Local Disaster Risk Assessment and Community Engagement to Improve Resilience

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Abstract

This paper presents the first-year results of the GISEC Project that creates an academic pathway and enhances technological applications for environmental hazards awareness and community engagement in Miami-Dade County. The educational pathway articulates a career from high school to undergraduate and graduate studies. The pathway focuses on GIS, and IT careers, with a research and project learning platform that delivers disaster risk analysis study cases under natural hazard conditions. This effort fills a gap in the GIS educational pipeline in South Florida, with a particular orientation to include minorities underrepresented in GIS occupations, serving a 68.6% Hispanic and 18.2% African American community.

The risk assessment research and project learning platform includes using remote sensors (drones) and the obtention and analysis of local data to define the topography, urban models, and building inventory. The flood depth grid is created by using Hydronia models. The risk analysis follows FEMA-HAZUS's methodology to determine the risk of hurricane winds and rain floods in a selected census tract in Miami-Dade County. Improvements are included to generate more precise results. Two models are defined: Model 1 uses public building inventory, and Model 2 uses the improved building inventory developed here. Risk results of building damage, economic losses, and social impact due to hurricane winds for 500 years and floods for 100-year return periods are presented. Total economic losses for hurricanes and floods using the improved inventory (Model 2) are 2.7 and 1.7 times the losses obtained with the public inventory (Model 1).

The availability of precise data and modeling results allows the assessment of expected losses in the face of extreme events and climate change.

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The improved information is included in the academic program, allowing students to comprehend the local risks fairly. The enhanced risk analysis methodology results are part of the cooperative effort defined by the Resilient305 strategy for Miami Dade County. This cooperation allows the dissemination of the results to local governments and communities. Further applications of this methodology (not part of this paper) include estimating losses prevented by adaptation projects, the annualized estimates of losses, and building-by-building analyses. Including damaging factors in buildings and their impact on risk is also part of the ongoing research. These additional efforts are part of the continuation of the project.

Keywords: Resilience, Disaster Risk Reduction, Natural Hazard, Vulnerability, Urban Model, FEMA-HAZUS, hurricane, flooding, sea-level rise, Southeast Florida, Risk assessment, Drones sensing data

1. Introduction

Natural hazards have produced significant human and economic losses. The United Nations Organization estimates an annual loss of $113 billion due to hurricanes, earthquakes, floods, tsunamis, and other events (UNISDR, 2015). Hurricane Andrew (1992) caused $25.3 billion in losses in Florida, damaging 101,241 dwellings and destroying 63,000. Hurricane Irma (2017) caused significant flooding throughout the peninsula and dropped nearly 15 inches of rainfall in 48 hours. Miami-Dade County comprises a metropolitan area of 2.8 million people exposed to substantial risks. Floods can originate in several ways: hurricanes, heavy rain, overflow of rivers, coastal flood, storm surge, and sea-level rise (SLR); these conditions can be worsened by climate change. Tsunamis are also a hazard.

Adaptation strategies in Florida are relatively recent (the first significant initiatives dating to 2010). Although there are important local projects in numerous communities and cities, the approach of a comprehensive strategy for adaptation to climate change, encompassing a sustainable future vision for the State, counties, and cities, is a task yet to be undertaken.

Many of the adaptation and resilience projects in Miami and Miami-Dade County are in the early stages of development. Therefore, it is necessary to design a global plan to adapt and improve the existing drainage, flood prevention, and control infrastructure and coordinate these efforts with neighboring counties (Lafuente, 2020). Adaptation and resilience measures require new infrastructures and the transformation of urban space within a framework with a comprehensive vision of a sustainable future; this can provide added value to cities and improve life quality. Flood risks can be effectively reduced if adequate spatial and urban planning is carried out in addition to technical adaptation measures. Sustainable urban planning includes constructing buildings in safe locations outside areas prone to frequent flooding, designing building codes to reduce flood damage, and repurposing flooding areas that could be used as parks, natural areas, or ecological reserves.

It is necessary to insert a shared and comprehensive vision of development, adaptation, and Resilience in policies, plans, and direct actions; the participation of the communities, the private sector, and the academic sector, in coordination with the public sector, is a critical factor for the success of these initiatives.

The project presented in this paper, GISEC (Geographic Information Systems for Environmental awareness and Community Engagement), started in 2020 with the following components:

- Create an articulated educational pathway from high school to undergraduate and graduate studies, with disaster risk analysis study cases and a research and project learning platform.
- Create capacities to manage technologies applied to risk mitigation and adaptation to climate change, such as drones, data analysis, GIS, hurricane and flooding hazard and risk analysis, and losses and impacts evaluation. Include those capacities in a project and research platform that supports the educational pathway.
- Make this Academic Pathway a replicable model that can be repeated in other locations, in and outside the US
- Promote and support programs with local governments, students, faculties, and communities to raise public awareness of disaster risk reduction and support ongoing resilience initiatives in Miami-Dade.

This project is innovative and significant mainly because it creates a complete educational pathway from secondary to graduate levels that did not exist in Southeast Florida. Second, it has developed local capacities and methodologies to improve public data needed to deliver more accurate results in risk assessment under natural threads, and it is making them available for students and faculty. These risk analysis capacities can be made available to municipalities and local governments.

In 2019, Greater Miami and the Beaches launched the Resilient305 Strategy, focusing on top-priority resilience challenges. This initiative establishes a collaboration between local governments and academic institutions, bringing the resilience offices of Miami-Dade County and those of Miami and Miami Beach with Miami Dade College, Florida International University, and the University of Miami (resilient305.com). This initiative is led by the Office of Resilience of Miami-Dade County. The activities described in this article contribute to several outcomes of the Resilient305 strategy, such as the improvement of natural disaster preparedness, by making people aware of the risks; the improvement of housing quality by providing information on the potential damage produced by the hazards, including costs; reduction of sea-level rise and coastal flooding impacts, and the reduction of the impact of stormwater flooding, both by providing a tool for the assessment of the impacts and cost/benefits of adaptation measures. GISEC contributes to students' learning process that enrolls the educational pathway from high school to graduate programs.

