INTEGRATED FLOOD AND SOCIO-ENVIRONMENTAL RISK ANALYSIS FOR PRIORITIZING ABC ACTIVITIES

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1. Background and Introduction

The need to accelerated bridge construction (ABC) activities due to flooding (e.g., accelerated bridge upgrade prior to flood events and accelerated bridge repair after flood events) has complex interdependencies with many physical, social, and environmental factors in urban areas. The interdependencies get exacerbated in coastal areas, such as southeast Florida, because of the pronounced effects of climate change such as extreme storm events and sea level rise (SLR) impacts on surface and ground waters. According to the National Oceanic and Atmospheric Administration (NOAA) reports, 612% increase in flooding in the United States has been reported from 1960s [NOAA 2015]. Flood-related factors can contribute to bridge scour, the biggest cause of bridge failure in the United States (52% of cases) [Cook et al. 2015]. Besides, depending on bridge location, rainfall patterns are highly functional in hydraulic failure of bridges [Kandel et al. 2019].

Because of the limited available budget for accelerated upgrade/repair processes, a comprehensive decision support tool is needed to prioritize bridges in terms of the vulnerability of bridge location and risk level of each bridge to support Department of Transportation (DOT) decision makers in project selection. To refine funds allocation for the ABC there is a need for a simplified, yet accurate, methodology to estimate bridge vulnerability to several interdisciplinary factors. The methodology should practice existing data and display important variables to assess the vulnerability of urban areas and risk of bridges against urban flooding considering various flood-related and socio-environmental factors. Considering factors such as extreme storm events, storm surges, and SLR mostly in coastal areas, flooding is not only the natural hazard with the distinguished impact on bridge failures and the amount of damage and costs resulting from that, but it is difficult to model and accordingly plan for as well. Furthermore, given population growth rates, urbanization, and poor land use practices in flood-prone areas, flood risk has increased significantly recently. Floods and associated hazards will become more persistent, extreme, and regular along with climate change and socio-environmental effects, notably in already vulnerable areas. The project first performs a vulnerability/risk assessment considering urban flooding and bridge scouring, social, and environmental factors, and then develops a multi-criterion, multi-stakeholder decision analysis framework in geographic information systems (GIS) environment to assign a risk factor to each bridge in the study area. The framework is applicable as a decision support tool for selecting accelerated bridge upgrade or accelerated bridge repair projects by decision makers. As a case study, the developed framework will be used for a risk-based prioritization of existing bridges in Miami-Dade County with the purpose of selecting projects for accelerated bridge upgrade or repair.

2. Problem Statement

The success of ABC projects depends on several factors which result in improving safety, reducing traffic load, costs, and yielding better overall travelling experience (Wang et al., 2011). Decision-makers need to assure that the ABC techniques are thoughtfully viewed since many of the projects will have only limited budgets and time (Chaphalkar et al., 2013). Feasible candidates for ABC may be suspended or cancelled due to safety hazards, standardization, inexperienced contractors and manufacturers, technical problems related to bridge strength and long-term performance, and the lack of funding. Therefore, the decision-making process considers one basic stage as an early involvement in ABC projects to propose a decision support tool for prioritizing ABC activities in the presence of limited budgets before the construction process.

ABC projects in urban areas interacted with traffic potentially have complex interdependencies with several natural hazard, (e.g., flood), environmental, and social factors (Jia et al., 2018). Past studies have asserted that flood has been the most common natural disaster, accounting for 43% of all disasters between 1995-2015 in the world (CRED, 2015). A study by Wardhana and Hadipriono (2003) found that 53% of bridge failures in the United States between 1989 to 2000 were because of scour due to floods. In point of fact, the rapid water flow generated by flood often gives rise to accumulated debris, which yields a compounded loading impact on bridges and may cause structural damage or failure (Kalantari et al., 2017). Meanwhile, the structural integrity of a bridge may be degraded by the corrosion of steel reinforcements. In this case the failure risk of bridges under flood hazards magnifies and their failure can become more sever (AASHTO, 2008). Therefore, reducing the construction time through ABC methods can potentially minimize the risk of flooding due to temporary flood diversions during the construction phase. High temperatures as an environmental risk factor, also can cause health issues for human, impacting ABC progress, and affect flooding conditions due to the effects on soil hydraulic properties and evapotranspiration processes. Social and demographic factors in adjacent areas of bridges (e.g., population, residents' age, race, and income, and age of the buildings) have implications in the need to an ABC process and can impact the construction speed. For example, ABC can help faster revitalization of a high crime rate neighborhood based on urban master plans while ABC activities may also be negatively impacted in those neighborhoods.

To obtain more realistic and accurate vulnerability assessment of bridge failure against floods, the flood-related factors and interdependence factors should be included in the risk analysis (Arneson et al., 2012). Complexity, multidimensionality, and inherent uncertainties of urban systems require the risk analysis to be comprehensive and able to address different criteria, multiple stakeholders, and spatial aspects of the problem (Glas et al., 2019). The proposed study addresses the need to a comprehensive risk-based multi-criteria multi-stakeholder decision analysis framework that can be used as a decision support tool for prioritizing ABC activities in the presence of limited budgets. Developing the multi-criteria multi-stakeholder decision analysis framework option will consider, among other things, early contractor involvement in order to ensure the project can be constructed in the construction site considering the time and budget allotted. The proposed project once would be focused on the vulnerability assessment of bridge failure against floods and will also be geared towards addressing socio-environmental factors.

