

# Storm Surge and its Effect- A Review on Disaster Management in Coastal Areas



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## Abstract

Globally, about 1.2 billion people reside in coastal areas presently, and this population scale is predicted to increase with time. With increase in coastal population the chances of exposure to storm surge is also increasing. Storm surge expose coastal areas and its residents to risk of loss of life, fatal injuries, property damage etc. Even though we cannot completely avoid the effect of this hazard, we can reduce the effect of hazard by proper study on the area under exposure and implementing a disaster management plan with adequate preparedness and mitigation strategies. Thus coastal hazard management has become an important aspect of coastal planning so as to develop the resilience of society towards coastal hazards. Hard engineering structures, soft protection measures, and managed retreat from the coastline are some of the possible management options.

In this paper the study focus on the storm surge phenomenon, its effects and risk on people, environment, engineering structures and other infrastructure. It also covers the pre-disaster phases of disaster management cycle that is the common preparedness and mitigation strategies described along with incidents during past storm surge disaster. All these aspects can improve the knowledge level of people to take necessary actions at right time, thus enhancing the capacity of the society to fight the hazard.

**Keywords:** Storm surge; Coastal hazard management; Disaster management cycle; Pre-disaster phases

## Introduction

Coastal hazards like storm surge expose a coastal area to risk of property damage, loss of life and environmental degradation. The unexpected rise of the sea level most commonly associated with a cyclone can cause significant flooding and cost people their lives; the severity is affected by the shallowness and orientation of the water body relative to storm path, as well as the timing of tides. Storm surge is the main reason behind most of the casualties during tropical cyclones.

While comparing itself with many other disasters, storm surge occurs frequently due to strong storms in coastal regions. Compared to past, occurrence rate of storm surge has increased drastically and the trend is expected to continue in future as a consequence of climatic changes, increase in world-wide sea levels, increase in temperature etc. In most cases a hazard becomes a disaster due to human intervention; in the form of residing practices, construction methods, and other activities like encroachment, fishing industry etc. Since early civilisation, human population finds coastal areas as the most suitable and attractive settling grounds, as they provided abundant marine

resources, possibilities for livelihood in the form of trade and transport etc. This view of population has eventually led to high population densities and high level development in many coastal areas. At present, about 1.2 billion people live in coastal areas globally, and this number is predicted to increase to 1.8-5.2 billion by the 2080's due to a combination of population growth and coastal migration [1].

Increase in coastal population, increases the chances of exposure. If coastal are not well protected and not timely informed about the evacuation needs and steps it can result to a huge disaster. As per records the deadliest storm surge recorded was the 1970 Bhola cyclone, which killed up to 500,000 people in the area of the Bay of Bengal [2].

We cannot completely avoid any hazard, but proper study of the area under exposure and an adequate disaster management plan. Thus coastal hazard management has become an important aspect of coastal planning so as to develop the resilience of society towards coastal hazards. Hard engineering structures, soft protection measures, and managed retreat from the

coastline are some of the possible management options. This review paper focuses on the risks of storm surge phenomenon and its effects; paper also covers the pre-disaster phases of disaster management cycle that is the effectiveness of common mitigation and preparedness strategies.

**Impact of Storm Surge**

A storm surge can lead to extreme flooding in coastal areas, causing property damage, loss of human life, coastal erosion, change in ecosystem etc. The two most vulnerable areas during

