

Assessing the Potential Flood Hazard Exposure, Vulnerability, and Impacts: The Case of St. James Parish, Jamaica

Ricordo McKenzie Tekleab Gala*
Department of Geography, College of Arts and Sciences, Chicago State University, Street, 9501 S King Dr, Chicago, IL 60628, USA.
*Corresponding author(s). E-mail(s): tgala@csu.edu.

Abstract
While the region of the Caribbean islands is the least contributor to global greenhouse gases (GHGs), it is extremely vulnerable to the negative impacts of climate change, such as but not limited to flooding from sea-level rise, increased storm intensity, and tropical cyclones. Floods are already major hazards causing large-scale socio-economic and environmental impacts in Jamaica. This study used the major factor affecting flood hazards of Montego Bay and surrounding areas of St. James Parish, Jamaica to estimate the chances of experiencing flood hazards in a given year. Accordingly, significantly populated, developed, and agricultural areas are exposed or vulnerable to high and very risky flood hazards. Therefore, given the city's relative importance to connect Jamaica to the regional economy, although curbing the global GHGs emission is beyond reach, policies of sustainable urban development, and citizens' environmental responsibilities could help the situation
Keywords: Flood hazards, Risk Assessment, Analytical hierarchy process, multicriteria analysis, St. James Parish, Jamaica
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1. Introduction

Climate and environmental changes in the Caribbean region are exposing Jamaica to the negative impacts of heightened flooding frequency and intensity (Wilson et al., 2014; Nandi et al., 2016). Flood in the region occurs as a hydrological phenomenon when the significant surge in the runoff water overwhelms and overflows a drain, river, or stream, usually after heavy rainfall, tropical storms, and cyclones. It also occurs when sea-level rise and high tides surge overflow shore and inundate the low-lying coastal area. As a natural disaster, flooding causes widespread destruction and catastrophic damages to the economy, humans, domestic animals, and properties in the region (Nandi et al., 2016; Smith, & Mandal, n.d.). Storm events between 2002-2007, resulted in the deaths of 60 civilians and damaged property worth USD 1.04 billion in Jamaica (Fontes de Meira, & Phillips,2019). Additionally, recorded 198 flood events between 1990-2017, caused damages worth US585 million in roads and bridges, US351 million in housing, US235 million in agricultural croplands, and US48 million in electrical installations in Jamaica (United Nations International Strategy for Disaster Reduction (UNISDR), (2015). the increasing conversion of natural ground into built-up areas, modification of the river channel by various landfills, and heavy rainfall causing an intense rush of water gushing down gullies, and rivers to flood the low laying area.

Consequently, the goal and objectives of this study are to use the Geographic Information Systems (GIS)-based Multicriteria Analysis (MCA) to investigate areas of flood hazard in the Port City of Montego Bay, and surrounding Saint James Parish, Jamaica. It is also to assess the risk associated with the estimated flood hazards. Areas of flood hazards are often estimated in terms of the likelihood of the 100-year floodplain inundation, areas that have a 1% chance of experiencing flood hazards in a given year. Several studies have been devoted to flood hazard mapping, forecasting, and risk assessment in Jamaica (Glas et al., 2014; Nandi et al., 2016; Glas et al, 2017; McKenzie, & Gala, 2022; McKenzie, 2022; Bouaakkaz et al., 2023). However, although the studies were consequential, they were not specific to St. James Parish. Besides, the utility of the Analytical Hierarchy Process (AHP) of Multi-criterial Analysis (MCA) presents a reliable and pragmatic approach for assessing areas prone to the likelihood of 100-year flood hazards and the vulnerability of properties and life to flood hazards (Siddayao et al., 2014; Swain et al., 2020).

2. The Port City of Montego Bay, and surrounding Saint James Parish

Saint James Parish is one of the 14 Parishes of Jamaica and is located in the northwest of the country (Figure 1). The Port City of Montego Bay is the largest in the parish and is also regarded as the tourist capital of the Island. Consequently, is home to some of the most beautiful beaches and resorts on the Island and the busiest airport in the English-speaking Caribbean. The parish receives a higher rate of precipitations, especially, on the mountainous highlands. Additionally, it is exposed to recurrent storm surges from hurricanes as an island that is found at the heart of the Atlantic Ocean hurricane belt. Both topographies draining excess runoff down and the storm surge expose the low-lying settlement areas of the city and the parish to extensive risks of flood hazards.

