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Abstract

This study analyses the effects of coastal erosion in the city of Loíza, Puerto Rico and how does the Carraízo Dam located at Trujillo Alto, Puerto Rico contributes to the sediment imbalance along the Loíza coast. The study centers on evaluating the hydrological impacts of anthropogenic disruption to the natural fluvial sediment transport dynamics, with emphasis on the alterations to the alluvial system and hydro morphological processes of the Río Grande of Loíza, resulting from the construction of the Carraízo Dam. Despite extensive research on mitigating coastal erosion, few studies have directly attributed shoreline degradation to dam construction. By analyzing the physical changes of the river using high-resolution bathymetric data and satellite imagery interpretation we can get preliminary results suggesting a correlation between coastal erosion and sediment imbalance cause by the Carraízo Dam high efficiency sediment retention. The reduction in sediment discharge not only exposed the riverbed material downstream but also it affects the environment, communities and families that live in nearby areas and on the Loíza coast.

Introduction

Coastal erosion in Puerto Rico is caused by natural factors and human activities such as deforestation, urbanization, dam construction, natural disasters and infrastructure development, leading to the loss of beaches, destruction of habitats, and risks to essential infrastructure. Sedimentation in water bodies like the Río Grande of Loíza is a natural process influenced by climate and watershed physiography. Eroded soils are washed away by runoff from rainfall, transported in streams and rivers from higher to lower areas. The Carraízo dam disrupts sediment flow, causing deficiencies in sediment reaching the coastal area of Loíza. Dams retain 70 to 95 percent of the sediments they receive, contributing to coastal erosion and environmental impacts.

