ENVS 5716 Modeling Geographical Space

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Exploring potential new sites for building shelters in Puerto Rico

Hang Zhao

Instructor: Dr Jill Kelly

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(Puerto Rico Lighthouse Ruins, Punta Borinquen; Photo by myself).

Introduction

Puerto Rico is a small Caribbean Island located at the Southeastern US continent, in between the Dominican Republic and the Virgin Islands, and is part of the US territory (Figure 1).

Figure 1. *Geographical location of Puerto Rico & municipalities. (Data Source: Princeton University Library, https://maps.princeton.edu/catalog/stanford-zj165kf9377)*

As Puerto Rico is in the Atlantic Basin where the Atlantic Hurricane Season occurs, it has a long history of being affected by strong hurricanes and other extreme weather events. On September 20, 2017, one of the most devastating hurricanes in the Puerto Rico's and even United States' history, named Hurricane Maria, struck the Puerto Rico Island as a Category 4 hurricane (National Hurricane Center, 2018). It brought heavy rainfall of approximately 30 inches maximum for 48 hours, triggered more than 40,000 landslides and over 10 feet of storm surge inundations (FEMA, 2018). Inland flash flooding and power loss caused by all these disastrous events killed even more people than hurricane and wind itself. More intensely,

Hurricane Maria made this landfall just 3 weeks after another major hurricane, named Hurricane Irma. As a result, Hurricane Maria led to a total estimated economic loss of 100 million dollars, and deaths of 3000 people (Guerra Velázquez, 2022). Figure 2 demonstrates the path of Hurricane Maria where Puerto Rico was at the center of the impact region.

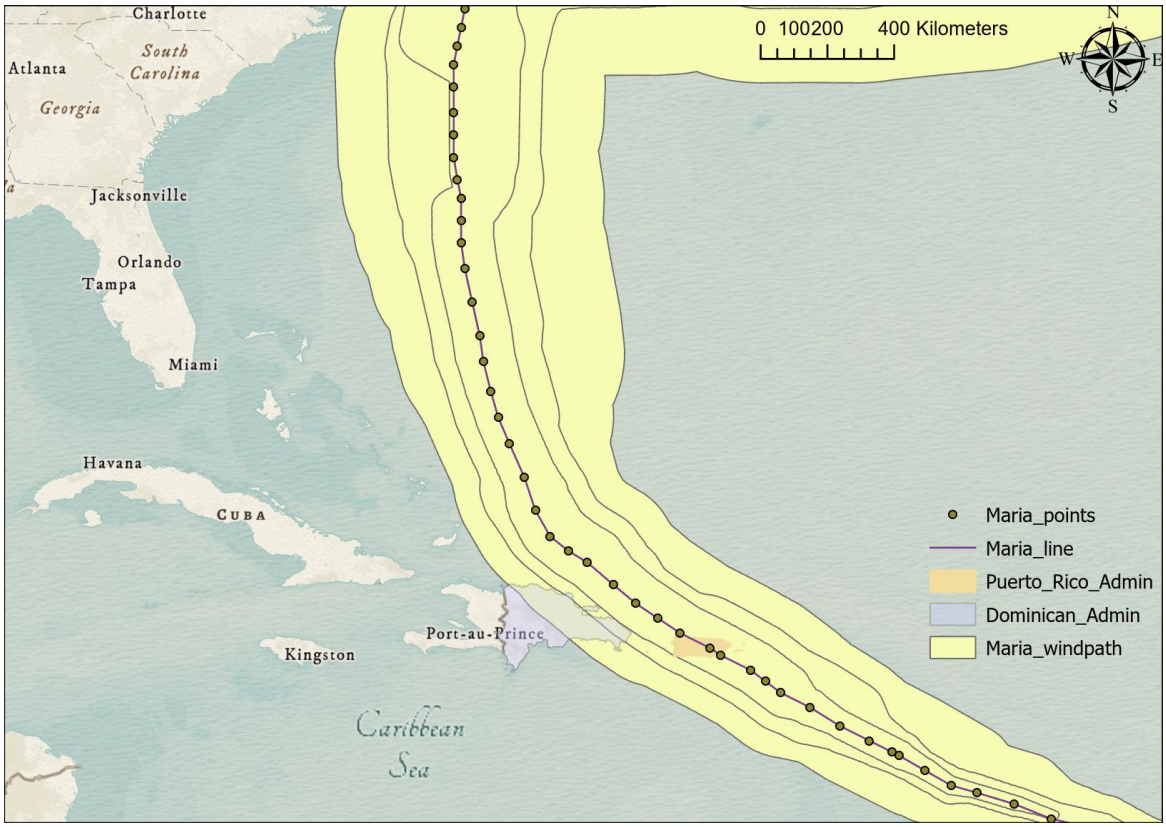

Figure 2. *Hurricane Maria wind path and main route. Puerto Rico and Dominican Republic were the two countries/regions being mostly impacted. (Data Source: National Hurricane Center, NOAA. https://www.nhc.noaa.gov/gis/archive_besttrack_results.php?id=al15&year=2017&name=Hurricane%20MARIA)*

There are several existing shelters in Puerto Rico. According to FEMA (2018), 257 event-specific shelters were open during and after Hurricane Maria, in addition to some school shelters designated for students. However, more shelters will be needed to encounter the happening climate change and global warming, which will lead to more intense and durable hurricanes in the future.