2. An academic program

An academic pathway has been created, structured by a GIS College Credit Certificate (CCC) with dual enrollment with high school, a stackable component of an Associate in Sciences and a Bachelor of Sciences degree in Information Technologies, and can articulate with a graduate certificate in GIS.

This Academic pathway has been created in Miami Dade County, a minority-majority community, in which Hispanics represent 68.6% of the population, Black or African-Americans 18.2%, and females

51.4%. The GIS-centered pathway will contribute to filling a noticeably significant minority underrepresentation in GIS occupations. Across the county, Hispanics occupy only 23.8% of GIS positions, while African-Americans and females fare worse with only 7% and 22.2% representation, respectively (EMSI, 2019).

GISEC enrolls students from the diverse community of Miami-Dade County, creating opportunities for underrepresented groups to enter the IT sector, particularly GIS. Minorities (primarily Hispanics and African-Americans) will be able to participate in this academic pathway with several entry levels (from high school to graduate studies). The potential impact is significant given the project's reach into this minority-majority community. Besides, one hundred percent of the faculty involved in the program are minorities and receive professional development opportunities in GIS, remote sensing, urban modeling, and risk analysis.

The College Credit Certificate (CCC) in GIS Technology is a 21-credit program that includes four GIS courses (Introductory, Intermediate, Advanced, and Applications), a Data Analysis course, and a capstone project (Geographic Information Systems College Credit Certificate | Miami Dade College (www.mdc.edu/gis/)). High School students can take all courses as part of a dual enrollment articulation program, and GIS Secondary courses can be credited as part of the College Credit Certificate. The CCC also prepares students for Certification exams in GIS. Courses include training in proprietary and open source GIS software.

All the CCC credits can be stackable into an Associate in Sciences degree in Computer Information Technology (https://www.mdc.edu/computerinformationtechnology/). Students can also continue their education and obtain a Bachelor of Sciences degree in Information Systems Technology (https://www.mdc.edu/informationsystems/).

The academic pathway includes risk evaluation applications under environmental hazards such as hurricanes, flooding, and sea-level rise. This article contains some of the information that is available for the program.

Higher education and secondary education institutions can replicate this academic pathway. The pilot dual enrollment program with Miami Dade County Public Schools (MDCPS) provides expansion opportunities. The goal is to enhance technological applications of public interest, emphasizing environmental hazards awareness in Miami-Dade County, a minority-majority urban area significantly impacted by and at ongoing risk for natural disasters.

This effort fills a gap in GIS educational pipelines in South Florida, with a particular orientation to include minorities underrepresented in GIS occupations. In addition, internships in local governments are included.

As part of the academic activity, a support document that reviews the fundamental concepts of evaluating the economic impact of natural disasters was developed. It analyses existing literature on estimating disasters' direct and indirect economic effects based on theoretical and empirical approaches (Lamar, 2020). Policymakers' Lessons include that national governments can limit disaster impacts through regulations, prevention measures, and early warning systems. In addition, local governments are well-positioned to fine-tune disaster risk management policies for local risks by implementing zoning and building code policies, evacuation planning, and emergency response plan designs. This document is a support for the academic program but also for decision-making.

3. Research and project learning platform

GISEC has completed the first phase of creating an improved methodology for assessing risk in urban areas impacted by hurricanes and flooding, based on FEMA-HAZUS's methods. This effort is intended to be taught to students, allowing the enhancement of environmental risk awareness and evaluation capacity to contribute to reducing risks generated by natural hazards. The methodology can also be used to analyze local and municipalities' risks and be replicated by educational institutions. The platform articulates the following activities:

- Drone flights for data acquisition.
- Photogrammetric data processing, high-resolution topographic models, and urban modeling.
- Modeling and application of Hydronia for flooding analysis.
- Hurricane hazard generation using FEMA-HAZUS for deterministic and probabilistic hazard generation.
- Compilation of public records data; use of this data in FEMA-HAZUS Models, detecting inconsistencies, and improving the data for the exposure and vulnerability assessment.
- Risk evaluation under hurricane and flooding following deterministic and probabilistic approaches, delivering estimations of economic losses and social impacts, using FEMA-HAZUS levels 1, 2, and 3, and including data generated with drone flights. Risk includes potential physical, economic and social losses.
- Creation of supporting documentation: Risk Assessment, Economic Impact of Natural Disasters, Adaptation to Climate Change.

4. Remote sensing and data processing

4.1 sUAS (small Unmanned Aircraft System) Operational plan and ground control points

An example is presented for the Census Tract 12086002100 of Miami-Dade County (Figure 1). The drone flights were performed at an altitude of 200-300 ft AGL (Figure 2), with the sensors aiming at different angles.

