Climate Change Vulnerabilities in Loíza: The Role of Transportation in Enhancing Resilience

Justine Iván González-Vélez

Thesis submitted to the faculty of the Virginia Polytechnic Institute and
State University in partial fulfillment of the requirements for the degree of
Master of Urban and Regional Planning
In
Urban and Regional Planning

Ralph Buehler
Shalini Misra
Raúl Santiago-Bartolomei

April 26, 2024
Arlington, Virginia

Keywords: Resilience, Adaptation, Mitigation, Vulnerability, Climate Change, Transportation, Social-Ecological Systems, Post-Disaster, Disaster, Recovery, Loíza, Puerto Rico

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ABSTRACT

Climate change-related vulnerabilities in Loíza are prevalent in both physical and social dimensions. The social-ecological systems indicate that a change in one component will trigger an effect in the other regardless if physical or not, suggesting that the examination of vulnerabilities cannot be done overlooking one dimension. Such is the case of transportation, as climate change vulnerabilities in Puerto Rico are exacerbated due to the capacity of the Island to recover from a disaster, mainly because there are nearly no options for mobility aside from a private vehicle. This research intended to describe the social vulnerabilities of the population and asses the physical vulnerabilities of the transportation infrastructure of Loíza to understand how resilience is threatened using the social-ecological systems approach. This study found that the transportation infrastructure is exposed and sensitive to sea level rise, flooding, and strong winds, mainly because these climate stressors cause damage to the roadways and inhibit the flow and traffic of people throughout the main roadway and evacuation route, the PR-187. The study also identified that Loíza is socially vulnerable. Many people belong to one of the described vulnerable groups, indicating that its population may experience hurdles in preparing for and recovering after a natural disaster primarily because the available resources greatly condition the level of preparedness and capacity to cope. It was evidenced that transportation plays an enormous role in decreasing or increasing resilience in Loíza, as it will determine how fast people can access supplies and necessary services to reconstruct and recover from a natural disaster. Adaptation strategies should be outlined alongside the community to ensure an equitable and inclusive approach, as well as ensure assertive and effective outcomes for all the residents of Loíza.

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GENERAL AUDIENCE ABSTRACT

Climate change-related vulnerabilities in Loíza are presented in both physical and social aspects. The social-ecological systems indicate that a change in one thing will trigger an effect in the other regardless if physical or not, suggesting that the study of vulnerabilities cannot be done overlooking one aspect. Such is the case of transportation, as climate change vulnerabilities in Puerto Rico are aggravated due to the capacity of the Island to recover from a natural disaster, mainly because there are nearly no options to move around other than an automobile. This research intended to describe the social vulnerabilities of the population and asses the physical vulnerabilities of the transportation infrastructure of Loíza to understand how resilience is threatened using the social-ecological systems approach. This study found that the transportation infrastructure is exposed and sensitive to sea level rise, flooding, and strong winds, mainly because these climate stressors cause damage to the roadways and stop the flow and traffic of people throughout the main roadway and evacuation route, the PR-187. The study also identified that Loíza is socially vulnerable. Many people belong to one of the described vulnerable groups, indicating that its population may experience problems in preparing for and recovering after a natural disaster primarily because the available resources greatly determine the level of preparedness and capacity to cope. It was evidenced that transportation plays an enormous role in decreasing or increasing resilience in Loíza, as it will indicate how fast people can access supplies and necessary services to reconstruct and recover from a natural disaster. Adaptation strategies should be outlined alongside the community to ensure an equitable and inclusive approach, as well as ensure assertive and effective outcomes for all the residents of Loíza.

DEDICATION

This thesis work is dedicated to Puerto Rico and my people inside and outside the Island. Since I was a little kid, my curiosity and intrigue always led me to think about how things are done and why they are done that way. Perhaps, to explore ways to do things better, even if we are doing fine. Coming from a small rural town in Puerto Rico, sometimes I felt that my contributions – and the contributions of my peers – were just little drops in a big container that vanished with time. That my ideas and potential would be thrown away because opportunities were just not enough – and the generalized mental headspace was somewhat reduced to conformity. But, I always had a stronger desire to be something else and to actually do something meaningful for my people, my fellow Puerto Ricans. After Hurricane María happened, I saw how a lot of Puerto Ricans lost everything, how some of them struggled to get access to goods and supplies, how many of them died… The damage was underestimated, and the infrastructure just could not bear the magnitude of the impacts. Then I knew that I wanted to do something for people who suffer the most from the impacts of climate change. There is a long way ahead to go – and much of the problem-solving initiatives rely on the hands of the government, but also on the hands of researchers who make evident and necessary the need for a policy change. Now I understand that those drops in the big container are necessary to contribute to larger efforts – and that change comes within the collective effort. To my people in Camuy, think twice before quitting and dissuading yourself from contributing your drop. Opportunities are scarce, and the road is very rocky and difficult, but there is always a path forward for those who work their way and forge their own lane.

ACKNOWLEDGMENTS

This thesis work could have not been possible without the help of many people who constantly encouraged me to move forward with my aspirations and to give my all in every single contribution. First, I want to thank my committee who always were there to give me the necessary advice and guidance to make this study a reality. Dr. Ralph Buehler, thank you for your endless knowledge about transportation and for teaching me that transportation is truly the core of society. Moreover, for pushing us forward with research ideas and demonstrating to us that from the smallest ideas come the biggest results. Dr. Shalini Misra, thank you for your unconditional support and encouragement. Thanks to you, I found the motivation and confidence that I needed to be able to start and finish this. One day, I aspire to be as smart, kind, and thoughtful as you are – thank you for your genuine help and guidance. Dr. Raúl Santiago Bartolomei, thank you for always being willing to answer my questions and grounding me in feasible ideas to produce the best possible outcome. Your tenure, work, and contributions to Puerto Rico are truly admirable. I would someday like to follow your steps and strong sense of social responsibility. To Planner Yeidy Mar Escobar del Valle and the Municipality of Loíza, thank you for your diligence and commitment to assisting me in the best possible way.

To my mother Migdalia Vélez Sonera, thank you for being the rock that me and my brother needed when we needed you the most, and thank you for demonstrating to us with actions that we are enough for each other. Furthermore, that times are not always bright, but the sun will always rise. To my brother Shaquille González Vélez, aunt Maribel Vélez Sonera, and cousin Zahira Jiménez Candelaria, thank you for your unconditional support and care. To my family in Puerto Rico, thank you for believing in me – even when I sometimes think that I am not capable of it. To my best

friends from Puerto Rico Liz Yaneliz Martínez Muñiz and Ismarie Serrano Rodríguez, thank you for being a vivid example that hard work pays off and that I should always aim to be the best in everything that I do. Thank you for your unconditional support and for being my constant motivation; your accomplishments and contributions are admirable. To Luis Vázquez Méndez, thank you for your support since the beginning of this trajectory. You were my rock when I needed you the most. Times were tough when I first moved from Puerto Rico, but you always tried to make times as warm as possible, showing genuine love and compassion. To my friends in Puerto Rico, Washington D.C., and Spain – thank you for caring, for being present, and for encouraging me to keep going, despite the workload and many responsibilities that I had to handle. To my high school Professor Dr. Luissette Rodríguez Bernier, thank you for seeing potential in me when no one else did. You really impacted my life in the best positive way that you will ever be able to imagine. Part of my achievement and success today, I owe it to you. Thank you for demonstrating to me that we matter and that we are not predetermined by the place we come from. Thank you for exploiting our potential in the most delicate and best way. Thank you for being a human with such a warm and bright light.

To Warner Santiago who motivated and assisted me before entering graduate school, thank you. Your words really resonated in my mind and gave me the boost to go higher. To my second family Martínez Muñiz, thank you for supporting me when I was in Puerto Rico and even now from a distance. Finally, to my colleagues and supervisors in Puerto Rico and the United States mainland, thank you for your words of encouragement and admiration through difficult times. They were really needed and cherished by me.

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1. Introduction

Climate change is not a distant issue for anyone in the United States of America, as it is affecting every single human being in every part of the country across almost every sector (Hayhoe, 2018). Climate change is mainly experienced through extreme weather events, which impact society, ecosystems, and the environment (Trenberth, 2018). Research suggests that the current pace of greenhouse gas emission reduction is not sufficient to recover from the impact that humankind has made – suggesting that climate change will not diminish, but rather will continue with climate risks appearing faster and becoming more severe sooner than previously expected (Hayhoe, 2018; WHO, 2023). The effects will become more severe and potentially dangerous as climate change accelerates (Hayhoe, 2018). Unless a drastic shift in emissions reduction is achieved, what we call today extreme and unusual weather events, will become common in a decade or two (Trenberth, 2018).

Although billions of people worldwide are affected by climate change, not everyone is affected in the same way. Rather than being uniform, climate change effects will depend on the region and will not be the same in time and intensity: “The effects of global CC [climate change] are expected to vary in both magnitude and timing as well as by geographic region” (Leon et al., 2022). This means that all places in the world will experience some degree of climate change effects. However, while some may experience relatively light effects of climate change, others will face high (or perhaps an unjust level of impacts from the many forms of extreme weather events. Despite being smaller contributors to carbon emissions, the perfect example is small islands (IPCC, 2023). Literature evidence provides that people living on islands are among the first and most adversely affected by the impacts of climate change for many reasons including larger coastal zones and the

feature of valuable ecosystems and natural environments (Veron et al., 2019; Russell et al., 2019, as cited in Leon et al., 2022). Loss of terrestrial, marine, and coastal biodiversity, ecosystem damages, loss of lives, food insecurity, economic disruption, and increased displacement due to coastal erosion are just a few of the many risks that small islands face against climate change (IPCC, 2023). Islands in the Caribbean are not exempt from climate change, but rather they are at the forefront of the most affected places on the planet.

A recent report from Global Americans (2023) stated: "Every year, extreme weather events like tropical cyclones, droughts, heat waves, and heavy rains expose Caribbeans to potentially life-threatening situations" (p.3). Furthermore, the region has been described as "ground zero" for the climate emergency due to the growing set of challenges climate change poses to the Caribbean (Global Americans, 2023). Since 1950, weather disasters that include tropical cyclones, droughts, floods, and landslides have caused 24,206 recorded deaths (excluding the ones not documented) and affected nearly 54 million people in the Caribbean – with data showing that hurricanes have traditionally represented the most common and disruptive extreme weather events in the region (Global Americans, 2023). A study analyzed future projections of hurricane rainfall in the Caribbean and found that the region is particularly vulnerable to climate change (University of Bristol, 2020). This same study identified that due to global warming there will be more extreme hurricane rainfall globally and as much as five times more in the Caribbean (University of Bristol, 2020). Hurricanes may become stronger with accumulated rainfall and intense wind speeds as they make landfall in the coming decades (Global Americans, 2023). This would aggravate inundation levels during hurricanes, therefore creating further flooding hazards – as a direct result of sea-level rise provoked by rising temperatures (Global Americans, 2023).

Being located at the heart of the Caribbean, Puerto Rico has become extremely vulnerable to climate change and the resulting extreme weather events. Méndez-Lázaro et al. (2015) concluded that Puerto Rico is warming and that extreme temperatures on the island can cause social and ecological effects. In fact, a recent article stated that Puerto Rico – amongst many other islands – is particularly vulnerable because of extreme weather events associated with climate change ("Climate and Health," 2022). The island is being increasingly challenged by coastal erosion, intense tropical heat, heavy rainfall, and stronger hurricanes (Ocko, 2017). The U.S. Environmental Protection Agency (EPA) stated that in the past 20 years, tropical storms and hurricanes have become more intense in wind speeds and rainfall (EPA, 2016). This adversely affects Puerto Rico's infrastructure which is highly vulnerable to the impacts of both winds and water during storms (EPA, 2016). More than 85 percent of Puerto Ricans live within five miles of the coast which is constantly and increasingly threatened by sea-level rise (Ocko, 2017). Coastal infrastructure – including residences – "are likely to flood more often as sea level rises because storm surges will become higher as well" (EPA, 2016).

Puerto Rico is not only vulnerable to climate change in terms of infrastructure, but also socially. A study from the United States Census Bureau stated that the population of Puerto Rico "had high levels of social vulnerability", which indicated that after a natural disaster, it would be hard for Puerto Ricans to recover (Gurrentz et al., 2023). Almost half the population of Puerto Rico was estimated to have three or more risk factors ranging from poverty to age (Gurrentz et al., 2023). In fact, this same study reflected that all municipalities in Puerto Rico had high levels of social vulnerability – with some having particularly high rates in comparison to the entire Island (Gurrentz et al., 2023). For example, after Hurricane Maria in Puerto Rico, factors that affected

housing recovery were an aging population, low-income, and poorly connected individuals due to barriers in the form of high costs of construction, difficulties obtaining permits or filling applications, time and energy required for the processes, permitting, and reconstruction labor (Talbot, 2022). Research demonstrates that certain demographic groups have a lower capacity to respond to certain barriers due to lack of time, money, sociopolitical standing, and resources (Talbot et al., 2022).

The latter highlights a combination of tangible and intangible vulnerability to climate change in Puerto Rico, with elements from the social aspect affecting the recovery and resilience of the Island at the structural-physical level and vice versa. The social-ecological systems (SES) approach suggests that a change in one component – whether it is physical or not – inevitably would provoke a change in other components of the system (Biggs et al., 2021). The reason is that we live in a highly interconnected and intertwined system with elements and dynamics that are interdependent on each other (Biggs et al., 2021). Human interactions and natural processes cannot be treated separately to understand the nature of the problems, as interactions in a system are multidirectional and will condition and influence every element in it (Biggs et al., 2021). Changing social vulnerabilities and changing physical hazards are both responsible for the increasing and rising costs of climate change in terms of economic damage and lives at risk (Adger et al., 2005). At a larger scale, specifically in the Caribbean, responsiveness to hurricanes and other extreme weather events depend heavily on social and ecological resilience, as it is important to work on structural problems at a physical and social level (Adger et al., 2005).

One clear example is transportation systems, whose infrastructure is threatened by climate change and extreme weather events worldwide (Kwiatkowski, 2009). Regardless of the transportation mode, climate change will impact them because of a variety of stressors that inflict vulnerabilities based on natural and human-induced changes (Moss et al. 2010; van Vuuren et al. 2011, as cited in Kwiatkowski, 2009). No matter what the scenario is, there are inescapable and unavoidable changes that will and are already impacting the transportation infrastructure (IPCC, 2015, as cited in Kwiatkowski, 2009). Puerto Rico, after Hurricane Maria in 2017, experienced a similar scenario under which mobility was paralyzed due to the lack of transport modes (Peña Rivera, 2018). Peña Rivera (2018) suggested that vulnerabilities in Puerto Rico when hurricanes and other extreme weather events happen are exacerbated because the most commonly used mode of transport (roadways for private-owned vehicles) is extremely affected by these types of events – therefore recovery efforts are delayed due to the inability to access resources and services. Under this prerogative, transportation functions as a buffer to mitigate and as a method to build resilience against climate change effects.

This study aims to describe the social vulnerabilities of the population and assess the physical vulnerabilities of the transportation infrastructure of the Municipality of Loíza to understand how climate change resilience is threatened in the study area using the social-ecological systems approach. The analysis discusses the potential role of transportation in helping diminish climate change-related vulnerabilities and enhancing resilience in the study area. The Municipality of Loíza is located in the northeast part of Puerto Rico, delimited by the Atlantic Ocean to the north, the Municipality of Canóvanas to the south, the Municipality of Río Grande to the east, and the Municipality of Carolina to the west – just a few minutes away from the Capital, San Juan (JJPR,

2021). It covers approximately 65 square kilometers and is divided into six barrios[1] (see Figure 1 below): Medianía Alta, Medianía Baja, Loíza Pueblo, Canóvanas, Torrecilla Baja, and Torrecilla Baja (JJPR, 2021). Loíza has experienced a significant population shift over the years. In 2010, the total population was more than 30 thousand residents (U.S. Census Bureau, 2023). Recent estimates reflected a loss of more than seven thousand residents, totaling less than 23 thousand people (U.S. Census Bureau, 2023) – a decline that is related to atmospheric or extreme weather events.

Loíza has a long history of impacts from climate change, particularly when it comes to sea-level rise, hurricanes, and storms. The most recent Plan of Mitigation Against Natural Hazards outlined many natural hazards that have or could affect Loíza, including climate-related hazards such as sea-level rise, floodings, tropical cyclones, coastal erosion, and storm surge (JJPR, 2021). A recent article stated that Loíza is the fourth municipality in Puerto Rico experiencing the most beach loss during the first ten months after Hurricane Maria (Guillama-Capella, 2023). According to Barreto, sea-level rise and climate change have accelerated these unattended processes in the Municipality over the past decades – making mitigation efforts harder to achieve (Guillama-Capella, 2023).

2. Problem Definition and Justification

Puerto Rico is an island located in the Caribbean that measures 180 kilometers long and 65 kilometers wide with a tropical climate and variable weather during the year (Méndez-Lázaro et al., 2015). Previous research demonstrated that the Caribbean is particularly affected by the impact

[1] *Barrios* is the word used in Puerto Rico to categorize the subdivisions within the municipalities. Puerto Rico is divided into 78 municipalities and those municipalities are divided into *barrios*. To some extent, they are the equivalent of neighborhoods or wards; *barrios* are bound to political divisions.

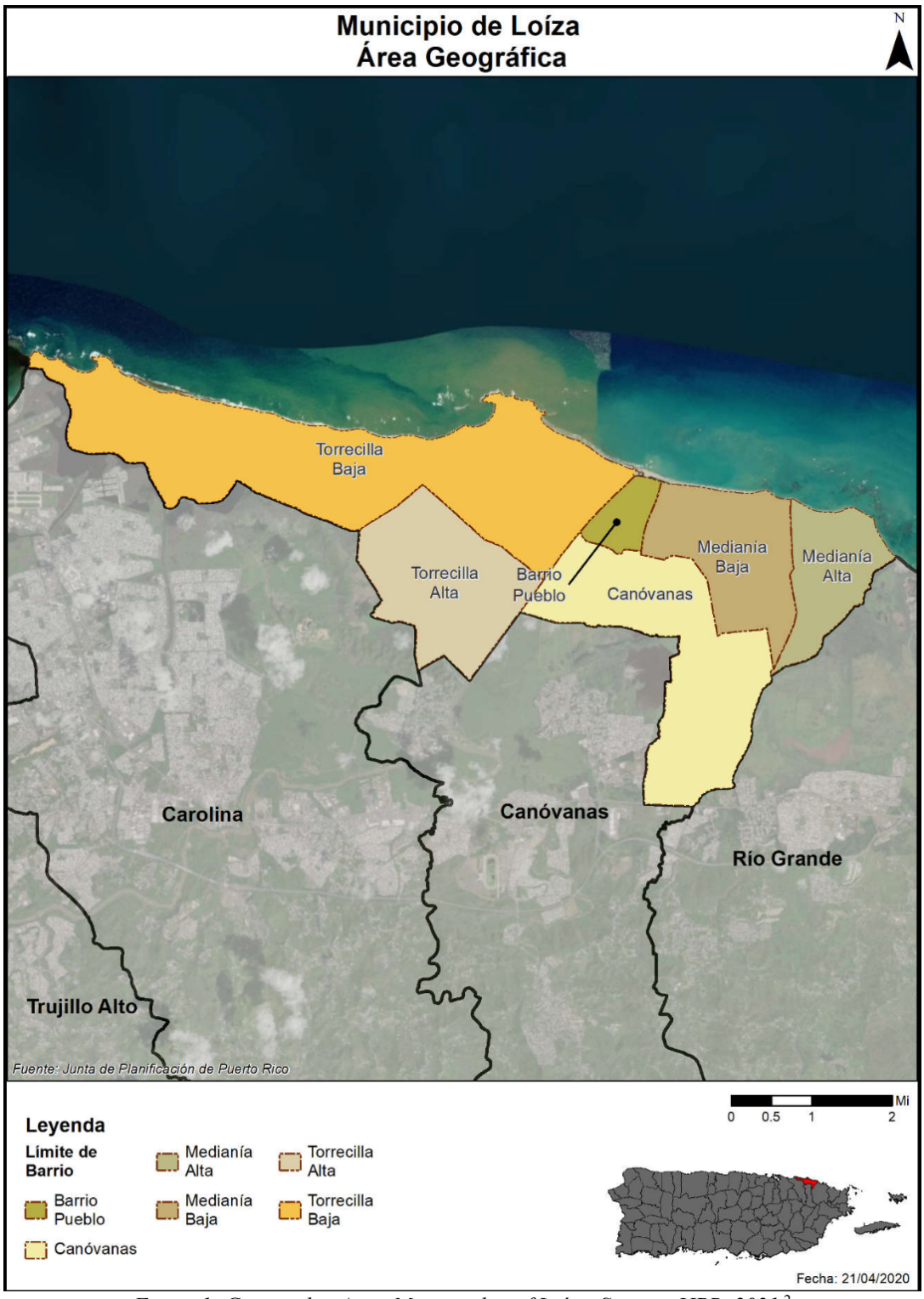


Figure 1: Geographic Area, Municipality of Loíza. Source: JJPR, 2021.[2]

[2] All the areas colored in yellow, green, orange, and brown are part of the Municipality of Loíza as barrios (previously explained), while the areas colored in gray are the municipalities that surround Loíza: Carolina to the southwest, Canóvanas to the south, and Río Grande to the southeast.

of extreme weather events exacerbated as a result of climate change: “Each year, between June and November, tropical cyclones sweep across the Caribbean, often triggering large-scale humanitarian crises and inflicting enormous economic losses” (Global Americans, 2023). Puerto Rico specifically, for the past two decades, has been the most affected country by extreme weather events in the world (Global Americans, 2023). Data show that since 2000, ten hurricanes and two tropical storms have impacted the Caribbean Island – including two catastrophic hurricanes in 2017 (Irma and Maria) that left 97 percent of the roads inoperable with damages totaling roughly $20 billion of dollars (Global Americans, 2023). Different numbers from various studies estimate deaths to be as high as 4645 from the impacts of Hurricane Maria (Kishore et al., 2018; Rivera and Rolke, 2019; Spagat and van Weesel, 2020; NIST, 2020, as cited in Stablein et al., 2022). Recently, Category 1 Hurricane Fiona struck the Island – proving how fragile and decayed the infrastructure still is, as well as its vulnerability to extreme weather events (Global Americans, 2023).

Climate change effects in Puerto Rico are not expected to diminish, but instead to increase. By 2100, models suggest that the Island will be increasingly at risk of anywhere between one and eleven feet of sea level rise (USGCRP, 2018, as cited in Stablein et al., 2022). Considering that 44 out of 78 municipalities in Puerto Rico are coastal municipalities, a significant portion of Puerto Rico’s population is vulnerable to sea-level rise – as around 53% of the coastal municipalities' total population live on the coast (Barreto, 2021). This means that thousands of residents who live in coastal areas are astoundingly threatened, as well as critical infrastructure situated along the coast (Amiri, 2018; Nunn, 2013, as cited in Stablein et al. 2022). Similarly, rising temperatures will increase the probability of frequent hurricanes like Maria and Irma, causing extensive disruption and damage to the water supply, transportation and road networks, electricity supply, and medical

care (Amiri, 2018; USGRP, 2018; Pasch et al. 2017; Santos-Lozada & Howard, 2018, as cited in Stablein et al., 2022). As mentioned above, this study will be focusing specifically on the Municipality of Loíza, Puerto Rico – which has been experiencing major challenges caused by climate change in a post-disaster era. Table 1 below outlines some of the most recent extreme weather events in chronological order that have impacted the Municipality of Loíza:

Date	**Event Type**	**Description**
2020 August 22	Tropical Storm Laura	Heavy rainfall and winds, causing severe flooding.
2020 July 29-30	Tropical Storm Isaías	Recurrent heavy rainfall and winds, causing severe flooding and storm surges.
2017 September 20	Hurricane María	Category Four (4) hurricane, causing catastrophic damages in the Island.
2017 September 5	Hurricane Irma	Category Five (5) hurricane, causing tropical storm winds and heavy rainfall in the northern part of the Island.
2011 August 22	Tropical Storm Irene	Category 1 hurricane, causing flooding and wind damage in the east and north parts of the Island.
2004 September 17	Tropical Storm Jeanne	Category Three (3) hurricane, causing extreme flooding and landslides in the Island.
2001 May 16	Flooding Event	Extreme flooding and landslides due to severe storms.

Table 1: Chronology of the Most Recent Extreme Weather Events Impacting Loíza. Source: JJPR, 2021.

Puerto Rican Oceanographer Barreto stated that coastal loss caused by erosion is an affection seen replicated in other municipalities of Puerto Rico, but that Loíza is particularly impacted by it (Guillama-Capella, 2023). According to a report from the United States Army Corps of Engineers (USACE), a portion of the coastal shoreline of the Municipality is "severely eroded" and, therefore affecting existing infrastructure: "This chronic erosion has already impacted and continues to threaten public infrastructure and facilities" (USACE, 2019) – which exacerbates its physical vulnerability. USACE (2019) also points out that hurricanes and coastal storm damages – including erosion causing receding shorelines – threaten infrastructure such as roadways, buildings, commercial businesses, schools, parklands, homes, and recreational beach access, as well as contribute to public safety hazards.

Being a municipality with a vast extension throughout the coast of Puerto Rico (see Figure 1 above), Loíza has nearly 70 percent of its critical infrastructure located in the vulnerable coastal fringe (Guillama-Capella, 2023). The Municipality also has around 92 percent of its population residing in areas subject to the impact of waves due to coastal erosion (Guillama-Capella, 2023). This makes Loíza even more vulnerable to sea-level rise by impacting the lives of many families that live near the coast (JJPR, 2021). The Mayor of Loíza Julia Nazario stated that around 14 communities are affected directly by coastal erosion and that they are "in need of an action plan", referring to coastal erosion mitigation strategies that could help reduce vulnerability to climate change (Guillama-Capella, 2023). These problems in the Municipality are aggravated by other socioeconomic factors in place. Loíza is also the fourth poorest municipality in Puerto Rico with over 47 percent of the population living in poverty levels with a median household income of less than $19 thousand of dollars (U.S. Census Bureau, 2023). Around 76 percent of the total population

has a high school diploma and only 17 percent holds a bachelor's degree or a higher educational level (U.S. Census Bureau, 2023).

In 2023, the Federal Emergency Management Agency (FEMA) categorized Loiza with a "very high" susceptibility to natural hazards when compared to the rest of the United States (FEMA, 2023). Loiza scored 91.94 out of 100 in social vulnerability, higher than 92 percent of the other Census tracts in the United States mainland and higher than 53 percent of the other Census tracts in Puerto Rico (FEMA, 2023). Academic research suggests that vulnerability to climate change in a place is also exacerbated by transportation infrastructure, as it can be either an obstacle or a facilitator of recovery efforts. According to Rouhanizadeh and Kermanshachi (2020), "the effectiveness of social and economic recovery of a society damaged by major disasters is significantly interrelated with pace of reconstruction of transportation infrastructure". This means that transportation infrastructure and systems play a role in minimizing or maximizing climate change resilience in a place. In the case of Puerto Rico, Peña Rivera (2018) explained how diversifying modes of transport could work as a solution to mobility problems in post-disaster contexts. On the other hand, the Academic touched on other benefits as a byproduct of diversification such as the inclusion of often excluded communities that do not have the economic resources to buy and afford the costs of maintaining a private vehicle (Peña Rivera, 2018).

