## UNDERGRADUATE RESEARCH REPORT

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# **Risk Assessment of Seismic Activity in Mayagüez-Puerto Rico using GIS**

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# Risk Assessment of Seismic Activity in Mayagüez-Puerto Rico using GIS

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#### Abstract

Risk assessment of seismic activity has an important role to determine which areas are at higher risk to experience serious damages in the case of an earthquake. It is important to have this information to know the possible consequences for the existing structures and to identify the best place to locate the new ones. Advances in computer-based Geographical Information Systems (GIS) provide very powerful tools to assess the risks of seismic activities. This study evaluated which areas of Mayagüez are at higher risk to experience serious damages by generating maps with ArcGIS using average velocities of shear waves at 30 m depth (Vs30), population, elevation model, buildings and land-use. To generate these maps four steps were followed: (1) acquisition of data, (2) spatial analysis, (3) risk map development, and (4) interpretation. A main goal of this research was to evaluate the potential of GIS tools for this assessment. Using two equations based on different rationale two risk maps for Mayagüez city were obtained and analyzed. The resulting maps identified areas of Mayagüez at different risk zones and clearly show that the coastal area is at more risk than the mountainous area. The whole city of Mayagüez and particularly the urban areas should be studied in more detail using additional GIS coverage layers for the city such as liquefaction hazard maps or tsunami hazard maps.

Keywords: seismic risk assessment, geographic information systems, Mayagüez, risk maps.

#### Introduction

Earthquakes are one of the most destructive natural hazards phenomenons, which could occur at any time without warning. They can destroy buildings and kill or injure habitants (Guragain, 2004). Puerto Rico is located within a complex boundary between the North America and Caribbean plates (Prentice and Mann, 2005). It is an island with significant seismicity, which produces a large potential for earthquake damage as revealed by historical seismic records dating back to the 1500's (Macari and Hoyos, 2005). Around the island, the seismic activity is concentrated at the North by the Puerto Rico Trench, at the east northeast by the Sombrero Basin, at the east by the Anegada Passage, to the south by the Muertos Trough, and at the west by Mona Canyon (Macari and Hoyos, 2005; Huerfano et al., 2005; Figure1). The island's seismicity is highly concentrated in the Southwestern zone, which during the last century has been the source of at least 25 felt earthquakes with maximum intensities of V in the Modified Mercalli Scale (Huerfano et al., 2005; PRSN, 2003).

Advances in computer-based Geographical Information Systems (GIS) now provided very powerful and cost-effective tools to assess the risks of seismic activities. Macari and Hoyos (2005) integrate a variety of analysis procedures to identify and mapping geotechnical hazards through GIS technology. A multiple software package was developed and used to assess the liquefaction potential for the western part of Puerto Rico. For this, they imputed a simulated seismic event similar to the one of 1918 ( $M_s$  7.5) and generated different contour maps of earthquake induced liquefaction hazard for areas near and within the city of Mayagüez.

Another work using GIS technology is presented by Guragain (2004). His main purpose was to carry out a seismic building vulnerability in the Lalitpur Sub Metropolitan city area, in Kathmandu, Nepal. The vulnerability developed by the National Society for Earthquake Technology Nepal and NGO working in Earthquake Vulnerability Reduction was used and a series of GIS operations were performed to link this relation to the building types in the Lalitpur area. With all the information gathered a building loss estimation where determined from three different earthquakes scenarios.

The current research developed a combined analysis of topographic, geologic and landuse characteristics to determine which areas are at higher risk based on a set of related parameters. This study evaluated which areas of Mayagüez are at higher risk to experience serious damages by generating a map with ArcGIS using Seismic hazard maps for Puerto Rico, average Vs to 30 m depth ( $V_s$ 30), population, digital elevation, land-use from aerial photographs, and buildings. The research objective was tested by following four steps: (1) acquisition of data, (2) spatial analysis, (3) risk map development, and (4) interpretation.

