University of Puerto Rico at Mayagüez

Faculty of Arts and Sciences

Department of Geology

A Case Study of Vulnerability of Landslides for New Jersey, USA

Ashlyann Arana Morales

Jennifer Toledo Rivera

Kevián A. Pérez Valentín

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Introduction

Throughout the years, the Earth has undergone geological changes (Monroe and Wicander, 2001). These changes are a result from the constant interactions between internal and external cycles (Monroe and Wicander, 2001). Therefore, it is evident that surface erosional processes sculpt the surface of the Earth (Monroe and Wicander, 2001). The type of landscape characteristic of an area will depend on the erosion agent taking place in the area (Monroe and Wicander, 2001). Unfortunately, some geological processes such as mass movement (also known as mass wasting), might imply a destructive effect on nature itself as well as on humans. According to Hamblin and Howard (2005) mass movement can be defined as the movement of material downslope, influenced by gravity, due to saturation of material with water, steep slopes, freezing and thawing and earthquakes. However, they can also occur due to anthropogenic activities such as deforestation, construction of roads, mining, quarrying, dredging and filling, among others (Muessig, 2009). The velocity at which they move and the degree of angle at which they occur, varies (Delano Wilshusen, 2001).

Mass movements can be classified in different types, landslides, being one of them. They are among the most common geologic hazards (Dhakai *et al*.,2000). In order for agencies to establish a database of places prone to landslides and prepare hazardous maps, it is important for the society to understand the severity and implications of such events as they can "cause loss of life, property of damage, or a general disruption of human activities" (Monroe and Wicander, 2001). It has been documented around the world that landslides have indeed injured people, and even impacted the economy of a place (Zaruba and Mencle, 1982). These types of mass wasting events can be seen along the United States. It has significantly impacted the economy in 25 states killing from 25 to 50 people on an average each year and causing annual costs exceeding $1.5 billion (Monroe and Wicander, 2001).

New Jersey is one of the states with a historical record since 1887 (Muessig, 2009) of these mass movements, occurring especially on the northern part of the state. The northern part of New Jersey is a physiographic province known as the New Jersey Highlands. It consists of 1000 square mile composed of mountains, ridges, woodlands, lakes and waterfalls (Volkert and Witte). Its highest point is located at the Wawayanda Mountain with an elevation of approximately 1,500 feet above sea level. This region is of great importance. It not only serves as a habitat for species, as well as being a water resource (since its drainage basin includes some aquifers), but this region is the oldest part of the state and contains the the oldest rocks dating one 1 billion years old (Volkert and Witte).

According to Muessig 2009, a state geologist from the New Jersey Geological Survey, New Jersey is a low relief area. However, New Jersey still is being affected by landslide and are due to slopes that have been cut by human activities or by water. Also, rock strength and attitude influence on the downward movement of material in such area. In order to establish which areas within the this state are prone to landslides and understand what factors are influencing them, maps were created using Geographic Information Systems. Geological parameters such as geology, slope, elevation, among others were studied to correlate the incidence of these landslides and be able to establish a link between them. The purpose of this research is to identify which areas in New Jersey, a low relief area, are prone to landslides and what factors distinguish landslide-prone areas.

Study Area:

The study area is the state of New Jersey located in the northeastern region of the United States (**Figure 1**) . The southeast of New Jersey is bounded by the Atlantic Ocean, on the west by the state of Pennsylvania, and the southwest by Delaware. New Jersey is divided into four topographic provinces or regions: Coastal Plains, Piedmont, Highlands and Valley and Ridge.

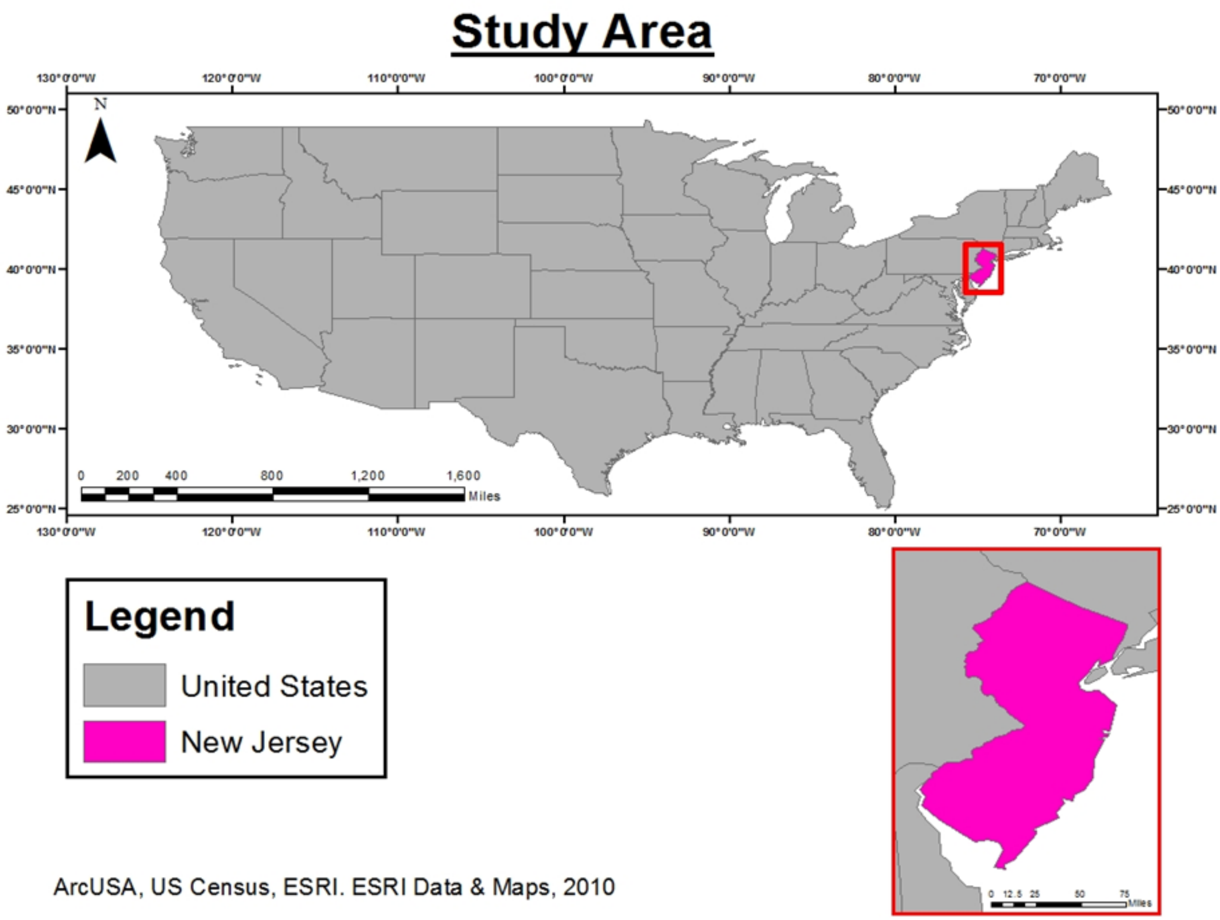


Figure 1. Study area for this work.

