Aggravation of climate change crisis in Gulf Regions of United States: A Review of Anthropogenic Factors

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Abstract

The Gulf Coast of the United States is increasingly at risk from the impacts of climate change, exacerbated by various human-induced factors. This review paper examined how human activities have worsened the effects of climate change in this region from 2005 to 2024, which is already vulnerable to hurricanes, sea-level rise, and coastal erosion. Key factors include intensive industrial operations, such as oil and gas production, which release significant amounts of greenhouse gases and disrupt the natural landscape, leading to land subsidence and weakening coastal defenses. Urbanization and population growth have resulted in the loss of valuable wetlands and other natural buffers that mitigate flooding and storm surges. Alterations to river systems for flood control and navigation have reduced sediment deposition; thereby affecting the preservation of coastal landforms. Agricultural practices in the region also play a key role; fertilizer and pesticide runoff contaminate waterways and create hypoxic zones, negatively impacting fisheries and marine habitats. This paper emphasizes the need for impactful policy interventions and sustainable behaviors to address these human-induced pressures. The paper also advocates a comprehensive mitigation strategy including stricter emission controls, financial support for renewable energy sources, habitat restoration, and improved urban planning to enhance climate change resilience. After conducting a thorough review, we have discovered that the Gulf Coast region has experienced over fifteen deadly hurricanes over the past twenty years alone and is poised to confront increasingly complex environmental and socioeconomic challenges if viable solutions are not implemented. These issues can potentially jeopardize the livelihoods of the region's inhabitants and the health of its diverse ecosystems.

Keywords: *Anthropogenic, Climate Change, Mitigation, Vulnerability, United States Gulf Region, Hurricane.*

Introduction

One of the scientific and social challenges that define the twenty-first century development model is global climate change (Damoah, 2023b). The evidence is clear: human activities, particularly the combustion of fossil fuels, have a negative influence on the global climate system (Keller & DeVecchio, 2019). The Gulf Regions in the United States have inarguably suffered from this emerging global climate catastrophe. The Gulf Coast region of the United States offers an ideal environment for researching the complexly linked natural and human interactions and feedback that have created deeply interconnected coastal systems. Both short-term episodic occurrences like hurricanes and broad-scale, long-term processes like river sediment deposition and coastal subsidence have greatly altered the physical topography of the area under discussion. Human modifications such as the construction of roads, buildings, and levees, as well as other structures, have left their mark on the natural environment.

Turner and Rabalais (2019) highlight that the Gulf Region includes Texas, Louisiana, Mississippi, Alabama, and Florida, which border the Gulf of Mexico. The region has a flattened U-shaped coastline that spans over 1200 miles and extends 100 miles inland. It runs north-northwest along western Florida, west along southern Alabama, Mississippi, and Louisiana, and southwest and south along southeastern Texas. The land elevations in the region are not higher than 500 feet (Turner and Rabalais, 2019). The precipitation ranges from over 60 inches in the southeastern and south-central parts to about 20 inches in the lower Rio Grande Valley in Texas. The area is susceptible to cyclonic tropical storms during late summer, autumn, and winter,

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with destructive hurricanes occurring in 1900, 1969, and 2005 (Mendelssohn et al.,2017; Lugo-Fernández & Gravois, 2010).

Hopkinson et al. (2019) emphasize that the vegetation around Florida consists of mangrove swamp forests, while the coastal areas of Texas and Louisiana are covered with marsh, broom, saw, and water grasses. Most of the natural vegetation has been compromised due to human activities. These regions are known for commercial crop production, including rice in southwestern Louisiana and southeastern Texas. Southern Louisiana and Florida grow sugarcane, which covers an area of approximately 500,000 acres and makes an invaluable contribution to the federal economy. Despite the severe drought in 2023, Louisiana produced over 1.8 million tons of sugar. Southern Florida includes the Everglades subtropical saw-grass marsh region, which is about 50 miles (80 km) wide and covers an area of 4,300 square miles (11,100 square km). This region joins the southward mangrove swamps bordering the Gulf of Mexico, citrus fruit plantations in central Florida, and the lower Rio Grande Valley in Texas (Ash et al., 2018; Pontif, 2022).

