Design Project Multi-Criteria Evaluation to Confirm the Ideal Location of a Shelter in the Municipality of Toa Baja, Puerto Rico.

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Abstract *— Vulnerability to natural hazards impacts the Puerto Rican population every year. This is accentuated in hurricane season. One of the effects generated by hurricanes is that of flooding. This causes fatalities and property damage on the island. Facing events of this type, shelters become the main alternative to preserve life, especially for the vulnerable population. Knowing the location of the shelters helps in the mobilization and evacuation of the population and thus has a rapid response to the emergency. Multi-criteria Spatial Analysis (MCEA) is an appropriate method for analyzing the location of shelters using Geographic Information Systems (GIS) tools. The methodology used in this research seeks to establish whether the locations of the current existing shelters in the municipality of Toa Baja are ideal. The shelters established by the municipality are expected to be in places not prone to flooding and are safe for access.*

Key Terms *— floods, multi-criteria spatial analysis assessment, shelter's ideal location.*

INTRODUCTION

The population in areas vulnerable to flooding has the need to relocate in the face of events that catapult this situation. Emergency management personnel of municipalities assist in the process of mobilizing the vulnerable population, exposing their lives to the risks of the situation. Adopting a process of action before, during and after the event is important to help reduce accidents and fatalities. The hazards faced by the vulnerable segment of the population are not limited to the hurricane season. Other types of natural phenomena can also adversely affect them. Management of emergency situations due to floods includes evacuation plans for the population, activating alert systems, and informing the population of safety measures among others.

Geographic Information Systems (GIS) provides a tool that helps make decisions about emergency management. With a Multi-criteria Assessment Analysis (MCEA) model, natural hazards and how they are spatially related to the evaluated environment can be assessed. This work aims to evaluate the spatial distribution of shelters and study the risks and local situations that disrupt their vulnerability.

BACKGROUND

The study of access to shelters in the face of natural events is documented in several studies. One of them is based on the impact of Hurricane Florence on the roads of coastal communities in North Carolina and the population's access to shelters [1]. This category 4 hurricane on the Saffir-Simpson scale left between 20 and 30 inches of rain, causing road closures. Many communities were "trapped" until water eventually receded. With data from road closures, shelter data, and population census, the time it would take for a citizen to reach the nearest shelter was calculated. Results showed that road closures mean that distances to reach shelters increase.

On the other hand, Hasan [2] shows a traffic prediction model after the passage of Hurricane Harvey in Houston, Texas, United States. For this study, he took into consideration data on roads and paths, their intersections, and the sections to reach a shelter. Hasan developed a case study with a sample of 30 residences randomly distributed in 5 sections. The goal was to automate the process of predicting traffic during the disaster at highway intersections prior to evacuation. This exercise showed the number of vehicles in a section and recommends more in-depth studies in the future.

In his study, Park [3] starts with the idea that when floods occur, people must be safely mobilized to shelters using optimal routes. This study was conducted in South Korea in the city of Siheung. They established an evacuation time relationship with the data from the shelters, optimal routes, and the pedestrian network base.

In a similar research, Sungwoo [4] explains the importance of recognizing evacuation alternatives since flash floods could force the evacuation of the population from a certain place. With an app, an appropriate route to reach the nearest shelter could be predicted. This study was done in Korea. They tested several map APIs for pedestrian routes accurately, and after several attempts, they selected the application called T-Map API, with a model that includes the user's current location and shows them the evacuation route.

PROBLEM

The main objective of this research is to study whether conditions exist that may represent vulnerability to shelters located in the municipality of Toa Baja and whether these aspects of vulnerability can adversely affect the population that seeks refuge in them.

The contribution of this work is to establish a replicable procedure so that each municipality can evaluate the ideal location of its shelters. This information helps government emergency management agencies save lives and make sound decisions.

EQUIPMENT AND MATERIALS

To generate the Multi-criteria Evaluation Analysis (MCEA), the Geographic Information System (GIS) software of ArcGIS Pro from ESRI was used. The geographic information layers included in the modeling were: location of the shelters published by the official website of the municipality of Toa Baja (social networks), legal limits in the format of information layers of Municipalities, Neighborhoods, Watersheds, CRIM Digital Elevation Model 1996-1998 with spatial resolution of 5 meters x 5 meters per pixel, Surface Coverage (*Landcover*), Flood Zones, and the Bodies of Water layer (General Hydrography).

