ANALYZING THE IMPACT OF SEA LEVEL RISE ON COASTAL FLOODING AND SHORELINE CHANGES ALONG THE COAST OF LOUISIANA USING REMOTE SENSORY IMAGERY.

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KEYWORDS: Hurricanes, Louisiana floods, Coastal Areas, Spatiotemporal, Tropical Storms, Flood Extent

ABSTRACT:

Sea level rise poses risks to coastal areas which is increasingly rendering such areas susceptible to flood and shoreline retreat. Notably, coastal areas like Southern Louisiana located along the Gulf of Mexico has experienced endangering events of land subsidence due to flood inundations resulting from incessant distribution of hurricanes and tropical storms. This research therefore employed remote sensing data to analyze the impacts of sea level rise on coastal flooding and shoreline retreat along the coast of Louisiana. That is, by assessing Sentinel-2 imagery data to evaluate flood prone and flood extent areas particularly during the Louisiana floods and Hurricane Harvey. Based on this, the results show most of the inland parishes in coastal Louisiana such as Assumption, St. James, Livingston, Lafourche and Terrebonne were within high flood risk zones of about 9.3. These parishes also suffered severe damage in terms of affected croplands, potentially flooded areas and affected urban areas. On the other hand, most of the parishes in close proximity to the waterbodies such as the Gulf of Mexico were interestingly within low flood risk zones of about 6.1 suggesting proximity to waterbodies not being the only indicating factor of a flood prone area. This research also highlights that Louisiana's shorelines are rapidly receding at a rate that could result in the loss of one million acres of the state's land in the next four decades. Hence, the results from this research are anticipated to contribute to sustainable shoreline setback plans and mitigative strategies to protect Louisiana's coast.

1. INTRODUCTION

The entire planet is experiencing climate change and global warming impacts such as sea level rise, of which the state of Louisiana is no exception to these effects. Although sea levels have been rising since the end of the last glaciation (nearly 11,000 years), the rate of sea-level rise has increased over the past 200 years due to an increase in average temperatures (Evans, 2004). Thus, the incidence of global warming has added more water to the oceans by melting ice in the polar regions, as well as thermal expansion of the oceans, resulting in a rise in sea level due to increasing water temperature. Unfortunately, based on the location of Louisiana along the Gulf of Mexico, its low-lying environs are particularly more prone to certain natural disasters especially, floods and hurricanes. This is due to the Gulf's warm water being an ideal spot for the formation of hurricanes each year because naturally, the water is expected to be at least 80 degrees Fahrenheit to sustain an event of hurricane, of which the Gulf has consistently recorded 83 degrees during summer (Barker, 2021), creating a perfect condition for the occurrence of hurricanes.

Due to the low coastal elevation of the state, major issues have been recorded concerning coastal flooding for the past ten years, during which most of the parishes suffered several natural disasters such as storms, tropical cyclones as well as hurricanes (Twumasi, et al., 2020). For instance, the recent floods in August 2016, destroyed parts of the surrounding coastal areas in southern Louisiana which were accompanied by damage to properties and loss of lives (Twumasi, et al., 2020). Notably, Louisiana has experienced series of hurricanes that date as far back as hurricane Audrey (1957), hurricane Betsy (1965), hurricane Camille (1969), hurricane Andrew (1992), hurricanes
Katrina and Rita (2005), hurricane Ike (2008), hurricane Laura (2020) and the most recent hurricane Ida that occurred in 2021. Highlighting the biggest and most devastating event being hurricane Katrina in 2005, 275,000 homes in New Orleans with more than 10 feet of water, resulted in approximately $100 billion in damages (NOAA, 2022). Also, according to the most recent National Hurricane Center (NHC) assessment, Katrina was also directly responsible for approximately 1,200 fatalities, making it the third worst hurricane to ever hit the United States (Blake & Gibney, 2011).

Considering the degree of damage that is caused during hurricanes, flooding and erosion events, New Orleans (Southeastern Louisiana) for instance has still not made full recovery from these events since the recent storm displaced more than 1 million people at its peak and more than 400,000 people permanently. More so, higher sea levels have been a major concern, especially in New Orleans as the city is getting warmer, with rising waters threatening low-lying residents and properties with flooding. Based on the rate of subsidence and the mid-range estimate of sea-level rise during the next 100 years (480 millimeters), the areas of New Orleans and vicinity that are presently 1.5 to 3 meters below mean sea level will likely be 2.5 to 4.0 meters or more below mean sea level by 2100 (Burkett & Hart, 2003). Similarly, Paine (2013), highlighted the incident along the upper Texas coast (southeastern Louisiana), where the shoreline is retreating at an alarming rate of about 1.6 meters each year. Thus, relative sea-level rise, local circulation patterns, high intensity storms and lack of sediment supply combined with human activities along developed areas of the barrier island are likely contributors to this chronic erosion (Paine, 2013).

