# UNDERSTANDING VULNERABILITY AND RESILIENCE OF CRITICAL INFRASTRUCTURE IN EXTREME WEATHER EVENTS

A School of Planning and Architecture, New Delhi Publication


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# PREFACE

Infrastructure development invariably interferes with the nature and it is a perpetual endeavour to draw a balance between the benefits of the infrastructure and the impacts they would have on the natural environment. A step further, the efforts are underway to reverse the impacts that developments make and it marks the beginning of new paradigm in infrastructure development. Even though the perceptible change may be far from a reality beyond scientific evaluations, it has created a dialogue around the sensitivities of nature wherein focus is on the impacts that such development cause. As a consequence of disturbance to the nature, human interventions as developments would always be at risk. The discussion presented in the book is aimed create a comprehension of vulnerabilities that exist and relate these to various aspects of development.

The challenge for infrastructure development is to mitigate against the probable vulnerabilities by way of specific measures, including those related to reduction in potential hazard itself. Indeed, such measures are possible for impact-neutral development but the question is what would be the economic impact? While infrastructure development is the need of the civilized society to survive, the sustainability on economic aspects cannot be overlooked.

This calls for an approach wherein nature versus development paradox is balanced and priorities are established. In this respect, it is important that the critical infrastructure is identified which has planned resilience against the vulnerabilities to the extent that benefits of mitigation measures outweigh the consequences in a probabilistic occurrence of an event.

In the recent times, it is also observed that the conventional outlook of the natural risks, referred to as disaster risks, is undergoing a definite change. Due to variety of reasons, including those related to climate change, occurrence of highly irregular weather events has rendered risk mitigation approach far more complex. The extreme weather events have further complicated the resilience building process with an added layer of uncertainty. Thus, it now becomes necessary to focus on critical infrastructure so that the crippling effect on the lives and livelihoods of citizens is contained. A large number of such extreme weather events, as presented in this book, validate this concern.

Thus, this book builds an argument on resilience principles in relation to the vulnerabilities that are presented due to extreme weather events in relation to the critical infrastructure. The authors firmly believe that the body of knowledge presented in this book would be useful for the stakeholders of critical infrastructure development, including professional and promotor organization who are responsible for the scope and resource optimization.

Chapter 1 is a comprehensive description of natural and man-made disasters plaguing globally. It builds upon current interpretation of events, and their devastation. This is a knowledge base of events for quick access and understanding of cause-impact. It further synthesizes the cause-impact from knowledge base to trace the cascading impact on built-environment. Whilst the impact is immeasurable, the chapter evaluates the degree of devastation in terms of critical infrastructure losses.

Chapter 2 evaluates the cascading impact on infrastructure through detailed chronological case study analysis of some of the most devastating natural and man-made disasters in India; from Cyclone Amphan (2020) to Bihar floods of 2008. Each case is detailing the impact, economic losses, and response.

Chapter 3 categorises the cause-impact of events and corresponding risks to built-environment; public building and healthcare infrastructure. The chapter collates critical information of events; governmental guidelines, WHO & ADB databases, and global learnings to mitigate such risks.

Chapter 4 brings together all the understanding to develop a framework for calculation of tangible and intangible losses from the events. It establishes a quantitative backbone against economic losses; often economic losses are what is quoted first when events happen, however no statistical analysis is made transparent. The offered framework intends to eliminate any uncertainty in numbers. Additionally, brings everything together by offering a detailed description of various tools available globally from evaluating the risks of events to identifying tangible and intangible loss parameters. Such a checklist of tools is vital for quick assessment, and also evident by its absence from popular literature on disasters.

Chapter 5 summarises the learning outcomes, critically analyses their significance and offers recommendations for impact on building resilience and preparedness for natural disasters and EWE(s).

This literature intends to cover the most significant aspects of disaster events that are becoming more invincible against human interventions, especially in context of built environment that takes time worth human-life to rebuild. We, as authors, and built-environment specialists hope to provide a stepping stone to enhance learning of the unpredictable.