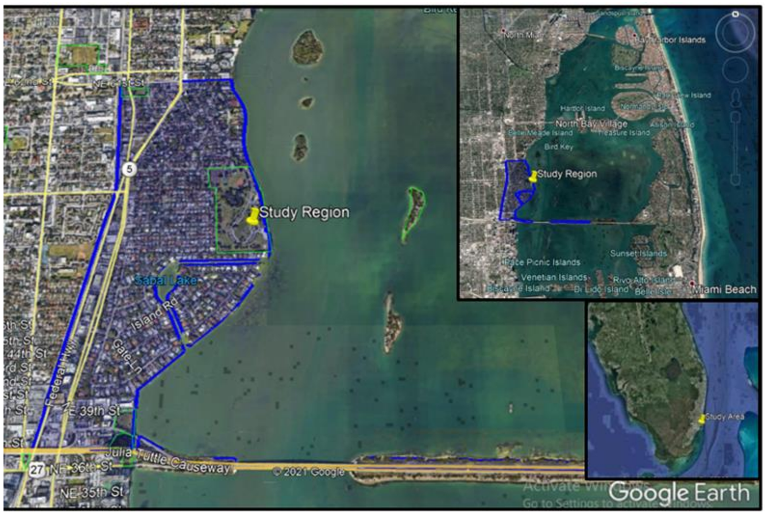


Figure 1. Census tract 12086002100 (Google Earth Image).

Figure 2. sUas launch and recovery positions.

Aerial targets with known coordinates were used to georeference the surface models. The Ground Control Points and Checkpoints layout is shown below (Figure 3).

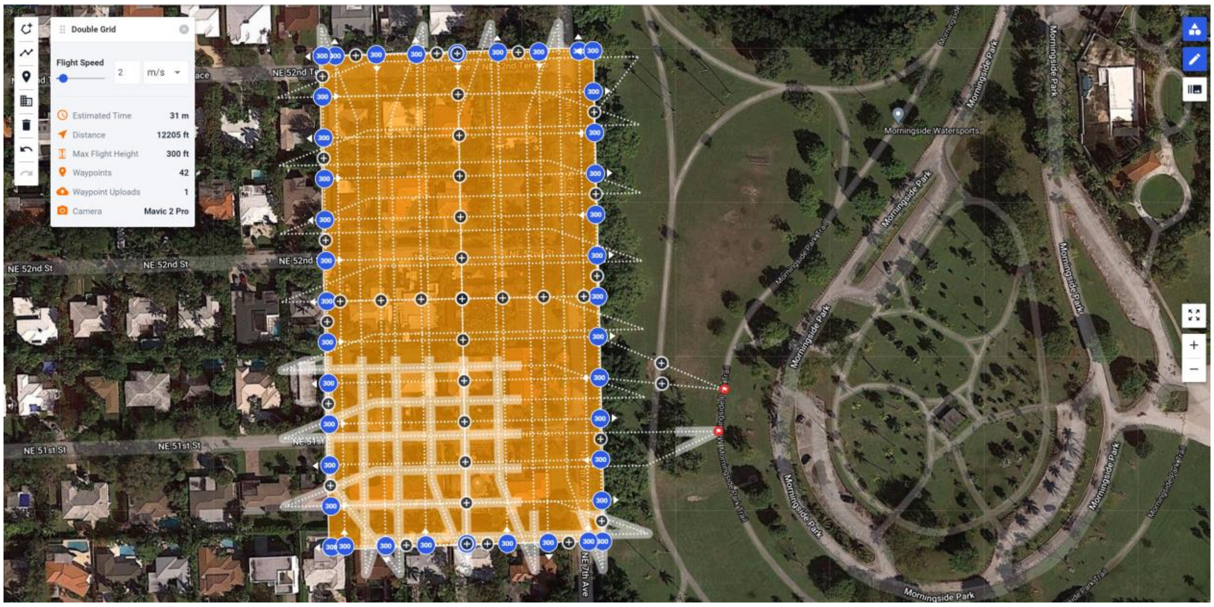
Figure 3. Location and distribution of aerial targets.

Survey-grade equipment was used to collect the coordinates of the aerial targets. Figure 4 shows examples of the aerial targets marked on the ground and the equipment used.

Figure 4. Coordinate referencing for aerial targets.

4.2 Photogrammetry

Three main steps were followed to process the photogrammetry project (1) aero triangulation; (2) generation of the Point Cloud and 3D Textured Mesh; (3) deliverables: Digital Surface Models (DSM), Digital Terrain Models (DTM), Orthomosaics, building footprints, seawall digitization. 21744 photos were taken to cover the selected Census Tract. Figure 5 shows part of the mission plan.



Double Grid

Flight Speed 2 m/s

Estimated Time	31 m
Distance	12205 ft
Max Flight Height	300 ft
Waypoints	42
Waypoint Uploads	1
Camera	Mavic 2 Pro

Figure 5. sUAS mission planning of waypoints and flight parameters.

4.3 Digital Models

The point cloud's refinement and classification were performed once the project had been georeferenced, allowing the preparation of digital elevation models. The densified point cloud contained 1,594,026,182 3D points with an Average Density of 21.17 per ft^3 (Figure 6).

3D Point Cloud (RGB)

3D Point Cloud (classified)

Figure 6. Point cloud and classified 3D Point Cloud.

Subsequently, a high-resolution orthomosaic covering the whole Census Tract was prepared with an Average Ground Sampling Distance (GSD) of 2.09 cm / 0.82 (figure 7).