Data Acquisition & Preparation

Total of five factors (standards) will be considered for this project: Slope, population, distance to waterways, cost distance to health facilities, and distance to existing shelters. All data were acquired online, downloaded and unzipped, and finally imported to the ArcGIS Pro for further manipulation. The data coverages are all clipped to the Puerto Rico main island, which was using either Raster Calculator, Clip Raster, or choosing the environment to Puerto Rico main island admin when running the tools. Table 1 presents the name of the data, the data source, and the links to download data.

Table 1. *GIS data names and sources.*

Data Name	Data Source	Link to the Source
Digital Elevation Model (DEM)	NOAA & USGS Lidar Puerto Rico DEM data	https://www.fisheries.noaa.gov/inport/item/60105
Population Count	HumData – Puerto Rico	https://data.humdata.org/dataset/worldpop-population-counts-for-puerto-rico
Major Roads	HumData – Puerto Rico	https://data.humdata.org/dataset/puerto-rico-roads
Waterways	HumData- Puerto Rico	https://data.humdata.org/dataset/hotosm_pri_waterways
Health Facilities	HumData – Puerto Rico	https://data.humdata.org/dataset/hotosm_pri_health_facilities
Existing Shelter	National Shelter System – Open Shelters	https://data.amerigeoss.org/dataset/national-shelter-system-open-shelters

In addition, all coordinate systems were projected to WGS 1984 for consistency.

Data Analysis & Result

1. SLOPE

Digital Elevation Model (DEM) data of Puerto Rico main island was shown below in Figure 3. Then, the slope tool in 'Spatial Analyst Tools' will be applied to create a Puerto Rico slope map, which is presented in Figure 4. Slope is a important factor when considering the location of shelters, as the higher slope regions are having greater risks of landslides and flooding. Therefore, low slope areas will be chosen for determining the potential sites for new shelters.

