

# VULNERABILITY OF SCHOOLS IN PUERTO RICO TO TSUNAMI EVENTS



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## ABSTRACT

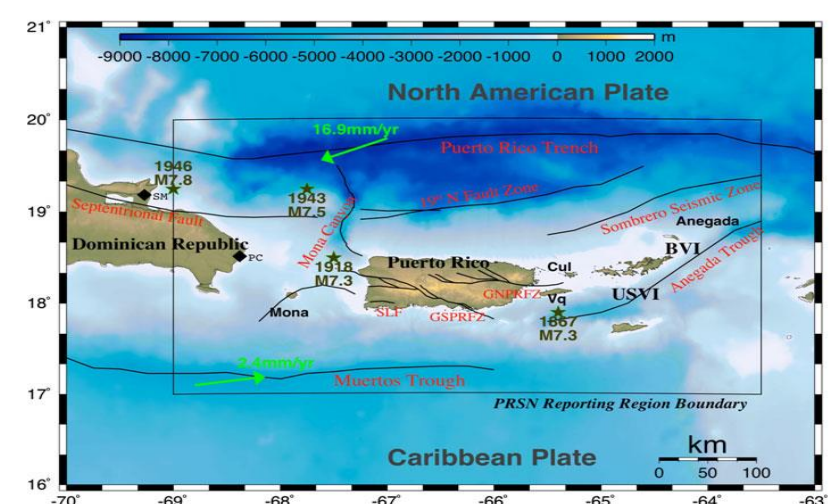
Puerto Rico is in an area of high seismicity, due to the presence of seismic faults around and within the Island. These faults have the potential to generate earthquakes that cause tsunamis, as occurred in 1918 in the western area of Puerto Rico. Considering that the school population between students and teachers is around 600,000 people, schools are essential facilities to safeguard against extreme events on the Island. For this reason, the objective of the research is to evaluate if the schools of Puerto Rico are vulnerable to tsunamis. To do this, the schools that are in a tsunami hazard zone were first identified and quantified for all the coastal municipalities of the Island. Then, two municipalities were selected as case studies in which a vulnerability assessment process was developed, which includes the analysis of pedestrian routes for the evacuation process and evacuation times to safe places. The study found that two schools are critical in vulnerability, one in each study municipality with excessive evacuation times and evacuation routes that are unsafe and unfit for the evacuation process.

## INTRODUCTION

Puerto Rico is susceptible to earthquakes and consequently tsunamis. Although tsunamis are rare in Puerto Rico, their historical events, seismic hazards, and other active earthquake-forming faults pose a potential tsunami-generating threat. According to the National Tsunami Risk Mitigation Program (2019), Puerto Rico has the highest tsunami danger in the US Atlantic. Due to the risk of earthquakes that can occur in the Puerto Rico Trench, a dangerous area of subduction. Tsunamis can have catastrophic impacts on human health and infrastructure in and out of coastal areas. Some of the infrastructures that may be at risk and be vulnerable are schools. According to a statistic made in 2015-2016 from the Puerto Rico Institute of Statistics (2019), Puerto Rico has an approximate total of 2,200 schools between the public and private sectors along with a population of 600,000 between students and teachers. In this way, this research focuses on making an analysis of the vulnerability of schools, identifying those that are in danger and at risk of tsunamis.

### Important Concepts Definitions:

- Earthquake** - is the oscillatory, rapid, and sudden movement caused by the release of energy that arises from the interior of the Earth (Puerto Rico Seismic Network, n.d.).
- Tsunami** - is a series of giant, traveling waves that is generated by large-scale impulsive disturbances on the ocean floor (United Nations Educational, Scientific and Cultural Organization, 2019).
- Vulnerability** - is a measure of the propensity of a community to suffer losses (Pine, 2008).



