

Advancing Flood Resilience in Grand Isle, Louisiana, in the United States of America, through Remote Sensing and GIS.

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Abstract

Flood risk in low-lying coastal zones is escalating due to a combination of climate change, land subsidence, and shifting land use patterns. This study develops a high-resolution flood-prone zone and resilience map for Grand Isle, Louisiana, employing remote sensing and GIS tools. The methods integrate supervised Land Use Land Cover (LULC) classifications, Cellular Automata-Markov modeling, hydrological indices (TWI, TPI, CTI), and multi-factor flood resilience metrics. Between 2015 and 2035, barren land more than doubled, and water bodies increased by over 33 km², indicating significant environmental degradation. By 2035, nearly 94% of the island is projected to lie within high-risk flood zones, while over 90% of the land is categorized as having very low resilience. These findings stress the urgent need for adaptive land use planning, ecological restoration, and infrastructure elevation to enhance flood resilience in Grand Isle.

1. Introduction

Flooding remains one of the most devastating natural hazards globally, affecting over 3.2 billion people and causing more than 218,000 deaths between 1990 and 2022 (Liu et al., 2024). Projections suggest that the number of people exposed to the 100-year flood hazard will rise from 1.6 billion in 2020 to 1.9 billion by 2100, a 24% increase driven by climate change, land-use shifts, and urbanization (Rogers et al., 2025). The global population living in flood-prone areas rose by 24.9% between 1970 and 2020, further highlighting the intensification of this risk (UNDRR, 2025). These developments make it imperative to develop refined, location-specific flood management tools.

Within the United States, flood-related disasters are increasingly frequent and costly, exacerbated by heavy precipitation, sea level rise, and intensifying storms.

Louisiana stands out as particularly vulnerable due to its low elevation, extensive wetland loss, and rapid land subsidence, averaging approximately 9 mm/year (Geosociety, 2023). Coastal Louisiana, especially the Mississippi River Delta, is suffering from shoreline retreat and wetland degradation, with the state accounting for up to 80% of U.S. coastal wetland loss (Burkett et al., 2003; Tibbetts, 2006).

Grand Isle is Louisiana's only inhabited barrier island and is uniquely vulnerable due to its geometry, elevation, and exposure to Gulf weather systems. It faces compounded threats from storm surges, sea-level rise, and changing rainfall patterns (Thomas, 2016; Miller, 2018). Although several studies have estimated potential property loss in Grand Isle under future climate scenarios (Mostafiz et al., 2021; Mostafiz et al., 2022), they typically focus on economic damage rather than spatially resolved hazard

mapping. Boesch (2020) provides policy insights on coastal adaptation but lacks the granularity needed for local planning. There also exists a methodological gap in integrating updated hydrological data, remote sensing outputs, and subsidence metrics into a unified flood-mapping model.

Recent work has underscored the role of nature-based solutions (Airoldi et al., 2021), spatial planning limitations (Oschmann & Lachenmann, 2021), and the potential of machine learning for flood forecasting (Nearing et al., 2023). However, these tools have rarely been tailored for small, subsiding coastal islands like Grand Isle. This research fills these gaps by using advanced geospatial techniques to develop high-resolution flood risk and resilience maps under current and projected future conditions.

2. Methods

The research was conducted in Grand Isle, Louisiana, where the area of interest was defined using shapefiles uploaded to Google Earth Engine (GEE). LULC classifications for 2015 and 2025 were derived from Landsat imagery using supervised classification with random forests. Future LULC for 2025 was projected using the CA-Markov model, which uses historical LULC maps (2005 and 2015) to generate transition probability matrices and simulates spatial dynamics using cellular automata. Suitability maps were created using slope, elevation, and distance to roads, all weighted based on expert literature (Sang et al., 2011; Naboureh et al., 2019).

DEM from the SRTM 30m dataset was used to compute slope, aspect, and several hydrological indices including the Topographic Wetness Index (TWI), Topographic Position Index (TPI), Compound Topographic Index (CTI), and drainage density. Flow accumulation and stream delineation were conducted using a D8 algorithm, with thresholds set at 1000 cells. Distance to streams and roads was also calculated.

LULC vulnerability was assigned based on land class susceptibility to flooding, and a resilience index was constructed using a weighted combination of eight normalized indicators: flood risk (25%), vulnerability (20%), TWI (15%), slope (10%), TPI (10%), and distances to streams and roads (10% each) (Zhang et al., 2023). Flood zones were defined based on elevation and refined using TWI and TPI to classify areas into high, medium, or low flood risk.