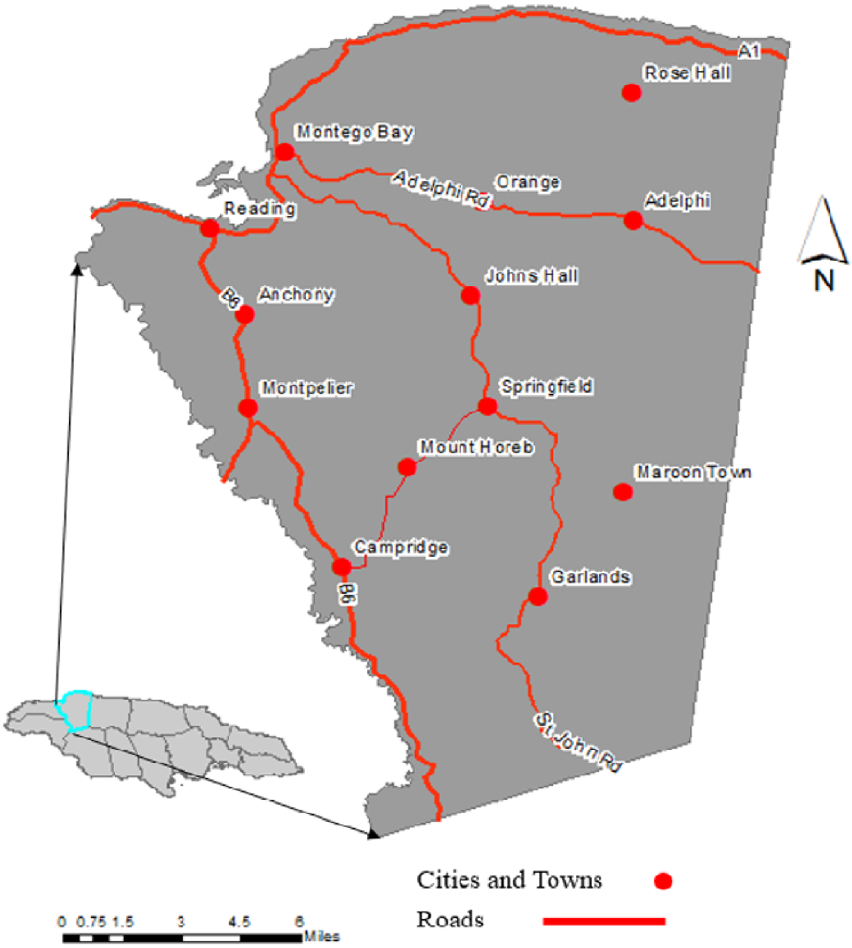


Figure 1: Study Area

3. Research Data

Several studies have established factors considered for estimating the 100-year flood hazard areas (Wondim, 2016; Gebeyehu et al., 2018). These are land cover, soil, drainage density, elevation, slope, and rainfall. The elevation influences the hydrologic balance and was obtained from the Digital elevation model (DEM) of the region, which was acquired from the national map viewer (https://apps.nationalmap.gov/viewer/) of the United States Geological Survey (USGS). The DEM is also used for deriving slope gradients and drainage density. The Slope gradient and drainage density affect the likelihood of flood hazard occurrences through their impacts on the magnitude and volume of surface run-off and the sediment load.

Land cover data influences both the likelihood and impacts of flooding and it is obtained from classified images of the Landsat Thematic Mapper (TM) satellite acquired from the Earth Explorer (https://earthexplorer.usgs.gov/). The quantity of surface runoff to cause flooding is directly linked with the duration and intensity of rainfall. The 30 years of rainfall was secondary data obtained from Jamaica Climate after being scanned, georeferenced and digitized. Finally, the rainfall-runoff partitions, which affect flooding are also influenced by soil particle distribution. The soil particle distribution regulates soil permeability, water holding capacity, and moisture content and was obtained from ArcGIS online.

Once, the 100-year flood hazard areas were modeled, the risk assessment for the flood hazards was estimated. These are modeled based on flood hazard areas, land use, and population data. The land use data highlighted the urban population areas, agricultural lands, and infrastructural developments exposed to modeled flood hazards, while population data is to depict population settlements along floodplains and areas prone to flood hazards. While the population data were obtained from the Statistical Institute of Jamaica (STATIN), the land use data were obtained from ArcGIS online (https://www.arcgis.com/home/item.html?id=4c219ea3ba924c319774a71aaf2a4af3).