The Gulf Coast, spanning Texas and Louisiana, plays a crucial role in offshore natural gas and petroleum production, as well as housing reserves of phosphates, sulfur, and magnesium (Turner and Rabalais, 2019; Board and National Research Council, 2013). The region's hinterland has experienced significant economic growth due to the widespread presence of manufacturing centers and the strategic positioning of ports in Houston, Galveston, and New Orleans. The Gulf Intracoastal Waterway covers nearly the entire Gulf Coast, supporting various economic activities such as fishing, both recreational and commercial. A significant portion of the local economy is derived from tourism, with places like New Orleans and the top beaches in Florida, Alabama, Mississippi, and Texas drawing tourists (Stanonis, 2011).

The establishment of a petroleum terminal in Houston can have several implications related to climate change both locally and globally. Fossil fuel extraction, refinement, and combustion are significant contributors to greenhouse gas emissions, particularly methane (CH_4) and carbon dioxide (CO_2). These gases trap heat in the Earth's atmosphere and cause global warming and climate change. Houston's status as a petroleum center may lead to an increase in emissions from various processes such as oil and gas transportation, storage, and refining. Petroleum hubs are usually where oil and gas products are stored, transported, and refined (Merem et al., 2020). These activities can release different pollutants into the air, including particulate matter, sulfur dioxide, nitrogen oxides, volatile organic compounds, and greenhouse gases such as carbon dioxide and methane (Board & National Research Council, 2013). The contamination of rivers, streams, and groundwater can negatively impact human health, wildlife, and aquatic ecosystems. Petroleum centers play a critical role in the economy, but they also have adverse effects on the environment and accelerate climate change. Creating sustainable energy development and climate resilience in areas like Houston depends on finding a balance between economic growth, environmental preservation, and public health concerns. Since 1970 for example, CO_2 emissions from fossil fuel combustion, cement production, and flaring have tripled, accounting for 2.4% of total emissions (IPCC AR5, 2014).

It is widely established by available literature and accepted that the current increase in global temperatures is mainly due to human activities. Extensive research findings indicate that the degree of global warming recorded during the industrial age cannot be explained by natural variability (Medhaug et al., 2017). The observed variations in climatic conditions over the past century can not only be partly attributed to variations in solar output and internal variability. There is no substantial evidence in the observational record to support the existence of natural cycles that could account for these variations. Human-caused climate change is said to have negatively impacted global climatic conditions (Hoogendoorn et al., 2020).

Between 1986 and 2016 for instance, the global annual average temperature over land and oceans has increased by over 1.2°F (0.65°C) compared to 1901–1960. Over the full period from 1901–2016, the temperature has increased by 1.8°F (1.0°C). The Earth's surface has been warming at a faster rate in the last three decades than any other decade since 1850. Between 1983 and 2012, the years in the Northern Hemisphere were the warmest 30-year span in the last 1400 years. The ocean has become more acidic due to CO_2 absorption, resulting in a 0.1 pH decrease in surface water and a 26% reported rise in acidity. The ocean's warming is the greatest near the surface, with the upper 75 m warming by 0.11 °C every decade

from 1971 to 2010. The top ocean (0-700 m) warmed between the 1870s and 1971 and then again between 1971 and 2010 (IPCC AR5, 2014).

Frederikse et al. (2020) assert that the rise in sea levels is attributed to the thermal expansion of seawater caused by higher temperatures, as well as the inflow of water into the ocean from ice caps, glaciers, and the Antarctic and Greenland ice sheets. Since 1900, the global mean sea level (GMSL) has increased by approximately 7 to 8 inches, with around 3 inches occurring since 1993. Projections indicate that the GMSL is likely to rise by 0.3–0.6 feet by 2030, 0.5–1.2 feet by 2050, and 1.0–4.3 feet by 2100 compared to 2000 levels. While there is a possibility of a GMSL increase of over 8 feet by 2100, the likelihood cannot be determined at this time. Ocean acidification is a consequence of the ocean's absorption of CO_2, leading to a 0.1 decrease in the pH of surface water and a 26% increase in acidity. As ocean acidification progresses, excess hydrogen bonds with available carbonate ions, reducing the number of carbonate ions available for calcifying organisms to construct and maintain their shells and skeletons (Breithaupt et al., 2021).

