Climate Action in Cities
CoCHAP

# Coastal Cities Resilience and Extreme Heat Action Project

## Coastal Hazards in Cities Fact Sheets #5

### Storm Surge

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USAID FROM THE AMERICAN PEOPLE
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# Storm Surge in Cities



## What is Storm Surge?

The World Meteorological Organization (WMO) defines storm surge as a sudden and significant rise in sea level along a coastline primarily caused by the strong winds and low pressure associated with a tropical cyclone (such as a hurricane or typhoon).[i] During the past 200 years, 2.6 million people may have drowned during surge events.[ii]

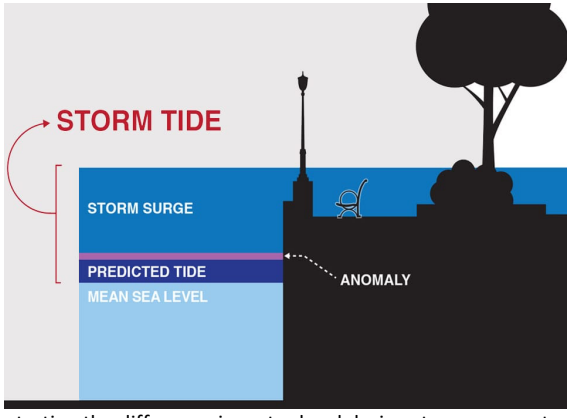


Figure 1: Figure illustrating the difference in water level during storm surge, storm tide and normal high tide as compared to sea level (Source: National Oceanic and Atmospheric Administration)

The IPCC Special Report on Ocean and Cryosphere in a Changing Climate[iii], concluded that. 1) the proportion of storms that reach Category 4–5 levels may increase (medium conference) and that the average intensity of storms will increase (by roughly 1–10%, assuming a 2ºC global temperature rise) (low confidence), 2) average storm precipitation rates (for a given storm) will increase by at least 7% per degree Celsius SST warming, owing to higher atmospheric water vapor content (medium confidence) and 3) Sea level rise will lead to higher

storm surge levels for the TCs that do occur, assuming all other factors are unchanged (very high confidence).

## Causes of Storm Surge:

- Low Atmospheric Pressure: Storm surges typically occur during tropical storms or hurricanes. These storms are characterized by low atmospheric pressure at their centers, i.e., the eye, and are higher at the cyclone's edge. The difference in pressure between the storm system and the surrounding atmosphere can lead to a rise in sea level, hence causing storm surges.[iv]
- Strong Winds: The force of the winds swirling around tropical storms and hurricanes can push large volumes of water toward the coast. This advancing surge combines with the normal tides and can increase the water level by 30 feet or more.[v]
- Geographic Location: Certain areas are more prone to storm surges because they are close to warm ocean waters and are influenced by weather patterns. For instance, the Gulf Coast of the United States and specific sections of the Atlantic coastline are more vulnerable to storm surges.[vi]

## How does Climate Change impact Storm Surge?

According to studies, the expected scenario is that storm surge heights in Europe will rise by approximately 15% on average by 2100 under high global emissions scenarios. The dominant drivers of increasing storm surge risk are increased relative sea-level and increased storm intensity.[vii]
More specifically:

- Increase in sea level: The most recent evidence suggests that sea-level rise could reach 1 meter or more during this century.[viii]
- Warmer Ocean Temperatures: According to IPCC Sixth AR, by 2100, the ocean is very likely to warm by 2 to 4 times as much for low emissions (RCP2.6) and 5 to 7 times as much for the high emissions scenario (RCP8.5) compared with the observed changes since 1970.[ix]
- Climate change leads to higher sea surface temperatures, providing the energy needed to fuel tropical storms. Warmer oceans can increase evaporation and moisture in the atmosphere, enhancing storm development and intensification.
- Increased Water Vapor in the Atmosphere: The IPCC Sixth AR Sixth states that the total atmospheric water vapor is increasing by 1% to 2% per decade.[x] As the GHG emissions increase, temperature increases, increasing water vapor

in the atmosphere. This additional moisture can fuel storm surges, leading to heavier rainfall and potentially more intense storms.