4. Methods

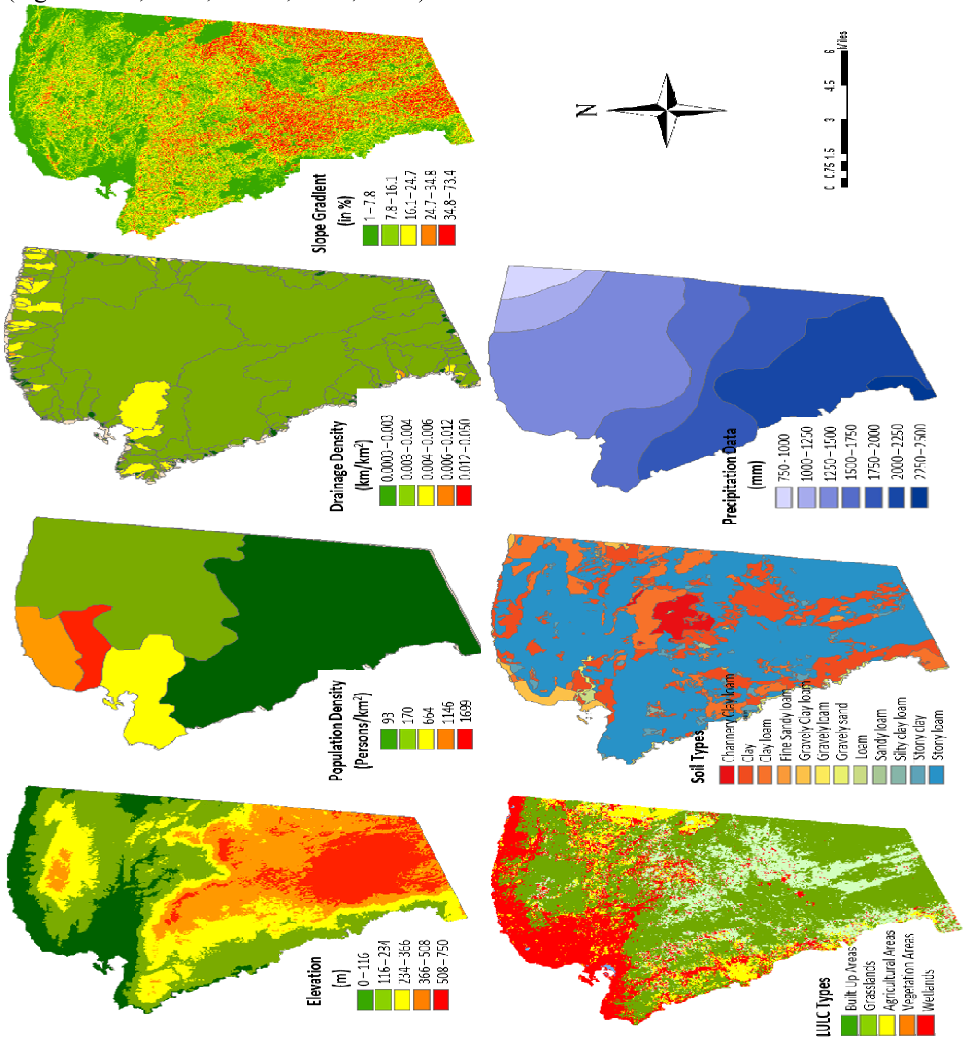
The Analytical Hierarchy Process (AHP) is a multicriteria decision support system used to the assessment of potential Flood Hazard exposure and vulnerability for St. James Parish, Jamaica. AHP is a five-stage decision assistance tool that uses a hierarchical structure of factors (criteria), to address extremely challenging decision-making processes (Hamidah et al., 2020; Mengisti, et al., 2021). These are: defining the problem, identifying and defining the factors that influence or aid decision making, establishing priority, ranking and scaling the factors, Check Consistency, and applying the decision rule (i.e. Weighted Sum Model (WSM)). The first two stages of defining the problem (i.e., assessing the potential flood hazard and risks) and factors affecting have been established.

4.1 Prioritization of the factors

Literature, local and expert knowledge supported the prioritization conducted for the factors affecting flood hazards in the study area (Gala, & Young, 2015; Wondim, 2016; Gebeyehu et al., 2018; Ogato et al., 2020). Accordingly, elevation and slope gradient as equally prioritized on top, followed by rainfall, drainage density, LULC types, and finally soil types data the least (Figure 2; Table 1).