**Prof. (Dr.) Virendra Kumar Paul**

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## LIST OF ABBREVIATIONS

**BMTPC**: Building Materials and Technology Promotion Council

**CAPRA**: Central American Probabilistic Risk Assessment

**DBELA**: Displacement-Based Earthquake Loss Assessment

**EEW**: Earthquake Early Warning

**EPEDAT**: Early Post-Earthquake Damage Assessment Tool

**ERS**: Emergency Restoration System

**ESPAS**: Earthquake Scenario Probabilistic Assessment

**ESZ**: Ecologically Sensitive Zone

**EWE**: Extreme Weather Event

**FEMA**: Federal Emergency Management Agency

**GDP**: Gross Domestic Product

**GIS**: Geographic Information System

**GLOF**: Glacial Lake Outburst Flood

**GSDMA**: Gujarat State Disaster Management Authority

**GSI**: Geological Survey of India

**HDI**: Human Development Index

**MCM**: Million Cubic Metres

**MGPS**: Medical Gas Pipeline System

**MHA**: Ministry of Home Affairs

**MMI**: Modified Mercalli Intensity (Scale)

**IMD**: Indian Meteorological Department

**IPD**: In-Patient Department

**IRS**: Incident Response Team

**KSEB**: Kerala State Electricity Board

**LiDAR**: Light Detection and Ranging

**NBLS**: Narrow Based Lattice Structure

**NDRF**: National Disaster Response Force

**NHEMATIS**: Natural Hazards Electronic Map and Assessment Tools Information System

**OSRE**: Open Source Risk Engine

**PPE**: Personal Protective Equipment

**PSHA**: Probabilistic Seismic Hazard Analysis

**SDRF**: State Disaster Response Force

**UNDRR**: United Nations Office for Disaster Risk Reduction

**WAPMERR**: World Agency of Planetary Monitoring and Earthquake Risk Reduction

**WHO**: World Health Organisation

**WMO**: World Meteorological Organisation

# CHAPTER 1 - NATURAL DISASTERS AND EXTREME WEATHER EVENTS

## 1.1 Learning Objectives

This chapter encompasses the fundamentals of occurrences and impacts of natural disasters and extreme weather events on communities, infrastructure, economy and environment. A complete gamut of disasters is presented in the chapter, aimed especially at building infrastructure and physical planners, who are the major stakeholders in the planning, designing, construction and execution processes of projects. The study helps build a versed approach through appraisal of natural disasters and the consequences, thereby informing the various facets of infrastructure & project planning considerations and conscious decision-making during the life cycle of the project.

## 1.2 Disasters and Extreme Weather Events

As stated by the United Nations Office for Disaster Risk Reduction (UNDRR), a **disaster** can be defined as "*a serious disruption of the functioning of a community or society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope with using its own resources*." (UN-SPIDER, 2021)

A disaster can be understood as a catastrophe, mishap, or calamity arising from natural or man-made causes. Disasters can be of the following types –

- **Natural** *(Hydrological, Geological)*
- **Chemical, industrial and nuclear**
- **Accident related** *(Fire, Oil spills, bomb blasts, Air, road and rail)*
- **Biological** *(Epidemic, Pandemic)*

An **extreme weather event** has been defined by Seneviratne et.al. (2012) as

"*The occurrence of a value of a weather variable above (or below) a threshold value near the upper (or lower) ends ('tails') of the range of observed values of the variable*."

Weather events, even if not extreme in a statistical sense, can lead to extreme impacts or extreme conditions nevertheless. This can occur either by critical threshold being crosses in an ecological, social, or physical system, or when these weather events occur simultaneously with other events. Depending on when and where the events occur, they can have varying impacts. For instance, a weather event such as a tropical cyclone can have extreme impact, depending on when and where it approaches landfall. On the other hand, not all extreme events lead to critical impacts. Some climate extremes, for instance, droughts and floods may occur as a result of the accumulation of weather or climate events, which may not be extreme themselves individually, but their accumulation is extreme. (Seneviratne, et al., 2012)

Most Extreme Weather Events and Extreme Climate Events are sub-set of disasters and are the result of variations in the natural climate, and natural decadal or multi-decadal variations in the climate provide the backdrop for anthropogenic climate changes.

