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Research Article

The Environmental Impact of Rising Sea Levels on the Global South

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Abstract:

Climate change is a worldwide emergency that has a much greater impact on developing countries. Extreme weather events like hurricanes, floods, and droughts are happening more often and are more severe, causing widespread damage and displacement. Sea levels are also rising, threatening coastal communities and displacing millions of people. The impacts of rising sea levels are wide-ranging and include flooding, coastal erosion, saltwater intrusion, and loss of biodiversity. The Global South is hit hardest by climate change because it is less developed and has fewer resources to adapt. It also depends more on natural resources that climate change is damaging. Sea level rise is not uniform across the globe and varies regionally. Increasingly elevated and extreme sea levels pose a significant threat to coastal areas, giving rise to a spectrum of coastal hazards. The Global South has contributed less to climate change than industrialized nations. Therefore, it is a matter of global justice that these regions be supported in their efforts to adapt to the impacts of climate change. In this article, the authors will discuss the impact of rising sea levels, along with the challenges and opportunities for adaptation to rising sea levels.

1. Introduction

The Global South is generally considered home to countries such as Brazil, India, Pakistan, Indonesia, and China, which, along with Nigeria and Mexico, are the largest Southern states in terms of both land area and population. Sea-level rise during the 20th Century exceeded the rates observed in the 18th and 19th Century [1,2]. Globally, the sea level has increased by approximately 8 inches since the beginning of the 20th century, with more than 2 inches of that increase occurring within the last two decades, as reported by NASA. The rate of sea-level rise has accelerated from around 1.2 inches per decade in the late 20th century to approximately 2 inches per decade in the most recent 20 years. According to the latest climate assessment conducted by the Intergovernmental Panel on Climate Change, there is a projected average global sea-level rise of about 20 inches by the year 2100. However, experts caution that under worst-case scenarios, there is a possibility that it could surge by as much as 3 feet. Top of FormThe majority of scientists agree that sea levels are rising due to anthropogenic global climate change. The ocean is rising due to rise in temperature that results in melting of glaciers and ice sheets [3]. In 1990, it was approximated that 1.2 billion individuals, constituting 23% of the global population, resided in the vicinity of coastlines. Their population densities stood at roughly three times greater than the global average [4]. Additionally, coastal populations are reported to be growing at a faster rate primarily due to net migration towards coastal areas. Moreover, numerous smaller cities and towns are anticipated to be clustered in close proximity to the coast. Various other facets of climate change will also have repercussions for coastal regions, although the specific impacts will differ from one location to another [5]. A significant point of

concern revolves around changes in the occurrence, strength, and trajectories of tropical and extra-tropical storms [6,7]. It's noteworthy that this matter often receives more focus than the increase in sea levels. The escalation of sea levels as a consequence of climate change poses a severe worldwide peril. Presently, the scientific consensus overwhelmingly supports this assertion. If the emissions of greenhouse gases persist in their upward trajectory, and the resultant global warming continues unchecked, there is a substantial likelihood of sea levels rising by a magnitude of 1 to 3 meters within this century. Moreover, the unexpected and swift deterioration of the Greenland and West Antarctic ice sheets could lead to a considerably greater rise in sea levels, estimated at 5 meters [8]. Climate change is also contributing to the heightened occurrence of droughts in north-western Bangladesh, posing significant challenges for smallholder farmers in their efforts to cultivate crops.

