Tram Nguyen
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The Social and Environmental Implications of Local Sea Level Rise on the Texas Gulf Coast

Introduction

Climate change has displayed its effects globally over the past 70 years. Unfortunately, some regions are more affected than others. The Texas Gulf Coast, for instance, reports higher statistics in its water level rise, flooding, storm surges, and social damages compared to the rest of the world. Global warming contributes majorly to the average global sea-level rise by eight inches. In Texas, however, that number is currently at 18 inches. Various reasons led to this major discrepancy including geographical location, regional as well as local activities. The Gulf Coast experiences a higher rise in water level due to land ice melting globally, high emission of heat-trapping gasses, and most importantly, groundwater pumping to support the regional economy.

With the issue of ocean water constantly rising every year, Texas continues to extract large volumes of groundwater from its land; mostly near the Gulf of Mexico for various economic activities. This process leads to major sinkage as the land tries to fill in the large holes underneath them. As for solutions, the state of Texas has yet to design a permanent and affordable method. They have only set aside approximately $12 billion to battle the consequences of sea-level rise including floods, storm surges, and erosion damages. Geographically, the gulf coast also faces challenges such as high tides during the fall season. These tides are several feet taller than normal tides, which, in addition to the existing water level, have caused major destruction to the local regions. Using advanced equipment such as Argo floats, satellites, and tidal gauges to produce real-time measurements, scientists have reported threatening predictions for the near future.

Over the past decade, sea surface level has increased by almost one inch per year. In the next 14 years, it's predicted that the water level would rise by another six inches. At first glance, these changes and predictions seem not damaging. Nonetheless, the effects have shown through the various events that occurred during the past few years in Texas. Several inches of sea-level rise has increased tidal flooding by almost 500%. This means storm surges or even small precipitation can cause more damage than usual for the people and their properties. High winds and higher launching points within the sea produce greater storm surges that reach farther into the city. The 100-year storm surges will soon become 10-year storm surges by 2050. These effects were seen during hurricane Harvey as the city of Houston suffered from the highest storm total rainfall report which was nearly 61 inches. This historic disaster cost the city about $125 billion in damage and ranks as the second-most costly hurricane in the U.S. since 1900. The number of people affected was nearly 13 million and 135,000 homes were damaged. Research has shown that if not for the rise in sea level, the 11-foot storm surge would have been lower. However, aside from increased rainfall and storm surges, cities within Texas still experience flooding even without the precipitation. Drainage systems, created as pathways for water to escape from the streets to the ocean, have displayed reversed effects as seawater pushes its way into drainage pipes and spill out into the streets. This is caused by the rising sea level and the increase in ocean pressure. As land sinks and the water level rises, beaches in the Gulf Coast gradually disappear, removing the natural boundaries once protected locals from disasters. Land erosion also destroys many natural habitats and important environmental features such as wetlands.

Other socioeconomic consequences due to high sea surface levels include a decrease in tourism due to loss of public access to beaches and the destruction of coastal properties. Locals are also at higher risks of being exposed to more and higher intensity disasters. Currently, 1500 homes in the Galveston Bay area are at risk but within 15 years, that number can double in size. "The region has a combined population of 4.1 million, employment level of over 2 million and total personal income of $183.2 billion." (1. Yoskowitz, Gibeaut, McKenzie, 2009). Making up nearly 18 percent of Texas' employment and population, the region faces a range of 0.7 meters of sea-level rise to 1.5 meters within the next 100 years. Major economic loss in the past and

future stem from water damages that destroy buildings, houses, industrial sites, water plants, etc. Under future circumstances, the public is at risk of experiencing environmental and health impacts as wastewater treatment plants and solid waste sites will be destroyed. Hurricane, for example, with the current water level, it could've caused an additional $1.7 billion in damages, an equivalent of 1.3% of gross state product for Texas.

Targeted Problem:

This research aims to report more recent statistics on the environmental and socioeconomic effects of sea-level rise. More specifically, regional reports from the Galveston Bay area will be included to enhance the seriousness of this issue. Research on the number of wetlands that disappeared or are affected recently will be reported as well as their effects on nearby species and water quality. Since wetlands act as the ecosystem filter system, the cease of their existence can harm animals and humans within the Galveston Bay area. Other indirect implications including damages from storm surges, an increase of precipitation, etc, will also be collected from major and reliable sources. The cost of this research remains low since the sample size is relatively small. However, with a larger budget, more data can be collected and help increase the accuracy of the reports.

