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A Software System for Multi-Hazard Assessment of Vulnerability, Risks and Potential for Economic Loss due to Weather and Climate Variability

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Abstract

Climate and weather related disasters are some of the greatest threats to the global economy. These hazardous events cause negative economic outcomes including damaged infrastructure, business disruption, and public health issues; they can be induced by human practices and natural climate variability. Research in the way of geographical impact of these environmental catastrophes is fairly substantial. However, research is still needed to fiscally account for impending severe natural hazard circumstances. Research and tools focusing on the methodology for assessing and estimating the potential economic loss from natural disasters is currently lacking. Thus, the purpose of this case study is to present a methodology in creating such tools for analysis. Using the theory behind the structure of geographic information systems (GIS), spatially enabled programming languages such as Python and Structured Query Language (SQL) can be utilized to create a multi-hazard assessment of economic loss on the county level. The weather and climatic phenomena modeled in this study are wildfires, landslides, and different flooding scenarios (e.g.) flooding caused by precipitation and coastal flooding brought on by storm surges). Given data that include property information, historic climate data and future climate model data, GIS processes are implemented to spatially join these hazard data on to the property level data and extract information about the infrastructure. Once the impacted infrastructure data is created, an assessment of loss can be made by taking summary statistics of the property values. These summary statistics show the total direct economic impact that multiple hazards on infrastructure in United States Dollar (USD) amount. These types of model outputs can be used in impact assessment and resilience planning efforts on the local, state, and federal scales.

Keywords: spatial programming, automated systems, catastrophe modeling

1. Introduction

In recent years, the United States has created policy and research to push preparedness for weather and climate related impacts. In May of 2014 the Third National Climate Assessment (NCA3) was released to the public via the White House[1]. The NCA3 breaks down the current knowledge regarding climate change and the issues that we are facing because of its increasing severity. Within the research needs of the NCA3 there were two bullet points that justified and guided this research. The first point being "to expand climate impacts and analysis to focus on understudied but significant economic sectors."[2] The second point being to "develop measurement tools and valuation methods for weather and climate related impacts."[3] An additional example of a White House initiative to better anticipate the effects of climate change and weather related impacts is the president's Climate Action Plan[4]. One of the goals within the action plan is to "prepare communities for the impacts of climate change."[5] These recent federal goals intersect and provide the backing needed to create tools that assess multi-hazard environmental threats to public and private assets. The outputs of the software employed in this study fulfill those needs and should be used to educate and prepare communities for the potential hazards associated with climate change they may face. The software tools developed in this study should be used to guide the public sector's resilience frameworks and processes. Likewise, this software can be used in the private sector within industries such as insurance real estate and finance. Since the data that the software consumes is available in almost all U.S. counties, this product could be used in synchrony across the country to produce a more accurate national climate resilience plan.

2. Data and Model Framework

2.1 Threat-Asset Data

There are two types of data that this model consumes. The first being environmental hazard data which is also known as threat data. The threat data then has to be cleaned, re-projected and reformatted into a spatial SQL format using the Geospatial Data Analysis Library (GDAL). Once the threat data has been processed, the second type of data that is consumed into the database management system is the asset data. This data also has to be cleaned, re-projected, and reformatted. At this point the threat and asset data are in the same relational database environment and further spatial analysis can be performed to create the asset-threat pair outputs. The asset-threat pairs that are created within this model are flooding, landslides, and wildfires paired to assets such as property parcels, buildings, and census information. These created asset-threat pairs define pure exposure of assets to environmental hazards. Since the asset-threat pair data are in a relational database it becomes quite easy for these pairs to be processed and filter to extract more information about the data.

The sources of the data range from a variety of governmental organizations on the federal, state, and local levels. Organizations such as the Federal Emergency Management Agency, North Carolina Department of Environmental Quality, and County GIS and Tax Departments. Given that this data is created through a public institution and because of the Freedom of Information Act all of this data is free. This allows for this software to consume data across many counties throughout the United States.