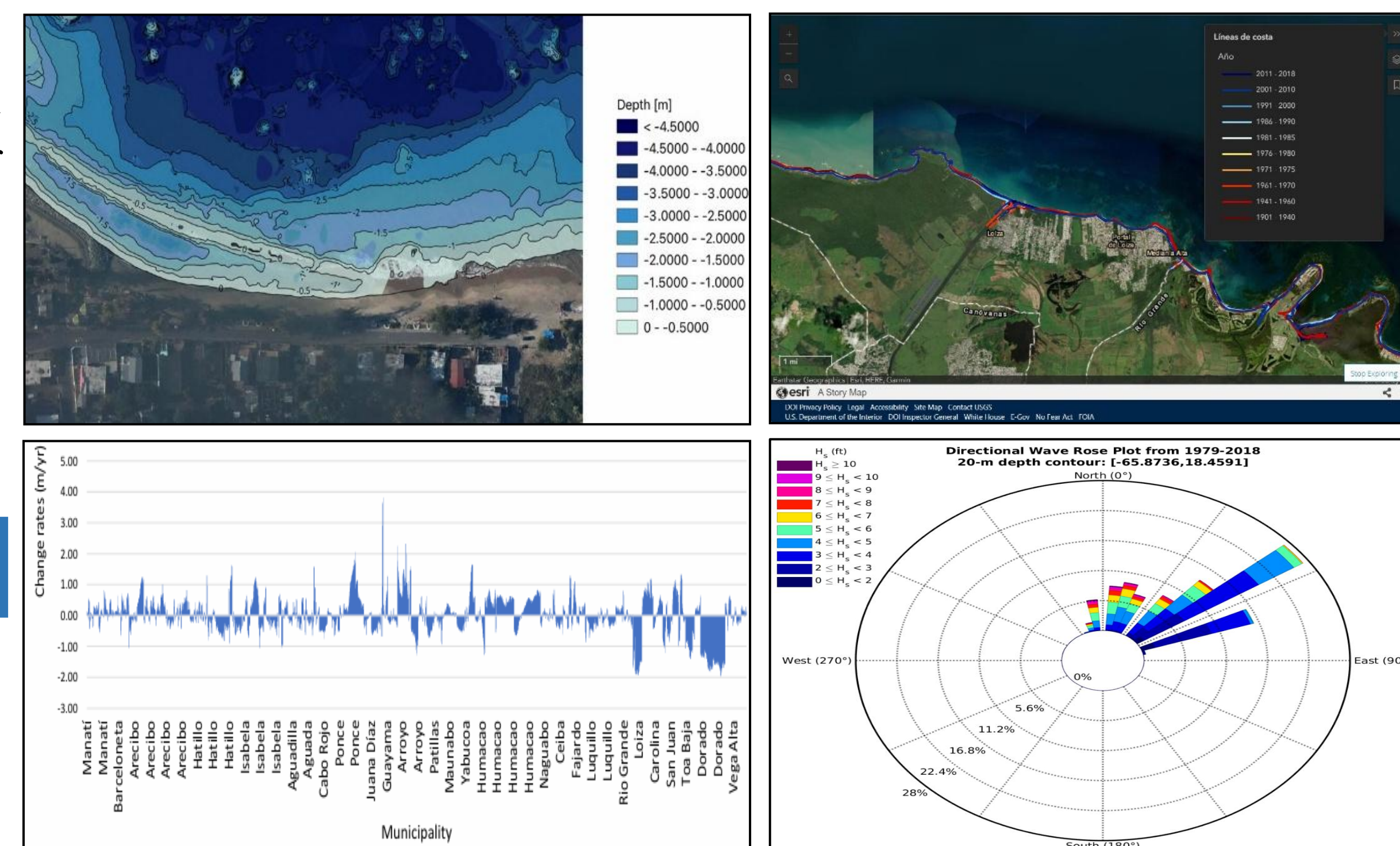
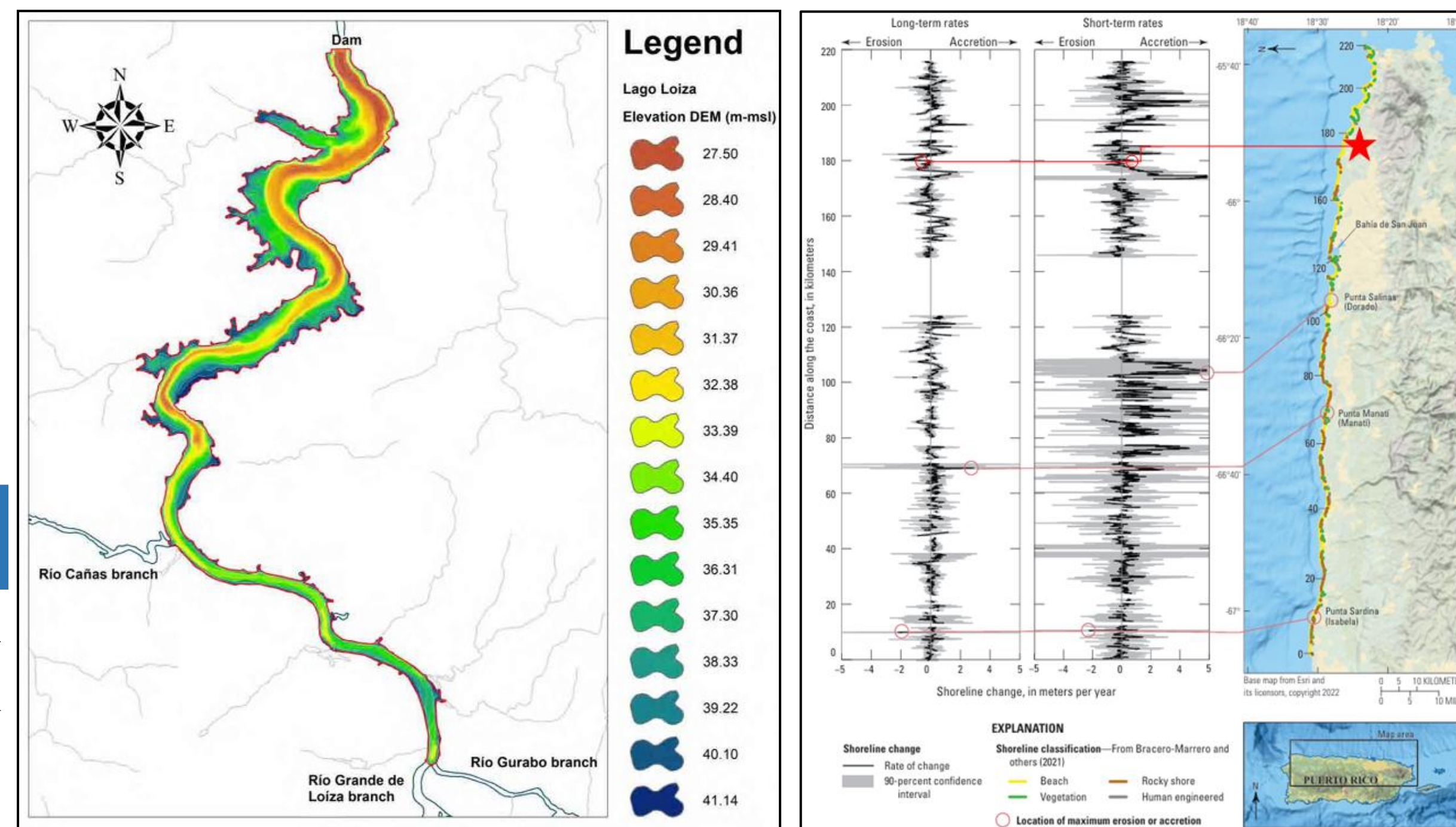
Background