Literature Review

Integrated Environmental Assessment & Management

Analysis and conclusions drawn from salt and fresh marshes data collected in 2009 help provide statistics that mirror the impacts from sea level rise in the Galveston Bay area. Wetlands and beaches, in general, are subsiding, but marshes in the local regions can be utilized to identify the potential changes since they provide prominent environmental as well as economic benefits to the city and its people. As sea level in the Texas Gulf Coast continues to rise, changes in marshes in the region cause "disturbance regulation, waste regulation, recreation and aesthetics" (Yoskowitz, 2017). The data provides a predictable trend that by 2100, Galveston city would suffer from a monetary loss of $40 million due to the disappearance of marshes hence leading to their reduction in ecosystem service values. Their results show a declining pattern of salt

marshes in the area of approximately 12% from the present amount. In conclusion, the authors discovered that between fresh and saltwater marshes, the fresh ones will suffer a greater area loss. This finding proves that although saltwater marshes are at a lower elevation, they are able to adapt to the changing sea level by creating their own barriers.

Estuarine, Coastal and Shelf Science

Besides marshes, another significant factor that displays the impact of sea-level rise within the Galveston Bay area is the rate of land subsidence. Due to a combination of all local activities such as groundwater extraction and constructions, the southern Gulf Coast region experiences an even greater increase in water level over the years. The Houston Ship channel region, where activities are highly concentrated, boasts the highest subsidence rates observed at about 0.2 $\mathrm{cm}\,yr^{-1}$. Further data collected within the area led to the conclusion that sedimentation rates have also increased significantly as the land tries to compensate for sinking areas thus causing more sedimentation to accumulate and move around rapidly. Various studies evidently show that the changes in sediment transport and reduction play important roles in land subsidence. Anthropogenic activities have caused the loss of wetlands as well as the conversion of land into the water. An increase in water volume can in return, heightens the fetch of wind and strengthens the wave actions leading to more erosive processes. The cycle continues and wetland loss ceases to stop; stronger tidal waves destruct more local communities unexpectedly, and flooding damages become more severe. By 2006, more groundwater withdrawal regulations have been enforced hence the deceleration of land subsidence. Nonetheless, the damages are done and salvations are helpless in recovering the land to its original state. The authors can only predict that future wetland loss will be primarily caused by a reduction in natural sediment supply.

Storm flooding sensitivity to sea-level rise for Galveston Bay, Texas

Mathematical analysis of the collected data from storm surges in recent years displays the possible impacts of climate change in the near future for Galveston city. The side by side comparison of two possible trends represented by scatter plots and regression line help provide visual changes in storm surges. Furthermore, these changes are proven to be related to the

increase in sea level rise and global warming by the plots. Calculations of probabilities support the predictions of storms and hurricanes' impacts by 2100. As the rate of water level increases, small hurricanes can manage to cause up to seven times the impact they do now to the Galveston Bay area as well as nearby regions. By using a fitted log-logistic model to examine the effect of future sea-level rises, the author was able to capture the increasing trend in flood damages. The results show that by the end of the century, hurricanes with an original return rate of 6.6 years will, in fact, take place annually. By 2100, Larger storms such as Hurricane Ike will double the size in impact while smaller storms impact will increase by a factor of six. In conclusion, the authors suggest many locals in the Galveston Bay area to consider obtaining flood insurance and prepare for future damages.

Methods:

Data are collected from local restaurants and households from the Galveston Bay areas. A sample of 30 places was contracted to survey the recent effects of storm surges, water damages, land sinkage, and disappearance of physical features including beaches, wetlands, marshes, etc. They were questioned about their observations of the damages if any, as well as their personal ratings from a scale of 1-10 (1 being the least effective and 10 being the most effective) of the impacts on their businesses. The survey also inquires on the different methods used by the locals to prepare prior to floods. This research will utilize the data and observations to help model the impacts and produce visual results. The final analysis will include data focusing on the social and economical effects caused by the increase of water level in Galveston. Ratings of the impacts from sea-level rise obtained from the locals are used to produce graphic and tabular results using Excel. Further statistic components such as the sample mean, mode, standard deviation, sample variance, and range are calculated to support the research data. Besides the numerical computations, qualitative responses from the locals including yes or no answers to whether there were impacts from the water level on their businesses and lifestyles, are also converted into charts. Lastly, the locations of the local businesses pose as significant factors to the research. Thus, the program ESRI ArcGIS was utilized to accurately pin all 30 of the contacts on a map of

Galveston Bay. This helps determine the relevance of their responses according to their regional sea-level, land subsidence rate, status, and distance from the Gulf.