3. Objectives and Research Approach

The objective of this study is to develop a multi-criterion, multi-stakeholder decision analysis framework in GIS environment to assess the vulnerability of urban areas and risk of bridges against flooding and socio-environmental factors. The framework can be used as a decision support tool for selecting accelerated bridge upgrade or accelerated bridge repair projects by decision makers. As a case study, the developed framework will be used for a risk-based prioritization of existing bridges in Miami-Dade County with the purpose of selecting projects for accelerated bridge upgrade or repair. The overall approach is to introduce GIS and multi-criteria decision analysis (MCDA) to assess the vulnerability of urban areas and risk of bridges against flooding and socio-environmental factors. The project also describes the use of GIS during the case study for different tasks including, but not limited to the collection and pre-processing of physical, social, and environmental data. Figure 1 presents the flowchart of the proposed methodology. This study considers three types of vulnerability: physical, social, and environmental vulnerability. Definition and details of each group are discussed in Task 2.

Once the GIS data discussed in Task 2 are collected, two major steps of the proposed methodology are as follows:

1. Creating vulnerability maps:

By using the collected physical, social, and environmental GIS data, the developed framework will identify vulnerable urban areas against flooding and socio-environmental factors and creates vulnerability maps. A vulnerability map is first created for each major criterion (i.e., physical, social, and environmental vulnerability maps). Then, the vulnerability maps will be combined using the developed MCDA framework. The output of this step would be an integrated vulnerability map against flood and socio-environmental factors. The framework is capable of handling problems with multiple stakeholders or decision makers. Therefore, the opinions of decision makers about the relative importance of physical, social, and environmental factors can be incorporated into the framework through a group decision making process.

2. Creating risk maps:

The vulnerability map will be combined with existing data about history of flooding, traffic loads and structural conditions of the bridges to generate risk maps that provide risk levels for each of the existing bridges in the study area. Example of bridge related data include type, number, and configuration of piers, scour countermeasures such as rip raps, collars, and sacrificial piles, age of bridges, and structural conditions based on inspections to assess scour potential. High risk bridges can be selected by decision makers (e.g., state DOTs) for accelerated upgrade (retrofit) prior to flood events or accelerated repair after flood events.

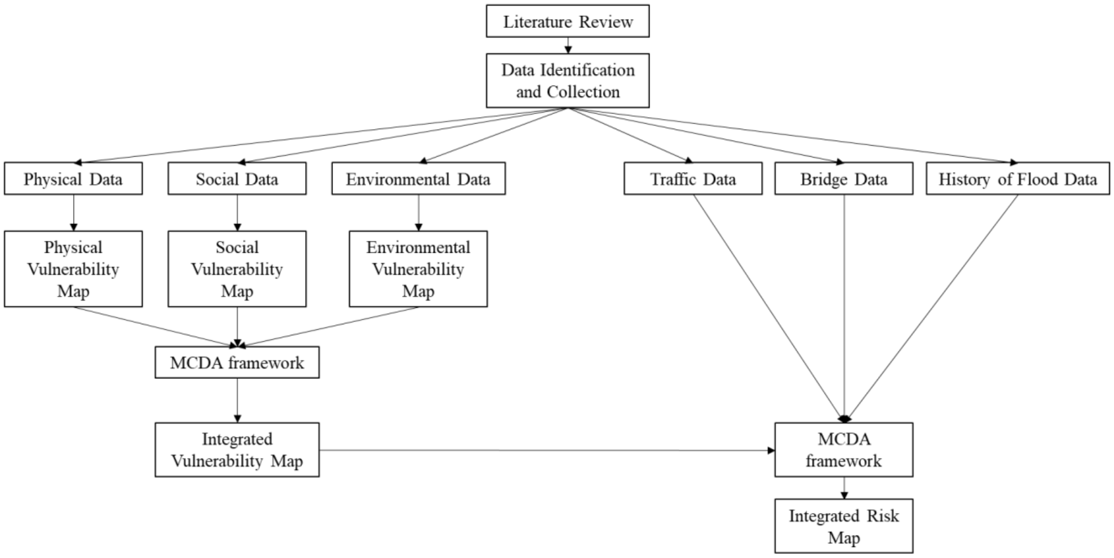

Figure 1. Flowchart of the proposed methodology. Comprehensive vulnerability map for the study area and comprehensive risk map indicating a risk level for each bridge are two final products of the study.

4. Description of Research Project Tasks

Task 1 – Literature Review

The objective of literature review is to identify existing state of the knowledge and practice about socio-techno-environmental risk analysis approaches for natural hazard problems in urban areas. Also, another literature review is performed to identify the existing studies on the interdependencies of climate factors, land factors, bridge characteristics, and bridge scour to be leveraged in the study.

Urban infrastructures, namely bridges, as the result of urbanization, are increasing in demand. However, due to natural hazards and climate change effects, such as floods, SLR in coastal areas, high temperature, and severe storms, construction might be in the risk of failure. According to the United Nations Office of Disaster Risk Reduction (UNDRR) risk is the combination of the probability of a hazardous happening and its negative consequences which develop out of interactions between natural or man-made hazard(s), vulnerability, exposure, and capacity (Birkmann et al., 2010). Vulnerability can be the combination of multi criteria categories, including physical, social, economic, environmental, psychological, structural, and institutional (Pescaroli and Alexander, 2019; Ghajari et al., 2017). The Intergovernmental Panel on Climate Change (IPCC) considered the risk concept, as a function of hazard, exposure, and vulnerability, instead of the vulnerability definition (IPCC 2012b). This new IPCC concept determines that the damaging effects of a hazard depend on the local vulnerability of an exposed society. Considering the vulnerability as one element of the hazard risk, it is required to decrease the vulnerability before and after the hazard's occurrence (IPCC 2014) and boost resilience (Golz, Schinke, and Naumann 2014), yet in many applications, vulnerability still is considered only as the impacts of a hazard (Yang et al. 2018; Weis et al. 2016; Kc, Shepherd, and Gaither 2015). In recent years, a better representation of hazard and vulnerability along with spatial science (e.g., GIS) has been challenging. Recent studies used 'integrated' (Weis et al. 2016), 'hybrid' (Roodposhti et al. 2016), 'MCDA' and 'system-thinking' terms (Gomez Martin et al. 2020). However, most definitions are not fitting to different areas of hazards because of geographical differences, human interactions, and inadequate data (Robinson et al. 2019), governance ordering (Driessen et al. 2018), the involvement of stakeholders and dynamism of cities (Ciullo et al. 2017). The vulnerability also varies over different time periods and due to different causes, which provide challenges for the assessment in different areas (Pescaroli and Alexander 2019). Yet, bridge failures are highly interdisciplinary, a mixture of various factors that might not result in a significant bridge failure if they occur individually. For instance, in coastal areas, such as southeast Florida, the pronounced effects of climate change such as extreme storm events and SLR impacts on surface and ground waters may cause bridges failure if they happen along with high traffic loads. Regarding the multidisciplinary nature of risk assessment, MCDA have been considered as a popular, common, and real-world-based challenge way focusing on the risk assessment problems.