The sediment imbalance and the erosion impact on communities along the Loíza coast lead to this study. While numerous studies have focused on climate change as the primary driver, they often overlook other critical factors contributing to sediment disruption and shoreline erosion. Case studies like the Elwha River dams have demonstrated that retention of sediments where causing coastline degradation. Understanding the factors contributing to coastline erosion and addressing sediment disruption are essential for effective mitigation. Satellite imagery, bathymetric studies and hidrologic models provide valuable data for analysis. Developing solutions to sediment retention in dams can reduce water resource costs and improve management, while also preserving the natural flow of rivers and ensuring sediments reach the coastline, supporting coastal stability

Methodology

The evaluation process is divided into the following:

- Bathymetric reports
- USGS Shoreline Imagery
- WCA Model Point Output



Problem

The main objective of this article is to determine the countermeasures that need to be implemented to maintain water availability to puertorrican communities and to avoid coastal erosion damages on houses, roads, hospitals, water treatment plants and any other structure that can be affected near the Loíza coastline while managing sediment transport to help restore the shoreline. Taking in consideration environmental regulations, and any other guidelines that help comply with the U.S. laws.

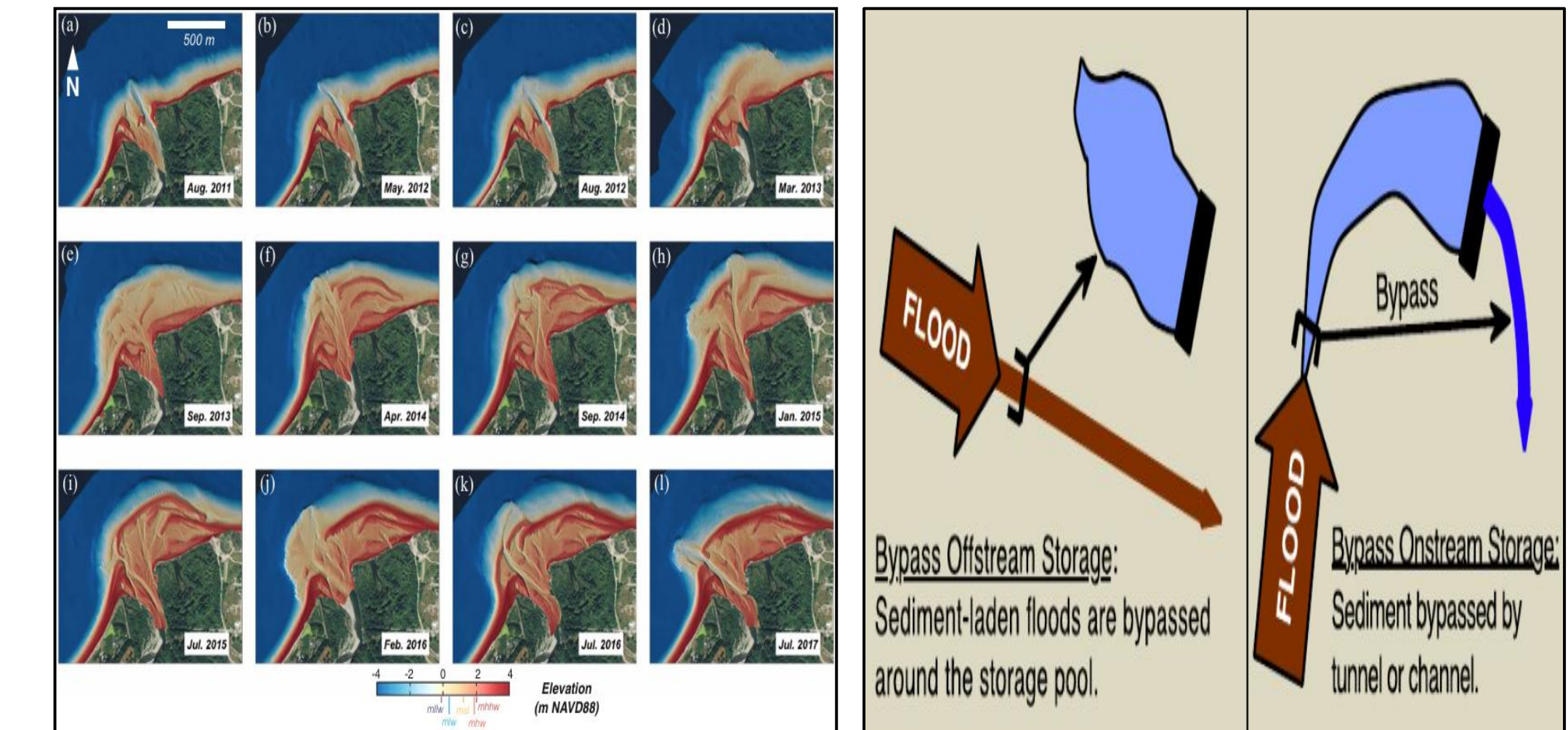
Results and Discussion

There are many factors that contribute to the erosion rate at the Loíza coastline. The retention rate of a dam in Puerto Rico varies from 70 to 95 percent of the sediments that they receive. That means that much of the sediment that the river transports get retained at the dam and does not get to the coastline. Let's remember that the alluvial valleys in the four coastal provinces of Puerto Rico were formed from soil eroded primarily by rainfall in the Mountainous Interior Providence.

Bathymetrical Data: The bathymetrical report illustrated on the cross section of the Loíza River demonstrates that the Carraízo dam reduced its capacity by 11.75 million m³ in 2019. As of December 31, 2022 Ferdinan Quiñones reported a decrease by 13.67 million m³ which represents 51 percent of the total capacity. A research study involving the Elwha and Glines Canyon dams on the Elwha River revealed the presence of 11.1 million m³ of sediment. The sediments that were trapped on the reservoir were the cause of the measurable changes in morphology and rates of change in the fluvial and coastal landforms. In 2011, the removal of dams on the Elwha River was the largest project of its kind at that time, resulting in the greatest sediment release from a dam removal.