Results

From the phone surveys, many locals provided insightful details about the sea-level rise situation in Galveston. Some sources were more credible than others depending on their time running the businesses in the same location. It is worth noting that although 30 contacts would produce a decent sample size, the current situation has caused many businesses to close down or not willing to cooperate with the surveys. Data from those who did respond were used to produce a histogram of ratings (Figure 1) and also calculated to show statistic figures (Table 2). A list of responses is organized in a tabular format (Table 1). The tables show that out of the 30 locals contacted, only 19 or 60% of that number responded with useful information.

Frequency Table	
Ratings	*Frequency*
1-1	2
2-2	1
3-3	0
4-4	0
5-5	8
6-6	4
7-7	3
8-8	0
9-9	1

Table 1.
This table shows the ratings collected from the locals that responded.

Your Histogram	
Mean	5.15789
Standard Deviation (s)	2.0073
Skewness	-0.74798
Kurtosis	0.97618
Lowest Score	1
Highest Score	9
Distribution Range	8
Total Number of Scores	19
Number of Distinct Scores	6
Lowest Class Value	1
Highest Class Value	9
Number of Classes	9
Class Range	1

Table 2.
This table shows the statistic figures calculated from the data set including mean, standard deviation, range, etc.

The histogram shows the frequency of the most popular ratings among the locals which helps portray how the water level has affected some people also known as the socio impact of this environmental issue.

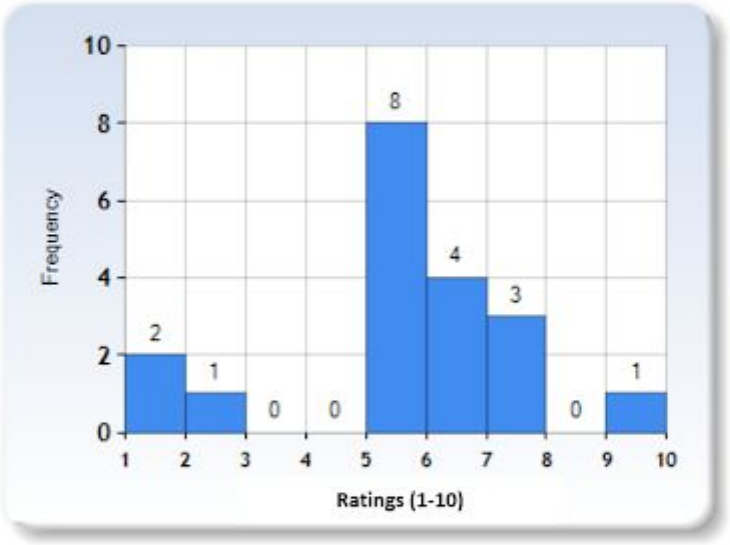


Figure 1. A histogram produced from the ratings to show the range and frequency of the numerical data.

Next, a pie chart was produced using the yes or no responses provided by the locals (Figure 2). This visually displays the percentage of those who have noticed a change in the water level within the past 20 years. The time of two decades was chosen because it is an appropriate time range for many climate factors to display their changes.

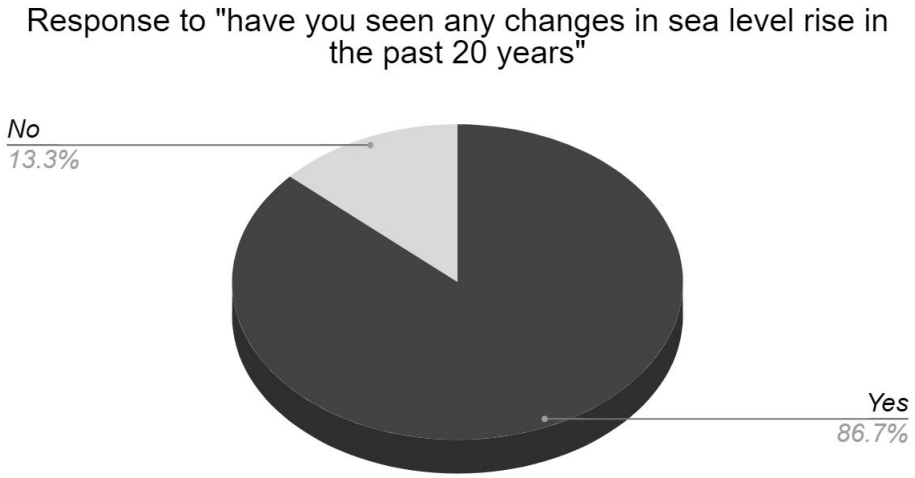


Figure 2.