For massive computational efforts on data collection and analysis, GIS technology including various spatial and temporal dimensions has been commonly applied to multi-dimensional problems (Abuzied et al., 2016; Pradhan et al., 2014; Razavi Termeh et al., 2018; Santos et al., 2017; Weerasinghe et al., 2018). Integrated analysis is feasible using GIS in both technical and socioeconomic features (Chen et al., 2015b; Gigovi et al., 2017; Santos et al., 2017). A geographic information system (GIS) can integrate and analyze data from various sources and report the results, which makes it a valuable tool in the management process (Eastman et al. 1997). GIS is applicable for damage assessment due to its ability to combine results from the hydraulic model and socio-environmental information. Complex decision-making situation like flood risk assessment that consists of several spatial criteria can be developed through Geographic Information Systems' capability of visualization, analysis, and management of spatial data (Meyer et al., 2009, Papaioannou et al., 2015, Tang et al., 2018). GIS is an important tool in analyzing and assessing the effects of natural hazards (Haq et al., 2012, Kanani-Sadat et al., 2014, Karimipour and Kanani-Sadat, 2016, Pourghasemi et al., 2013); therefore many studies have investigated flood analysis and developing flood risk assessment map using the capabilities of GIS (Sanyal and Lu, 2009, Strobl et al., 2012, Tehrany et al., 2014a, Tehrany et al., 2014b, Termeh et al., 2018, White et al., 2010, and Khosravi et al. 2018). Considering mapping approaches, the discussion of selecting an appropriate indicator is a challenge (Malczewski and Rinner 2015). Indicator's assignment and the quality of available data require a deep conception of the complex system. Another challenge is the criteria weights allotment as the complexity of systems is limiting the criteria to have equal influence in a hazard (Jung et al., 2011). For vulnerability and exposure mapping assessments, studies mostly assess equal weighting (Hazarika et al. 2018) or either subjective or objective (Birgani and Yazdandoost 2018) methods for weights calculation. Furthermore, data collection/preparation is the most important step and can be the most time-consuming part of an analysis. Generally, study of natural hazards requires multiple datasets to distinguish the spatial changes and the processes of hazards (Martinez and Le Toan 2007). Natural hazards could be under the effects of several factors, namely geomorphology, vegetation, geologic and hydrologic parameters, and patterns that must be considered in providing of the flood risk assessment maps. Therefore, risk assessment mapping is a MCDA process (Hwang and Lin, 2012, Malczewski, 2006). Multi-criteria decision analysis (MCDA) has been recognized as an essential tool for analyzing complex decision problems that often concern for incomparable data or criteria (Hwang and Yoon 1981; Malczewski 2006). Analytical Hierarchy Process (AHP) is a well-liked method of MCDA (Pourghasemi et al. 2012), based on experts' knowledge in assignment groups and weighted grading. Fernandez and Lutz (2010) have estimated the efficiency of MCDA and GIS for mapping any area adjacent to a river, lagoon, or lake likely to have floods anytime the water level rises in Tucuman Province, Argentina. According to this study, the AHP method in the GIS environment is effective in generating natural disaster hazard maps with reasonable accuracy. Zou et al. (2013) described the AHP technique as a cost-effective with a clear understanding and effective analysis method for flood hazard evaluation. Subramanian and Ramanathan (2012) applied the AHP technique in urban and regional research. To evaluate natural disaster risks there are other methods of MCDA, namely Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Multi Attributive Border Approximation Area Comparison (MABAC). TOPSIS has been indeed used in flood hazard management due to its ability to cope with multiple attributes (Brito and Evers 2016). Mojtahedi and Oo (2016) presented an integrated non-parameter resampling bootstrap technique and TOPSIS to assess the flood risk of Australia's states. Zhu et al. (2018) extended a TOPSIS-based model for Reservoir flood control operation (RFCO) problem. Luu et al. (2019) developed the brand-new multiple linear regression TOPSIS for Vietnam's evaluation flood risk. Several studies also have used the fuzzy-TOPSIS technique (Jung et al. 2011; Lee et al. 2014; Shariat et al. 2019). In general, MCDA methods are approaches that have been most popular in flood hazard assessment applied by many researchers in recent studies (Rahmati et al. 2016; Rahman et al. 2019; Ogato et al. 2020). Improving the accuracy of these models has always been one of the main concerns of researchers and decision makers. While the existing literature provides no universal guideline in finding the best model in a region due to the models' limitations, some studies (e.g., Shafapour Tehrany et al. 2019; Hong et al. 2018; Costache et al. 2020; Rahman et al. 2019) showed that combining several methods may lead to higher accuracy in flood susceptibility assessment. Table 1 lists some of the GIS-based, MCDA, and combined GIS-MCDA studies regarding the flood risk assessment in urban areas.