Objectives

The main objective of this study was to apply Geographic Information Systems (GIS) to the state of New Jersey. Landslides locations were identified using data and reports from the Department of Environmental Protection of the State of New Jersey. Areas of low landslide frequency and susceptibility for landslide occurrence were defined and areas where landslides occurred, the type of mass movements, and its causes, were identified. Historical data was used in order to provide a quantitative, spatial assessment for future landslide occurrence. Correlation of landslides events with geological, environmental and anthropogenic parameters were done in order to evaluate the effects landslides have on nature itself (environmental disturbances) as well as on the population living in the surrounding areas (fatalities and injuries).

Methodology

For this work the following parameters were used in order to provide new statistical data: geology, slope, folds, faults, landslides locations, topography, and hillshade (**Figure 2**). Geographic Information Systems (GIS) were used to overlap landslide point locations on the New Jersey state geological map, digital elevation model (DEM), Hillshade, relief and slope maps. Each of these maps were created using geographic information systems.

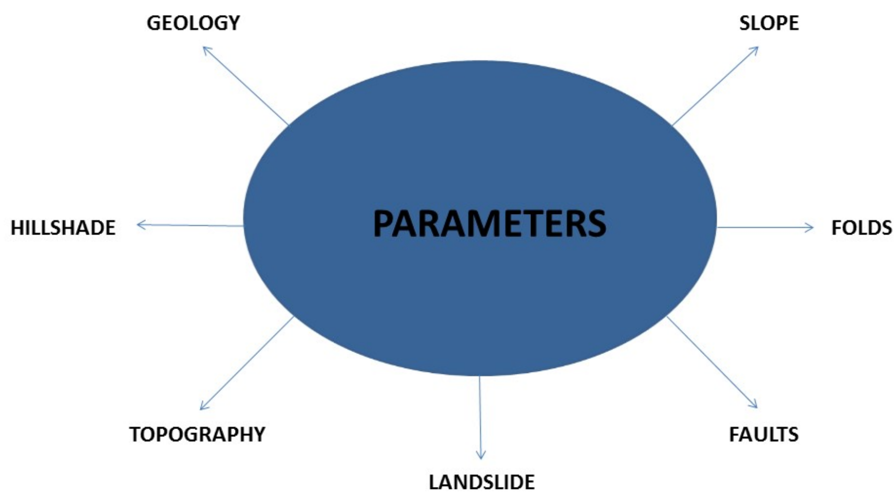


Figure 2. Parameters used to study landslides in the state of New Jersey.

In order to manipulate and calculate the statistical data the attribute tables were exported, converted to a text file and then opened in an excel file to create the graphs. Spatial Analysis was the main tool used to create the slope map. In addition, the Spatial Analysis tool was also used to create contours maps from a Digital Elevation Model. The Digital Elevation model was obtained from the USGS Earth Explorer web page (http://earthexplorer.usgs.gov/) and modiffy for this work. The following schematic diagram illustrate the main procedures accomplished in ArcGIS (**Figure 3**).

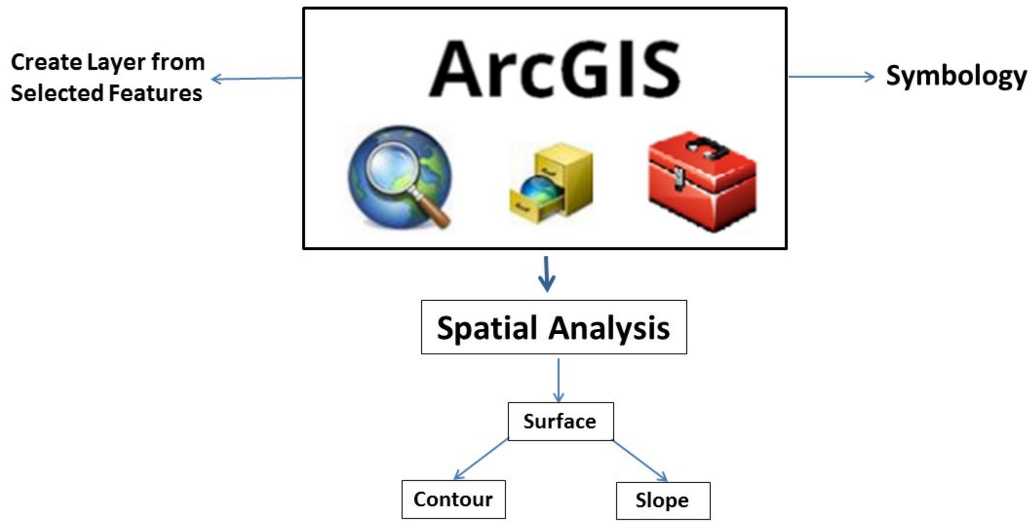
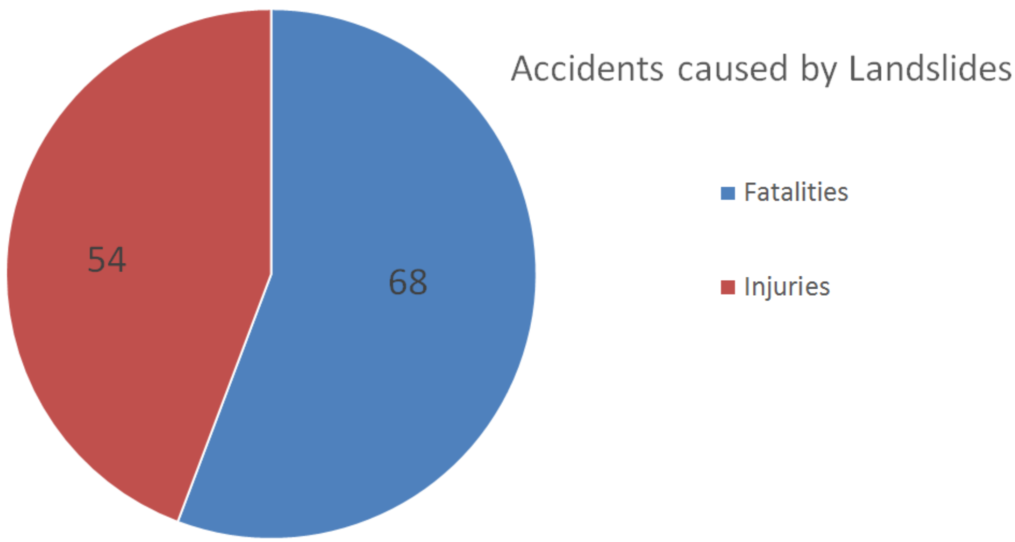