#### **Objective Statement**

This research evaluated which areas of Mayagüez Puerto Rico were at higher risk to experience serious damages in a case of an earthquake occur. Based on the parameters mentioned before and proving the hypothesis that areas with higher population, lower shear wave velocities and increasing number of urbanization are at higher risk to suffer serious damages. Thus, a risk assessment of seismic activity was developed. The main goal of this research was to evaluate the potential of computer-based Geographical Information Systems (GIS) for this assessment. To accomplish this goal the specific objectives were:

- 1. Generate multiple geo-referenced maps of selected parameters along the Mayagüez municipality using ArcGIS.
- Determine which areas are at higher risk to experience serious damages based on the selected parameters.
- 3. Provide recommendations for future GIS studies trough the Puerto Rico Island based on these parameters.

#### **Geologic Environment of Mayagüez Puerto Rico**

The northwestern region of Puerto Rico is composed by limestone and surface deposits of sandy clays and sands that belong to the Miocene age. To the south of the city of Aguadilla through the North of Mayagüez city can be found deposits of the Tertiary and Cretaceous formations mostly composed of limestone, siltstone, and quartz diorite (Beinroth, 1969 cited in Macari and Hoyos, 2005). The Mayagüez area (Figure 2) is founded on loose, alluvial, cohesionless deposits with some silt deposits from the Alto Rio, Rio Cañas, and Rio Guanajibo rivers. These deposits follow the Rio Guanajibo and Rio Rosario and extend to the southwestern direction from Mayagüez (Figure 3) (Macari and Hoyos, 2005). The hills south of Rio

Guanajibo, toward Cabo Rojo are older sandy clay deposits. The southwestern part of the island is mostly composed of loose cohesionless deposits which extend to the west along the southern part of the island (Beinroth, 1969 cited in Macari and Hoyos, 2005).

#### Methods

This research was focused in the study of Mayagüez city, in Puerto Rico, using a computer-based Geographical Information Systems. Multiple maps with different layers of information were used to determine which areas could be more affected based on the shear wave velocities to a 30 m of depth and other related parameters. For this purpose, the work was divided into four parts (Figure 4a and 4b).

**Part 1- Data Acquisition:** The geospatial databases identified for this research included the Seismic hazard maps for Puerto Rico, average Vs to 30-m depth ( $V_s$ 30), population, digital elevation, buildings, land-use from aerial photographs.

- Seismic Hazard Maps for Puerto Rico of probabilistic PGA of 0.2-second spectral acceleration, including the contributions from all modeled sources, for a probability of exceedance of 2% in 50 years (approximately 2500-year return time) were provided by the USGS (Mueller et al., 2003; Figure 5).
- V<sub>s</sub>30 (Odum et al., 2007) were provided by the Puerto Rico Seismic Network (Figure 6).
- Population for the Mayagüez area was obtained from the last census of Puerto Rico that was done in 2000 (U.S. Census Bureau, 2000).
- Digital elevation model (DEM) was obtained from the USGS (2008).
- Buildings of Mayagüez with their respectively height were provided by the Puerto Rico Water Resources and Environmental Research Institute.
- Aerial photographs from 2007 and at high spatial of resolution were used to develop a land-use map, especially to determine the areas highly urbanized. This information was provided by Puerto Rico Water Resources and Environmental Research Institute and Puerto Rico Gap Analysis Project.

**Part 2- Spatial Analysis.** All collected data in the first part of this study were organized and compiled into a format easy to use in the software ArcGIS version 9.2. "This software is a complete system for authoring, serving, and using geographic information. It is an integrated collection of GIS software products for building and deploying a complete GIS wherever it is needed. It provides a complete set of tools for modeling geographic information and it is used for: discover and characterize geographic patterns, model and analyze against all sources of geographic information, optimize network and resource allocation, and automate workflows through a visual modeling environment" (ESRI, 2008). Once the parameters were imported into ArcGIS multiple geo-referenced maps were generated for the same geographic region to facilitate the comparison between the different layers of information (Appendix 1).