The average yearly temperature in the contiguous United States has been increasing since 1895. The Antarctic and Greenland ice sheets have been losing mass between 1992 and 2011, with the rate of mass loss increasing between 2002 and 2011. Glaciers are shrinking in almost all regions. Precipitation has been increasing since 1901 when averaged throughout the Northern Hemisphere's mid-latitude land areas. The US has spent billions of dollars on natural disasters since 1980. Between 1980 and 2020, there were 279 weather and climate disasters with total damages and costs of at least $1 billion, totaling over $1.825 trillion. This excludes Hurricanes Zeta, Delta, and Sally. Earth's climate is changing more rapidly than at any other time in modern civilization. The overwhelming and growing body of evidence points to human activity as the primary cause of these changes. The effects of climate change are already apparent nationwide, and the risks to Americans' economic, social, and physical security are increasing. Americans' response has the potential to increase livelihoods and resilience. However, neither regional nor global initiatives to slow down the causes of climate change nor their impacts mitigation are currently approaching the necessary scale to prevent significant harm to the American economy, environment, and public health and welfare in the coming decades (National Academies of Sciences, 2018; Sfetcu, 2018).

The combined impact of climate change trends or events on vulnerability and exposure leads to risks for individuals, property, and ecosystems. In societies at all development levels, the dangers associated with climate change are generally greater for marginalized individuals and communities. Ohenhen et al. (2024) argue that, in 24 US cities, rising sea levels will exacerbate flooding due to sinking coastal lands. By 2050, one in every 50 residents in these 24 coastal US communities may experience flooding. Research has shown that the combination of rising sea levels, sinking shoreline terrain, and land subsidence can cause coastal areas to flood earlier than previously anticipated. Out of the 32 coastal communities studied, 24 were found to be sinking more than 2 millimeters annually. Sections of half of these cities are subsiding more quickly than sea levels worldwide. Over the next 30 years, floods may affect up to 500,000 residents in these areas, potentially resulting in damage to one out of every 35 private properties. It was found that racial and ethnic minorities may be disproportionately affected, particularly in the Gulf Coast area. In the 11 Gulf Coast communities included in the study, minorities make up around 43% of the total population. However, the study indicates that by 2050, they will account for 64–72% of the population vulnerable to flooding. It is anticipated that African Americans will comprise more than half of this vulnerable group (McDonald, 2024).

The Gulf Coast region is unique due to its diverse energy-related infrastructure. However, this interconnected natural-human coastal system and its separate physical, ecological, and human components are facing increased strain from escalating environmental pressures, including rising sea levels (Ohenhen et al., 2024), stronger hurricanes, and continued population growth through coastal urbanization. Enhancements are required to support resilience and ensure the long-term habitability of the Gulf Coast. According to Wu et al. (2017), coastal wetland ecosystems are facing the challenge of enduring the detrimental impacts of human activity and sea level rise amid intense human activity and globally accelerated climate change. Therefore, this research focuses on identifying and analyzing the various anthropogenic factors that are impacting the climate in this specific geographical area.

Objective

This paper investigates specific human activities contributing to the worsening climate change crisis in the Gulf Regions of the United States.

Materials and Methods

The paper extensively relied on secondary data to address the primary research objective. It rigorously searched through the databases of Google Scholar, Web of Science, and reputable journals with a specific focus on environmental sciences, geology, and geography. In the quest for relevant literature, the paper emphasized keywords related to climate change, the Gulf Coast, anthropogenic factors, and pertinent concepts on sea level rise, wetland loss, and natural disasters in the Gulf Regions. Following this, the paper meticulously screened the titles, abstracts, full texts, and publication years spanning from 2005 to 2024 of selected articles to establish inclusion criteria for the review.

Study Site

The Gulf Coast of the US spans the shoreline of the Gulf of Mexico, encompassing a substantial stretch of coast. Although the precise measurement may vary based on different methodologies and specific boundaries, a rough estimate suggests a total length of around 1,680 miles (2,700 km) as depicted in Fig. 1

The Gulf region of the United States, including states such as Texas, Louisiana, Mississippi, Alabama, and Florida, is facing several environmental challenges worsened by human activities. Climate change, largely caused by human actions, poses significant threats to the Gulf Coast's delicate ecosystems, communities, and economies. In this thorough analysis, we will investigate the various human-induced factors contributing to climate change in the Gulf region. These factors range from greenhouse gas emissions to land use changes and energy production. Fig. 1 depicts the five states and cities which constitute the Gulf regions and Fig. 2, highlights the various cities within the catchment of the Gulf of Mexico.