METHODOLOGY

The Multi-Criteria Evaluation Analysis (MCEA) method was used to help in decision-making. Multi-criteria analysis allows solutions to be identified using cartographic variables. Raster data stores information in a grid and pixel cells that, in turn, represent a physical spatial position in the world.

The Multi-Criteria Evaluation Analysis process has four (4) stages: geographic information system layers, topics to be evaluated, geo-processes, analysis, and conclusion. The layers of Geographic Information Systems (GIS) will be evaluated by theme (factors). In turn, these layers will be standardized and classified with the accepted or unaccepted values according to their category. The geographic information layers went through a process of vector transformation to raster. The layers are then weighted according to their values, and a map is generated with the shelter that meets the evaluated categories (Figure 1).

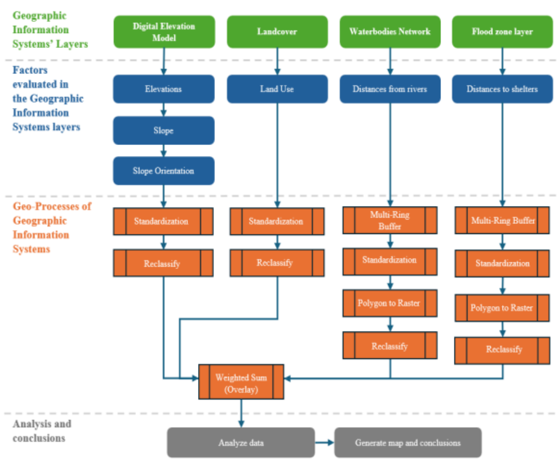

Figure 1
Methodology Flowchart

The municipality of Toa Baja (Figure 2) was selected as the study area. The territorial area of the municipality is 60.82 Km^2. It is located on the north coast bounded by the Atlantic Ocean between the municipalities of Dorado and Cataño. Precipitation is characterized between the months of April and November, with September being the month with the highest rainfall with an average of 115 millimeters of rain (4.5 inches). The month of January is the least rainy with an average of 33 millimeters (1.30 inches).

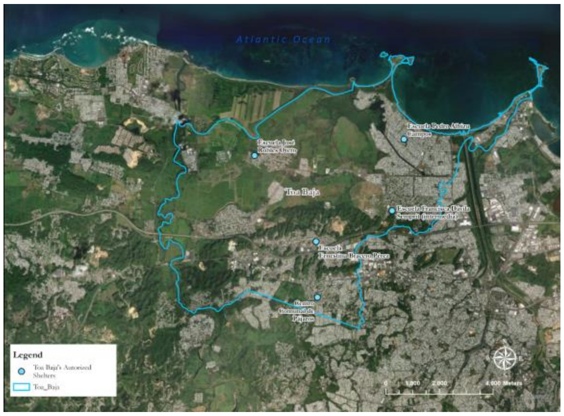

Figure 2

Toa Baja's Authorized Shelters

The municipality of Toa Baja in official publications on its social networks in August 2024, informed citizens about the official list of shelters. The municipality identified five (5) shelters. A breakdown of these is shown in Table 1:

Table 1

List of Shelters Published by Municipality

Region	Shelter name	Address	Lat	Long
East	Escuela Francisca Dávila Semprit (intermedia)	Carr. 866 Ave. Principal, Sabana Seca	18.426	-66.185
North	Escuela Pedro Albizu Campos	Ave. Boulevard, 4ta sección Levittown	18.449	-66.181
West	Escuela José Robles Otero	Carr. 867 km 5.0, Barrio Ingenio	18.444	-66.232
West	Escuela Ernestina Bracero Pérez	Carr. 865 km. 1.4, Barrio Candelaria	18.416	-66.211
South	Centro Comunal de Pájaros	Carr. 863 km. 1.0, Barrio Pájaros	18.399	-66.210

The Río de la Plata to Cienaga watershed of the San Pedro Coastal Drainage Watersheds (Figure 3) is located between the municipalities of Dorado and Toa Baja with an area of 84.84 Km² or 8,4946,287.58 m². These shelters are mostly located in the Río La Plata to Cienaga basin.

