Citation: Lesikikabara, K., Y. Fujii, B. Shibazaki (2023), Enhancing tsunami early warning system in Fiji using tsunami database, Synopsis of IISEE-GRIPS Master's Thesis.

ENHANCING TSUNAMI EARLY WARNING SYSTEM IN FIJI USING TSUNAMI DATABASE

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ABSTRACT

This study aims to enhance Fiji's tsunami early warning system by employing a tsunami database, which includes 64 (four magnitudes and depths at four source points) precomputed simulation results stored in a MySQL database. The current system predominantly relies on manual input of forecasting messages, making it time-consuming and error-prone. Five methods for retrieving tsunami height from the database were assessed, revealing significant variations in the estimated tsunami heights. The most simple approach was defined as Method 2, which selects the maximum tsunami height among the four source points based on the searched magnitude and depth. This method was used for its simplicity and ease of implementation, primarily due to its avoidance of complex interpolation techniques. Compared to the existing system, which takes 10 to 15 minutes to generate and dispatch tsunami warnings, the enhanced system can produce forecasting messages in seconds using Method 2 after earthquake parameters are obtained.

Keywords: Tsunami Early Warning, Tsunami Database, Tsunami Height Estimation, Information Dissemination, Tide Gauges.

1. INTRODUCTION

Even though Fiji has implemented a tsunami early warning system, the current infrastructure and methods must be improved in disseminating timely and accurate information to relevant authorities and the media. The existing system relies heavily on manual processes for assembling and disseminating tsunami information, leading to delays and inaccuracies that could ultimately cost lives. This study focuses on Fiji's coastal blocks, initially defined by Rawaikala (2011) for a tsunami hazard assessment (Figure 1).

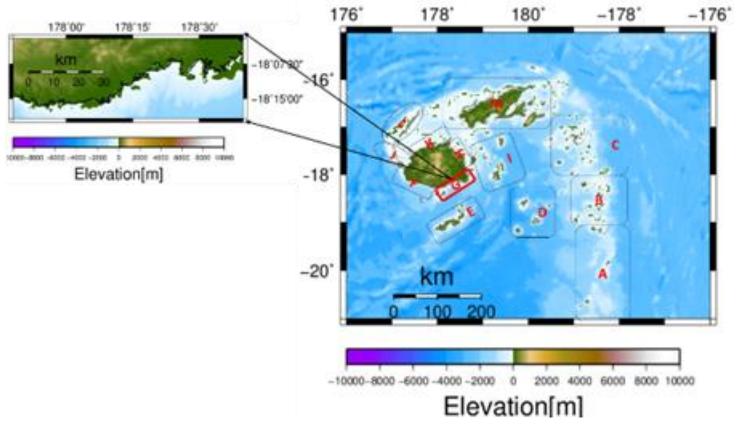

Figure 1. Fiji forecasting coastal blocks.

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This study aims to create a tsunami database to improve Fiji's tsunami early warning system. The study highlighted a remarkable improvement in information dissemination time by using the tsunami database. The current process takes 10 to 15 minutes to generate a tsunami message, while utilizing the tsunami database reduced the time to mere seconds.

2. DATA

The original GEBCO bathymetry data (GEBCO Compilation Group, 2023) were resampled to a coarse resolution of 1 arc minute. In addition to the resampled bathymetry data, the GMT coastline database was utilized to define the land grid within the computational area where the land grids are set to -999 m and sea grids are set to positive values.

3. METHODOLOGY

3.1. Setting source points

For this case study, four source points (SP) were established as shown in Figure 2. Each source point corresponds to a specific magnitude range: 7, 7.5, 8, and 8.5. The depth range for these source points spans from 0 km to 60 km, with increments of 20 km (i.e., 0 km, 20 km, 40 km, and 60 km).

3.2. Setting coastal and forecast points

10 coastal points (CPs) and forecast points (FPs) were established along the coast as shown in Figure 3. CPs are positioned nearer to the shoreline, specifically in areas where the depth of the sea is less than 10 meters. On the other hand, FPs are located along the coast where the water depth is approximately 50 meters.