**Figure 1:** Gulf States map of the United States

Figure 2: Gulf Coastal Cities of the United States

Source: worldAtlas.com

The Gulf Coast region spans from Texas to Florida. In Texas, major cities bordering the Gulf Coast include Houston, Galveston, and Corpus Christi. Louisiana encompasses a significant portion of the Gulf Coast, with cities like New Orleans, Baton Rouge, and Lake Charles. The Mississippi Gulf Coast is home to cities such as Gulfport, Biloxi, and Pascagoula. Alabama's Gulf Coast includes cities like Mobile and Gulf Shores. Florida boasts a sizable Gulf Coast region, with cities such as Pensacola, Panama City, Tampa, and Naples (Sledge, 2019).

Earthquake Prone Zones in the United States

The Gulf Coast is far from major tectonic plate boundaries, where most seismic and volcanic activity occurs. Unlike regions like the Pacific Ring of Fire, where tectonic plates converge, leading to frequent earthquakes and volcanic eruptions, the Gulf Coast is located on the relatively stable North American Plate. Consequently, the region does not have any active volcanoes. Volcanic activity typically occurs near plate boundaries, where magma from the Earth's mantle can rise to the surface, as illustrated in Fig. 3.

Figure 3: Map of Active Earthquake Prone zones in the United States
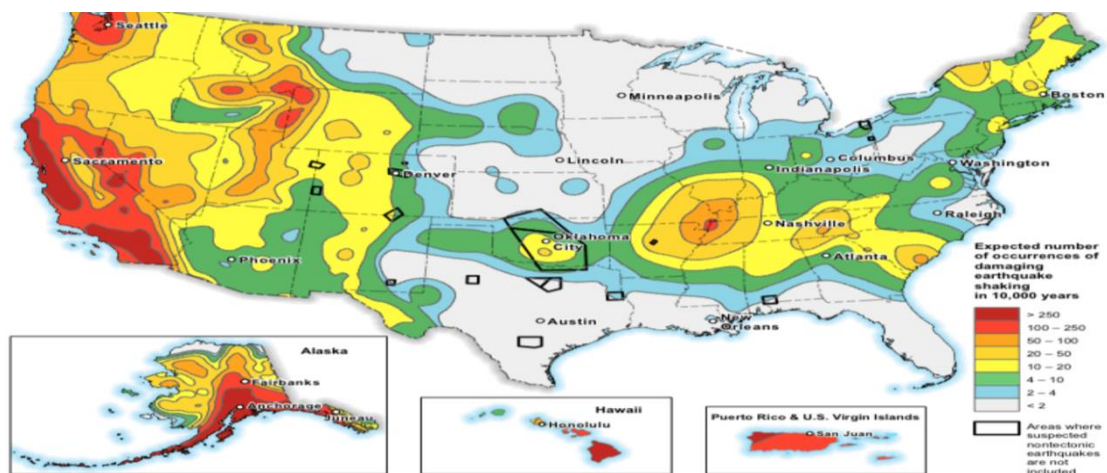
Source: USGS

Since the Gulf Coast is not near any convergent plate or subduction zones, boundaries, or hot spots, volcanic eruptions are not a significant threat in this region. While the United States does experience some seismic activity, particularly in regions like California and Alaska, the Gulf Coast is located thousands of miles away from these tectonic plate boundaries, reducing its susceptibility to earthquakes and related hazards. The Gulf Coast has a minimal level of risk from tectonic activities. Nevertheless, the region is exposed to natural disasters, including hurricanes, coastal erosion, sea-level rise, and storm surges, which can have significant impacts on coastal communities and ecosystems (Duarte & Schellart, 2016).