2. Review of Literature

2.1 Climate Change Impacts on Ocean and Land

The rise in ocean heat content is a consequence of global warming, and this, in turn, becomes a significant contributor to the overall increase in mean sea levels due to the thermal expansion of seawater. Various methods have also been developed to rectify past data collected by expendable bathythermographs (XBT) in order to generate more dependable estimates of changes in ocean heat content. Human-caused global warming is raising the Earth's temperature and causing glaciers to melt. This is making the oceans warmer and causing sea levels to rise [9]. In terms of the ice sheets in Greenland and Antarctica, although precise quantitative evaluations remain challenging, there has been progress in comprehending the mechanisms that govern the growth or reduction of ice sheet masses [10]. There has been discussion about how human activities, particularly industrialization, deforestation, and agriculture, are intensifying the Earth's greenhouse effect. This presumed greenhouse effect appears to be primarily driven by industrialization and its associated emissions, accounting for 77% of the effect, and by changes in land use, which contribute 23%. Within this 23%, deforestation makes up 9%, and agricultural practices constitute 14%. It is worth noting that this heightened greenhouse effect has the potential to eventually result in alterations in the Earth's atmospheric environment and its climate [11]. Coastal erosion is happening quickly in other parts of the world due to both environmental and human causes [12-14]. Coastal cities face many challenges from both human and environmental stressors, including sea level rise and extreme weather events. These events can cause flooding, erosion, and wetland loss. Coastal cities are especially vulnerable because they are often densely populated and have valuable infrastructure and property at risk. Adapting to climate change is challenging and needs different tiers of government and the private sector to work together [15]. Climate change and its consequences, such as sea level rise, are major challenges [16]. Salt intrusion [17]; Costal erosion [18]; Flash floods [19]; Landslides [20]; Cyclones and storm surges [21]; Food insecurity [22]. Coral bleaching [23]. The elevation of the Earth's oceans, known as sea level rise, is a consequence of global warming. The combustion of fossil fuels results in the emission of greenhouse gases into the atmosphere. These gases act as heat-trapping agents, leading to the warming of the planet. The oceans absorb most of this heat, which causes them to expand and rise. Over the past two decades, vehicular pollution in India has surged dramatically, estimated to have grown by a factor of eight. This particular source of pollution is believed to account for approximately 70 percent of the overall air pollution in the country. In the year 1999, India contributed a substantial 243.3 million tons of carbon to the atmosphere through the utilization and burning of fossil fuels. This positioned India as the fifth-largest emitter of carbon globally, following the United States, China, Russia, and Japan in terms of carbon emissions. India is expected to witness a surge in its global carbon emissions in the coming years due to various factors. These include swift urbanization, a transition from non-commercial to commercial fuels, a rise in vehicular usage, and the ongoing operation of older, less efficient coal-fired, and fuel-based power plants [24]. Vehicular pollution in India has experienced a substantial surge, witnessing an eightfold increase over the last two decades. This singular source is projected to contribute to around 70% of the total air pollution in the country. The occurrence of compound events, where climate coastal flooding is coupled with multiple hazardous processes, is on the rise [25]. Discernible increase in the frequency of compound coastal flooding over the past few decades [26]. Unexpected flooding in recent times has been triggered by heavy rainfall associated with hurricanes like Harvey, Irma, Maria, Florence, and Dorian. Additionally, compound flooding may arise when fluvial floods align with storm surges, particularly in river deltas [27]. The recent destruction wrought by Storm Daniel in Libya has once more brought attention to the grave challenges

confronting communities affected by conflict and susceptible to climate-related issues. Libya, a country already struggling with the repercussions of over a decade of conflict, finds itself on the edge due to the escalating effects of climate change. The International Rescue Committee (IRC) emphasizes that climate change has heightened the impact of extreme weather events, rendering them more frequent, longer-lasting, and more severe, thereby worsening the predicament of vulnerable populations. To adapt to growing food demand and uncertain climate in the 21st century, we must identify the critical challenges and opportunities in groundwater use. Climate change will increase our reliance on groundwater resources, as it is projected to bring more extreme climate conditions and higher low flow frequency in many parts of the world [28]. This will likely lead to increased groundwater pumping during prolonged drought events.