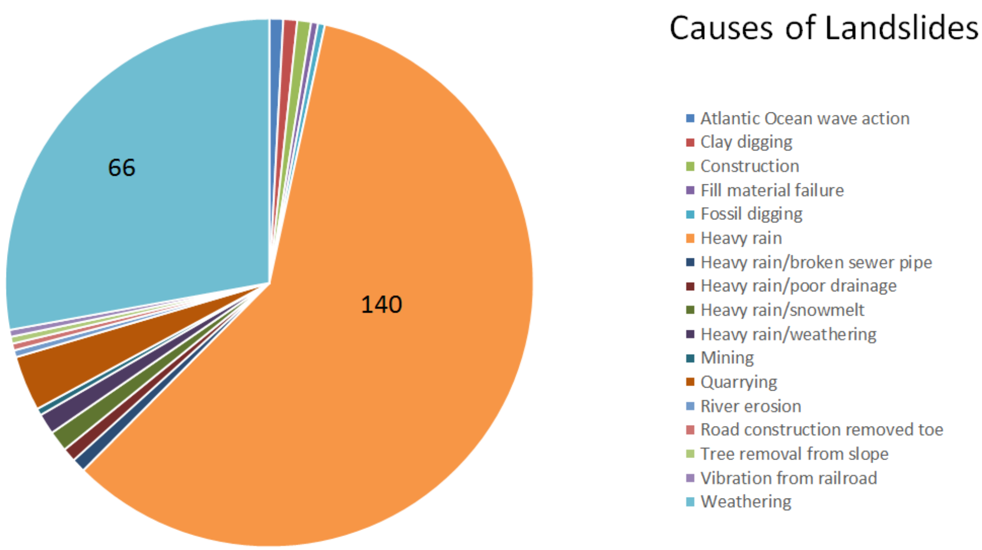
Figure 3. Flowchart showing the most important procedures performed in ArcMap.

Results and Discussion

Landslide point locations were obtained from a database of 181 historical landslides compiled by the New Jersey Department of Environmental Protection. The database covers the period from 1782 to 2013 and include landslides that caused 68 fatalities and 54 injuries (**Graph 1**). The majority of the landslides in this area are triggered by heavy rain and weathering (**Graph 2 and Figure 8**). In order to be able to overlay landslide point locations on maps of geology, hillshade, and slope, ArcMap was used. The majority of landslides (**Graph 3** and **Figure 4**) occurred on slopes of 10° or less (**Graph 3**) in the province of Highlands, a province characterized for having igneous rocks. Five lithologies types were identified: clastic sedimentary, non-clastic sedimentary, igneous intrusive, igneous extrusive and metamorphic (**Figure 5**). Igneous intrusive rocks have the highest incidence of landslides per unit area (**Graph 4**) therefore they are the most susceptible rock-type for landslides occurrence. Even though the causes for landslides to occur are due to natural factors, study of the database revealed that human activity, such as, construction, mining and quarrying, also contributed to the occurrence of landslides on gentle slopes (≤10°).



Graph 1. Major injuries or accidents caused by landslides. Landslides caused 68 fatalities and 54 injured in the state of New Jersey in a period of 1782 to 2013.



Graph 2. Causes of major landslides from 1782 to 2013 in the state of New Jersey. Note the majority of the landslides in this area are triggered by heavy rain and weathering

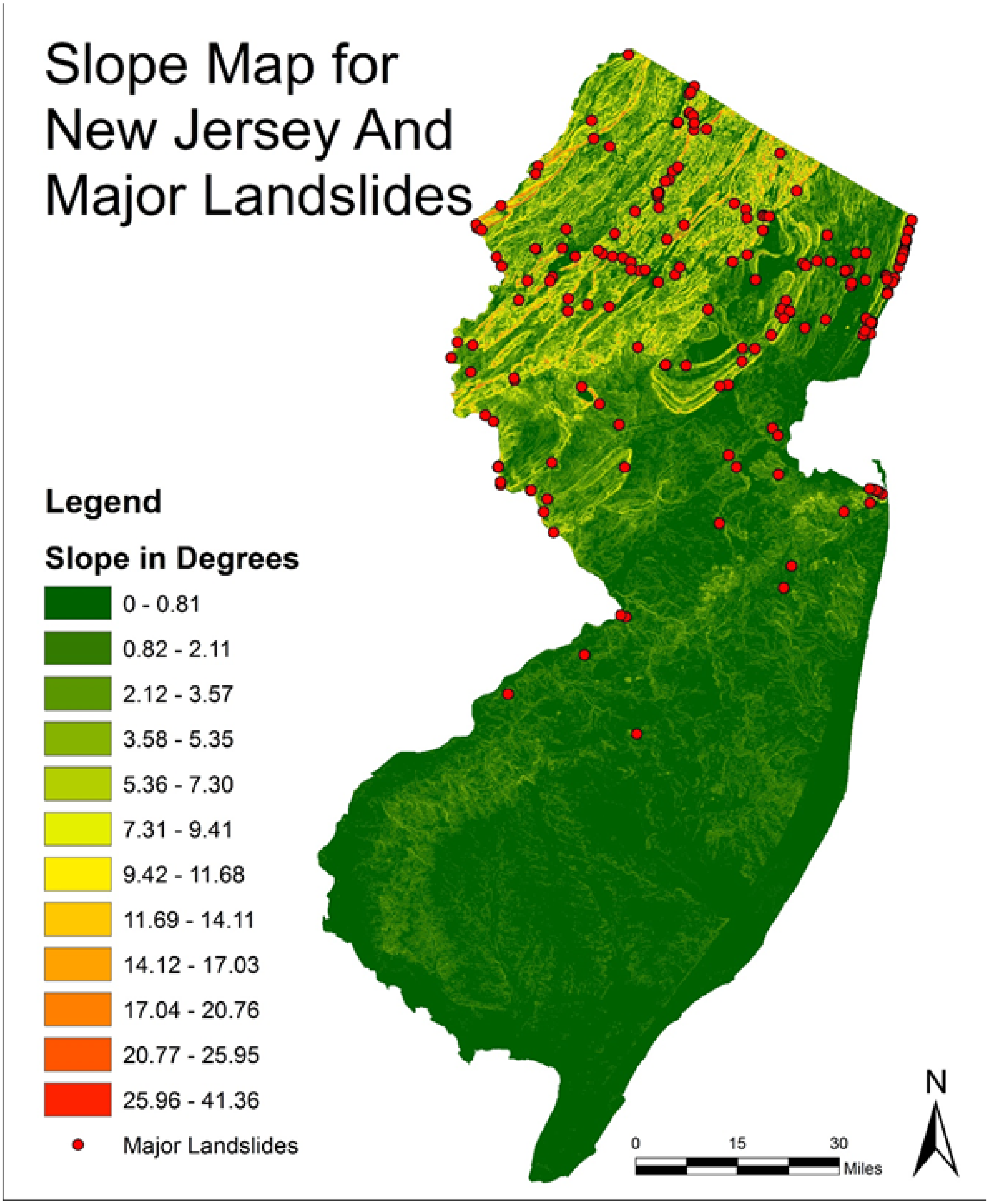


Figure 4. Slope Map and major landslides from 1782 to 2013 in the state of New Jersey.