### 1.3 Man-Made Disasters

Hazards which are entirely or predominantly induced by human activities and choices are known as Man-made (i.e., anthropogenic, or human-induced) hazards. This time period does now no longer cover the prevalence or chance of armed conflicts and different conditions of social instability or anxiety which might be difficult for worldwide humanitarian regulations and country wide legislation. Technological hazards are generally taken into consideration as a subset of man-made hazards.

Hazards which are originated from technological or industrial conditions, infrastructure failures, dangerous procedures, or specific human activities come under **chemical, nuclear and radiological hazards.** Industrial pollution, toxic wastes, ionizing radiation, transport accidents, dam failures, fires, factory explosions, and chemical spills are some the prominent examples of the same.

Technological hazards additionally may also rise up immediately due to the influences of natural hazardous events. A technological hazard caused naturally is called a **Natech**. (UNISDR, 2018)

#### 1.3.1 Natech Hazards

Natural-hazard-triggered technological (Natech) events can aggravate the effect of a natural disaster on the surroundings and on human health due to the discharge of unsafe materials, fires and explosions. Due to a combination of growing urbanisation and industrialisation, coupled with the expected growth of hydro- meteorological hazards as a consequence of climate change, the risk and effect of Natech events is increasing. (World Health Organisation, 2018)

Natech events have been found to be potentially more hazardous than chemical events during normal plant operation for various reasons. Firstly, Natech events may cover a huge geographical area and hence, can affect numerous chemical sites simultaneously. There is a significant possibility of multiple and simultaneous events of damage, failure and chemical releases, even on one site. Further, the procedures or mechanisms designed for prevention or mitigation of a chemical release and its consequences may get damaged during the event. Secondly, the other effects of Natech events such as damaged, blocked, or flooded roads, and high demand for rescue can jeopardize the ability of local authorities and services to respond to the chemical release. Additional risks posed to the emergency response personnel can also obstruct rescue operations. (World Health Organisation, 2018)

### 1.3.2 Environmental Hazards Associated with Natural Disasters

Environmental deterioration after a natural calamity can pose a threat for outbreak of diseases cause by an increase in vector breeding sites and rodent populations. Management of this risk through the extensive use of insecticides and rodenticides (by public health authorities) may lead to an increased risk of contact of the workers or the local communities to these chemicals or unless suitable precautions are taken.

## 1.4 EARTHQUAKES

Earthquakes constitute one of the worst natural hazards causing widespread destruction and loss to life and infrastructure. The effects of an earthquake depend on its magnitude and intensity.

Seismic waves are created by the result of a sudden release of energy from the earth’s crust. The seismic activity of a region is defined by the frequency, size and type of earthquakes experienced over a time duration. (Krishna, 2013)

The point on the fault where rupture occurs and the location from which seismic waves are released is called as the focus or hypocentre. The Epicentre is the point on surface of the earth that is directly above the focus, or the point of origin of an underground explosion or earthquake.

Surface traces of a fault or the line of intersection between the earth's surfaces are Fault Lines. The sudden slips of the land or cracks are Fault Planes. The displacement of land surface due to movement along faults is responsible for topographic expression of faulting, known as fault scrap. (Krishna, 2013)

### 1.4.1 Causes of Earthquakes

The major causes of earthquakes are –

i. **Surface Causes**

   Huge engineering initiatives, great explosions, landslides, slips on steep coasts, dashing of sea waves, avalanches, railway trains, heavy trucks, etc. are the cause for minor tremors.

ii. **Volcanic Causes**

   Earthquakes may lead, accompany and frequently follow volcanic eruptions. Eruption can trigger the quakes as well as they are caused by sudden displacements of lava within or underneath the earth's crust.

iii. **Tectonic Causes**

   The main cause of this type of earthquake, which is also the most destructive one, is the structural disturbance which results in parts of the lithosphere, and originate in the areas of great fractures and faults. Great transform faults are produced by sudden yielding to strain generated on the rocks due to accumulation of stress that causes displacements, especially along old fault zones. (Krishna, 2013)

### 1.4.2 Building Related Significance of Seismic Waves

During an earthquake, the large strains of energy released, which travel in all directions through the layers of the Earth, are known as seismic waves. At every interface, these strains or energy refract and reflect. Body waves and surface waves are the two types of seismic waves.