4.2 Scaling of the factors

The factors affecting flood hazards are scaled using Saaty's 9-point scale. It is done in preparation for the AHP comparison matrix to generate weights for the factor (Table 1). The weight for the flood hazard factors, according to the 9-point AHP factors' pairwise comparison formulated by Saaty (2008), is such that elevation and slope gradient are weighed equally and highly important as floods often occur on low-lying and relatively flat areas as compared with those occurring on hills as well as hilly landscapes. Precipitation and drainage density follow as these factors are generating runoff water, which causes flooding. Relatively, soil types and LULC types weighed the least. The results of the scaling and the pairwise comparison thereof corroborate other findings (Ogato et al., 2020; Swain, et al., 2020).



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4.3 Validation

The robustness of prioritizations and the integrity of the weight generator and the weights produced thereof are performed by an online Automated AHP Matrix (Goepel, 2018) and Consistency Ratio (CR). CR is given by:

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$$CR = \frac{CI}{RI}$$

Where CI represents the consistency index and RI is the random index. It is the tabulated indices whose values vary according to the number of criteria involved in the decision rule.

$$\mathrm{CI} = {(\lambda_{maz} - n)}/{(n - 1)}$$

Where λmax is the sum of the product of the column of the comparison matric and the corresponding weight, whereas n is the factors considered. The decision rule is robust if the CR is ≤ 0.1 and CR is ≤ 10% (Ogato et al., 2020). Accordingly,

$$\mathrm{CI} = {(6.44 - 6)}/{(6 - 1)} = 0.088$$

$\mathrm{CI} = 0.08$ is less than the threshold CI is ≤ 0.1, showing that the pair-wise matrix prioritization, ranking, and scaling of the flood hazards factors for St. James Parish, Jamaica is robust. The RI (Random Index) = the 6 flood hazard factors for which the pairwise comparison made is 1.24.

$$CR = \frac{0.08}{1.24} = 0.07$$

$\mathrm{CR} = 0.07,$ is less than the threshold CR is ≤ 0.1, again showing that the pair-wise matrix and weight calculated thereof for the flood hazard factors for St. James Parish, Jamaica is robust.

4.4 Decision rule: Weighted Sum Model

The final decision on the varying probability of flood hazard occurrences and associated risk assessment was determined by applying the decision rule, i.e., the weighted sum model, (WSM). It is given by

$$V = \sum_j W_j R_{ij}$$

Where: V is the total score of an area with regards to the probability to flood hazards and risks, w is a relative weight of the j-th factors and Rij is the indexed factors into a ranking scale.

The probability of Flood hazard occurrence in St. James Parish, Jamaica is

V = 0.35 [Slope] + 0.35 [Elevation] + 0.14 [Precipitation] + 0.08 [Drainage Density] + 0.05 [LULC Types] + 0.04 [Soil Types].

Table 1: Parameters (elements) of the flood factors and associated ranks in the order of their relative importance to flood hazard occurrences

Factors	Weight	Result of classification based on Natural Break	Ranking	Hazard Levels
Drainage Density (km/km2)	0.08	0.00 - 0.12	1	Very Low
		0.12 - 0.31	2	Low
		0.31 - 0.41	3	Moderate
		0.41 - 0.48	4	High
		0.48 - 0.52	5	Very High
Elevation Data (m)	0.35	0.00 - 116	1	Very High
		116 - 234	2	High
		234 - 366	3	Moderate
		366 - 508	4	Low
		508 - 750	5	Very Low
LULC Types	0.05	Vegetation Areas	1	Very Low
		Grasslands (Field)	2	Low
		Agricultural Areas	3	Moderate
		Built-Up Areas	4	High
		Wetlands	5	Very High
Precipitation (mm)	0.14	750 - 1000	1	Very Low
		1000 - 1250	2	Low
		1250 - 1750	3	Moderate
		1750 - 2000	4	High
		2000 - 2500	5	Very High

Factors	Weight	Result of classification based on Natural Break	Ranking	Hazard Levels
Slope Gradient (%)	0.35	0 - 7.78	1	Very High
		7.78 - 16.11	2	High
		16.11 - 24.75	3	Moderate
		24.75 - 34.82	4	Low
		34.82- 73.38	5	Very Low
Soil Types (Texture)	0.04	Gravely sand, Stony loam	1	Very Low
		Gravely loam, Sandy loam	2	Low
		Fine sandy loam, Loam	3	Moderate
		Silty clay loam	4	High
		Channery clay loam, Gravely clay loam, Stony Clay, Clay, Clay loam	5	Very High

5. Results

Areas exposed to probabilities of flooding hazards were modeled such that 44.5% of the study area experiences a very low and low probability of flood hazard occurrence, while 35.6% of the study endures a high and very high probability of flood hazard occurrence (Figure 3a). Additionally, the socio-economic exposure and vulnerability to the risk of heightened flood hazards were estimated such that 51% of the study area experiences a very low and low risk of exposure or vulnerability to flood hazards, while 25% experiences high and very high risks (Figure 3b). The majority (76%) of these high exposure and vulnerability risk areas are built up (i.e., homes, properties, and infrastructures), followed by agricultural croplands (24%), indicating the dire socio-economic impact of flooding in the region ((Figure 3c).