## OBJECTIVES

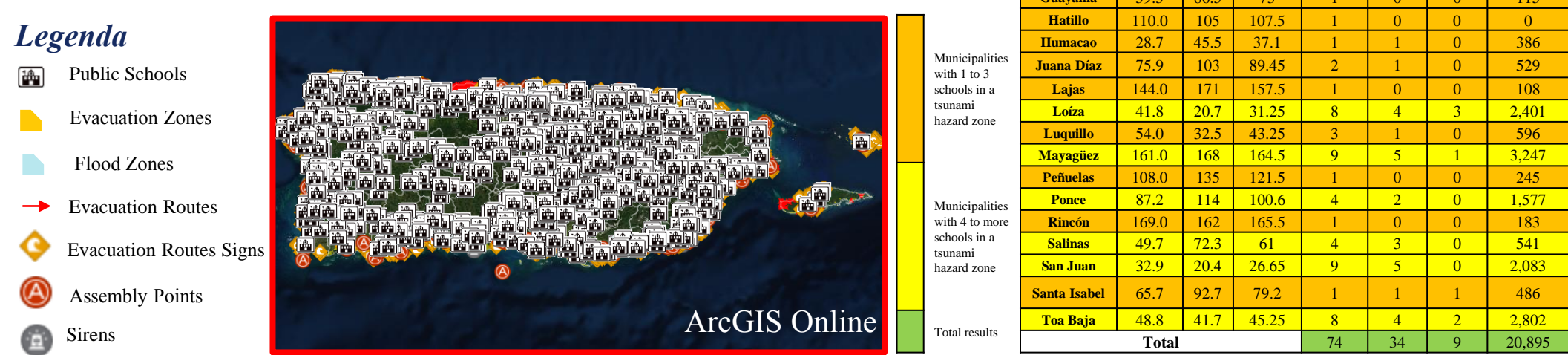
The objective of this project is to evaluate the potential vulnerabilities of schools in Puerto Rico to tsunami events by identifying the schools that are in a tsunami hazard zone, determining evacuation times and evaluating the routes of evacuation of these schools.

## METHODOLOGY

The methodology consists of four phases that employ: hazard identification (Phase I), case study (Phase II), vulnerability analysis (Phase III), and analysis of the results (Phase IV).

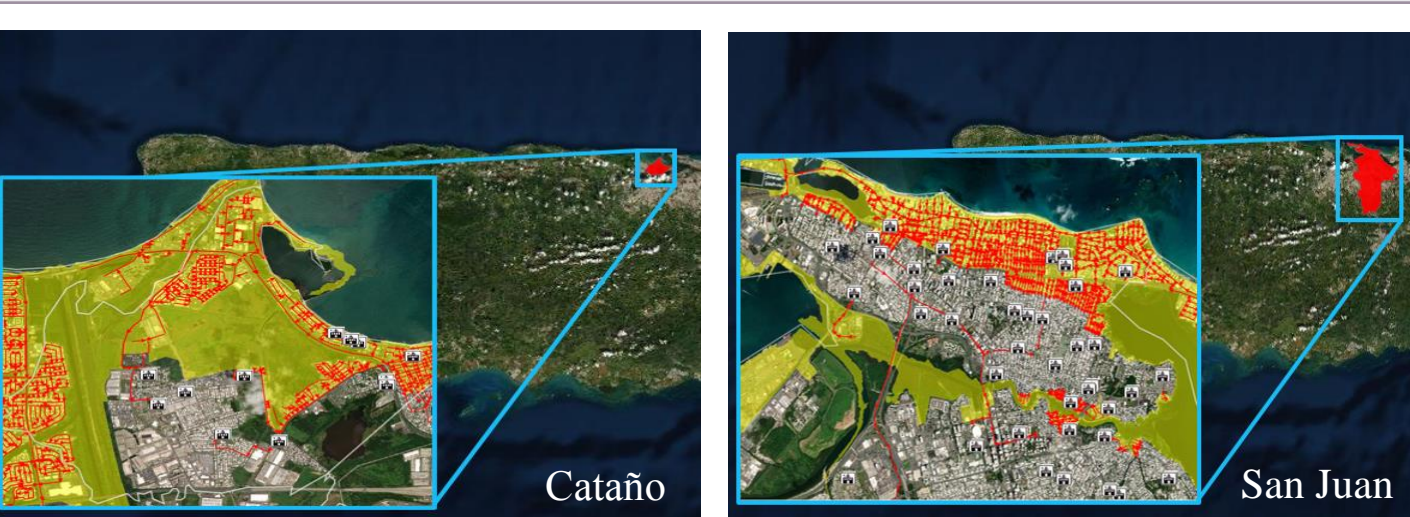
### I - Hazard Identification

In ArcGIS Online, the public schools that are in a tsunami hazard zone were identified for the 46 municipalities of Puerto Rico that are part of the TsunamiReady of the Puerto Rico Seismic Network. The number of these schools that are used as shelters and voting centers and that are in the affected areas were quantified. The amount of population that could be affected among students and teachers for these schools was evaluated. The table presents the findings of this phase.



