is along the path of the tsunami ray and is also a cape whereby the wave rays are liable to cluster, therefore amplifying the tsunami height. The highest tsunami height of 2.3 m is recorded at the coast of Lakeba (TG9) for source E2.

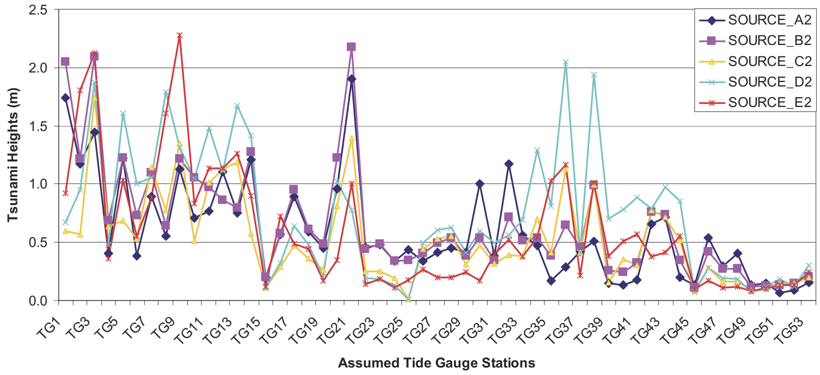

Figure 6. Maximum tsunami heights at each assumed tide gauge station for all the M_w 8.5. sources along the Tonga Trench.

High tsunami risk areas are identified to be the Lau Islands (Region A), Pacific Harbor (TG21) in Region J, Udu (TG36) and Natewa (TG38) both in Region C (see Figure 4).

3.1.3 Maximum Tsunami Heights for M_w 8.0 earthquakes along the New Hebrides Trench

Figure 7 shows the maximum tsunami heights at each of the 53 assumed tide gauge stations from each of the New Hebrides Mw 8.0 source.The highest tsunami is calculated as 1.0 m at the coast of Natadola (TG24) generated by source VA2. This was followed by source VA1 generating 0.6 m tsunami height at the coast of Yalobi (TG48). Source VA3 generate tsunami height of 0.3 m at the coast of Ono I Lau (TG1) in Region A, Vunisea Kadavu (TG20) in Region D, Pacific Harbor (TG21) in Region J, Korotogo (TG22), Natadola (TG24) both located in Region E, and Tavewa (TG53) in Region H. For source VA4, the highest tsunami height of 0.4 m is recorded at the coasts of Kadavu (TG20), Malolo Lailai (TG46) in the Mamanuca Group (Region G), Yalobi (TG48) and Tavewa (TG53) both in the Yasawa Group (Region H). Lastly, VA5 generate 0.2 m of tsunami height at the coasts of Suva (TG17) in Region I, Vunisea Kadavu (TG20) in Region D, Lautoka (TG25) in Region F, Malolo Lailai (TG46) in Region G and Yalobi (TG48) in Region H (see Figure 4).

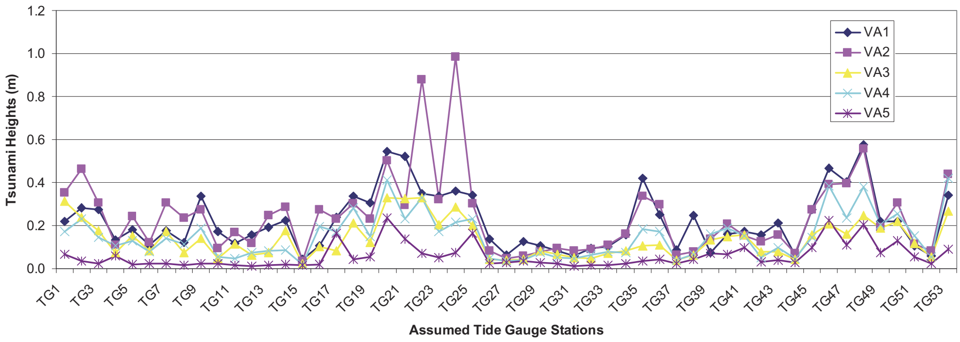

Figure 7. Maximum tsunami heights at each assumed tide gauge station for all the M_w 8 sources along the New Hebrides Trench.

Sources VA3, VA4 and VA5 are located at the rear of the Vanuatu Islands so most of the tsunami energy is dissipated along the coastlines of these islands before it propagates towards Fiji. The energy of tsunami spreads and weakens with distance resulting in the decrease of tsunami heights as it approaches the coastlines of Fiji.

Tsunami high risk areas from the New Hebrides Trench include Region D specifically the coast of Vunisea Kadavu (TG20), Pacific Harbor (TG21) in Region J, Coral Coast of Viti Levu (Region E) especially the coast of Korotogo (TG22) and Natadola (TG24), Malolo Lailai (TG46) in the Mamanuca Group (Region G) and the Yasawa Group in Region H (Yalobi (TG48)).

3.2 Tsunami Travel Time

Tsunami travel times were obtained from the waveforms of the tsunami simulation computed from the TUNAMI-N2 code.

For the first five sources (A1-E1) their first tsunami waves are recorded at tide gauges within the Lau Group in Region A whereas for source F1 the first tsunami wave is recorded at a tide gauge station within the Vanua Levu Islands in Region C. This is because source F1 is much closer to the

Vanua Levu Islands than to the Lau Group. For any tsunami sources of Mw 8.0 from the Tonga Trench, the estimated tsunami travel times are around 63 minutes.

For source A2, the first tsunami wave reaches the coast of Ono I Lau (TG1) within 52 minutes from the origin time of the earthquake. For sources B2, C2 and D2 the waves arrive first at the coast of Vatoa (TG2) in 52, 53 and 64 minutes, respectively. As for source E2 the expected arrival time is 58 minutes at Cikobia (TG35). For any source models of M_w 8.5 from the Tonga Trench the expected arrival times are within 56 minutes.

For sources VA1, VA2 and VA3 their first tsunami waves are recorded at the coast of Natadola (TG24) at the time of 79, 87, and 94 minutes, respectively. As for sources VA4 and VA5 the tsunami waves will arrive first at the coast of Viwa (TG49) in Region H at a time of 99 and 97 minutes, respectively. For any tsunami sources of Mw 8.0 along the New Hebrides Trench, the expected tsunami travel times to reach the coast of Fiji are within 91 minutes (about 1 hour 30 minutes).

4. CONCLUSIONS

For source models of M_w 8.0 along the Tonga Trench, tsunami high risk areas were identified to be the coasts of the Lau Islands, Natewa and Udu. The tsunami arrival time calculated for an earthquake source of M_w8.0 from the Tonga Trench is generally 63 minutes. As for source models of M_w 8.5 along the Tonga Trench, tsunami high risk areas include the Lau Islands, Pacific Harbor and the Vanua Levu coastlines of Udu and Natewa Bay. Tsunami arrival time was computed to be within 56 minutes after the earthquake occurrence. Tsunami high risk areas for an earthquake source from the New Hebrides Trench of M_w 8 include the coast of Malolo Lailai in the Mamanuca Group, Yalobi in the Yasawa Islands, Kadavu, Pacific Harbor and the Coral Coast of Viti Levu particularly Korotogo and Natadola. The travel time of tsunami from the New Hebrides Trench was computed to be generally 91 minutes. In view of these tsunami simulation results, the residents of the tsunami high risk areas would have adequate time to evacuate to higher grounds in time of a tsunami.

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