Aside from climate-related hazards, there are a variety of elements that act as barriers to transportation infrastructure. These barriers could delay post-disaster reconstruction of transportation infrastructure (Rouhanizadeh & Kermanshanchi, 2020), therefore recovery in general. By these means, understanding the impacts of these barriers and finding ways to mitigate

them is required to minimize adverse consequences (Rouhanizadeh & Kermanshanchi, 2020). Kwiatkowski (2009) explained how despite having research in place that describes the impacts of climate change and policy recommendations to adapt to those impacts, adaptation remains limited in practice. However, to minimize the severity of impacts, transportation infrastructure can be adapted to become more resilient to anticipated climate change (Kwiatkowski, 2009). Loíza only has one main roadway that connects the communities and the residents, crossing through five of the six barrios in the Municipality: the PR-187 (Y. Escobar, personal communication, March 27, 2024). Aside from being the main roadway for private vehicles, it is also the main roadway used by the available public transit services in the Municipality of Loíza (ABC & LGP, 2022). The PR-187 is also identified as the evacuation route[3] in case of any emergency, but it constantly floods (Y. Escobar, personal communication, March 27, 2024; Advantage Business Consulting & LGP Consultoría[4], 2022).

3. Goals and Objectives

It is important to study and analyze problems with an approach that permits a holistic understanding of its dimensions. This belief is rooted in the understanding that problems are not unidirectional, but rather multidirectional – perhaps entangled in a multiplicity of factors quite difficult to see at first glance (Biggs et al., 2021; Folke et al., 2006). Sometimes what we initially see is only the tip of the iceberg. In the case of Loíza, details have been provided on how it is being affected by climate change, therefore suggesting increasing vulnerability as time passes. Moreover, a discussion previously manifested that vulnerabilities are not only upon and extended to physical

[3] See Appendix IV for the full map illustrating the evacuation route in the Municipality of Loíza.
[4] From now on, the citation "Advantage Business Consulting & LGP Consultoría, 2022" is shortened to "ABC & LGP, 2022" to promote fluency throughout the text.

structures, but also to social elements. Therefore, this study has as its ultimate goal to discuss the potential role of transportation in helping diminish climate change-related vulnerabilities and enhancing resilience in the study area. The social-ecological systems approach is used to provide an understanding of how the social and physical environments cannot be separated from each other, as both are conditioned by one and the other. The study does not intend to employ the use of quantitate data to perform any analysis, nor rank how vulnerable the Municipality of Loíza is to climate change-related threats. The study will not make future inferences about the probability of future scenarios, but rather provide information based on existing literature. When elaborating on the importance of transportation infrastructure adaptation, the study will not provide actions for adaptation. The study will not evaluate the performance of any plan enacted by the Municipality of Loíza. Instead, suggestions will be made on the identified gaps concerning the inclusion of transportation as a resilience strategy. For these reasons, we have developed the following goals and objectives to further outline and explain our purpose (see Table 2 below):

Goals	**Objectives**
1. Elaborate a physical vulnerability assessment of the transportation infrastructure of the Municipality of Loíza.	1. Identify climate change-related variables that affect the transportation infrastructure of Loíza. 2. Select climate-change related stressors that affect the transportation infrastructure of Loíza. 3. Assess exposure, sensitivity, and adaptive capacity of the transportation infrastructure of Loíza. 4. Understand how the transportation infrastructure of Loíza is affected by the selected climate change-related stressors.

2. Describe the social vulnerability against natural hazards of the population of the Municipality of Loíza.	1. Identify social vulnerability indicators of the population of Loíza. 2. Describe social vulnerability indicators of the population of Loíza. 3. Understand how social vulnerability indicators affect climate change resilience in Loíza.
3. Describe the impacts of shocks and stresses in the Municipality of Loíza.	1. Identify climate change-related and non-related shocks and stresses that affect the Municipality of Loíza. 2. Understand how climate change-related and non-related shocks and stresses affect climate change resilience in Loíza.
4. Discuss the role of transportation in diminishing climate change-related vulnerabilities and enhancing resilience in the Municipality of Loíza.	1. Explain how adapting the transportation infrastructure reduce vulnerabilities and increase resilience in Loíza. 2. Explain how the diversification of modes of transport reduce vulnerabilities and increase resilience in Loíza.

Table 2: Goals and Objectives. Source: Self-Elaborated; González-Vélez, 2023.

4. Research Methods

For this study, several tools of investigation were used to assess the physical vulnerability of the transportation infrastructure and identify and describe the social vulnerability of the population of Loíza against natural hazards. Amongst the tools of investigation are (1) the analysis of state and local government documents and reports, (2) the analysis of reports from non-government agencies, (3) the evaluation of databases containing sociodemographic information, (4) a review of the academic literature, (5) the use of interactive maps and modeling tools, and (6) the use of vulnerability assessment and adaptation frameworks. The analyzed government documents and reports included the Mitigation Plan Against Natural Hazards of the Municipality of Loíza, the

Community-Based Climate Change Adaptation Plan of the Municipality of Loíza, and the Federal Emergency and Management Agency (FEMA) National Risk Index. The evaluated sociodemographic databases included the American Community Survey and the United States Census Bureau Tracts. The interactive maps and modeling tools used included the Sea Level Rise Viewer from the National Oceanic and Atmospheric Administration. The used vulnerability assessment and adaptation frameworks included the United States Agency International Development (USAID) framework for Climate Vulnerability Assessment (Climate Resilient Development Framework)[5] and the Federal Highway Administration (FHWA) framework for Vulnerability Assessment and Adaptation Framework (Third Edition)[6].

4.1 Elaboration of the Physical Vulnerability Assessment

This study performed a physical vulnerability assessment for the transportation infrastructure of the Municipality of Loíza. This was conducted to understand how the transportation infrastructure is affected by climate change and understand how to enhance the resilience of the Municipality of Loíza through transportation. According to Fuchs et al. (2018), "physical vulnerability […] refers to the degree of susceptibility within the physical environment and as such to the negative impact of hazards" (p.32). When talking specifically about transportation, the FHWA states that transportation assets such as roads bridges, rail systems, and other transportation infrastructure can be affected by extreme weather events caused by climate change (Filosa et al., 2017). These physical elements may affect the well-being and activity of communities and places (Goujon et al., 2003). Likewise, Goujon et al. (2003) stated that "structural constraints impact both the life of the poorest populations but also the capabilities of the public and private sectors to operate" (p.23).

[5] From now on called the USAID Climate Resilient Development Framework to shorten the title and promote fluency within the text.
[6] From now on called the FHWA Vulnerability Assessment and Adaptation Framework.

In this sense, vulnerabilities in the physical infrastructure can affect greatly resilience in the face of disasters and conditions greatly post-disaster recovery efforts.

The physical vulnerability assessment was performed mainly based on the guidelines provided by the FHWA Vulnerability Assessment and Adaptation Framework and using the USAID Climate Resilient Development Framework guidelines as a supporting document. Likewise, two books from the National Wildlife Federation were used as supporting documents: (1) *Climate-Smart Conservation: Putting Adaptation Principles into Practice*; and (2) *Scanning Conservation Horizon: A Guide to Climate Change Vulnerability Assessment.* These resources provided a clear understanding and guided the process of how to assess physical vulnerability in a climate change-related context. Before designing a vulnerability assessment, both guidelines the FHWA Vulnerability Assessment and Adaptation Framework and the USAID Climate Resilient Development Framework, require clarifying key decisions the assessment will inform (Cook et al., 2016; Filosa et al., 2017). In this sense, the physical vulnerability assessment will inform what climate change-related hazards the transportation infrastructure of the Municipality of Loíza is more vulnerable to and, therefore, how climate change resilience is affected in the study area.

This aligns with the FHWA Vulnerability Assessment and Adaptation Framework, which strives "to identify the risks of climate change and extreme weather events to current and planned transportation systems, and to integrate consideration of these risks into its planning, operations, policies, and programs in order to promote preparedness and resilience" (Filosa et al., 2017). In our case, the focus will be on the existing infrastructure and not on planned transportation systems due to limitations on information and data collection. For the physical vulnerability assessment,

the FHWA Vulnerability Assessment and Adaptation Framework outlines the following items to use as a guideline for assessing vulnerability: (1) Articulate Objectives and Define Study Scope; (2) Select and Characterize Relevant Assets; (3) Identify Key Climate Variables; (4) Obtain and Compile Data on the Asset and Climate Variables; (5) Assess Vulnerability; (6) Identify, Analyze, and Prioritize Adaptation Options; and (7) Incorporate Results into Decision-Making (Filosa et al., 2017. The last two items were not performed due to the purpose of this study, which ultimately intends to provide a list of adaptation options for the transportation infrastructure of the Municipality of Loíza, rather than providing the mechanisms for incorporating results in decision-making. Figure 2 below aims to serve as a flow chart to illustrate the items performed for the physical vulnerability assessment of this study.

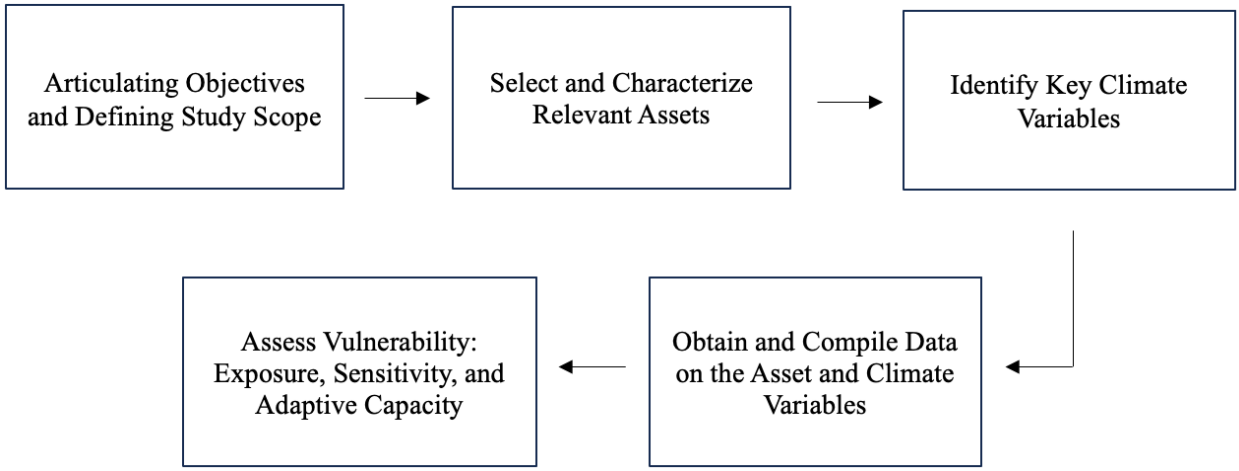


Figure 2: Flow chart of steps of items performed for the physical vulnerability assessment of this study. Diagram: Self-Elaborated, González-Vélez, 2024.

The main objective of this physical vulnerability assessment is to understand how the transportation infrastructure of the Municipality of Loíza is affected by climate change-related hazards. The transportation infrastructure of the Municipality of Loíza was selected as the locality to be assessed (which has been previously described and delimitated). For the purpose of this study,

the transportation infrastructure is only limited to surface transportation, specifically roadways and bicycle and pedestrian facilities. A lack of detailed information about each type of transportation infrastructure prevented the individual assessment of each surface transportation asset. Under the FHWA Vulnerability Assessment and Adaptation Framework, the vulnerability assessment to climate change of the overall transportation infrastructure of a place is permitted (Filosa et al., 2017) Data about the transportation infrastructure of the Municipality of Loíza (the asset) and the climate change threats was gathered using mainly reports and studies from government agencies at the federal, state, and municipal levels, the Mitigation Plan Against Natural Hazards of the Municipality of Loíza, the Community-Based Climate Change Adaptation Plan of the Municipality of Loíza, interactive maps, and modeling tools.

The assessment proceeded with the evaluation of climate data for the identification of key climate change-related variables impacting the transportation infrastructure of the Municipality of Loíza (the asset). According to Filosa et al. (2017), a climate variable is "the condition that affects the transportation system and will be analyzed in a vulnerability assessment" (p.12). In this sense, climate variables are also parameters used to measure and describe climate (FHWA, 2023). Some examples of climate variables are temperature, precipitation, relative sea level change, storm surge and waves, streamflow, and drought (Filosa et al., 2017; FHWA, 2023). When selecting climate variables for the vulnerability assessment, a focus should be put on those that will have the biggest impacts on the local transportation network and "those who matter for your assessment" (Filosa et al., 2017; Cook et al., 2016). To determine which climate variables will affect the transportation infrastructure, climate stressors should be identified (Filosa et al., 2017). Climate stressors can also be referred to as hazards or threats and they indicate the magnitude of a climate variable by

including changes in meteorological conditions (Filosa et al., 2017; Cook et al., 2016). For example, climate stressors include variability in climate, differences in rainfall, temperature changes, and extreme events such as heavy precipitation, flooding, heatwaves, tropical storms, and tornadoes (Cook et al., 2016; FHWA, 2023).

Based on the Mitigation Plan Against Natural Hazards of the Municipality of Loíza, from 1910 to 2020, two of the most frequent climate hazards are hurricanes and tropical storms (strong winds/tropical cyclones) and floodings (JPPR, 2021). In addition to this, the Mitigation Plan Against Natural Hazards of the Municipality of Loíza identified seven potential risks with greater impact on the study area: (1) sea level rise, (2) earthquake/liquefaction, (3) flooding, (4) strong winds, (5) tsunami, (6) storm surge, (7) coastal erosion (JPPR, 2021). Due to the extensiveness of the coastal line of the Municipality of Loíza, sea level rise was selected as one of the climate stressors. Similarly, based on the frequency of the occurrence in the study area flooding and strong winds[7] were the other two selected climate stressors. The physical vulnerability assessment was performed using the key parameters identified and discussed in the following subsections below: exposure, sensitivity, and adaptive capacity. Results were described and further discussed in the following subsections. This physical vulnerability assessment was purely descriptive and based on qualitative taking stock and desk review exercises, in which existing and available information from the previously outlined sources – therefore no quantitive data was analyzed or employed when performing this physical vulnerability assessment.

[7] Per the Mitigation Plan Against Natural Hazards of the Municipality of Loíza, strong winds include tropical cyclones, therefore storms and hurricanes.

4.2 Identification and Description of the Social Vulnerabilities

Before the 1970s, researchers usually focused on the physical elements like infrastructure and technology when dealing with disaster management situations, rather than focusing on more intangible elements that could affect a population (Flanagan et al., 2011). Nevertheless, there are other factors besides physical and tangible ones that affect the resilience of a community such as the socioeconomic elements. According to Flanagan et al. (2011), "social vulnerability refers to the socioeconomic and demographic factors that affect the resilience of communities" (Juntunen, 2005, as cited in Flanagan et al., 2011). On the other hand, Katic (2017) defines social vulnerability to natural hazards as "the differential capacity of groups and individuals to deal with hazards, based on their positions within physical and social worlds" (Dow, 1992, as cited in Katic, 2017). While the first definition points directly to factors that determine and encompass social vulnerability, the latter refers more to the ability of a group to respond to hazards based on the factors that were previously mentioned. Social vulnerability includes socioeconomic and demographic indicators such as poverty, low socio-economic status, low educational level, poor living standards, age (elderly or children), income, disabilities, housing types, and transportation (Lee, 2014; Flanagan et al., 2011).

Lee (2014) further explained that social factors like the previously mentioned "magnify the effects of disasters or extreme climate events" – meaning that social vulnerability "not only determines local sensitivity to external effects but also affects the capacity to cope with environmental change" (Lee, 2014; Brooks et al., 2005; Khan, 2012; Roger et al., 2007, as cited in Lee, 2014). In this sense, social vulnerability greatly conditions physical vulnerabilities and, therefore, determines how vulnerable a place is in the face of disasters, whether climate change-related or not. Based on the literature that explained which indicators contribute to social vulnerability, a total of five social

indicators were identified: age, single parent, income, people with disabilities, and level of education. Data from the Mitigation Plan Against Natural Hazards of the Municipality of Loíza, the Community-Based Climate Change Adaptation Plan of the Municipality of Loíza, the United States Census Tract, and the American Community Survey was used to describe the social vulnerability indicators of the population of the Municipality of Loíza. The purpose of identifying and describing the social vulnerability in the Municipality of Loíza against natural hazards is to explain how these social indicators contribute to vulnerability and undermine climate change resilience in the study area. When referring to communities, Fabre (2020) stated that those communities with more quantity of individuals per indicator are considered to be more socially vulnerable. In our case, the greater the number of individuals per social indicator, the more vulnerable the Municipality of Loíza is considered to be. The identified and selected indicators represent characteristics of a population that is more exposed to danger in response to recovery before and after a disaster (Fabre, 2020).

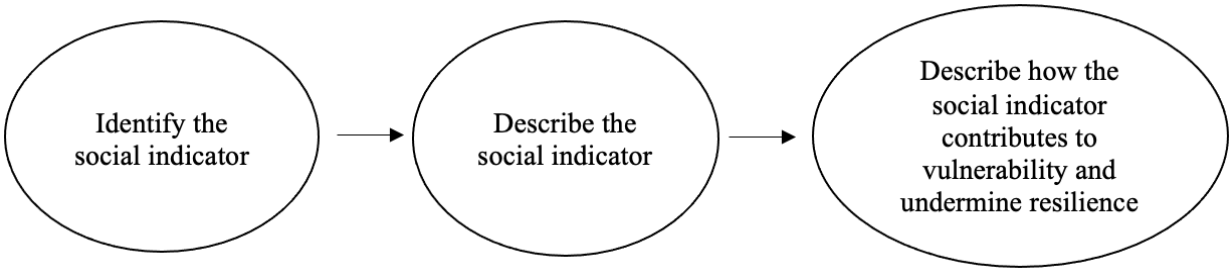


Figure 3: Flow Chart of steps to describe social vulnerability indicators. Diagram: Self-Elaborated, González-Vélez, 2024.

5. Theoretical and Conceptual Framework

5.1 Climate Change: A Concept Hard to Address

Academics, scientists, policymakers, and people worldwide often talk about climate, perhaps and foremost about the effect of such a concept on our environment (Bothe, 2018). It turns out that climate itself is a concept extremely hard to explain – as it evolves over time and takes its own

identity depending on the place (Bothe, 2018; Werndl, 2014). Because it is such a complex and changing concept, people often confuse climate with weather. According to the National Oceanic and Atmospheric Administration (NOAA), “weather is the mix of events that happen each day in our atmosphere”, while climate is narrowly defined by the Intergovernmental Panel on Climate Change (IPCC) “as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years” (NOAA, 2020; IPCC, 2028). This means that while “weather refers to short-term changes in the atmosphere, climate describes what the weather is like over a long period of time in a specific area” – meaning that the main different between them is the time scales (NOAA, 2020). In this sense, climate can tell you what to expect (temperatures, average precipitation, and winds), but weather is what actually happens (NOAA, 2020). In other words, weather can change instantly, but climate changes over extended period of times.

Now, climate change is the long-term alteration or variation of the Earth's local, regional, and global typical weather patterns and conditions – for example, conditions becoming warmer, drier, or wetter for extended periods of time (Esty & Massie, 2021; Turrentine & Denchak, 2021). Climate change occurs primarily due to the burning of fossil fuels like oil, coal, and natural gas – which are used in our daily lives to power our homes and vehicles, as well as to realize most agricultural and manufacturing processes (Etsy & Massie, 2021). When we burn fossil fuels, we emit greenhouse gasses that go directly into the atmosphere and function as a “heat-trapping blanking over the planet” by preventing the heat that comes from the sun from leaving the atmosphere – therefore resulting in an accumulation of heat on our planet, commonly referred to as “global warming” (Etsy & Massie, 2021; Trenberth, 2018). Climate change manifests in our

planet through higher temperatures in the atmosphere, land, and ocean, ice melting, sea level rise, and increasing extreme weather events such as heat waves, wildfires, heavy rains, floodings, hurricanes, and storms (Trenberth, 2018).

In times where climate change is rampant, addressing it turns imperative as a recent report from the White House estimated that the cost of climate and weather disasters in 2022 totaled more than $165 billion dollars – not including the loss of lives, impacts on our healthcare and displacements (Vahlsing & Liscow, 2023). This same report stated: "As temperatures continue to increase – causing more severe heat waves, coastal flooding worsened by sea-level rise, and other natural disasters – the costs of climate rise will likely continue to rise in the coming years" (Vahlsing & Liscow, 2023). The reality is that changes in the climate are occurring and will continue to occur for the next few decades due to greenhouse gases already in the atmosphere and the more to come if they continue to increase (Glick et al., 2011). The potential of long-term harmful impacts of climate change must be a motive to revisit old mechanisms to address climate change with another lens, perhaps through the adaptation lense (Glick et al., 2011).

5.2 Adaptation and Resilience in a Constantly Changing World

Until recently, scientists focused mostly – if not solely – on reducing greenhouse emissions as a way to mitigate climate change (Glick et al., 2011). Nevertheless, adaptation is increasingly becoming a widely acknowledged and embraced approach as a response to climate change – as it "serves as an essential complement" to climate change mitigation efforts (Glick et al., 2011). Climate change adaptation focuses on preparing for and coping with the impacts of climate change (Glick et al, 2009, as cited in Glick et al., 2011). In this sense, mitigation and adaptation are

intrinsically connected in the sense that less adaptation is required the more we mitigate (El-Ashry, 2009). However, such a statement does not mean that if we reduce drastically greenhouse emissions, we do not need adaptation. Contrary to that notion, adaptation is and will always be necessary because some degree of climate change is inevitable and will lead to adverse impacts – which means that adaptation is necessary to build resilience and reduce vulnerability (El-Ashry, 2009).

The most recent report from the Intergovernmental Panel on Climate Change (IPCC) stated that adaptation planning and implementation are generating multiple benefits all around the globe in different sectors and regions (IPCC, 2023). Around 170 countries and many cities have included adaptation in their climate policies and planning processes – as adaptation can produce multiple additional benefits that include reduction of risks and damages (IPCC, 2023). However, when selecting adaptation strategies, one must take into consideration how effective in reducing climate risks each strategy can be in each given context because effectiveness will vary depending on the place and its internal dynamics (IPCC, 2023). One important part of adaptation is to understand the effects, dangers, and uncertainties related to climate change, but also to understand that climate change operates differently in each place and by doing so comprehend that the vulnerability of each place to climate change will also vary and be subject as a whole to its specific dynamics (Glick et al., 2011). Could this mean that resilience – as the ultimate finality of adaptation – will vary accordingly and its operationalization will be entitled to the place where it is introduced?

The concept of resilience has evolved over time and has been used in various disciplines – meaning that its usage and employment vary depending on the context in which it is used (Subiyanto et al.,

2020; Wang et al., 2023). In a transportation setting, the concept of resilience has no standard definition or perhaps been transformed from time to time. In the case of the American Association of State Highway and Transportation Officials (ASSHTO), resilience is defined as “the ability to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events” (ASSHTO, 2017). On the other hand, the FHWA slightly expanded on the definition: “the ability to anticipate, prepare for and adapt to changing conditions and withstand, respond to and recover rapidly from disruptions” (National Academies of Sciences, Engineering, and Medicine, 2018, as cited in Daniels & MacArthur, 2022). One thing that stands out from these two definitions is that, although they differ in scope, both definitions emphasize the necessity of a system’s ability to react to and recover from interruptions (Daniels & MacArthur, 2022).

However, resilience in a more broad scope is defined as the capacity of a system to absorb disturbance and recover while undergoing change as it retains the same functionality (Walker et al., 2004, as cited in Folke, 2006). According to Folke (2006), the first portion of this definition has received much attention in research on ecosystem resilience, even though it has also been used in relation to social change. Social resilience is the “ability of human communities to withstand external shocks to their social infrastructure, such as environmental variability or social, economic, and political upheaval” (Adger, 2000, as cited in Folke, 2006). However, resilience is not only about being robust to disturbance, but rather about the opportunities that disturbance opens to reimagine systems and renew processes in the face of unanticipated events (Folke, 2006). This means that resilience allows for continuous development by providing adapting capacity between sustainability and analog evolving with change (Smit & Wendel, 2006, as cited in Folke, 2006). In

this sense, we can see how resilience encompasses both ecological and societal dimensions in environmental settings.

5.3 Revisiting Resilience with a Social-Ecological System Approach

In a highly interconnected world, it is hard to separate elements to identify the root causes of certain problems. Recent studies confirm that current pressing environmental and social sustainability challenges are clearly intertwined (Biggs et al., 2021) – as these are a result "from the confluence and interaction of multiple, mutually reinforcing social and ecological processes at multiple scales" (Folke et al., 2016, as cited in Biggs et al., 2021). While social processes include political, technological, economic, and cultural processes, ecological processes include biotic (population dynamics) and abiotic (climate patterns) processes (Biggs et al., 2021). This means that problems cannot be addressed without acknowledging the systemic, intertwined nature of human problems (Liu et al., 2015, as cited in Biggs et al., 2021). In the past, academics treated humans and nature as two independent things, although recently they are starting to view human systems as "interdependent, inseparable, and intertwined with ecosystems, embedded within and dependent upon the biosphere and the broader Earth system" – with the urgent need for knowledge production that accounts for and engage with the complex interconnections between the social and ecological features, problems, and opportunities they might provide (Folke et al. 2016; Reyes et al. 2018; Schlüter et al., 2019; Preiser et al., 2018, as cited in Biggs et al., 2021).

Social-ecological systems (SES), as an emerging concept, help us understand the interconnected and interdependent nature of human and natural systems by emphasizing that people and nature are intertwined and coevolve (Biggs et al., 2021). Therefore, the concept of SES not only tells us

that nature is no longer the space in which social interactions take place, but also that people are not an external force in ecosystem dynamics (Folke et al., 2011; Schoon & Van der Leeuw, 2015, as cited in Biggs et al., 2021). This clarified that SES are in fact cohesive, integrated systems distinguished by "strong connections and feedbacks within and between social and ecological components that determine their overall dynamics" (Folke et al., 2010; Biggs et al., 2015, as cited in Biggs et al., 2021). This showcases SES as a "type of complex adaptive system" composed of many interdependent elements that interact to give rise to emergent, unpredicted system-wide patterns from the individual components (Biggs et al., 2021). Now, these system-wide patterns will influence the individual system and its interaction with other parts, resulting in a feedback process that will shape the system over time and allow it to adapt to the changing context (Lansing, 2003, as cited in Biggs et al., 2021).