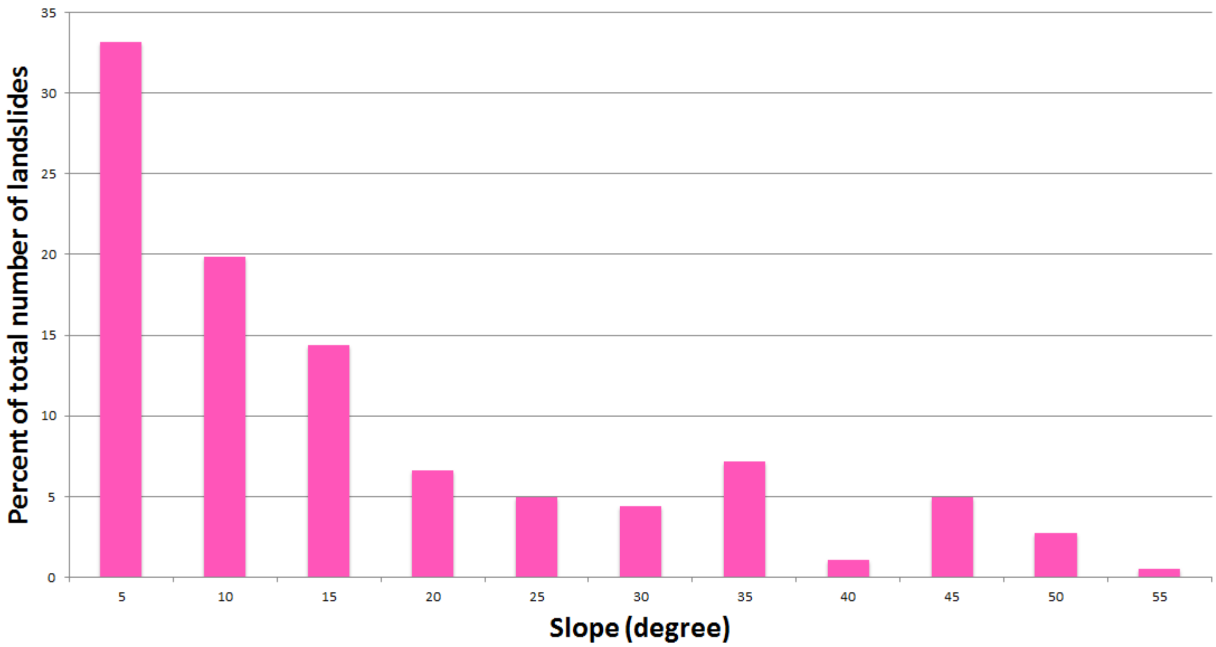


Figure 3. This graph shows the relationship between the slope gradient at which landslides occur with the percentage of landslides occurring at a certain slope. Approximately 34% of landslides occur at a slope less than 10 degrees.

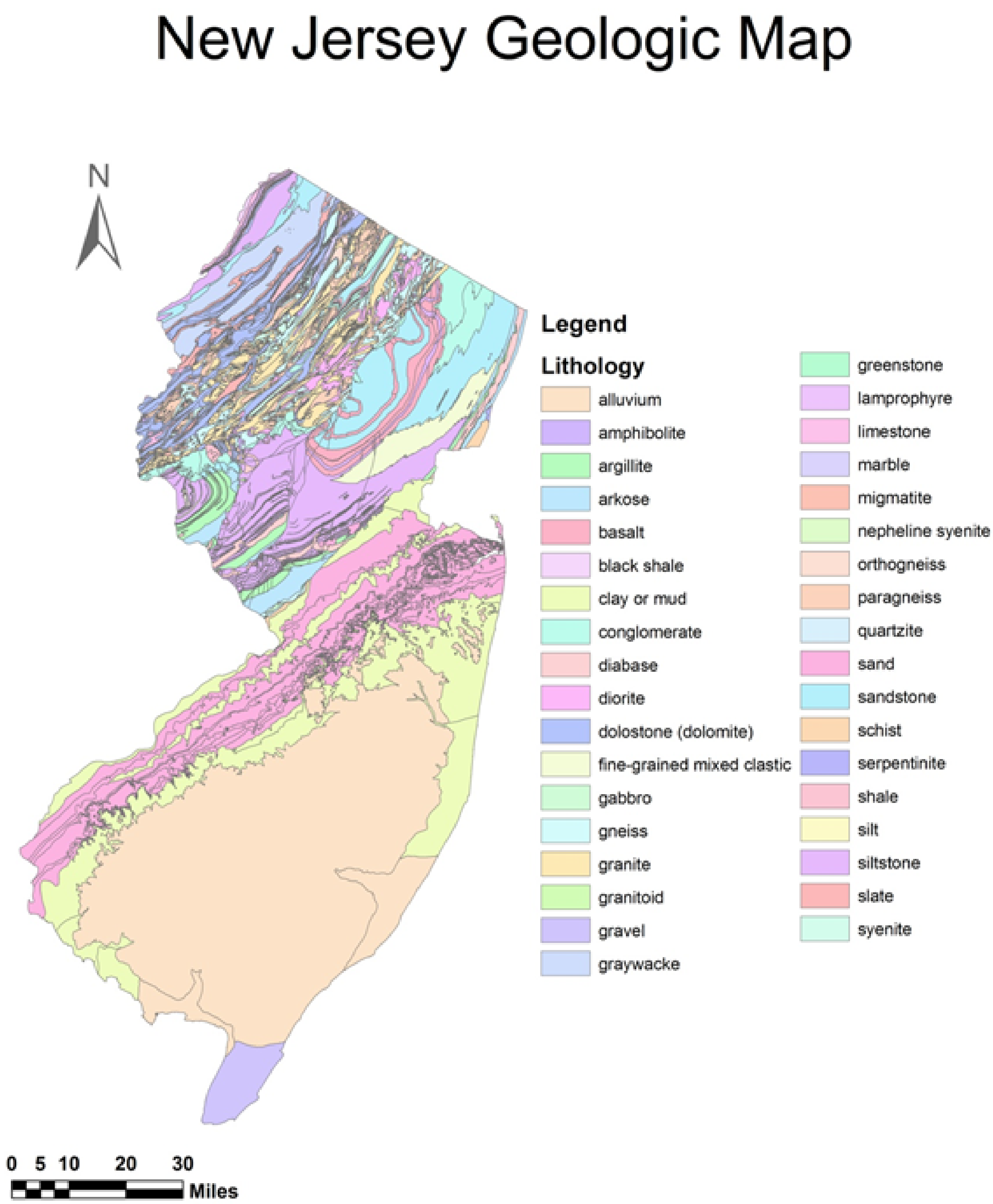
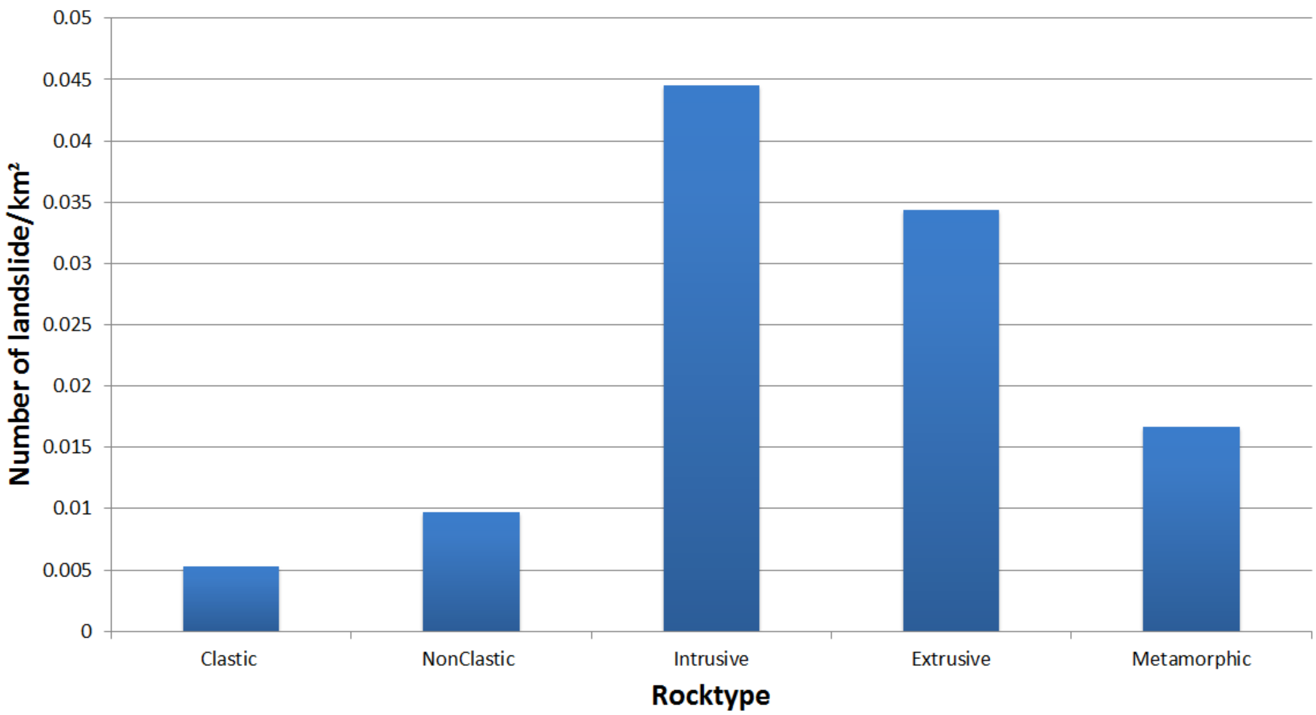