Generally, the rate at which Louisiana's coast is retreating can be translated into a gradual sinking phenomenon of the whole state into the Gulf of Mexico and surrounding waterbodies. Agreeably by the United States Geological Survey (USGS), the coastal change forecast predicts that more than half of Louisiana's barrier islands and beaches will be inundated or continuously submerged with flooding behind the dunes as a result of the storm surge from Hurricane Laura (USGS, 2020) for instance. This leaves the coast of Louisiana highly threatened by constant events such as intense flooding, erosion, hurricanes and subsequent coastal loss as a result of the uncontrollable or inevitable rise in the level of the sea. This research is therefore significant by utilizing remote sensing to map flood-prone and flood extent areas especially during the Louisiana floods, Additionally, this research holds significant importance in providing valuable spatial information for understanding the extent of the floods, assessing their impacts, and informing future flood management strategies.

2. RESEARCH METHODOLOGY

2.1 Research Study Area

Louisiana being a state located in the United States of America is delineated from its neighbors Arkansas to the North, Mississippi to the East, Texas to the West with the Gulf of Guinea lying to its South. The total area of Louisiana includes about 4,600 square miles (12,000 square km) of inland waters (Norrell, 2022). That is, in addition to lakes, Louisiana is home to many rivers such as the Mississippi River, the Atchafalaya River, the Red River, and the Sabine River (WorldAtlas, 2023). The state receives substantial amount of precipitation throughout the year, with northern regions averaging around 50 inches and certain southeastern areas reaching up to approximately 70 inches (NCEI, 2022). The highest point in Louisiana is Driskill Mountain at 535 ft, while the lowest point is -9 below Sea Level (WorldAtlas, 2023). According to the U.S Geological Survey (USGS), even though the state's unique geography and associated ongoing geologic processes are environmentally significant, they contribute to coastal erosion, wetland loss, saltwater encroachment into surface and ground waters, land subsidence, and flooding.

2.1.1 Study Site – Coastal Louisiana:

Coastal Louisiana (fig 1) is located on the North American continent between 29° and 31° north latitude, a third of the way from the equator to the North Pole. North of the Tropic of Cancer (23.5° N), it possesses a humid subtropical climate greatly influenced by its position on the Gulf of Mexico, a relatively warm body of ocean (Snead et al., 2019). Some of the parishes in coastal Louisiana include Orleans, St Mary, St Martin, Charles, Cameron, Jefferson, Assumption, Plaquemines and Terrebonne. The coastal zone of Louisiana encompasses approximately 37,780 square kilometers (km2) of lowland plains, deltaic lobes, and open water (Couvillion et al., 2017).

2.2 Data Acquisition

The data to map out flood-prone areas along the coast of Louisiana were retrieved from the United States Geological Survey (USGS) 3D Elevation Program with a resolution of 5m. In assessing areas that are below the elevation of the sea level and are prone to flooding, the elevation data from the USGS 3D Elevation Program was downloaded data and analyzed in ArcGIS Pro. By creating a single mosaic elevation image map of the study area, Spatial Analyst tool was further used to classify areas with low and high elevations.

To assess the flood extent areas and the impacts of flooding events in Coastal Louisiana, some case studies of a recent tropical storm or hurricane were used. Also, this study followed the flood analysis methodology recommended by UN SPIDER, which involves utilizing Google Earth Engine (GEE) for flood mapping. The Sentinel-1 Level-1 Ground range Detected (GRD) data collection was selected as the primary data source.