SES research is broadly problem-oriented and plays an enormous role in not only informing sustainable policies and practices, but also in improving the development of resilience, adaptive approaches, and sustainability (Biggs et al., 2021; Stokols et al., 2013). In this sense, SES brings us an opportunity to analyze the concept of resilience in a new way that enables a broader conceptualization of resilience for understanding human-environment transactions (Stokols et al., 2013). For example, a society can demonstrate great ability to cope with change and adapt if analyzed exclusively through the social lens, even though such adaptation can result at the expense of changes in the capacity of ecosystems (Smith & Wandel, 2006, as cited in Folke, 2006). Likewise, if we focus exclusively on the ecological side to make a decision for sustainability, we may encounter narrow and wrong conclusions – as every system dynamic is not being taken into consideration when performing such analysis (Folke, 2006). The reason is that environmental

settings are not only characterized by their physical components, but also by their social ones: natural and built features, objective and subjective qualities, and participants in environments that include individuals, communities, organizations, and entire populations (Stokols et al., 2013).

In this sense, rather than forcing us to break the components of the system individually, SES provides us with a system-based framework to understand the system with its components as a whole (Briggs et al., 2021; Stokols et al., 2013). In fact, under SES, resilience can usefully serve as a bridging concept and facilitate a discussion of complex system dynamics – informed by a variety of viewpoints – to potentially provide innovative theoretical and applied insights (Baggio et al., 2015, as cited in Biggs et al., 2021). Ultimately, resilience in relation to SES "incorporates the idea of adaptation, learning, and self-organization in addition to the general ability to persist disturbance" (Folke, 2006). Analyzing resilience through the SES lens in synthesis improves our understanding of complex and entangled problems in multiple ways, including paying attention to responses exchanged between systems and emphasizing the transactions between natural and semiotic dimensions (Stokols et al., 2013). Therefore, resilience in a SES context, "refers to the magnitude of disturbance that can be absorbed before a system changes to a radically different state as well as the capacity to self-organise (sic) and the capacity for adaptation to emerging circumstances" (Carpenter et al., 2001; Berkes et al., 2003; Folke, 2006, as cited in Adger, 2006). The latter definition builds up to the previous one, but adds two crucial elements: (1) the capacity for self-organization and (2) the capacity to adapt jointly with uprising situations.

5.4 Assessing Vulnerability in Social-Ecological Systems

In a climate change context, vulnerability refers to the "degree to which a system is susceptible to and is unable to cope with adverse effects" of climate change or in a short way as "the susceptibility to be harmed" (Adger, 2006, p.269). Species, habitats, ecosystems, and infrastructure can be vulnerable to climate change. The more vulnerable an asset is to climate change, the more likely it is to experience greater harm (Stein et al., 2014). Contrary, assets with less vulnerability to climate change are less affected by it. To know and understand how vulnerable an asset is to climate change, a vulnerability assessment can be performed. Vulnerability assessments provide essential information needed for adaptation planning such as (1) the identification of assets that are likely to be vulnerable to climate change and (2) the understanding of why they are vulnerable (Stein et al., 2014). According to Stein et al. (2014), identifying which assets are vulnerable is important for helping set priorities for adaptation action. Similarly, understanding the how and why of those vulnerabilities is important and necessary for elaborating strategies and actions capable of reducing those vulnerabilities (Stein et al., 2014).

In essence, this type of information is important for adaptation planning because it encompasses the own definition of adaptation (Stein et al., 2014), as "initiatives and measures to reduce the vulnerability of natural and human systems actual or expected climate change effects" (IPCC, 2007a, as cited in Stein et al. 2014). This means that in order to adapt to climate change, one needs to assess vulnerability to make the right-informed decisions about our assets. Although vulnerability assessments are important for helping set priorities for adaptation action, it is important to note that they are not meant to set priorities for action, but instead to provide information as a basis for organizing priorities (Stein et al., 2014). In this sense, "vulnerability assessments do not predetermine those decisions" (Stein et al., 2014). In other words, this means

that they do aim to serve as a foundation for making the right informed decisions. When talking specifically about climate change, the literature points out that "among adaptation planners, vulnerability assessment is a preferred framework for understanding the likely effects of climate change on natural resources, as well as on human communities and social assets (Turner et al., 2003; Adger, 2006, as cited in Stein et al., 2014).

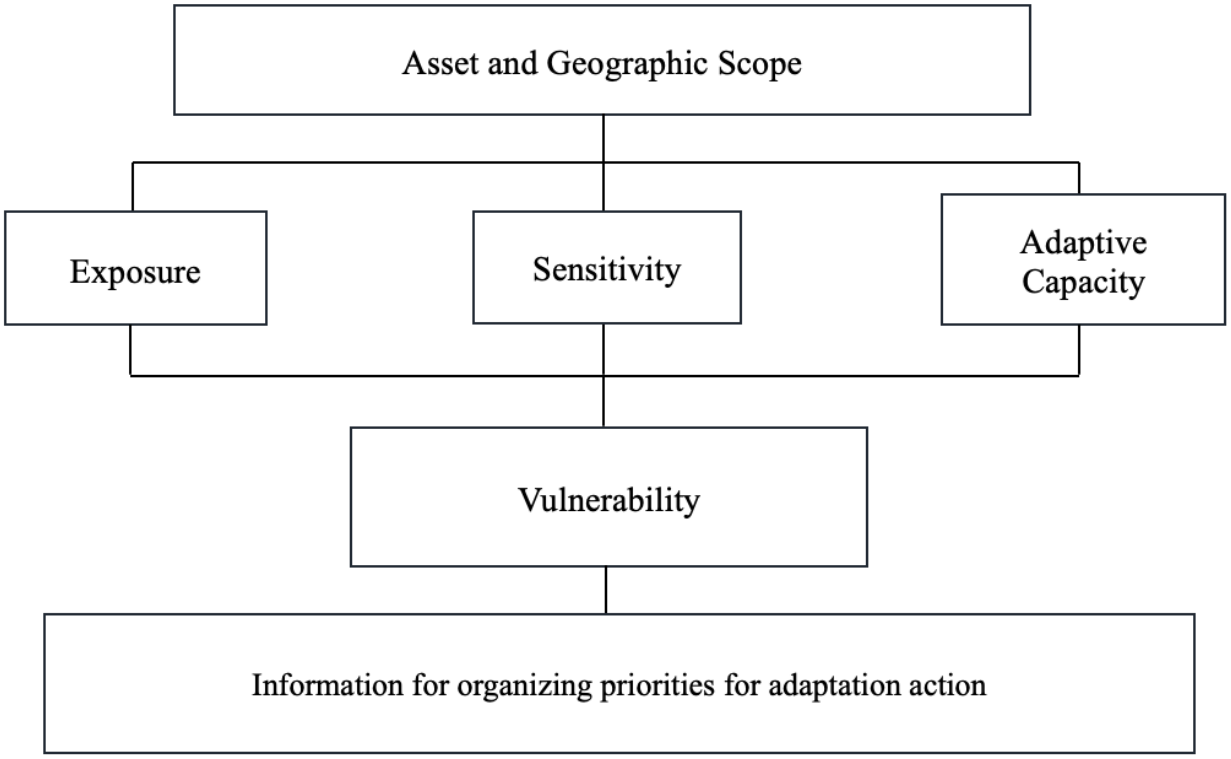


Figure 4: Components of vulnerability assessments. Diagram: Self-Elaborated, González-Velez, 2023. Source: Stein et al., 2014, pp.96.

There are a few preparatory steps before performing a vulnerability assessment. According to Cook et al. (2016), the very first you need to do is clearly articulate what decisions the vulnerability assessment will inform. This way you will be able to identify what are you trying to accomplish and what is needed. This means that vulnerability assessments are unique to the purpose of the research: "There is no one-size-fits-all approach […] approaches to conducting vulnerability

assessments differ widely, and the scope and level of detail need to match an organization or project's needs" (Stein et al., 2014, p.98). Knowing this, before assessing vulnerability you also need to select your asset and your geographic scope (Cook et al., 2016; Filosa et al., 2017). Since climate change effects vary depending on the place and time, it is important to contextualize and clearly define the asset to be studied and where it is located. For example, when performing a vulnerability assessment of the transportation infrastructure, the United States Department of Transportation (2017) recommends (1) selecting and characterizing important transportation assets to study and (2) identifying key climate variables that could impact those assets (Filosa et al., 2017). Including assets to be assessed will depend on a multiplicity of factors, but heavily on the data available (Filosa et al, 2017). Similarly, when selecting the assets, a variety of factors can be taken into consideration: repeatedly impacted (subject to frequent hazards), stage of life (outdated infrastructure), and most critical (elements) (Filosa et al., 2017).

According to Adger (2006), in all scenarios, the key parameters to assess vulnerability are (1) exposure, (2) sensitivity, and (3) adaptive capacity. "Exposure and sensitivity interact to determine potential impact, with adaptive capacity representing the ability of the species or system to accommodate or cope with the impact" (Stein et al., 2014). Table 3 below summarizes the definitions of these three parameters.

Parameter	**Definition**	**Instruments**
Exposure	The degree to which a system or asset species may experience climate change	Understanding of historic and current observed climate combined with modeled projections

Sensitivity	The degree to which a system or asset is responsive, modified, or affected by climate change	Understanding how the asset works and how it will be affected by factors provoked by climate change
Adaptive capacity	The ability of a system or asset to evolve and expand to cope with environmental hazards	Understanding of how internal and external variables affect the adaptive capacity of the asset

Table 3: Parameters to assess vulnerability, definitions, and instruments. Sources: Stein et al., 2014; Hayhoe et al., 2011; Lawler et al., 2011, as cited in Stein et al., 2014, & Adger, 2006.

As stated below, exposure refers to the degree to which a system or asset species may experience climate change, which includes changes in climatic variables such as temperature and precipitation, but also changes in related factors such as sea-level rise, water temperatures, and drought intensity (Stein et al., 2014). In this sense, climate variables are the conditions that affect the asset or system and are subject to change. The selection of climate variables will depend heavily on the variables that have the greatest effects on the asset (Filosa et al., 2017). One of the ways that exposure can be assessed is through an "understanding of historic and current observed climate (retrospective assessment) combined with the use of modeled climate projections (prospective assessment)" (Hayhoe et al., 2011; Lawler et al., 2011, as cited in Stein et al., 2014) – meaning that a modeling database is often needed to understand how exposed the asset is and will be in the near future. This will help identify the spatial distribution of the variables, as well as how they may evolve over time (Cook et al., 2016). Determining the appropriateness of climatic exposure data to use would depend heavily on the availability and the level of expertise to interpret climatic data, but also on the scope and scale of the vulnerability assessment (Daniels et al., 2012, as cited in Stein et al., 2011).

While exposure refers to the exposition of a system or asset to factors that are typically external, sensitivity can be summarized as to what extent that specific asset will be affected if exposed by factors either external or provoked by climate change (Adger, 2006; Stein et al., 2014). In other words, how positively or negatively affected the asset will be if exposed to a certain climatic variable. This means that the more sensitive an asset is to a certain variable, the more vulnerable it tends to be (Cook et al., 2016). According to Cook et al. (2016), reviewing "past events can serve as a useful indicator of future sensitivity" (p.19). However, relying solely on past information and data is not recommended, rather it is important to take into consideration recent events, as well as projected in the pursuit of including new and anticipated variables (Cook et al., 2016). As a result, the potential harm to an asset from climate change can be mitigated by reducing exposure and sensitivity, but also "by ensuring that something is more capable of anticipating or recovering from climate-related impacts" (Cook et al., 2016). This is where adaptive capacity comes into play as the third parameter of the vulnerability assessment.

Adaptive capacity describes the ability to take actions to reduce adverse impacts, reduce harm, or maximize beneficial opportunities from current climate variables affecting an asset (Cook et al., 2016). In other words, adaptive capacity provides you with a step further into exploring the opportunities to actually adapt the asset to climate change. Looking at adaptive capacity can provide you with a more holistic overview by considering external factors that can influence vulnerability (Stein et al., 2014). Therefore, as more understanding you have about internal or external variables affecting the adaptive capacity of an asset, the more information you will have to enhance adaptive capacity (Stein et al., 2014). The adaptive capacity of an asset will also depend on access to information, access to resources, and the ability to assess climate issues and make

decisions (Cook et al., 2016). This information on adaptative capacity can be useful when identifying adaptation options (Cook et al., 2016). With these three parameters assessed, exposure, sensitivity, and adaptive capacity, "you can develop an understanding of the overall vulnerability of a system to climate variability and change" (Cook et al., 2016).

So far, vulnerability assessment discussions have been solely talking about climate-related variables that could influence the vulnerability of an asset. However, climate-related variables are not just the only ones contributing to vulnerability of a system because there are non-climate-related variables that also come into play when assessing vulnerability. The SES approach states that "vulnerability to environmental change does not exist in isolation from the wider political economy of resource use" (Adger, 2006, p.2). The latter suggests another dimension of vulnerability that not only portrays the physical aspects, but also the social processes that influence the vulnerability of an asset (Adger, 2006). According to Fabre (2020), socioeconomic vulnerability can be measured by variables such as the age of the population, income of the families, method of transport, single parents with kids, level of education, age of the population, unemployment, and people with disabilities. These variables turn a place more vulnerable because response after a disaster may not be as immediate as it should be due to lack of mobility or resources to reconstruct in a promptly manner (Fabre, 2020). Moreover, it may prevent people from accessing resources for personal protection against natural disasters – further enhancing vulnerabilities (Fabre, 2020).

5.5 Shocks and Stresses: Undermining Resilience in Social-Ecological Systems

Although climate variables share some similarities with climate shocks and stresses, they are not the same. On the one hand, a climate variable is a condition that affects the asset or system and

will be analyzed in the vulnerability assessment (Filosa et al., 2017). On the other hand, climate shocks and stresses are more related to the magnitude or intensity of the variable that may harm or impact an asset or system. According to Sagara (2018), shocks are "external short-term deviations from long-term trends that have substantial negative effects on people's current state of well-being, level of assets, livelihoods, safety or their ability to withstand future shocks", while stresses are "long-term trends or pressures that undermine the stability of a system and increase vulnerability within it" (p.1). Shocks and stresses are similar in form, but differ in various elements that range from duration and intensity. The first occurs abruptly and suddenly, therefore causing immediate consequences. The latter occur over time and in a prolonged period of time, influencing the surrounding environment in a gradual way. In sum, from a resilience and adaptation point of view, stresses could provide some time to prepare due to its anticipatory process, but shocks may severely undermine the stability and resilience of a system due to its unpredictable character.

Stresses and shocks can also be categorized as covariate or idiosyncratic, which refers to the amount or extent of people affected (Sagara, 2018). According to Sagara (2018), "covariate events affect large numbers of people in a given geographic area, while idiosyncratic events affect specific individuals or households within a community" (p.4). Stresses and shocks do not have to be necessarily climate-related, but also non-climate-related. Table 4 below lists some common shocks and stresses:

Climate-Related	**Non-Climate-Related**
Hurricanes, storms, tornadoes…	Poverty
Flooding	Social exclusion or discrimination

Heat or cold waves	Crime or violence
Drought	Fire
Wildfires	Population pressure
Land degradation	Land or soil degradation

Table 4: Common Shocks and Stresses. Source: Sagara, 2018, p.3.

5.6 Puerto Rico and Loíza: Climate Change and the Post-Disaster Era

Climate change in Puerto Rico is inescapable. It is here and will continue to damage and produce innumerable losses – unless action is taken to counterattack its effects. In fact, a study conducted by Lázaro-Méndez et al. (2015) provided evidence that "Puerto Rico is warming up and extreme heat events in San Juan are increasing in both intensity and frequency" – while explaining that such events can contribute to social and ecological effects (p.6). On the other hand, Fabre (2020) explained how Puerto Rico has experienced major atmospheric events as a result of climate change: Hurricane Hugo in 1989, Hurricane George in 1998, Hurricane Irma, and Hurricane María, both in 2017. The Island is also exposed to other climate change-related hazards such as coastal erosion, sea-level rise, major flooding events, and extreme weather events, which according to Fabre (2020) impose a burden on communities. The reason why is that experiencing these types of hazards exposes communities to face vulnerabilities that affect their socioeconomic and environmental stability – therefore affecting their functioning under normal circumstances (Fabre, 2020).

When talking about climate change and resilience in Puerto Rico, it is imperative to understand that the Island is currently under a post-disaster era scenario. Hurricane María in September of 2017 marked a before and after in Puerto Rico due to the destruction that it brought to thousands

of people and communities (Fabre, 2020). Hurricane María followed just around two weeks after Hurricane Irma, which brought tropical storm winds and significant heavy rainfall (Main et al., 2021). The effects of the 2017 hurricane season in Puerto Rico were numerous, with various negative connotations and a bitter remembrance taste for those who experienced the effects of it on the Island. Hurricane María alone left the entire island without power and damaged thousands of homes, telecommunications infrastructure, roads, bridges, schools, and around 80 percent of the value of the crops (Resilient Puerto Rico Advisory Commission, 2018). According to the Resilient Puerto Rico Advisory Commission (2018), Hurricane María also impacted the physical infrastructure of all the hospitals and health clinics on the Island, as well as 70 percent of the potable water distribution system. After Hurricane María, the Government of Puerto Rico estimated that the Island "will need $94.4 thousand million dollars to recover completely", while the National Oceanic and Atmospheric Administration (NOAA) estimated that the damages provoked by Hurricane María made it the third most costly hurricane in the history of the United States of America, only being succeeded by Hurricane Katrina in 2005 and Hurricane Harvey in 2017 (Resilient Puerto Rico Advisory Commission, 2018).

In 2023, a report from Global Americans stated: "More than five years following the Hurricane [referring to Hurricane María in 2017], reconstruction efforts continue to face significant challenges" (p.24). This same report outlined some of the major hurdles that led to delays in disaster recovery, pointing out many factors at the fund management level such as limited institutional knowledge, capacity to manage disaster recovery programs, difficulties between grant applicants and the Federal Emergency Management Agency (FEMA), and increasing costs of projects (Global Americans, 2023). The Resilient Puerto Rico Advisory Commission (2018)

explained that the gravity of the impacts [referring to Hurricane María] unveiled the vulnerability of the physical and natural infrastructure of the Island in the face of extreme weather events, while also highlighting the necessity of better preparing for future events. However, the 2017 hurricane season not only uncovered problems at the physical-structural level, but also at the less tangible area. Structural socioeconomic vulnerabilities were also unveiled and exacerbated because of the impacts of the hurricanes – therefore testing the resilience capacity of the Island through a combination of physical, natural, and socioeconomic factors (Resilient Puerto Rico Advisory Commission, 2018). Five years later, as expected, Hurricane Fiona – a significantly less powerful Category 1 hurricane – struck the Island in September of 2022, knocking down the fragile power grid and exacerbating other long-standing structural problems, all as a result of climate change (Global Americans, 2023).

Hurricane María exposed the infrastructure of Puerto Rico – including the transportation systems – to extreme wind velocities (Main et al., 2021). A study conducted by the United States Department of Commerce, National Institute of Standards and Technology (NIST), stated that the buildings and structures affected the most, were the ones not designed by engineers; and that informal settlements were severely impacted and damaged – meaning that it had a deficient performance (Main et al., 2021). This type of settlement does not comply entirely with permits, planning, soil studies, or the design and supervision of an architect and an engineer (Tolentino, 2018). This makes informal settlements a very concerning issue due to their vulnerability and fragility (Tolentino, 2018). It is estimated that around 55% of the housing structures in Puerto Rico have some sort of informal factors; and more than 75 thousand of them were constructed informally from 1999 to 2018 (Tolentino, 2018). From a post-disaster recovery standpoint, this is

highly prejudicial for recovery efforts. Since most of the informal settlements do not have written deeds or titles of property, when a catastrophe happens, the FEMA is unable to advance or agile disbursements (Alex, 2018). Similarly, the majority of these informal settlements do not have any type of insurance (Alex, 2018). This means that many of the people living in informal settlements do not qualify for immediate assistance to reconstruct their homes or remedy the damages caused to the properties. Instead, they have to undergo through an entire process to "legalize" their homes, and then wait for federal assistance, which can take a very long time.

Situated almost 20 minutes away from San Juan, the Municipality of Loíza faces an even worse scenario than the rest of Puerto Rico in the post-disaster era context. It is especially vulnerable to hurricanes – not only physically due to its location near the sea and other water forms, but also because of its marginalization (Amnistía Internacional, 2018). In 2018, the year following Hurricanes Irma and María, the United States Army Corps of Engineers explained how the northern shore was being severely impacted by erosive forces in the form of natural factors including winds, tides, currents, waves, and storm events, but also others such as sea level rise and climate change (USACE, 2018). Furthermore, how the "preponderance of the coastal flooding, shoreline erosion, and generally all of the roadway, structural, and property damage along the shoreline" of a specific study area would seize to exist if action was not taken (USACE, 2018). Persistent erosion along the Loíza shoreline due to hurricanes and coastal storms will continue to threaten infrastructure and public safety (USACE, 2018). In 2018, there was reported that a portion of a roadway failed due to erosion impacts; and that it was further threatened by recent storm events (USACE, 2018).

5.7 Mitigation Plan Against Natural Hazards of the Municipality of Loíza

The Mitigation Plan Against Natural Hazards of the Municipality of Loíza[8] states that "the planning process, for natural hazards mitigation, is defined as sustained actions for reducing or eliminating, in the long run, the risks associated with the occurrence of natural hazards" (FEMA, 2013, as cited in JPPR, 2021). The Mitigation Plan also explains the objective of planning for natural hazards mitigation as identifying policies and actions from the municipal government to reduce the risks and loss that could result from those hazards (JPPR, 2021). Similarly, the Mitigation Plan clearly states the following: "The Municipality of Loíza has the responsibility of protecting the safety and well-being of its citizens. A proactive mitigation program reduces risks and helps create safer and more resilient communities" (JPPR, 2021). The Mitigation Plan was developed with the help of local state agencies and a wide public participation promulgation – in the pursuit of developing a mitigation plan that could not only help the Municipality to prepare and reduce the possible impact of natural hazards, but also to be more resilient (JPPR, 2021).

The Mitigation Plan has as its main goal to identify the natural hazards that the Municipality of Loíza is vulnerable to and develop measures of mitigation to prevent or reduce future loss of lives and property (JPPR, 2021). In this sense, the Mitigation Plan allows for preparing and responding to any event of danger – resulting in a vital tool for the resilience of communities in the Municipality (JPPR, 2021). In sum, the Mitigation Plan provides: (1) a summary of the natural hazards that the Municipality is exposed to; (2) a description of the vulnerability of the municipality against hazards; (3) measures of protection for critical installations; (4) strategies for mitigation to reduce the loss of lives and property and the adverse impact in economic and social

[8] From now on called the Mitigation Plan, instead of the Mitigation Plan Against Natural Hazards of the Municipality of Loíza, to shorten the title and promote fluency within the text.

structures in the region (JPPR, 2021). The Mitigation Plan identified the natural hazards to which the Municipality of Loíza is exposed to based on the priorities identified in the previous 2016 Mitigation Plan and the updated process of the analysis of risks, which takes into consideration recent weather events Hurricane María and Irma (JPPR, 2021). Some of the natural hazards identified were sea level rise, drought, earthquakes, floodings, landslides, strong winds, tsunamis, storm surges, coastal erosion, and wildfires (JPPR, 2021). All of these hazards were identified as a priority for the Municipality, as they are potentially very likely to occur frequently or periodically (JPPR, 2021).

The Mitigation Plan projects major impacts of the hazards identified due to the effects associated with climate change (JPPR, 2021). At the same time, it states that the infrastructure of cities and towns is vulnerable in the face of extreme climatic changes as a byproduct of sea level rise, erosion, drought, wildfires, and flooding associated with climate change (JPPR, 2021). According to the Puerto Rico Planning Board, not only the health and human well-being will be negatively impacted, but also the ecosystems, biodiversity, agriculture, and physical infrastructure (JPPR, 2021). Furthermore, climate change exacerbates and creates new dangers, while boosting the vulnerability of Puerto Rico, its municipalities, and its communities – as it poses new challenges to public health, safety, quality of life, and economy (JPPR, 2021). To these ends, the Mitigation Plan states that municipalities should incorporate measures to reduce risks and costs associated with climate change, so that significant damages to the economy, environment, and human health are avoided (JPPR, 2021).

5.8 Community-Based Climate Change Adaptation Plan of the Municipality of Loíza

The Community-Based Climate Change Adaptation Plan of the Municipality of Loíza[9] evaluates the risks and the vulnerability that Loíza is exposed to and "develops adaptation strategies alongside the community" (Marine Awareness Research & Education Society [MARES], 2018). The Adaptation Plan explains that because climate change is continuous and persistent, designing strategies that contain action initiatives against climate change is necessary – while ensuring sustainable and long-standing establishment and implementation through community participation (MARES, 2018). The Adaptation Plan also aims to create awareness amongst the Loíza residents about the risks of climate change and, therefore, achieve community involvement (MARES, 2018). It includes a report that outlines the level of understanding that the residents of Loíza have about climate change, while learning about the risks that they are exposed to through a set of community activities in which the own residents were able to identify the climate change-related hazards that affect them (MARES, 2018).

The main purpose of the Adaptation Plan is to "evaluate the exposure and vulnerability to the risks related to climate change that could affect areas in the Municipality of Loíza with structures or critical infrastructure, and sensitive coastal ecosystems" (MARES, 2018). To this end, it aims to sensibilize the residents of Loiza regarding risks associated with climate change and develop strategies of adaptation, while involving the public in each stage of the Adaptation Plan – including the stages of creation, execution, and implementation of the Adaptation Plan (MARES, 2018). With the information gathered, the Adaptation Plan will develop and prioritize strategies of adaptation alongside the community, as well as recommend strategies and actions for adaptation

[9] From now on called the Adaptation Plan, instead of the Community-Based Climate Change Adaptation Plan of the Municipality of Loíza, to shorten the title and promote fluency within the text.

with guidelines on how to implement them (MARES, 2018). The Adaptation Plan identified future climate scenarios increasing temperatures, sea level rise, more intense hurricanes and storms, increasing heavy rainfall events, and ocean acidification (MARES, 2018). As for climate change hazards, the Adaptation Plan identified extreme heat waves, more intense and frequent droughts, coral bleaching, flooding, coastal erosion, coastal flooding, wind damage, increasing heavy rainfall events, water table elevation, sea level rise, more intense hurricanes and winter storms, and ocean acidification (MARES, 2018).

5.9 Transportation Infrastructure: Climate Change Vulnerability and Adaptation Importance

The vulnerability of the transportation infrastructure to climate change not only has to do with hazards associated with climate change itself, but also with the time that it was built. In most cases, when designing and constructing infrastructure for transportation, a series of parameters are taken into consideration – including a range of expected climate variations (Kwiatkowski, 2009). However, changing climate still affects the transportation infrastructure because – regardless – it may still be operating in a climate substantially different from the one for which it was initially designed (Kwiatkowski, 2009). Kwiatkowski (2009) stated that "transportation will be impacted by both extreme weather events and gradual changes in climate" and that the primary risks of transportation are: increasing temperatures, increases in arctic temperatures, sea level rise, increasing heavy rainfall events, and increasing hurricane intensity (p.18). Similarly, additional risks may include freeze-thaw cycles, increasing drought conditions, increasing wind velocity, and increasing storm intensity (Kwiatkowski, 2009).