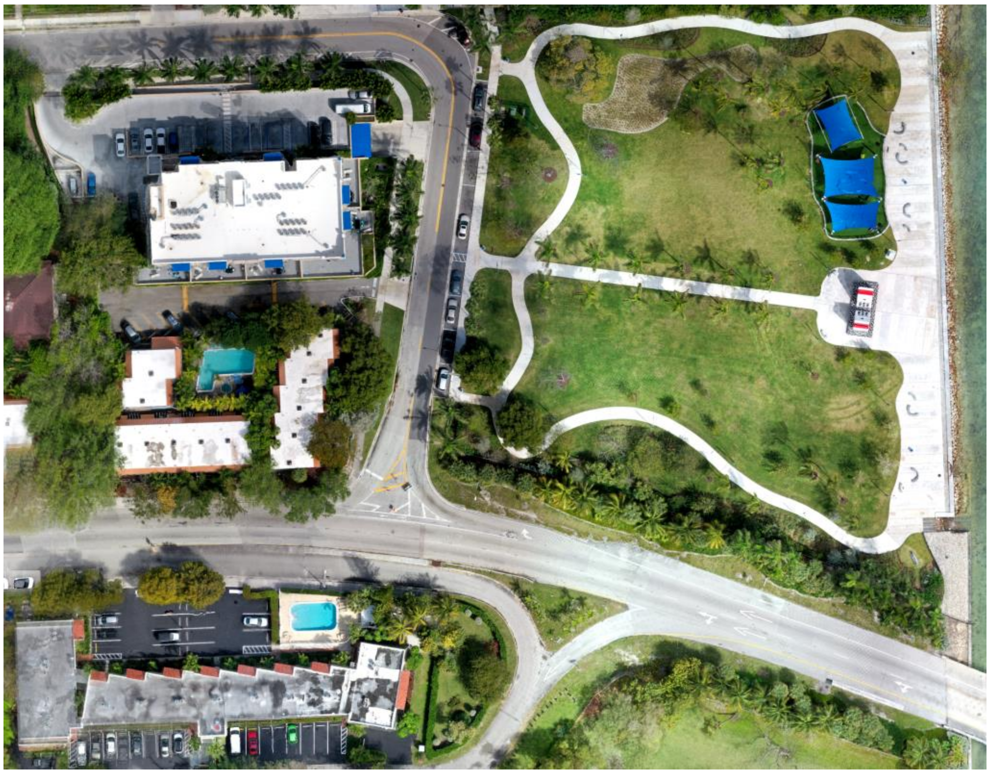
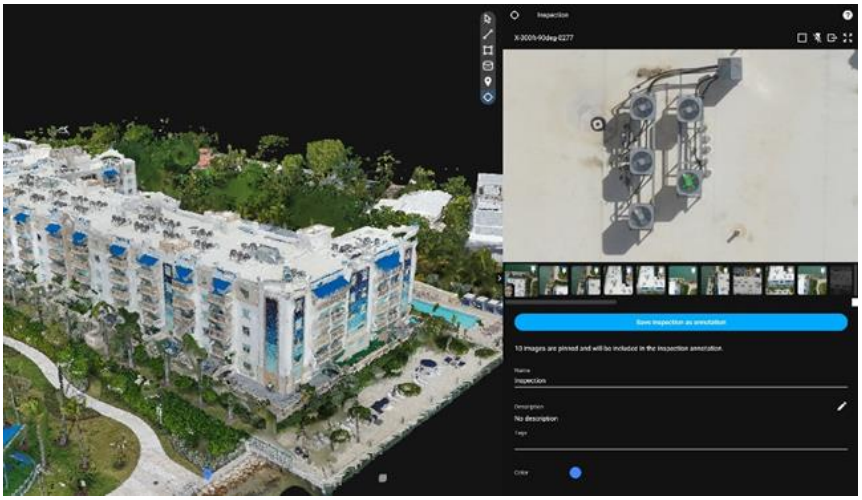


Figure 7. Section of the orthomosaic.

A 3D representation of the surfaces was prepared for virtual inspections, helpful in updating the building inventory, measuring elevations, and observing the conditions of the buildings, seawalls, debris, or other features that affect flooding (Figure 8).



10 images are pinned and will be included in the inspection annotation.

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Inspection

Description
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Figure 8. 3D visualization for inspections of buildings.

The building footprint inventory provided by Miami-Dade County's GIS service was improved with observations made with drone flights. Figure 9 shows some inconsistencies between both data sets.

Figure 9. Aerial image captured with drones and footprints as present in the City of Miami GIS data.

A 3D profile of the shoreline used for flooding simulations is included in figure 10.

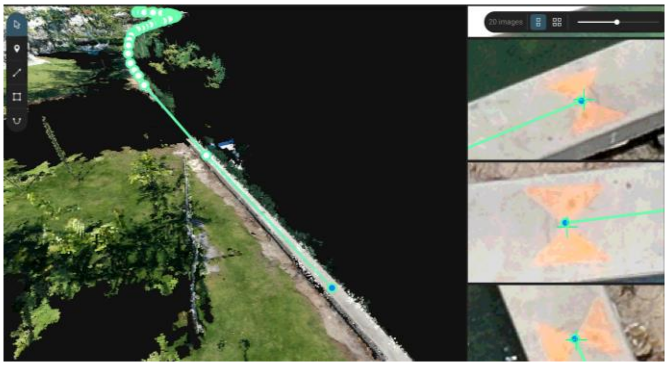


Figure 10. 3D Digital model of the seawall.