Ozturk and Batuk, 2011, apply AHP to identify the flood vulnerability, and then, use GISto generate the flood risk map. Zou et al. 2013, consider AHP as one of the most intellectual, affordable, and decisive methods for flood risk assessment. Some studies have been assessing flood risk integrated with socio-economic and environmental factors. Cutter et al., 2013 present a methodology to assess flood risk along with social vulnerability in USA. Escuder-Bueno et al., 2012 and Ballesteros-Canovas et al., 2013, apply integrated flood risk assessment in Europe. Gain et al., 2011 and 2013, indicate that seasonal rainfall, upstream flow, and sea-level rise increase the flood risk in flood-prone countries. Gain et al., 2012; Gain and Schwab, 2012; Dewan, 2013 and Rouillard et al., 2014, introduce the random economic changes, population growth, urbanization, poor policies, and land-use changes as the flood risk assessment factors. Bubeck et al., 2012, relate the anthropogenic activities such as land-use changes to flooding risk. Nicholls et al., 1999, assert that coastal as well as low-laying areas are more prone to the flood risk because of climate change effects and population migration. Khosravani et al., 2016, consider geo-morphological and geo-environmental factors as the effective factors on the flood risk. Furthermore, GIS-based MCDA can apply combining process to spatial data and information layers for the decision-making process (Malczewski, 1999, Malczewski, 2006). Arabsheibani et al., 2016, Boroushaki and Malczewski, 2010, and Chen et al., 2011, and Shariat et al., 2019, combine GIS and MCDA to come up with a powerful spatial decision support system.

Table 1. Examples of GIS-based, MCDA and the combined GIS-MCDA studies for flood risk assessment in urban areas

Study	*Dimension(s)*	*Method(s)*
Allen, 2004	Social, Economic, Environmental	MCDA
Meyer et al. 2009	Social, Economic, Environmental	MCDA-GIS
Saaty, 2013	Social, Environmental	MCDA
Tran et al. 2008, Dewan 2013, Winsemius et al. 2015	Social	GIS
Te Linde et al. 2011, Zou et al. 2012, Dewan 2013c, Ouma and Tateishi 2014, Gain et al. 2015, Ronco et al. 2015	Social, Environmental	MCDA
Wang et al. 2011, Peduzzi et al. 2009, Zou et al. 2012, Dewan 2013, Gain et al. 2015, Ronco et al. 2015,	Social	GIS
Scheuer et al. 2011, Dewan 2013, Ronco et al. 2015	Social	GIS
Dewan 2013, Terti et al. 2017	Environmental	GIS
Lee et al. 2017	Social, Environmental	GIS-MCDA
Rincon et al. 2018	Social, Environmental	GIS-MCDA

Toosi, 2019	Environmental	GIS-MCDA
Vignesh et al. 2020	Environmental	GIS-MCDA
Hadipour et al. 2020	Social, Environmental	MCDA

Different metrics or indicators have been used by researchers in flood risk analysis studies. Singh et al., 2020, consider six different factors that have significant impact on flooding in India. The introduced factors are rainfall intensity, curve number, time of travel, surface slope, Manning's coefficient, and drainage density. Kia et al., 2012, introduce rainfall, slope, and flow as the effective natural hazard factors in urban sectors. Zou, et al., 2012; Quan, 2012, and Gao, 2016, apply population disaster and housing loss effective in assessing flood-prone region disaster risk. Zhang et al., 2008, focus on the relation of temperature fluctuation with flood disasters in the context of climate change. Ruiling et al.,2020, select five primary and nineteen secondary flood risk assessment indicators, including annual precipitation, frequency of rainstorm, vegetation coverage, drainage density, urbanization rate, population density, building density and economic density. They consider two vulnerability indicators including the old and young population per unit area and the proportion of crops per area; two secondary indicators including economic and crop loss were considered as the disaster loss criterion. Gain et al., 2015 indicate the flood risk is the result of extreme hydrological events in addition to physical and social indicators. They introduce building age and types, building materials, land-use map, number of cars and population density as the vulnerability indicators. Wang et al., 2020 address fourteen flood risk assessment indicators including physical geography and socio-economic ones, out of which there are seven hazard indicators and seven vulnerability indicators. Digital elevation model (DEM), soil texture, rainfall intensity, the normalized difference vegetation index (NDVI), rainstorm frequency, drainage density, and slope data were defined as the hazard indicators by Wang et al. (2020) while they used gross domestic product, road network density, average schooling years, population density, grain output, and per capita disposable income as the vulnerability indicators. Glas et al., 2019, develop flood risks maps integrated with social, economic, and physical vulnerability maps for the catchments of the river Moustiques, Haiti, a data poor region. They use rainfall depth, DEM, soil texture, land-use/cover, and channel characteristics in the hydrological model. Only material damages to buildings and roads considered as the physical vulnerability, whereas economic vulnerability also consider the economic damages to farmlands.

Karatzetzou et al., 2021, present homogenizing methodology to combine the single flood risk indicators and derive a combined flood risk assessment scenario for roadways, bridges, and tunnels in Greece. Andrić et al., 2016, classify the potential hazards based on the collapse reason into six groups, including windstorm, hydraulic, traffic, construction, and human-made hazards. They introduce fifteen risk indicators contributed to bridge failure, including earthquakes, tsunamis, hurricanes, floods, debris, scour, ice, soil, the age of the bridge, collision, overloading, deterioration, construction and design, fire, and terrorist attack. Kattell and Eriksson, 1998, indicate that flowing water cause scouring effect around the bridge piles and foundation, which remove the material and lead to the bridge failure. They also consider the scour as the most important factor in highway bridge failure in the United States. Yang et al., 2020, bring in a risk-oriented method to evaluate the vulnerability of coastal bridges under climate change and socio-economic changes. In this research, five factors are under consideration including temperature fluctuation, SLR, hurricane frequency, storm surge, aggregated appreciation, population growth and asset appreciation. Barankin et al., 2020, use Federal Emergency Management Agency (FEMA) to determine the critical elevation cutoffs, annual average daily traffic, evacuation routes, and bridge height over water ways as indicators for analyzing the vulnerability of transportation assets to socio-economic and flooding events on costal Massachusetts regions. Mondoro et al., 2016, propose an optimal risk-based method for costal region bridges, which address natural hazards including hurricanes and the updated flood maps along the coastal regions performed by FEMA as well as economic and social indicators including length of the detour, duration of the detour, average daily traffic, average vehicle occupancy, and average detour speed.