Anticipated sea level rise is expected to result in a range of physical consequences for islands, encompassing shoreline erosion, inundation, flooding, the intrusion of salinity into freshwater areas, and a reduced capacity of coastal ecosystems to withstand adverse conditions [29]. The repercussions of sea level increase will vary depending on geographic locations and will be shaped by a multitude of environmental characteristics and socioeconomic factors, including human responses. When extreme weather events transpire, the elevated sea levels contribute to more potent storms, particularly in close proximity to major urban centers. Furthermore, a significant portion of the global population resides in coastal areas that are progressively susceptible to flooding. The principal outcomes of rising sea levels manifest as modifications in the natural environment. These modifications, in turn, impact a wide array of human activities along the coastlines, encompassing tourism, residential settlements, maritime transportation, commercial and recreational fishing, agriculture, and wildlife observation. However, it is difficult to plan for sea level rise because we do not know exactly how much it will rise or how quickly it will happen. This is why it is important to have a flexible approach to adaptation and to be prepared to change our plans as needed [30,31]. There is increasing awareness and knowledge of the issues and impacts of sea level rise, but more needs to be done to support adaptation [32].

2.2 Challenges to Readiness for Adaptation

Recent research indicates that financial constraints and insufficient leadership consistently hinder coastal resilience [33,34]. Emlinger (2014) found that small Massachusetts communities face a number of barriers to coastal resilience, including political constraints, lack of resources, and public disagreements [35]. Ford and King (2015) found that multiple institutions working together on climate adaptation can face challenges, including
a)Limited interaction between actors
b) Difficulties making collective decisions
c) Conflicting objectives among interest groups
d)Unclear roles and responsibilities
e)Uncertainty about the information needed to make decisions [36].

This underscores the necessity for cross-sector collaboration in climate adaptation endeavors. It is imperative for organizations to acquire the ability to adapt to climate change and integrate this learning into their operational framework. While this can be a daunting task, it is crucial for organizations to build resilience against the impacts of climate change.

A research identified significant obstacles to the implementation of adaptation plans in mountain communities in the southern Rocky Mountain region of the United States[37]. These challenges included budget constraints, a lack of political will, limited locally specific information, and a shortage of effective leadership. Another study revealed that political leadership hindered adaptation efforts in small Massachusetts communities due to the influence of private property interests[38]. Additionally, they encountered obstacles such as insufficient support for planners, limited resources, a lack of public awareness regarding the necessity of adaptation, and conflicts over responsibilities and downstream costs. Further study highlighted the substantial challenges that climate change poses to ports. These challenges arise from factors such as their exposed locations in coastal zones, low-lying areas, and deltas, the long lifespans of critical infrastructure assets, and their interconnectedness with trade, shipping, and inland transport services, all of which are susceptible to climate-related risks [39,40]. The threats posed by climate change to these areas include mean sea level rise [41-43]. Additionally, there is the concern of higher storm surges, river floods, droughts, and increased cyclone intensities or destructiveness. Adaptation can reduce the risk to coastal communities, but managers still need to make sure that the decision-making process is legitimate so that stakeholders accept the adaptation decisions [44]. Information such as the cost of damage to dwellings over time can help to build legitimacy by showing the community how the costs increase over time and why policy decisions are made based on economic thresholds. Land reclamation using coral stones is

risky, as it can damage reefs and make islands more vulnerable to waves and erosion. Corals are already degraded, so this practice should be avoided [45]. Islanders use various adaptation strategies to reduce disaster risk, such as elevating belongings and pathways, collecting rainwater, and adapting evacuation behaviour [46]. Jakarta, Indonesia, is sinking at an alarming rate due to groundwater extraction [47,48]. Coastal areas are also being elevated throughout the city, and land reclamation is being proposed for luxury projects, which would expand the city towards the sea [49]. Community-based adaptation (CBA) is a way of addressing climate change that is led by communities and is consistent with their long-term development goals. It aims to find solutions that benefit communities both now and in the future [50,51]. Proactive adaptation to climate change involves:

a) Building sponge cities to absorb excess rainfall and balance out changes in precipitation patterns

b) Upgrading stormwater drainage and detention systems to handle more extreme rainfall events.

c) Implementing proactive, environmentally-conscious, and comprehensive strategies to safeguard coastal regions from the inundation brought about by climate change and rising sea levels [52]. It was also contended that leaders should take a more proactive stance in tackling climate change [53]. They emphasized the necessity of devising novel policies and fostering partnerships to strike a harmonious balance between economic and environmental objectives.