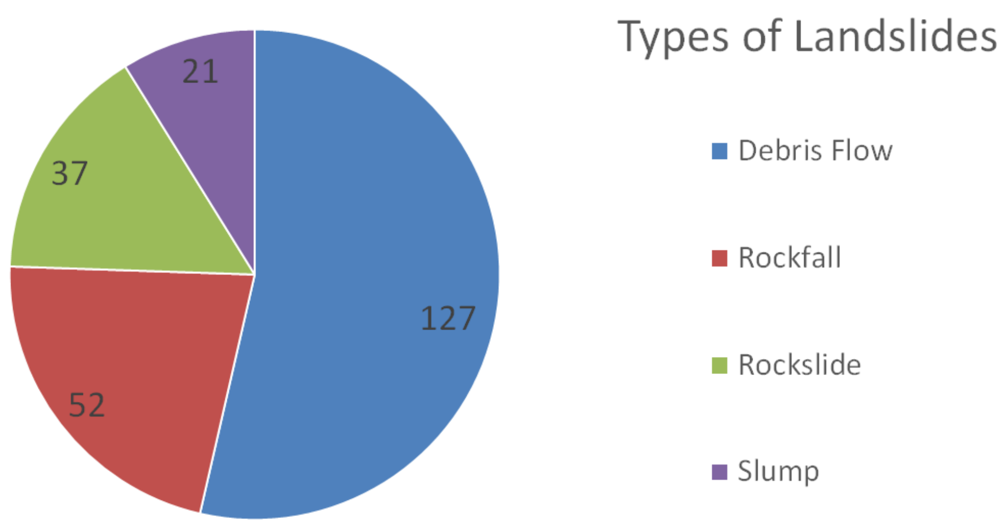
Figure 5. Geology of New Jersey.



Graph 4. Igneous intrusive rocks with the highest incidence of landslides per unit area

From the attribute table on ArcGIS we extract the bedrock lithology information for each landslide. This information was exported to Microsoft excel as a single file and lumped it into five general categories. The parameters used were the numbers of landslides in square kilometers of extension and the lithology. The purpose of this procedure is to associate and identify the the most susceptible lithologies to landslides occurrence.

Four types of landslides were identified for the state of New Jersey: *debris flow, rockfall, rockslide and slump* (**Graph 5**). Of these four types of landslides occurring in New Jersey, debris flow resulted to have the largest amount of incidents with a total of 127 (**Graph 5**). This is supported by the evidence that water is needed for this mass to move, therefore, precipitation is a crucial factor in this project.



Graph 5. Major types of landslides identified for the state of New Jersey: *debris flow, rockfall, rock slide and slump.* Note: debris flow is the most common type of mass movement.

To create a slope map a Digital Elevation Model was needed. For this work we use the slope tool located in the Spatial Analysis toolbox at the Arctoolbox section. Then, in the slope section dialog box the Input Raster was the New Jersey Digital Elevation Model. The Output

Raster was a new folder named Slope Map for New Jersey and the output measurement unit was one degree (**Figure 6**).