Body waves comprise of Primary Waves (P-waves) and Secondary Waves (S-waves), and surface waves comprise of Love waves and Rayleigh waves. Material particles undergo compressional and extensional strains along the direction of transmission of energy under P-waves. However, the material particles oscillate at right angles with the direct of transmission of energy under S-waves. Surface motions caused by love waves are quite similar to S-waves but there is no vertical component to it. Material particles oscillate in the vertical plane in an elliptic path under Rayleigh waves (with horizontal motion along the direction of transmission of energy). The sequence from fastest to slowest waves is – P-waves followed by S-waves, Love and Rayleigh waves. (Murty, 2005)

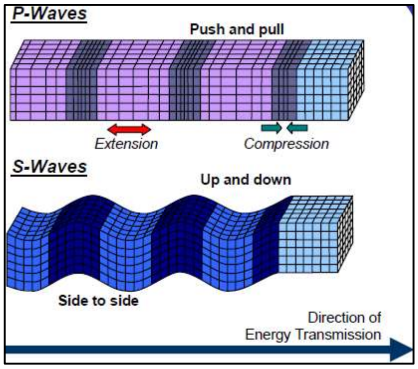


*Figure 2 Motions caused by Body Waves Source: (Murty, 2005)*

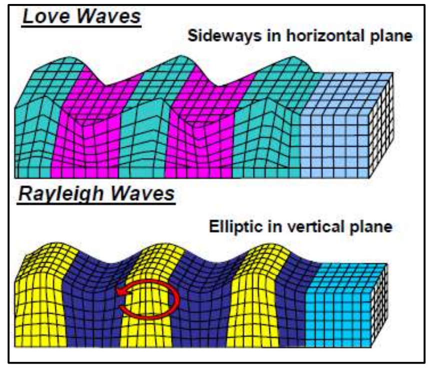


*Figure 1 Motions caused by Surface Waves Source: (Murty, 2005)*

Seismic wave motions move the ground and thereby, also the structure depending upon the proximity to the focus of the earthquake, and according to their wave motion. Reflections and refractions off boundaries within the earth, and combinations of waves produce many types of seismic waves, shaking the ground in different ways.

The P wave, or primary wave, is the fastest of the three waves and the first detected by seismographs. P-waves can move through both liquids as well as solid rock. Similar to sound waves, which are compressional, and move air back and forth as the waves travel to reach the sound receiver from a source of sound, the P-waves are also longitudinal or compressional in nature, and oscillate the ground back and forth. Compressional waves expand and compress matter as they move through. (Incorporated Research Institutions for Seismology, 2020)

S waves, or secondary waves, are the waves directly following the P waves. S waves oscillate with a shearing behaviour at right angles to the direction of motion, in the same direction, instead of compressional nature of the P-wave. Therefore, they do not travel through liquid like molten rock, water, or the Earth's core, since liquid does not sustain shear stresses. They travel about 1.7 times slower than P waves. Due to higher amplitude and vertical-horizontal motions of the ground surface, S waves are more dangerous than P waves.