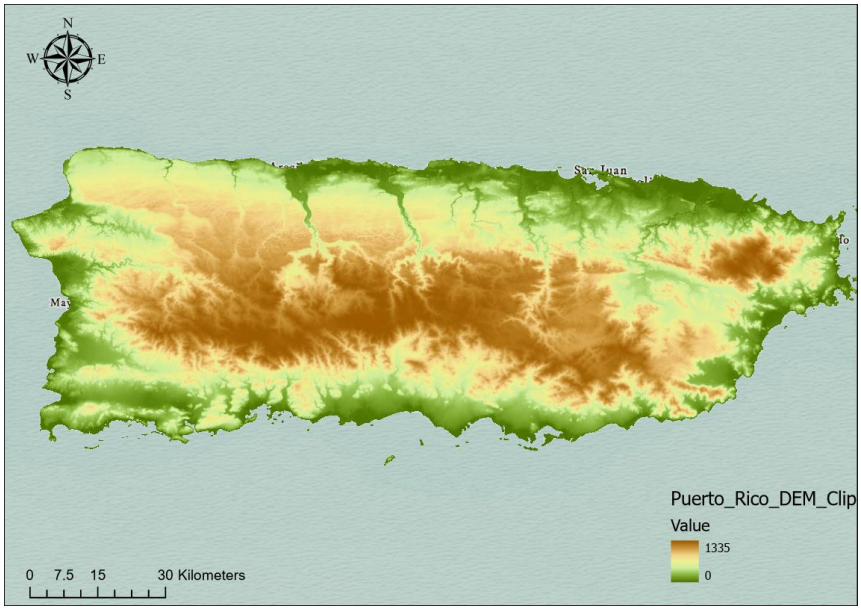

Figure 3. *Digital Elevation Model (DEM) of Puerto Rico main island.*

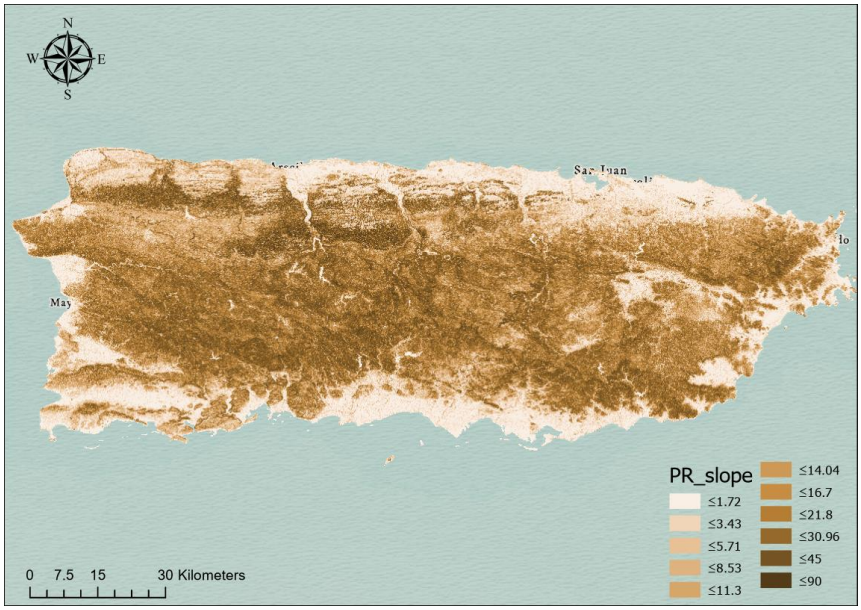

Figure 4. *Puerto Rico Slope.*

After that, the slope was reclassified to 1 for slope between 0-5, and all other values are NODATA, keep the output (Figure 5) for further analysis.

Figure 5. *Classified Slope value between 0-5.*

2. POPULATION

Population data was a 'tiff' image form which demonstrates the population density distribution across the whole island, with a resolution of 100m and the unit of 'population per pixel'. Figure

6 shows the population count data visualization. The higher populated areas are more desirable to build new shelters, even though there are problems of social inequity and inequality to consider, building shelters in denser populated regions are the most economical and effective measure for government.

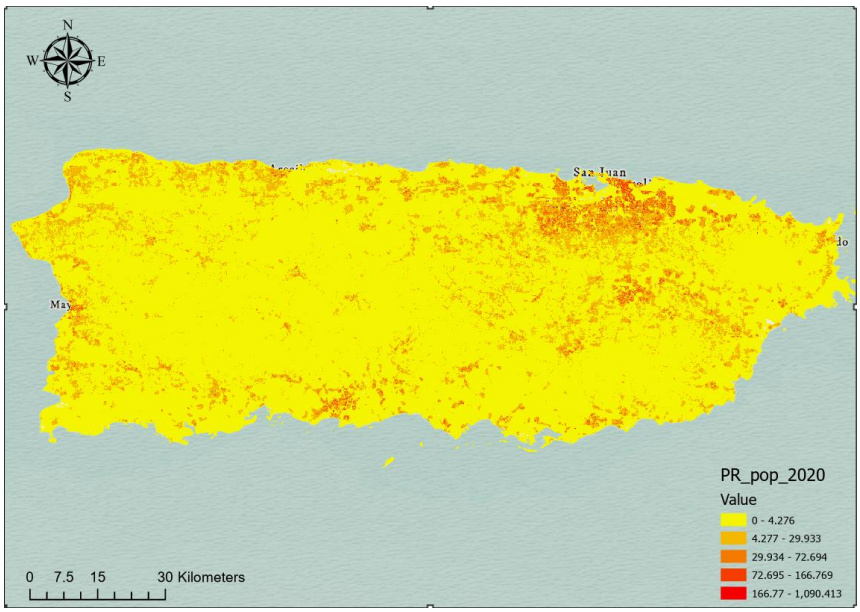

Figure 6. *Puerto Rico population count in 2020.*

Then the same reclassify tool will be applied to population data, keep the population greater than 50 (50-1090.413) as a value of 1, and all other data as NODATA. The new classified population data will be left for further analysis later (Figure 7).

Figure 7. *Classified population count data greater than 50 per pixel in 100m resolution.*

3. DISTANCE TO WATERWAYS

Streams data are in polyline form. Major waterways in Puerto Rico were all shown in blue lines in Figure 8. Storm surge and heavy rainfalls can both trigger inundation and flooding, so living near to waterways are getting higher chance to be flooded during an extreme weather event. Therefore, building shelters farther away from the major waterways is included in the calculation.