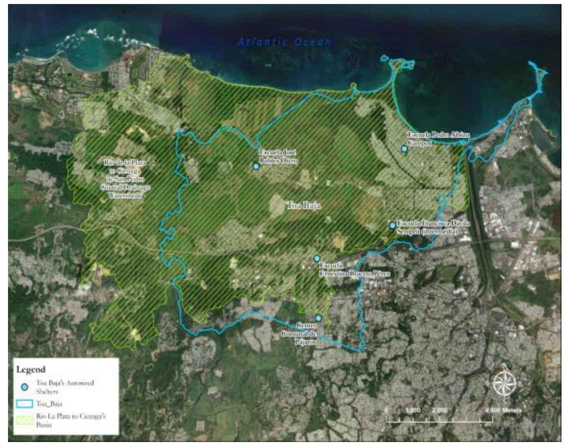

Figure 3

Toa Baja's Main Basin and Authorized Shelters

The Rio de la Plata to Cienaga basin of San Pedro Coastal Drainage Watersheds covers 84% of the municipality of Toa Baja (Figure 4).

Figure 4

Coverage of the Río La Plata Basin to Cienaga in Toa Baja

The Digital Elevation Model (DEM) is a raster layer of the Monthly Revenue Collection Center (CRIM). The Río La Plata to Cienaga basin has elevations that do not exceed 192.77 meters (632.45 ft), as shown in Figure 5.

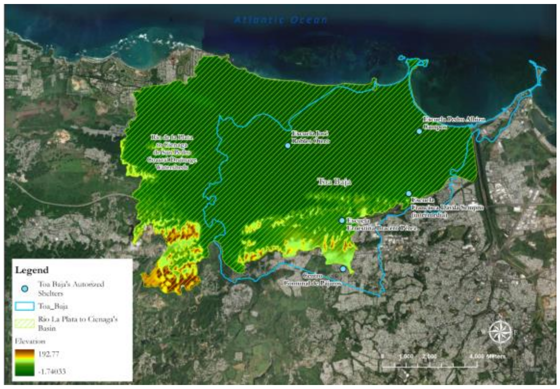

Figure 5
La Plata River Basin Elevation Model

With the Elevation Model, slopes of the area were generated. This variable is important since it influences the speed with which surface runs off from precipitation travels, affecting the time it takes for a drop of rain to reach the drainage network. The elevations of Río La Plata Basin to Cienaga vary between 1.72 meters (5.64 ft) to 90 meters (295 ft) due to its varied topography. Figure 6 shows the slopes of the municipality. You can see the flat and semi-flat configuration with a tendency to the coast with the most marked slopes in the southern area of the municipality.

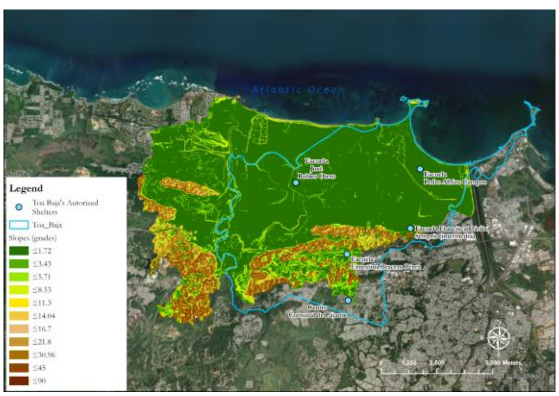

Figure 6
Slopes From Rio La Plata to Cienaga's Basin

Slope orientation indicates the cardinal direction to which the slope descends at each location (Figure 7). It is measured clockwise in degrees ranging from zero (0º) to the north to three hundred and sixty degrees (360º) to the north again. Values were reclassified to establish the appropriate ranges for the location of the shelters.

Figure 7
Rio La Plata's Basin Slope Orientation

Landcover classifications establish the use of the different land areas of the basin (Figure 8). The predominant use in the basin is Wetlands, with 32.51% of the total area. In second place, is development with 25.87%, and in third place Grasses and Shrubs with 21.89% (Table 2). The values were reclassified to establish the appropriate ranges for the location of the shelters.