3.3. Fault parameter setting

Dimensions of fault models, including its length (L), width (W), and slip amount (D), were calculated using scaling law (Utsu, 1984). The strike angle of each fault model was set parallel to the Tonga trench.

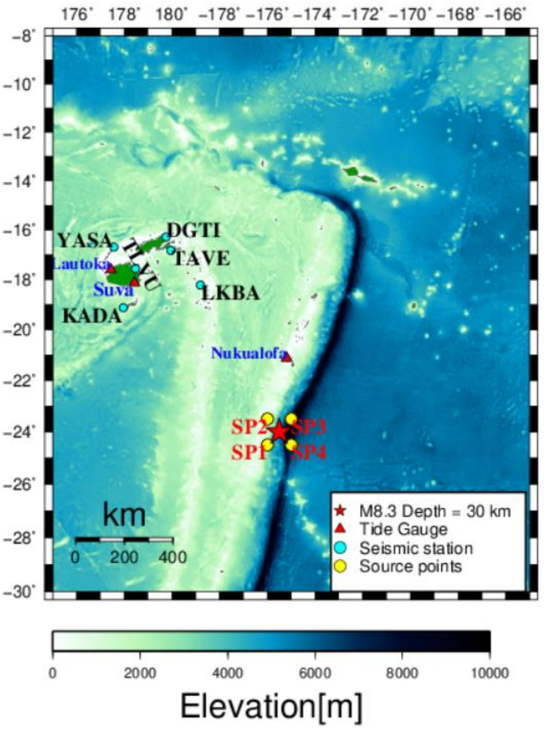

Figure 2. Locations of SPs, tige gauge, seismic stations and M8.3 scenario earthquake.

3.4. Initial condition for numerical simulation

An initial deformation of the sea surface is assumed to be identical to the deformation of the sea floor. It will be given to the numerical tsunami simulation as an initial value (Mansinha & Smylie, 1971).

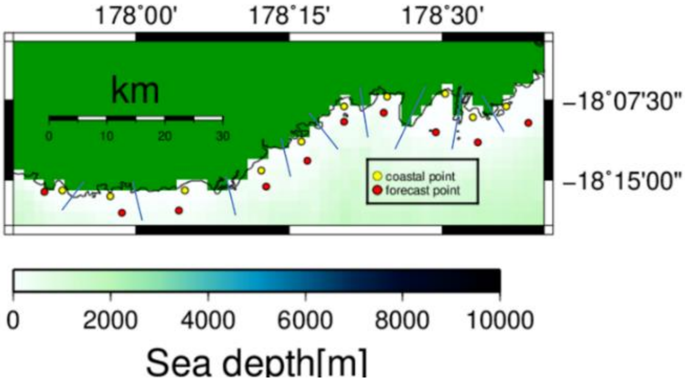

Figure 3. Distribution of CPs and FPs.

3.5. Numerical simulation of tsunami propagation

TUNAMI code by Yanagisawa (2022-2023) was used for tsunami simulation. Non-linear long wave equations were used as the governing equation using a spherical coordinate system.

3.5.1. Single grid computation

A 1-arc minute grid size was used throughout the computation area for tsunami database computation. To satisfy the CFL condition, a time step of 3 seconds was used in a tsunami propagation time of 10,800 seconds (3 hours).

3.5.2. Nesting grid computation

Nesting grids shown in Figure 4 were used for computation to test for accuracy of using Green's law to estimate tsunami height at the coast. The first grid has a grid size of 1 arc minute, the second region has a grid size of 20 arc seconds and the last region has a grid size of 20/3 arc seconds. To satisfy the CFL condition a time step of 0.5 seconds was used in a tsunami propagation time of 10,800 seconds (3 hours).