3. Results and Discussions

3.1 Consequences of Elevated Sea Levels

- **Coastal Flooding:** Elevated sea levels elevate the likelihood of coastal flooding, potentially causing harm to infrastructure, residences, and farming, along with the potential displacement of communities.
- **Erosion:** Higher sea levels can exacerbate coastal erosion, leading to the loss of valuable land, habitats, and even cultural heritage sites.
- **Impact on Agriculture:** Coastal agriculture is particularly vulnerable to rising sea levels due to increased salinity and the potential submersion of arable land. Crop yields may decline, affecting global food security. The loss of agricultural land contributes to economic challenges for communities reliant on farming.
- **Saline Intrusion:** As seawater infiltrates coastal aquifers and groundwater, it can contaminate freshwater sources, affecting both drinking water supplies and agriculture.
- **Loss of Biodiversity:** Rising sea levels threaten coastal ecosystems, including mangroves, salt marshes, and coral reefs, which serve as nurseries for marine life and act as buffers against storm surges.
- **Economic Impact:** Coastal areas are often economic hubs, and sea-level rise can have far-reaching economic consequences, including impacts on tourism, shipping, and fisheries.
- **Human Migration:** Displacement of communities due to sea-level rise can lead to climate-induced migration, adding pressure to urban areas and potentially causing conflicts over resources.

3.2 Challenges for adaptation to rising sea levels

Financial Constraint

The challenges associated with financial constraint in the Global South are substantial and have wide-ranging consequences. Developing countries often lack the financial resources needed to fund comprehensive adaptation efforts. These nations may already grapple with poverty, inadequate healthcare, education, and other development challenges. The additional financial burden of climate change adaptation can strain their limited budgets. Scarce financial resources can lead to trade-offs between addressing immediate development needs and investing in long-term climate resilience. As an example, a government might find itself in a dilemma where it must decide between constructing climate-resilient infrastructure or delivering vital services such as healthcare and education. International mechanisms for climate finance, such as the Green Climate Fund and grants earmarked for climate-related initiatives, are designed to provide assistance for adaptation efforts in developing nations.

However, accessing these funds can be challenging due to complex application processes, competition among countries for limited resources, and stringent eligibility criteria. Even when funds are allocated, they may not cover the full costs of adaptation, leaving countries with funding gaps. This shortfall necessitates the allocation of domestic resources, diverting funds from other critical development priorities. Developing countries in the Global South are often the most vulnerable to the impacts of climate change due to factors like geography, socio-economic conditions, and limited technological capacity. These vulnerabilities are compounded by financial constraints. Vulnerable communities within these countries, including marginalized and low-income populations, are particularly affected. They often lack the financial means to adapt individually, leaving them exposed

to climate risks. Some developing countries resort to loans to finance climate adaptation projects. While these loans may be necessary to address immediate adaptation needs, they can lead to increased debt burdens, particularly for countries with limited capacity to generate revenue. High levels of debt can hinder economic development and limit a country's ability to invest in essential public services and social welfare programs. Insurance is an important tool for managing climate risks. However, many developing countries have limited access to insurance coverage for climate-related events. High premiums, lack of insurance infrastructure, and insufficient data on climate risks can impede the availability of affordable climate insurance.