**Part 3- Risk Map Development.** A "Risk Factor" was assigned to each selected layer. This factor was based on a scale from 1 to 10, in which the number one (1) represents low risk and number ten (10) represents extreme risk. The Risk Factor assigned to every information layer was assigned following this rationale. Then, all the layers were incorporated into two equations to create two Risk Maps for the Mayagüez City. These two equations were developed based in the different opinion of two experts from the Puerto Rico Seismic Network. The first Risk Map for Mayagüez (RM 1) was based in the following equation:

#### **RM-1** = [Vs30 RF] + [Population RF] + [DEM] + [Building Heights RF] + [Land-Use RF]

This equation was generated based in the criterion that each layer has the same importance in the case of an earthquake in or near the Mayagüez City. Using this equation into the ArcGIS program, all the layers were combined to generate a map which indicates the different risk zones in a case of an earthquake.

The second equation considers more important the Vs30 and therefore this layer is multiplied by two, considering the strong role of the velocities for the shear wave. The equation for this second Risk Map (RM 2) is:

RM-2 = [Vs30 RF\*2] + [Population RF] + [DEM] + [Building Heights RF] + [Land-Use RF]

**Part 4- Interpretation.** After the maps were generated, all the information was analyzed by using multiple visualization techniques in ArcGIS. This final step helped to determine which areas were more in risk to experience serious damages based on the acquired data.

#### Results

A seismic risk assessment of the seismic activity in the municipality of Mayagüez was done using geographical information techniques based on the lateral variations of the hazard map for Puerto Rico, the shear wave velocity (Vs30), the population, topography (DEM), buildings and land-use. However, in this the Seismic Hazard Map for Puerto Rico (Figure 5) was not useful for Mayagüez because the whole city is in the same hazard zone. The Vs30 for Mayagüez (Figure 7) has a range of velocities that goes from 1.89 m/s to 952 m/s. This map shows that the lower velocities concentrate in areas near the coast of Mayagüez which mostly consists of unconsolidated sediments and the higher velocities concentrate in areas of consolidated sediments. The population of Mayagüez (Figure 8 and Table 1) has a range of values that goes from 1,118 to 32,043 habitants for its 20 neighborhoods. Figure 8, shows that the higher number of population is concentrated along the coast and the lower number of population concentrates to the east side of Mayagüez, in the mountainous area. The digital elevation model was used to calculate the slopes for Mayagüez. The slope values (Figure 9) go from 0 to ~45°, the lower slopes values are at the west side of Mayagüez and the higher values are at the east area where the mountains are located. The buildings along Mayagüez (Figure 10) have a maximum height of 65 m, where most of them and the highest ones are also located near the coast and the structures with lowest heights are located at the east part of Mayagüez. The Land-Use for Mayagüez (Figure 11) was divided into four classes: High-density, which is the area with high urban development; Low-density, which is the area with low urban development; Barren land, which are the areas of recent developments cleared for construction, and Not Urban, that includes water bodies and different type of soils. The high density classification is mostly concentrated along the Mayagüez coast; the other three classifications are distributed along all the study area.

After all this five (5) parameters were compared a risk factor was assigned to each one. This factor was based on a scale from 1 to 10, in which the number one (1) represents low risk and number ten (10) represents extreme risk. For example (Figure 12), the area with less population there was assigned the number 1 because less people will be affected in comparison with areas with high population, which were assigned the number 10 because more people will be affected.

Once the risk factor was assigned and the equations were developed, the results obtained were two Risk Maps for the city of Mayagüez. The first Risk Map (RM 1) (Figure 13 & Table 2) shows different zones of risk based in equation RM-1. The second Risk Map (RM 2) (Figure 14 and Table 3) was based in equation (RM-2) which considers more important the Vs30 and the results of this second risk map shows areas with different stages of risk based in this rationale.