A pie chart showing the percentage of responses that admit they have seen changes in sea-level rise versus the responses that did not see any changes.

Next, from the software, ESRI ArcGIS, maps of the locations contacted from the Galveston Bay were produced to show their accurate positions. Figure 3 is a map of the entire map with the green pins representing the locations of the contacts. As one can see, there are some areas denser with green pins than others. For the purpose of the research, certain locals are chosen because of their availability and length of operation. The data are only relevant if the businesses have remained active for at least 10 years or so in order to witness the changes surrounding them.

Figure 3.

A map with all the contacts located and pinned. The research aims to contact most locations along the bay and peninsula while accounting for a few from nearby cities.

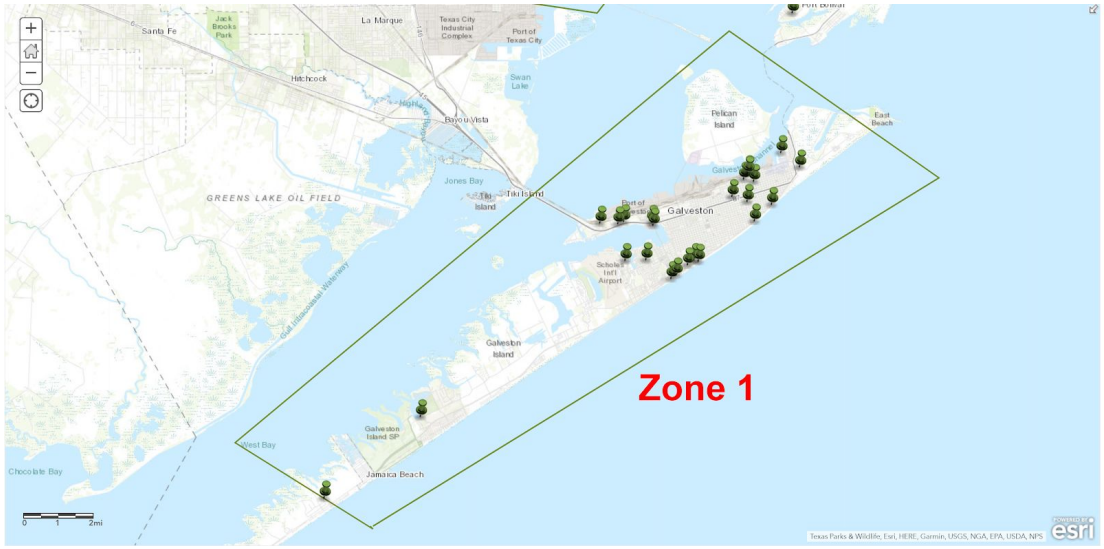


Figure 4.

A close-up map of the first zone that the research focused on where most of the contacts are located. These are more significant because of their close proximity to the large body of water.