Infrastructure Retrofitting The challenges associated with infrastructure retrofitting in the Global South are substantial and have wide-ranging consequences. Retrofitting existing infrastructure to meet climate resilience standards can be an expensive endeavor. It involves substantial investments in engineering, design, construction, and the incorporation of advanced materials and technologies to enhance infrastructure's capacity to withstand extreme weather events and changing environmental conditions. Many nations in the Global South struggle with limited financial resources, making it challenging to allocate funds for large-scale infrastructure retrofitting projects. This financial constraint can slow down adaptation efforts and leave vulnerable communities at greater risk. Retrofitting infrastructure is time-consuming. From planning and design to implementation and monitoring, it can take years or even decades to complete large-scale retrofitting projects. In the meantime, existing infrastructure remains susceptible to climate-related risks. Inadequate retrofitting can lead to infrastructure damage and disruptions during extreme weather events. The economic consequences include repair costs, business interruptions, loss of livelihoods, and reduced economic growth. Infrastructure failures due to climate impacts can disrupt the daily lives of communities. For instance, damaged roads can hinder access to healthcare, education, and emergency services, affecting the overall well-being of the population. Infrastructure retrofitting projects must be carefully planned to minimize their environmental impact. Poorly executed retrofitting may harm ecosystems, alter water flow patterns, or contribute to deforestation, which can have negative repercussions for biodiversity and the environment. Vulnerable communities, often located in low-lying coastal areas or informal settlements, may bear the brunt of inadequate infrastructure retrofitting. Due to limited resources, these individuals may find it challenging to shield themselves from the consequences of climate change and are at a higher risk of enduring displacement and adversity. Retrofitting efforts should not only address current climate risks but also anticipate future changes. Climate resilience measures must be designed to adapt to evolving climate conditions to ensure infrastructure remains robust over time.

Resource Allocation The challenge of resource allocation in climate change adaptation can have significant and far-reaching impacts. Differing priorities and interests among stakeholders can lead to disagreements and conflicts over how resources should be allocated. For example, there may be debates about whether to allocate resources to infrastructure development, disaster preparedness, agriculture, public health, or other sectors. Resource allocation decisions can result in some areas or communities receiving more attention and funding than others, even if they are not the most vulnerable to climate change impacts. This can lead to unequal access to adaptation measures and exacerbate existing social and economic disparities. If resources are not allocated strategically, there is a risk of missing opportunities to implement high-impact adaptation measures. For example, investments in early warning systems and disaster risk reduction may be overlooked in favor of more visible but less effective projects. Adequate resource allocation is essential for building the capacity of local communities and institutions to adapt to climate change. When resources are scarce or misallocated, capacity-building efforts may be inadequate, leaving communities ill-prepared for climate impacts. Inefficient resource allocation can lead to wasted resources, delays in adaptation projects, and suboptimal outcomes. This inefficiency can undermine the effectiveness of adaptation efforts and hinder progress toward resilience. Resource allocation challenges can also result in a lack of integration and coordination among different adaptation initiatives. Without a holistic approach, adaptation measures may be disjointed and less effective in addressing interconnected climate risks. Poorly allocated resources can lead to maladaptation, where adaptation measures inadvertently exacerbate vulnerabilities or create new risks. For example, investing in infrastructure that is not climate-resilient may provide a false sense of security and lead to greater damage during extreme events.