According to Kwiatkowski (2009), all types of transportation infrastructure – including roads, airports, seaports, rails, tunnels, and bridges – are at risk from extreme weather events like

temperature and precipitation (Humphrey et al., 2008; IPCC, 2014, as cited in Kwiatkowski, 2009). Climate change variables have the "potential to accelerate infrastructure deterioration, increase severe damage and failures, decrease safety, and increase traffic" – which will also have an economic impact, in additionally to the direct impact on the infrastructure itself and its users (Nemry et al., 2012, as cited in Kwiatkowski, 2009). In this sense, having a reliable transportation system is crucial to any economy (Ecola et al., 2020). This means that transportation is indispensable and imperative in the pursuit of having a normal life, as the United States Department of Homeland Security "considers transportation to be lifeline infrastructure, without which normal life or disaster recovery is impossible" (Ecola et al., 2020). In sum, transportation performs an essential function in every country, especially after a major event occurs – whether climate change-related or not – in a post-disaster context.

Talking specifically about Puerto Rico, after Hurricane María and Irma in 2017, all modes of transportation on the Island were severely affected – including ground transportation (surface), water transportation (maritime), and air transportation (Ecola et al., 2020). Concerning ground transportation, the primary immediate result was the obstruction of roads due to debris, landslides, and the collapsing of weakened bridges (Ecola et al., 2020). In fact, the Puerto Rico Department of Transportation reported over six thousand incidents in regard to roadway-related events (Ecola et al., 2020). Public transit in the metropolitan area of San Juan was severely impacted too. Specifically, "bus service in San Juan was suspended for several weeks, and rail service for three months" (Ecola et al., 2020). The amount of devastation to the road network led to "major dislocations to daily life and the ability to move relief supplies around the island" (Ecola et al.,

2020). This impacted the ability of people to access emergency services, healthcare, employment, educational opportunities, and friends and family (Ecola et al., 2020).

5.10 Transportation Infrastructure: A Resilience Mechanism

The transportation infrastructure plays an essential role in facilitating the daily routines of people, as it connects them to workplaces and services (Daniels & MacArthur, 2022). This means that transportation systems are vital for people to be able to perform their activities on a daily basis. However, transportation systems are very susceptible to disruptions caused by disasters, including climate change-related ones (Daniels & MacArthur, 2022). In this sense, when a disruption occurs people that depend on them can be negatively impacted (Daniels & MacArthur, 2022). This is why, Daniels and MacArthur (2022) state that "improving the resiliency of transportation systems is a critical part of emergency response and recovery after disasters" (p.2). This implies that the resilience of a place depends heavily on the resilience of the transportation infrastructure. At the same time, the ability of a place to recover from a disaster will also heavily depend on the resilience of its transportation infrastructure. In sum, without transportation, disaster recovery is considered to be impossible, as a reliable, efficient, and interconnected transportation network is necessary for the success of post-disaster actions (Ecola et al., 2020; Daniels & MacArthur, 2022).

According to Ecola et al. (2020) "transportation in Puerto Rico is an essential component of both recovery and economic development" (p.146). All around the continental United States, transportation is essential to economic development and recovery, but Puerto Rico's transportation context differs in various ways (Ecola et al., 2020). For example, because Puerto Rico is an island, the port system is extremely important – even more so when we take into consideration that Puerto Rico imports approximately 85 percent of its food and all of its liquid fuel (Ecola et al., 2020).

Another important aspect of the Island is that, unlike in the United States mainland, all freight within Puerto Rico moves via truck – primarily through the strategic highway network and mostly within the metropolitan area in San Juan (Ecola et al., 2020). This means that "during a serious disruption, goods can be moved via alternate routes, but not via alternate modes" (Ecola et al., 2020). Given the topography of Puerto Rico, communities were awfully and severely impacted, as many small towns and remote areas only have access to one or two roads at the most (Ecola et al., 2020). This situation in addition to the disruptions at the Port of San Juan, "meant that emergency supplies were slow to reach people in need" (Ecola et al., 2020).

6. Analysis and Findings

The previous exposition has provided explanations of how physical and social vulnerabilities are tied up and, perhaps, entangled when speaking about climate change adaptation and resilience. Therefore, there are no separate systems, as the built environment is intrinsically and closely intertwined with the nonphysical dimensions of vulnerabilities in the face of climate change. Human problems are by nature interconnected and interdependent – which means that taking a deep look and putting all senses into understanding the complexity within them is extremely important. Otherwise, overlooking important factors that condition one and the other may result in the misunderstanding of such complex problems. That is the social-ecological systems: the recognition of the interdependency of human and natural systems in a constant coevolution in the pursuit of improving resilience and adaptation development (Biggs et al., 2021; Stokols et al., 2013). In this sense, every dynamic of a system must be taken into consideration when analyzing and evaluating resilience and adaptation in a place.

6.1 Loíza: An Assessment of the Physical Vulnerability of the Transportation Infrastructure

Previous discussion has contributed to the understanding that Loíza is one of the municipalities in Puerto Rico affected the most by climate change. It is located in a place where it has suffered severe impacts from climate change and continues to suffer – with projections pointing out that impacts associated with climate change will not cease or diminish to severely impact the study area. In fact, the Mitigation Plan elaborated on a list of potential natural hazards and risks in Loíza and included strong winds/tropical cyclones, storm surge, coastal erosion, flooding, and sea level rise – classifying all of them as a high priority for the municipality to address due to their imminent probability of occurrence, therefore further supporting the previous statement (JPPR, 2021). In this sense, the exposure of Loíza's transportation infrastructure to natural hazards is imminent and persistent. Figure 5 below intends to serve as a reference for the location of the main roadway in the Municipality Loíza (PR-187, see red arrows below).

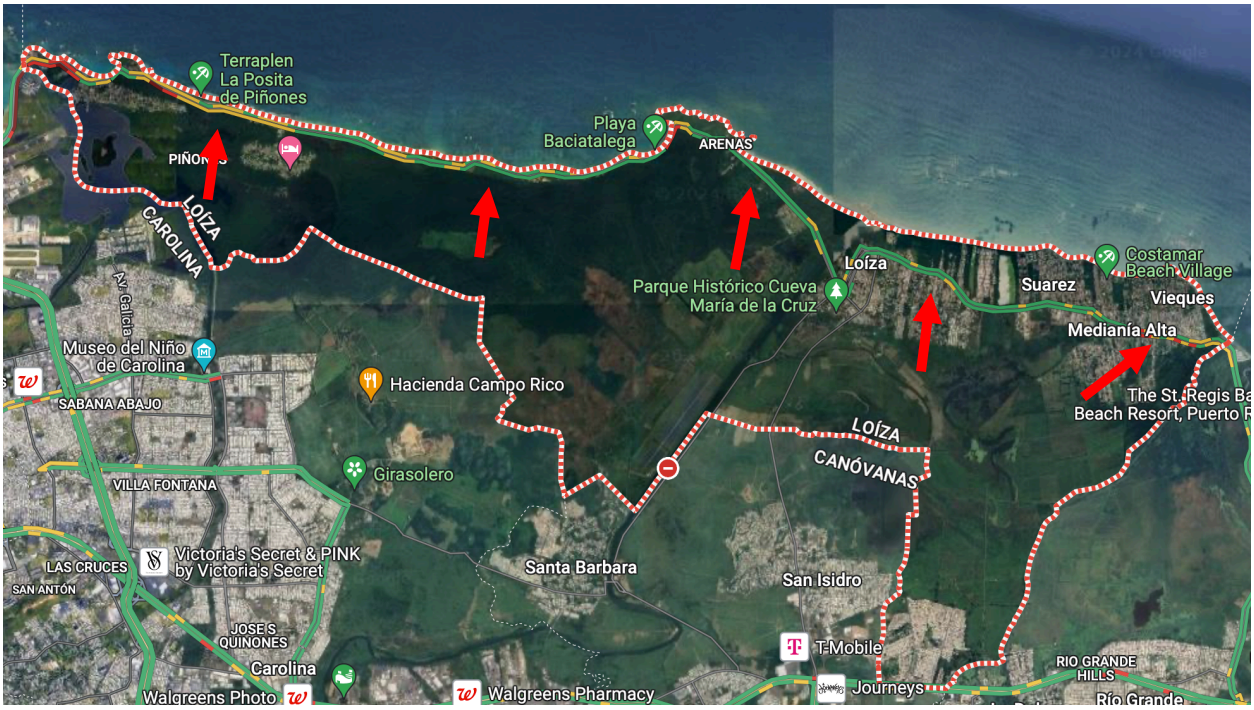


Figure 5: Loíza and the main roadway, PR-187. Source: Google Maps, 2024.

Regarding sea level rise, the Mitigation Plan stated that since Loíza is a coastal municipality, it is exposed to sea level rise (JPPR, 2021). In fact, the Adaptation Plan explained that a 2.01 millimeters annual sea level rise has been observed from 1962 to 2017, meaning that in 55 years the level of the sea has increased by 11.05 centimeters (MARES, 2018). In a scenario of a one-foot sea level rise, the Municipality of Loíza – including its main roadway and certainly many minor others – is expected to be affected. Figure 6 below is a projection of that scenario by the NOAA. Areas that are hydrologically connected to the ocean are shown in shades of blue — the darker the blue the greater the depth of the impact (NOAA, 2024). Areas displayed in green are low-lying areas that are hydrologically "unconnected" areas that may also flood (NOAA, 2024).

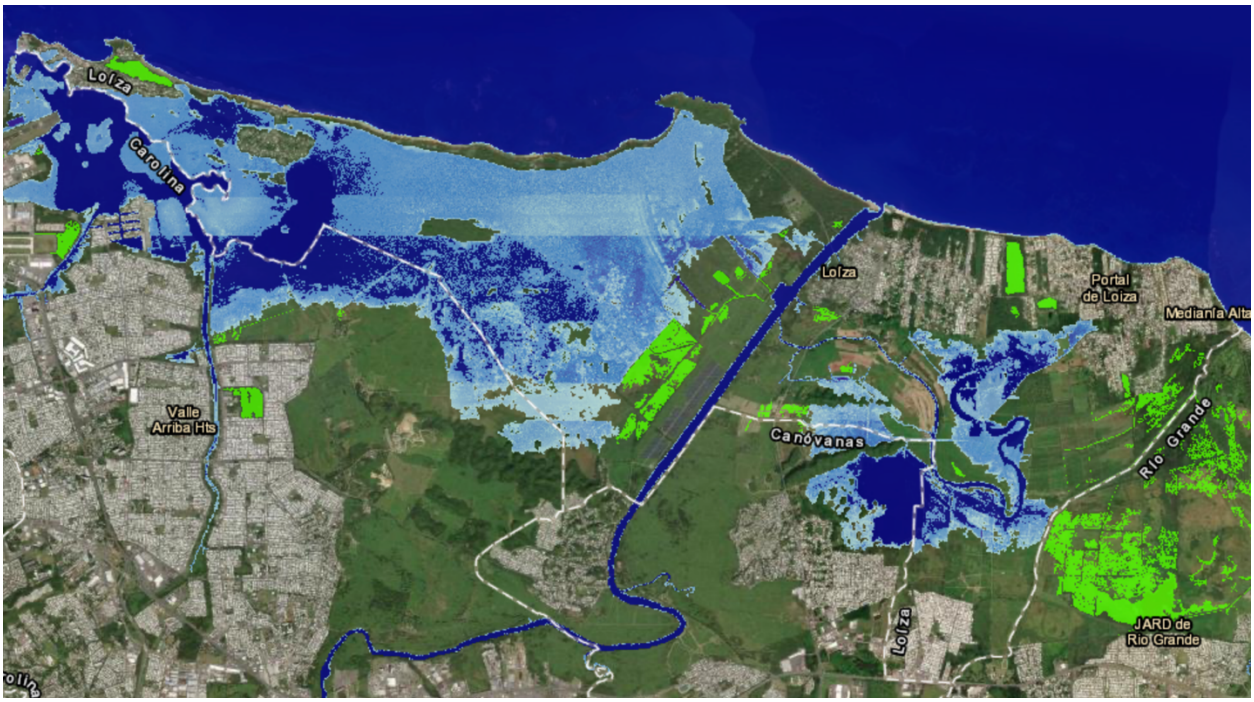


Figure 6: Loíza in a one-foot sea level rise scenario. Source: Sea Level Rise Viewer, NOAA, 2024[10].

[10] Areas that are hydrologically connected to the ocean are shown in shades of blue — the darker the blue the greater the depth of the impact. Areas displayed in green are low-lying areas that are hydrologically "unconnected" areas that may also flood.

Under this scenario, a great portion of the Municipality – including the transportation infrastructure – seems to be affected by flooding caused due to sea-level rise. The Mitigation Plan explains that in a one-foot sea level rise scenario the most affected areas would be the *barrio* to the northwest Torrecilla Baja – along with several surrounding communities (JPPR, 2021). The Mitigation Plan also explains that danger and vulnerability increase as the level of the sea increases (JPPR, 2021).

Now, under a scenario of four feet of sea level rise, the situation would be more complicated, as almost the entire Municipality will flood due to sea level rise (see Figure 7 below). The entire main roadway PR-187 seems to be strongly affected from one side to the other side of the municipality.

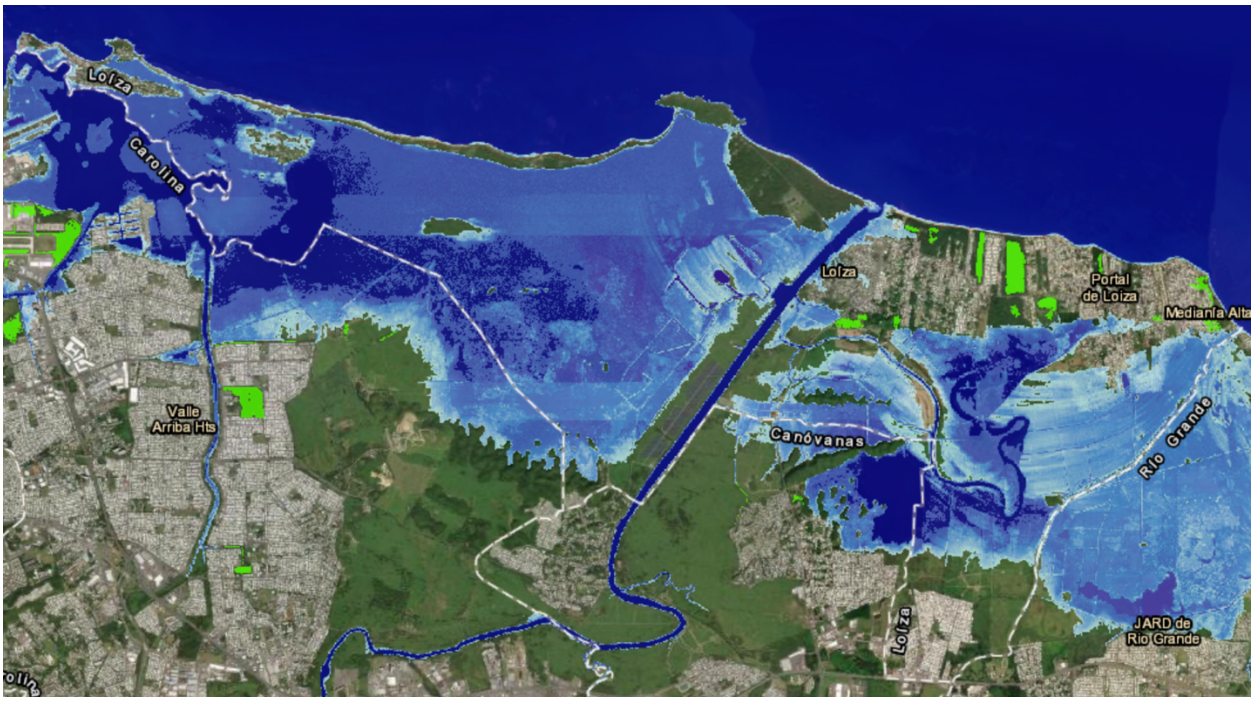


Figure 7: Loíza in a four-foot sea level rise scenario. Source: Sea Level Rise Viewer, NOAA, 2024.

A more extreme case would be a 10-foot sea level rise scenario (contemplated in the Mitigation Plan)[11] – in which almost the entire municipality seems to be flooded, including the main roadway, and nearly 73 percent of all the structures affected (JPPR, 2021). In this sense, under all three

[11] Refer to Appendix I, in which an illustration of *Loíza in a ten-foot sea level rise scenario is shown.*

scenarios, the transportation infrastructure of the Municipality of Loíza becomes negatively sensitive to sea level rise. Sensitivity "refers to how the asset or system fares when exposed to a climate variable" (Filosa et al., 2017).

Hooper and Chapman suggested that flooding, as a result of sea level rise, combined with extreme precipitation exacerbates risks of coastal transport infrastructure, in comparison to inland (as cited in Dawson, 2016). This has to do largely because "rising sea levels present the risk of permanent or periodic inundation of coastal infrastructure as well as increased coastal erosion…" – as well as "jeopardize low-lying access roads" (Filosa et al., 2017). Similarly, Titus (2016) explains that roads in many low-lying communities are situated below the surrounding terrain to allow for the inflow of land into the streets, which can cause streets to be the first to flood. Another problem with persistent flooding is that this can become an immense hurdle for evacuation efforts in case of an emergency, therefore delaying or even limiting the evacuation process (Titus, 2016).

Moving aside from flooding as a result of sea level rise, exposure to flooding in the Municipality of Loíza is commonly a result of heavy rainfall (FEMA, 1997, as cited in JPPR, 2021). However, contrary to this, the Municipality itself has identified that the presence of rain is not needed in Loíza for flooding events to occur, as the river that crosses the Municipality could be charged with rainwater from other municipalities and create an acute flooding event (JPPR, 2021). On the other hand, the season between the months of May and November of each year, storms and hurricanes, can be responsible for the rainfall in the municipality – although the minor weather events are the ones that provoke the majority of the heavy rainfall events (JPPR, 2021). The Mitigation Plan explains that flooding is one of the most severe atmospheric threats – and its frequency can cause severe damage to life and property (JPPR, 2021). In the United States of America, the majority of impacts on human life associated with flooding are from people dragged in their own cars by

flooding events (FEMA, 1997, as cited in JPPR, 2021). The Mitigation Plan explains that flooding events in the Municipality of Loíza cause damage to essential infrastructure such as the power grid, water distribution, roads, and bridges – which, at the same time, interrupt daily operations (JPPR, 2021). Therefore, the transportation infrastructure of the Municipality of Loíza is negatively sensitive to flooding events.

The main roadway PR-187 is also affected by flooding, as it suffers mainly from coastal flooding – which makes it impassable during events of storm surges or hurricanes (MARES, 2018). The Mitigation Plan outlines various sectors in the Municipality of Loíza affected the most by flooding: Villa Cristiana, Villa Batata, Villa Santos, El Parrilla, Los Vizcarrondo, Los Sánchez T Vizcarrondo, Las Minas, Miñi-Miñi, Urbanización Palmarena Zapatería Pizarro, and Honduras y La 23 (JPPR, 2021). The majority of these sectors are located near or alongside the main roadway PR-187. After Hurricane Irma and Maria in 2017, transportation infrastructure (roadways) was also adversely affected, as well as other municipal assets (JPPR, 2021). "Flooding especially flash flood events that start rapidly as a result of intense precipitation, is the predominant cause of weather-related disruption to the transport sector" (DfT, 2014a, as cited in Pregnolato et al., 2017). In this sense, flooding inflicts both physical damage to the transport infrastructure and indirect impacts in the form of disruption to traffic flow, business, and increased emissions – and closure of a major roadway (Pregnolato et al., 2017; Markolf et al., 2019). According to Rebally et al. (2021), flooding events can impact adversely the infrastructure function in the form of economic disruption by reducing or canceling travel for passengers, goods, and services because roads might be submerged, closed, or unsafe to travel. Similarly, at the physical infrastructure level, damage can be caused through direct contact with water, therefore provoking monetary expenses (Rebally

et al., 2019). The Mitigation Plan stated that the principal access roadways in Loíza (PR-187, PR-188, and PR-951) are all at flooding risk (JPPR, 2021).

The transportation infrastructure of the Municipality of Loíza is also exposed to strong winds and tropical cyclones[12], as they are the most common and frequent natural hazards in Puerto Rico (JPPR, 2021). Hurricanes are very dangerous due to their potential for destruction and their capability to affect larger zones (JPPR, 2021). Tropical cyclones are often accompanied by storm surges and heavy rainfall, which can also cause flooding events (JPPR, 2021). The Mitigation Plan identified the northwest side of the Municipality of Loíza as the most affected area by strong winds – which includes a large portion of PR-187 (see Figure 8 below and full map in Appendix II).

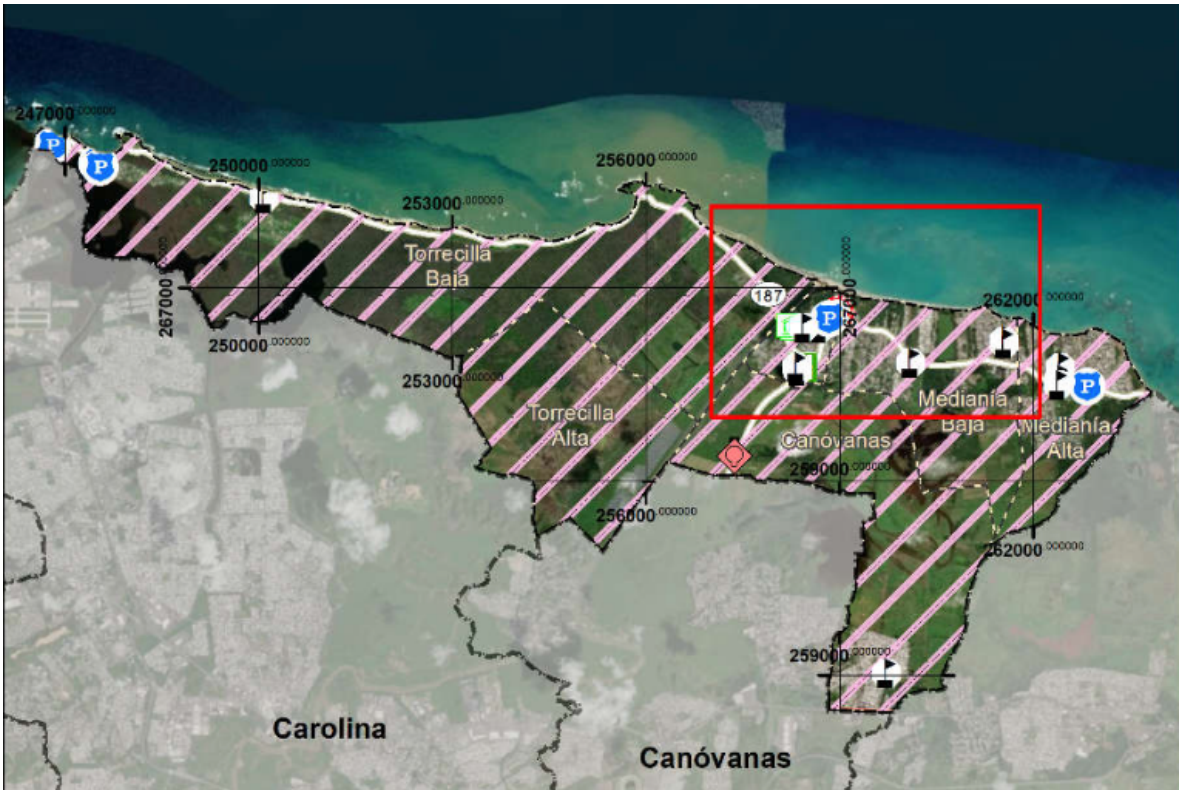


Figure 8: Affected Area in Loíza by Strong Winds. Source: Sociedad Americana de Ingenieros Civiles, 2018; JPPR, 2021.

[12] Under the Mitigation Plan, tropical cyclones, storms, and hurricanes are interchangeable terms of strong winds. Therefore, when using them, we will be referring to the same hazard.

However, when talking about hurricanes, the entire Municipality of Loíza is identified as a risk area (JPPR, 2021). In this sense, all the assets of Loíza are extremely vulnerable, including structures and critical installations (JPPR, 2021). The Adaptation Plan stated that strong winds in Loíza provoke damage to the roadway infrastructure, therefore suggesting negative sensitivity to strong winds (MARES, 2018).

According to Abkowitz et al. (2017) "frequent storms bring excessive rainfall that often lead to local and widespread flooding, as well as rock slides and sink holes" (p.4423). Similarly, storm occurrences may manifest as tornadoes and be accompanied by destructive winds and hail (Abkotwitz et al., 2017). The latter suggests the damage that strong winds could cause to the transportation infrastructure. In support of this, Filosa et al. (2017) explained that Hurricane Irene (2011), Superstorm Sandy (2012), Hurricane Harvey, and Hurricane Irma, and Maria (2017) caused substantial damage to the transportation infrastructure and that more frequent precipitation "can also cause increased structural vulnerability and damage to transportation infrastructure" (p.12). During hurricane events, Anarde et al. (2017) explained that the transportation infrastructure is "crucial for evacuation and post-storm recovery operations". At the same time, suggested that hurricanes can affect greatly transportation infrastructure such as bridges by making them inaccessible – whether through loss of structural integrity or sustained high water (Anarde et al., 2017).

Adaptive capacity "refers to the system's ability to adjust to or cope with existing climate variability or future climate impacts" (Filosa et al., 2017). The interrelation and interconnection of sea level rise, flooding, and strong winds suggest that the adaptive capacity of the transportation infrastructure of the Municipality of Loíza is mutually interdependent and multi-dimensional, rather than an individual issue. The Mitigation Plan and the Adaptation Plan both suggest that with

expected climate projections, these climate stressors are not going to diminish, but instead, they will increase (JPPR, 2021; MARES, 2018). In this sense, with one climate stressor conditioning the other – the adaptive capacity seems to be determined by what is done in regard to the situation as a whole. On the one hand, flooding by sea level rise could be mitigated and become less frequent by incorporating some adaptation strategies along the coast, but what would happen when a heavy rainfall event occurs? On the other hand, if the roadway infrastructure is not adapted as well, then it will flood – probably due to elements such as drainage blockage or even the high proportion of impervious surfaces that prevent infiltration or the free passage of stormwater (MARES, 2018; JPPR, 2021; Pregnolato et al., 2017). The latter suggests another dimension of adaptive capacity and the influences of the system as a whole – that will be further explored and discussed later on.

6.2 Loíza: A Municipality with a High Social Vulnerability in the Face of Disruptions

In 2024, FEMA scored Loíza's social vulnerability as "very high" when taking into consideration risk factors by hazard types such as avalanches, coastal flooding, cold wave, drought, heat wave, hurricane, landslide, riverine flooding, strong wind, tornado, and wildfire (FEMA, 2024). Out of 100, the Municipality of Loíza scored 91.9 – with a very high susceptibility to adverse impacts of natural hazards when compared to the rest of the United States (FEMA, 2024). According to FEMA (2024), 92 percent of United States Census tracts have a lower social vulnerability, as well as 53 percent of Census tracts in Puerto Rico. "Low risk is driven by lower loss due to natural hazards, lower social vulnerability, and higher community resilience" (FEMA, 2024). In the case of Loíza, it is the opposite. The Municipality's expected annual loss is relatively high, scoring 90.4 out of 100 (FEMA, 2024). The expected annual loss is the average economic loss in dollars resulting from each natural hazards (FEMA, n.d.). For hazards such as coastal flooding, hurricanes, riverine

flooding, and strong winds, the Municipality of Loíza is expected to lose more than 1.5 million dollars annually (FEMA, 2024).