In the context of socio-economic vulnerability in risk analysis of highway bridges, literatures have been using various combinations of factors. Tobin and Montz, 1997 introduce age, gender, race, and income as the vulnerability indicators. Schmidt-Thome, 2005 present land management/development and disaster mitigation plans as the social vulnerability factors. Table 2 lists some of the bridge failure risk assessment indicators due to socio-economic, environmental, and physical factors.

Table 2. Socio-economic, environmental, and physical factors affecting risk assessment of bridges

Study	*Dimension*	*Vulnerable Factors*
Turner et al, 2003	Social	Population, land-use
Chen et al., 2003	Physical	Land-use/cover, vegetation, topography, climate, geology, soil texture
	Socio-economic	Population, building structure, income rate, access utility, security, ethnicity, political, historical, cultural, psychological, institutional, legal
GTZ, 2004	Physical	Location, material, soil texture
	Social	Population growth/ density, education level, legal framework, human rights, civilization, public health, information accessibility
	Economical	Poverty and nutrition, diverse economic activities, structure of income, financing opportunities
	Environmental	Water quality, vegetation, biodiversity, ecosystem stability
UNDP, 2004	Social	GDP, population density
UN/ISDR, 2004	Physical	Remoteness of a settlement, design and material
	Social	Education, social equity, ideological beliefs, public health, education systems, social power relations
	Economical	Poverty, credit access, level of dept, loans and insurance, diverse economic activities, communication network, utilities and supplies, transportation, water facilities, sewage and health care condition
	Environmental	Natural resources, resource degradation, toxins and pollutants, biodiversity, air quality, water quality, soil degradation
Allen and Thanassoulis, 2004	Social	Population density, Risk perception, Spiritual values, Income level

	Economical	Residential buildings, Special use buildings, Public infrastructure, Agricultural areas
	Physical	Flood depth, Flood duration, Flood velocity
Cardona et al., 2005	Social	Population density, Poverty, Unemployment and loans, Social welfare, Hospital facilities
Messener and Meyer, 2005	Social	Residents coping capacity to hazards, Population structure, Age
Rygel et al., 2006	Social	Population age, Disabled residents, Vulnerable group to the hazards
Lee et al., 2009	Social	Household property, Gender, Disposable income
Meyer et al., 2009	Social	Population density, People and community location affected
	Economical	Poverty, Annual average damage
	Physical	Soil type, Potential erosion
Cheng-Hsien et al., 2011	Social	Residential density, distance for substitution, aging index, Ratio of disabled resident, Low-income household, Employment rate, Household income
Te Linde et al. (2011), Zou et al., 2012, Dewan, 2013	Social	Land-use
Saaty and Vargas, 2013	Social	Population density
	Physical	Distance from the mainstream, Elevation, Slope, Land-use/cover, Soil type, Distance to discharge channels
Yamin et al., 2013	Social	Population, Transportation network
	Physical	Flood, Hurricane, Landslide, Soil type
Dewan, 2013	Physical	Distance to river
Ouma and Tateishi 2014, Gain et al. 2015, Ronco et al., 2015	Social	Land-use
Gain et al., 2015, Ronco et al., 2015	Social	Population density
Ronco et al., 2015	Social	Road density
Terti et al., 2017	Physical	Distance to river
Lee et al., 2017	Social	Type of building utilization, Population density, Critical Traffic spots, Land-use
Rincon et al., 2018	Social	Age, Family structure, Language proficiency, Income, Education level, Land tenure, Population density
	Physical	Slope, Distance from rivers, Land-use and altitude, Annual maximum precipitation, Total precipitation, Effective precipitation, Floodplain
Toosi, 2019	Physical	Flood Hazard Index, Runoff coefficient, Elevation, Slope, Distance from the drainage network, Rainfall intensity, Soil erosion, Land use
Vignesh et al. 2020	Physical	DEM, Soil type, Slope, Rainfall, Geology, Geomorphology, Surface runoff, Drainage density, Topographic wetness index
Hadipour. 2020	Social	Population density, Age, Gender, Employment rate
	Physical	Tidal range, Wind speed, Storm Surge, Wave set-up, SLR

Task 2 – Data Identification, Collection, and Analysis

Study Area

Miami-Dade County, in southeast Florida (Figure 2), one of the low-lying areas on the southeast coast of the United States exposed to the risk of flood and storm surge (Chen et al. 2015), is used as the case study. Miami is the ninth in population exposure to climate extremes among world port cities. Florida is the first ranked vulnerable state in the United States to sea-level rise, and Miami has the largest amount of exposed assets and the population vulnerable to sea-level rise in the world. Miami-Dade's estimated beachfront property value is more than $14.7 billion, not including infrastructure. King tides, flood events with high tide conditions, have been causing serious damages to the constructions including bridges and transportation systems. These damages due to the coastal flooding will become even worse with the rising sea.