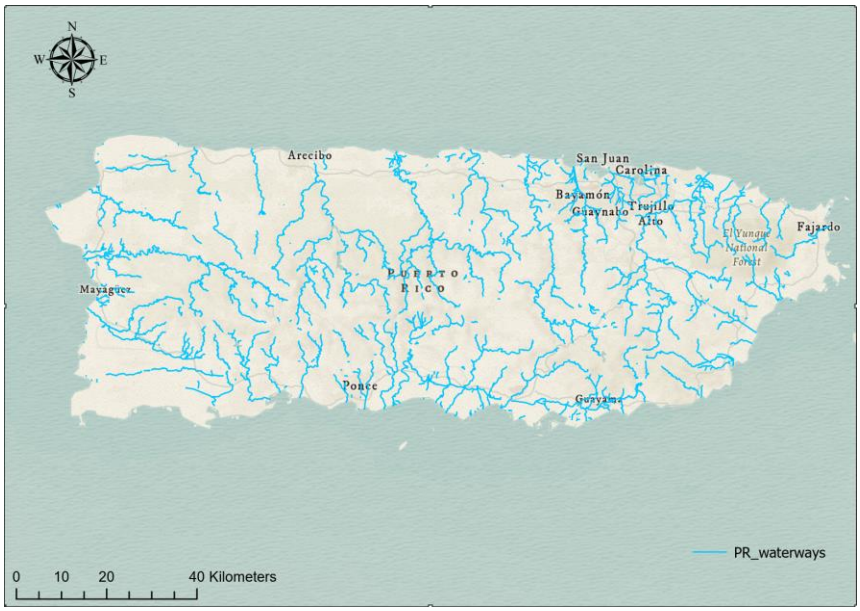

Figure 8. *Puerto Rico major waterways (hydrology).*

The 'Euclidean Distance' tool was used to separate the distant regions, the output was clipped to the Puerto Rico Island boundary. After that, the output will be reclassified to 1 for regions where the Euclidean distance is greater than 0.01 (0.01-0.266), and all other regions as NODATA. Figure 10 illustrates the result output.

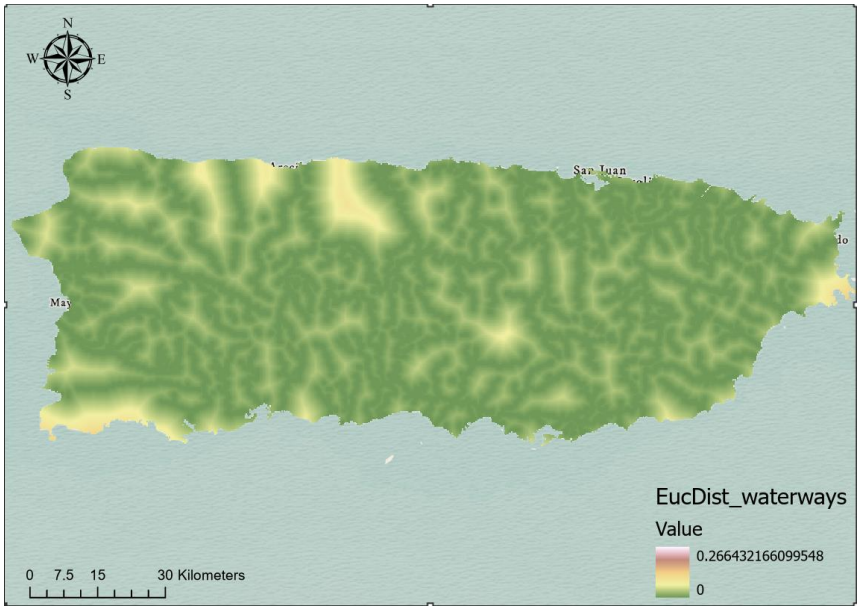

Figure 9. *Euclidean Distance of Puerto Rico waterways clipped to Puerto Rico Island.*

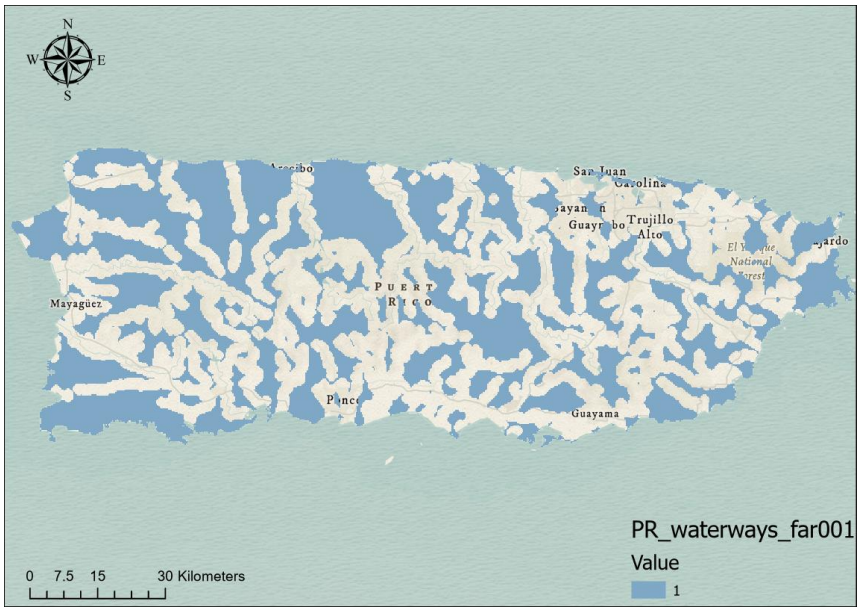

Figure 10. *Reclassified result of Euclidean Distance to waterways farther than 0.01.*

4. Cost Distance to Health Facilities

Access to health facilities is undoubtedly necessary for local people during and after a natural disaster. These health facilities include hospitals, clinics, doctors, dentist, and pharmacy. The health facilities data is presented in Figure 11 below.