Environmental Challenges

Coastal ecosystems, such as wetlands and mangroves, are experiencing habitat loss as rising sea levels encroach on their territories. This can lead to the degradation and eventual loss of these valuable habitats. Many species rely on coastal habitats for breeding, feeding, and shelter. The loss of these habitats threatens the survival of numerous plants and animals, including migratory birds, fish, and invertebrates. Rising sea levels contribute to increased erosion along coastlines. The sediments carried by rising waters can smother critical habitats and disrupt the delicate balance of coastal ecosystems. Disrupted Life Cycles: Coastal species, including turtles, crabs, and certain fish, depend on specific conditions for their life cycles. Changes in coastal ecosystems due to sea-level rise can disrupt these life cycles, affecting population dynamics. Species Vulnerability: Some species are more vulnerable to habitat loss and fragmentation caused by sea-level rise. Endemic species with limited ranges are particularly at risk. Invasive Species: Altered coastal ecosystems may become more susceptible to the introduction of invasive species, further threatening native biodiversity. Saltwater Intrusion: Rising sea levels can result in saltwater intrusion into coastal aquifers, contaminating freshwater resources. This poses a significant challenge for drinking water supplies, especially in regions reliant on groundwater. Agricultural Impact: Salinization of freshwater resources can harm agriculture by reducing crop yields and damaging soil quality. This affects food security and livelihoods. Ecosystem Health: Changes in water quality can disrupt the health of aquatic ecosystems, impacting fish populations and other aquatic life. Restoration of Coastal Habitats: Implementing habitat restoration projects can help mitigate the loss of critical coastal ecosystems. Strategic relocation of human communities away from vulnerable coastal areas can aid in preserving natural habitats. Incorporating climate change adaptation into land-use planning can help reduce environmental impacts. Developing strategies to protect coastal aquifers from saltwater intrusion is crucial for safeguarding freshwater resources.

Equity and Social Justice The impact of the equity and social justice challenge in adaptation is significant: Failing to address the specific needs of vulnerable communities can deepen existing social, economic, and environmental inequalities. This can result in marginalized groups experiencing more significant hardship and suffering as climate impacts intensify. Climate change can exacerbate existing vulnerabilities. Vulnerable communities may already face challenges related to poverty, access to healthcare, education, and social inclusion. Climate impacts can compound these challenges, leading to greater disparities in well-being. Effective adaptation measures require the active participation and representation of all stakeholders, including marginalized groups. When these communities are excluded from decision-making processes, their unique vulnerabilities and needs may be overlooked. Vulnerable populations, often dependent on climate-sensitive livelihoods such as agriculture or fishing, may experience the loss of income and food security due to climate change impacts. This can push them deeper into poverty and marginalization. The nexus of climate change and human rights concerns becomes evident when we consider fundamental rights like the right to life, access to healthcare, and a pollution-free environment. Neglecting these aspects in our endeavors to adapt to climate change can result in the infringement of human rights.

3.3 Opportunities for Adaptation to Rising Sea Levels.

Nature-Based Solutions

- *Explanation*: Nature-based solutions involve using natural ecosystems, such as waterlogged areas, coastal forests, and woodland to enhance resilience to climate change impacts. For example, restoring mangroves along coastlines can act as a natural buffer against storm surges and coastal erosion.
- *Benefits*: These solutions not only improve resilience but also provide additional benefits such as habitat restoration, carbon sequestration, and recreational opportunities. They are often cost-effective and sustainable over the long term.

Engineering Solutions

- *Explanation*: Innovative engineering solutions can help protect vulnerable areas from climate change impacts. Examples include building sea walls, storm surge barriers, and sustainable coastal development projects.
- *Benefits*: These solutions are engineered to endure the tangible effects of climate change, including rising sea levels and severe weather occurrences. They offer immediate protection to infrastructure and communities, reducing the risk of damage and displacement.

Climate-Resilient Infrastructure

- *Explanation*: Designing infrastructure with climate change in mind involves making modifications to ensure that buildings, roads, and other critical assets can withstand the impacts of climate change. This may include elevating structures above anticipated flood levels or using more resilient building materials.
- *Benefits*: Climate - resilient infrastructure reduces the vulnerability of communities and ensures that essential services remain functional during extreme events. It can lead to long-term cost savings by avoiding frequent repairs and replacements.

Community Engagement

- *Explanation*: Engaging local communities in adaptation planning and decision-making processes is crucial. Empowering residents to contribute their knowledge and perspectives can lead to more effective and equitable adaptation solutions.
- *Benefits*: Community engagement builds local ownership and buy-in for adaptation initiatives, making them more likely to succeed. It also helps identify community-specific vulnerabilities and needs that might otherwise be overlooked.