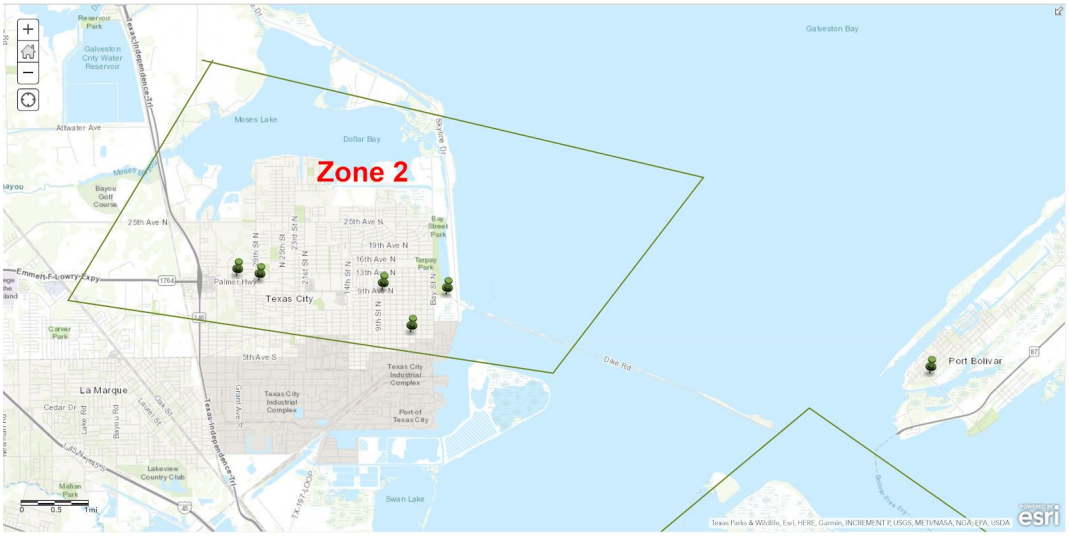


Figure 5.

This is another close-up map of zone two with the contacts chosen from the outskirt of the bay city. These areas are expected to have better flood draining systems and less damages from water events.

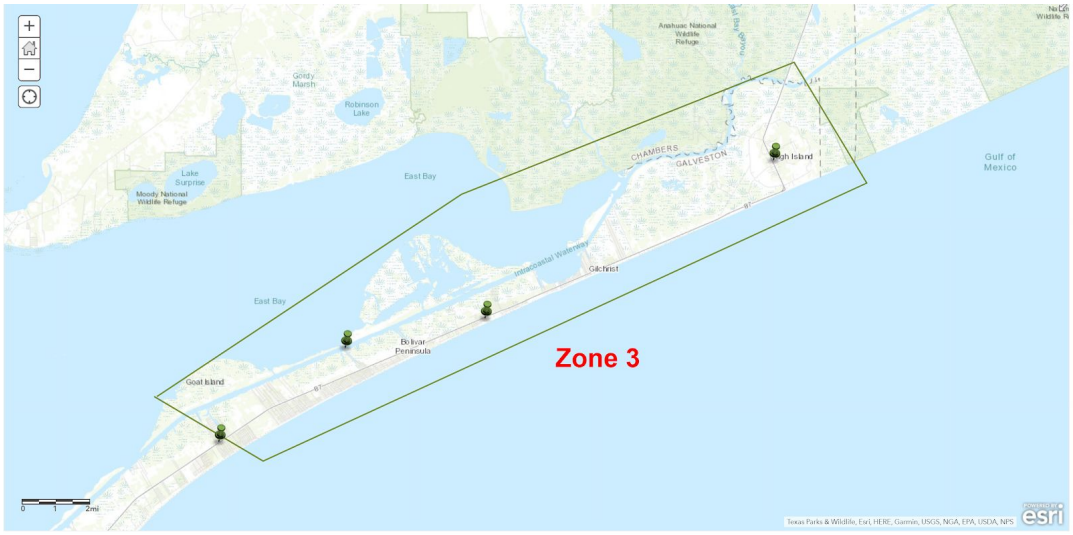
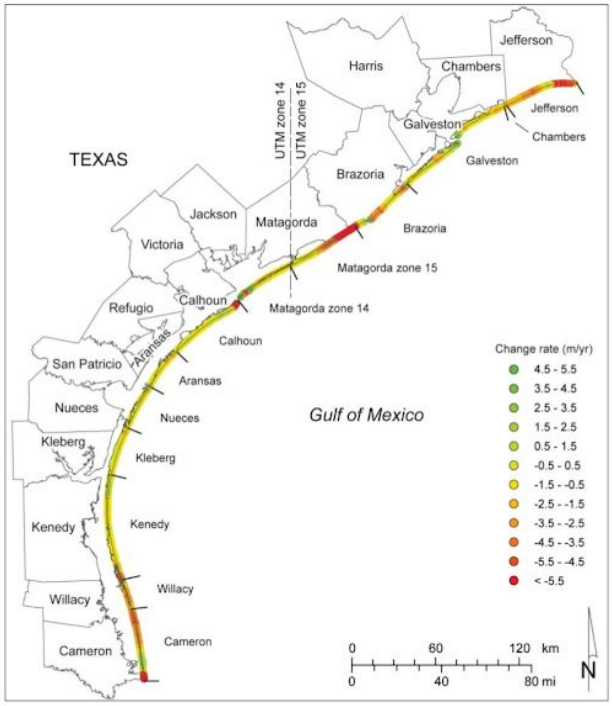


Figure 6.

The third close-up map includes straggling locations that might aid the research by providing beneficial information.



Source - Subedee, M., Dotson, M., & Gibeaut, J. (n.d.). Investigating the environmental and socioeconomic impacts of sea-level rise in the Galveston Bay, Texas region.