2.2 Data Processing

To ensure accurate flood mapping, a series of pre-processing steps were undertaken including thermal noise removal, thus,

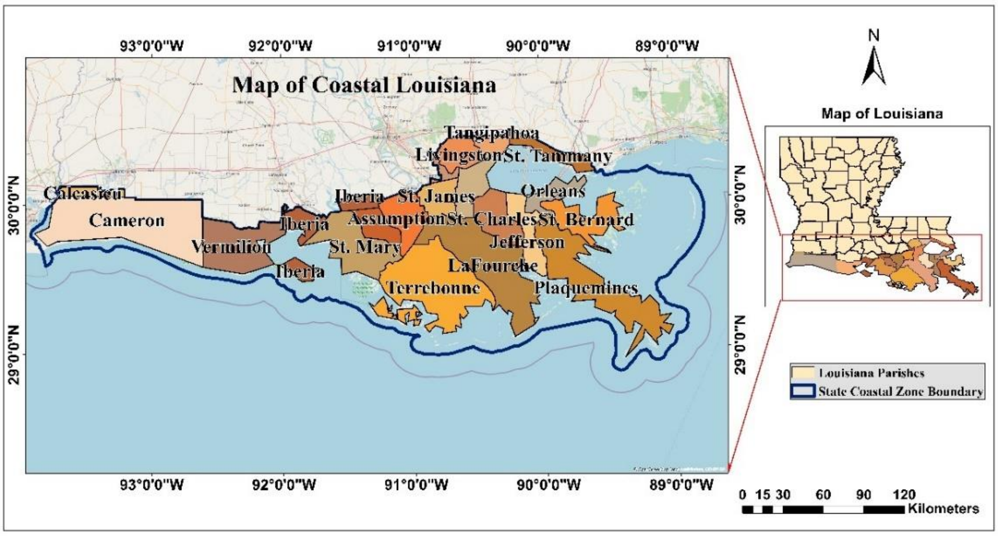

Figure 1 - Map of Coastal Louisiana

eliminating noise caused by temperature variations and atmosphere interference in order to improve the reliability of the flood detection process. Next, radiometric calibration was also performed to standardize the data across different acquisitions. This process involved adjusting the raw radar measurements to a common scale, enabling meaningful comparisons between different images. By calibrating the data, variations in radar response due to sensor and environmental conditions were accounted for, resulting in more consistent flood analysis. Terrain correction such as layover and shadow effects, were also carried out to account for the effects of topography on the radar signal and to obtain accurate measurements of the backscatter signal and reliable flood detection or delineation. The pre-processing tasks were then accomplished using the Sentinel-1 toolbox to ensure access to the latest algorithms and functionalities, improving the overall accuracy and reliability of the flood mapping process. Given that like-polarization is considered more effective than cross-polarization in delineating flooded areas, the study specifically utilized VV-backscatter for flood inundation mapping. By focusing on the VV polarization, which represents the vertical transmit and vertical receive orientation, the methodology aimed to optimize the detection and mapping of flooded regions.

3. RESULTS AND DISCUSSION

3.1 Flood prone areas in coastal Louisiana

Sea level rise has had a significant impact on coastal flooding and shoreline retreat in numerous regions worldwide, including coastal Louisiana. The rising sea levels exacerbate the risk of flooding by elevating baseline water levels during high tides and storm surges (Sweet et al., 2017). As sea levels continue to rise, the frequency and severity of coastal flooding events increase, threatening both human settlements and natural habitats.

The combination of rising sea levels and land subsidence also tends to intensify coastal erosion and contributes to shoreline retreat. As the sea encroaches further inland, waves, currents, and storm surges erode the coastline, resulting in the loss of land (Kulp and Strauss, 2019). This erosion does not only affect the physical landscape but also leads to the destruction of valuable wetland ecosystems that serve as natural buffers against storms and provide vital habitat for diverse species.

With reference to the phenomenon along the coast of Louisiana, the flood prone areas that were mapped as shown in figure 2 indicate that most of the parishes are at high flood susceptibility risks. Parishes such as Livingston, Tangipahoa, St. James, Orleans and some parts of St. John the Baptist parish are showing high vulnerability to flood risks. Notably, most of these parishes are inland regions that are not in proximity to the Gulf of Mexico but are considered high flood areas. This is because flood risk areas that are associated to sea level rise events take into consideration the elevation or slope of these regions, respective regions' land cover types, the amount of precipitation received as well as the flow accumulation and direction.

According to Sea Level Rise.org, other major causes of sea level rise incidents in most of these parishes especially in coastal Louisiana is attributed to the sinking of the land due high extraction of underground water for domestic or industrial activities, the drying up of wetlands which loses its density and causes the land to sink lower, as well as the increase in built-up areas in heavily populated areas which pushes down the land below sea levels. More so, due to pressure from rising sea levels and higher tides, seawater can also be pushed into these pipes and spill out into the streets which can cause flooding in these inland parishes even on days without rain (nuisance flooding).