Both Rayleigh and Love waves produce little motion deep inside the earth, but produce significant ground shaking on the surface of the Earth. As compared to the amplitude of P or S waves, the amplitude of surface waves diminishes less rapidly with distance. Hence, the most important component of ground shaking, far from the source of the earthquake, are surface waves, thereby being the most damaging. (Incorporated Research Institutions for Seismology, 2020)

### 1.4.3 Measurement of Earthquakes

**Magnitude**

The actual size of the earthquake when measured quantitatively is known as the Magnitude of the earthquake. Professor Charles Richter noted that (a) seismograms (records of ground vibration during an earthquake) of larger earthquakes have bigger wave amplitude at the same distance, as compared to those of smaller earthquakes; and (b) seismograms have smaller wave amplitude at farther distances than those at close distances, for a given earthquake. These observations paved ground for him to propose the Richter scale, which is the most commonly used magnitude scale currently. With every 1.0 unit Richter scale magnitude (M) increase, 10-times higher waveform amplitude and approximately 31-times higher energy is released. (Murty, 2005)

**Intensity**

The actual shaking of ground at a location during an earthquake, measured in qualitative terms is known as Intensity of the earthquake, and is commonly assigned Roman Capital Numerals. The two most commonly used intensity scales are the Modified Mercalli Intensity (MMI) Scale and the MS Scale. Both scales are similar and range from I (least sensitive) to XII (most severe). The three features of shaking on which the intensity scales are based on, are – performance of buildings, perception by people and animals, and variations in natural surroundings. (Murty, 2005)

### 1.4.4 Seismic Zones of India

The likelihood of occurrence of damaging earthquakes at different locations is different, depending upon the geology of the particular location. Therefore, a seismic zone map has been drafted to identify these regions considering past data on the levels of intensities sustained during earthquakes. The zone map, 1970 version, has the Indian subcontinent subdivided into five zones – I, II, III, IV and V. The maximum Modified Mercalli (MM) intensity of seismic shaking probable in these zones were V or less, VI, VII, VIII, and IX and higher, respectively. (Murty, 2005)

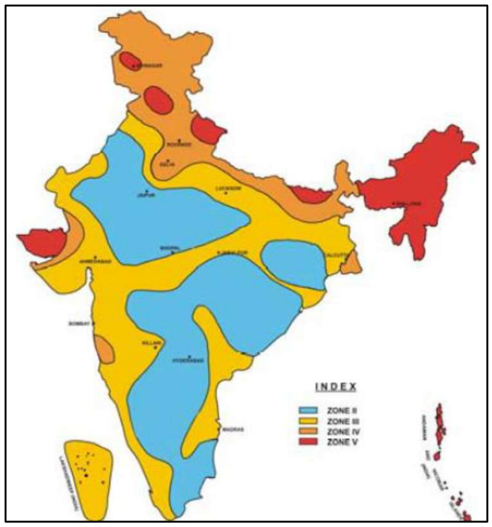


*Figure 3 Indian Seismic Zone Map as per IS: 1893 (Part 1)-2002; Source: (Murty, 2005)*

With enhanced research and understanding on the seismo-tectonics, geology and seismic activity, the seismic maps are revised periodically. The map was revised in 2002, and has four seismic zones – II, III, IV and V. the regions belonging in seismic zone I in the 1970 version of the map have been merged with those of seismic zone II. (Murty, 2005)

A largescale view of the country's seismic zones has been presented in the national Seismic Zone Map. However, at this scale, the local variations in geology and soil type cannot be represented. Hence, for important projects like nuclear power plants and dams, the seismic hazard is assessed and analysed specifically for that site. Further, seismic micro-zonation is prepared for metropolitan areas for the purpose of urban planning. This includes variations in local soil profile, geology, etc. (Murty, 2005)

### 1.4.5 Seismic Micro-zonation

Sub-division of a region into smaller areas that have different potential for hazardous effects of earthquake is called as seismic micro-zonation. The effects of earthquake depend primarily on ground geomorphological attributes which comprise of geomorphology, geological, and geotechnical information. Some of the important geomorphological attributes are the parameters of geomorphology and geology, rock depth/outcrop and soil coverage/thickness. Other attributes, the earthquake parameters, are estimated by effects of local soil for a hazard, i.e. local site response in case of an earthquake, and hazard analysis. Some of the important seismological attributes are predominant frequency, site response/ amplification, Peak Ground Acceleration (PGA) (from probabilistic or deterministic approach), and landslides and liquefaction due to earthquakes. (National Institute of Disaster Management, 2013)

#### 1.4.5.1 Seismic Zoning and Seismic Micro-zonation

Seismic zoning involves sub-division of a national territory into various seismic zones, which indicates progressive level of the seismic intensity expected, or the PGA for varying return periods, based on predicted and historic intensity of ground motion. Usually, countries are divided into 3, 4, or more seismic zones, and each zone has a defined set of seismic design requirements for buildings. Such maps are small scale, and cover bigger territories.