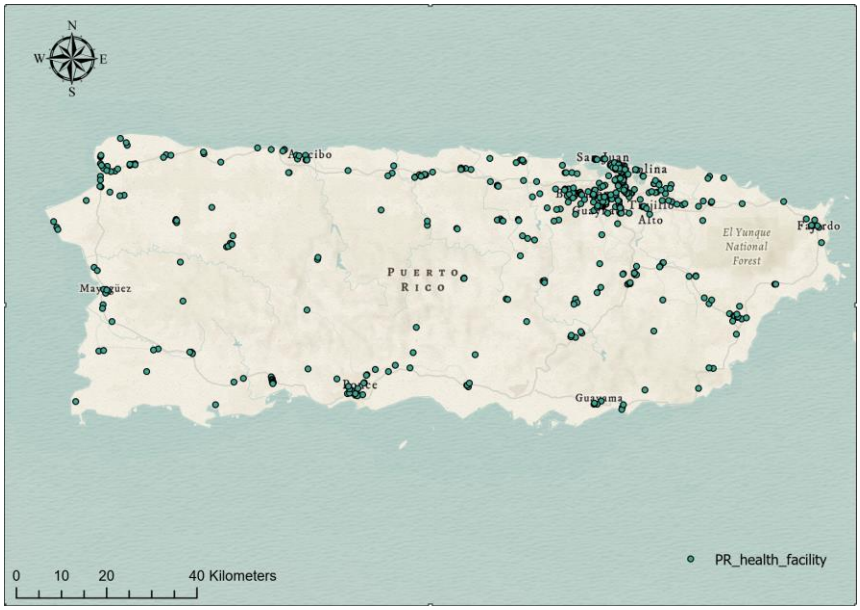

Figure 11. *Puerto Rico health facilities.*

Cost Distance was used as the topography of Puerto Rico is mountainous which means that it may take much effort for a person to access the nearby health facility if no roads exist between them. Therefore, firstly the major roads in Puerto Rico will be transferred from polyline to raster, then reclassified to 1 for anywhere that has a road pixel, and 10 for places that are NODATA, so that the cost raster can be obtained.

After that, the cost distance will be calculated using the road cost raster, and then clipped to the Puerto Rico Island boundary, to get the output shown in Figure 12.

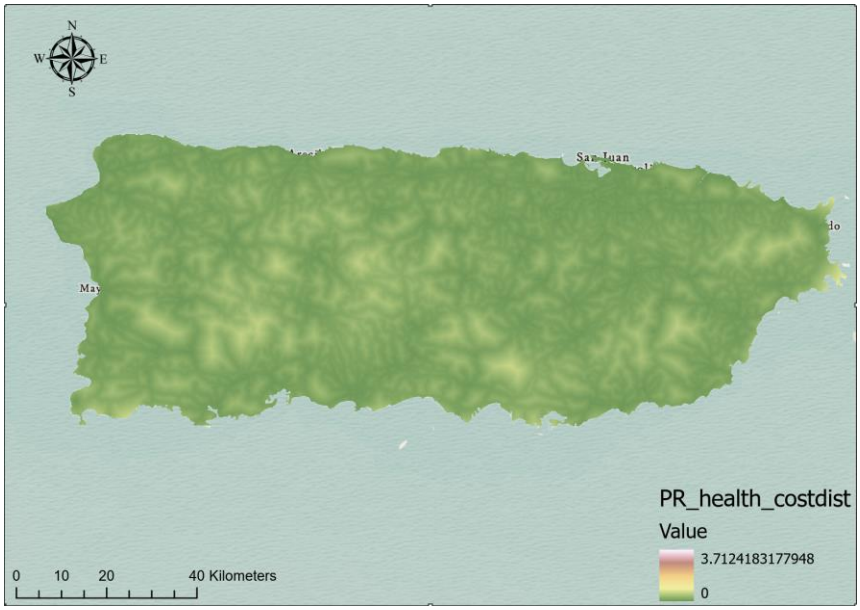

Figure 12. *Cost Distance to health facilities, Puerto Rico.*

The Reclassify tool will then be applied, for cost distance between 0 – 0.2 the reclassified value will be 1, and all other distance will be NODATA, which is finally shown in Figure 13.