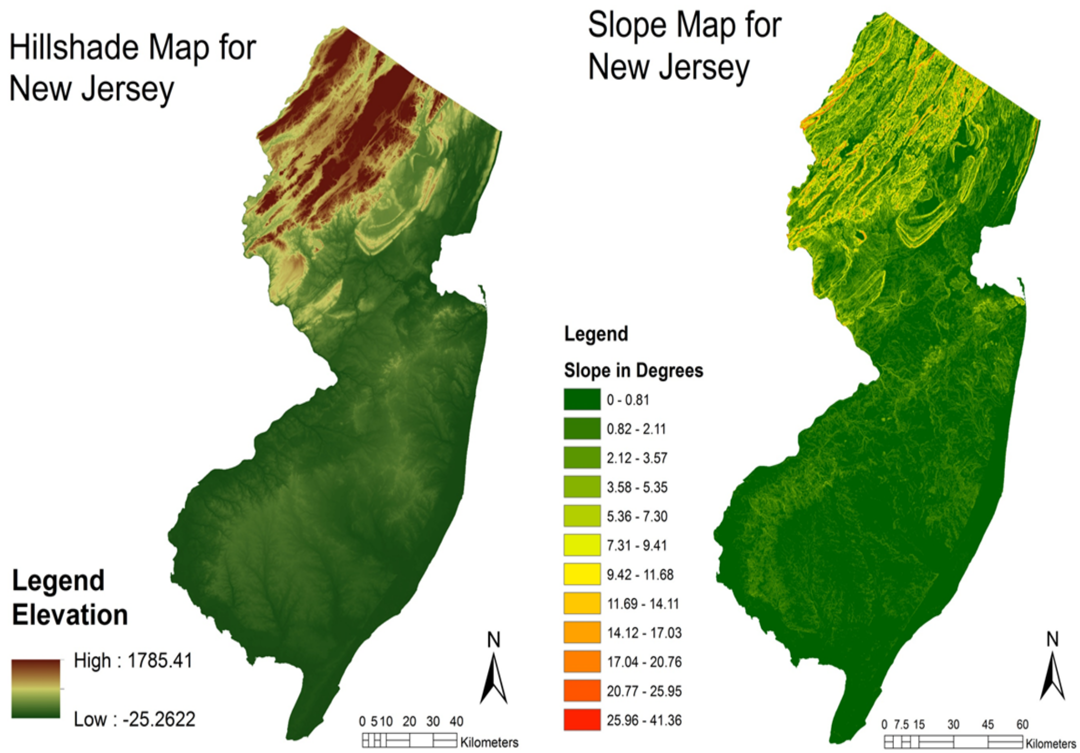


Figure 6. Left: Hillshade or DEM for the state of New Jersy. Righ: Slope Map for the State of New Jersey.

For this work landslide locations were obtained from a two database of 237 historical landslides from 1782 to 2013 (**Figure 7**). Landslide locations were obtained from the Department of Environmental Protection Division of Water Supply and Geoscience (http://www.state.nj.us/dep/njgs/geodata/dgs06-3.htm). Landslide information were overlapped with other information using Geographic Information Systems (GIS).

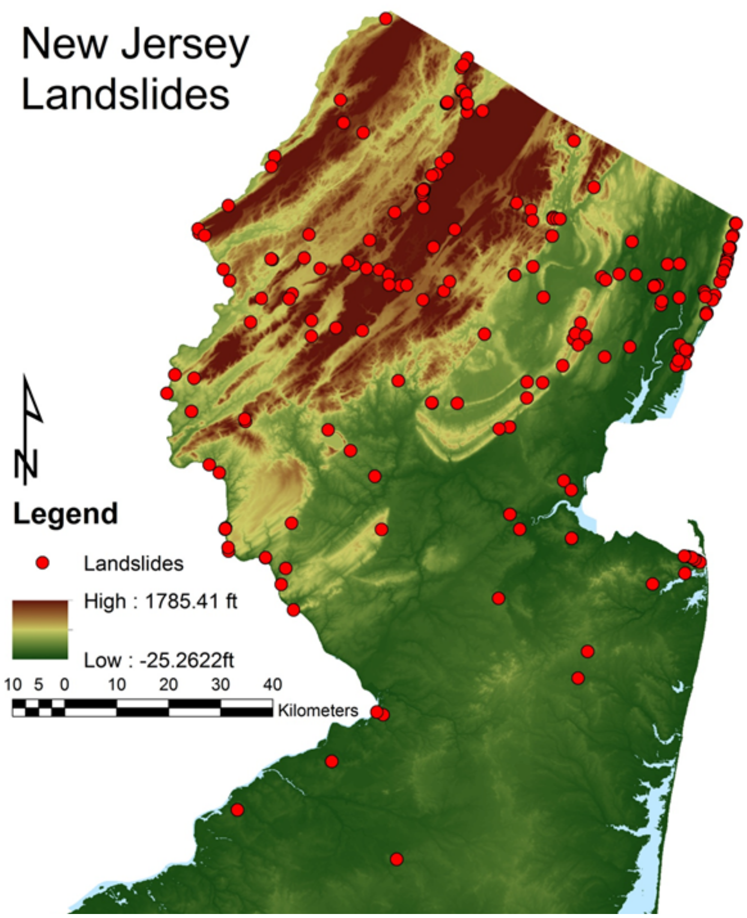


Figure 7. New Jersey Landslides from 1782 to 2013.

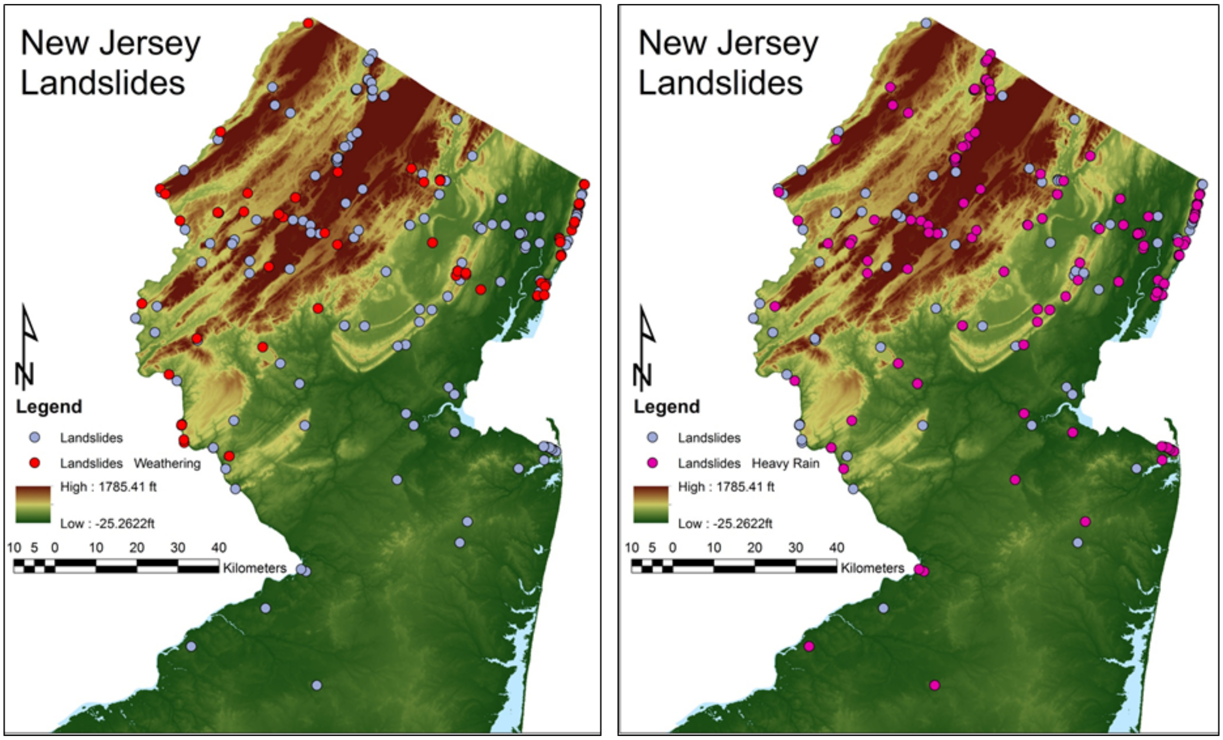


Figure 8. Landslides caused by heavy rain (Right) and landslides caused by weathering (Left).