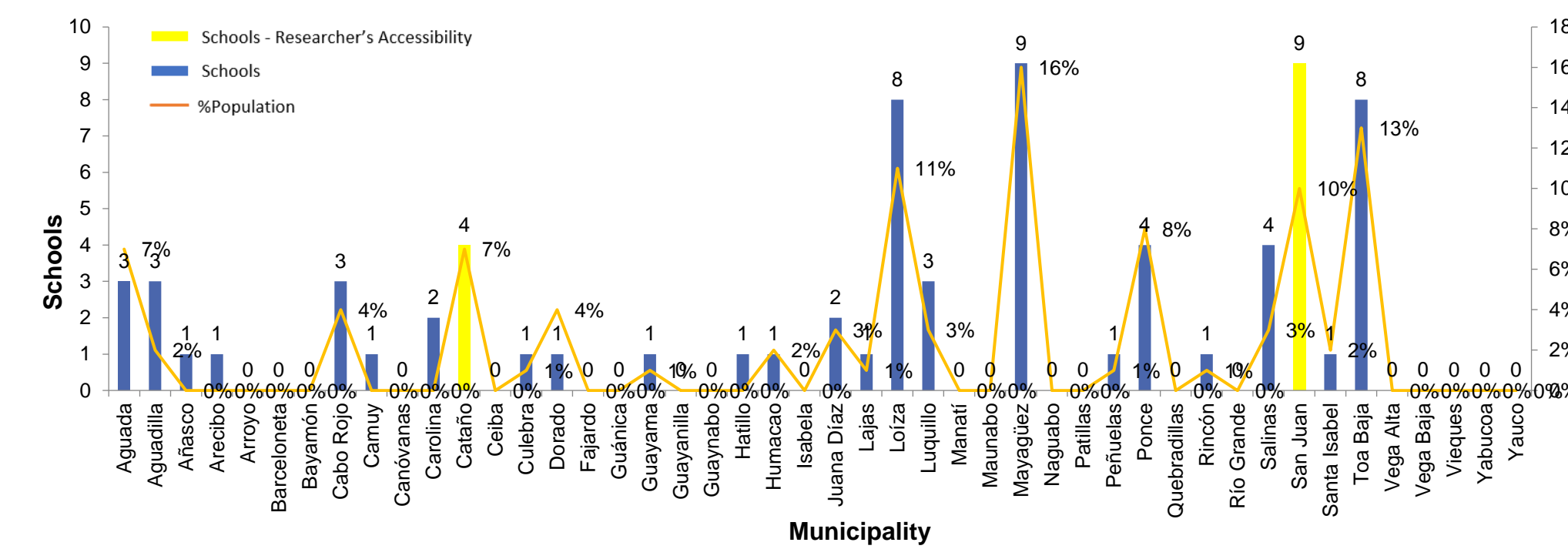
### II - Case Study

Municipalities with schools located in danger zones were selected to determine its vulnerability. The municipalities of Cataño and San Juan were selected according to the established criteria.