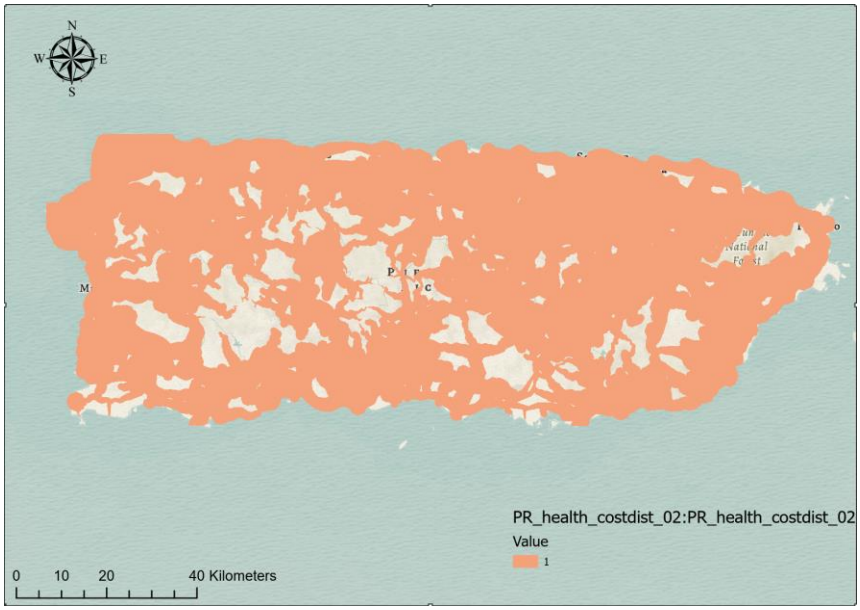

Figure 13. *Reclassified cost distance to health facilities, Puerto Rico.*

5. DISTANCE TO EXISTING SHELTERS

As there are many existing shelters in Puerto Rico, it would be better if the new shelters will be built more evenly distributed to regions where there are no existing shelters. Therefore, the Euclidean Distance to existing shelters will be set as a factor for this purpose. Figure 14 displays the existing shelters as points in Puerto Rico.

Figure 14. *Existing shelters in Puerto Rico.*

Euclidean Distance tool will be applied to the existing shelters data, which will be clipped to get the result output shown in Figure 15.

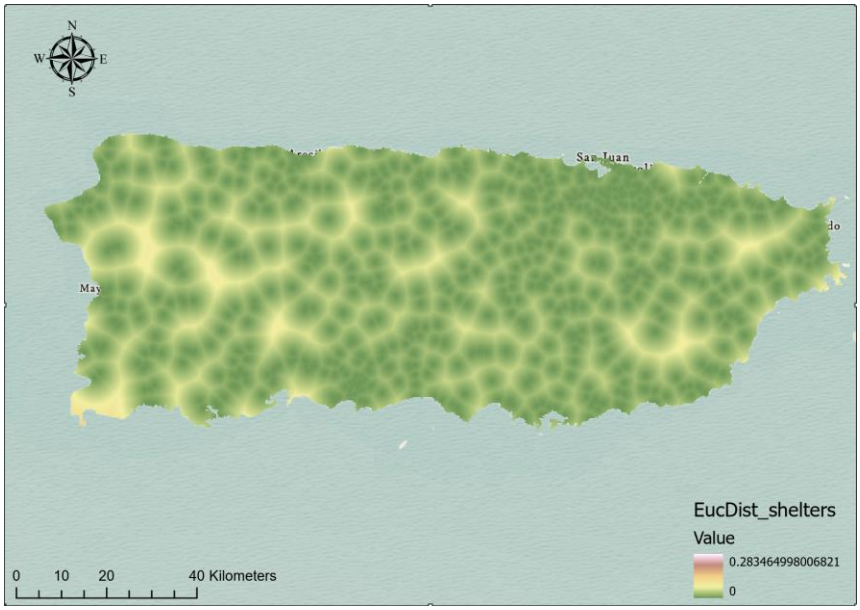

Figure 15. *Euclidean Distance to existing shelters.*

This will be then reclassified to 1 for distance greater than 0.01 (0.01-0.28), and all other distance to NODATA, which is shown in Figure 16.