## How does Coastal Erosion affect city systems?

**Physical Impacts**

- Power Grid: The storm surge during Typhoon Haiyan, Philippines (2013), knocked down power transmission lines and towers, disrupting the flow of electricity across regions.[xi]
- Transportation Networks: Storm surges can lead to the closure of roads, highways, and bridges due to flooding, debris, or structural damage. Mass transit systems, including buses and trains, can be severely affected by flooding and power outages caused by the storm. The storm surge during Hurricane Ike, which struck the Gulf Coast of the United States in September 2008, caused significant damage to transportation infrastructure, damaging at least 53 bridges. [xii]
- Communication Infrastructure: Storm surges can disrupt communication networks, including cellular and landline services. This hinders emergency communication and coordination efforts during emergencies. During Cyclone Amphan in Bangladesh and India (2020), Winds reached 185 km/h (115 mph), and the Indian city of Kolkata, home to 15 million people, saw severe damage to buildings, power outages and destruction of communication infrastructures, some of which could have been the result of storm surge.[xiii]

**Socio-Economic Impacts**

- *Loss of Life and Injury:* Storm surges causing floods, high winds, and debris can result in fatalities and injuries among residents. The storm surge during Typhoon Haiyan, in the Philippines in 2013 affected more than 16 million people and left 4 million homeless. The Philippine government confirmed 6,300 dead and more than 1,000 still missing.[xiv] It is possible that some of these mortalities were contributed to by storm surge though fortunately the storm made landfall during low tide.
- *Displacement and Relocation:* Storm surges can force communities to relocate to safer areas, disrupting daily life and adding mental and emotional stress. Cyclone Idai in Mozambique in 2019 caused the displacement of 400,000 individuals, of which 160,927 were sheltering in 164 temporary accommodation centers.[xv] Some of this impact was associated with the impact of storm surge.

- *Community Disruption and Social Inequity:* The displacement can fragment communities and cause social inequity as they are forced to start their lives elsewhere.
- *Health and Safety:* Storm surges can cause accidents and injuries. Access to healthcare, emergency services, and safe drinking water may also be hampered.[xvi]
- *Increased Vulnerability:* Vulnerable populations, such as the elderly, disabled, and low-income individuals and children, are often disproportionately affected by storm surges due to limited resources and mobility challenges.

**Environmental impacts:**

- Habitat Destruction: Storm surges can uproot trees, and damage vegetation impacting habitats. The storm surge during Cyclone Nargis in Myanmar (2008) caused significant damage to ecological habitat. [xvii]
- Landslide and Erosion: Storm surges can lead to coastal erosion and landslides, which can alter the shape of coastlines
- Water contamination: Heavy rainfall and winds can introduce pollutants, sediments, and debris into rivers, lakes, and coastal waters, causing harm to marine species.
- Coral Reefs and Mangroves: The increased wave action associated with Storm surges can cause physical damage to coral reefs and mangrove ecosystems. The storm surge from Cyclone Nargis in Burma, Myanmar, in 2008 inundated the coastal mangroves and rice paddies in the Irrawaddy Delta.[xviii]
- Wetlands and Marshes: Storm surges and heavy rainfall can alter wetlands and marshes' water levels and salinity, affecting the flora and fauna that depend on these environments. The storm surge associated with Hurricane Sandy in the north-eastern USA in 2012 led to the inundation of salt marshes, beaches, and coastal dunes.[xix]

## Adaptation Strategies for Storm Surge

**Community Level**

Regenerating natural mangrove forests and mangrove plantations along riverbanks and around villages.[xx] Consideration of health impacts of sea level rise and subsequent occurring of storm surge in community-level planning approaches.[xxi] Moving communities, structures and/or assets from areas that are likely to be significantly affected by storm surges.[xxii]

- Raise public awareness to encourage the local population to adapt and be prepared for the likely impacts of storm surges and to foster community participation in decision-making.[xxiii]
- Develop post-storm recovery plans to facilitate rapid response and aid distribution.
- Application of Nature-Based-Solutions like mangrove restoration, beach nourishment, and wetland restoration to reduce the impact of storm surge.xxiv
- Implement green infrastructure practices such as, permeable pavements, and bioswales to manage stormwater in urban areas.[xxv]
- Educate and create awareness among local communities about tropical storm risks, their causes, and the importance of adaptation through community workshops, training, information campaigns, and programs in schools and communities.

**Municipal/Government Level**

- Provide financial and technical assistance to farmers to deal with weather-related changes. [xxvi]
- Better environmental management, including the creation of artificial reefs and environments. [xxvii]
- Installation of devices to prevent seawater from back flowing into storm drains. [xxviii]
- Planning (1) to avoid the worst consequences of the forecasted weather events, which involves the production and frequent update of flooding and hazard maps; (2) legislation focused on (a) not permitting development on land vulnerable to hazards, or (b) establishing building codes appropriate for the projected climatic conditions.[xxix] [xxx]
- Beach and shoreface nourishment in which the sand is spread over the beach where erosion is occurring to compensate shore erosion and restore the recreational value of the beach. [xxxi]
- Construction of sea walls and sea dikes, dams, channels, breakwaters, jetties, and artificial reefs, along the coastline to protect land from the impact of waves and storm surges. [xxxii]
- Labour and professional skills adjustment and enhancement so that new construction codes and new farming standards can be put in place.[xxxiii]
- Support small-scale businesses and micro-enterprises that can be quickly restarted after a storm[xxxiv]