For this reason, areas such as Orleans parish are also susceptible to more flood incidents due to its natural geography. Thus, the original levee on which New Orleans was built was quite small and as the city's population grew, New Orleans expanded into the swamps and marshland below the levee (Hore-Kelman, 2021). This has rendered New Orleans the largest population center at risk from sea level rise in the country and is now experiencing one of the highest rates of sea level rise in the world. More so, an example of a Louisiana parish that suffered from sea level rise and flooding incidents during the Louisiana floods is Plaquemines Parish. Plaquemines Parish, located in southeastern Louisiana (fig 2) along the Mississippi River and the Gulf of Mexico, is particularly vulnerable to the impacts of sea level rise and coastal flooding. Particularly, this parish has experienced recurrent flooding events, with rising sea levels exacerbating the risk of storm surge and inundation in low-lying areas,

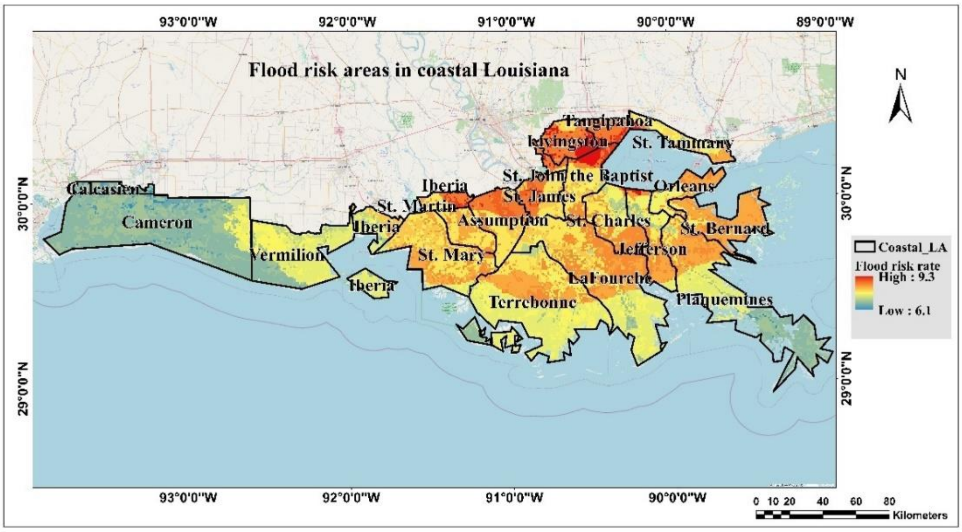

Figure 2- Map of flood prone areas in coastal LA

including communities such as Braithwaite, Pointe-a-la-Hache, and Port Sulphur.

Due to this, the state is already losing approximately 25 square miles of land per decade as a result of sea level rise thereby threatening Louisiana's coastal marshes, which provide protection for inland communities and habitat for countless species (Scott, 2022). However, considering the low flood risk rates observed in parishes like Cameron as shown in figure 2, this challenges the assumption that regions in close proximity to the Gulf of Mexico are inherently at high risk of flooding events. This therefore highlights the significance of other contributing factors that link sea level rise to likely flood events occurring in inland regions.

3.2 Flood extent areas in coastal LA (August 2016 – August 2017)

Most areas along the coast of Louisiana are noted for major and frequent flood events since the 1900s such as the Great Mississippi Flood in 1927 or the Great Flood of 1993 which occurred during the Spring and Summer of 1993. This was preceded by other major flood events during Hurricane Katrina in 2005, Louisiana Floods in 2016 and Hurricane Harvey floods in 2017. According to the National Weather Service, the Louisiana floods for instance, killed 13 people, and damaged about 40,000 homes as a result of the severe rainfall that drenched the Baton Rouge area. Other areas that are known to have experienced serious flood damage include Lafayette and the Acadiana region which extends to parishes such as like Vermilion, Iberia, and St. Martin, were heavily impacted, with homes, businesses, and roadways submerged. Terrebonne and Lafourche Parishes, located southwest of New Orleans, faced flooding in both urban and rural areas, affecting communities like Houma and Thibodaux. Additionally, Lake Charles and Calcasieu Parish in southwest Louisiana witnessed flooding in various neighborhoods during the Louisiana floods.