#### Discussion

According to the risk map using equation RM-1 (Figure 13 and Table 2) an area of 10.98 km<sup>2</sup> (8%) in Mayagüez city are at extreme risk and included the neighborhoods of Mayagüez Pueblo and Sábalos. As shown in the map, the neighborhoods of Guanajibo and Quebrada Grande are at the high risk zone, which covers an area of 19.11  $\text{km}^2$  (13%). The medium risk zone covers an area of 50.08  $\text{km}^2$  (35%) and includes the neighborhoods of Algarrobos, Juan Alonso, Limón, Mayagüez Arriba, Miradero, Rosario and Sabanetas. Finally the low risk zone covers an area of 62.32 km<sup>2</sup> (44%) and includes the neighborhoods of Bateyes, Leguísamo, Montoso, Naranjales, Quemado, Río Cañas Abajo, Río Cañas Arriba and Río Hondo. The extreme risk and high risk zones concentrates along the coastal plain of Mayagüez. This finding is attributed to the high urban development in that area, where the majority of the peoples lives there, and the lower velocities of the shear wave that are located in that area (Figure 7). This is due to the site categories in NEHRP provisions (Table 4), where the areas with velocities 180 to 360 m/s has a classification of soil type "D" that is stiff soil (Odum et al., 2007). In this type of soil the velocity of the shear waves attenuate and occurs seismic wave amplification affecting for more time the area. In the mountainous area the velocities are greater, having a velocity range of 360 to 760 m/s which in NEHRP provisions this is a soil type "C" that is dense soil, soft rock. Other areas have velocities that go from 760 to ~ 950 which is soil type "B" that is firm to hard rock. In these zones the seismic wave travels faster affecting for less time the area.

A second risk map generated using equation RM-2 (Figure 14 and Table 3). As previously mentioned, this map was done giving the double of importance to the Vs30 layer. Such recommendation is based on previous studies who established that in the shallow

subsurface (e.g. 30- to 60-m) observed earthquake ground motion is greatly influenced by the shear wave velocity due to the wave amplification and duration of such wave (Borcherdt and Gibbs, 1976 cited in Odum et al., 2007). This map shows that the extreme risk zone covers an area of 7.89 km<sup>2</sup> (6%) and includes the neighborhoods of Mayagüez Pueblo and Sábalos. The high risk zone covers an area of 21.87 km<sup>2</sup> (15%) and the only neighborhood that belongs to this zone is Guanajibo. The medium risk zone covers an area of 43.82 km<sup>2</sup> (31%); including Algarrobos, Juan Alonso, Limón, Mayagüez Arriba, Miradero, Quebrada Grande, Rosario and Sabanetas. Finally, the low risk zone covers an area of 68.91 km<sup>2</sup> (48%) and Bateyes, Malezas, Leguísamo, Montoso, Naranjales, Quemado, Río Cañas Abajo, Río Cañas Arriba and Río Hondo belong to this zone. Once again the extreme risk and the high risk zones cover the coastal plain of Mayagüez and the areas of medium and low risk concentrates along the mountains.

Essentially, both maps show similar results. Each one has located the risk zones almost in the same geographic area. The main difference is presented in the extension of the areas, in which the first map (Figure 13) covers more area in the extreme and medium risk zones and the second map (Figure 14) covers more area in the high and low risk zones. The implications behind both risk maps controlling the extensional areas is due to the sensibility of the equations used to calculate the risk, suggesting that each layer is independent from each other.

#### **Conclusions and Future Work**

The population and urbanization of Puerto Rico have increased by years and most of the people live along the coastal plains. Therefore, studies such as seismic risk assessments are needed to determine the areas with high risk. The western coastal plains of Puerto Rico have high vulnerability to earthquakes because of the propensity to seismic wave amplification, liquefaction and landslides. The resulting maps from this research identify areas of Mayagüez at different risk zones and clearly show that the coastal area is at more risk than the mountainous area. The whole city of Mayagüez and particularly the urban areas should be studied in more detailed using additional GIS coverage layers for the city such as liquefaction hazard maps or tsunami hazard maps. The analysis presented here should be further extended and refined. The

same work must be done in a region composed of other municipalities of Puerto Rico located at different zones of the hazard map developed by the USGS (Mueller et al., 2003).