Change detection between LULC classes was performed using subtraction and transition matrices. Road vulnerability was assessed by overlaying buffers (50m, 100m, 200m) with

flood-prone and hydrologically vulnerable zones (Tehrany et al., 2015).

3. Results

From 2015 to 2025, significant LULC transformations occurred. Barren areas increased from 2.27 km² in 2015 to 5.58 km² by 2025, while developed land expanded from 3.71 km² to 9.39 km² by 2025 and stabilized thereafter. Marsh areas decreased from 10.40 km² to 8.67 km², with a partial rebound by 2025. Vegetation cover fell sharply from 7.38 km² to 4.82 km² in 2025 before recovering slightly to 5.99 km². The most dramatic change was in water bodies, which grew by over 33 km², reaching 295.34 km² by 2025. These shifts suggest both anthropogenic development and climate-induced transformations such as sea level rise and land submergence.

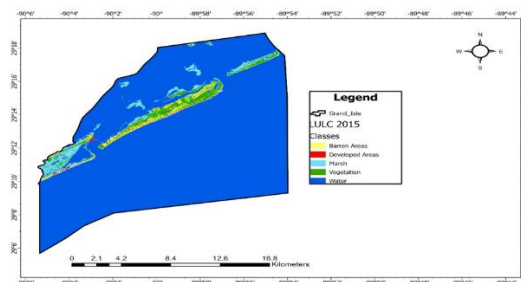


Figure 1: 2015 Land Use Land Cover (LULC) Map of Grand Isle

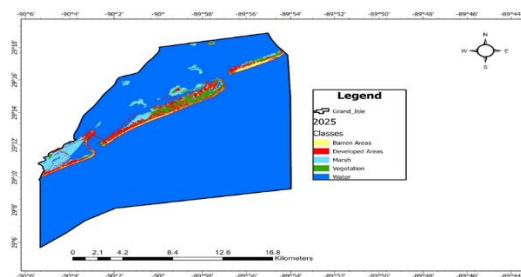


Figure 2: 2025 Land Use Land Cover (LULC) Map of Grand Isle

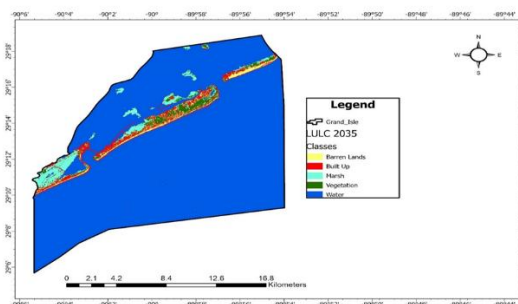


Figure 3: 2035 Land Use Land Cover (LULC) Map of Grand Isle

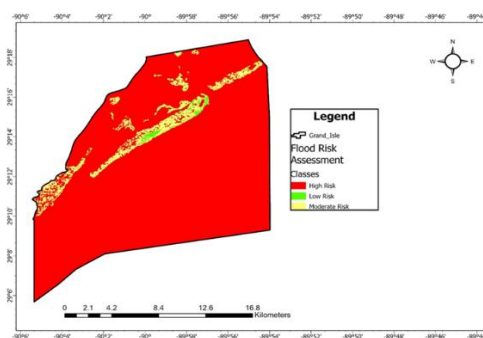


Figure 5: Flood Risk Map of Grand Isle

Change detection analysis revealed that 95.51% of the land remained unchanged between 2015 and 2025. However, conversions of marsh to developed (0.78%) and vegetation to marsh (0.62%) reflected mounting pressures on natural systems. Developed land also encroached into barren, vegetation, and even water zones, while some developed areas reverted to natural states, possibly due to abandonment or erosion.

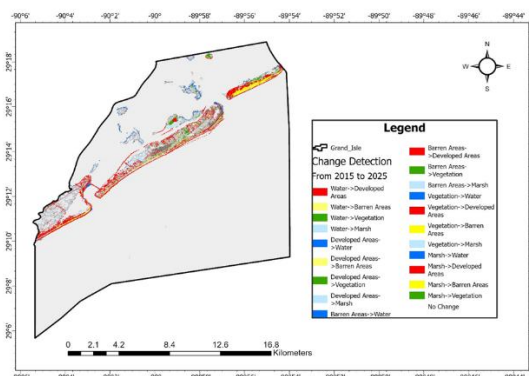


Figure 4: Change Detection for Grand Isle

The flood risk assessment showed that by 2035, 93.97% of the island falls within high-risk zones, primarily those under 2 meters in elevation. Only 0.81% was classified as low risk, indicating a lack of safe zones for development or evacuation.