2.2 Dynamic Geospatial Model

Since the data is available practically everywhere in the United States this model has been constructed in an abstract way to be applied to any county. As seen in Figure 1 and Figure 2 the model takes in data into the GDAL command line script given the difference between the two data formats. GDAL then re-projects, and reformats the data into a PostGIS enabled PostgreSQL database where it becomes spatially indexed. Once spatially indexed, the data is in a SQL format that can be queried. PostGIS is an extension onto PostgreSQL that allows for spatial queries to be performed just like a geographic information system, such as ESRI's ArcMap. Using the PostGIS extension, spatial queries are then preformed (e.g. spatial intersection) on the asset and threat data to create the asset-threat pairs. Once the asset-threat pairs have been created they are grouped by a unique identification number and more filters are applied that extract out and apply parameters of exposure and adaptive capacity to the pairs. From exposure, the outputs of total losses are taken. Once the variables exposure and adaptive capacity are derived from the asset-threat pair's attributes the vulnerability of the asset-threat pair can be assessed using a modified equation (1) from Hutchins 2016[6].

$$\text{Vulnerability} = \text{Exposure} - \text{Adaptive Capacity} \tag{1}$$

Once vulnerability is assessed, the outputs of the geometries from the tables are taken and consumed into a geospatial web viewer that is written in JavaScript. This streamlines the entire process of taking raw data from a public source, creating information out of it, using spatial analytics, and then producing a data visualization for the user. Figure 1 is a flow chart of the system that is used to make up the automated software system.

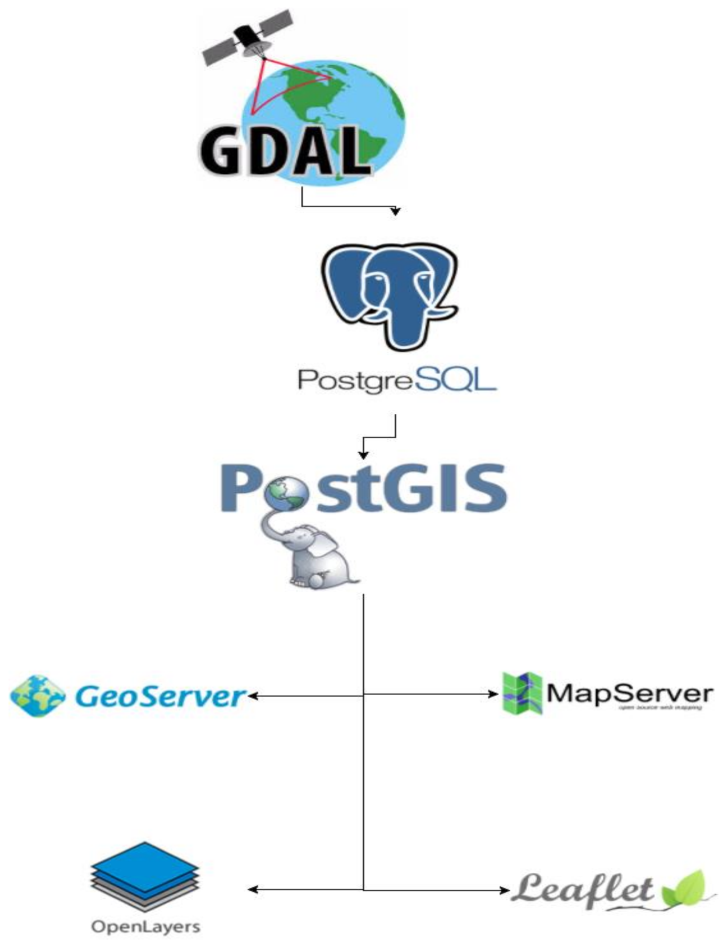

Figure 1. Software stack and flow that is used within this software system.