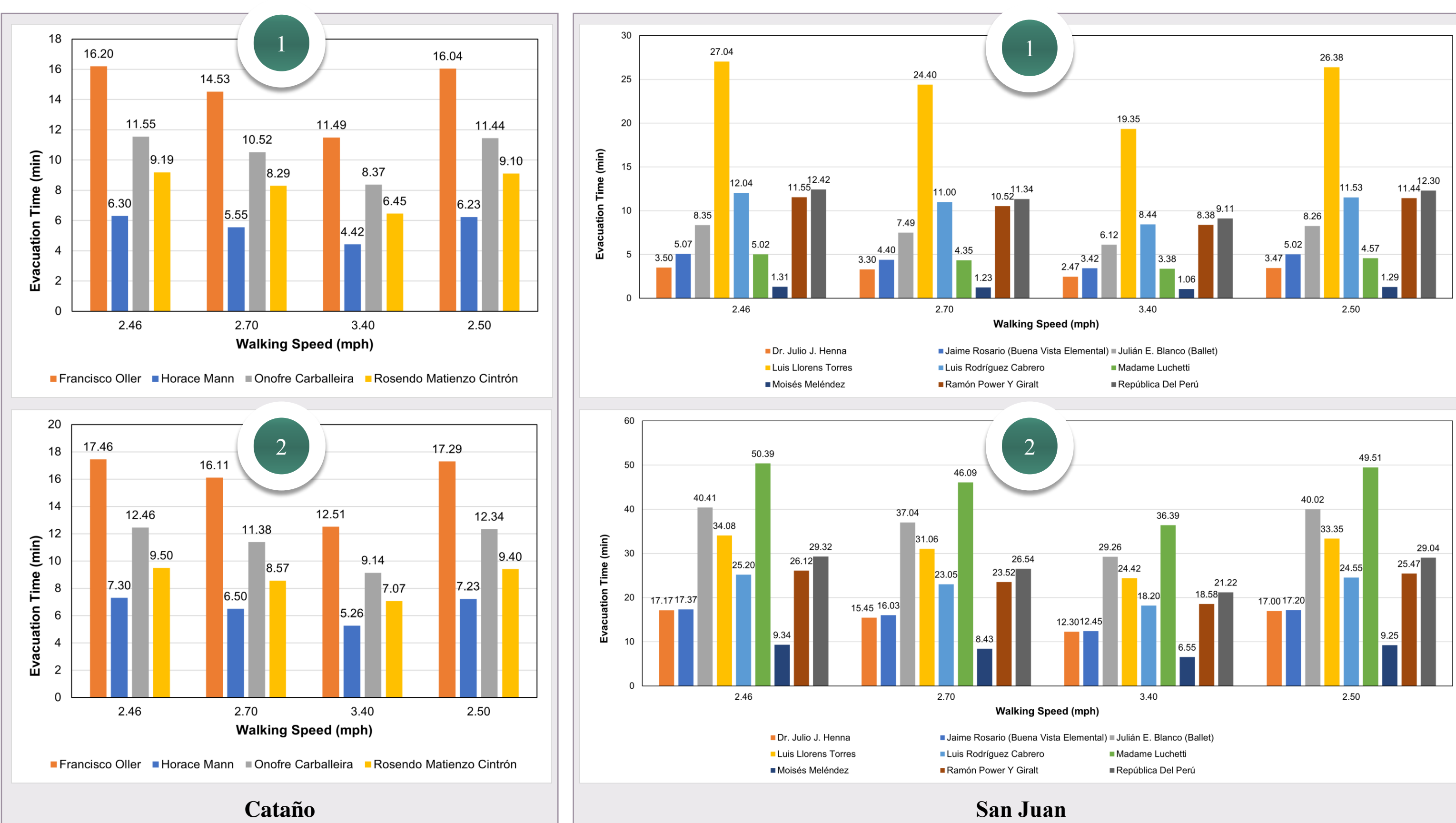
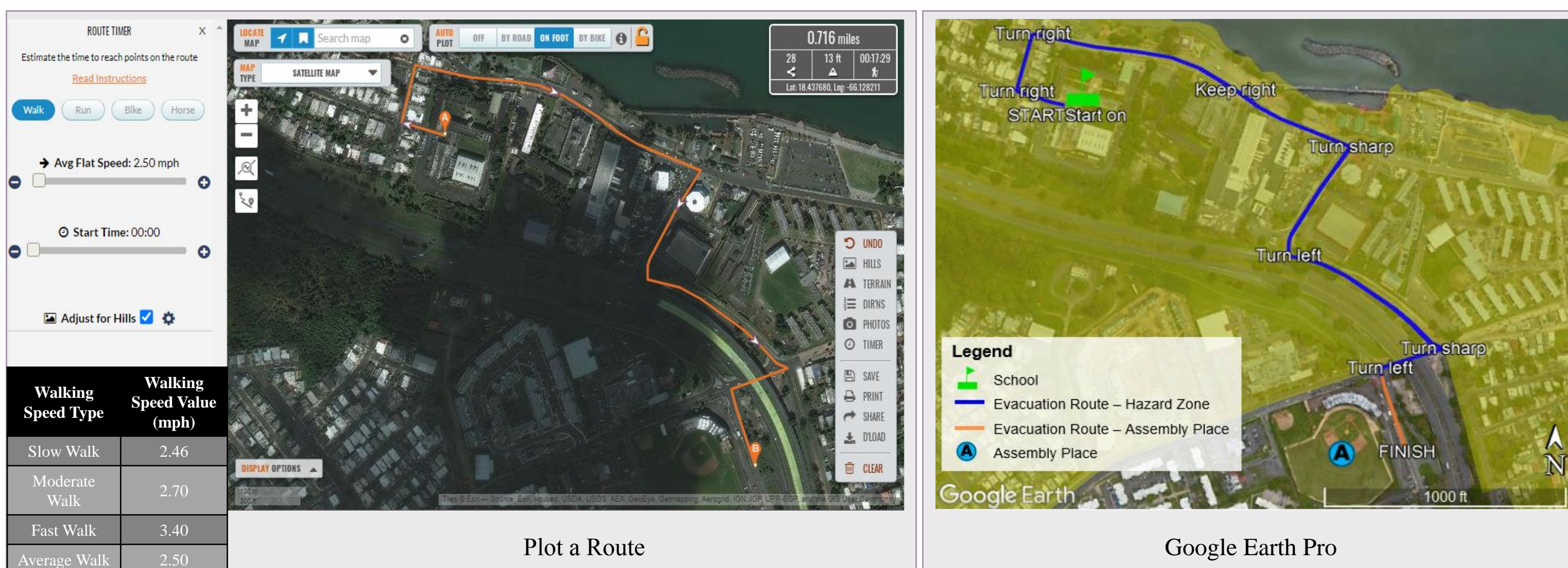
The selection criteria considered in this phase are the following:

- Researcher's accessibility
- Number of schools located in the tsunami hazard zone
- Number of schools used as shelters or voting centers located in the tsunami hazard zone
- Number of population that could be affected by a tsunami



### III - 1 Vulnerability Assessment – Evacuation Time

Evacuation routes were plotted using "PlotARoute" and the evacuation time was computed for four speeds recommended by the U.S. Geological Survey (USGS): slow walk (2.46 mph), moderate walk (2.70 mph), fast walk (3.40 mph), and an average walk (2.50 mph). This analysis was performed for all schools in the municipalities of the study case. Under two scenarios: (1) one is taken from the school until leaving the tsunami hazard zone and (2) the other is taken from the school until reaching the assembly site.



## ANALYSIS AND RESULTS

In evaluating evacuation times, the graphs of Phase III summarize the evacuation times (1) until leaving the hazard zone and (2) until reaching the assembly site at an average walking speed of 2.50 mph. These represent:

- For the evacuation time outside the tsunami hazard zone (1), the critical schools were Francisco Oller school for Cataño and Luis Llorens Torres school for San Juan, with times of 16.04 min and 26.38 min respectively, considering the average speed of 2.50 mph.
- For the primary evacuation time elapsed until reaching the assembly site (2), the subcritical schools were Francisco Oller school for Cataño and Madame Luchetti school for San Juan, with times of 17.29 min and 49.51 min respectively, considering the average speed of 2.50 mph.
- Because the potential hazard of vulnerability for schools lies in leaving the tsunami hazard zone, those schools with the largest evacuation times until they leave the tsunami evacuation zone are considered critical; the evacuation time until reaching assembly site was considered a secondary condition, since although they are outside the tsunami impact area, this is the site were assistance and help will be channelized (so reaching this site is important).