Figure 7.

The disappearance rate of the shoreline within the Texas Gulf Coast. The highest change rate is displayed in the darkest green shade at 4.5 to 5.5 meters per year.

Socio-Economic Parameter	2.5 m (8.2 feet) Extreme	2 m (6.5 feet) High	0.5 m (1.64 feet) Intermediate	0.2 m (0.65 feet) Low
Population	40,260	23,168	759	245
Homes	27,543	17,761	814	312
Property Value	$5,661 million	$4,401 million	$301 million	$112 million
Houses of Worship	106	83	0	0
Schools	22	18	0	0
Hospitals	6	2	0	0
Colleges and Universities	2	0	0	0
Libraries	1	0	0	0

Table 3.

Table created from collected data to show the economic costs of various water levels

Discussion

Starting from table 1, it is worth mentioning that the sample size for this research is not completely appropriate with only 60% of locals contacted returned useful feedbacks. Table 2 shows the statistic figures with a standard deviation of 2.0073 which is significant for a small sample data set. Looking at the histogram, the most popular rating from all the responses is around 5.5 which lies on top of the mean being the same value. This means that there isn't any significant variance within the data set worth emphasizing. Next, the pie chart shows 86.7% of yes responses to "changes within the past 20 years". This means that although the ratings did not provide beneficial support towards the research, the 'yes or no' survey question produce a new discovery. While the locals answered the survey, a few also mentioned that they have been opened for over 10 years and they have noticed "significant changes". When asked what were

some methods of preventing flood damages, they mostly state that the use of sandbags was the primary and most effective solution. They have discussed that the occurrence of floods affect their businesses negatively because customers do not enjoy outings when the weather is harsh. Water level rising also causes leakings and damages to restaurants, buildings over the years. This cost them money to repair after every large storm surge. For example, Hurricane Harvey wiped out many of the local buildings in the area leaving many with no homes. This brought down businesses and the locals suffer economically as well as socially. As expected, those contacts from zone 1 location (Figure 4) reported higher ratings such as 6 and 7 and more severe damages over the years.

Figure 7 focuses on the disappearance rate of shorelines showing the opening of the Galveston port colored green with the highest changing rate of 4.5 to 5.5 meters per year. This affects regional industries including tourism, fishing, oil and causes negative impacts on the various waste sites as well as the surrounding environment. Table 3 was created during the research to show the estimated economic losses of various water levels. The Texas Gulf Coast sea-level has risen 18 inches since 1950 reaching a mark of 2 meters in the near future. The tabular results displayed nearly 17,000 homes could be displaced costing almost $4 billion in financial damages.

Conclusion

After analyzing all the data, it's determined that three main factors define the social aspects of the impacts which are displaced homes, unemployment, and change of lifestyles. With over 100,000 households in Galveston city, a worst-case scenario of sea-level rise could displace approximately 89,000 homes, causing an increase in anxiety, fear, and mental health illnesses. On another note, economic impacts are defined by damage control costs, flood prevention costs, and loss of businesses. The consequences have been calculated and organized as represented in table 3. Lastly, the environmental impacts are also included, such as waste site damages, beach erosion, land subsidence, and loss of wetlands. 1.5 meters of water from the ocean could possibly damage a total of 33 waste sites causing them to release toxic pollutants and impact public

health. The increase in wetland loss will kill off various species that rely on natural habitats, and the ecosystem will suffer from losing its filtering systems.

The research was able to provide more information about the socio and economic impacts of sea-level rise in the Galveston Bay area. Data collected from locals and businesses show that the increase in water volume leads to a higher frequency in storm surges. Businesses are affected negatively in return and people are forced to adjust their lifestyles living by the Bay. Beaches disappearing and the declination of marshes, wetlands, as well as other physical features, ruin the natural aesthetics of the Galveston Bay area and the tourism industry suffers in return. With the number of displaced homes increasing in the future, and the growth of fear as well as anxiety within the communities, various policies should be enforced to prevent further impact from sea-level rise. The Texas Gulf coast needs to increase the budget on its flood prevention projects to quickly mitigate the issue and protect hundreds of thousands of people that are endangered by 2050. The cities also need to enhance their draining systems and expect the worst-case scenario of a flood. If everything continues to remain on standby, the people and city of Galveston Bay will suffer the most damages leading to more deaths and economic losses. Without better protection and advance planning, the impacts could be unsalvageable.

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