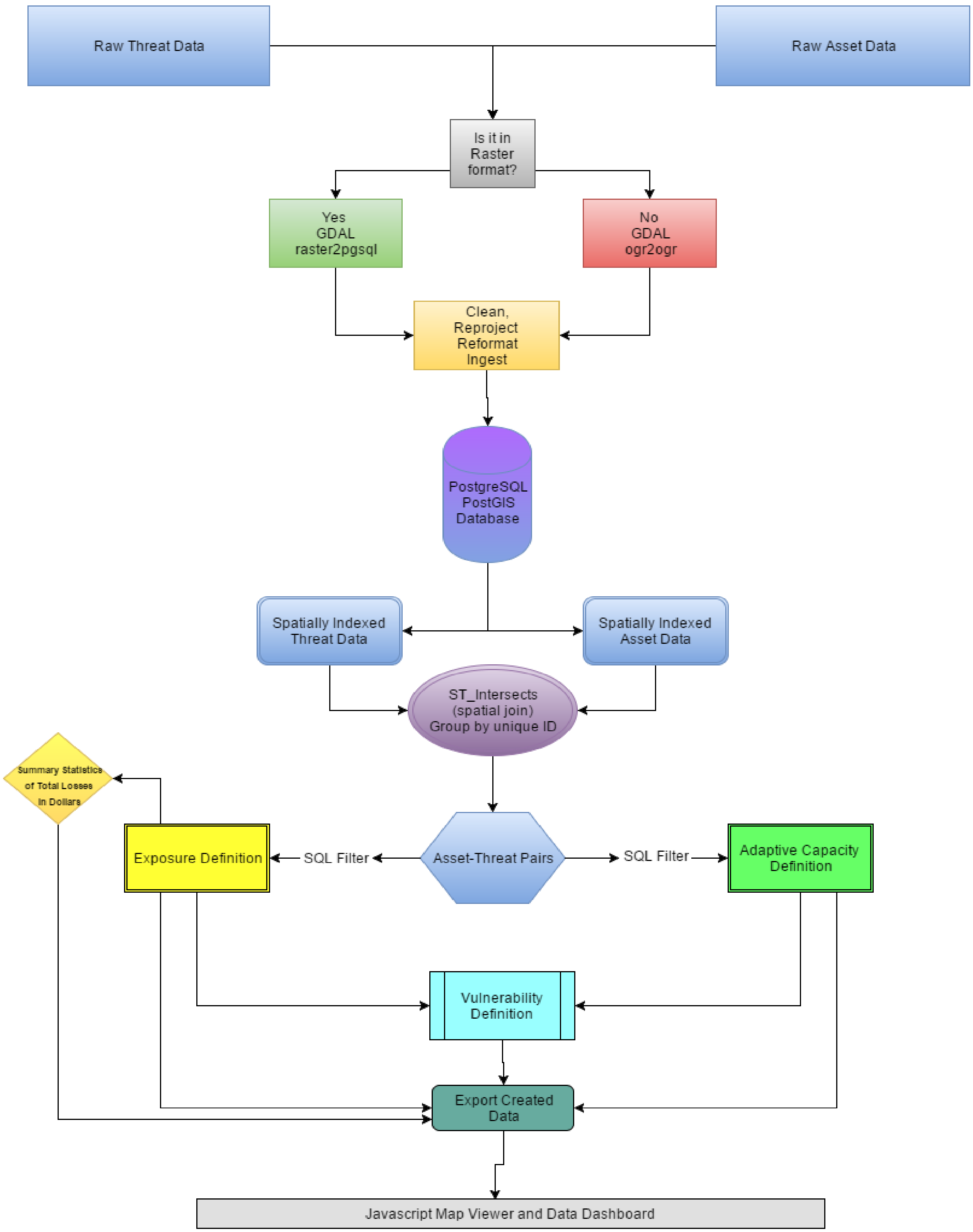

Figure 2. Flow chart that shows the work flow that the software takes to create the multi-hazard assessment of threats to assets.

3. Results

The outputs are shown in Table 1 and Table 2 for two different asset-threat pair scenarios. Table 1 shows the amount of total losses caused by 100 and 500 year flooding threats to property parcel assets. These are computed by taking the summation of the total appraisal values after the flooding scenarios have been spatially joined to the property parcel. A noticeable trend drawn from Table 1 is that residential parcels are impacted the greatest. This could be due to the fact that residential parcels are typically the most prevalent kind of parcel in counties. Another point drawn from Table 1 is the sizeable impact of 4 billion USD in potential losses in the event of a 500-year flooding threat. Table 2 shows the amount of total losses caused by landslide threats. The key issues to take away from the analysis in Table 2 are that 26 thousand parcels exposed to the landslide debris flow pathway total up to potential losses over 8.5 billion USD in assets. That many parcels is almost a quarter the amount of parcels within Buncombe County, the area of study.