International Cooperation

- *Explanation*: The Organisation for Economic Cooperation and Development (OECD) serves as a platform for international collaboration, facilitating cooperation among member countries and fostering partnerships with non-member nations. By promoting knowledge exchange and sharing best practices, the organization contributes to a unified global response to the challenges posed by rising sea levels.
- *Benefits*: Global cooperation allows for the exchange of best practices and lessons learned, accelerating adaptation efforts. Additionally, it can streamline the transfer of funds and technology to nations that may be deficient in the essential resources required for effective adaptation.

3.4 New and Modern Technologies for Controlling Rising Sea Levels

The Netherlands is one of the country's most vulnerable to rising sea levels due to its low-lying topography and extensive coastline. With about 26% of its land area lying below sea level, the country has a long history of protecting its coast from flooding. In recent years, the Dutch have been working on a number of new and innovative approaches to adaptation to sea level rise.

a) **Room for the River (RfR)**: It that means giving the rivers more space to flow. This can be done by creating floodplains, deepening riverbeds, and removing obstacles from the riverbank.One of the most ambitious examples of Room for the River is the New Maas Room for the River project. This project will create 3,000 hectares of new floodplains along the Nieuwe Maas River.
b) **Artificial reefs**: Artificial reefs are being used to create new habitats for marine life and to protect coastlines from erosion. They can also be used to improve water quality. Artificial reefs are being deployed and studied in various countries worldwide, including India. In India, the Central Marine Fisheries Research Institute (CMFRI) has been actively involved in establishing artificial reefs along the country's coastline. In addition to CMFRI, the M.S. Swaminathan Foundation (MSSRF) is also actively involved in promoting artificial reefs in India. The use of artificial reefs in India is still in its early stages, but the initial results are promising.

3.5 Recent Developments

Advanced Sea Level Monitoring: Technological advancements in satellite altimetry and coastal observation systems are providing increasingly accurate and detailed sea level measurements. This data is crucial for understanding sea level trends, predicting future impacts, and informing adaptation strategies.

4. Conclusion

Coastal flooding is a significant consequence of rising sea levels, with far-reaching impacts on infrastructure, homes, agriculture, and communities. As the effects of climate change continue to intensify, proactive mitigation and adaptation strategies are essential to minimize the damage and protect vulnerable coastal regions. Collaboration between governments, communities, and international organizations is crucial in addressing this growing threat. Failure to do so may result in irreversible damage to coastal areas and the displacement of countless communities. All the Challenges are often interconnected, making adaptation planning even more complex. For example, addressing financial constraints may involve making difficult decisions about resource allocation, which in turn can impact social equity and justice considerations. The interplay between these challenges requires holistic and integrated approaches to adaptation planning. Failure to consider these interconnections can result in suboptimal outcomes and missed opportunities for effective adaptation. In summary, effectively addressing the challenges of adapting to climate change necessitates a comprehensive and cooperative strategy that considers financial limitations, infrastructure requirements, resource distribution, and factors related to environmental and social equity. Policymakers, scientists, communities, and stakeholders should collaborate closely to formulate and execute comprehensive adaptation strategies that enhance resilience and sustainability in the context of a shifting climate. Coastal resilience initiatives play a crucial role in diminishing the exposure and susceptibilities of coastal communities to rising sea levels. These programs require long-term planning, investment, and outreach to affected residents, as well as extensive modelling and testing to ensure their effectiveness. The relocation or safeguarding of at-risk or displaced communities can present difficulties, yet it is imperative for safeguarding coastal communities and ecosystems against climate change repercussions. This subject demands a comprehensive approach, with governments, communities, researchers, and international organizations collaborating to create and put into action successful adaptation measures. Climate change is studied in literature [54,55].

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
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