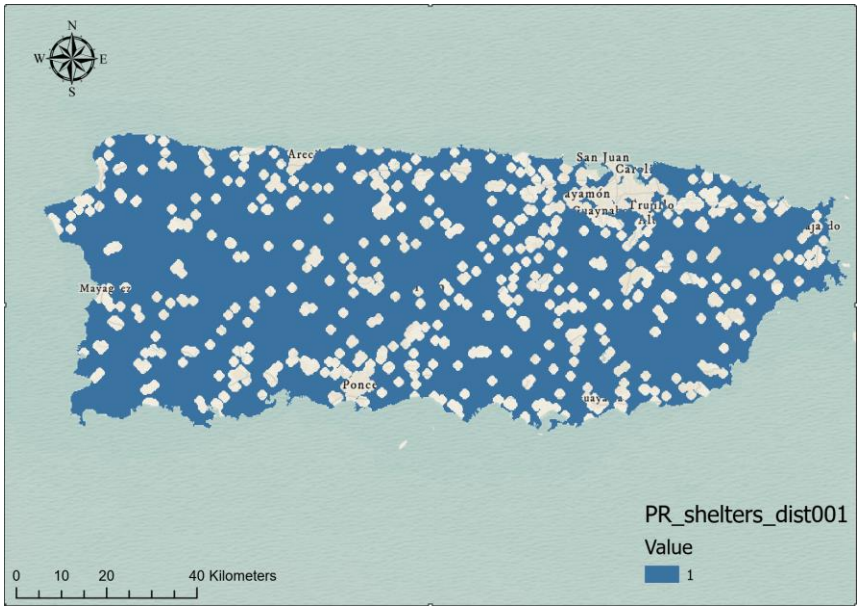

Figure 16. *Reclassified Euclidean Distance to existing shelters in Puerto Rico.*

6. RASTER CALCULATOR

Finally, all the outputs created above will be imported into the 'raster calculator' tool for final analysis. Outputs will be multiplied to each other so that the overlapping pixels will be kept. The result is shown below in Figure 17.

Figure 17. *Possible new places to build/reconstruct shelters.*

new_shelters:new_shelters

Field: Add Calculate

	Value	OBJECTID *	Count
1	1	1	52
	Click to add new row.		

Figure 18. *Number of pixels of the final outputs.*

Here only the pixels in/nearby San Juan, the capital of Puerto Rico, will be focused. From Figure 19, it is quite obvious that most of the pixels land on the community and residential areas where there are existing buildings on the sites. Due to technical limitations, it is hard to observe from satellite imagery or other ways to know the functions/types of these existing buildings.

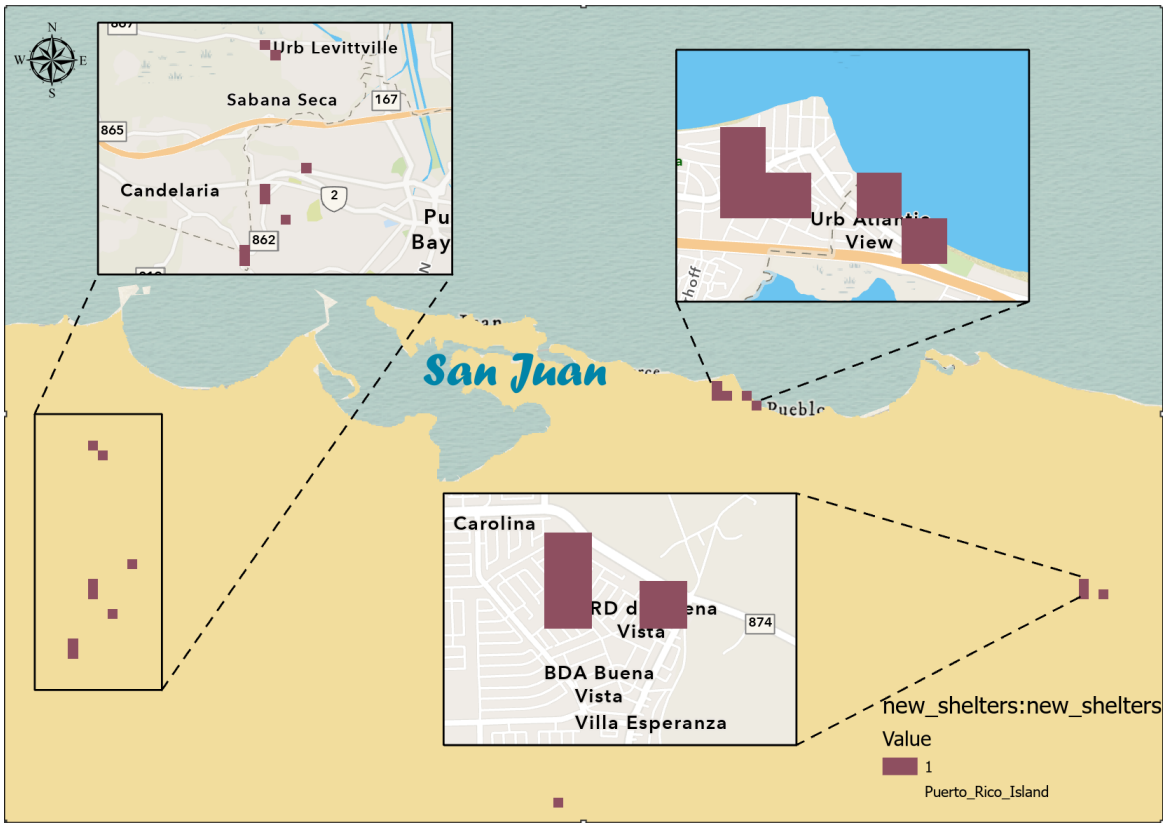

Figure 19. *A more detailed exhibition of the calculated sites for new shelters.*

Discussion & Conclusion

Although there are already five factors considered for this project, in reality it is definitely not enough for considering the feasibility of building new shelters on sites that have existing functioning buildings, or the safety / risks of those sites. For instance, other factors including the vulnerable groups, the existing shelters density, accessibility to food & drinking water, and elevations can also be considered for calculations. Moreover, the result generated for this project is still in a theoretical phase. In reality, most of the shelters are functioning normally in other disciplines such as stadiums for sports and activities centers for entertainment when there is no hurricanes, but will also be able to prepare for the extreme events when they will become shelters. Figure 20 is an example of a sport stadium that was being used as a shelter during Hurricane Maria.