Seismic micro-zonation helps obtain detailed information on earthquake hazards on a larger scale by identifying the variation in spectral acceleration values within a seismic zone for different sites, with geological conditions that are location specific. Therefore, all the possible earthquake induced hazards can be mapped using seismic micro-zoning. Further, the levels of hazard distribution, useful for engineers, architects and urban planners, can be provided by the geological, geotechnical, seismological, and hydro-geological mapping, and their integration. (National Institute of Disaster Management, 2013)

The seismic zonation map of India depicts a large scale view, thereby inhibiting the interpretations of site behaviour in the event of an earthquake, due to local variations in geology and soil type. Earthquake disasters are unavoidable, but the after-effects can be minimised by identification of zones that are more vulnerable to experience maximum ground motion. The need for mitigation against the earthquake hazards can be solved by seismic micro-zonation, since it provides a pragmatic solution in terms of ground motion at higher resolution. (Ministry of Earth Sciences: GeoScience Division, 2011)

#### 1.4.5.2 Need for Seismic Micro-zonation

Seismic micro-zonation is a significant stepping stone towards risk mitigation against earthquakes, with a multi-disciplinary approach. Contributions from fields of geophysics, geology, seismology, structural and geotechnical engineering make the research more detailed and operative. Identification of the geological and tectonic formations in this area of study is significant in determination of seismic sources and for establishing realistic hazard models of the earthquake for further investigation.

A detailed field investigation is required in seismic micro- zonation for evaluation of hazard risks. Spatial variations in the hazard can be effectively delineated through seismic micro-zonation, in addition to evaluation of risk scenarios. Seismic micro-zonation maps can also help in prediction of the effects of future earthquakes, thereby becoming a useful tool, in urban planning. They can also be used for locating crucial facilities like fire stations, hospitals, emergency operation centres etc. Additionally, studies in micro-zonation also help save heritage and important structures from any possible upcoming earthquakes. (National Institute of Disaster Management, 2013)

#### 1.4.5.3 Levels of Seismic Micro-zonation

The levels of seismic micro-zoning typically float with – a) degree of scientific investigation, b) choice of scale of mapping, and c) scope of scientific investigation designed to reduce uncertainties in hazard evaluation for a defined set of objectives. However, the quality and quantum of basic information and maps necessary to begin the cartographic work is rarely available. Since the seismic micro-zoning work cannot wait to obtain all the necessary information, a first-cut map of the micro-zonation is prepared the basis of the minimum programme of investigation. The level of detail and scrutiny increase as the scale of mapping increases. The three levels of seismic micro-zonation – Grade 1: General Zonation; Grade 2: Detailed Zonation and Grade 3: Rigorous Zonation were preferred by the Technical Committee on Earthquake Geotechnical Engineering of the International Society of Soil Mechanics and Foundation Engineering (1993). The recommendation suggests beginning with mapping of relative small scales, moving on to higher levels when large scale mapping cab ne justified by obtaining quality inputs. (National Institute of Disaster Management, 2013)

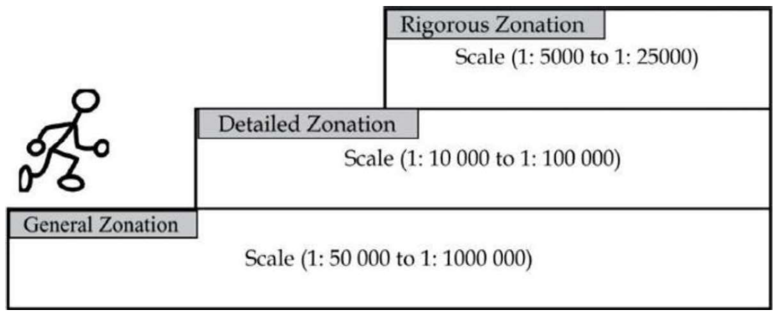


*Figure 4 Three Grades of Seismic Micro-zonation recommended by the Technical Committee of the International Society of Soil Mechanics and Foundation Engineering (ISSMFE)*