#### Acknowledgements

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# Figures



Figure 1. Areas around Puerto Rico in which the seismic activity is highly concentrated (Larue et al., 1998).



Figure 2. Map of Puerto Rico and study area.



Figure 3. Geologic map of the Mayagüez and Rosario Quadrangle (Curet, 1986).



Figure 4-a. Flowchart showing the study concepts and steps for the Phase 1 of the research.



Figure 4-b. Flowchart showing the study concepts and steps for the Phase 2 of the research.



Figure 5. PGA (%g) with 2% probability of exceedance in 50 years from all modeled sources (Mueller et al., 2003).



Figure 6. Geology VS30 Grid File (Modified by Vélez and Huérfano, 2007).



Figure 7. Shear wave velocities for Mayagüez, the lower velocities concentrate along the coast and the highest velocities along the mountains.



Figure 8. Population by Neighborhoods for Mayagüez; the blue area represents the areas with lower population, and near the coast the purple area is the one with higher population.

Cens	us 2000						
Population by neighborhoods for Mayagüez	Habitants						
Algarrobos	4,792						
Bateyes	1,205						
Guanajibo	7,165						
Isla de Mona e Islote Monito	0						
Juan Alonso	1,371						
Leguísamo	2,080 1,622 1,143 32,043 6,098						
Limón							
Malezas							
Mayagüez Pueblo							
Mayagüez Arriba							
Miradero	5,510						
Montoso	1,118						
Naranjales	1,197						
Quebrada Grande	6,333						
Quemado	3,017						
Río Cañas Abajo	2,318						
Río Cañas Arriba	1,495						
Río Hondo	3,865						
Rosario	1,630						
Sábalos	10,271						
Sabanetas	4,161						
Total	98,434						

## Table 1. Population by neighborhoods of Mayagüez (U.S. Census Bureau, 2000).



Figure 9. Topography of Mayagüez, the slopes values goes from 0 to 45° degrees from the coast to the mountains.



Figure 10. Buildings along the city of Mayagüez, the highest buildings concentrate along the coast.



Figure 11. Land-Use for Mayagüez, High-density is the area with high urban development; Low-density is the area with lower urban development; Barren land are areas of recent developments cleared for construction and Not Urban are areas with general classifications that includes water bodies and different type of soils.



Figure 12. Risk Factor for Population in Mayagüez, to each area were assigned a number from 1 to 10 in which the number 1 represents the areas with lower risk because has less population and number 10 represents areas with extreme risk because has more population.



Figure 13. Risk Map for Mayagüez base on equation RM-1.

Seismic Risk Assessment for Mayagüez								
Risk Factor	Area Km^2	Neighborhoods						
Low Risk	62.32 Km^2 (44%)	Bateyes, Leguísamo, Malezas, Montoso, Naranjales, Quemado, Río Cañas Abajo, Río Cañas Arriba, Río Hondo						
Medium Risk	50.08 Km^2 (35%)	Algarrobos, Juan Alonso, Limón, Mayagüez Arriba, Miradero, Rosario, Sabanetas						
High Risk	19.11 Km^2 (13%)	Guanajibo, Quebrada Grande						
Extreme Risk	10.98 Km^2 (8%)	Mayagüez Pueblo, Sábalos,						

Table 2. Areas of Mayagüez at different levels of risk based in RM-1.

\*The selection of the neighborhoods for each Risk Factor area is based on visual techniques of which area of risk is more abundant for each neighborhood.



Figure 14. Risk Map for Mayagüez based in equation RM-2.