Therefore, following the recommended practices outlined by UN SPIDER and employing advanced techniques in data pre-processing and polarization selection, the study aimed to enhance the accuracy and effectiveness of flood mapping using the Sentinel-1 GRD data within the Google Earth Engine platform. The two main flood events that were used were the Louisiana Floods in August 2016 and the flooding event during Hurricane Harvey in August 2017. Based on this, the flood status that was used in GEE for the analysis was between 2016-08-15 and 2017-08-25. According to the map generated in GEE, as seen in figure 3, some of the parishes that showed main flood extents during the flood status include St. James, St. Charles, St. John the Baptist, Assumption parish, Terrebonne and some parts of Lafourche. Moreover, after processing the flood status in GEE, the estimated flood extent areas covered about 151,746 hectares with an estimated 79,121 number of exposed people. An estimation of 21,551 hectares affected cropland and 43,825 affected urban areas were also projected within the given period.

Other southern Louisiana parishes that are not indicated in the coastal Louisiana map (especially in figures 2 and 3) such as Baton Rouge also experienced a fair share of damage resulting from the flooding events. Its surrounding parishes, such as Livingston and Ascension, were heavily affected by the floods in 2016, with widespread inundation and damage to homes and infrastructure (FEMA, 2016). Similarly, Hurricane Harvey in 2017 brought substantial rainfall and caused extensive flooding in southwestern Louisiana, particularly in Calcasieu Parish, including the city of Lake Charles (NOAA, 2018). These flood events resulted in large-scale flood extent areas, disrupting communities and necessitating significant recovery and relief efforts.

More so, floods in coastal Louisiana during the Louisiana floods and Hurricane Harvey highlighted the vulnerability of low-lying regions to extreme weather events and the challenges posed by sea level rise. The combination of heavy rainfall and rising sea levels worsened the flooding incidents, leading to widespread inundation of coastal areas. The impacts of these flood events extended beyond the immediate floodplains, affecting neighboring communities and straining existing infrastructure and emergency response systems (LDTD, 2018). These events therefore underscore the importance of integrating remote sensing techniques to map flood prone/extent areas to enhance community preparedness, and the development of resilient infrastructure to effectively mitigate the risks associated with flood extent in coastal Louisiana. Most importantly, sustainably efforts in these areas are prudent for enhancing resilience and minimizing the impacts of future flood events in coastal Louisiana.

Figure 3- Map of flood extent areas in coastal LA

Similar to figure 3, figure 4 is also a google earth image showing coastal Louisiana including the flooded areas, affected croplands and affected urban areas during the Louisiana floods and Hurricane Harvey.

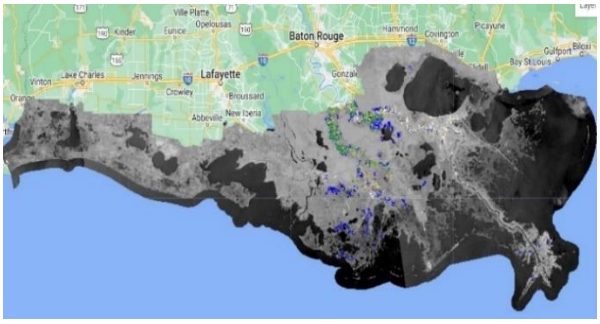

Figure 4- Map of flood extent areas in coastal LA with affected flooded areas, croplands, and urban areas.

Figures 5 to 7 therefore show zoomed-in images from GEE depicting the potential flood extent areas, the affected croplands and the affected urban areas. That is, the cropped image (fig 5) shows the potentially flooded areas depicted in blueprints or patches, along the coastal Louisiana during the Louisiana floods and Hurricane Harvey flooding incident. The areas showing deep black prints are waterbodies including the Gulf of Mexico located in the south.