Literature Review

Global warming is leading to an increase in energy from warmer ocean water being released into the atmosphere. This is expected to result in more frequent and severe extreme weather events, such as thunderstorms, tornadoes, and hurricanes. A United Nations panel's examination of global extreme-weather occurrences suggests an increase in heavy precipitation events in midlatitude regions since the 1950s. Furthermore, global warming is contributing to an increase in the severity of storms in the Gulf Regions. This paper then analyzed the key anthropogenic climate change drivers that consequentially lead to the intensity of hurricanes and other natural disasters in the Gulf Regions.

The Gulf Region's Hurricane Vulnerability

The Gulf region in recent years has been susceptible to severe hurricanes due to geographical, meteorological, and anthropogenic factors. Between 2005 and 2024, the Gulf region of the United States has been hit by numerous hurricanes. Notable events include Hurricane Katrina in 2005, Hurricane Harvey in 2017, and Hurricane Laura in 2020. Table 1 provides details of the hurricanes, tropical storms, and other significant disasters that have affected the Gulf region, highlighting their economic losses, damage, and casualties.

Table 1: Summary of significant natural disasters recorded in the Gulf regions of the United States from 2005 to 2024

Year	Disaster Type	Specific Event	Location(s) Affected	Human Impact	Economic Impact
2005	Hurricane	Hurricane Katrina Hurricane Rita	Louisiana, Mississippi, Florida Texas	Over 1,800 deaths; many displaced, severe flooding, and wind damage	Estimated $125 billion in damages-Katrina $18 billion in damages-Rita
2008	Hurricane	Hurricane Ike	Texas, Louisiana	Over 100 deaths; extensive evacuations	Estimated $30 billion in damages
2012	Hurricane	Hurricane Isaac	Louisiana, Mississippi	Deaths and injuries; thousands evacuated	Several billion dollars in damages
2014	Hurricane	Hurricane Arthur	Florida	2 fatality recorded	Category 1 estimated $39.5 million in damages
2016	Hurricane	Hurricane Hermine	Florida	I fatality recorded, power outages, and flooding	Category 1 estimated $550 million in damages
2017	Hurricane	Hurricane Harvey	Texas	Over 100 deaths; tens of thousands displaced	Over $125 billion in damages
2018	Hurricane	Hurricane Michael	Florida	59 deaths; widespread displacement	Estimated $25 billion in damages
2020	Hurricane	Hurricane Laura Hurricane Sally	Louisiana, Texas Florida, AL	77 deaths; significant displacement-Laura Over 9 deaths reported-Sally	Over $19 billion in damages-Laura $7.3 billion in damages-Sally

		Hurricane Zeta Hurricane Delta		Over 9 deaths reported-Zeta Over 6 deaths-Delta	widespread power outages, $4.4 billion in damages-Zeta $3.09 billion in damages-Delta
2021	Winter Storm	Winter Storm Uri	Texas	Dozens of deaths; millions without power	Estimated economic loss over $130 billion
2022	Hurricane	Hurricane Ian	Florida	Over 100 deaths; massive displacement	Estimated $50 billion in damages
2024	Tropical Storm	Tropical Storm Bonnie	Florida, Alabama	Minor injuries and displacement	Economic disruptions, cost not fully assessed yet

Source: National Hurricane Center (NHC)

The table illustrates the devastating impacts of hurricanes in the Gulf Regions over the past 20 years. The data from the NHC demonstrates climate change's influence on human lives and the US economy. The Gulf of Mexico typically maintains warm sea surface temperatures, especially during the summer and early fall. Hurricanes thrive on warm water, which provides the energy necessary for their formation and intensification (Mousavi, 2011; Beven et al., 2018).

The Gulf Coast's shallow coastal waters are an important factor in maintaining the intensity of storms as they approach landfall. Storm surges can be amplified by shallow waters, leading to increased floods and coastal erosion. This supports the findings of Pielke et al. (2008), who suggest that the flat land and long shoreline along the Gulf Regions may have contributed to the intensity of hurricanes in that area by providing less resistance to approaching storms. The impact of strong storms is worsened by the low-lying geographical areas, which are more susceptible to wind damage and storm surge inundation.

Elsner et al. (2008) argue that hurricane disasters in the Gulf Regions have been adversely affected by atmospheric conditions and climate patterns. Specific weather conditions in the area promote the development and intensification of storms. Strong hurricanes occur when a combination of atmospheric disturbances, low wind shear, and high humidity coincide.