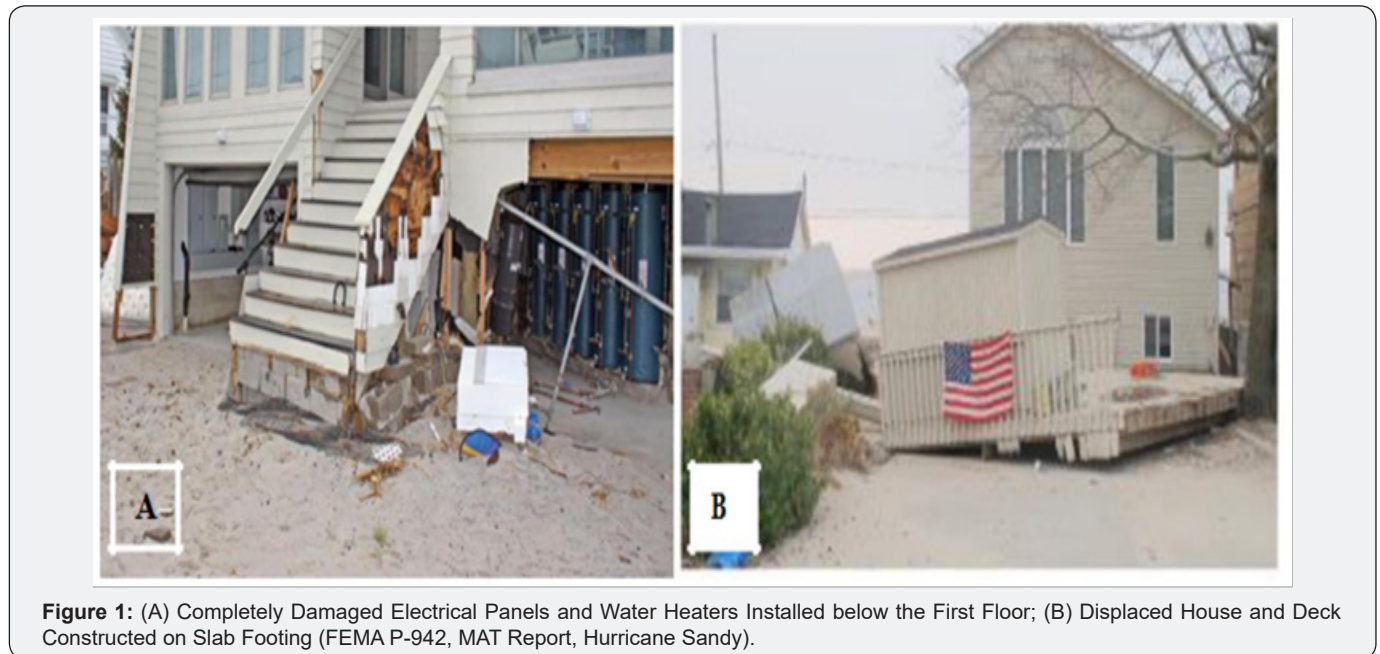
storm surge are the estuaries and coastal areas. The severity of a surge is impacted by the wind intensity, forward speed and the angle of the approaching storm, the width and slope of the continental shelf. Table 1 shows the level of damage of storm surge followed by different categories of hurricanes and Table 2 shows impact of some of the past events [3]. The deadliest storm surge on record was the 1970 Bhola cyclone, which killed up to 500,000 people in the area of the Bay of Bengal. Table 2 shows list of death followed by various scenarios of storm surge [3].

**Table 1:** Damage Level of Storm Surge (NOAA U.S, 2015).

Category	Sustained Winds (MPH)	Damage	Storm Surge
1	74-95	Minimal	4-5 Feet
2	96-110	Moderate	6-8 Feet
3	111-130	Extensive	9-12 Feet
4	131-155	Extreme	13-18 Feet
5	>155	Catastrophic	>18 Feet

**Table 2:** Impact of Past Storm Surge Events.

Category	Storm Surge Height in Feet	Death	Property Damage in \$	
Galveston(1900) U.S	4	Aug.15	8000	30 Million
Floyd (1999) North Carolina	4	9.Oct	57	6.9 Billion
Katrina (2005) U.S	5	25-28	1836	108 Billion
Rita (2005) U.S	5	>5	125	12 Billion
Irma (2017) U.S	5	Oct.15	134	>64.66 Billion



Briefly, storm surge can cause damage to building foundation, framing, finishing collapsing the entire stability of the structure. Non-structural damage, like failure of MEP systems (depends on the location), affecting the usability of the building are also common during storm surge [4] (Figure 1).

In most cases transportation facilities like roads, railways, bridges, ports, communication systems etc. (Figure 2) get damaged delaying the response and recovery thereby making disaster worse. Table 2 shows cost of property damage of certain past storm surge events [3].



**Figure 2:** (A) Extensive Damage of Road after Storm Surge (Hurricane Jeanne, 2004), (B) Port Damaged after Storm Surge (Hurricane Irma, 2017) (NHC, U.S).

In some way or other environment is also vulnerable to such natural hazard. Loss of soil fertility due to saltwater intrusion not only affect the agricultural land but also makes changes in the wetland ecosystems, turning them inhabitable for some organisms. As Per the US Geological Survey after hurricanes Katrina and Rita, about 560km<sup>2</sup> of land was transformed to water destroying the breeding grounds for marine mammals, brown pelicans, turtles, and fish, and migratory species such as redhead ducks [5]. The floodwater often carries toxic substances such as heavy metals, ammonia, pesticides, untreated sewage and phosphate. These substances cause problems like degradation

of water quality and decrease in dissolved oxygen, resulting in dead organisms and can also often lead to epidemic disaster. Hurricane Katrina caused oil spills from 44 facilities throughout south eastern Louisiana, which resulted in over 26,000m<sup>3</sup> of oil being leaked. Most were contained on-site, though some oil entered the ecosystem and residential areas [5]. After Murphy Oil refinery spill, 1,800 homes were oiled in the towns of Chalmette and Meraux. The flood waters that covered New Orleans were pumped into Lake Pontchartrain, which took 43 days to complete [5].