The model outputs are geospatial so they are inherently a visualization. These visualization are then imported into a JavaScript library that produces an interactive web map. Figures 1 and 2 below are examples of the asset-threats outputs being consumed into a JavaScript library and displayed into such web map viewer. Figure 2 is an example of flooding scenario threat which is colored in the blue being spatially joined to the parcels assets which is in the grey. While Figure 3 is an example of a landside scenario threat that is colored in green being spatially joined to the parcels assets that is colored yellow. The key take away from these figures is the amount of model error within the outputs. Even if one color slightly touches the other color it counted within the output statistics. This means that there is an overestimation of the amount of total losses.

Table 1. Model output of summary statistics of total losses by class type exposed to 100 and 500 year flooding scenarios for Buncombe County, North Carolina.

Class Type	Total Losses in 100yr Floodplain ($)	Parcels in 100yr Floodplain (#)	Total Losses in 500yr Floodplain ($)	Parcels in 500yr Floodplain (#)
Community Services	1,090,014,100	218	1,219,261,200	235
Residential	955,686,300	4727	1,047,948,300	5314
Vacant Land	173,284,900	2052	182,583,400	2192
Unclassified	157,531,800	12	157,531,800	12
Industrial	120,490,700	50	125,637,000	52
Commercial	1,107,031,300	851	1,184,967,700	941
Recreation	122,427,500	15	122,427,500	15
State Assessed/Utilities	100,611,100	57	106,046,600	63
TOTAL	3,827,077,700	7982	4,146,403,500	8824

Table 2. Model output of summary statistics of total losses by class type exposed to 100 and 500 year flooding scenarios for Buncombe County, North Carolina.

Class Type	Total losses ($)	Total Parcels (#)
Community Services	1,849,473,700	343
Residential	3,594,594,700	15216
Vacant Land	736,472,300	8935
Unclassified	153,771,900	16
Industrial	159,753,300	60
Commercial	1,880,450,900	1059
Recreation	130,665,800	15
State Assessed/Utilities	100,016,800	81
TOTAL	8,605,199,400	25725

Figure 3. Screenshot of the interactive web tool used for climate resilience planning showing the asset-threat pair of flooding to property parcel

Figure 4. Screenshot of the interactive web tool used for climate resilience planning showing the asset-threat pair of landslide to property parcel

4. Conclusion and Future Work

This software was created to fulfill the research needs that were stated within the Third National Climate Assessment (NCA3) and the president's Climate Action Plan**.** Understanding the location of multiple natural hazard exposure areas and vulnerabilities bridges the gap for public and private entities to be able to investigate options for developing plans and building practices that take into account weather and climate resilience. This automated multi-hazard environmental model outputs asset exposure, vulnerabilities, and risk analyses that are vital to planning efforts of local administrators, federal governments, and politicians, as well as industries such as real estate, insurance, finance, and local and state governments.

An example of usage for this model could be for an insurance underwriter who determines annual premiums for policyholders. A property insurance underwriter could first use this software to assess the potential liabilities of a policyholder's assets given the location of the asset in the exposure model. A liability would be if a building or property parcel that was spatially exposed, vulnerable, or at risk to a natural hazard area. If the policyholder's building or parcel is liable to a hazardous area, the underwriter may assume risk. From there, the underwriter can use the software's summary statistics to extrapolate the amount of potential total losses incurred if a hazardous event were to occur. From there the underwriter would have substantial, usable evidence for creating premiums that will generate profit for the insurance broker and properly insure the policy-holders assets in the event of a natural disaster.

Some of the future steps to scale up this model is to include a more detailed damage framework that involves a building classification system that assesses the specific material a building is constructed of. This will allow for a true assessment of risk. Some additional future research could also include moving from a static model that uses climatological data to a live threat analysis of short to medium range weather related losses. That being said, the spatial intersections that define the exposure to the asset-threat pairs also need to become more precise to assess the true risk of the situation.

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