According to Rohland (2018), the urbanization and modernization of the Gulf Coast have resulted in a notable population increase and significant development in hurricane-prone areas. Consequently, residents and infrastructure in these areas are now more susceptible to storm-related threats. The infrastructure, encompassing utilities, roads, buildings, and impermeable surfaces, may not have been adequately designed to withstand powerful hurricanes, leaving it prone to substantial damage. These factors significantly heighten the Gulf region's vulnerability to powerful hurricanes, emphasizing the imperative of implementing preparedness, mitigation, and resilience measures to minimize the impact on infrastructure and coastal communities (Klein et al., 2003).

Anthropogenic Factors Contributing to Climate Change in the Gulf Region of the United States

Tchounwou (1999) asserts that the Gulf of Mexico has an overall surface area of 1.63 million square kilometers (630,000 square miles), with its watershed area in the United States spanning 4.69 million square kilometers (1.81 million square miles). This region is home to one of the largest natural systems in the country and is closely linked to a significant portion of the national economy. The Gulf Coast region relies heavily on energy, fishing, agriculture, and tourism as its key economic sectors. Notably, five of the top ten fishing ports in the United States are situated in the Gulf, and the region's commercial fisheries yield approximately two billion tons of fish, oysters, shrimp, and crabs annually. Additionally, Gulf ports handle half of all import-export cargo in the country. The Gulf of Mexico produces about 80% of the country's offshore petroleum.

Callen et al. (2014) indicate that the economy of the Gulf Coast region relies heavily on various natural resources to support many important economic sectors. However, the health and vitality of the Gulf have

recently declined. This is partly due to the increasing population along the Gulf's coast and the growing demand for its resources as a result of years of irresponsible environmental degradation, abuse, and neglect. The impact of climate change, whether natural or human-induced, on the economy and living standards of millions of residents in the Gulf Coast region is substantial. These consequences have resulted in alarming increases in the devastation and harm to the region's ecosystems and habitats. Climate change, driven largely by human actions, poses significant threats to the Gulf Coast's delicate ecosystems, communities, and economies. This paper delves into the various anthropogenic factors contributing to climate change in the Gulf region, ranging from greenhouse gas emissions to land use changes and energy production.

Dai et al. (2020) argue that one of the main human-caused factors contributing to climate change in the Gulf region is the emission of greenhouse gases, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases are released into the atmosphere through various human activities, such as burning fossil fuels for energy, transportation, industrial processes, and deforestation. The Gulf Coast is home to large oil and gas refineries, which are significant sources of CO_2 emissions. Additionally, agricultural activities, including cattle farming and rice cultivation, contribute to CH_4 and N_2O emissions through the digestive systems and processes of the animals and the use of various chemicals/fertilizers for farming activities.

According to Bridgham et al. (2013), human-induced changes in land use and land cover have a significant impact on climate change in the Gulf region. Greenhouse gas emissions have increased because of deforestation, wetland loss, and soil degradation caused by urbanization, agriculture, and infrastructure development. These factors have also disrupted natural carbon sequestration processes. The reduction in the land's capacity to absorb and store carbon, caused by the conversion of natural habitats such as wetlands and forests into agricultural and urban areas, leads to higher concentrations of CO_2 in the atmosphere.

Again, the Gulf region is heavily involved in the extraction, refining, and distribution of oil and gas. While these activities create jobs and drive economic growth, they also result in the release of greenhouse gases. The combustion of fossil fuels emits pollutants such as CO_2, leading to global warming, air pollution, and environmental damage. Refineries and petrochemical plants are concentrated in one of the greatest areas in the world along the Houston Ship Channel. Large amounts of methane and CO_2 are released by these facilities. Growing urbanization has raised energy consumption and automobile emissions. Because of the vast constructed environment, the urban heat island effect is also more prominent (Perera, 2018; Lessoff, 2023).

Moreover, wetland loss in the Mississippi River Delta has resulted from levee construction and other flood control measures, which have decreased the region's ability to sequester carbon. In the Gulf of Mexico, New Orleans is a major hub for offshore oil and gas operations, which considerably increases greenhouse gas emissions in the area. The region between Baton Rouge and New Orleans is heavily industrialized, with numerous petrochemical plants contributing to high levels of greenhouse gas emissions. from livestock and fertilizer use also contribute to regional greenhouse gas emissions (DeLaune & White, 2012; Shields et al., 2017).