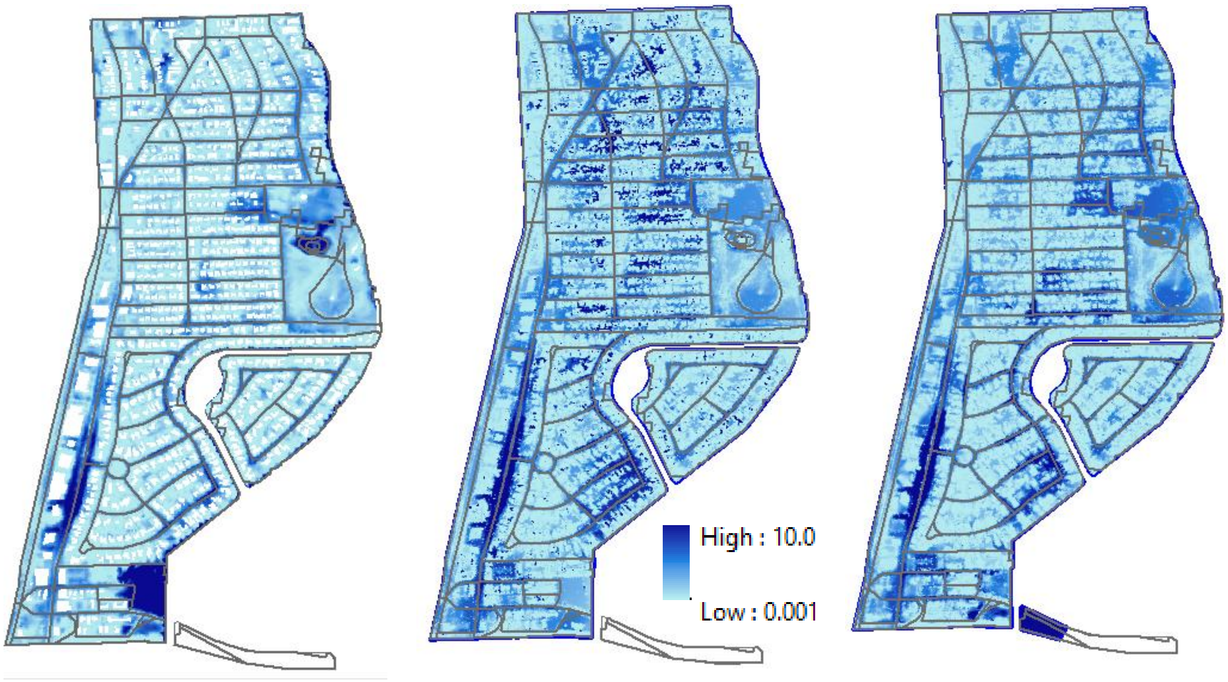
5. RiverFlow2D flooding model

RiverFlow2D (www.hydronia.com) is a combined two-dimensional (2D) hydrologic and hydraulic, sediment transport, and water quality mesh model for rivers, floodplains, estuaries, and coastal areas. RiverFlow2D computes velocities, depths, sediment, and pollutant concentrations in triangular cell meshes that can be adapted to irregular boundaries and represent bathymetric gradients. The model generates stable and accurate finite-volume solutions with virtually exact local and global mass conservation at the triangular-cell level. The model computes at each triangular cell the water velocity vector and depth. Velocities and depths are a function of the time-dependent wind field and tides. This software determined the depth grid for flooding analysis. Figure 11 presents the results for a 100-year event (Hydronia, 2020). The flood maps display the distribution of flood depth for each block using:

- The existing public topography.
- Updated using Digital Surface Model.

- Updated using Digital Terrain Model.

Updated maps show larger and deeper flood areas than the public map. Minor differences can be appreciated between the DSM and the DTM. The maximum depth reached at specific sites in the tract is 10 ft.



a) Using Existing Public Topography

b) Using Updated DSM

c) Using Updated DTM

Figure 11. Water depth (ft) for a 100-year event (Hydronia, 2020).

6. Improving Disaster Risk Assessment

6.1 Models

The methodology followed in this project uses FEMA-HAZUS software (FEMA 2009a and 2009b) and is carried out in four steps (Figure 12): 1) Hazard, 2) Exposure, 3) Vulnerability, and 4) Risk (Coronel and López, 2020). In this application, hazards considered hurricane-force winds for 500 years and flooding due to rain for a 100-year return period. The buildings' exposure is defined by their geographical location, physical characteristics (area, height, age, materials, typology, and others), and their exposed value in economic terms and occupants. The intensity of the event defines vulnerability by building damage and loss functions. The risk and its physical, economic, and social impacts are expressed in damage to buildings, direct economic losses, displaced population, short-term shelter requirements, and debris generation. HAZUS is used for hazard and risk analysis, developed, and freely distributed by FEMA.

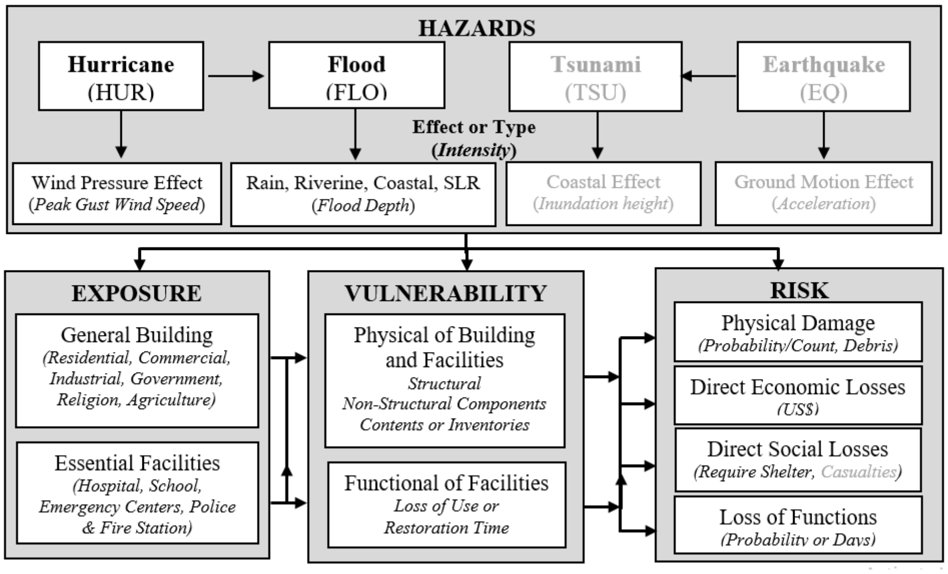


Figure 12. Hazard, Exposure, Vulnerability, and Risk, to determine the impacts of natural hazards.