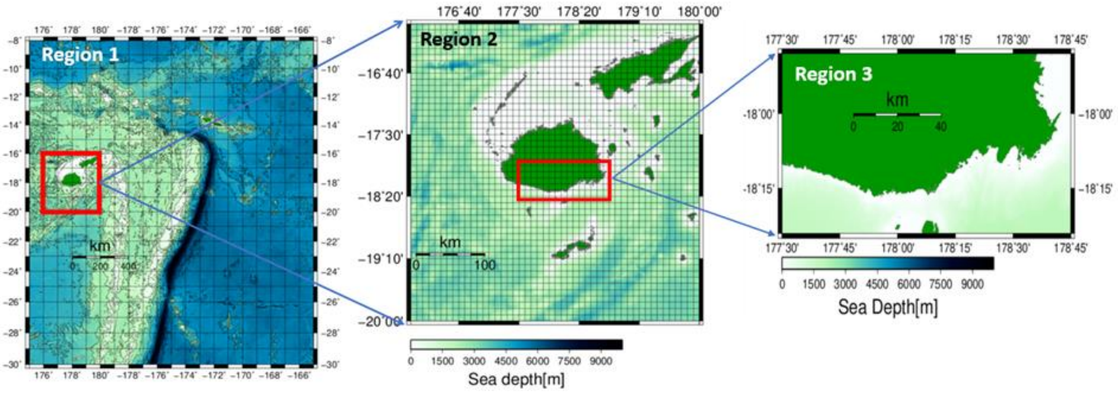

Figure 4. Nesting grid regions.

3.6. Tsunami height estimation at the coast

To optimize simulation computation time, a coarse grid of 1 arc minute is used. Green's law is applied at the FPs to accurately estimate the tsunami height at the coast, with the water depth of CPs assumed to be 1 meter based on guidelines from the Japan Meteorological Agency (JMA, 2013).

3.7. Methods of tsunami height retrieval from tsunami database

3.7.1. Method 1a

In this method, all three interpolation techniques (magnitude, depth, and location) were utilized at each FP. Firstly, two-dimensional linear interpolation was used to interpolate magnitude and depth using two magnitudes and two depths from the tsunami database. The resulting tsunami heights after magnitude and depth interpolation was then used in location interpolation. Finally, the maximum tsunami height from all FPs will be used for the tsunami forecasting message.

3.7.2. Method 1b

This method also employs all interpolation techniques. However, instead of interpolation at each FP, the maximum tsunami height from all FPs was used in magnitude and depth two-dimensional linear interpolation. The resulting interpolated tsunami height was then used in location interpolation. Then final tsunami height after location interpolation will be used in the tsunami forecasting message.

3.7.3. Method 2

This involves selecting the closest four SPs. Then the highest closer magnitude and closer shallower depth is selected from each SP in the database. The highest tsunami height among the four selected SPs is chosen to be used for tsunami forecasting message.

3.7.4. Method 3a

This method uses the maximum risk method where all SPs in the rectangular fault model are selected. The rectangular fault model is calculated using Utsu (1984) scaling law equation. The highest closer magnitude and closer shallower depth will be selected from all selected SPs in the fault model and the highest estimated tsunami height among them will be used for tsunami forecasting message.

3.7.5. Method 3b

This method also uses the maximum risk method. However, location interpolation is conducted at each FP. The maximum interpolated tsunami height will be selected from all FP to be used for the tsunami warning message. In the case where there are less than 4 SPs in the fault model then the four closest SPs from the epicenter will be selected from the database for location interpolation to be possible.

3.8. Tsunami arrival time estimation

For Tsunami Travel Time (TTT) calculation, TTT Software Package Version 4.0.1 provided by International Tsunami Information Center was used together with GMT 4 to make an inverse refraction diagram. Tsunami travel time from FP to the epicenter is added together with tsunami travel time from FP to CP. This total tsunami travel time is stored in the tsunami database. To estimate tsunami arrival time at the coast, the total tsunami travel time stored in the database is added to the earthquake origin time.

3.9. Tsunami forecasting messages

The determination of the tsunami forecast grade in this study is based on the maximum coastal tsunami height shown in Table 1. This tsunami height is computed by applying Green's law to the tsunami height calculated at the forecast point.

Table 1. Tsunami forecasting messages. H is the estimated tsunami height.