Similarly, real estate development, urbanization along the coast, and agricultural runoff increase the risk of gas emissions in the Gulf regions. The devastation of mangroves and other coastal ecosystems that act as carbon sinks is in jeopardy because of extensive urban development. This corroborates Carić and Mackelworth's (2014) disposition on gas emissions because of cruise tourism. The tourism business in Miami is heavily dependent on-air travel and cruise ship traffic, both of which greatly increase CO_2 emissions exacerbating Climate Change risk and vulnerability.

It also follows that the mining and processing of phosphate, which increases greenhouse gas emissions, is well-known in the Tampa Bay area. Infrastructure and Coastal Development Real Estate Construction-related emissions have increased along with habitat loss due to Tampa Bay's substantial coastal development. The Tampa Bay Estuary Program and the Florida Department of Environmental Protection both published studies in 2018. Energy Production Oil Refineries and Petrochemical Plants, Corpus Christi hosts significant oil refining and petrochemical production facilities, contributing to high levels of CO_2 and methane emissions. Port Operations, The Port of Corpus Christi is a key hub for exporting petroleum and chemicals, with emissions from shipping and associated logistics operations (Dontis et al., 2020). Mobile,

Alabama Chemical Manufacturing, Industrial Activities, Mobile's chemical manufacturing sector emits CO_2, methane, and other pollutants. Urbanization Port Operations, The Port of Mobile is one of the largest ports in the Gulf, contributing to emissions from maritime and land-based transportation (Uddin, 2022).

From 2005 to 2024, the Gulf region of the United States has witnessed a significant increase in the economic impact of human-induced disasters, driven largely by the effects of climate change and industrial activities. The analysis of these two decades shows a clear trend toward greater frequency and severity in weather-related disasters, particularly hurricanes and floods, which have been intensified by global warming. The rising sea levels and heavier rainfall have exacerbated the impact of these events, leading to increased economic losses (MacDonald et al., 2012; Srivastav & Srivastav, 2019).

Among the notable events impacting the economy, the Deepwater Horizon oil spill in 2010 stands out as a critical example, with its massive clean-up costs and profound disruptions to key industries such as fishing and tourism. The economic fallout from this event highlighted the vulnerabilities of the region's environment and economy to industrial accidents (Thakur & Koul, 2022). Furthermore, the region has continued to face economic strains from chemical spills, which have occurred with alarming regularity due to the extensive petrochemical facilities along the Gulf Coast. These spills contribute to a steady economic impact, demonstrating the ongoing risks associated with these industries.

According to Sumaila et al. (2012), oil spills, particularly the Deepwater Horizon spill in 2010, have had a significant impact. The immediate clean-up costs exceeded $14 billion, requiring extensive efforts. The tourism industry suffered losses estimated at $1 billion due to oil-contaminated beaches deterring visitors. The fishing industry also took a hit, with closures and losses estimated at $2.5 billion due to reduced fish populations from contaminated waters. BP faced over $65 billion in fines, penalties, and settlements, covering economic losses, natural resource damages, and legal fees (Murawski et al., 2023).

An Han et al. (2020) state that chemical spills have disrupted the Gulf Coast economy. The 2019 Intercontinental Terminals Chemical (ITC) Deer Park chemical fire, led to air and water contamination, resulting in clean-up and legal costs exceeding $100 million. These spills have caused significant health costs, increasing healthcare expenses due to acute and chronic health issues among affected populations. Environmental remediation following chemical spills is expensive and time-consuming, often costing tens of millions of dollars and taking years to complete, disrupting local ecosystems and economies. Property values in affected areas typically decline, leading to reduced tax revenues and financial losses for homeowners.

Climate Change Mitigation Measures in the Gulf Region

In the Gulf regions of the United States, comprehensive mitigation measures have been adopted to combat the impacts of anthropogenic climate change. These initiatives span a variety of sectors, each with targeted strategies to enhance regional resilience and sustainability.