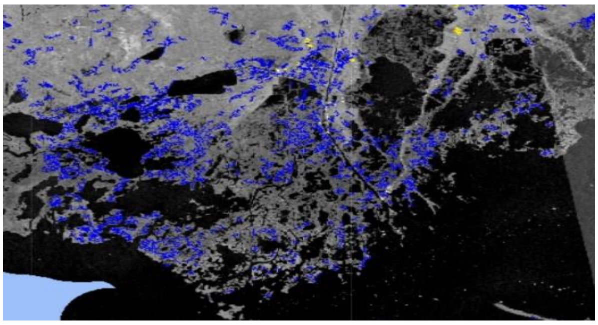

Figure 5- Cropped flood extent areas showing potentially flooded areas (blue)

In figure 6 also shows cropped sections of coastal Louisiana depicting flood extent areas illustrated with blueprints, with the affected croplands marked in green prints while some of the pink patches depict the affected urban areas. From fig 6, it

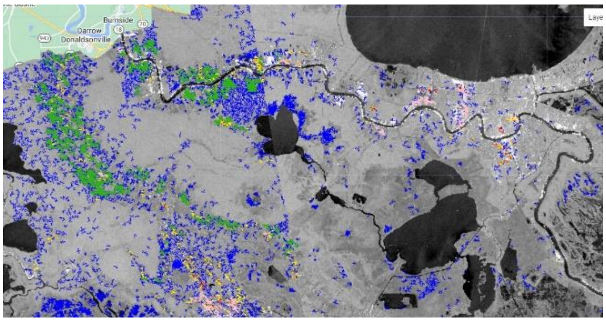

Figure 6 - Cropped flood extent areas showing some affected croplands (green)

is also deduced that most of the affected croplands were in Terrebonne, Lafourche and Assumption parishes. Figure 7 also shows patches of affected urban areas in parishes like Livingston, St. John the Baptist ant Tangipahoa parishes. Figure 8 therefore shows all sections of flood extent areas that were cropped from the main coastal LA area. Evidently aside some the areas in proximity to the Gulf of Mexico being susceptible to flooding incidents, some inland areas also suffer from flood risk events during sea level rise events.

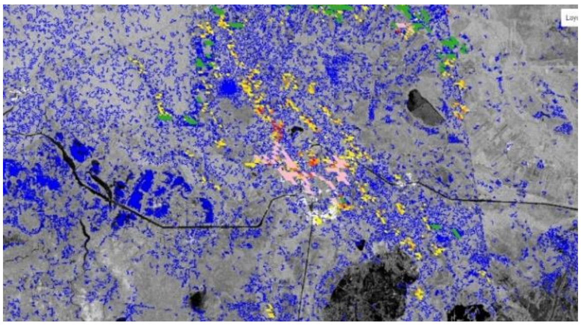

Figure 7 - Cropped flood extent areas showing affected urban areas (pink).