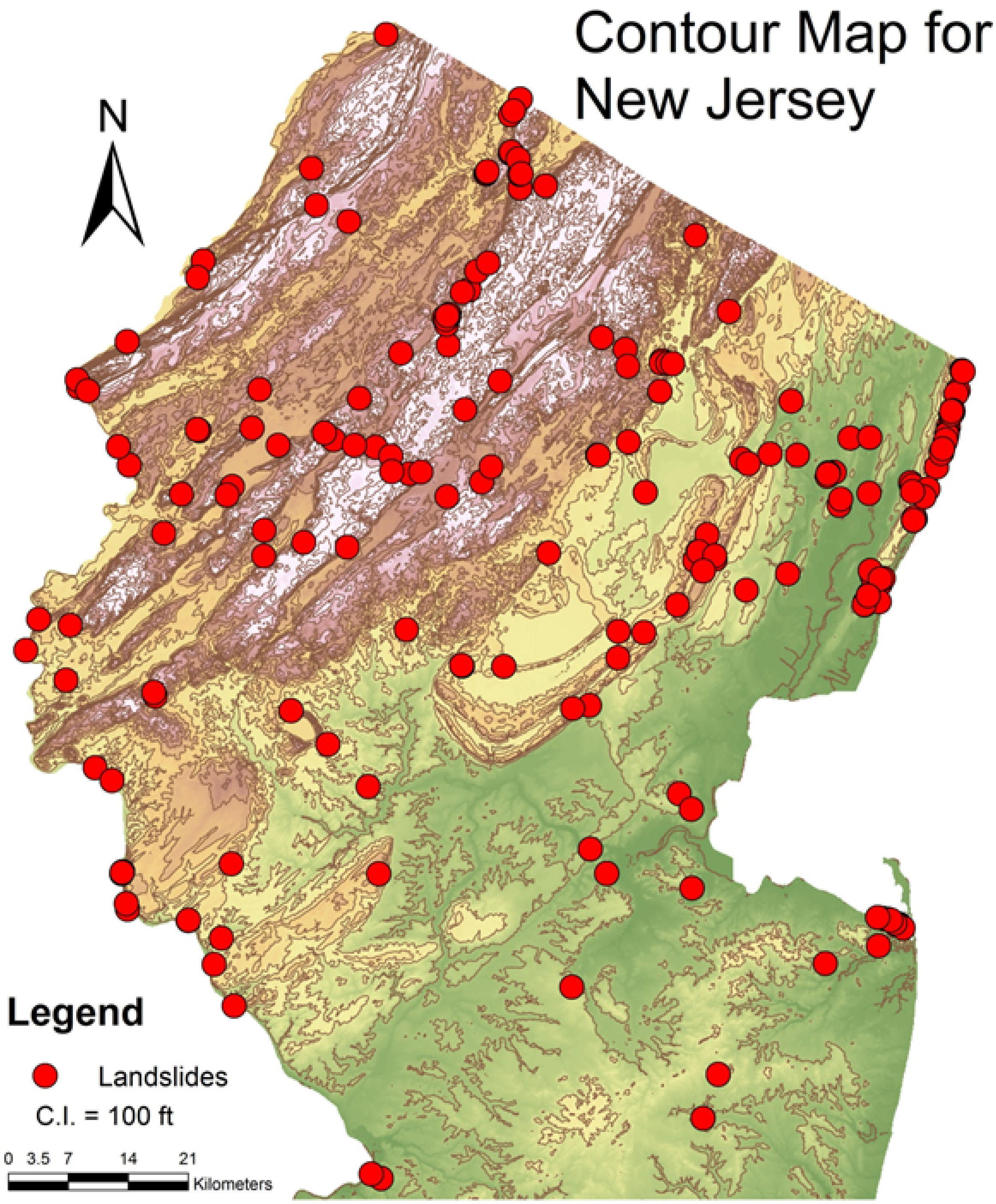


Figure 9. Major landslides for the state of New Jersey overlap

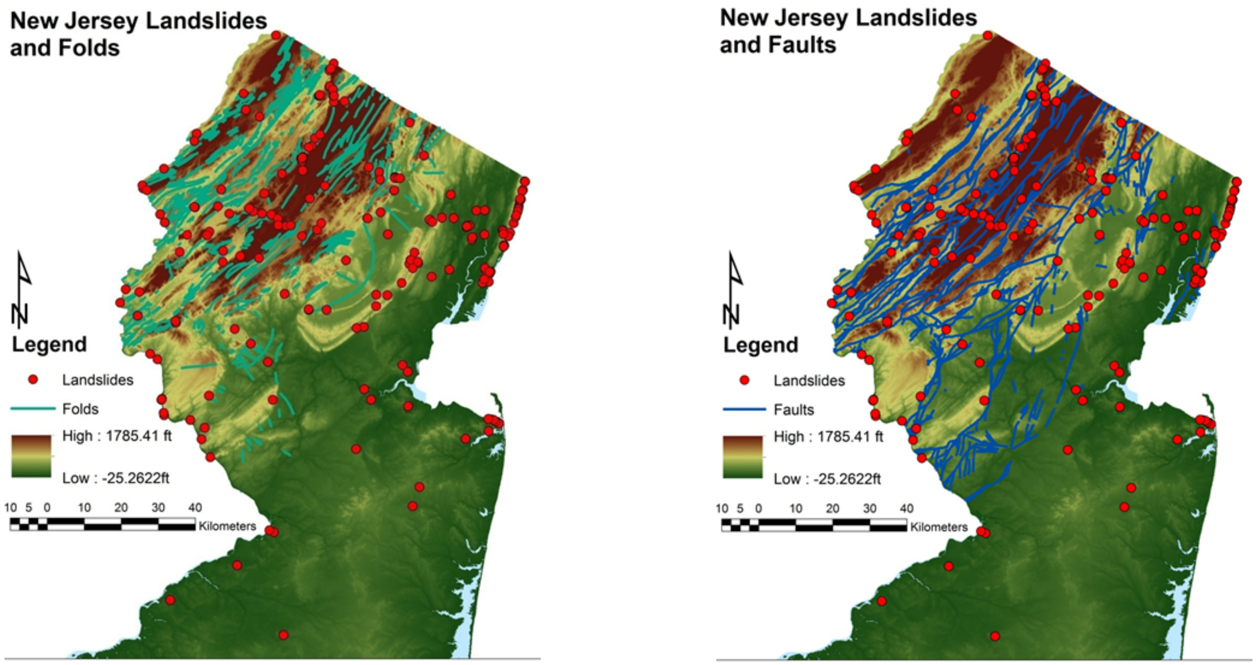
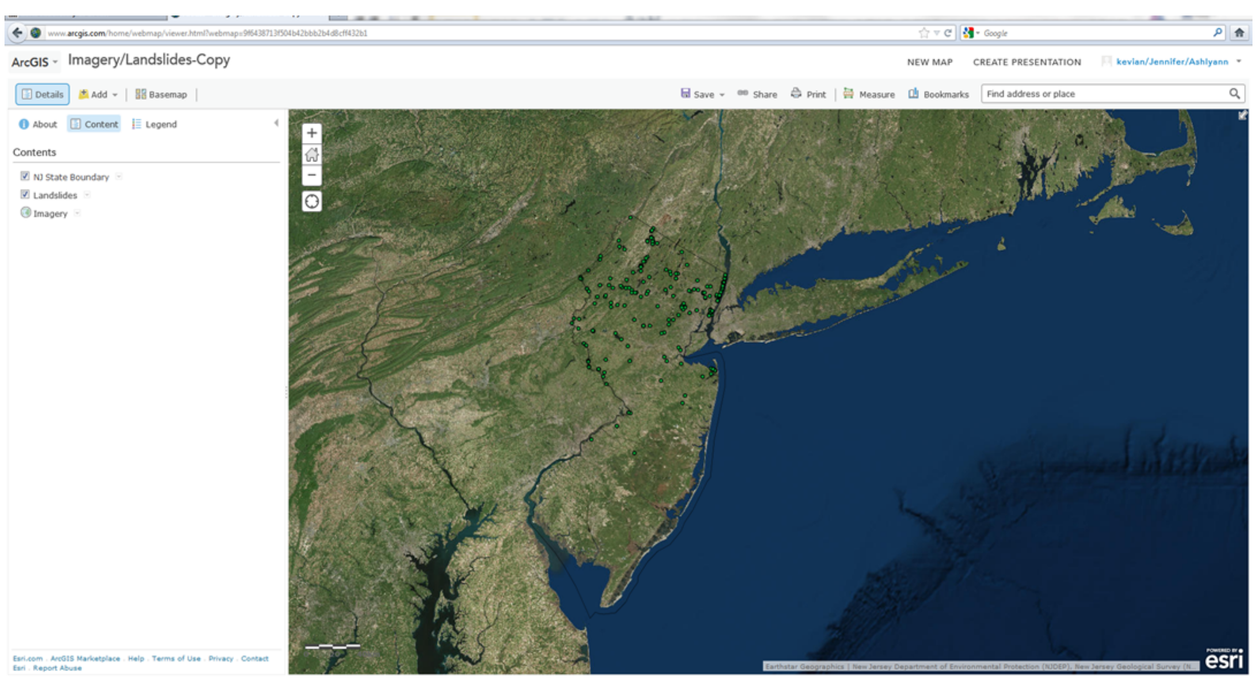


Figure 10. Major landslides associated with faults (right) and Folds (left). The presence of landslides in the northwest region of New Jersey are directly associated with the presence of major landslides.

Online Maps



Conclusions

Results show that the main controlling factors in the evolution of landslides are the precipitation (saturation condition of soil and rocks) and weathering. The results suggests a relationship between landslides occurrence and slopes less than 10 degrees. The majority of the landslides occurs in the north-west section of the state. This region is dominated by igneous rocks. In most cases these rocks are highly weathered. Of the different rock groups the igneous are the most affected by landslides. Precipitation is one of the main causes of landslides.

Landslide hazards mapping is the most important aspect to consider when making decisions at a local, regional and global scale. Identifying areas with a high potential for slope failure aids planners, developers , geologists and engineers to establish methods in order to minimize the risks the damages this mass movement causes. In order for this to happen, they need to take into account several parameters such as geology, slope gradient, hillshade, topography, landslides movements, among others. In this study, due to the complexity of its nature and unavailable data at the moment of doing the research, certain