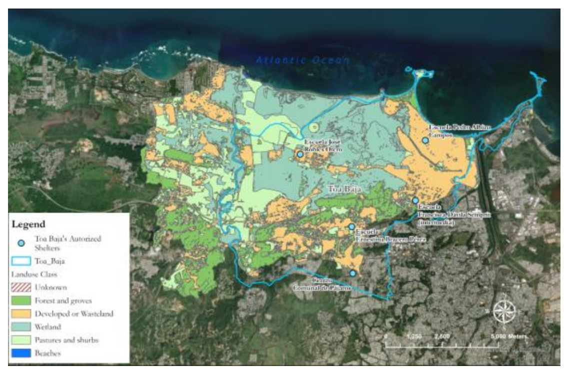

Figure 8
Rio La Plata's Basin Land-use Class

Table 2
Landcover of the Río La Plata to Cienaga Basin

Basin's Landcover	Frequency	Area Km²	Percent
Forest and groves	4540	16.42	19.39%
Developed or Wastelands	1257	21.91	25.87%
Unknown	5	0.0011	0.001%
Wetlands	1569	27.55	32.51%
Pastures and shrubs	3106	18.54	21.89%
Beaches	84	0.29	0.35%
	Σ	84.72	100.00%

It is important to know the bodies of water present in the basin and their relationship with shelter (Figure 9). A Multiple Ring Buffer was made for the bodies of water (Figure 10) to determine their proximity to the locations of the shelters. The values were then reclassified with the appropriate ranges.

Figure 9
Hydrology Network in Rio La Plata Basin

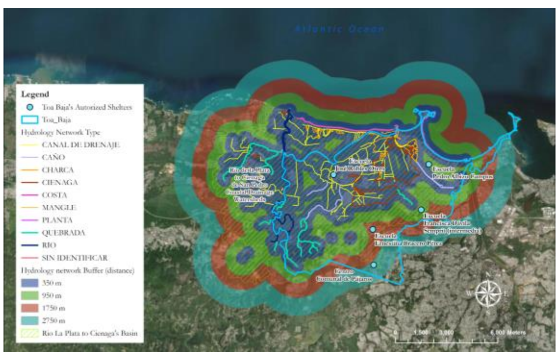

Figure 10
Hydrology Network Buffer

Table 3 describes several classifications for the flood zones in the Río La Plata basin (Figure 11).

Table 3
Basin's Flood Zones Descriptions

Zone	Description
0.20%	Flood area with 0.2% chance of occurring each year (500-year flood).
AE	Areas of high risk of flooding, due to proximity to a pond, stream, river, or a protective barrier under construction.
A	Areas of high risk of flooding, due to proximity to a pond, stream, river, or a protective barrier under construction.
VE	High risk in coastal areas due to storm surge.

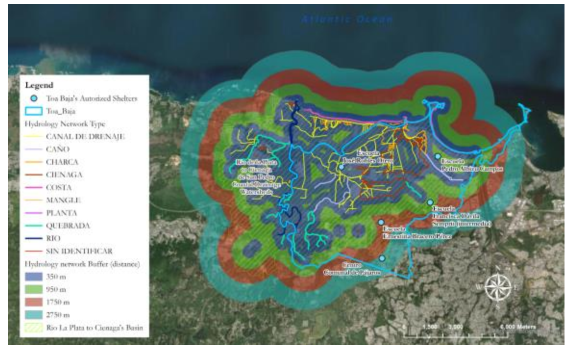

Figure 11
Basin's Flood Zones

To know the proximity of the shelters to the flood zones, a Multiple Ring Buffer (Figure 12) was made to determine the distance of these to the locations of the shelters. The values were then reclassified with the appropriate ranges.