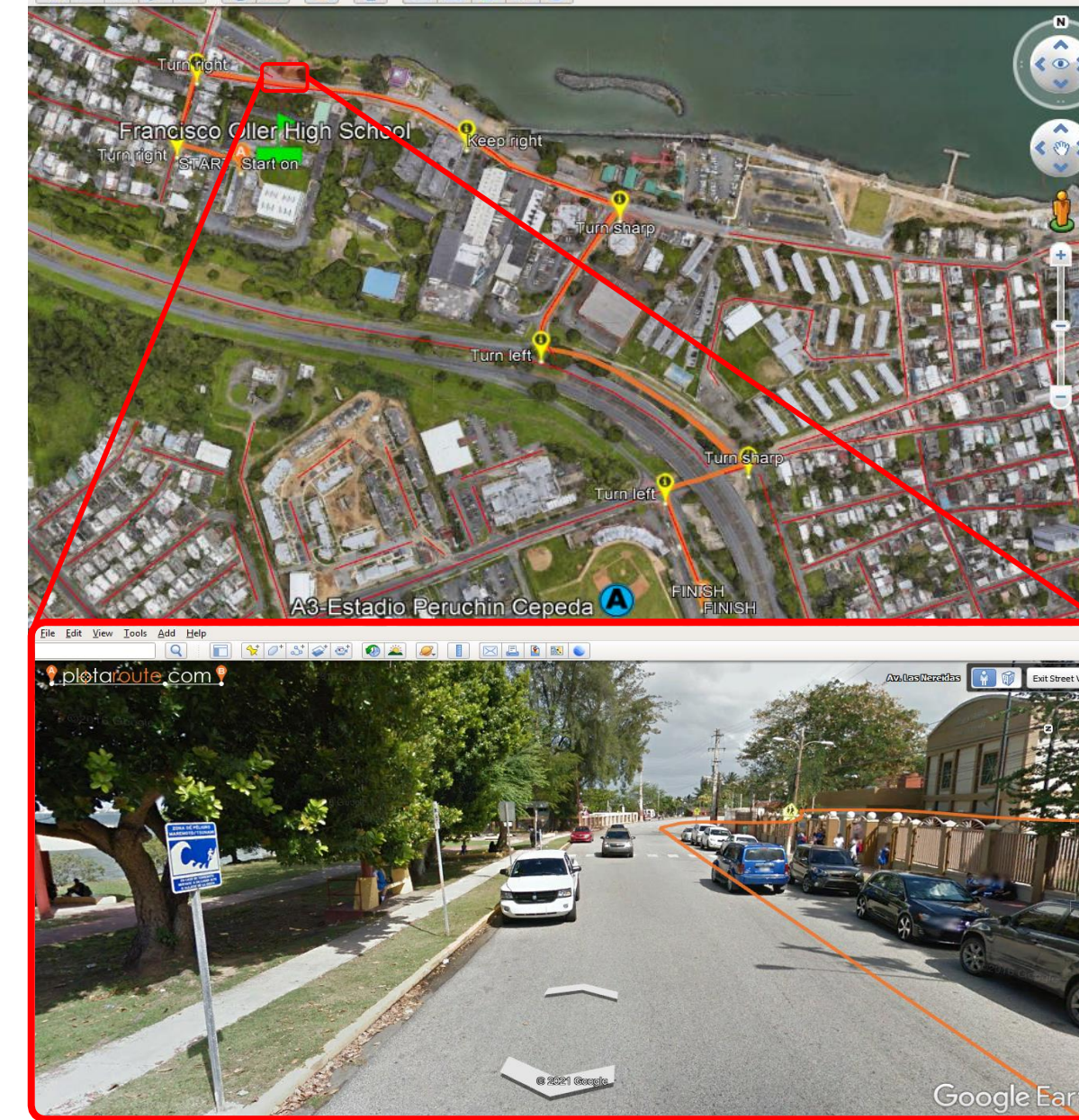
Of the municipalities evaluated in Phase I, 7 have more than 4 schools located in a tsunami hazard zone, of these, only Cataño and San Juan meet all the selection criteria. The shorter the travel distance, the greater the accessibility, and with this criterion, together with the greater number of schools in the tsunami hazard zone, use for voting centers and shelters, and the affected population, the greater the possibility of selecting the case study.

### III - 2 Vulnerability Assessment – Survey to Schools

Google Form was developed and administered to make an analysis of the vulnerability of schools in general (not individually by study municipality). By collecting data from public schools in tsunami hazard zones that includes the year the school was built, the details of the evacuation plan for two stages of evacuation (one to leave the school campus to the internal assembly site and another to exit with the entire school campus to the external assembly site), and special cases of the school.

### III - 3 Vulnerability Assessment – Walkways Conditions

Google Earth's Street View was used to evaluate the evacuation routes available for the schools with the longest evacuation times in both study municipalities. In this way, it was evaluated whether the routes are accessible and suitable for transit during the evacuation process. Accessible and suitable in terms that it does not have any obstacles on the way and that it has good signage that indicates its direction.



For the evacuation routes to be suitable during the evacuation, four conditions were considered:

- That the route moves away from the coast in the shortest possible time.
- That the route avoids walking parallel to the sea.
- That the route avoids possible obstructions to the route, such as bridges that may collapse.
- That the route has adequate width and does not present obstacles to the pedestrian flow, such as urban furniture.