Almost 30 percent of the population of the Municipality of Loíza is advanced in age with 60 years and over (SDC-PR, 2022). Nearly 21 percent is considered to be elderly with an age of 65 years and over (SDC-PR, 2022)[13]. From a total population of little more than 23 thousand residents, almost five thousand are part of the elderly community. Research stated that while everyone in the population is affected by natural disasters, elderly people are often disproportionately vulnerable to immediate and underestimated long-term repercussions of disasters (Glass et al., 1977; Bolin & Klenow, 1983; Tanida, 1996, as cited in Ngo, 2001). Elderly people often face functional decline, mainly manifested through problems with mobility, balance, cognitive functioning, sensory deficiencies, and ability (Bodstein et al., 2014). All of these increase their vulnerability in disasters, as response and rescue efforts could be difficult and even hard to achieve (Bodstein et al., 2014).

Age of the Population	**Population Estimate**	**Percentage**
60 to 64 years	1,697	7.20%
65 to 74 years	2,772	11.80%
75 to 84 years	1,577	6.70%
85 years and over	504	2.10%

Table 5: Social Vulnerability Indicator: Distribution of the Age of the Population. Source: American Community Survey, SDC-PR, 2022.

[13] The National Institutes of Health (NIH), states that "traditionally, the 'elderly' are considered to be those persons age 65 and older".

Similarly, consequences as a result of accidents are much more serious for elderly people, as they might require additional time in hospitals and for rehabilitation – having a higher chance of being dependent and dying later (Bodstein et al., 2014). In addition to this, elderly people are often injured twice than younger groups of the population – and post-disaster effects could even exacerbate existing health conditions (Ngo, 2001).

According to the U.S. Census Bureau (2023), almost 46 percent of the population of Loíza lives in poverty. The median household income in 2022 was less than 22 thousand dollars (U.S. Census Bureau, 2023). When these facts are broken down, an alarming 10 percent of the total population of Loíza has no registered income (SDC-PR, 2022). On the other hand, more than one-fourth of the households live with an annual salary of less than 10 thousand dollars, while nearly another 13 percent of the households live with less than 15 thousand dollars (SDC-PR, 2022).

Income[14]	**Estimate**	**Percentage**
No income, unemployed*	2,057	10.40%
Less than $10,000	2,164	25.10%
$10,000 to $14,999	1103	12.80%
$15,000 to $24,999	1,349	15.70%

Table 6: Social Vulnerability Indicator: Distribution of Income. Source: American Community Survey, SDC-PR, 2022.

[14] The social indicator "income" represents the income per household in the Municipality of Loíza. The total of households in the Municipality of Loíza is 8,608 and the percentages are calculated based on that number. The only exception is the category at the top of Table 8 "no income, unemployed*" – which include date solely on the total number of people unemployed in the Municipality of Loíza, rather than the total number of households. Source: American Community Survey, SDC-PR, 2022.

Overall, around 64 percent of the households – more than half of the population – live with less than 25 thousand dollars per year (SDC-PR, 2022). In addition to this, the mean of social security income is less than 14 thousand dollars and the mean for retirement income is less than 19 thousand dollars (SDC-PR, 2022). Research indicates that "poor people are disproportionally affected by natural hazards and disasters" (Hallegatte et al., 2020). Regardless of their location or circumstance, poor people will be more vulnerable to natural disasters or hazards because any impact on their belongings or pace of consumption will threaten substance and long-term prospects because they have fewer resources to reduce risks and cope with the situation's aftermath (Hallegate et al., 2020).

In fact, poverty is an important aspect of vulnerability to natural hazards, as poor people often have less capacity to recover because they may lack essential services and the means to do so (Kanh, 2005, as cited in Fayazi & Bornstein, 2021). Similarly, their settlements and homes could be prone to hazards or even located in high-risk areas (Fayazi & Bornstein, 2021). Furthermore, Ogie and Pradhan (2019) explained how low-income individuals tend to be less prepared because they have less money and resources to spend on preventative or mitigation measures – which can result in more damage to their structures, homes, and assets, therefore limiting or delaying their recovery process. Likewise, "when disasters strike, the people of low income are also likely to have very limited access to lifelines such as communication and transportation options" (Rygel et al., 2006, as cited in Ogie & Pradhan, 2019, p.407). This could prevent them from getting immediate help and accessing the necessary supplies to feed their families, treat an existing condition or disease, and even reconstruct their homes.

The latter ties up to the single-parent social indicator for vulnerability in a place. In the case of single women, research states that married women – a couple – generally receive more assistance preparing for and recovering from a disaster, contrary to single women in charge of the household (Morrow, 1997, as cited in Tobin-Gurley et al., 2010). An example of this is the 1997 Red River flood, when "a high proportion of the occupants who remained in FEMA trailers were women, often single mothers with large families, on public assistance, or marginally employed" (Enarson, 2001, as cited in Tobin-Gurley et al., 2010). Similarly, dating back to Hurricane Katrina, single mothers lacked the resources to prepare for and respond to the massive devastation (Ransby, 2006, as cited in Tobin-Gurley et al., 2010). Single mothers were most likely forced to relocate to places they did not know – therefore facing problems with securing housing, finding employment, and reestablishing vital support networks (Peek & Fothergill, 2008). This was due largely because 47 percent of all single mothers in the United States of America were considered either near poor or had incomes below the national poverty level (Women's Work, 2005, as cited in Tobin-Gurley et al., 2010). In 2019, around 70 percent of all single mothers in Puerto Rico lived under poverty levels, according to the United States Office of Budget and Management (Del Mar-Quiles, 2019).

The Center for Disaster Philanthropy, regarding single mothers of color, stated that they had "a harder time mustering the resources to rebuild after disaster strikes than a family made of two white parents" (Gulliver-Garcia, 2021). Generally speaking, Cutter et al. (2003) explained that single-parent households frequently lack the resources to hire caregivers for dependents, forcing them to balance job obligations with family care, and therefore limiting them financially – which ultimately affects their resilience to and recovery from natural hazards. In the case of Loíza, more than 55 percent of the households are composed of single parents, while – of these households –

more than 40 percent correspond solely to single mothers (SDC-PR, 2022). Furthermore, more than 23 percent of the total number of households headed by a single parent are headed by grandparents instead – which means that the household is maintained by an elderly in charge of a child (SDC-PR, 2022).

Single Parent[15]	**Household Estimate**	**Percentage**
Male householder, no spouse/partner present	1,275	14.80%
Female householder, no spouse/partner present	3,519	40.9%

Table 7: Social Vulnerability Indicator: Distribution of Single Parents Households. Source: American Community Survey, SDC-PR, 2022.

Combined, more than 20 percent of the population of Loíza have no high school diploma (SDC-PR, 2022). Nearly 39 percent of the total have only graduated from high school, which almost accounts for half of the population of the Municipality of Loíza (SDC-PR, 2022). Less than 30 percent of the population have either an associate's or a bachelor's degree, while almost nine percent have some college education, but no degree at all (SDC-PR, 2022). According to Muttaarak and Lutz (2015), more educated individuals may be more capable to respond and act upon events when a disaster strikes. In this sense, they could reduce vulnerability by having a better understanding of the risk and how to respond to it. Another important element is that education can also influence the level of risk perception, as they could be more aware of the effects and be

[15] The social indicator "single parent" represents the number of households headed by a single parent in the Municipality of Loíza. The total of households in Loíza is 8,608 and the percentages are calculated based on that number. Source: American Community Survey, SDC-PR, 2022.

more likely to undertake disaster preparedness – which could contribute to vulnerability reduction (Muttaarak & Lutz, 2015). Similar to this, Cutter et al. (2003) stated that "lower education constrains the ability to understand warning information and access to recovery information" (p.248). Striessnig and Loichinger (2015) explained that several studies have clearly demonstrated the decisive role of education in risk reduction. A higher level of education is also associated with access to more resources and information, so they can understand the risks of the hazards and prepare adequately – therefore reducing their vulnerability (Muttarak & Lutz, 2014).

Level of Education[16]	**Population Estimate**	**Percentage**
Less than 9th grade	2,142	12.50%
9th to 12th grade, no diploma	1,740	10.20%
High school graduate (includes equivalency)	6,657	38.90%
Some college, no degree	1,524	8.90%
Associate's degree	2,200	12.80%
Bachelor's degree or higher	2,864	16.70%

Table 8: Social Vulnerability Indicator: Distribution of Level of Education. Source: American Community Survey, SDC-PR, 2022.

In the Municipality of Loíza, five thousand residents have some sort of disability – accounting for more than 20 percent of the total population (SDC-PR, 2022). Of that number of people with a disability, around five percent of those are under 18 years old, while 14 percent of people between the ages of 18 and 64 have a disability (SDC-PR, 2022). The largest group with some type of

[16] The social indicator "level of education" represents the number of people of 25 years and over. The total population of 25 years and over is 17,127 and the percentages are calculated based on that number. Source: American Community Survey, SDC-PR, 2022.

disability are people over 65 years old – accounting for more than 54 percent of the total population with a disability in the Municipality of Loíza (SDC-PR, 2022). According to Stein et al. (2023), people with disabilities are disproportionately vulnerable to the effects of slow-onset climate change and experience mortality rates that are two to four times greater during climatic emergencies. This is due largely because people with disabilities are often marginalized and invisibilized within the government and civil society – even when we talk about disaster, health, and humanitarian services (Stein et al., 2023). From a simple point of view, the vulnerability of disabled people to natural hazards and disasters can be seen from the physical and cognitive standpoint of their limited ability to escape from hazards – although there are other barriers such as inaccessible warning signs and blocked escape routes that may impact their ability to evacuate during a major event (Hemingway & Priestley, 2014). The latter statement suggests a combination of two dimensions – physical, but also structural at the governmental level and the emphasis we place on people with disability before, during, and after a natural disaster.

People with Disability	Population Estimate	Percentage
Under 18 years	231	5.30%
18 to 64 years	2,013	14.00%
65 years and over	2,621	54.10%

Table 9: Social Vulnerability Indicator: Distribution of People with Disabilities. Source: American Community Survey, SDC-PR, 2022.

6.3 Resilience: The Social-Ecological Systems Vulnerability Interactions, Stresses, and Shocks

Previous discussions on the SES have made it evident how interconnected, intertwined, and interdependent our surrounding environments are. There seems to be virtually no element in the

world that does not rely on other factors for its subsistence or occurrence. Biggs et al. (2021) explained how the challenges we face in the 21st century "are clearly deeply intertwined", as these originate from the convergence and interplay of several, reciprocally supportive social and ecological processes at various levels that range from economic, cultural, political, and technological dimensions (Folke et al., 2016, as cited in Biggs et al., 2021). In a transportation-related context, considerations of the impacts of climate change-related hazards on the transport infrastructure "requires recognition of changing nature of natural hazards, and the vulnerability of the communities and built environment affected" (IPCC, 2014a, as cited in Hayes et al., 2019). To go even further into a more technical area, "the interconnectedness of social, built environment, and natural systems is generating highly complex, dynamic challenges that require new design and engineering approaches" (Allenby & Chester, 2018, as cited in Hayes et al., 2019). The latter suggests that to understand vulnerability and resilience in a place we must first understand that several factors need to be taken into consideration and how they interact. In our case, this includes shocks and stresses. To this end, the situation that the Municipality of Loíza faces is no different, as the relationship between social and physical vulnerabilities is closely tied – with shocks and stresses interacting to undermine resilience and, contrary, opening endless possibilities to enhance resilience through their understanding.

The Mitigation Plan states that erosion is the process in which storms, flooding, storm surge, sea level rise, and other human activities erode beaches and shorelines throughout the coast (FEMA, 1997, as cited in JPPR, 2021). It also points out that there is no solution for mitigating erosion events (JPPR, 2021). Coastal erosion is caused by slow events such as sea level rise, changes in precipitation, and global warming, as well as by events such as development, and elimination of

coastal sediments (JPPR, 2021). Natural hazards such as hurricanes, flooding, and sea level rise are also events that can cause severe damage in the form of erosion to the coast of Loíza (JPPR, 2021). The Mitigation Plan explains that coastal erosion is an ongoing threat that is not intended to diminish, but instead, it will continue to increase (JJPR, 2021). In fact, the Mitigation Plan states that infrastructure located alongside the coast in the Municipality of Loíza is already facing problems with coastal erosion, including the main roadway PR-187 (see Figure 9 below).

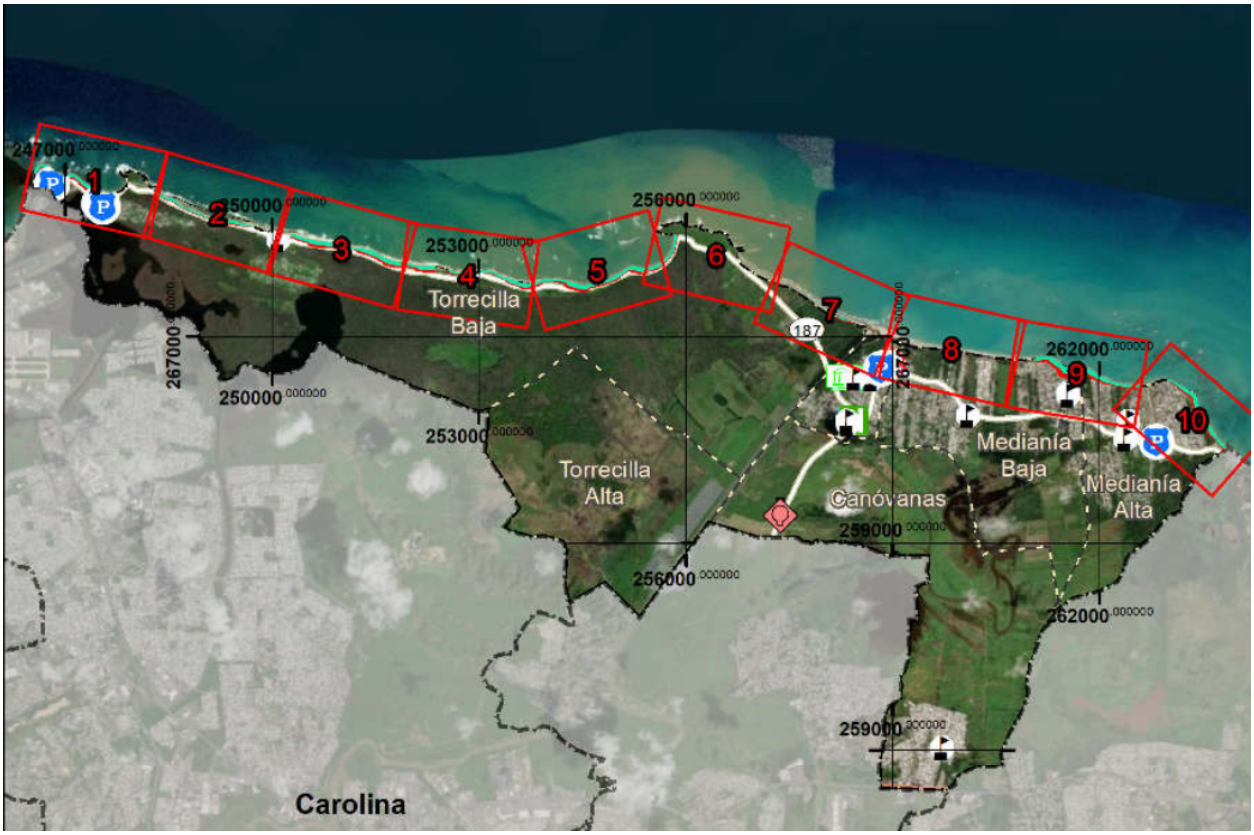


Figure 9: Geographic Area in Loíza Affected by Coastal Erosion. Source: FEMA, 2018; JPPR, 2021.

Boxes in red 1 to 6 and 9 to 10 below in Figure 9 are the most affected areas in the Municipality by coastal erosion, which include barrios Torrecilla Baja, Medianía Baja, and Medianía Alta. In the next 30 years, a total of 58 structures are projected to be affected due to coastal erosion, while

176 will be impacted under a 60-year scenario due to coastal erosion (JPPR, 2021). This number could either increase or diminish, as well as the timeline due to the frequency or severity of the damages caused by natural hazards and provoking coastal erosion (JPPR, 2021).

In 2014, coastal erosion caused the collapse of the PR-951 roadway, one of the principal for the population (JPPR, 2021). The main roadway PR-187 is also at risk due to coastal erosion, especially the portions alongside the northwest side of the Municipality (see Figure 9 below). Boxes number 9 and 10 are areas with a great population density in the barrios Mediania Baja and Mediania Alta (JPPR, 2021). It is estimated that more than 1,649 people will be affected by coastal erosion in 30 years, while 2,856 will be impacted in 60 years (JPPR, 2021). In this sense, coastal erosion would fall as a climate-related covariate stress of the Municipality of Loíza and even the transportation infrastructure because it is considered to be a long-term pressure that undermines stability and increases vulnerability within the population and the infrastructure of the Municipality of Loíza, including the transportation systems.

On the other hand, storm surge is considered to be a climate-related covariate shock because it is a short-term deviation from long-term trends that causes negative effects on the population and the infrastructure of the Municipality of Loíza, including the transportation systems. Storm surge occur due to the excessive increase of water alongside the coast, as a result of rainfall, strong winds, and others (Castro Rivera & Lopez Marrero, 2018, as cited in JPPR, 2021). Storm surges cause severe damages to coastal areas, including damage to structures and infrastructure located in the impacted area (JPPR, 2021). The Mitigation Plan explains that storm surges are hard to predict because their development depends heavily on a multiplicity of factors (FEMA, 1997, as cited in JPPR, 2021).

Figure 10 below illustrates the areas at risk in the Municipality of Loíza in case of a storm surge event caused by a category 1 hurricane (see highlighted in blue).

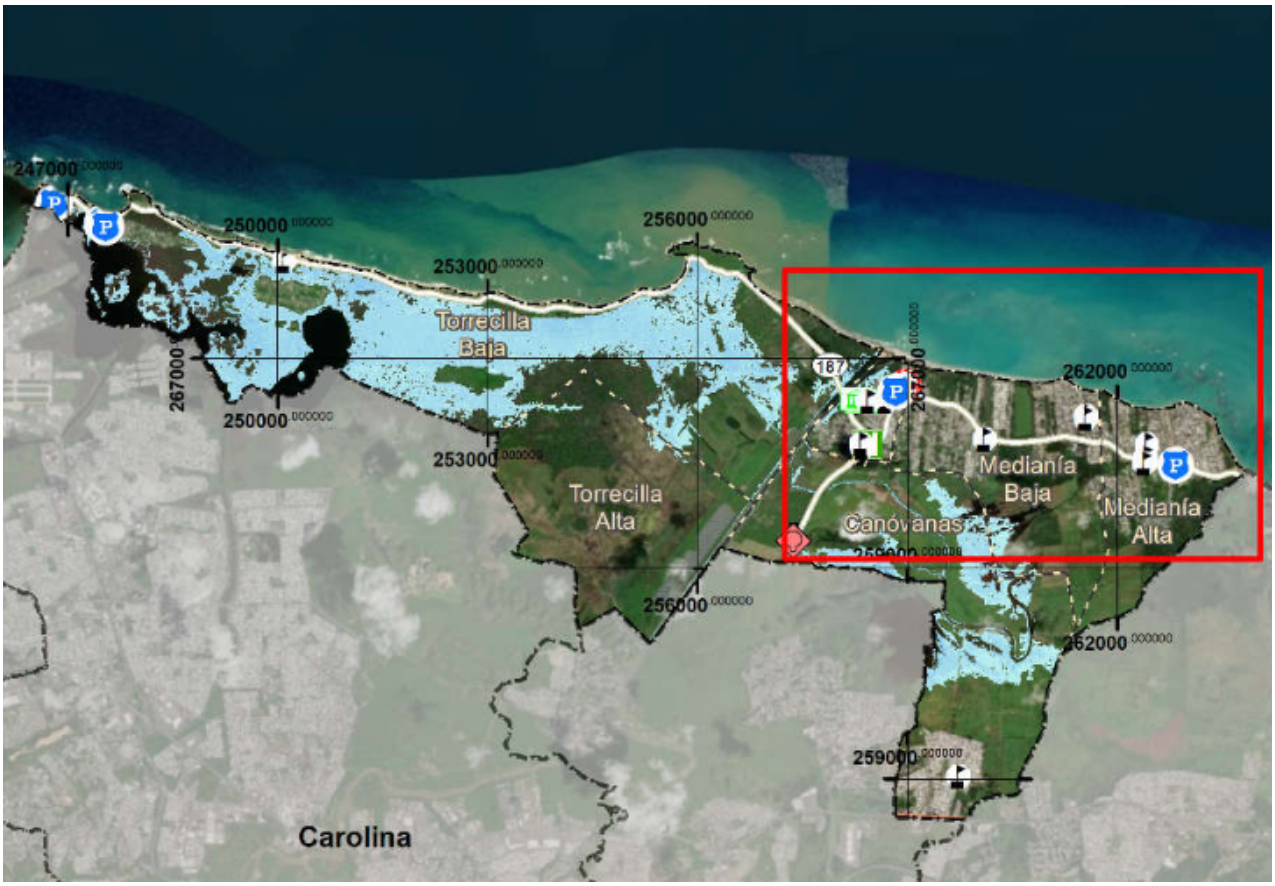


Figure 10: Geographic Area in Loíza Affected by Storm Surge in a Category 1 Hurricane Scenario. Source: NOAA, 2018; JPPR, 2021.

During a category 1 hurricane, the northwest side of the Municipality of Loíza seems to be the most affected, including barrios Torrecilla Baja, Canóvanas, Medianía Baja, and Loíza pueblo (JPPR, 2021). Similarly, storm surges usually cause the closure of the main roadway PR–187 in the barrio Torrecilla Baja area, specifically from December to March, limiting the flow of vehicles (JPPR, 2021). The extension of affected structures varies depending on the storm surge's intensity by hurricane category (JPPR, 2021). For example, under a category 1 hurricane and one-foot flooding caused by storm surge, a total of 85 structures would be affected – whereas, under the

scenario of a category 2 hurricane, a total of 205 structures would be affected; category 3 hurricane, 440 affected structures; category 4 hurricane, 1,293 affected structures; and category 5, 1,873 affected structures (JPPR, 2021). Figure 11 below illustrates the areas at risk in in case of a storm surge event caused by a category 5 hurricane (see highlighted in blue, and Appendix III).

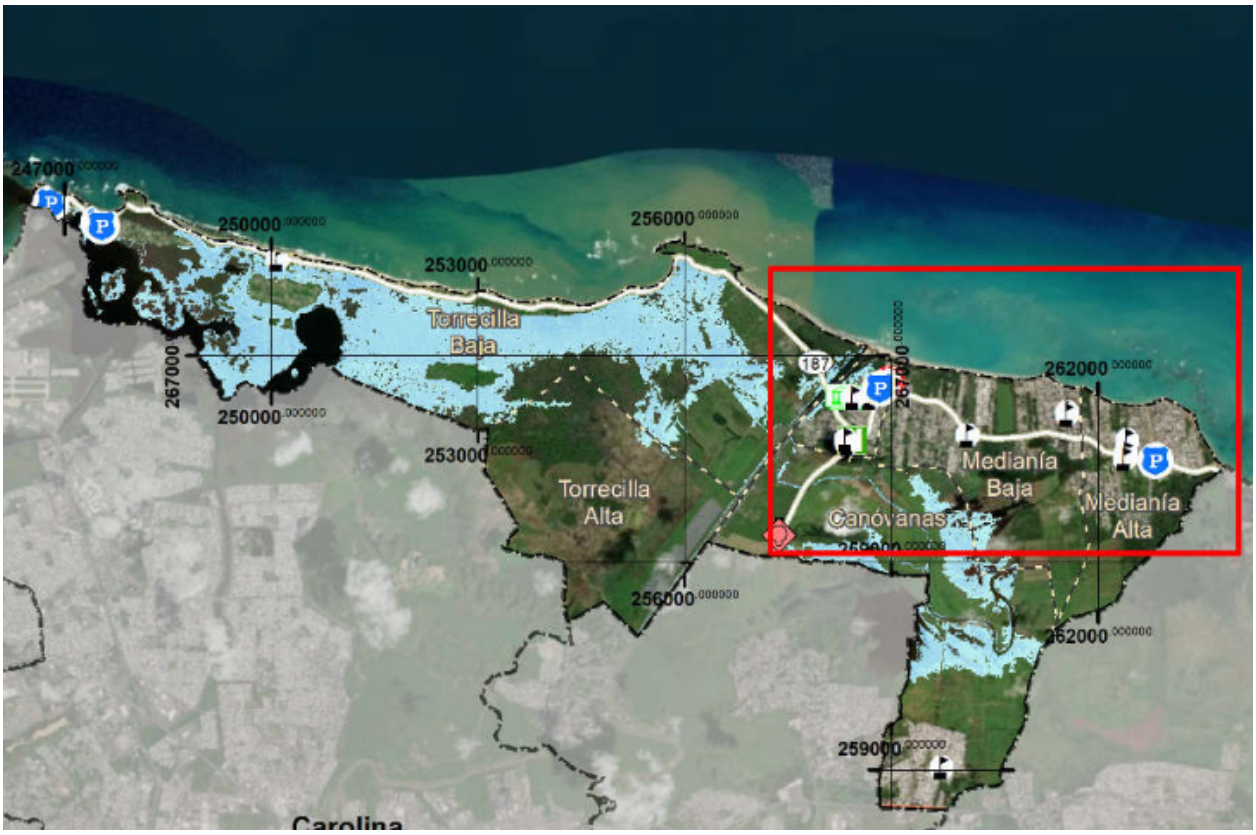


Figure 11: Geographic Area in Loíza Affected by Storm Surge in a Category 5 Hurricane Scenario. Source: NOAA, 2018; JPPR, 2021.

The discussed stress (coastal erosion) and shock (storm surge) provide evidence of how underlying factors can exacerbate the effects and impacts of natural hazards threatening a place. In the case of the Municipality of Loíza, coastal erosion effects often manifest in constant flooding of some areas, affection of structures, and loss of infrastructure – even including part of the main roadway PR-187 (JPPR, 2021; USACE, 2019). In the case of storm surges, the same case applies – as they

can result in catastrophic flooding that can wipe out roads, submerge areas completely, and destroy or cause harm to structures in coastal areas (NOAA, 2023). To the transportation network, flooding can cause damage to the infrastructure and affect recovery efforts – potentially affecting economies (Rebally et al., 2021). In this sense, vulnerability is enhanced and resilience is undermined constantly and repeatedly over time.