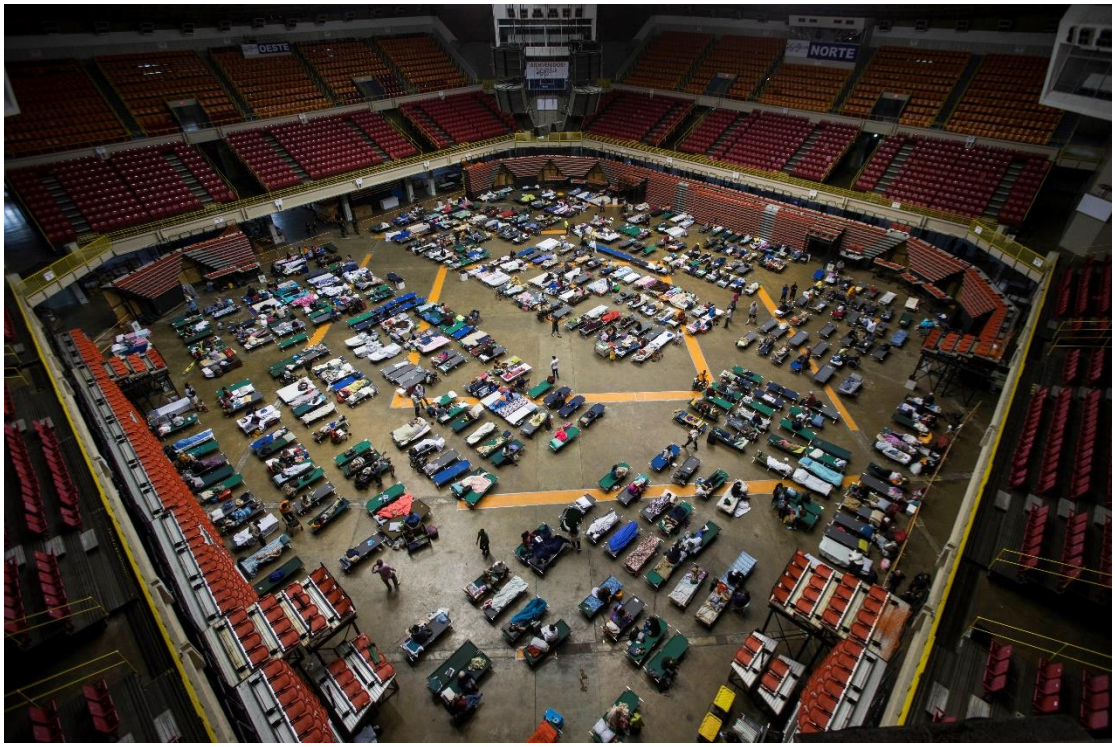

Figure 20. *Inner view of a shelter in Puerto Rico. (Source: The Washington Post. https://www.washingtonpost.com/news/post-nation/wp/2017/09/21/hurricane-maria-churns-through-caribbean-as-ravaged-puerto-rico-takes-stock-of-an-island-destroyed/)*

In conclusion, five factors were included in this project to calculate the potential suitable sites

for building new shelters in Puerto Rico, in order to help local people get higher chance to survive in the natural disasters such as hurricanes and floodings. Lower slope, denser population, greater distance to waterways, lower cost distance to health facilities, and farther distance to existing shelters were all considered as pre-conditions for calculations. Using raster calculator to multiply all the factors, the resulting output was displaying 52 pixels where all conditions were met. However, most of the pixels landed in areas where communities and residential neighborhoods are located. Further investigations on the feasibility of reconstructing those districts for shelters need to be conducted, and the social, economic, and environmental aspects should be also reviewed.

Reference

FEMA. (2018). *Hurricanes Irma and Maria in Puerto Rico.* Federal Emergency Management Agency. https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-irma-maria-puerto-rico_2.pdf

Guerra Velázquez G. R. (2022). Hurricane María and Public Health in Puerto Rico: Lessons Learned to Increase Resiliency and Prepare for Future Disasters. *Annals of global health*, *88*(1), 82. https://doi.org/10.5334/aogh.3869

National Hurricane Center. (2018). *Hurricane Maria.* National Oceanic and Atmospheric Administration (NOAA). https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf

Model Structure