Seismic Risk Assessment for Mayagüez								
Risk Factor	Area Km^2	Neighborhoods						
Low Risk	68.91 Km^2 (48%)	Bateyes, Malezas, Leguísamo, Montoso, Naranjales, Quemado, Río Cañas Abajo, Río Cañas Arriba, Río Hondo						
Medium Risk	43.82 Km^2 (31%)	Algarrobos, Juan Alonso, Limón, Mayagüez Arriba, Miradero, Quebrada Grande, Rosario, Sabanetas						
High Risk	21.87 Km^2 (15%)	Guanajibo						
Extreme Risk	7.89 Km^2 (6%)	Mayagüez Pueblo, Sábalos						

Table 3. Areas of Mayagüez at different levels of risk based in RM-2

\*The selection of the neighborhoods for each Risk Factor area is based on visual techniques of which area is more abundant for each neighborhood.

Soil profile type	Rock/soil description	Average S-wave velocity (m/s) top 30 m				
А	Hard rock	> 1,500				
В	Rock	760 – 1,500				
С	Very dense soil/soft rock	360 - 760				
D	Stiff soil	180 - 360				
Е	Soft soil	< 180				
F	Special soils requiring site-					
	specific evaluation					

Table 4. Site categories in NEHRP provisions (BSSC, 1997).

#### **APPENDIX 1**

## Spatial Analysis - Development of the layers used for the research

One of the layers used for the research was the layer with the buildings and minimal areas of construction around the Mayagüez City. These structures have heights that go from 0.1m to 65 m. This information was obtained from Puerto Rico Water Resources and Environmental Research Institute.



This figure shows the buildings around a portion of Mayagüez.



To arrange the information needed for this layer there was followed three steps:

- 1. Double-click in the name of the layer, then appears a window named Layer Properties.
- 2. Click the tab of symbology.
- 3. Then in categories select unique values, at this part the buildings were arranged and grouped with right click by their heights into four categories.



1118; 1143; 1197; 1205

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Other layer used for this research was the one of population. The population was obtained by the last census realized in Puerto Rico in 2000.

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This figure represents the neighborhoods of Mayagüez. The different color zones are the four categories of Population of this city.

To obtain the necessary information there was followed this five steps:

- 1. Right click in the name of the layer, and select Open Attribute Table.
- 2. There appears the Attribute Table of the layer.
- 3. At the inferior part of the window to the right select Options.
- 4. There select Add Field, at this part the information obtained for the population of Mayagüez from the census was added to the Attribute Table by editing it.
- 5. Finally, the population values were categorized following the same three steps used in the buildings layer.



Other of the layers used was the land used and it was provided by the Puerto Rico Gap Analysis Project.

This figure shows the Land use for the area of Mayagüez by the Puerto Rico Gap Analysis.



Because the PR Gap Analysis has a lot of information that were not necessary for this research there was done a reclassification.

- 1. Click on Arc Toolbox.
- 2. Select Spatial Analyst Tool.
- 3. Select Reclass.
- 4. Select Reclassify.
- 5. There appears a window named Reclassify.
- 6. At this part, there was located the layer needed and finally click ok.



After the layer was reclassified:

- 1. Right click on the name of the layer
- 2. Select Open Attribute Table and there appears the window of Attributes of the layer.
- 3. In this window select options.
- 4. Click on Select by Attributes
- 5. In the window of Select by Attributes, select "Gridcode" and classify the different areas.



This figure is the final product with the four classifications for the land use of Mayagüez.



This Figure shows the DEM for the Mayaguez City.



To calculate the slope using the elevation model there was followed these three steps:

- 1. Click on the toolbar Spatial Analyst the option of Surface Analysis.
- 2. Select Slope.
- 3. Then appears a window named Slope, in here the parameters were chosen.

The next layer used was the Digital Elevation Model (DEM) from the USGS (2008).