The results obtained using two analysis models are presented herein. They differ in terms of the quality and quantity of information presented herein. Model 1 using FEMA-HAZUS public building inventory based on the 2010 US Census. Model 2 used improved inventory with updated data captured with drones and other sources.

HAZUS FEMA level 3 analysis for building-by-building evaluation is being carried out with a detailed building-by-building inventory; results will be presented in another paper.

6.2 Inventory of Exposed Buildings

An application example is presented for the selected Census Tract. According to the FEMA-HAZUS Public Inventory, this Census Tract has 86 Census Blocks, a population of 2,453 and 920 buildings. The National Inventory of Structures (NSI) public database reports 923 buildings. A review of FEMA-HAZUS and NSI's public data shows that buildings' quantity differs from the building footprints observed when inspecting the aerial images.

An Improved Inventory of buildings is developed with the drone's data and other sources of information. An optimizing procedure for GIS data has been implemented. Significant differences were observed between the Improved Inventory and the Public Inventory. The total exposed square footage for all buildings in the improved inventory is twice the public data area. Table 1 shows the total economic value exposed (defined as the replacement cost of Building and Content) in thousands of dollars, grouped by Occupancy Type. The total cost in the improved inventory is 2.6 times that of the Public Inventory; the increment is more notorious for Residential Buildings, 3.2 times.

Occupancy Type	Public Inventory FEMA-HAZUS	Improved Inventory This Study
Residential	366,433	1,153,585

Commercial	227,422	473,395
Industrial	13,252	0
Agriculture	1,346	0
Religion/Non-Profit	33,562	56,581
Government	2,656	2,370
Education	16,710	38,202
TOTAL	661,381	1,724,133

Table 1. Total Replacement Cost (thousands of dollars) by Occupancy Type for the Improved Inventory compared to the Public Inventory.

6.3 Risk results: physical, economic, and social impacts

The results presented below were determined using HAZUS, considering the improved inventory. Results obtained with the public inventory are shown for comparison. The input topography was the public map (Figure 11. a).

a. Damage

Figure 13 shows the building count for each damage state produced by hurricane winds. When the improved inventory is used (Model 2), more buildings reach complete damage. Figure 14 shows the damage distribution in the 86 blocks for the 100-year flood. The improved inventory (Model 2) leads to a different spatial distribution of the damage as compared with the public inventory (Model 1); the concentration of damage no longer appears in block 1021 (42 buildings), now being block 1008, the one with the highest density with 24 buildings with damages.

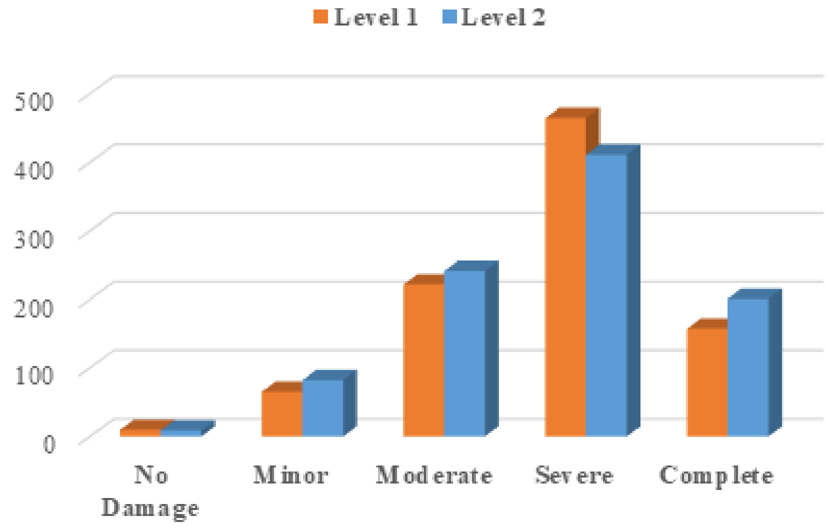


Figure 13. Building count by damage state for Hurricane Winds (500-year return period).