7. Recommendations and Conclusions

Neither the Mitigation Plan, nor the Adaptation Plan provides detailed information on the current conditions of the transportation infrastructure in the Municipality of Loíza. Similarly, both plans do not discuss how the transportation infrastructure is or will be affected by climate change. Research suggests that in the next upcoming years, the transportation infrastructure will face several challenges because it might not be designed for the conditions it will be undergoing through, the funding it receives is poor and insufficient, and its lifetime is often long overdue (Chester & Allenby, 2017, as cited in Markolf et al., 2019). In this sense, Humphrey (2008) states that "transportation professionals should acknowledge the challenges that will result from climate change and should incorporate current scientific knowledge about climate change into planning, design, construction, operation, and maintenance of transportation systems" (p.21). Knowing that transportation plays an enormous part in either decreasing or increasing resilience in a place, this study makes as its main recommendation the need to incorporate and consider transportation infrastructure when examining vulnerability to climate change and outlining adaptation strategies. More specifically, the urgency for diversifying modes of transportation in the Municipality of Loíza to minimize the impacts that natural disasters have on post-disaster recovery efforts and the community members.

In Puerto Rico, almost 92 percent of the workers commute to work using an automobile (ABC & LGP Consultoría, 2022). In Loíza, the number of automobile users goes up, as nearly 94 percent of the residents use a private vehicle as their main mobility source to commute to their jobs (ABC & LGP Consultoría, 2022). On average, more than 69 percent of the population have access to one or two cars, while nearly 24 percent do not have access to a vehicle in the Municipality of Loíza (ABC & LGP Consultoría, 2022). Hurricane María demonstrated the need to diversify modes of transportation with the inclusion of other transport modes such as train, bus, bicycle, and pedestrian facilities (Peña Rivera, 2018). According to Peña Rivera (2018), mobility [and having different alternatives of transport] is important to lessen the impacts of disasters – as people with more mobility options would do better after a natural disaster, compared to those with fewer alternatives. Various modes of transport would mean that people will not only depend on their private vehicle to address their needs after a disaster – therefore enhancing their ability to bounce back quicker from a disaster and advancing post-recovery efforts at large (Peña Rivera, 2018). In this sense, thinking about diversifying modes of transportation in the Municipality of Loíza would be necessary and imperative to reduce vulnerabilities and enhance resilience. Without this lens [diversification of modes of transportation], pre-existing problems can be exacerbated after a natural disaster and affect recovery efforts (Peña Rivera, 2018).

The Adaptation Plan mentioned that since the 1950s, the beaches in Loíza have suffered from sand extraction when around half a mile of dune extension was eliminated for the construction of the nearby airport (MARES, 2018). As a result, constant floodings along the main roadway were occurring, which obligated the Army Corps of Engineers to elevate the road from Punta Maldonado to the east of the Municipality (MARES, 2018). Nevertheless, the Adaptation Plan and the

Mitigation Plan state on numerous occasions how the main roadway PR-187 still suffers from coastal flooding that makes it impassable during these events (JPPR, 2021; MARES, 2018). Projections from the NOAA were already discussed above and illustrations were provided on how the PR-187 is negatively affected by sea level rise under three scenarios – two of these showing the roadway covered almost entirely by water (see Figures 6 and 7). Thus, the Adaptation Plan only incorporates one adaptation strategy to mitigate coastal flooding problems for the main roadway PR-187: the restoration of coastal vegetation and dunes from the sector La Torre to the Loíza Bridge (MARES, 2018).

The latter adaptation strategy is meant to prevent further coastal loss and mitigate flooding events, as some areas of the coast alongside Loíza are narrower – which eliminates the protection that vegetation and dunes could offer in the form of mitigation against the effects of erosion and coastal flooding (MARES, 2018). The Adaptation Plan states that the whole beach ecosystem with its dunes and vegetation is vital for the protection of the transportation and housing infrastructure (MARES, 2018). The dune with its vegetation stabilizes the beach and absorbs the energy of the waves, therefore reducing the impacts of erosion, sand abrasion, and flooding events on the nearby infrastructure (MARES, 2018). However, reinforcing and adapting the coast alone is not enough for the enhancement of resilience in the Municipality of Loíza. What about the other natural hazards such as hurricanes and storms that damage and put transportation facilities and infrastructure at risk? Similarly, extreme heat events that may end up damaging the roadway by causing the concrete pavements to buckle and the asphalt roads to soften – therefore leading to rutting and subsidence (Meyer & Weigel, 2010). Furthermore, the intensity and frequency of precipitation can affect transportation facilities and networks, leading to an adverse impact on daily

operations (Meyer & Weigel, 2010). To this end, it is important to keep in mind that coastal flooding is not the only cause of flooding in the Municipality, as flooding as a result of heavy rainfall and river overflow is also prevalent (JPPR, 2021; MARES, 2018).

Therefore, in addition to this outlined adaptation strategy for the transportation infrastructure of the Municipality of Loíza, the Adaptation Plan should include other adaptation strategies that tackle the problem more holistically. For example, the Adaptation Plan mentioned that part of the main roadway PR-187 was elevated in a specific sector (MARES, 2018). Knowing that the entire PR-187 floods easily, why not make this an adaptation strategy for the entire roadway? FEMA (2022b) suggests localities to consider elevating the road to mitigate flooding and maintain the service during the event. Similarly, another strategy is to change the configuration or shape of the road (see Appendix VIII) for stormwater to run off easier to the sides of the road or existing drainage (FEMA, 2022b; Caltrans, 2023). Now, it is important to note that these two strategies would also require to assessment of the adequacy of other infrastructure elements such as drainage (FEMA, 2022b; Caltrans, 2023). The Adaptation Plan does include the improvement of drainage and stormwater management in order to reduce and mitigate flood impact in the Municipality of Loíza (MARES, 2018). Nevertheless, the adequate implementation of any of these two strategies may not only reduce the harm that is inflicted on the roadway, but also maintain open evacuation routes, as such is the case of the PR-187 in the Municipality of Loíza (FEMA, 2022b).

On a similar note, the relocation of the PR-187 is never contemplated either on the Adaptation Plan or the Mitigation Plan – although it is considered to be the only evacuation route (see Appendix IV) and the main roadway for all modes of transportation – including public transportation. One

special consideration that the Municipality of Loíza should evaluate is how the resilience of the Municipality, in general, is undermined by only having one main access roadway. Aside from the evacuation element – which is mainly important to prevent further loss of lives and aggravated situations, Zhou et al. (2019) explained how transportation networks also advance recovery efforts. According to the authors, transportation networks function as lifelines that allow access to impacted areas to support emergency response and recovery operations in the long term after a disaster happens (Zhou et al., 2019). In this sense, having the transportation networks in stable conditions with full functionality would not only signify good things from an economic standpoint, but also from a welfare perspective (Zhou et al., 2019). In the case of Loíza, where projected routes of public transit[17] and most residents use that roadway daily to get access to jobs, goods, and services, rethinking the PR-187 would be important when considering adaptation strategies and, therefore resilience efforts.

In a Municipality with a high number of elderly, poor, and disabled people, diversifying modes of transportation is another form of resilience and equity enhancement. Although this consideration is incorporated in the Strategic Transport Plan of the Municipality of Loíza, it is not contemplated in the Adaptation Plan. The Strategic Transport Plan recommended improvements to the existing public transport services that included improving the roadway and pedestrian facilities, redesigning routes to optimize services, and relocating bus stops based on demand (ABC & LGP Consultoría, 2022). The purpose of this is to ensure "a just distribution of services and infrastructure, and the enhancement of transportation equity including services for individuals with disabilities" by adapting existing infrastructure and future bus stops for people with disabilities to

[17] The Strategic Transport Plan of Loíza includes the projected routes for buses and paratransit service, which will be further discussed in the subsections below.

be able to move easily (ABC & LGP Consultoría, 2022). Paratransit service is also envisioned to be offered for people 65 years or older (ABC & LGP Consultoría, 2022). However, the main problem with this is that almost all the routes for public transit are envisioned to be located alongside the PR-187, which has already been discussed above as a problematic area that constantly floods and is threatened by other natural hazards such as hurricanes and storms (see Appendix V).

The latter is something to keep in mind when choosing the location of the routes because if public transport fails and is unable to operate due to a major climate change-related event, the most impacted ones would most probably be people of low income, the elderly, and people with disabilities. If public transportation and mass transit cannot be provided due to a natural hazard, low-income individuals who do not own private vehicles may be stuck in their homes (Flanagan et al., 2011, as cited in Ogie & Pradhan, 2019). Therefore, this could slow the recovery process for low-income people due to limited resources and the lack of savings to counter the effects (Dwyer et al., 2004, as cited in Ogie & Pradhan, 2019). Similarly, Stein et al. (2023), explained the necessity of integrating disabilities across climate policy and all other sectors – therefore explicitly stating the necessity for an inclusive approach in which people with disabilities do not fall behind during a climate change-related event or emergency. The authors explained how "public-health responses and top-down systems fail to collaborate with or learn from persons with disabilities regarding climate harms and effective interventions" (Stein et al., 2023, p.108). In this sense, prioritizing equity and justice in adaptation planning and implementation would lead to more effective and sustainable adaptation outcomes (Stein et al., 2023). This would prevent the

exclusion of people with disabilities when outlining adaptation strategies, therefore reducing their vulnerabilities and increasing resilience in the area.

The role of transportation in increasing resilience in an area is undeniable. However, when thinking about how the transportation infrastructure can become more resilient to climate change, having in mind the frequency and magnitude of the natural hazard events would be imperative to be assertive when outlining adaptation strategies. Markolf et al. (2019) suggested that the robustness of a system does not mean resilience because vulnerabilities are various and a single approach would not be sufficient to meet the poorly understood vulnerabilities. For example, the authors explained that while much transportation infrastructure may be built to meet design-storm criteria to withstand the magnitude of a 100-year storm event, this approach is only effective when addressing "well-defined and well-understood direct physical vulnerabilities" (Markolf et al., 2019, p.175). Contrary to this, Markolf et al. (2019) questioned how relevant 100-year design criteria would be if extreme events become more frequent and intense. In this sense, the assessment of how vulnerable the transportation infrastructure is to natural hazards becomes more than important to be effective and actually build resilience in a place.

The discussion above has served as a basis to confirm that the Municipality of Loíza is vulnerable to climate change in both physical and social dimensions. Therefore, resilience is constantly threatened in the study area. Rather than being separate, both dimensions seem entangled in which one conditions the other and vice versa. The physical vulnerability assessment performed for the transportation infrastructure of the Municipality of Loíza described and explained how climate stressors such as sea level rise, flooding, and strong winds increase vulnerability for the

transportation infrastructure of the study area. The three climate stressors seemed to be interrelated as well. For example, sea level rise can cause flooding, but tropical cyclones can also cause flooding due to extreme weather events such as hurricanes and storms (JPPR, 2021). In this sense, flooding can be exacerbated by both sea level rise and tropical cyclones. Another way that sea level rise can exacerbate flooding is because heavy rainfall tend to generate and provoke more flooding in coastal areas because sea level rise impede and obstacle the rate at which areas drains (Titus, 2016). The latter could imply that floods may not be able to desist if sea level rise is not contained or mitigated.

Throughout the latter discussion, evidence was provided that the transportation infrastructure is imminently exposed to the climate stressors of sea level rise, flooding, and strong winds. Upon examining to what degree the transportation infrastructure would be affected by climate change, it was found that it is negatively affected by these three climate stressors. In the case of sea level rise, modeling projections from the NOAA illustrated the extension of the impact under different scenarios – all of them affecting the main roadway PR-187. Titus (2016) explained how sea level rise could accelerate erosion and threaten some roads. In more extreme cases, if the road is situated near or parallel to the shore, it can also be affected by it. Therefore, that may block or remove the only roadway access to a particular area (Titus, 2016). Such is the case of Loíza, where the PR-187 is aligned alongside the coastal area. In 2018, 2021, and 2022 coastal flooding and storm surge events provoked the closure of the main roadway PR-187 due to flooding, sand accumulation, and sea debris – which prevented the safe passage of people (Pérez Méndez, 2018; Delgado, 2021; Primera Hora, 2022).

During extreme events of large floods, “structural integrity and the safety of the infrastructure can be compromised, which can lead to serious consequences” (Esposito et al., 2018, as cited in Rebally et al., 2021, p.1). Perhaps, one of the most serious consequences is the inability of people to evacuate during an emergency or natural disaster – which can result in catastrophic consequences for the residents of Loíza. The principal access roadway in Loíza is the PR-187, but there is also the PR-188 that connects Loíza to the Municipality of Canóvanas in the south and the PR-951 that also connects to Canóvanas through a bridge structure (Y. Escobar, personal communication, March 27, 2024). All three roadways are at constant risk of flooding (JPPR, 2021). In fact, the PR-951 was closed after Hurricanes Irma and María due to severe impacts and reopened almost five years later in 2023 (Y. Escobar, personal communication, March 27, 2024). Similarly, hurricanes and storms can flood entire roadways, cause the collapse of structural support, and debris can land in the roadway, blocking traffic flow (FEMA, 2022a). In the case of bridges, floods can exceed the level of bridges and provoke serious structural damage due to the debris that the water may carry (FEMA, 2022a).

FEMA (2024) already scored Loíza’s vulnerability as “very high” when taking into consideration risk factors by hazard types. Flanagan et al. (2011) stated: “Vulnerability to hazards is influenced by many factors, including age or income, the strength of social networks, and neighborhood characteristics” (p.2). Upon examination of the selected social vulnerability indicators age, income, single parent, level of education, and people with disability, it was found that a large number of people in Loíza belongs to one of these vulnerable groups – therefore increasing the vulnerability of this Municipality to climate change-related hazards or disasters. The Strategic Plan justifies the need for more paratransit services because Loíza has a population that is mostly

composed of individuals above 65 years of age (ABC & LGP Consultoría, 2022). In the face of disasters, the elderly population can face serious problems that strike mostly with mobility issues, but also a high probability of injury during and after an extreme weather event (Bodstein et al., 2014). Similar to this, more than 20 percent of the total population of Loíza has some type of disability (SDC-PR, 2022). Aside from explaining the hurdles that this segment of people faces before, during, and after a natural disaster – the need for an inclusive policy approach was highlighted as a way to reduce vulnerability within this group. Stein et al. (2023) explained the need to think about people with disabilities in climate adaptation and mitigation approaches so that they can have better access to resources to prepare and cope with the effects of natural disasters. This would, therefore, decrease their vulnerability to climate change-related hazards. Both groups of people may experience problems when undergoing evacuation, which can delay efforts and reduce responsiveness – exacerbating the consequences of natural hazards.

It was also found that more than 46 percent of the population of Loíza lives in poverty (U.S. Census Bureau, 2023). More than 50 percent of the households in the Municipality make less than 25 thousand dollars per year (SDC-PR, 2022). This increases the risk of vulnerability for an enormous portion of the population of Loíza because people of low income tend to have fewer resources to prepare and cope with natural disasters (Hallegate et al., 2020; Ogie & Pradhan, 2019). This, therefore, decreases their ability to quickly respond and recover from the impacts of natural hazards. One aspect to keep in mind is the historic pattern of systemic racism and neglect towards the population of Loíza. More than 34 percent of the population of Loíza is Afro-Caribbean and has been largely forgotten by all sectors, including the government, private industries, media outlets, and even Puerto Ricans in general (SDC-PR, 2022; Rodríguez-Velázquez, 2020). From a

policy standpoint, many communities in Loíza have organized themselves to denounce and hold accountable bad decision-making in planning directly related to the location of communities, projects and structures on the coast, and the lack of project continuity (Rodríguez-Velázquez, 2020). Many activists and even several Mayors of Loíza, have stated that Loíza have been discriminated against for decades, mostly due to their skin color and the high number of people living in poverty, which have eventually forced community members to organize themselves, take action, and claim a better share of what is theirs as Puerto Ricans (Primera Hora, 2012; Rodríguez-Velázquez, 2020).

Similarly to this, more than 55 percent of the households in Loíza are headed by a single parent (SDC-PR, 2022). Research suggests that single parents usually fall under the line due to the lack of assistance they receive before and after a major extreme weather event (Tobin-Gurley et al., 2010). Moreover, they often lack a support system in relocation scenarios – which sometimes leads to exacerbation of their financial status (Cutter et al., 2003). This would mean fewer resources to prepare and cope with the aftermath of natural disasters. Finally, it was found that more than 61 percent of the total population of Loíza do not have some sort of higher education, indicating low levels of educational attainment (SDC-PR, 2022). Lack of education is often associated with a lack of access to more resources and information to be able to understand the risks and prepare for natural disasters (Muttarak & Lutz, 2014). To this end, Muttarak and Lutz (2014) stated that "education may indirectly reduce vulnerability through many other means" such as increasing their ability to improve their socioeconomic status, which would allow them to better prepare against natural disasters.

As discussed above the SES indicates how interconnected and intertwined human interactions are with the environment. Social, physical, and natural features cannot be separated within each other – as they are fundamental for a clear understanding of the multidimensions that a problem might encapsulate. In the case of Loíza, it can be inferred that the latter is clearly exhibited in the study area. Throughout this discussion, evidence has been provided on how social and physical vulnerabilities are entangled with each other. Rather than going separately, they go hand in hand. For example, the most common denominator might be that the mobility of people would be nearly impossible if the transportation infrastructure is not adapted to mitigate sea level rise, flooding, and tropical cyclones. Similarly, if all the routes of public transport are located alongside the main roadway PR-187, which constantly closes due to floods, what good would it do? Nevertheless, there seems to be no other alternative when most of the population is mostly located along that roadway and it is the only connection to all the communities in Loíza. Seemed to be a hard task to address in which sea level rise needs to be addressed to mitigate coastal flooding, but at the same time, flooding by overflow of the river and tropical cyclones need to be also mitigated.

To this end, inferences can be made to urge the necessity of addressing physical and social vulnerabilities as part of the same problem, rather than treating them separately. Evidence was provided on how the assessed physical vulnerabilities and the described social vulnerabilities undermine resilience in the Municipality of Loíza. As a result, both come into play to increase climate change-related vulnerabilities – including the shocks and stresses that continuously exacerbate vulnerability to climate change. The SES provided an opportunity to analyze how resilience is undermined, while not only taking into consideration the physical dimensions, but also the social. This allowed the thinking of adaptation in a different set of ways, including the

framing of policies that can lead to sustainable results in the long run. It seems to matter little to adapt the transportation infrastructure if the social vulnerabilities are not considered. Going a little beyond, mitigation and adaptation in little countries such as Puerto Rico seems to be a hard task when the major contributors to climate change do little to reduce their contributions to global warming.

Therefore, it is recommended that the Municipality of Loíza consider and act upon the following items when doing revisions or updates to the Mitigation Plan and the Adaptation Plan, as well as moving forward with their climate change mitigation and adaptation policy drafting, enacting, and implementation. First, the Municipality of Loíza should aim to include transportation as a core element for mitigation and adaptation planning, considering the previous discussions that have explained how transportation can either decrease or increase resilience and vulnerabilities. In this same line, the Municipality should also aim to clearly differentiate between mitigation and adaptation planning, as those concepts have two different ends. However, the latter exposition served as evidence to understand that although mitigation and adaptation are two different concepts with two distinct purposes, they are closely interrelated to the extent that adaptation seems hard to accomplish without mitigation and mitigation hard to address without adaptation. Both adaptation and mitigation are important in helping diminish the impacts of climate change; and both have repercussions within each other as adaptation actions have consequences over mitigation and vice versa (Klein et al., 2007). This means that both concepts are closely interrelated and thinking about them as two separate concepts that have repercussions for each other would be extremely important to ensure that the correct adaptation and mitigation strategies are selected and implemented effectively (Klein et al., 2007).

Taking into consideration that social and physical dimensions are both clear determinants for resilience and vulnerability identification, moving forward, the Municipality of Loíza should consider including the discussion of both in the Mitigation Plan and Adaptation Plan. Rather than being a separate discussion, it should be integrated to examine how they interact and outline effective adaptation actions. Climate change adaptation planning should be able to address both physical and social vulnerability, but perhaps place close attention to the social dimensions – which are often understudied and not taken into consideration (Kehler & Birchall, 2021). In this sense, it would be necessary to understand entirely the complexity of vulnerability and focus on the social and economic components of vulnerability to overcome social barriers that may contribute negatively to vulnerability (Kehler & Birchall, 2021). This, perhaps, could lead to major policy shifts such as investing more efforts in educating people on the risks that climate hazards pose, so that people can better prepare and cope before and after a disaster. Nevertheless, the point is to understand what are the areas that the population struggle the most and narrow the resources to reinforce those areas.

8. Limitations

This study had several limitations. The lack of detailed information on how specifically the transportation infrastructure of the Municipality of Loíza is affected and will be affected by the climate stressors of sea level rise, flooding, and strong winds/tropical cyclones prevented us from discussing the adaptive capacity for each climate stressor individually. “Adaptive capacity describes the ability to take actions to reduce adverse impacts” of future climate extremes (Cook et al., 2016). This can mainly be done by having an understanding of how internal and external variables affect the adaptive capacity of the asset (Stein et al., 2014). This means that the more

information you have, the easier it will be to understand and enhance adaptive capacity –depending heavily on access to information and resources about an asset (Stein et al., 2014). Therefore, the adaptative capacity of the transportation infrastructure became a topic hard to address. General suggestions were made. The main observation of the adaptive capacity of the transportation infrastructure is that the climate stressors used to assess the transportation infrastructure seemed to be closely related and conditioned to one another. For example, sea level rise and tropical cyclones could cause flooding, likewise, tropical cyclones and sea level rise can cause coastal erosion. The Adaptation Plan itself concluded that the risks of flooding are aggravated by a wide range of reasons because heavy rainfall is projected to increase in frequency and intensity, as well as the intensity of hurricanes (MARES, 2018). To this end, adaptive capacity seems to rely heavily on how well the Municipality of Loíza is able to mitigate and adapt not just for one stressor, but for all. In fact, the Adaptation Plan suggested a similar explanation by pointing out that a multiplicity of aggravating factors makes the Municipality of Loíza extremely vulnerable to climate change-related hazards (MARES, 2018).

The lack of clear information and data on how the transportation infrastructure is affected by climate change and natural hazards prevented the individual assessment of each transportation mode. The Mitigation Plan and the Adaptation Plan focused more on the Municipality of Loíza at large and little discussion on the transportation assets was provided. Therefore, the assessment of the transportation infrastructure was performed generally for the surface transportation, mainly drawing conclusions for the main roadway PR-187 – which was mentioned several times in the Mitigation Plan and the Adaptation Plan. The vulnerability of the pedestrian and bicycle infrastructure was not able to be assessed. This limited the ability to holistically understand how

climate stressors affect the resilience of the Municipality of Loíza – since transportation systems can work as a strategy to mitigate the impacts of climate change, mainly in determining how fast a place can recover from disaster (Ecola et al., 2020; Daniels & MacArthur, 2022). In the case of Puerto Rico all freight and virtually all personal mobility is done via roadways, the constant threat that climate stressors pose to the main roadway PR-187 became one of the ways to determine the vulnerability of the transportation infrastructure of the Municipality of Loíza – due to the disconnection of the Municipality when a major flood occurs (JPPR, 2021; MARES, 2018). The Adaptation Plan clearly outlined that due to coastal flooding, the main roadway PR-187 in the northwest part of the Municipality of Loíza becomes inaccessible – therefore limiting the transit of cars through the area (MARES, 2018).

What could have helped to fill that void of information on how the transportation infrastructure of the Municipality of Loíza is affected by climate change is the involvement and engagement of different stakeholders and residents, which this study did not envision or intend to do. Site visits and community interaction would have provided us with first-hand information and data on how the residents are being affected by climate change and even their perception of how climate change-related hazards affect their mobility ability. The Adaptation Plan did include the participation and engagement of residents, as it was intended to be a community-based adaptation plan. However, it did not provide any sections discussing the status of the transportation infrastructure, nor documented the mobility hardships that the residents face when a natural disaster occurs. Engaging different stakeholders from a diverse background is an important aspect so that decisions can be legitimized because people are being included and empowered in the decision-making process by having a say in what is done in the Municipality. The Adaptation Plan

stated that the residents of Loíza are aware that climate change is occurring and that threats are real, therefore are willing to take action to protect themselves from climate change-related hazards (MARES, 2018).

The Mitigation Plan and the Adaptation Plan sometimes overlapped in the similarity of the content that it offered. Both plans focused greatly on discussing how the Municipality of Loíza is being affected by climate change-related hazards. Moreover, both the Adaptation Plan and Mitigation Plan identified the natural hazards and climate stressors that affect Loíza the most. However, both plans failed including transportation as part of the respective assessment and analysis. Based on our previous discussions, this is a policy item that the Municipality of Loíza should take into consideration when updating its Mitigation Plan and Adaptation Plan – since the transportation infrastructure and systems play an essential role in either decreasing or increasing resilience in a place, as it more specifically determines how fast and to what extent a locality will be able to recover from a natural disaster (Ecola et al., 2020; Daniels & MacArthur, 2022; Humphrey, 2008). Nevertheless, the Adaptation Plan used a community-based approach to identifying natural hazards and understanding how the residents of Loíza are being affected by them (MARES, 2018). Likewise, outlined the adaptation strategies based on the input and feedback provided by the community members (MARES, 2018).

According to Dodman & Mitlin (2011), it is important to recognize that the involvement, immersion, and engagement of local residents and citizens is vital for the decision-making process in their respective areas and even more for the development of adaptation strategies. Thus, a community-based adaptation approach recognizes that numerous low-income groups are currently

bearing the costs of climate change in their immediate surroundings and will continue to do so in the future (Dodman & Mitlin, 2011). Therefore, they should be involved in local solutions, as they are the ones who know and understand their own needs and – with the necessary technical help – can achieve the most assertive adaptation measures and strategies (Dodman & Mitlin, 2011). However, one thing that the Municipality of Loíza should be aware of when updating its community-based Adaptation Plan is to avoid a homogenous representation of the population. Rather, community-based adaptation should aim to include people from all backgrounds including age, gender, socioeconomic status, race, and even amount of influence or political power to ensure that decisions are representative of the community, instead of a particular agenda (Dodman & Mitlin, 2011). Perhaps, provide the necessary accommodations for people who are limited or constrained to participate in locally based adaptation activities (Dodman & Mitlin, 2011). To this end, the community-based adaptation approach should be seen as a direct response to the proven inefficient top-down adaptation approach that fails to attend to the needs of those in society who are the most vulnerable (Boyd et al., 2009, as cited in Dodman & Mitlin, 2011).

The value of using the social-ecological systems approach in this study is that it allowed the understanding of the social and physical complexities that undermine resilience in the Municipality of Loíza in a more complete way. Similarly, the presented discussions on how the social-ecological systems approach fits into the adaptation and resilience discussion can be used by local policymakers when addressing a problem in the future. As discussed earlier, the social-ecological systems approach is problem-oriented and due to its holistic nature, the development of resilience, adaptive approaches, and sustainable policies can be better achieved when employed (Stokols et al., 2013). It has been discussed how not only social indicators undermine resilience, but also how

physical elements contribute to vulnerabilities in the Loíza, therefore affecting the capacity of the Municipality to cope and bounce back from the effects of climate change. In this sense, this was greatly achieved due to the opportunity that the social-ecological systems approach brings and offers for examining problems from a whole new different standpoint, in which special consideration is provided to the complexities of the problem to understand that everything is conditioned by other elements within or outside the system.