1. After the program calculated the slopes this was the final product, with 10 categories with slopes ranging from  $0^{\circ}$  to ~  $45.2^{\circ}$ .

The next layer used was the Vs30; this information was provided by the Puerto Rico Seismic Network (PRSN).

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This figure shows the data provided by the (PRSN). This Data was saved into a text format in Excel for our work purpose.



To generate the Velocities Map there was followed this steps:

- 1. Select the Tools icon.
  - 2. Then select Add XY Data.
  - 3. Then appears a window in which have we to browse for the folder which contained the Excel file with the Vs30 data and set Coordinate the System that is NAD 83 for our work.
  - 4. Then click Ok.



When the data appears into the project:

- 1. It was converted into shapefile by clicking Conversion Tools and selecting from raster to Point.
- 2. Then the information needed appears in the project in shapefile of points.



To have a figure representing the velocities of the Vs30 there was followed these three steps:

- 1. In the Spatial Analyst toolbar select Interpolate to Raster.
- 2. Then select Inverse Distance Weighted.
- 3. Then appears a window in which is browsed the shapefile of the Vs30 and then click ok.



is the velocities of the shear wave for the Mayagüez

area.

# **Conversion from Shapefile to Raster**

All the information presented above were the steps to prepare all the data needed to develop the final product of our work. To get the final maps, all the five layers of information has to be in a Raster format, "a raster consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information" (ESRI, 2008). Before the conversion of these layers into raster, there was added a column of values to their Attribute Table including values of Risk Factor, this values were assigned using a scale from 1 to 10, where the number 1 represents minor risk and 10 represents higher risk.



One of the layers used for this research that wasn't in raster format was the one of population. To convert it to raster there was followed these steps:

- 1. In the Arc Toolbox there was selected Conversion Tools.
- 2. The next step was to select the Raster option.
- 3. Then select the option of Polygon to Raster.
- 4. In the window that appeared we browsed for the file of population.
- 5. Then in the Value Field was selected Risk Factor and finally ok.



This figure shows the Population Layer based on the Risk Factor converted into raster. The same steps were followed for the other layers that were not raster.

# **Development of Risk Maps**

Once all the layers were converted to raster based in the Risk Factor there was created an equation that consists in the sum of all the layers.



The steps followed to generate these maps were as follow:

- 1. Select Spatial Analyst.
- 2. Select Raster Calculator.
- 3. Double click into the layers needed for the calculation and add the plus symbol between each one and finally click evaluate.



This figure shows the Risk Map for the Mayaguez area based on the information for this study, for this equation all the layers have equal importance.



This figure shows the calculation for the Second Risk map for Mayagüez. In this case the Vs30 layer was multiplied by two giving more importance to it because all the implications that it has for our study.



This figure is the Risk map for the Mayagüez area based on the equation in which the Vs30 layer was multiplied by two.

# **Calculation of the Areas**

To calculate the areas of the Risk Maps for Mayagüez there was necessary to change the Raster Data obtained from the calculation of the equations into shapefiles.



The data of the Risk Map was converted into shapefiles by following these steps:

- 1. In Arc Toolbox select Conversion Tools.
- 2. Select Raster to Polygon.
- 3. In Input Raster browse the layer of calculations.
- 4. Click ok.



This figure shows the raster data converted into shapefiles.



Once the previous steps were done, the next part was calculating the area by following these steps:

- 1. In Arc toolbox select spatial Statistics Tools.
- 2. Select Utilities.
- 3. Select Calculate Areas.
- 4. In the window of Calculate Areas look for the layer to work.
- 5. Click Ok.

At this step we have the area of all the features that composed the layers, because we want to have the area of the polygons with the same characteristics we have to follow the next steps:

- 1. Look for the layer of the Calculated Areas.
- 2. In Arc Toolbox select Data Management tools.
- 3. Select Generalization.
- 4. Select Dissolve.
- 5. In the window browse for the layer desired to work and select sum.
- 6. Click Ok.