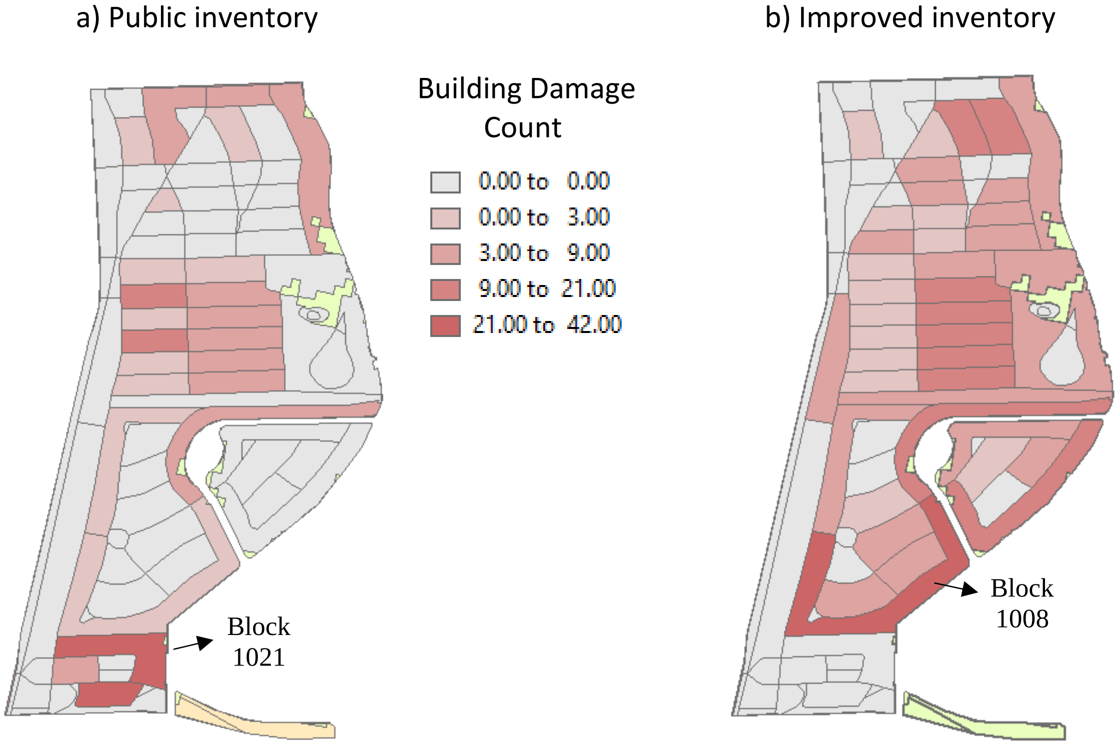


Figure 14. Distribution of building damaged by blocks for flooding (100-year return period). Arrows show the blocks with the highest concentration of damage.

b. Economic losses

Figure 15 shows the Economic Losses for all buildings for the 500-year Hurricane using the improved (Model 2) and the public inventory (Model 1). Model 2 total losses are $937.6 million (54.4% of replacement cost). Losses predicted by Model 2 are 2.5 times the predicted by Model 1. Two hypotheses were analyzed to cover data uncertainty: a strong one that considers the building types' strongest characteristics and a weak one for the weakest characteristics. The strong hypothesis leads to a significant decrease in the economic losses, of 54.4% to 47% of the replacement cost.

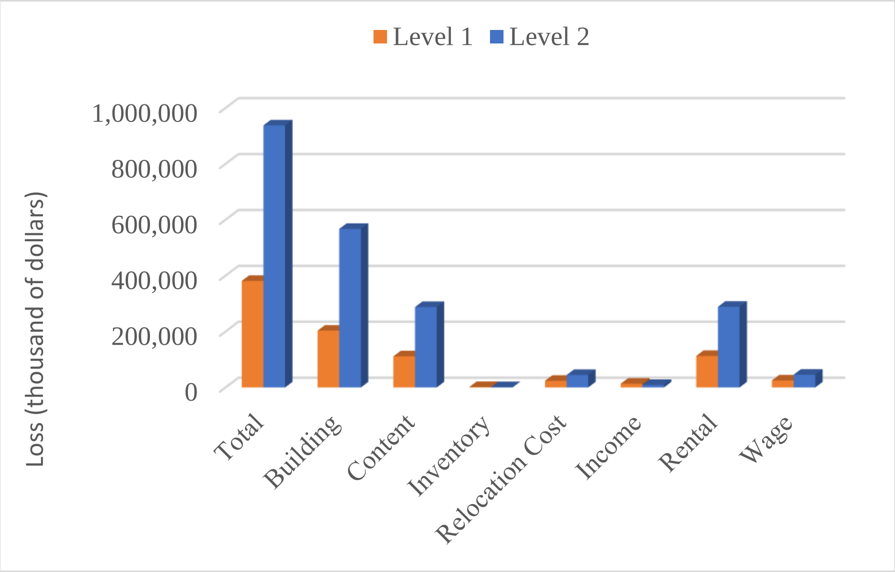


Figure 15. Comparison of Direct Economic Losses using improved inventory (Model 2) and public inventory (Model 1) for 500-year Hurricane winds.

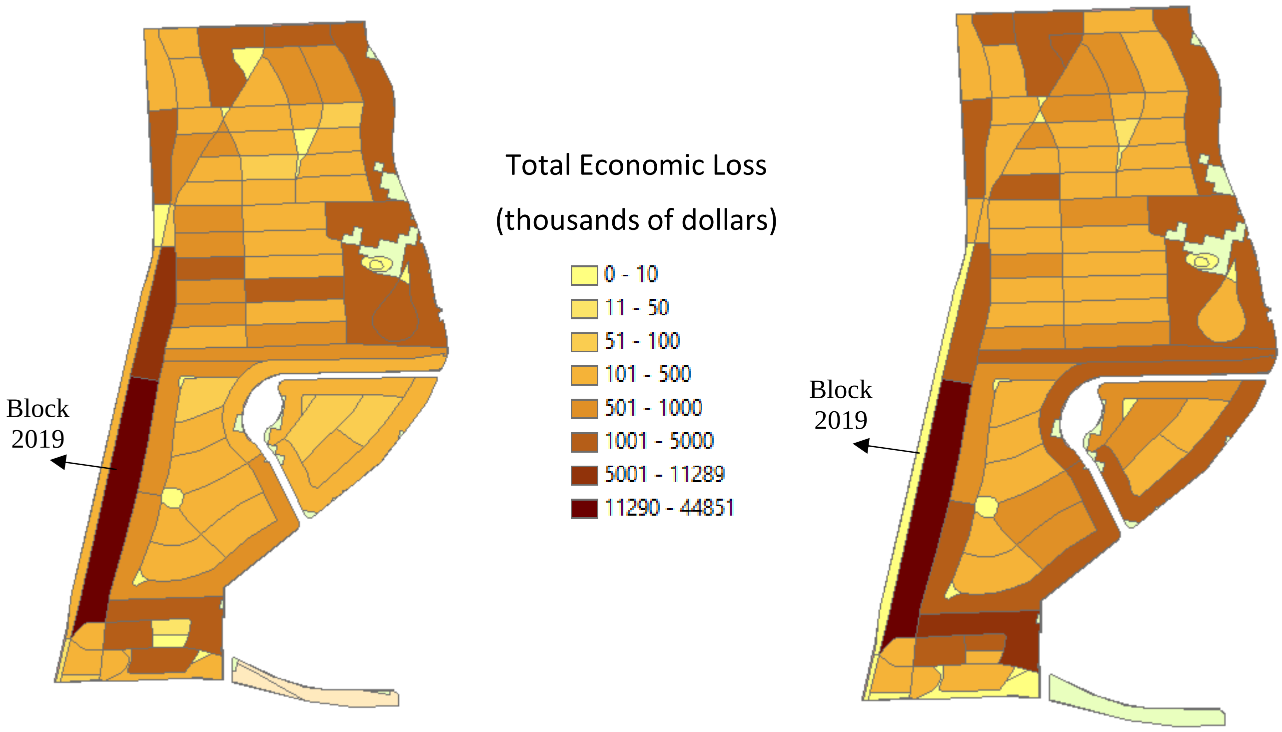
For the 100-year floods, the Total Economic Losses represent 6.1% of the replacement cost using the improved inventory (Model 2). Changes are also observed in the spatial distribution of losses (Figure 16). The most considerable losses are in the 2019 census block: $14,118,000 in Model 1, increasing to $44,851,000 in Model 2. The mean total economic loss is 1.7 times the loss obtained with the public inventory.