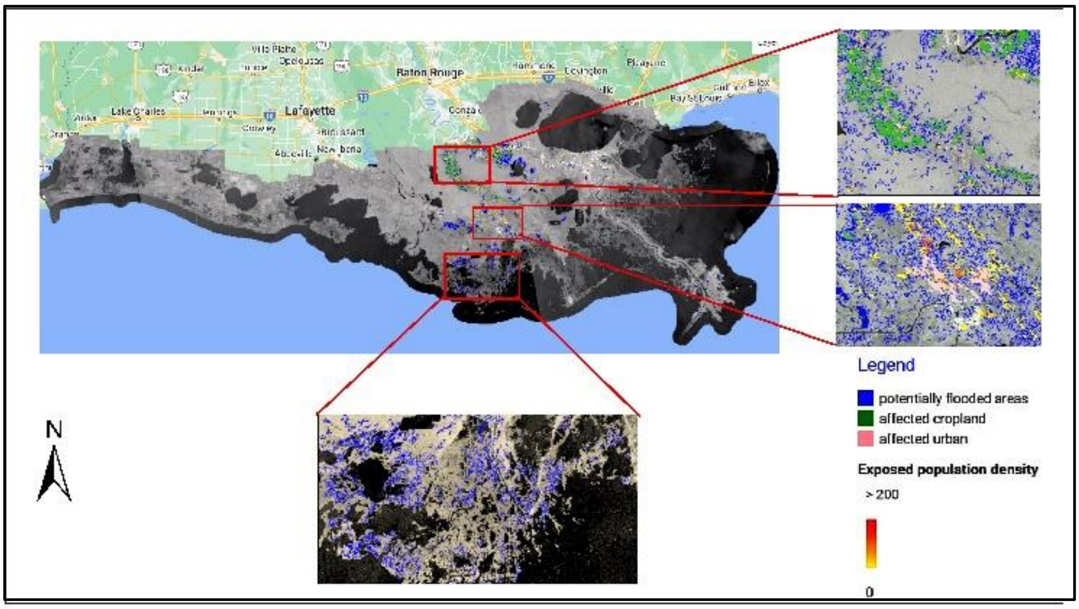

Figure 8 - Flood extent areas from coastal LA

3.3 Shoreline changes in Coastal Louisiana

Louisiana’s shoreline represents a dynamic and intricate coastal landscape that encompasses a diverse array of ecosystems, including marshes, barrier islands, and estuaries (Chabreck, 2006). Situated along the Gulf of Mexico, this region exhibits a rich biodiversity, hosting a multitude of unique flora and fauna species that thrive within its intricate ecological tapestry (Conner, 2003). However, the shoreline confronts terrifying challenges, primarily stemming from land subsidence, coastal erosion, and the escalating sea levels attributed to climate change (Day Jr, 2000). These ecological pressures have engendered notable transformations along the coastline, which is triggering substantial land loss and posing a significant threat to the delicate equilibrium of the area's ecosystems (Turner, 2019).

Most of these parishes found in Louisiana’s coast are currently disappearing at the rate of fifty square miles per year by which within the next century, four coastal parishes will sink largely below water while within half that time one may entirely disappear (Houck, 2021). This region therefore has one of the highest rates of relative sea level rise in the world, which is gradually leading to the subsidence, or sinking of the land rendering most of the coastal plain not walkable or inhabitable, with many places at or below sea level (NOAA, Coastal Louisiana added to NOAA Sea Level Rise Viewer-Addition completes lower 48-state sea level projection data, 2015).

For instance, one million acres of the nation’s coastal land has been lost in Louisiana since the 1930s and without an effective decisive action, the state will lose another million acres in the next 40 years (Clipp, 2002). This is because the beachless coast of Louisiana is eroding and by the end of the 20th century, the land will be vanishing at a rate of about 24 square miles (62 square km) per year, especially with the incidence of Hurricane Katrina in 2005 which eroded an additional 73 square miles (189 square km) of the Louisiana coastland (Norrell, 2022). The rate of coastal retreat and land loss in Louisiana is therefore among the highest recorded in the world (Dietz & Bianchette, 2018). Hence, these effects have necessitated the need to understand and mitigate these impacts which are crucial for the preservation and sustainability of this valuable coastal treasure for current and future generations.

4. CONCLUSION

The vulnerability of most parishes in Louisiana to flooding, especially during the Louisiana floods, highlights the persistent and widespread nature of this environmental challenge. By accessing data from the USGS 3D Elevation Program and analyzing in ArcGIS Pro, this study identified some of the parishes along the coast of Louisiana that are flood prone, subjected to frequent flood events with a likelihood of experiencing shoreline retreat due to sea level rise incidents. Parishes such as Assumption, Lafourche, Livingston, St, James and Terrebonne are all indication of flood prone areas that also suffered the most damage during the Louisiana floods and Hurricane Harvey. The state's unique geography, with its extensive coastline, low-lying areas, and proximity to major water bodies have been contributing factors which expose numerous communities to the risk of flooding. The catastrophic events, such as the Louisiana floods in 2016, has ever since served as a reminder of the devastating impact that excessive rainfall and subsequent inundation can have on these susceptible regions. Recognizing the recurrent threat, the significance of the study is to contribute to the resources such as flood risk assessment maps, that can be leveraged to evaluate areas along the coast of Louisiana that are subsiding and are prone to flood due to sea level rise. By this, Disaster Risk Management Team or Town Planners can develop effective adaptation strategies to protect coastal communities and ecosystems. Also, this can help town planners to design and build infrastructure and buildings that are more resilient to flooding and erosion and avoid investing in projects that may become unsustainable in the long term. That is, efforts of town planners can be enhanced through flood preparedness, improving infrastructure resilience, and implementing effective flood management strategies. Hence, mitigating the risk and minimizing the impact of future flood events remains a critical and evolving priority for the communities located along the coast of Louisiana.

5. ACKNOWLEDGMENT

The authors express their profound appreciation to the USDA National Institute of Food and Agriculture (NIFA) McIntire Stennis Forestry Research Program (award number NI22MSCFRXXXG077) for providing financial support through Student Graduate Assistantships. Sincere gratitude also goes to the American Society for Photogrammetry and Remote Sensing (ASPRS) – the Imaging & Geospatial Information Society for the student grant award to participate in the Summer 2023 virtual ASPRS International Technical Symposium.

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