**Figure 3:** Erosion of Beaches (Before and After) (United States Geological Survey, USGS).



Erosion of Beaches is another impact of storm surge. In Case of Dauphin Island, Alabama (Figure 3), repeated attacks by hurricane waves and surge have taken a toll on Island, carving a breach in the narrow island, toppling beachfront homes, and eroding large stretches of coast. The yellow arrow in each image points to the same feature Error! Reference source not found.

### Effectiveness of different types of Mitigation Measures

#### Hard engineering techniques

Hard coastal defensive structures are the most effective option for surge mitigation and stabilizing shoreline at a fixed position. Groins, Sea walls, Revetments, Breakwaters, Fixed dams, Retaining walls are some protection structures used commonly in developing countries due to its low instalment and maintenance cost compared to higher technology option like storm surge barriers which is effectively implemented in developed countries. Some examples include, the Thames movable barrier located in central London, prevents London from being flooded by storm surges moving up from the North Sea. It needs to be raised only during high tide and at ebb tide it can be lowered to release the water that backs up behind it. Movable barriers also require simultaneous investment in flood warning systems to inform when to close the barrier. Number of examples of effectively performed fixed structures like Sea walls, Groins, Breakwaters is visible throughout different countries.

Apart from its merits, hard structures also have some price to pay. It adversely influences the recreational use and ecological matters within the coastal zone. For example, when seawalls

are constructed erosion of the beach in front of the seawall continues to become very narrow to completely disappear later. In case of groins, when it traps sediment on the up drift side, there is corresponding shoreline erosion on the down drift side because of the interruption in longshore transport.

#### Soft engineering techniques

Soft coast measures make use of environmental friendly techniques to achieve the same objective of hard defence structures. Soft techniques aims in achieving a balance between the need for protection against erosion while maintaining and enhancing shoreline functions. It includes developing a natural shoreline, mangrove forest, bioengineered seawalls, Geotubes, Beach replenishment etc. Even though in most cases they are considered to be temporary defence structure with a fair amount of success, the long term goal of the planners is to develop soft coast so that we can completely abandon the hard structures [6].

As per UNEP during Tsunami 2004, it was natural defence structures who performed well compared to engineered structures. After storm surge in Orissa state (India) October 2009, a study in Kendrapada District [409 villages], indicated that 1.72 additional deaths per village within 10km of the coast were avoided due to the existence of Mangrove forest from 30,766 ha to 17,900 hectare .Similarly for same event the loss of US\$33.31 was observed in Bankual village which was protected by Mangrove Ecosystem Wildlife Sanctuary (145km<sup>2</sup>) compared to Bandhamal village protected by embankments with a loss of US\$153.7 [7].

#### Building Practices



**Figure 4:** Houses with Different First Floor Elevations and Foundation Type Red Line shows the Level of Storm Surge (AIR Worldwide 2015, Hurricane Sandy).

Foundation type and first floor elevation are the main determinants of a residential building's vulnerability. Buildings with an elevated first floor are found to be less vulnerable to damage compared to buildings with the first floor on street

level; however buildings with an elevated first floor could still sustain significant damage, depending on the foundation type [4] (Figure 4).

Main two types of foundations are the closed and open foundation: Closed foundation walls create large obstructions to hydrodynamic loads associated with moving water, thus

closed foundations are also more vulnerable to scour than open foundations. Figure 5 shows a successful pile foundation following Hurricane Katrina (Dauphin Island, Alabama).



Figure 5: Elevated Buildings (FEMA 549, Hurricane Katrina in the Gulf Coast).

### Managed retreat and controlled construction practices

Congested construction practices near coastal area is a major threat during storm surge as it will increase the exposure and slow down the evacuation process. Case of Bay of Bengal where thousands of people killed in the overpopulated coastal regions during series of cyclones events is the best example for uncontrolled coastal construction disaster. Managed retreat is a non-structural measures where a certain area is cleared for surge flooding is a good choice of mitigation measure. Managed Retreat of Pacifica State Beach in 2005 become a success with reduction of flood hazards, increase in functioning wetland habitat, and expanded recreation opportunities [8].

