Spring 2020 Project Summary

Toa Baja Disasters
Utilizing Open-Source Earth Observations to Inform the Toa Baja Municipality's Flood Mitigation Efforts and Educate the Public

Project Team

Project Team:
Nara McCray (Project Lead)
Scott Harrison
Wilfredo A. Garcia Lopez
Adriana S. Le Compte Santiago

Advisors & Mentors:
Dr. Kenton Ross (NASA Langley Research Center)
Dr. Venkataraman Lakshmi (University of Virginia)

Project Overview

Project Synopsis: In partnership with the Municipio Autonómo de Toa Baja, ResilientSEE, and the Massachusetts Institute of Technology (MIT) Urban Risk Lab, this project utilized datasets representing the topographic and demographic characteristics of Toa Baja, Puerto Rico to generate a spatial flood risk and susceptibility model. The outputs of this project serve to educate the public on flood risk and provide the Toa Baja Municipality with data-driven evidence to inform disaster mitigation efforts. Datasets were sourced in part from the National Oceanic and Atmospheric Administration (NOAA), the National Landcover Database (NLCD), and the European Space Agency's (ESA) Sentinel-2 MSI. Additionally, Sentinel-1 C-SAR data were utilized to visualize flood inundation from hurricane Maria in September of 2017.

Abstract:
Toa Baja, located just west of San Juan in Puerto Rico, is known as "the underwater city" due to its propensity to flood. The city contains the mouth of the island's longest river, Río de la Plata, which drains into the Atlantic Ocean on the northern edge of the municipality. Proximity to these major water features and the flat, low terrain contribute to the flood-prone nature of the area. During tropical storm events, such as Hurricane Maria in 2017, Toa Baja experienced inundation of up to 20 feet. Changes in the global climate system are causing more intense and frequent tropical storms, making places like Toa Baja subject to irreparable damage. This NASA DEVELOP project collaborated with the Municipio Autonómo de Toa Baja, ResilientSEE, and the Massachusetts Institute of Technology Urban Risk Lab to supplement recent 2018 Federal Emergency Management Agency Hydraulic Engineering Centers-River Analysis System flood maps, which designated 63% of the area as a flood plain. The analysis provides a high-resolution interpretation of flood susceptibility using a variety of factors that collectively influence the likelihood of flooding. Sentinel-1 C-Band Synthetic Aperture Radar (C-SAR) data processed with Google Earth Engine scripting identified historical inundation and was used for validation purposes. Socioeconomic factors were combined with the inundation layer producing a final risk output. These outputs will improve public understanding of exposure to flood risk in Toa Baja and provide scientific evidence for flood mitigation advocacy.

Keywords:
ESA, NASA, Google Earth Engine, ArcGIS Pro, SAR, flood risk, flood susceptibility, tropical storms

National Application Areas Addressed: Disasters, Water Resources, Urban Development
Study Location: Toa Baja, Puerto Rico
Study Period: January 2000 to January 2020

Community Concerns:

- During tropical storm events, such as Hurricane Maria, the city is inundated by floodwater from both storm surge of coastal areas and riverine flooding largely influenced by the Rio de la Plata.
- In the 2017 hurricane season, over 14,000 homes were flooded and damages amounted to over $1.3 billion, limiting the service provision capacity of the municipality.
- The government has formerly used 2009 FEMA Flood Insurance Rate Maps (FIRM) for risk analysis and 2018 FEMA Hydrologic Engineering Center's River Analysis System (HEC-RAS) maps to interpret flood susceptibility in the region. HEC-RAS designates 63% of Toa Baja's total area as floodplain.

Project Objectives:

- Utilize Earth observation products to model flood susceptibility
- Pair flood susceptibility with human vulnerabilities to gauge relative flood risk
- Compare the team's measure of flood susceptibility with FEMA flood susceptibility maps
- Provide a flood risk map to educate the public on localized flood risk

Partner Overview

Partner Organizations:

Organization	POC (Name, Position/Title)	Partner Type	Boundary Org?
Municipio Autonómo de Toa Baja	Desiree Pearlman, Executive Assistant, Division of Economic Development and Tourism; Edgar Gomez, Community Outreach Director; Orlando Santaella, Municipality GIS Expert	End User	Yes
ResilientSEE	Yanel de Angel, Project Manager and Principal at Perkins & Will	End User	Yes
Massachusetts Institute of Technology, Urban Risk Lab	Larisa Ovalles, Research Associate: Latin America, Prototyping, Design, and Urbanism	Collaborator	No

Decision-Making Practices & Policies:

Decisions for future infrastructure and emergency planning in the municipality of Toa Baja are made by the Mayor, based on available data from a team of professionals and associated resources. Remote sensing and NASA Earth observation data and analyses are not integrated into their current decision-making process. The 2009 and 2019 FEMA FIRM and HEC-RAS flood hazard maps are the municipality's main source for interpreting flood risk in the area. Following Hurricane Maria, the municipality found the resolution of these maps to be too coarse.

Project Benefit to End User:

The NASA DEVELOP project improves upon the level of detail provided by previously used maps. The Static Flood Susceptibility map utilizes parameters such as elevation, soil infiltration rate, and land cover to model the areas most vulnerable during flood events in Toa Baja. The Static Flood Risk map includes infrastructure density and population density to inform planning decisions with respect to damages to life and property. Our team compared the flood susceptibility map to the available FEMA HEC-RAS maps that delineate flood susceptible areas. The municipality will continue to use the flood risk maps to enhance their community outreach and public understanding of areas most vulnerable to flooding. The municipality will also be able to utilize the ArcGIS Story Map for effective public outreach about flood risk.