Forecast Grade		**Estimated Tsunami Height (m)**
Warning	Major Tsunami	H >= 3
	Tsunami	1 >= H < 3
Advisory		0.5 >= H <1
No tsunami threat		H < 0.5

4. RESULTS AND DISCUSSIONS

4.1. Greens law evaluation

Figure 5 illustrates that the direct measurement of tsunami height at the coast using a coarse grid tends to underestimate the tsunami height when compared to the more precise fine grid of 20/3 arc seconds. Furthermore, the graph shows that the tsunami height estimated at the coast using Green’s law in conjunction with the coarse grid aligns well with the tsunami range determined using the fine grid. These findings highlight the significance of utilizing Green's law and coarse grids to accurately estimate tsunami height at the coast, thereby decreasing computation time and maintaining tsunami height estimation accuracy.

4.2. Retrieving tsunami heights from the database

The obtained results from the five methods, namely Method 1a, Method 1b, Method 2, Method 3a, and Method 3b, are derived from the scenario earthquake represented by the red star in Figure 2. This earthquake scenario has a magnitude of 8.3 and a depth of 30 km.

4.3. Comparing the five methods

Method 2 and Method 3a result produce the highest estimated tsunami height because both methods choose the maximum tsunami height from the tsunami database among the four closest SPs (Figure 6). The simplicity of Method 2 offers practical advantages in terms of implementation. It avoids the need for complex interpolation techniques.

4.4. Tsunami travel time

Figure 7 presents the total tsunami travel time for each location in the study area. The quickest tsunami travel time among all FPs is recorded in the tsunami database and utilized in the computation of the tsunami's arrival time. By selecting the quickest time among these nearest SPs, we can offer more crucial minutes for people to evacuate and seek safety.

4.5. Tool to generate tsunami forecasting message

Tsunami simulation results are first stored in Excel files, then imported from MySQL to create a tsunami database. We used Python programming language to create a Graphical User Interface (GUI) to input earthquake parameters. In the automated generated message shown in Figure 8, the content of the tsunami forecasting message will be determined based on the tsunami height at the coast, as indicated in Table 2. The specific type of forecasting message, whether it be a major tsunami warning, tsunami warning,

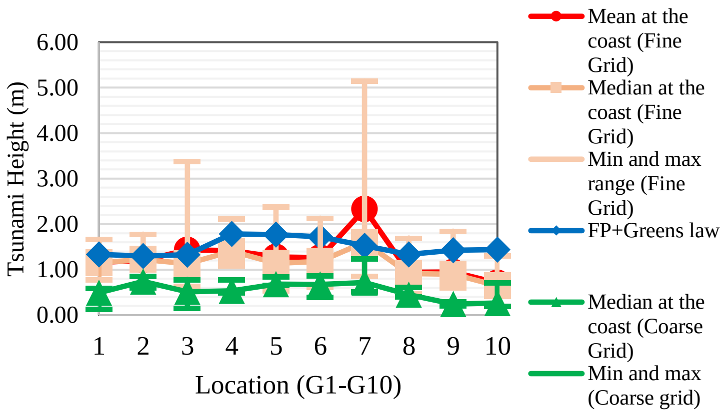

Figure 5. Green's law evaluation.

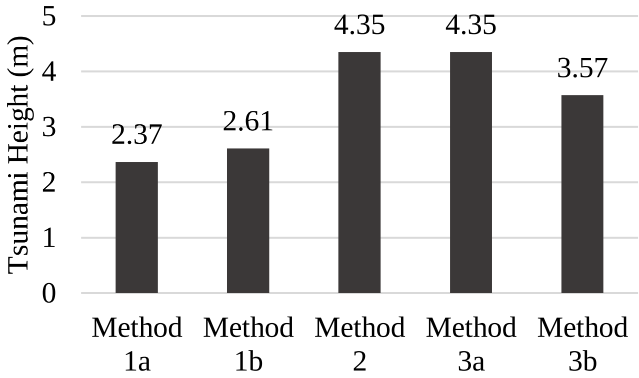

Figure 6. Estimated tsunami heights using the five methods.