### Challenges in Implementation of Mitigation Measures

The high cost and the requirement for specialist knowledge in the design and implementation phases may prove a barrier to implementation of hard engineering structures like Storm surge barriers. For structures like Seawall, Break water etc. availability of suitable material, space transportation of this building material to location etc. is a major challenge. All type of engineered structure face challenge of periodic maintenance. Case of villages of Kerala in Ernakulam district affected during event of Ockhi cyclone (December, 2017) is an example for lack of periodic maintenance of existing Seawall.

In case of Soft engineering structures, extreme events with very high water levels and wind speeds may severely damage or destroy mangrove areas, vegetation etc. making them less effective and time taken for its natural recovery act as another challenge.

Since construction of elevated structure is more costly compared to non-elevated, Residents are unwilling for such practice making them in danger.

Attitude of coastal community to settle in storm surge prone area neglecting danger due to congestion and exposure is a major challenge for managed retreat project.

### Community Preparations for Storm Surge Event

Preparedness is one of the most important pre-disaster phase of disaster management cycle which aims not only in increasing the community resilience (capacity to face a disaster), but also focus on the sustainable development of the community. In case of most of the disaster events more than 90 percentage of fund is used for post-disaster phase, if more care is provided in pre-disaster phase it will eventually reduce the expense for recovery.

### Early forecasting and warning system

Early warning is a major element of disaster risk reduction. Early action often prevent a hazard turning into a human disaster, warning provides people enough time to implement the action plan. One of the main reason behind the pathetic condition in Kerala during Ockhi Cyclone (December, 2017) was the absence of an early warning. People were unaware of the occurrence cyclone or the surge followed by it.

### Educating people at risk

Coastal residents can be empowered by giving proper education regarding the storm surge impacts, actions to be taken, 72 hour disaster kit etc. It also helps in keeping themselves

alive until rescue arrives. In case of Myanmar (Cyclone Nargis, 2008) it was found that damages (138,000 fatalities) became worse not only due to improper evacuation plan but also due to lack of perception of threat of storm surge and residents fewer experiences of storm surge, because of which people didn't get any image of the possible disasters when the storm surge came. This is a clear example for lack of proper education among coastal people [9].

### Evacuation Plan in case of emergency

An evacuation plan lays out how to escape safely from the vicinity of disaster prone area to rescue shelters during an emergency. It involves activities like provision of transportation and communication facilities, opening shelters, rescue & relief etc. The entire action plan developed will be executed response phase. During Storm Surge by Cyclone Sidr in Bangladesh (2007) absence of evacuation information along with lengthy evacuation distance to shelters made the situation worse since people were washed away before reaching the shelter and some of them were trapped inside the houses as they couldn't open the doors and windows due to flooding. There are some other cases like Storm surge (2012) due to hurricane Sandy in New York which caused widespread devastation to infrastructure like electricity and subway system. But unlike other failure cases, for a highly urbanized area of New York, since subway system was stopped before storm and residents in highly flood prone area was evacuated immediately before flooding further personal loss was prevented [10-15].

### Conclusion

Compared to other natural disasters storm surge is a hazard which occurs frequently due to strong storms in coastal areas. In most cases storm surge becomes a disaster when they occur unexpectedly without proper preparations and any preventive measures Storm surge not only has inverse impact on human life but also the environment, animals, infrastructural facilities, structures etc. All of them are in one way or another vulnerable to the hazard [16].

History of past events shows us that the money spend for post disaster management phases of response and recovery is higher, the reason behind such a situation is due to the lack of importance given to the pre-disaster management phases that is the preparation and mitigation phases. Since prevention is said to be always better than cure, if proper care and importance is given for the strategies before any hazard, then we can not only reduce the effect but can also prevent the expenditure during the post disaster periods [17-19].

Common structural and non-structural preventive measures that can be opted for storm surge event include engineered structures like sea walls, storm surge barriers, closure dams, natural defence structures like mangrove forest, proper building practices etc. Even though in most cases hard engineering structures are found to be more effective than soft engineered and non-structural measures, it is always better to go for

environmental friendly techniques and all present studies are looking forward to Soft coast rather than a Hard coast. The importance of effectiveness of Preparation techniques like provision of early warning system, 72 hour disaster kit, evacuation plan etc. is another important factor, which is clear from the examples already discussed in this paper. All these management techniques seek the assistance from government for establishment, but some of the preparation techniques can be achieved without outside assistance such as use of sand bags, coastal vegetation, proper construction materials and practices, provision of drainage, periodic maintenance of individual buildings etc. These kind of study helps to increase the resilience of community to fight the hazard in all possible, so as to ensure the safety and sustainability of the people.

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