parameters (**Figure 11**) were not taken into consideration. It is highly recommended to update the database for landslides for New Jersey in order to relate effectively the causes of landslides occurring at such low gradients. Also, since correlation between these factors are crucial for this type of study, it is recommended to use Geographic Information System when processing the data and developing landslides risks and mitigations maps, which would be ideal to future generations in terms of urban planning and decision making. Also, it is important to educate the people of New Jersey in order for the, to have an insight of the risks and dangers of landslides.

Recommendations

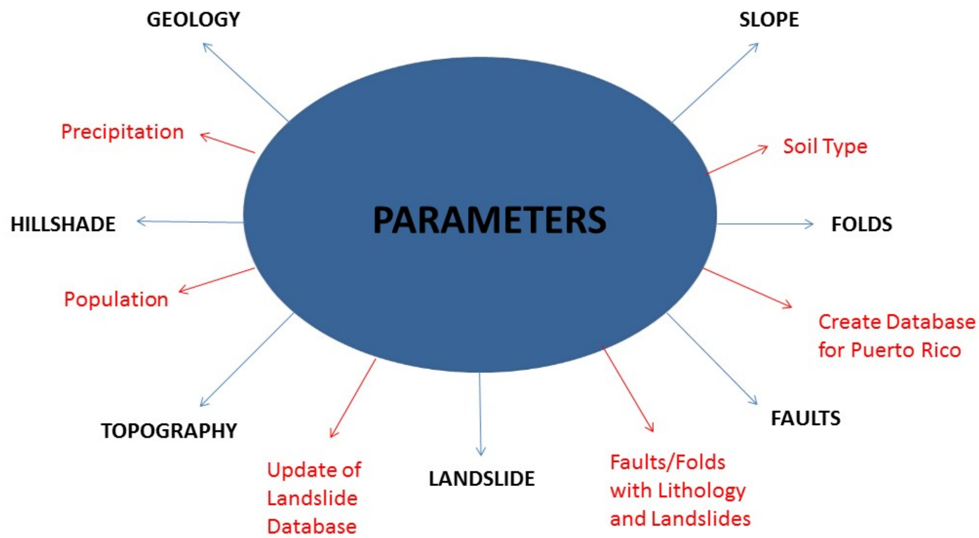


Figure 11. Parameters taken into consideration for this study are painted in black. Recommended parameters are in red.

References

Monroe, J.S., Wicander, R., 2001. The Changing Earth: Exploring Geology and Evolution. 3rd ed. Published by Brook/Cole. pp. 302, 323

Hamblin, W.K., Howard, J., 2005. Exercises in Physical Geology. 12 ed. Published by Pearson, Prentice Hall. pp. 123.

New Jersey Geological and Water Survey, 2014: http://www.state.nj.us/dep/njgs/geodata/dgs06-3.htm

USGS, Earth Explorer: http://earthexplorer.usgs.gov/

New Jersey Geological Survey: Geologic History and Visual Field Trip of the New Jersey Highland: http://www.state.nj.us/dep/njgs/enviroed/freedwn/HighlandsVFT.pdf

New Jersey Geological Survey: New Jersey Landslides: http://www.state.nj.us/dep/njgs/enviroed/infocirc/landslides.pdf

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