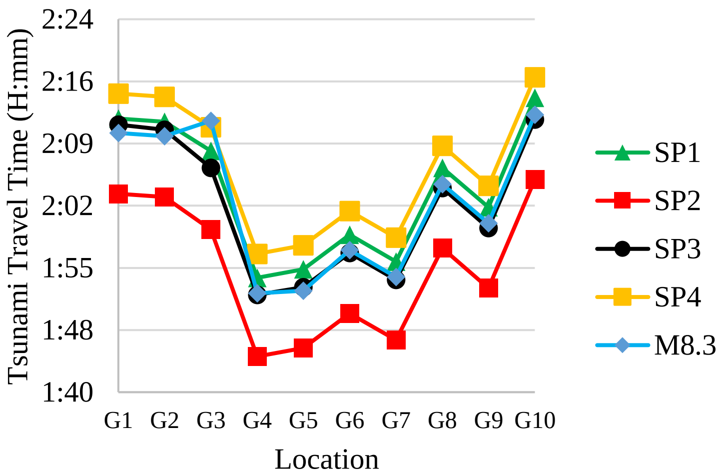

Figure 7. Total tsunami travel time to each coastal area.

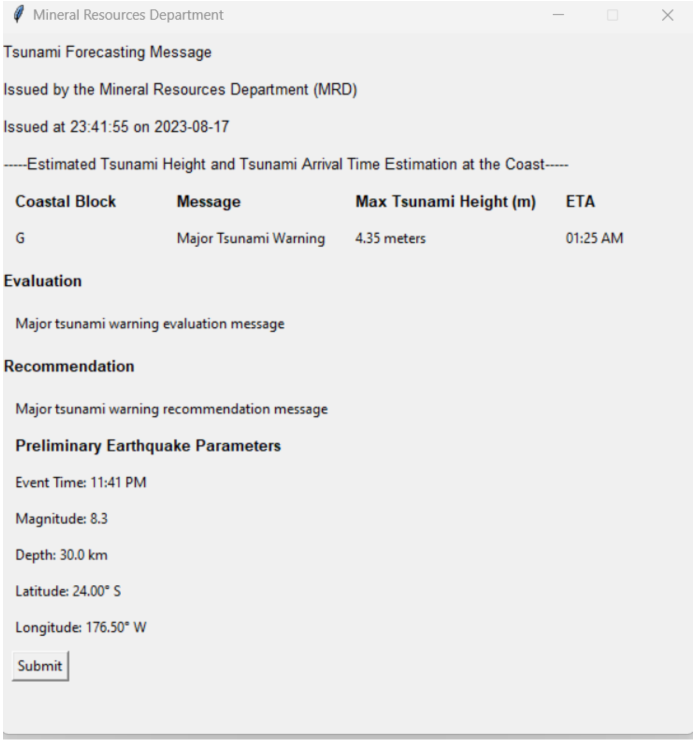

Figure 8. Sample of "Major Tsunami Warning" message. The preprepared message is also stored in the tsunami database.

advisory or no tsunami threat will be determined by the calculated tsunami height value. Additionally, the evaluation message and recommendations message will be tailored according to the type of forecasting message selected.

5. CONCLUSIONS

In conclusion, this study focused on enhancing the tsunami early warning system in Fiji through the utilization of a tsunami database. the study highlighted a remarkable improvement in information dissemination time by using the tsunami database. The current process takes 10 to 15 minutes to generate a tsunami message, while utilizing the tsunami database reduced the time to mere seconds. This swift access to pre-computed tsunami simulation results and messages stored within the database enables the rapid generation of accurate tsunami messages for forecasting, facilitating timely response and decision-making during tsunami events. Furthermore, considering the results obtained from the Nuku'alofa tide gauge, the study demonstrates the usefulness of tide gauges around Fiji in monitoring tsunami sources near SPs in the tsunami database. The evaluation of tsunami travel time differences between Nuku'alofa and Suva can aid MRD in promptly responding to potential tsunami threats and issuing timely warnings to coastal communities, further enhancing Fiji's disaster preparedness and safety.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation and gratitude to my supervisors, Dr. Yushiro Fujii and Dr. Bunichiro Shibazaki, for their exceptional guidance, unwavering support, and extensive expertise throughout the entire process of completing this report. Their valuable insights and advice have played a crucial role in shaping the outcome of this study, and I am sincerely indebted to their mentorship and encouragement.

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