c. Displaced Population and Shelter Requirements

The impact of 500-year hurricane winds for Model 2 indicates that 781 households (or 2,343 people) will be displaced. Of these, 477 people (out of a total population of 2,453) will seek short-term shelter needs, which is slightly higher (4.5%) than the results for Model 1. The 100-year flood will displace an estimated 666 households (or 1,998 people). Displacement includes households evacuated from within or near the inundated area; of these, 123 people will seek temporary shelter.

d. Debris

47,927 tons of debris is estimated to be generated by the 500-year Hurricane using the improved inventory (Model 2) (1.9 times more than using Model 1). For the 100-year flood, Model 2 estimates a total of 297 tons (1.8 times more than Model 1) that will require 12 truckloads (@25 tons/truck) to remove the debris.


a) Public inventory

b) Improved inventory

Figure 16. Distribution of Total Economic Loss by blocks for 100-years Flood.

7. Ongoing research

The continuation of GISEC includes several research and capacity development activities that are being deployed:

- Building by building risk evaluation, using FEMA Level 3 and building data.
- Use lidar for Digital Surface models, allowing vision under vegetation.
- Analysis of Social Vulnerability and Community Resilience.
- Analysis of Socially Vulnerable Census tracts with high Risk in sea-rise level affected areas of Miami Beach
- Analysis of corrosion and its impact on fragility and vulnerability curves for risk assessment.

8. Conclusions

GISEC Project developed an academic pathway and the enhancement of technological applications for environmental hazards awareness and community engagement in Miami-Dade County. An educational pathway from high school to undergraduate and graduate studies was created. This pathway is centered on GIS and includes study cases related to disaster risk analysis, climate change, and a research and project learning platform.

The Census Tract 12086002100 of Miami-Dade County was selected as the first study area.

The Risk evaluation process includes the following steps:

- Target Zone selection
- Drone flight planning, completion, and data generation.
- Photogrammetric data processing, high-resolution topographic models, and urban modeling.
- Modeling and application of Hydronia for flooding analysis.
- Hurricane hazard generation using FEMA-HAZUS for deterministic and probabilistic hazard generation.
- Compilation of public records data; use of this data in FEMA-HAZUS Models, detecting inconsistencies, and improving the data for the exposure and vulnerability assessment.
- Risk evaluation under hurricane and flooding following deterministic and probabilistic approaches, delivering estimations of economic losses and social impacts, using FEMA-HAZUS, and including data generated with drone flights and inventory optimization. Risk includes potential physical, economic and social losses.
- Analysis of results.

Drone flights were performed to capture aerial images and create georeferenced data and 3D models in Census Tract 12086002100. Topographic maps, digital surfaces, and digital terrain maps were generated. Drone operations allowed for updating and improving the inventory of buildings reported by the National Inventory of Structures (NSI) public database, FEMA / HAZUS public database, and the available public topographic maps.

Significant differences were observed between the improved inventory here developed and the public inventory. The total exposed square footage for all buildings in the improved inventory is about twice the area included in the publicly available data. These differences show significant consequences in risk analysis. A more precise inventory allows better assessment of the social and economic losses in the event of disasters.

The RiverFlow2D software and the FEMA-HAZUS platform were used to model flooding input and hurricane-wind data and to estimate risk in terms of economic and social losses. The total economic losses for hurricanes and floods using the improved inventory (Model 2) are about 2.7 and 1.7 times the losses obtained with the public inventory (Model 1).

An analysis of the primary methodologies employed in assessing the economic impact of natural disasters, direct and indirect losses, mitigation factors, and guidelines for policymakers was carried out.

The availability of precise data and modeling results allows the assessment of expected losses in the face of extreme events and climate change. Planners and decision-makers can helpfully use risk assessment methodologies like the one described herein.

The project continues: HAZUS FEMA level 3 analysis for building-by-building evaluation is being carried out with a detailed inventory, additional data collected with drones, and analysis of uncertainties included in building models. The following steps also cover the risk assessment due to storm surge floods and sea-level rise generated by climate change following multi-hazard integrated models. These ongoing developments also include determining social vulnerability and community resilience at the local level and its application to areas with high social and environmental vulnerabilities and high risks. Further applications of this methodology (not part of this paper) include estimating losses due to potential events and evaluating the losses prevented by adaptation projects.

This project is innovative and significant mainly because it creates a complete educational pathway from secondary to graduate levels that did not exist in Southeast Florida. It has also developed local capacities and methodologies to improve public data needed to deliver more accurate results in risk assessment under natural hazards.

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