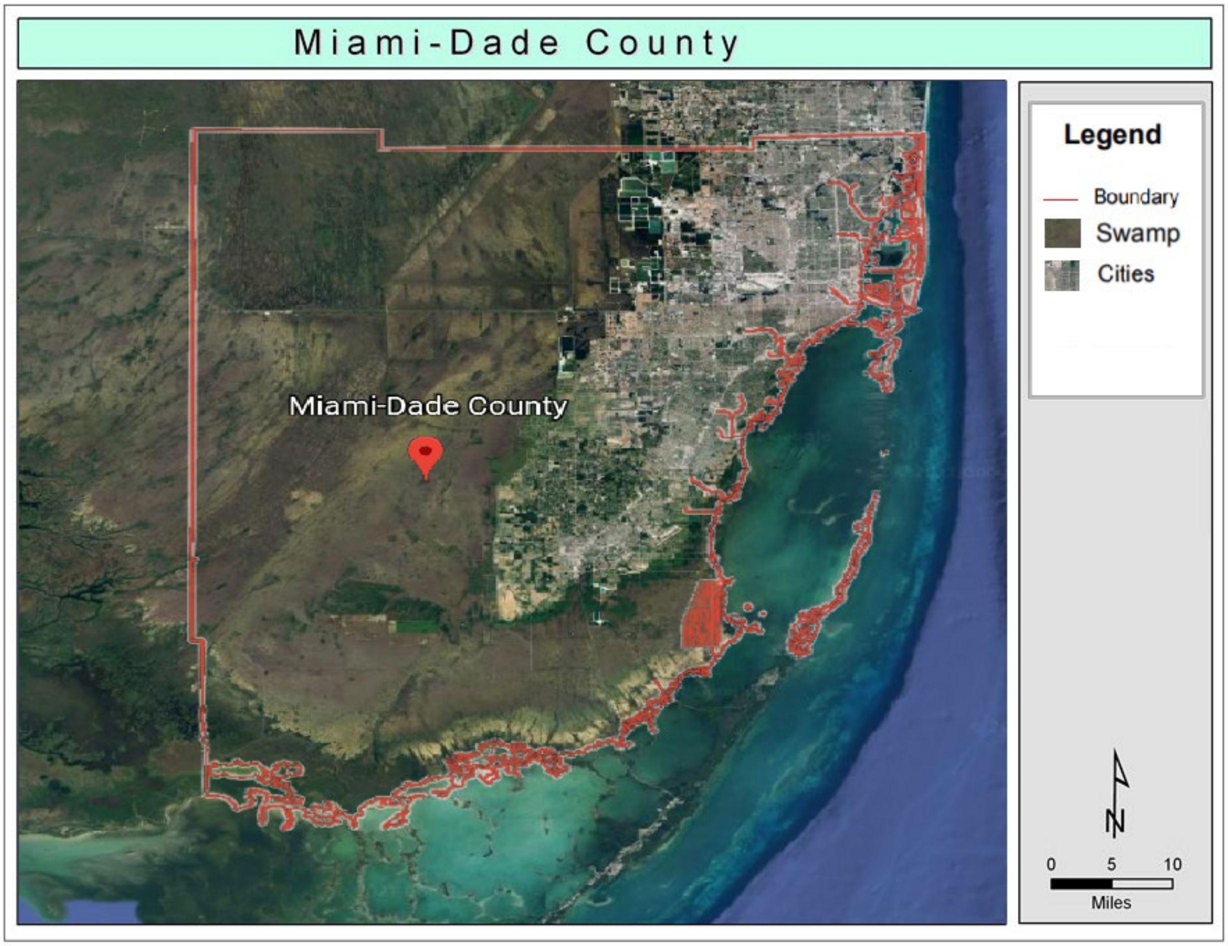

Figure 2. Miami-Dade County Boundary

Determining Suitable subdivisions in the study area

In the MCDA method, the aim is selection of well-determined and favorable locations in the study area where the defined indicators can be established. In this study, to take the criteria into account, choosing the most suitable subregions in Miami-Dade County is required. Non-urban areas or area of vegetation are not considered in the risk assessment process. Therefore, the main idea in this section is to eliminate those areas of the map to form the initial layer of the base map. The subdivision is used for regions and sites when a large area of land is to be observed as smaller individual parcels. In this study, we consider two different subdivision strategies: a subdivision based on zip code, Figure 3, and a subdivision based on subwatersheds, Figure 4. Biscayne Bay watershed (2500 km^2) is located along the southeastern coastline of Florida, Miami-Dade County, which includes the city of Miami. Its western boundary lies close to the Florida National Park and green spaces. Figure 4 presents subwatersheds in the study area from the South Florida Water Management District models.