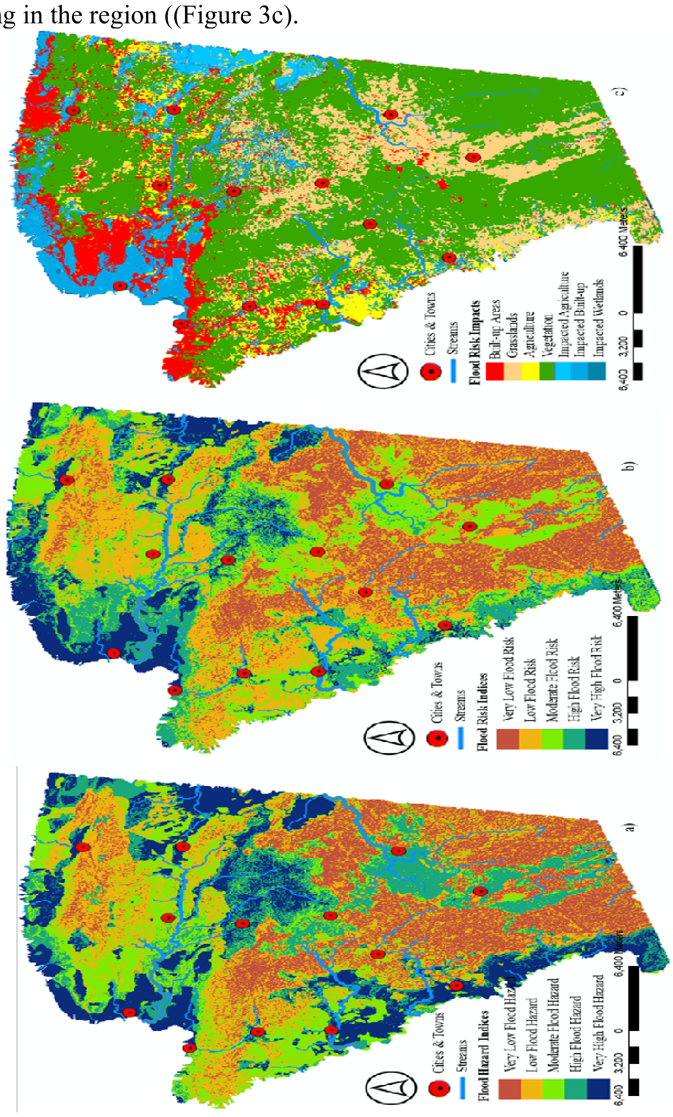

Figure 3: Maps showing a) areas exposed to varying probabilities of flooding hazards; b) socio-economic exposure and vulnerability to the heightened risk of flood hazards; and c) impacts in Montego Bay and surrounding areas of St. James Parish of Jamaica.

6. Discussions and Conclusion

This study has revealed the unique likelihood of the occurrence of devastating flood hazards in Montego Bay and surrounding areas of St. James Parish, Jamaica. In general, inadequate environmental responsibilities, unsustainable and unplanned urban growth, deforestation, and reckless LULC conversions are to blame. Therefore, appropriate solid waste management and sanitation practices, centralized garbage collection and landfill mechanisms, as well as public education to enforce citizens' environmental responsibilities are advised. Additionally, re-engineering the gully structure to clean and free garbage and debris is also recommended. Sustainable urban development policies of incorporating green and open space areas, relocating and discontinuing development along floodplains and vulnerable areas, road engineering with the use of permeable bedding materials; roadside storm drainage and gutters to collect, divert and remove rainwater from causing flash flooding are recommended.

These findings are based on the use of a rather simple and reliable AHP model for flood hazard analysis and risk assessment, and high-resolution imagery for ground truthing; which are a pragmatic response to the extent of data availability. Future studies aimed at deploying wide ranges of mechanistic hydraulic modeling and simulations that utilize more complex data, and extensive technical capabilities would likely improve the results. Caribbean islands are often connected to the global economy through tourism and the proximity to North America's vast wealth and its natural beauty will continue making St. James Parish and its port city of Montego Bay an ideal destination for tourism, warranting the investments.

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