9. Contributions

Notwithstanding limitations, this study makes several valuable contributions to the understanding of climate change-related vulnerabilities in the Municipality of Loíza. First, the study performs a physical vulnerability assessment of the transportation infrastructure of Loíza. The physical vulnerability assessment described exposure and sensitivity to the climate stressors of sea level rise, flooding, and strong winds. This indicated the degree to which the transportation infrastructure experienced the three climate stressors, likewise the degree to which it is affected by sea level rise, flooding, and strong winds. The physical vulnerability assessment provided information that was not available either in the Mitigation Plan, or the Adaptation Plan. To this end, the gathered findings could function as a motivation and foundation for future work now that further understanding has been provided on how these three climate stressors affect the transportation infrastructure and undermine resilience in the study area. Perhaps, different modes of transportation can be individually examined to understand the adaptative capacity of the transportation infrastructure, and therefore be able to clearly outline adaptation options for the study area.

The identification and description of social vulnerability indicators provided insight into how socially vulnerable the population of Loíza is against climate change. Information was provided on the social indicators of age, single parent, income, people with disabilities, and level of education in the Municipality of Loíza. The description of the social indicators allowed for a discussion on how climate change affects the group of people under each social indicator. At the same time, it permitted the understanding of how climate change can undermine resilience in a place where social vulnerabilities are very prevalent. The findings gathered from this description fill a knowledge void on how the population of Loíza is affected per the identified social indicators. Likewise, that is not included either in the Mitigation Plan or the Adaptation Plan. Social vulnerability in the Mitigation Plan was illustrated by the extension of the hazard, rather than described using sociodemographic or economic data (see examples in Appendix VI and Appendix VII below). For example, social vulnerability to sea level rise would be illustrated in a map that indicated the number (extension) of people exposed to this climate stressor, instead of thoroughly describing how the population is impacted by it.

The consideration of shocks and stresses opened a door for understanding that there are often overlooked dynamics that are constantly undermining resilience in a place, to which we should pay close attention. Finally, the discussion on how transportation infrastructure and systems can either decrease or increase climate change resilience in the Municipality of Loíza is information that is also not included in the Mitigation Plan, or the Adaptation Plan. Throughout these discussions, evidence was provided on how transportation can facilitate recovery efforts and provide people with relief after a natural disaster. Moreover, information was provided on how prioritizing the adaptation of the transportation infrastructure can be beneficial in the pursuit of

reducing climate change-related vulnerabilities and enhancing resilience in the Municipality of Loíza.

10. References

Abkowitz, M., Jones, A., Dundon, L., & Camp, J. (2017). Performing A Regional Transportation Asset Extreme Weather Performing A Regional Transportation Asset Extreme Weather Vulnerability Assessment. *Transportation Research Procedia, 25*, 4422-4437. https://doi.org/10.1016/j.trpro.2017.05.344

Adger, W.N. (2006) Vulnerability. *Global Environmental Change, 16,* 268-281. http://dx.doi.org/10.1016/j.gloenvcha.2006.02.006

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström, J. (2005). Social-Ecological Resilience to Coastal Disasters. *Science, 309*(5737), 1036–1039. https://doi.org/10.1126/science.1112122

Advantage Business Consulting & LGP Consultoría. (2022). Strategic Transit Plan: Municipality of Loíza. Advantage Business Consulting.

Alex, P. (2018, July). *Complejidad de categoría 4.* Lincoln Institute of Land Policy. https://www.lincolninst.edu/publications/articles/complejidad-categoria-4

Allenby, B., & Fink, J. (2005). Toward Inherently Secure and Resilient Societies. *Science, 309*(5737), 1034–1036. http://www.jstor.org/stable/3842539

Amnistía Internacional. (2018, September 19). *Puerto Rico un año despúes del Huracán María. Amnistía Internacional.* https://www.amnesty.org/es/latest/research/2018/09/puerto-rico-a-year-after-hurricane-maria/

Anarde, K., Kameshwar, S., Irza, J., Nittrouer, J., Lorenzo-Trueba, J., Padgett, J., Sebastian, A., & Bedient, P. (2017). Impacts of Hurricane Storm Surge on Infrastructure Vulnerability for an Evolving Coastal Landscape. *Natural Hazards Review, 19*(1). https://doi.org/10.1061/(ASCE)NH.1527-6996.00002

ASSHTO. (2017). *Understanding Transportation Resilience: A 2016-2018 Roadmap for Security, Emergency Management, and Infrastructure Protection in Transportation Resilience.* American Association of State Highway and Transportation Officials. https://transportation.org/ctssr/wp-content/uploads/sites/37/2023/01/UTR-1-book-vers-5.pdf

Barreto, M. (2021, August). *Hacia la planificación de una nueva costa ante el escenario del aumento del nivel del mar en Puerto Rico* [Presentation]. Repositorio Institucional Zaloamati. http://zaloamati.azc.uam.mx//handle/11191/8637

Biggs, R., Clements, H., Vos, A., Folke, C., Manyani, A., Maciejewski, K., Martín-López, B., Preiser, R., Selomane, O., & Schlüter, M. (2021). What are Social-Ecological Systems and Social-Ecological Systems Research? *The Routledge Handbook of Research Methods for Social-Ecological Systems,* 3-26. Doi: 10.4324/9781003021339-1

Bodstein, A., Vanda Azevedo de Lima, V., & Barros, A. (2014). The Vulnerability of the Elderly in Disasters: The Need for An Effective Resilience Policy. *Ambiente & Sociedade, 7*(2), 171-188. https://www.scielo.br/j/asoc/a/mVBdgwpNz5YymN4tTQZHGXR/?lang=en&format=pdf

Bothe, O. (2018). What even is 'Climate'? *Geoscience Communication Discussion, [preprint]*. https://doi.org/10.5194/gc-2018-11

Caltrans. (2023, May). *Adaptation Strategies for Transportation Infrastructure: Educational Resource*. Caltrans. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/adaptation-strategies-transportation-infrastructure-a11y.pdf

Castle, A., García, J., McLaughlin, K., Sharif, H., & Woods, A. (2020). San Juan, Puerto Rico: Recommendations for a More Climate Resilient Future. *City Resilience and Climate Change: A Report from the Inter-Policy School Summit 2020,* 43-52. Aspen Institute. https://www.jstor.org/stable/resrep42654.9

Climate and Health. (2022, July 22). U.S. Climate Resilience Toolkit. Retrieved October 10, 2023, from https://toolkit.climate.gov/regions/us-caribbean-climate-and-health

Cook, J., Frankel-Reed, J., Bruzgul, J., Helmuth, M., Hurley, B., Mack, C., Schultz, P., Strange, E., & Anderson, G. (2016). *Climate Vulnerability Assessment: An Annex to the USAID Climate-Resilient Development Framework.* United States Agency for International Development. https://pdf.usaid.gov/pdf_docs/PA00KZ84.pdf

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social Vulnerability to Environmental Hazards. *Social Science Quarterly, 84*(2), 242–261. http://www.jstor.org/stable/42955868

Daniels, J., & MacArthur, J. (2022). *Transportation System Resiliency and Disaster Response and Recovery: A Review on U.S. Metropolitan Long-Range Transportation Plan.* Submitted for Presentation at The 101st Annual Meeting of the Transportation Research Board. https://ppms.trec.pdx.edu/media/project_files/TRB_TRBAM-22-00866_Paper.pdf

Dawson, D., Shaw, J., & Gehrels, W. (2016). Sea-Level Rise Impacts on Transport Infrastructure: The Notorious Case of the Coastal Railway Line at Dawlish, England. *Journal of Transport Geography, 51,* 97-109. http://dx.doi.org/10.1016/j.jtrangeo.2015.11.009

Del Mar-Quiles, C. (2019, May 1). *La realidad de las madres puertorriqueñas.* Todas PR. https://www.todaspr.com/la-brutal-realidad-de-las-madres-puertorriquenas/

Delgado, J. (2021, January 31). Removerán arena de tramo de carretera afectado por inundaciones costeras en Piñones. *El Nuevo Día.* https://www.elnuevodia.com/noticias/locales/notas/removeran-arena-de-tramo-de-carretera-afectado-por-inundaciones-costeras-en-pinones/

Dodman, D., & Mitlin, D. (2011). Challenges for Community-Based Adaptation: Discovering the

Potential for Transformation. *Journal of International Development, 25,* 640-659. https://doi.org/10.1002/jid.1772

Ecola, L., Davenport, A., Kuhn, K., Rothenberg, A., Cooper, E., Barrett, M., Atkin, T., & Kendall, J. (2020). *Rebuilding Surface, Maritime, and Air Transportation in Puerto Rico After Hurricanes Irma and Maria: Supporting Documentation for the Puerto Rico Recovery Plan.* Homeland Security Operational Analysis Center operated by the RAND Corporation. https://www.rand.org/pubs/research_reports/RR2607.html

El-Ashry, M. (2009). Adaptation to Climate Change: Building Resilience and Reducing Vulnerability. *Brookings, Climate Change Policy: Recommendations to Reach Consensus,* 58-65. https://www.brookings.edu/articles/climate-change-policy-recommendations-to-reach-consensus/

Esty, D., & Massie, M. (2021, June 25). *Yale Experts Explain Climate Change.* Yale Sustainability. https://sustainability.yale.edu/explainers/yale-experts-explain-climate-change

EPA. (2016, August). *What Climate Change Means for Puerto Rico.* United States Environmental Protection Agency. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pr.pdf

Fabre, A. (2020). Guías de acción para el desarrollo de una comunidad resiliente ante los desastres (huracanes, tormentas tropicales, inundaciones y terremotos) en tres comunidades en Hato Rey Norte, San Juan, Puerto Rico (Order No. 28001221). [Master's thesis, University of Puerto Rico, Río Piedras Campus]. *ProQuest One Academic.*

Fayazi, M., & Bornstein, L. (2021). The links between vulnerability, poverty, and natural hazards: A focus on the impacts of globalization trends. In Martins, N., Fayazi, M., Kikano, F., & Hobeica, L. (Eds.), *Enhancing Disaster Preparedness: From Humanitarian Architecture to Community Resilience* (pp.259-272). Elsevier. https://doi.org/10.1016/B978-0-12-819078-4.00014-9

FEMA. (2024, March 17). *National Risk Index: Census tract 72087110600, Loíza Municipio, Puerto Rico.* Federal Emergency Management Agency. https://hazards.fema.gov/nri/report/viewer?dataLOD=Census%20tracts&dataIDs=T72087110600

FEMA. (2023, November 2). *National Risk Index: Census tract 72087110600, Loíza Municipio, Puerto Rico.* Federal Emergency Management Agency. https://hazards.fema.gov/nri/report/viewer?dataLOD=Census%20tracts&dataIDs=T72087110600

FEMA. (2022a, March). *Hurricane and Flood Mitigation Handbook for Public Facilities: Fact Sheet 1.01: Roads.* Federal Emergency Management Agency. https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-0-roads.pdf

FEMA. (2022b, March). *Hurricane and Flood Mitigation Handbook for Public Facilities: Fact Sheet*

1.1: Road and Highway Surfaces. Federal Emergency Management Agency. https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-1-road-surfaces.pdf

FEMA. (n.d.). *National Risk Index: Expected Annual Loss*. Federal Emergency Management Agency. https://hazards.fema.gov/nri/expected-annual-loss#:~:text=Expected%20Annual%20Loss%20(EAL)%20represents,buildings%2C%20people%2C%20and%20agriculture.

FHWA. (2023, October 13). *Climate Stressors.* Federal Highway Administration, Office of Research, Development, and Technology at the Turner-Fairbank Highway Research Center. https://highways.dot.gov/research/infrastructure/resilient-pavements/definitions

FHWA. (2023, October 13). *Resilience Definitions.* Federal Highway Administration, Office of Research, Development, and Technology at the Turner-Fairbank Highway Research Center. https://highways.dot.gov/research/infrastructure/resilient-pavements/definitions

Filosa, G., Plovnick, A., Stahl, L., Miller, R., & Pickrell, D. (2017). *Vulnerability Assessment and Adaptation Framework, Third Edition.* United States Department of Transportation: Federal Highway Administration, Office of Planning, Environment, and Realty. https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/

Flanagan, B., Gregory, E., Hallisey, E., Heitgerd, J., & Lewis, B. (2011). A Social Vulnerability Index for Disaster Management. *Journal of Homeland Security and Emergency Management, 8*(1), 1-22. http://www.bepress.com/jhsem/vol8/iss1/3

Folke, C. (2006). Resilience: The Emergence of a Perspective for Social-Ecological Systems Analyses. *Global Environmental Change, 6*(3), 253-267. Doi: 10.1016/j.gloenvcha.2006.04.002

Fuchs, S., Frazier, T., & Siebeneck, L. (2018). Physical Vulnerability. In S. Fuchs & T. Thaler (Eds.), *Vulnerability and Resilience to Natural Hazards* (pp. 32-52). Cambridge University Press. https://doi.org/10.1017/9781316651148

Gaskin, C. J., Taylor, D., Kinnear, S., Mann, J., Hillman, W., & Moran, M. (2017). Factors Associated with the Climate Change Vulnerability and the Adaptive Capacity of People with Disability: A Systematic Review. *Weather, Climate, and Society, 9*(4), 801-814. https://doi.org/10.1175/WCAS-D-16-0126.1

Glick, P., Stein, B.A., & Edelson, N. (Eds). (2011). *Scanning Conservation Horizon: A Guide to Climate Change Vulnerability Assessment.* National Wildlife Federation.

Global Americans. (2023). *High-Level Working Group on Climate Change in the Caribbean: Extreme Weather Events and Resilience.* Global Americans. https://theglobalamericans.org/wp-content/uploads/2023/05/Extreme-Weather-Events-and-Resilience-in-the-Caribbean.pdf

Goujon, M., Santoni, O., & Wagner, L. (2003). The Physical Vulnerability to Climate Change Index Computed at the Sub-National Level. *Foundation pour les études et recherches sur le développement international.* https://ferdi.fr/dl/df-bkMSsFLrDt9rahw7WnRGbHrY/ferdi-wp305-the-physical-vulnerability-to-climate-change-index-computed-at.pdf

Guillama-Capella, M. (2023, March 16). Loíza: a la merced de la erosión costera. *El Nuevo Día*. https://www.elnuevodia.com/noticias/locales/notas/loiza-a-la-merced-de-la-erosion-costera/?r=66597

Gulliver-Garcia, T. (2021, August 3). *Parenting Alone – Single Parents in Disasters.* Center for Disaster Philanthropy. https://disasterphilanthropy.org/blog/parenting-alone-single-parents-in-disasters/

Gurrentz, B., Scurry, J., & Notter, I. (2023, June 7). *New Community Resilience Estimates Show Almost Half of Puerto Rico Population Had Three or More Risk Factors.* United States Census Bureau. https://www.census.gov/library/stories/2023/06/how-socially-vulnerable-is-puerto-rico-to-disasters.html#:~:text=All%20municipios%20in%20Puerto%20Rico,0%20risk%20factors%20(14.7%25)

Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Bangalore, M., & Beaudet, C. (2020). From Poverty to Disaster and Back: a Review of the Literature. *Economics of Disaster and Climate Change, 4,* 223-247. https://doi.org/10.1007/s41885-020-00060-5

Hayes, S., Desha, C., Burke, M., Gibbs, M., & Chester, M. (2019). Leveraging Socio-Ecological Resilience Theory to Build Climate Resilience in Transport Infrastructure. *Transport Reviews, 39*(5), 677-699. https://doi.org/10.1080/01441647.2019.1612480

Hayhoe, K. (2018, November 26). *Highlights from the Fourth US National Climate Assessment* [Lecture]. The 4th National Climate Assessment, Virtual.

Hemmingway, L., & Priestley, M. (2014). Natural Hazards, Human Vulnerability and Disabling Societies: A Disaster for Disabled People? *Review of Disability Studies, 2*(3). https://www.rdsjournal.org/index.php/journal/article/view/337/1037

Hernández, R. (2023, March 3). El 42% de las playas en Loíza se erosionarion luego del huracán María. *Presencia: Tu Regional del Noreste.* https://www.presenciapr.com/el-42-de-las-playas-en-loiza-se-erosionaron-luego-del-huracan-maria/

Humphrey, N. (2008). *Potential Impacts of Climate Change on U.S. Transportation.* TRB Special Report, Transportation Research Board. https://onlinepubs.trb.org/onlinepubs/trnews/trnews256climate.pdf

IPCC. (2023). Sections. In: Climate Change 2023: Synthesis Report. In Lee, H. & Romero, J. (Eds.),

Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 35-115). Intergovernmental Panel on Climate Change. Doi: 10.59327/IPCC/AR6-9789291691647

IPCC. (2018). Annex II – Glossary. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-AnnexII_FINAL.pdf

JPPR. (2021). *Planes de Mitigación Contra Peligros Naturales: Resiliencia Planificada. 2021 Municipio de Loíza: Plan de Mitigación contra Peligros Naturales.* Junta de Planificación de Puerto Rico. https://jp.pr.gov/wp-content/uploads/2022/01/Loiz-Approved-HMP.pdf

Katic, K. (2017). *Social Vulnerability Assessment Tools for Climate Change and DRR Programming: A Guide to Practitioners.* United Nations Development Programme. https://adaptation-undp.org/sites/default/files/resources/social_vulnerability05102017_0.pdf

Kehler, S. & Birchall, J. (2021). Social vulnerability and climate change adaptation: The critical importance of moving beyond technocratic policy approaches. *Environmental Science & Policy, 124,* 471-477. https://doi.org/10.1016/j.envsci.2021.07.025

Klein, R., Huq, S., Downing, T., Richels, R., Robinson, J., & Toth, F. (2007). *Inter-relationships between adaptation and mitigation. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp.745-777). Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg2-chapter18-1.pdf

Kwiatkowski, K.P. (2009). Modeling Climate Change Adaptation in Transportation Infrastructure Organizations (Order No. 10617042). [Doctor of Philosophy thesis, University of Colorado]. *ProQuest One Academic.*

Lee, Y. (2014). Social vulnerability indicators as a sustainable planning tool. *Environmental Impact Assessment Review, 44,* 31-42. https://doi.org/10.1016/j.eiar.2013.08.002

Leon, C., Lam-González, Y., Ruggieri, G., & Calò, P. (2022). Assessing Climate Change Adaptation and Risk Management Programmes: Stakeholder Participation Process and Policy Implications for Transport, Energy and Tourism Sectors on the Island of Sicily. *Land, 11*(1206). Doi: https://doi.org/10.3390/ land11081206

Main, J., Dillard, M., Kuligowski, E., Aponte-Bermúdez, L., Cline, J., Davis, B., Dukes, J., Harrison, K., Helgeson, J., Johnson, K., Kirsch, T., Levitan, M., Mitrani-Reiser, J., Weaver, S., & Yeo, D. (2021). *Aprendiendo del Impacto del Huracán María en Puerto Rico.* National Institute of Standards and Technology: U.S. Department of Commerce. https://doi.org/10.6028/NIST.SP.1262es

Markolf, S., Hoehne, C., Fraser, A., Chester, M., & Underwood, S. (2019). Transportation Resilience to Climate Change and Extreme Weather Events – Beyond Risk and Robustness. *Transport Policy, 74,* 174-186. https://doi.org/10.1016/j.tranpol.2018.11.003

Marine Awareness Research & Education Society. (2018). *Plan de Adaptación de Base Comunitaria al Cambio Climático del Municipio de Loíza.* Department of Natural Resources of Puerto Rico. https://www.drna.pr.gov/wp-content/uploads/2019/07/Plan-Adptc-Loiza-RVSN_9-22-18.pdf

Méndez-Lázaro, P., Martínez-Sánchez, O., Méndez-Tejeda, R., Rodríguez, E., Morales, E., & Schmitt-Cortijo, N. (2015). Extreme Heat Events in San Juan Puerto Rico: Trends and Variability of Unusual Hot Weather and its Possible Effects on Ecology and Society. *Journal of Climatology and Weather Forecasting, 3*(2), 1-7. Doi: 10.4172/2332-2594.1000135

Meyer, M., & Weigel, B. (2010). Climate Change and Transportation Engineering: Preparing for a Sustainable Future. *Journal of Transportation Engineering, 137*(6), 393-403. https://doi.org/10.1061/(ASCE)TE.1943-5436.000010

Muttarak, R., & Lutz, W. (2014). Is Education a Key to Reducing Vulnerability to Natural Disasters and Hence Unavoidable Climate Change? *Ecology and Society, 19*(1). http://www.jstor.org/stable/26269470

Ngo, E. B. (2001). When disasters and age collide: Reviewing vulnerability of the elderly. *Natural Hazards Review, 2*(2), 80-89. https://doi.org/10.1061/(ASCE)1527-6988(2001)2:2(80)

NOAA. (2024, March 14). *Sea Level Rise Viewer.* National Oceanic and Atmospheric Administration: Office for Coastal Management Digital Coast. https://coast.noaa.gov/digitalcoast/tools/slr.html

NOAA. (2023, October 8). *Know Your Risk: Water & Wind.* National Oceanic and Atmospheric Administration. https://www.noaa.gov/know-your-risk-water-wind

NOAA. (2020, March 23). *What's the Difference Between Weather and Climate?* National Oceanic and Atmospheric Administration: National Centers for Environmental Information. https://www.ncei.noaa.gov/news/weather-vs-climate

Ocko, I. (2017, October 3). *Puerto Rico a tragic reminder of why climate action cannot wait*. Environmental Defense Fund. https://www.edf.org/blog/2017/10/03/puerto-rico-tragic-reminder-why-climate-action-cannot-wait

Ogie, R.I., & Pradhan, B. (2019). Natural Hazards and Social Vulnerability of Place: The Strength-Based Approach Applied to Wollongong, Australia. *International Journal of Disaster Science, 10,* 404-420. https://doi.org/10.1007/s13753-019-0224-y

Peña Rivera, N. (2018). Huracán María: Nueva Oportunidad para Promover en Común una Mejor Movilidad en Puerto Rico. *Revista De Administración Pública, 49*, 147–156. https://revistas.upr.edu/index.php/ap/article/view/13783

Pérez Méndez, O. (2018, March 5). El mar nos castigó bien duro. *Primera Hora.* https://www.primerahora.com/noticias/puerto-rico/notas/el-mar-nos-castigo-bien-duro/

Pregnolato, M., Ford, A., Wilkinson, S., & Dawson, R. (2017). The Impact of Flooding on Road Transport: A Depth-Disruption Function. *Transportation Research Part D, 55,* 67-81. http://dx.doi.org/10.1016/j.trd.2017.06.020

Primera Hora. (2022, December 9). Cierran carretera PR-187 en Loíza por fuerte marejada. *Primera Hora.* https://www.primerahora.com/noticias/puerto-rico/notas/cierran-carretera-pr-187-en-loiza-por-fuerte-marejada/

Primera Hora. (2012, August 24). Olvidado Loíza. *Primera Hora*. https://www.primerahora.com/noticias/puerto-rico/notas/olvidado-loiza/

Rebally, A., Valeo, C., He, J., & Saidi, S. (2021). Flood Impact Assessments on Transportation Networks: A Review of Methods and Associated Temporal and Spatial Scales. *Frontiers in Sustainable Cities, 3*(732181). https://doi.org/10.3389/frsc.2021.732181

Resilient Puerto Rico Advisory Commission. (2018). *ReImagina Puerto Rico. Informe Sectorial de Vivienda.* UNA-USA Puerto Rico. https://www.unausapr.org/uploads/3/1/1/7/3117189/reimaginapr_vivienda.pdf

Rodríguez-Velázquez, V. (2020). In the Afro-Caribbean heart of Puerto Rico, locals fight erosion, government indifference. *USA Today.* https://www.usatoday.com/story/opinion/voices/2020/02/06/puerto-rico-erosion-hurricane-maria-afro-report-for-america-column/4658501002/

Rouhanizadeh, B. & Kermanshachi, S. (2020). Post-Disaster Reconstruction of Transportation Infrastructures: Lessons Learned. *Sustainable Cities and Society, 63*(102505). https://doi.org/10.1016/j.scs.2020.102505

Sagara, B. (2018). *Resilience Measurement Practical Guidance Note Series 2: Measuring Shocks and Stresses.* United States Agency for International Development. https://www.fsnnetwork.org/sites/default/files/GN_Overview_Final_0.pdf

SDC-PR. (2022). Encuesta sobre la Comunidad. Instituto de Estadísticas de Puerto Rico. https://censo.estadisticas.pr/EncuestaComunidad

Sosa-López, O., Santiago-Bartolomei, R., & Lamba-Nieves, D. (2019). *La informalidad urbana: tendencias y políticas internacionales relacionadas con la tenencia de la tierra y los asentamientos informales.* Center for a New Economy. https://grupocne.org/wp-content/uploads/2019/08/Blueprint-Informe-Informalidad-Urbana-FINAL.pdf

Stablein, M.J., González Cruz, J., Fidan, E.N., Talbot, J., Reed, S.P., Walters, R.S., Ogunyiola, A.J., Fernández Frey, M., Ramírez, M., Rosado Casanova, B., Heemstra, J., Marshall, A., & Rodríguez, L.F. (2022). Compound[ing] Disasters in Puerto Rico: Pathways for Virtual

Transdisciplinary Collaboration to Enhance Community Resilience. *Global Environmental Change, 76*(102558), 1-11. https://doi.org/10.1016/j.gloenvcha.2022.102558

Stein, B.A., Glick, P., Edelson, N., & Staudt, A. (Eds). (2014). *Climate-Smart Conservation: Putting Adaptation Principles into Practice*. National Wildlife Federation.