USGS Shoreline Imagery: The shoreline image illustrates the coastline's expansion, impacting communities such as Parcelas Suárez in the Loíza municipality. Also, the erosion factor on the Loíza coast is one of the largest -1.93 m/yr, then Arcibo follows with -1.04 m/yr, and we have the Manatí showing ± 0.5 m/yr. A comparison of these three municipalities reveals a significant difference as you can see, Arcibo and Loíza have dams that hinder sediment transportation to their coastlines, while Manatí does not have a dam blocking the sediment flow of Río Grande of Manatí, thus defining it as a stable or unaffected area by the erosion.

WCA Model Point Output: The Atlantic Ocean wave pattern significantly influences coastal erosion in Loíza. Particularly when the waves originate from the northern or northwestern direction. The directional wave rose plot at a depth of 20 meters, indicates that 5.6 percent of the waves originate from the northwest with heights of up to 2.74 m. Although waves from the northwest are less frequent compared to those from the northeast, their impact on the coast is significantly greater. Waves from the northeast account for 27 percent of occurrences, with wave heights of 1.52 m or less. Strong wave action leads to the removal of beach sediments, causing the shoreline to retreat.



Conclusions

Erosion and climate change pose ongoing challenges for Loíza's coast and Puerto Rico. The removal of the Carraízo dam may assist in restoring the shoreline in the Loíza municipality. Additionally, constructing an off-channel reservoir to maintain the water supply and reduce the sediment that gets trapped would help reverse the anthropogenic disruption that has been caused. Coastal resilience projects should be implemented to restore coral reefs, mangroves, and coastal dunes that serve as natural barriers absorbing wave energy, protecting shorelines from storm surges, and helping protect inland areas from erosion and flooding.

Future Work

As a next step for this research, it would be great to develop an hydraulic model that represents the Carraízo dam break and the transport of the sediments through the Loíza river.

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