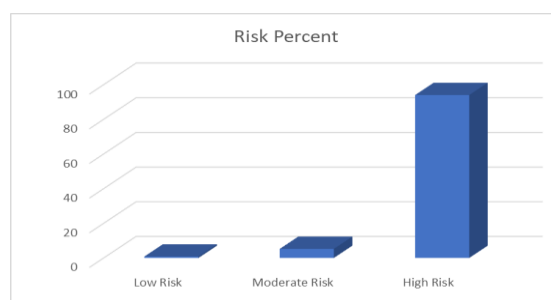


Figure 6: Flood Risk Chart

Resilience mapping underscored this vulnerability, with very low resilience covering 90.7% of the land in 2025 and 90.72% in 2035. Moderate and high resilience zones remained under 6% combined, suggesting that little progress has been made toward improving flood preparedness.

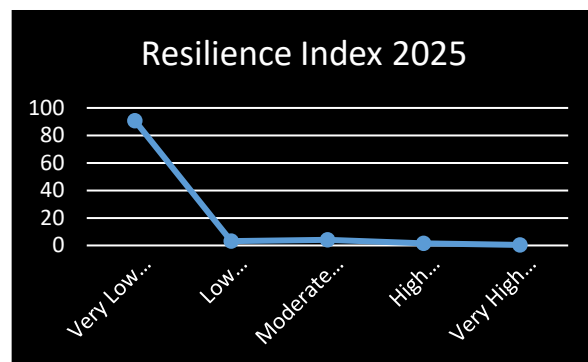


Figure 7: 2025 Flood Resilience Map of Grand Isle

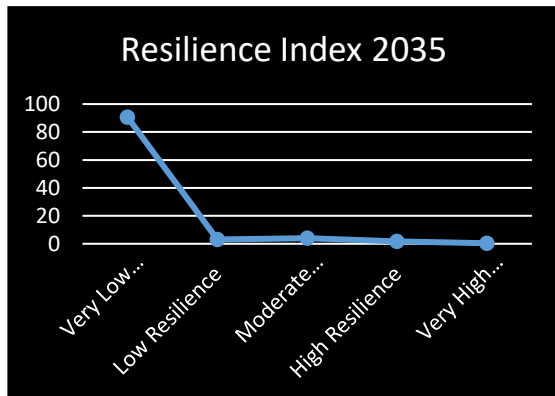


Figure 8: 2035 Flood Resilience Map of Grand Isle

4. Discussion

The findings from Grand Isle illustrate the complex interaction between anthropogenic development and environmental degradation driven by climate stressors. The increase in barren areas and reduction in vegetation and marshland reflect both natural shoreline erosion and human activities such as infrastructure expansion. These patterns are consistent with regional trends across the Gulf of Mexico, where sea-level rise and subsidence have led to accelerating wetland loss (Couvillion et al., 2017; Turner et al., 2018).

The expansion of developed land between 2015 and 2025 is particularly concerning. While it may reflect post-Katrina recovery and tourism development, it likely contributed to the loss of vegetation and marsh cover, reducing the island's natural capacity to buffer floods (Kim et al., 2019; CPRA, 2023). Although some marsh recovery is visible by 2035, it remains insufficient to offset the earlier loss. Likewise, the significant increase in water coverage may be indicative of permanent land loss due to sea-level rise, as predicted in several NOAA and IPCC models (Sweet et al., 2022; IPCC, 2022).

Resilience mapping paints a stark picture of Grand Isle's limited ability to adapt or recover from flood events. Over 90% of the island remains in a state of very low resilience, with negligible improvements over two decades. The small gains in high and very high resilience areas suggest localized efforts or inherent advantages such as higher elevation or intact marshes, but these are exceptions rather than the norm.

The implications of these results are profound. With almost the entire island at high flood risk and minimal resilience, Grand Isle faces potential long-term uninhabitability without urgent adaptation measures. Strategies must include wetland restoration (Arkema et al., 2015), elevation of infrastructure

(FEMA, 2021), nature-based defenses like living shorelines (Opitz et al., 2015), and strict zoning regulations to reduce exposure (Anderson & Stancioff, 2021). Without coordinated action, the current trajectory suggests increasing displacement and ecological collapse.

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