Only two schools participated in the Google Form, one from Cataño and the other from San Juan. The following was found:

Question	Cataño	San Juan
1. Municipality	Cataño	San Juan
2. Reduce the educational level of the school	Yes (0%)	No (100%)
3. When was your school built?	1987 (100%)	1987 (100%)
4. Have you been selected about the reasons for your school?	Yes (100%)	No (0%)
5. Have you received any training or lecture in disaster preparation at your school?	Yes (100%)	No (0%)
6. Does your school have a disaster evacuation plan?	Yes (100%)	No (0%)
7. Has the disaster warning system at your school been clearly audible?	Yes (100%)	No (0%)
8. Do you have an evacuation route for your school? (Detailed description of evacuation routes for both schools)	Yes (100%)	Yes (100%)
9. How you have practiced the first stage of the disaster evacuation plan at your school?	Yes (100%)	No (0%)
10. Please indicate how often you have practiced the first stage of the evacuation plan at your school (Daily)	Never (0%)	Once a month (100%)
11. What is the most of the natural assembly place indicated for your school? (The more of the last place while the school goes to a common place)	Other (100%)	Other (100%)
12. What is the most of the natural assembly place indicated for your school? (The more of the last place while the school goes to a common place)	Other (100%)	Other (100%)
13. What is the most of the natural assembly place indicated for your school? (The more of the last place while the school goes to a common place)	Other (100%)	Other (100%)
14. Have you practiced the second stage of the disaster evacuation plan at your school? (Exit walking with the school campus to the external assembly site)	Yes (100%)	No (0%)
15. Please indicate how often you have practiced the second stage of the evacuation plan at your school (Daily)	Never (0%)	Once a month (100%)
16. Do you have an evacuation plan for your school? (Detailed description of evacuation routes for both schools)	Yes (100%)	Yes (100%)
17. How you have practiced the evacuation plan at your school? (Detailed description of evacuation routes for both schools)	Yes (100%)	No (0%)
18. Do you have a vertical evacuation plan? (Detailed description of evacuation routes for both schools)	Yes (100%)	No (0%)
19. If you have a vertical evacuation plan, indicate which building would be used for this purpose.	Other (100%)	Other (100%)
20. If you have a vertical evacuation plan, what was the last time for this stage in disaster?	Other (100%)	Other (100%)

- Both schools show a varied age range due to their educational level, which affects walking speed for evacuation time.
- Both schools were built before 1987, indicating that they were not built under building codes for seismic events.
- Both have tsunami evacuation plans.
- The evacuation time for the Cataño school is not comparable to that obtained in Phase III, while for San Juan the evacuation time is comparable to the one obtained in the analysis.

## CONCLUSIONS AND RECOMMENDATIONS

The results of the evacuation times indicate that the schools with the longest times to leave the tsunami hazard zone are critical and vulnerable to a tsunami event. These show that schools in San Juan are more vulnerable than schools in Cataño. The characteristics of the evacuation routes evaluated using Google Earth Pro for the two most critical schools are not suitable for transit during the evacuation process due to the criteria used in the evaluation. Because both routes do not meet the evaluation conditions: they do not leave the coast in the shortest possible time, they walk parallel to the sea and cross obstacles that prevent a continuous passage. In this way, Google Earth Pro in conjunction with ArcGIS and PlotARoute are useful to perform analysis and evaluation of the conditions of the characteristics of schools. The results of the forms validate the established assumption regarding the assembly places. As a recommendation, it would be ideal to include layers with the geolocation of private schools (not available at the time of this study), stimulating getting the answers from the school that received the Google form, and to extend the study to include all the municipalities with schools in tsunami evacuation areas. Loiza and Mayagüez are considered a high priority. A detailed evaluation of the physical condition of walkways, and their redesign to provide adequate pedestrian transit condition is advisable.

## FUTURE WORK AND EXPANSION OF THE RESEARCH

- Those aspects of the project with potential for improvement and expansion are the following:
  - Evaluate the possibility and requirements for vertical evacuation of critical schools.
  - Evaluate alternatives to include site and building characteristics in the vulnerability analysis (i.e., compliance of buildings with earthquake resistance design codes).
  - Perform an investigation of human and geometric factors that may affect the initial gathering time and pedestrian flow, and develop a more refined model to estimate the total evacuation time. This is a spin off research project under development.

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The following images represent the signs and obstacles present in both the Francisco Oller school evacuation route and the Luis Llorens Torres school evacuation route.