Coastal defense systems have been strengthened through the construction of levees and sea walls, alongside the restoration of natural barriers such as mangroves and wetlands, which are essential for protecting against storm surges and erosion. These efforts are supported by programs from the National Oceanic and Atmospheric Administration (NOAA), which emphasize enhancing natural and man-made coastal barriers (Miller et al., 2024).

Water management has been improved with the enhancement of drainage systems designed to handle increased rainfall volumes, alongside strategies for rainwater harvesting to mitigate drought conditions, as outlined by the Environmental Protection Agency. The building sector has seen the implementation of stricter building codes aimed at increasing resilience to hurricanes and flooding, with existing structures also being retrofitted to meet new standards.

The shift towards sustainable energy is marked by increased investment in renewable energy sources such as wind and solar, and efforts to enhance energy efficiency in residential, commercial, and industrial buildings, as reported by the Department of Energy. Urban planning includes the creation of green infrastructure like urban parks and green roofs, which help to reduce urban heat and improve air quality

Agricultural methods have been adapted to focus on conservation techniques that reduce emissions and increase soil carbon storage. Transportation reforms are geared towards enhancing public transportation

networks and promoting the use of electric vehicles, supported by infrastructure improvements and incentives. Damoah (2023a) argues that education and policy initiatives are vital in promoting public awareness and involvement in climate action, backed by comprehensive policies and incentives that encourage the adoption of renewable energies and sustainable practices.

To mitigate the impact of climate change in the Gulf region and beyond, it is vital to transition to cleaner, renewable energy sources like solar, wind, and hydroelectric power. Effective climate change mitigation and adaptation plans for the Gulf region require strong policies, laws, and governance mechanisms at the local, state, and federal levels (Damoah et al., 2024). Although there has been some progress, more must be done to improve coastal resilience, promote renewable energy sources, and achieve emission reduction targets. Political and economic considerations often influence policy choices, which pose challenges in addressing the root causes of climate change and transitioning to sustainable, low-carbon pathways (Summers et al., 2021).

Conclusion and Recommendation

The Gulf Region has experienced over fifteen severe hurricanes for the past 20 years due to the increasing seawater warming, which fuels such deadly catastrophes. In 2024, weather forecasters have warned that a severe hurricane season is expected. The Atlantic hurricane season typically lasts from June 1 to November 30. The National Oceanic and Atmospheric Administration (NOAA) has provided an overview of the climate factors influencing storm development and their forecast for the 2024 hurricane season. Meteorologists anticipate that La Niña and near-record ocean temperatures will lead to more than twice the number of tropical cyclones. Warmer oceans in 2024 may also result in stronger storms. NOAA expects 17 to 25 named storms, 8 to 13 of them becoming hurricanes with 74 mph or higher winds. Forecasters predict that 4 to 7 of these hurricanes will be major hurricanes with winds of 111 mph or more, falling into categories 3, 4, or 5. According to a new NOAA projection, the 2024 hurricane season will be "above normal" (Caller-Times, n.d.; Miller et al., 2024). NOAA's analysis and projections reveal an alarming increase in climate-related disasters in the Gulf Regions. The data indicates a rapid worsening of these events over a relatively short period.

Wehner et al. (2017) posit that as the climate warms, substantial winter and spring snowfall decreases are expected in the Southeastern United States. There is high confidence that earlier spring melt and reduced snow water equivalent are officially linked to human-induced warming. These effects are expected to worsen as the climate continues to warm. In the Gulf Coast region, human activities are mainly responsible for the worsening impact of climate change. Cities like Houston, New Orleans, and Miami are experiencing significant effects due to factors such as energy production, urbanization, industrial pollution, and coastal development. These activities have major consequences for the environment, economy, and society, including changes in land use, increased greenhouse gas emissions, and energy production. Addressing climate change requires collective action, innovative ideas, and stringent laws, customs, and behavior changes (Damoah and Omodan, 2022).

The impact of climate change is not influenced by political affiliations or ethnic demographics (Owusu and Damoah, 2024). It is imperative to have strong bipartisan legislation supported by both Republicans and Democrats to address this global catastrophe. These legislations should reinforce practical and robust state policies aimed at minimizing climate change risks and vulnerability. By recognizing and tackling the human-driven causes of climate change, we can safeguard the Gulf Coast's ecosystems, communities, and livelihoods for future generations.

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