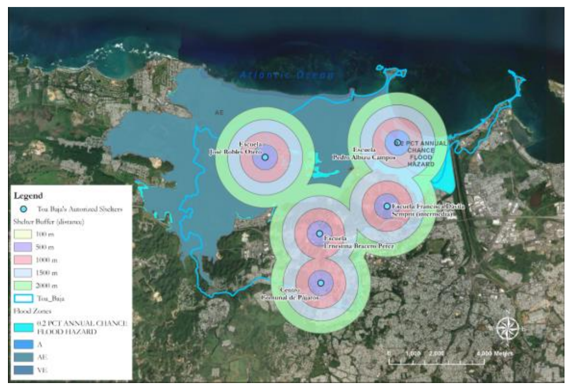

Figure 12
Map Distances From Shelters to Flood Zones

To make the multi-criteria evaluation, several factors were taken and integrated to generate necessary thematic maps. For these maps, information layers were converted into raster layers and DEM layer of the CRIM was also used. These raster layers were reclassified with weighted weights (Table 4) ranging in values from one (1) to five (5), with five (5) being the most favorable value. The weighted sum was assigned according to the influence of these factors in relation to the location of the shelters, and ranged from restrictive to favorable values. After reclassifying the raster layers with the weighted values, the summation tool was used with all the layers. Then, the control tool was used where the favorable value was selected, and this generates a raster layer, the ideal area to establish in shelter.

Table 4
Factors and Punctuation to Multi-Criteria Evaluation

Factor	Classification		Punctuation
Elevations: Elevation between 40 m will be given values and are favorable		< 2.50m	1
		2.50-12.50	2
		12.50-22.50	3
		22.50-32.50	4
		> 32.50m	5
Slopes: The favorable slopes are 4 and 5		< 1.7 grades	5
		1.7-8.7	4
		8.7-16.7	3
		16.7-24.7	2
		> 24.7 grades	1
Slope orientation: The favorable value is given by sunset.	FLAT	> -1	1
	N-NE	0-67.5	5
	E	67.5-112.5	5
	S-SE	112.5-157.5	3
	S-SW	1157.5-247.5	4
	W-NW	247.5-337.5	2
	N	337.5-360	1
Land use: Developed soils, grasses, and shrubs are favorable. However, forests, wetlands, and beaches are not favorable.	Forests and Groves		3
	Developed or Wasteland		5
	Unknown		2
	Wetlands		1
	Pastures and Shrubs		4
	Beaches		1
Distance to a body of water [m]. The greater the distance to the body of water, the better the score.		0-350m	1
		350-950	2
		950-1750	3
		1750-2750	4
		<2750 m	5
Location in flood zone. The shelter that is not in the flood zone is the favorable one.		0-100 m	1
		100-500	2
		500-1000	3
		1000-1500	4
		1500-2000 m	5

RESULT AND DISCUSSION

The largest hydrographic basin that covers the municipality of Toa Baja is Río La Plata to Cienaga. In this context, several shelters were evaluated based on their proximity to this watershed. Pájaros Community Center is not located within the basin, while the other shelters are.

The first factor evaluated was the elevation of the shelters. A higher elevation is considered more favorable. Pedro Albizu Campos School is at 2.38 m, José Robles Otero School at 2.57 m, Francisca Dávila Semprit School at 16.00 m, Ernestina Bracero Pérez School at 35.21 m, and Pájaros Community Center at 73.73 m. Therefore, Ernestina Bracero Pérez School and Pájaros Community Center are the highest.

The second factor was the slope of the watershed. Slopes less than 1.7 degrees are more favorable. Francisca Dávila Semprit School has a slope of 0.16 grades, Pedro Albizu Campos School has 0.51 grades, José Robles Otero School has 0.59 grades, and Ernestina Bracero Pérez School has a 1.20 grade. Pájaros Community Center was not evaluated in this category. All schools have favorable slopes.

The third factor evaluated was the orientation of the slopes. The north, northeast, and east orientations are more favorable. Francisca Dávila Semprit School is oriented to the south, Pedro Albizu Campos School to the west, José Robles Otero School to the northwest, and Ernestina Bracero Pérez School to the northwest. Pájaros Community Center was not evaluated in this category. Francisca Dávila Semprit School is the most favorable in this regard.

The fourth factor was land use. Developed or vacant soil is more favorable. Francisca Dávila Semprit School, Pedro Albizu Campos School, and Ernestina Bracero Pérez School are on developed land. José Robles Otero School is on land classified as forests and groves. Pájaros Community Center was not evaluated in this category. Schools on developed soil are the most favorable.

The fifth factor evaluated was the distance from the body of water. Distances greater than 2,750 meters are more favorable. José Robles Otero School is less than 350 m away, Pedro Albizu Campos School and Francisca Dávila Semprit School are less than 950 m away, Ernestina Bracero Pérez School is less than 1,750 m away, and

Pájaros Community Center is less than 2,750 m away. Pájaros Community Center is the most favorable in this criterion.