Stein, P.J.S, Stein, M.A., Groce, N., & Kett, M. (2023). The Role of the Scientific Community in Strengthening Disability-Inclusive Climate resilience. *Nature Climate Change, 13,* 108-109. https://doi.org/10.1038/s41558-022-01564-6

Stokols, D., Pérez-Lejano, R., & Hipp, J. (2013). Enhancing the Resilience of Human–Environment Systems: a Social Ecological Perspective. *Ecology and Society, 18*(1). http://dx.doi.org/10.5751/ES-05301-180107

Striessnig, E., & Loichinger, E. (2015). Future Differential Vulnerability to Natural Disasters by Level of Education. *Vienna Yearbook of Population Research, 13*, 221–240. http://www.jstor.org/stable/24770031

Subiyanto, A., Boer, R., Aldrian, E., & Kinseng, R. (2020). Climate Resilience: Concepts, Theory, and Methods of Measuring. *Environment Asia 13*(1), 1-13. Doi: 10.14456/ea.2020.1

Talbot, J., Poleacovschi, C., & Hamideh, S. (2022). Socioeconomic Vulnerabilities and Housing Reconstruction in Puerto Rico After Hurricanes Irma and Maria. *Natural Hazards, 110*, 2113-2140. https://doi.org/10.1007/s11069-021-05027-7

Titus, J. (2016). *Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?* United States Department of Transportation. https://www.transportation.gov/sites/dot.gov/files/docs/titus_Sea_Level_Rise_Matter_Transportation_Atlantic_Coast.pdf

Tolentino, C. (2018). ¿Formal o informal? El eterno debate en la construcción puertorriqueña. *Diálogo UPR.* https://dialogo.upr.edu/formal-o-informal-el-eterno-debate-en-la-construccion-puertorriquena/

Tobin-Gurley, J., Peek, L., & Loomis, J. (2010). Displaced Single Mothers in the Aftermath of Hurricane Katrina: Resource Needs and Resource Acquisition. *International Journal of Mass Emergencies & Disasters, 28*(2), 170-206. https://doi.org/10.1177/028072701002800202

Transport & ICT. (2015). *Moving Toward Climate-Resilient Transport: The World Bank's Experience from Building Adaptation into Programs.* World Bank Group. https://thedocs.worldbank.org/en/doc/326861449253395299-0190022015/render/WorldBankPublicationResilientTransport.pdf

Trenberth, K. (2018). Climate change caused by human activities is happening and it already has major consequences. *Journal of Energy & Natural Resources, 36*(4), 463-481. Doi: 10.1080/02646811.2018.1450895

Turrentine, J. & Denchak, M. (2021, September 1). *What is Climate Change?* Natural Resources Defense Council. https://www.nrdc.org/stories/what-climate-change#solutions

UK Climate Resilience Programme. (2019, December 20). *What is climate resilience?* [Video]. YouTube. https://www.youtube.com/watch?v=tbewtd6OgM4

University of Bristol. (2020, August 27). *Hurricanes could be up to five times more likely in the Caribbean if tougher targets are missed.* ScienceDaily. www.sciencedaily.com/releases/2020/08/200827130612.htm

U.S. Census Bureau. (2023). *Quick Facts: Loíza Municipio, Puerto Rico.* United States Department of Commerce. https://www.census.gov/quickfacts/fact/table/loizamunicipiopuertorico/PST045222

U.S. Census Bureau. (2022). *Loíza Municipio, Puerto Rico.* United States Department of Commerce. https://data.census.gov/profile/Lo%C3%ADza_Municipio,_Puerto_Rico?g=050XX00US72087

U.S. Federal Government. (2023). *Steps to Resilience Overview.* U.S. Climate Resilience Toolkit. https://toolkit.climate.gov/steps-to-resilience/steps-resilience-overview

USACE. (2019). *Final Supplemental Environmental Assessment. Loíza, Puerto Rico Section 14 Project*. United States Army Corps of Engineers. https://usace.contentdm.oclc.org/digital/collection/p16021coll7/id/12242/rec/37

USACE. (2018). *Final Integrated Feasibility Report and Environmental Assessment.* United States Army Corps of Engineers. https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/9463

Vahlsing, C., & Liscow, Z. (2023, March 14). *The Importance of Measuring the Fiscal and Economic Costs of Climate Change.* The White House. https://www.whitehouse.gov/omb/briefing-room/2023/03/14/the-importance-of-measuring-the-fiscal-and-economic-costs-of-climate-change/?utm_source=link

Vosper, E.L., Mitchell, D.M., & Emanuel, K. (2020). Extreme Hurricane Rainfall Affecting the Caribbean Mitigated by the Paris Agreement Goals. *Environmental Research Letters, 15*(104053), 1-9. Doi: 10.1088/1748-9326/ab9794

Wang, T., Yao, C., & Wei, Q. (2023). Resilience Assessment and Influencing Factors of Chinese Megacities. *Sustainability, 15*(6770), 1-27. https://doi.org/10.3390/su15086770

Watson, G., & Ahn, J.E. A Systematic Review: To Increase Transportation Infrastructure Resilience to Flooding Events. *Applied Sciences, 12*(12331). https://doi.org/10.3390/app122312331

Werndl, C. (2014). On Defining Climate and Climate Change. *The British Journal for the Philosophy*

of Science, 67(2), 1-29. https://doi.org/10.1093/bjps/axu048

WHO. (2023, October 12). *Climate Change.* World Health Organization. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health#:~:text=Research%20shows%20that%203.6%20billion,diarrhoea%20and%20heat%20stress%20alone

Willyard, K., Scurry, J., King, H., Gurrentz, B., & DeSalvo, B. (2023). *Developing a Data-Driven System for Identifying the Most Vulnerable Communities in Puerto Rico.* United States Census Bureau. https://www.census.gov/content/dam/Census/library/working-papers/2023/demo/sehsd-wp2023-19.pdf

Zhou, Y., Wang, J., & Yang, H. (2019). Resilience of Transportation Systems: Concepts and Comprehensive Review. *IEEE Transactions on Intelligent Transportation Systems, 20*(12), 4262-4276. Doi: 10.1109/TITS.2018.2883766

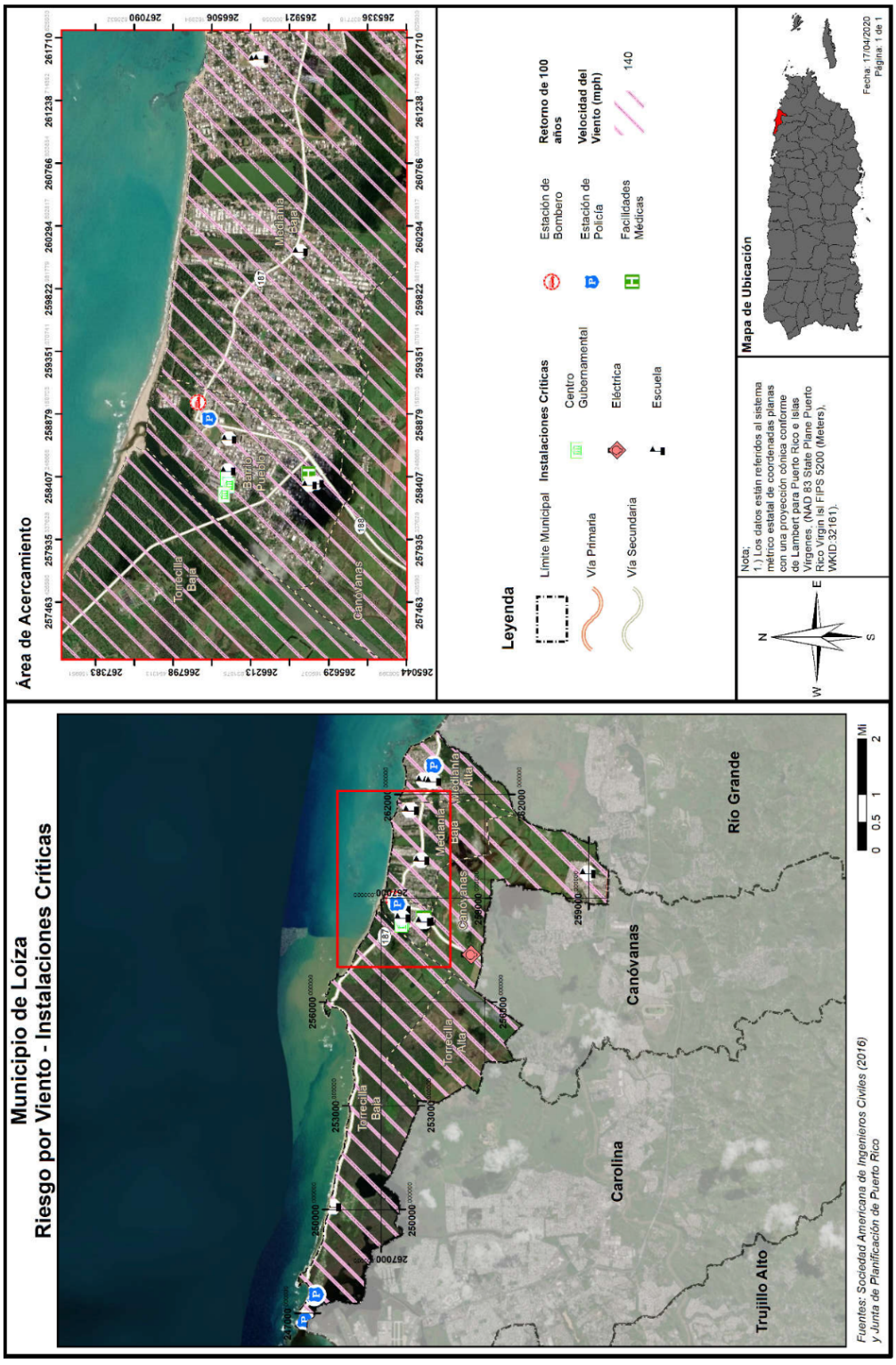
11. Appendices

11.1 Appendix A: Loíza in a ten-foot sea level rise scenario.
Source: Sea Level Rise Viewer, NOAA, 2024.

Appendices

4.5.6.1 *Área geográfica afectada*

Figura 20: Área geográfica del municipio afectada por el peligro de vientos fuertes



11.2 Appendix B: Geographic Area of Loíza Affected by Strong Winds.

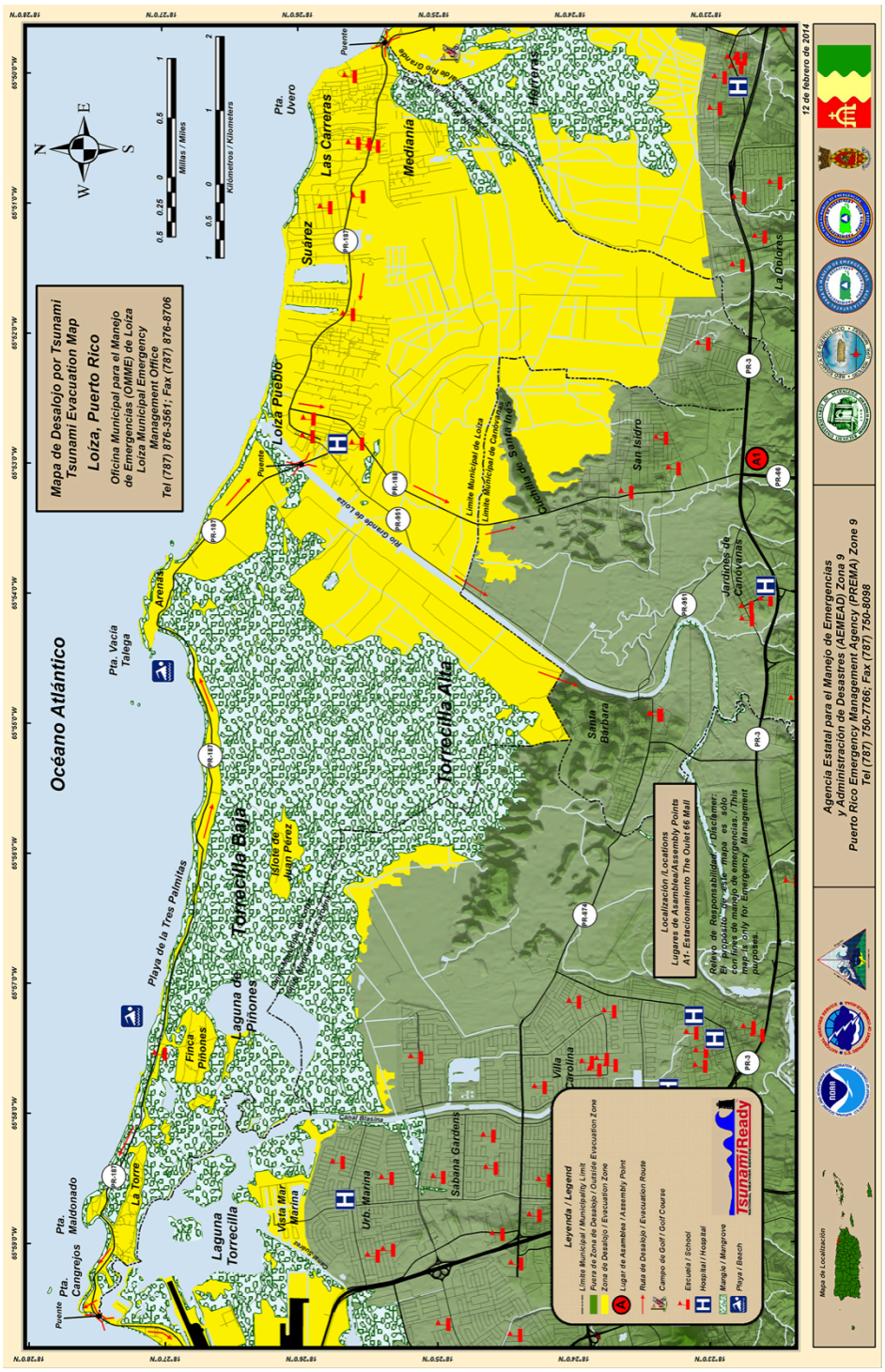
Sources: American Society of Civil Engineers, 2016; JPPR, 2021, p.124.

Appendices

Inundación por marejada	Categoría de huracán				
	Categoría 1	Categoría 2	Categoría 3	Categoría 4	Categoría 5
0 a 1 pie	85	205	440	1,293	1,873
1 a 2 pies	33	101	281	1,008	2,114
2 a 3 pies	1	30	114	460	1,047
3 a 4 pies	0	0	50	138	619
4 a 5 pies	0	0	10	69	331
5 a 8 pies	0	0	0	22	126
8 a 11 pies	0	0	0	0	3
11 a 14 pies	0	0	0	0	0
Más de 14 pies	0	0	0	0	0

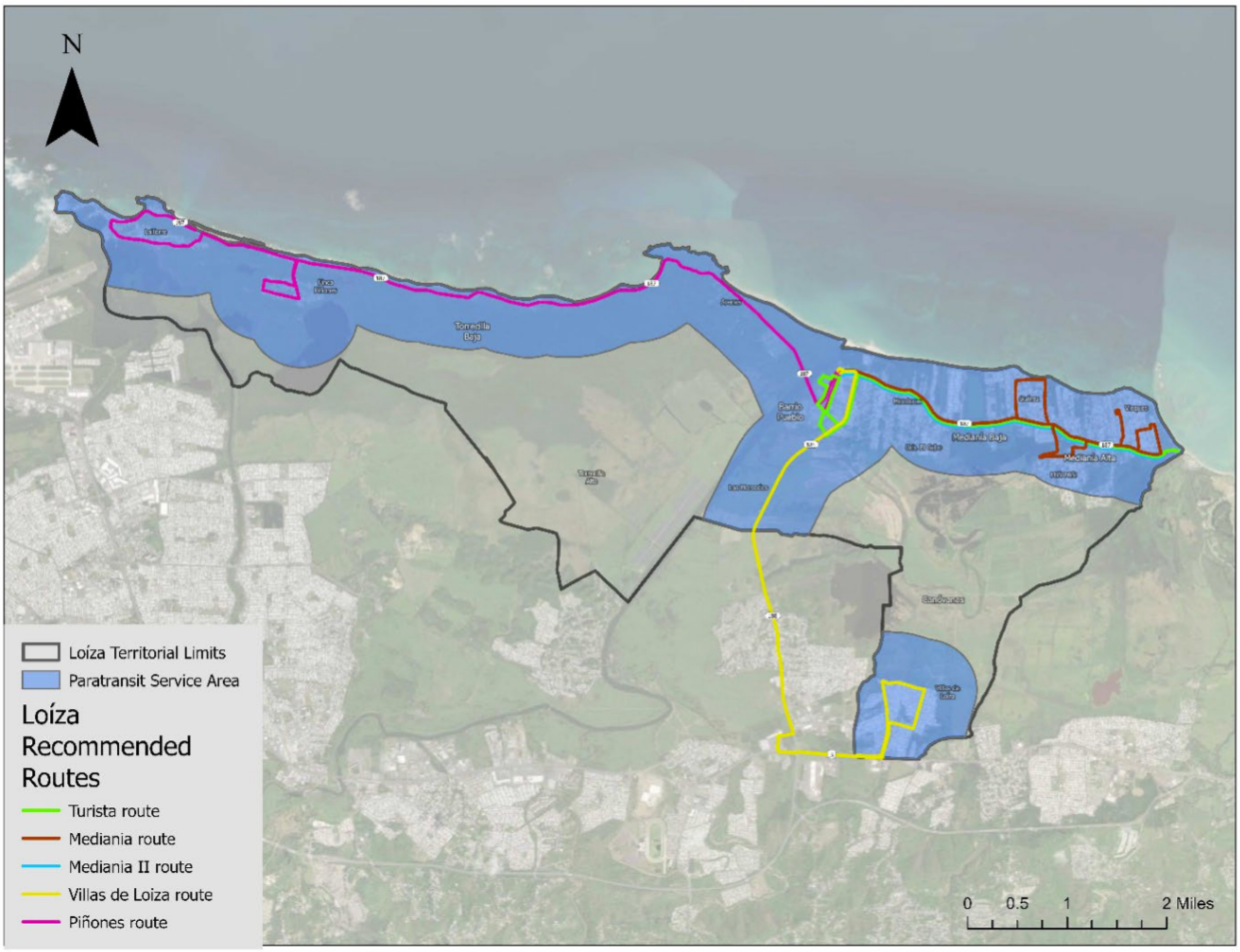
11.3 Appendix C: Number of Structures Inside Risk Areas by Storm Surge in Loíza.
Sources: Puerto Rico Planning Board, 2019; JPPR, 2021, p.240.

Appendices



11.4 Appendix D: The Municipal Office for Emergency Management of Loíza, Evacuation Map. Sources: PRSN, UPRM, OMME, 2014.

Appendices

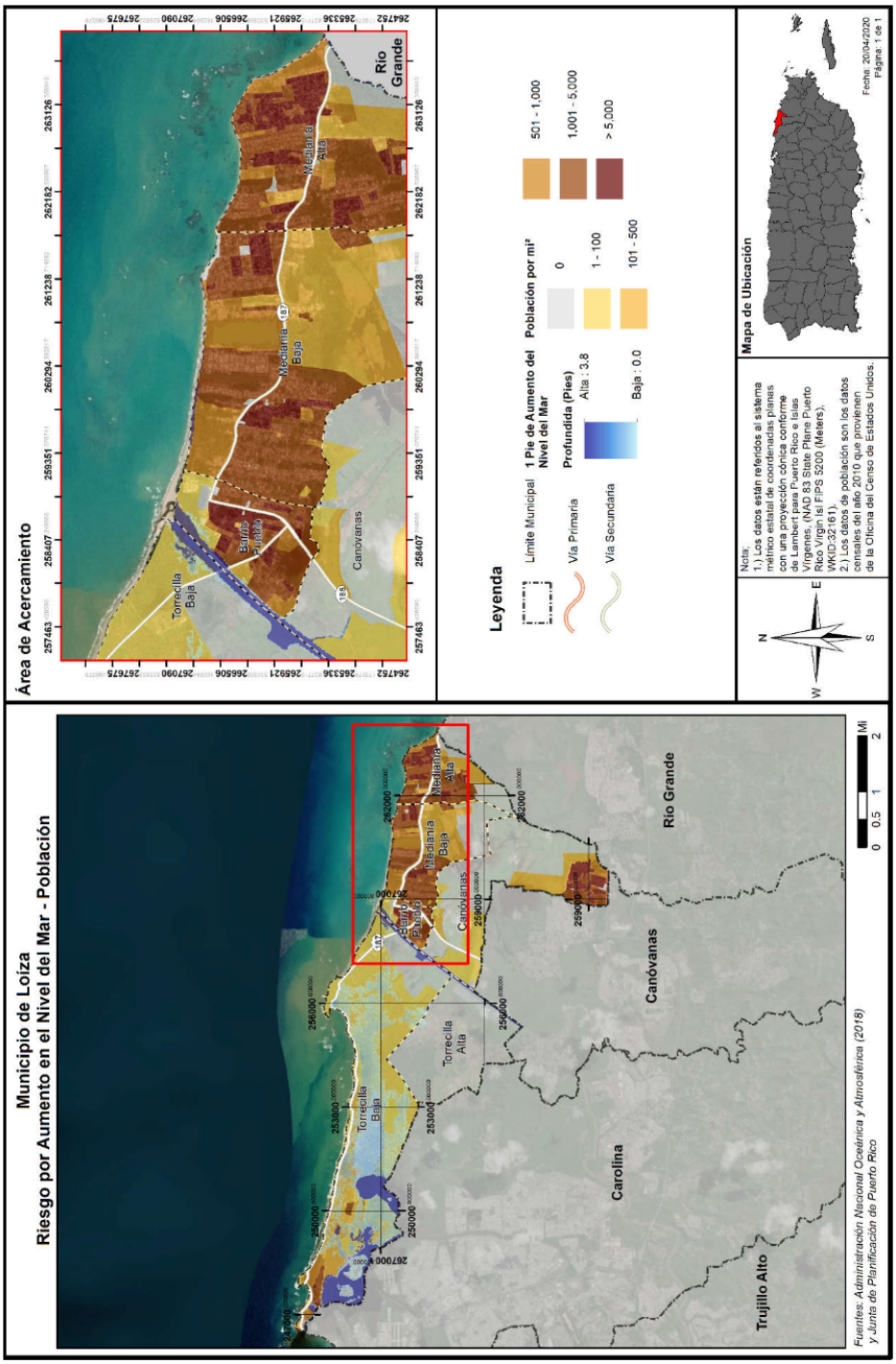


11.4 Appendix E: Recommended Loíza Routes.
Sources: ABC & LGP Consultoría, 2022, p.78.

Appendices

4.6.3.1.3 Vulnerabilidad social

Figura 30: Áreas de peligro por densidad poblacional - 1 pie de Aumento en el nivel del mar



Appendix F: Social Vulnerability Map. Danger areas by Population Density – 1 foot of Sea Level Rise.
Source: Mitigation Plan Against Natural Hazards of the Municipality of Loíza, 2021, p.175.

Appendices

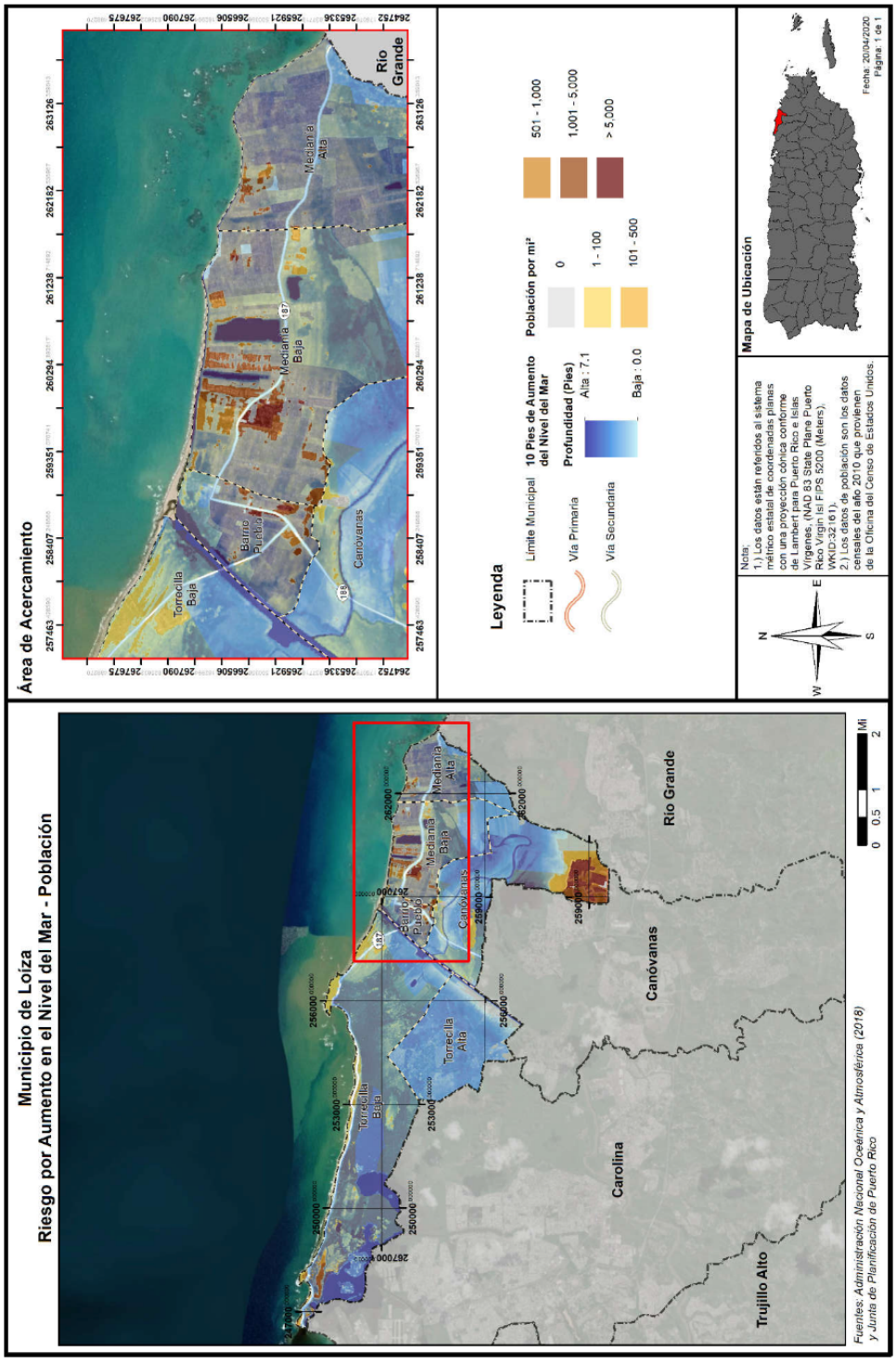


Figura 31: Áreas de peligro por densidad poblacional - 10 pies de aumento en el nivel del mar

Appendix G: Social Vulnerability Map. Danger areas by Population Density –10 feet of Sea Level Rise.
Source: Mitigation Plan Against Natural Hazards of the Municipality of Loíza, 2021, p.175.

Appendices

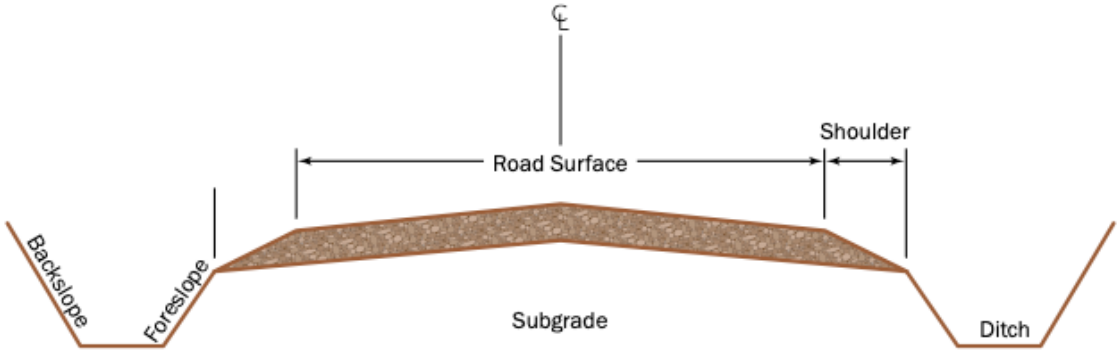


Figure 1.1.1. Reshaping the roadway can improve drainage and decrease flood impacts.

Appendix H: Reshape Roadway.
Source: Hurricane and Flood Mitigation Handbook for Public Facilities: Fact Sheet 1.1: Road and Highway Surfaces, FEMA, 2022b.