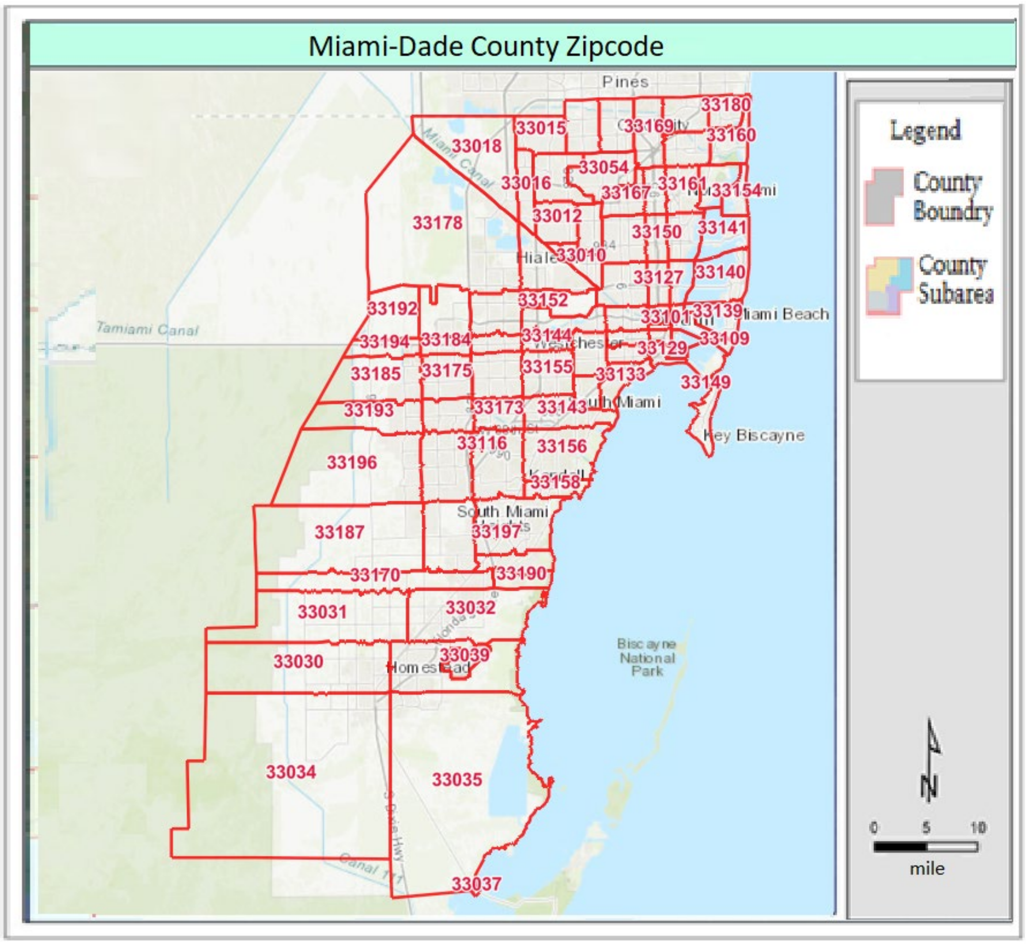

Figure 3. Miami-Dade County Zip Code Boundary

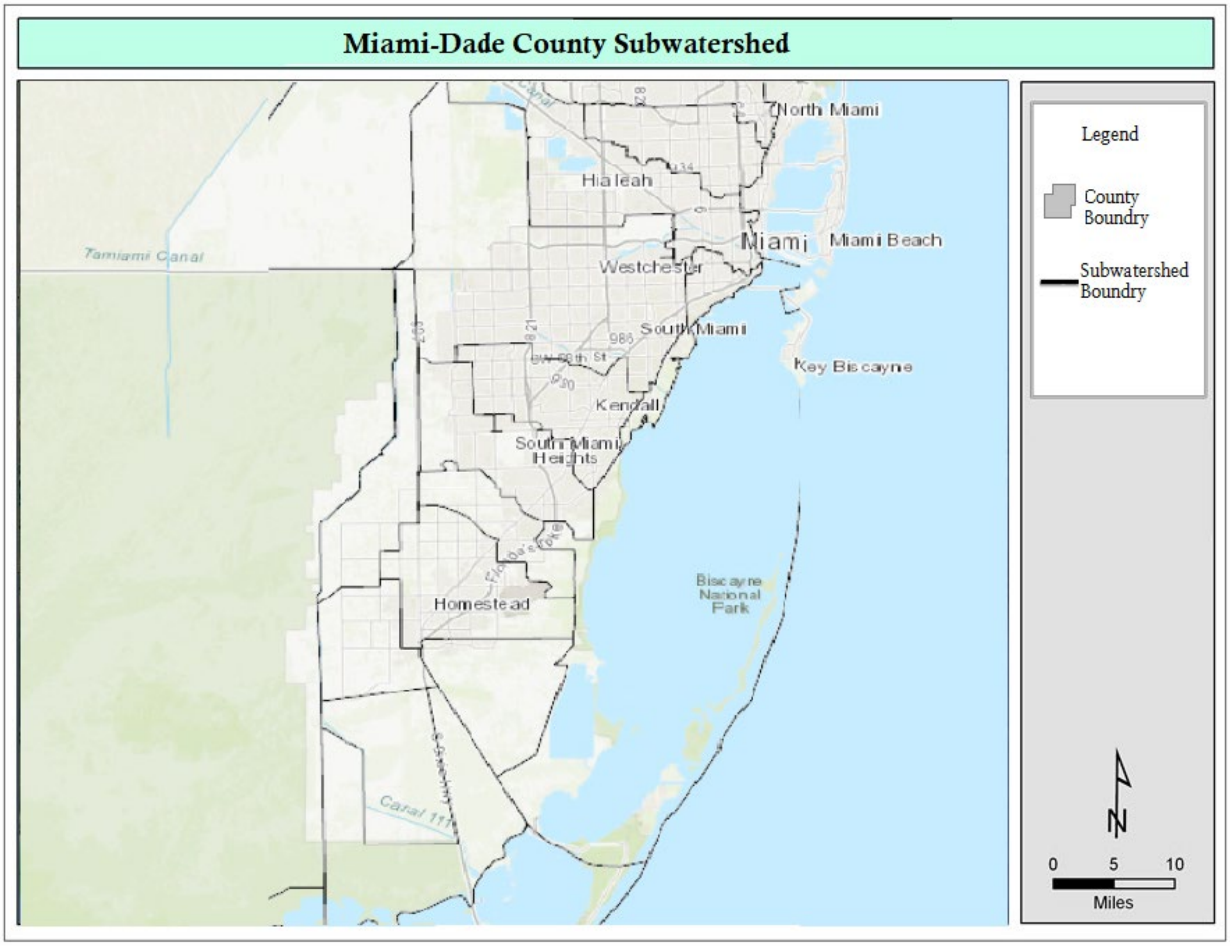

Figure 4. Miami-Dade County Subwatersheds Boundary

Geographic information system (GIS) uses data referenced by spatial coordinates. Observation and collection of data as well as storage and analysis to the use of the information derived are crucial part of a decision-making process. Historical data is important while assessing hazards and vulnerability (WMO 2013). Data sets used in this study include integrated data collected from different sources. In the risk assessment context, this study will consider three types of vulnerability: physical, social, and environmental vulnerability data, Table 3.