- Dune construction and strengthening by planting grass, covering the face of the dune with plant debris, construction of fences along the seaward front of the dune to reduce wind speed on the surface and applying a combination of hard man-made structures topped with sand, dunes and vegetation.[xxxv]
- Establish early warning systems to monitor and create communication systems about tropical storms to alert residents to potential threats.[xxxvi]
- Retreat from high-risk areas by removing infrastructures too close to the beach or rivers without proper authorization by providing compensation and demolition costs[xxxvii]
- Cliff strengthening and stabilization, changing the slope angle, and/or reducing cliff heights by removing unstable blocks, eliminating surface runoff and infiltration on the slope, securing unstable rocks to increase cohesion and stability and prevent slippage etc.
- Building storm surge gates and flood barriers to protect highly vulnerable urban areas and infrastructure where storm surges and sea flooding could have significant impacts[xxxviii]
- Facilitate the integration between different government levels (regional, state and national) so that complex and expensive responses (e.g., rapid evacuation and/or construction of dykes) can be put in place promptly.[xxxix]

## Case Examples

**Case Example 1**

Colombo, the largest city in Sri Lanka, implemented the Colombo Urban Regeneration Project (CURP) to enhance resilience to storm surges and sea-level rise. The project is a combined effort between the government and local authorities in designing and implementing systems aimed at reducing flooding in the Colombo Water Basin's catchment and strengthening local authorities' capacity through large-scale investments. The project includes a flood and drainage management component by managing street and drainage infrastructure, including canals and flood gates. A concerted effort has been made to provide a higher quality of life through increased public space for the residents, such as protecting wetlands coupled with providing access and education, enhancing pedestrian walkways, and rehabilitating parks.[xl]

**Case Example 2**

In 2016, several cities in Vietnam initiated a project led by the Ministry of Agriculture and Rural Development, with the involvement of the Ministry of

Construction and the seven provincial People's Committees, intending to improve the resilience of vulnerable communities in the provinces of Nam Dinh, Thanh Hoa, Quang Binh, Thua Thien Hue, Quang Nam, Quang Ngai, and Ca Mau. The project has added storm- and flood-resilient design features to 4,000 new houses on safe sites, benefiting 20,000 people in disaster-prone communes to date, to build 5,000 homes in total by June 2023. The project has replanted or regenerated 4,003 hectares of mangrove forest to restore Vietnam's green shield, which protects against waves and storm surges. The rejuvenated mangroves have boosted local livelihoods, with the project also supporting 4,358 people. The project has invested in improving data collection, risk mapping, and information sharing, as well as local capacity-building as well.[xli]

**Case Example 3**

As a coastal megacity, Shanghai faces risks from storm surges and sea-level rise exacerbated by climate change. The city has implemented a range of measures to enhance resilience, including the construction of seawalls and flood barriers along the Huangpu River to provide protection against typhoon-induced flooding. This project also includes upgrading drainage systems and investing in green spaces and sponge city initiatives to absorb excess water and reduce flood risk. However, there is limited insight into the actual safety level of the flood defenses in Shanghai, and recent failures have highlighted their vulnerability.[xlii]

**Case Example 4**

Dhaka, one of the world's most densely populated cities and highly vulnerable to flooding and storm surges, has undertaken the Dhaka Integrated Flood Protection Embankment Project. This project involves the construction of reinforced embankments along major rivers surrounding the city, along with flood shelters and early warning systems to protect residents and infrastructure during extreme weather events. According to the Project Completion Report by ADB, the Project has had significant positive environmental impacts as it successfully protects the western half of Dhaka from annual floods. In particular, the poorer segments of the population who inhabit the low-lying areas benefited from the Project. By improving the efficiency of disposing internal floods from rains, through pumping and the drainage system, the chance of frequent localized floods has also been minimized. The living conditions in the poorer areas of the city were enhanced through the physical improvement of slums, and the improvement and wider application of the solid waste management system.[xliii]

## End Notes

[i] https://climate-adapt.eea.europa.eu/en/metadata/publications/projections-of-extreme-storm-surge-levels-along-europe

[ii] https://www.cgdev.org/sites/default/files/1422836_file_Future_Storm_Surge_Disasters_FINAL.pdf

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[xi] https://www.climate.gov/news-features/understanding-climate/2013-state-climate-record-breaking-super-typhoon-haiyan

[xii] https://www.researchgate.net/publication/273025037_Impact_of_2008_Hurricane_Ike_on_Bridge_Infrastructure_in_the_HoustonGalveston_Region

[xiii] https://www.dw.com/en/cyclone-amphan-kills-dozens-leaves-trail-of-destruction-in-india-bangladesh/a-53521178

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[xv] https://www.undp.org/publications/mozambique-cyclone-idai-post-disaster-needs-assessment-pdnadna

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[xvii] https://earthobservatory.nasa.gov/images/19880/cyclone-nargis-floods-burma-myanmar

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