The sixth factor was the location in flood zones. Distances greater than 2,000 m are more favorable. Francisca Dávila Semprit School and Ernestina Bracero Pérez School are more than 1,500 m from the flood zones. José Robles Otero School and Pedro Albizu Campos School are less than 100 m away. Pájaros Community Center is not in flood zones. Francisca Dávila Semprit and Ernestina Bracero Pérez schools are the most favorable.

When adding the weighted rasters, it is concluded that the areas where Ernestina Bracero Pérez School and Pájaros Community Center locations are the most favorable (Figure 13). It should be noted that Pájaros Community Center was not evaluated for several factors because it is not located in the basin of the La Plata River to Cienaga.

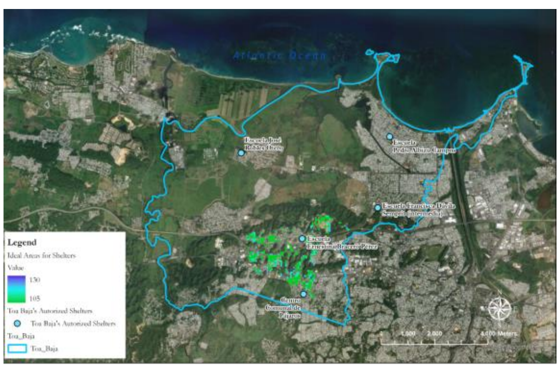

Figure 13
Ideal Areas for Shelters

CONCLUSION

Based on the factors evaluated, it is concluded that the safest shelters are Pájaros Community Center and Ernestina Bracero Pérez School. Pájaros Community Center stands out for its high altitude of 73.73 meters, its favorable distance from bodies of water (more than 2,750 meters), and its location outside flood zones, which significantly minimizes the risk of flooding. Ernestina Bracero Pérez School, located at an elevation of 35.21 meters, also has an adequate slope of 1.20 degrees, is on developed land, and is located more than 1,500 meters from flood zones, which makes it equally safe. On the other hand, the less safe shelters are José Robles Otero School and Pedro Albizu Campos School. José Robles Otero School, with a low elevation of 2.57 meters, a slope of 0.59 degrees, located on land classified as forests and groves, and less than 350 meters from a body of water, in addition to being less than 100 meters from flood zones, presents a high risk of flooding. Similarly, Pedro Albizu Campos School, with an elevation of 2.38 meters and a slope of 0.51 degrees, although on developed land, is less than 950 meters from a body of water and less than 100 meters from flood zones, which also makes it vulnerable. In summary, the combination of higher elevation, distance from bodies of water, and location outside of flood zones makes Pájaros Community Center and Ernestina Bracero Pérez School the safest shelters, while José Robles Otero School and Pedro Albizu Campos School are the least safe in flood events.

The results of shelter assessment can be used meaningfully in making decisions about future locations. First, site selection for new shelters should prioritize areas with higher elevations and adequate slopes to minimize the risk of flooding and landslides. In addition, it is crucial to choose locations that are at a safe distance from bodies of water, preferably more than 2,750 meters, to reduce the risk of flooding. In terms of design and construction, water-resistant materials and construction techniques that strengthen structures against flooding and high winds must be used, and efficient drainage systems must be implemented to handle rainwater. Zoning and land use also play an important role. Areas intended for shelters should be planned on developed or vacant land, avoiding flood zones or implementing mitigation measures such as flood barriers. In addition, emergency planning should include the installation of early warning systems and community training, conducting regular drills to ensure effective emergency response. Finally, it is essential to conduct periodic reassessments of existing and potential shelters, using advanced technology to monitor environmental and meteorological conditions in real-time, allowing a rapid and effective response to potential threats. By implementing these strategies, the assessment results can guide urban planning and infrastructure construction, improving the safety and resilience of communities to natural disasters.

Figure 14
Ideal Shelter Ernestina Bracero Perez School

FUTURE WORK

This work is the first phase to verify the suitability of a shelter. As a follow-up to this analysis, it is good to integrate the most affected communities and calculate the time it would take to reach these shelters on the main roads. Another piece of information to evaluate would be to add more localities that could be shelters and make the analysis of suitability.

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