The choice of major indicators that influence socio-environmental and physical vulnerability represents a critical point as it depends extremely on both the quality of the available data and time period of their selection (Nardo et al., 2005). No solid guideline concerning which data to choose and how to analyze is existing in the literature. In terms of social factors, social and cultural heterogeneity changes in different urban communities and then, many various methodologies can be applied to assess social vulnerability at each scale and system. This process of identifying data consists of several processes, including acquiring satellite or aerial photographs, maps, collecting demographic information or data on rainfall-runoff, and conducting field surveys. Table 3 present all of the data that were collected and will be considered for possible using in this study.

Table 3. Data and indicators information

Index	***Sub-Index***	***Indicator***	***Data source***
Vulnerability	Social	Income	https://gis-mdc.opendata.arcgis.com/
		Poverty rate	https://gis-mdc.opendata.arcgis.com/
		Age of buildings	https://gis-mdc.opendata.arcgis.com/
		Age of people	http://edr.state.fl.us/content/population-demographics/data/
		Employment status	https://gis-mdc.opendata.arcgis.com/
		Multi-unit structures	https://gis-mdc.opendata.arcgis.com/
		Crime rate	https://crimegrade.org/safest-places-in-miami-dade-county-fl/
		Population density	https://gis-mdc.opendata.arcgis.com/
		Land-use	https://gis-mdc.opendata.arcgis.com/
	Physical	Road networks	https://gis-mdc.opendata.arcgis.com/
		Bridge networks	https://gis-mdc.opendata.arcgis.com/
		Imperviousness	SRTM-DEM
		DEM	United States Geological Survey (USGS)
		Rainfall intensity	National Meteorological Information Center (http://data.cma.cn/)
		Stream and canals	SRTM-DEM
		Soil type	USDA’s web soil survey
		Soil permeability	USDA’s web soil survey
		Groundwater level	https://gis-mdc.opendata.arcgis.com/
		Land cover	https://gis-mdc.opendata.arcgis.com/
		Road accessibility	https://www.openstreetmap.org/
		Landslide	United States Geological Survey (USGS)
		SLR	https://coast.noaa.gov/slrdata/
		Slope	United States Geological Survey (USGS)
		Rainstorm frequency	https://gis-mdc.opendata.arcgis.com/
	Environmental	Green space	United States Geological Survey (USGS)
		NDVI	LANDSAT 8 data from USGS
		Leaf Area Index (LAI)	United States Geological Survey (USGS)
		Tree canopy	https://www.arcgis.com/
		Air quality	https://geodata.dep.state.fl.us/datasets/
		brownfield	https://gis-mdc.opendata.arcgis.com/
Risk	Traffic data		https://www.fdot.gov/statistics/gis/default.shtm
	Bridge data		https://gis-mdc.opendata.arcgis.com/datasets/bridge/explore
	Flood history data		https://gis-mdc.opendata.arcgis.com/

Task 3- Framework Development

An effective, MCDA technique that is compatible with the problem in hand and is capable of handling group decision making will be used in GIS environment to develop the decision support framework. The details and interrelationship between the elements in the framework will be determined based on the data from Task 2. The combined risk analysis maps represent a better elaboration of the risk (hazard) zones, determine the proportions of areas subjected to varying degrees of risk factors. In this phase, all data collected would be used to develop the decision model. Integrated risk assessment maps are generated as a spatial overlay between the various given hazard data and maps.

Task 4- Spatial multi-criteria group decision analyses

The developed framework will be applied to the case study and vulnerability and risk maps will be generated.

Task 5- Reporting

The results and findings of the study will be reported in a manner consistent with existing protocols. Future directions and recommendation for applying the framework to other geographic regions will be provided in the final report.

5. Expected Results and Specific Deliverables

The proposed framework can be used as a decision support tool by state or regional decision makers in prioritizing ABC activities (e.g., accelerated upgrade/repair solutions) for existing bridges as part of the maintenance/rehabilitation programs. The framework can be leveraged to develop an online (cloud-based) decision support tool that generates vulnerability and risk maps by taking several spatial input data from the user (or automatically from public databases) and the decision maker's opinion on the relative importance of different physical, social, and environmental factors. Applicability of the framework to different geographic regions hinges on the availability of the input GIS data. Most of the input data are available for the entire country through national, state, or regional datasets. Therefore, the methodology is not limited to any specific geographic region. However, the decision-making criteria and their associated GIS data need to be determined for each study region. For example, groundwater data may be more important in coastal regions with shallow water tables compared to inland areas with deeper groundwater levels. Also, the importance of social criteria and socio-cultural/demographic data may be different when the study region houses underrepresented communities and minority groups. The project is planned for future extensions in multiple phases, providing opportunities for developing larger proposals to seek funding from other agencies. Future extensions of the project include, but are not limited to, the consideration of larger case studies (e.g., the entire bridge and road networks in Florida), incorporation of climate change effects into the framework, development of risk management scenarios in concert with ABC activities to address the identified risks, and addition of uncertainty analysis to further assist the end users (e.g., state DOTs) in practical applications. As an example, development of risk management scenarios to address the identified risks are expected to result in complementary elements in the ABC project site (e.g., implementing storm water green infrastructure to alleviate flood effects and risk of bridge scouring) or additional activities related to site preparation and geotechnical tests that can be included in bridge specifications to increase the efficiency of ABC activities.

6. Schedule

Progress of tasks in this project is shown in the table below.

Item	%
Percentage of Completion of this project to Date	45

Research Task	2021										2022	
	M	A	M	J	J	A	S	O	N	D	J	F
Task 1. Literature review	🟥	🟥	🟥	🟥								
Task 2. Data identification, collection, and analysis			🟥	🟥	🟥	🟥	🟦	🟦				
Task 3. Framework development					🟥	🟥	🟦	🟦	🟦			
Task 4. Spatial multi-criteria group decision analyses							🟦	🟦	🟦	🟦	🟦	
Task 5. Reporting												🟦
	🟥	Work Performed										
	🟦	Work To Be Performed										

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