Earth Observations & End Products Overview

Earth Observations:

Platform & Sensor	Parameters	Use
Sentinel-1 C-SAR	Land cover	Sentinel-1 SAR data were used to map historical flood extent and were included in the interactive flood mapping tool to map recent flood events.
Sentinel-2 MSI	Surface reflectance	Sentinel-2 images were used to map the historical flood extent from 2015 to 2020. The imagery was ingested in the flood mapping tool and processed using a flood extent algorithm to map the most recent flood events.
Landsat 8 OLI	Surface reflectance	Landsat 8 OLI images were evaluated for use in mapping historical flood extent from 2013 to 2020, primarily image captures masked longstanding water bodies
Landsat 7 ETM+	Surface reflectance	Landsat 7 ETM+ images were evaluated for use in mapping historical flood extent from 2013 to 2020.

Ancillary Datasets:

- National Oceanic and Atmospheric Administration LiDAR Digital Elevation Model of Puerto Rico (2015 to 2017) – Integrated with susceptibility and risk map
- USGS National Land Cover Database – Integrated with static vulnerability map
- OpenStreetMap Road Vectors – Incorporated in susceptibility map
- WorldPop Puerto Rico raster dataset – Estimated population density for risk map
- Municipio Autonómo de Toa Baja Informal Housing Settlement Blueprints – Provide the location of informal housing settlements in risk mapping
- Municipio Autonómo de Toa Baja Drainage Infrastructure – Integrated with susceptibility and risk map

Software & Scripting:

- Google Earth Engine – Processing of Sentinel-1 data using an open source script
- Esri ArcGIS Pro 2.3.0 – Generation of susceptibility map and risk maps
- R – Flood susceptibility validation through comparison of histogram of raster values

End Products:

End Products	Earth Observations Used	Partner Benefit & Use	Software Release Category
Static Flood Susceptibility Map	Sentinel-1 C-SAR Sentinel-2 MSI Landsat 8 OLI Landsat 7 ETM+	The Static Flood Susceptibility Map will help partners identify areas that may be in need of prioritization during flooding events.	N/A
Static Flood Risk Map	Sentinel-1 C-SAR	The Static Flood Risk Map incorporates additional information such as population and informal settlement locations to provide flood risk information for the region.	N/A
Toa Baja Flood Risk ArcGIS StoryMap	Sentinel-1 C-SAR Sentinel-2 MSI Landsat 8 OLI	The ArcGIS StoryMap will allow our partners to begin their outreach and education efforts immediately after the term. This will provide a simplistic explanation of the results relative to the technical paper and is suitable for a general audience.	N/A

Project Handoff Package

Transition Plan: A handoff took place in week 10 of the term. The partners were presented with the final products of this analysis remotely via video call. Static maps, an interactive story map, and an accuracy assessment were all provided to the municipality for use internally, particularly to inform them of the comparison with the 2018 FEMA HEC-RAS flood maps which were previously used for flood mitigation efforts. The interactive story map will serve to disseminate the results to the public.

Team POC: Nara McCray, nara.mccray@gmail.com
Partner POC: Yanel De Angel, Yanel.deAngel@perkinswill.com

Handoff Package:

- Static Flood Susceptibility Map
- Static Flood Risk Map
- Toa Baja Flood Risk ArcGIS StoryMap

References

Urban Land Institute (2018, December). Toa Baja Puerto Rico, building physical, economic, and social resilience. https://americas.uli.org/wp-content/uploads/sites/2/ULI-Documents/ULI-ASP_Report_ToaBaja_PR_Final.pdf

Cian, F., Marconcini, M., & Ceccato, P. (2018). Normalized Difference Flood Index for rapid flood mapping: Taking advantage of EO big data. *Remote Sensing of Environment, 209*, 712-730. Retrieved from https://www.sciencedirect.com/science/article/pii/S0034425718300993?via%3Dihub

In Detail: Recommended Practice: Flood Mapping and Damage Assessment using Sentinel-1 SAR data in Google Earth Engine (2019) Retrieved from http://www.un-spider.org/advisory-support/recommended-practices/recommended-practice-google-earth-engine-flood-mapping/in-detail

Roopnarine, R., Opadeyi, J., Eudoxie, G., Thong, G. & Edwards, E (2018). GIS-based flood susceptibility and risk mapping Trinidad using weight factor modeling. *Caribbean Journal of Earth Science, 49*, 1-9. Geological Society of Jamaica. Retrieved from

https://www.researchgate.net/publication/326925603_GIS-based_Flood_Susceptibility_and_Risk_Mapping_Trinidad_Using_Weight_Factor_Modeling

DeVries, B., Huang, C., Armston, J., Huang. W., Jones, J., & Lange, M. (2020). Rapid and robust monitoring of flood events using Sentinel-1 and Landsat data on the Google Earth Engine. *Remote Sensing of Environment, 240*. Retrieved from https://www.sciencedirect.com/science/article/pii/S003442572030033X?dgcid=author#f0005

Stevens, F. R., Gaughan, A. E., Linard, C. & Tatem, A. J. (2015). Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data. PLoS ONE. https://doi.org/10.1371/journal.pone.0107042