There is a need of seismic micro-zonation in current and upcoming urban areas falling under the high hazard zone. Some of the important Indian cities, where seismic micro-zonation works have been executed, are Delhi, Jabalpur and Sikkim. Work on seismic ground motion in large urban areas in other parts of the world are carried out in Bucharest, Bursa, Alexandria, Algiers, Napoli, Beijing, Sofia, Santiago de Cuba, and Zagreb as recorded in 2011.

The micro-zonation map helps serve many targets for Urban Development Authorities. It can provide engineers with valuable information for seismic design of structures, seismic risk assessment for existing structures and construction, land use management, and future construction of heavy industry, defence installations, and other important structures such as nuclear power plants, dams, and other public utility services. (Ministry of Earth Sciences: GeoScience Division, 2011)

**1.4.6 Seismic Fragility and Seismic Capacity**

The development and integration of structural design and analysis using advanced computer technologies has paved the way for increased accuracy and a variety of methodologies of seismic assessment. The probabilistic approaches for seismic assessment include fragility analysis and seismic capacity analysis. (Korkmaz, 2008)

In structural behaviour assessment analysis, with the technological advancements in computing in civil engineering, the methods of deterministic assessment are believed to be insufficient in defining the structural behaviour under the effects of earthquakes. Probabilistic assessment approach is necessary to be included in the analysis due to the uncertainty and random variables, which can produce more rational results. A probabilistic methodology is implemented and used to make a rehabilitation decision based on seismic risk and the performance of the system. (FEMA 440, 2005)

Seismic Fragility:

The tendency of a structural component or system to fail to perform satisfactorily in a predefined limit state, when subject to seismic action of extensive range, is known as Seismic Fragility. The seismic fragility analysis can be considered as a probabilistic measure for assessment of seismic performance of the structural components or systems. Seismic fragility analysis produces two different end products: fragility curve and damage probability matrix. (Erberik, 2015)

A system reliability analysis, with correlated capacity and demands is performed with different methods to establish the probabilistic characterization of the demands in different aspects, is also a part of seismic fragility analysis. (Korkmaz, 2008)

Seismic Capacity:

Capacity Spectrum Technique is a useful and important tool for evaluation of the structure for its performance point in performance-based seismic design of buildings. The method consists of two key elements, namely seismic demand and capacity (as proposed in ATC-40). The earthquake ground motion is represented by the seismic demand, and is presented in terms of displacements and forces exerted by earthquake on the structures.

The seismic capacity represents the inelastic behaviour of structure in terms of spectral acceleration and spectral displacement, which is known as capacity curve. The procedure for determination of capacity curve relies on the pushover method, i.e. the use of nonlinear static seismic analysis. The point of intersection between demand and capacity, where the structure's ductility is matched, is known as the performance point. (Panyakapo, 2008)

### 1.4.7 Geological Impact of Earthquakes

The impacts of an earthquake on the surrounding environment are known as Earthquake Environmental Effects (EEEs). In other words, EEEs are the processes brought forth by an Earthquake in the surrounding environment. (Silva, et al., 2013)

Surface faulting, tectonic uplift, subsidence, landslides, liquefaction of soil, etc. are some of the examples of these effects, which can be directly associated with the earthquake or can be prompted by the shaking of ground. EEEs can be observed in areas near or far away from the epicentre of the earthquake. EEEs affect the natural environment as well as man-made structures. (Tatevossian, et al., 2009) EEEs are being used increasingly as a tool for measurement of the intensity of an earthquake.

The consequences of an earthquake can be categorised as primary and secondary. The primary effects are the direct results of the earthquake, and the secondary effects are induced or caused by primary effects. Primary effects are manifested on the surface of the Earth due to interferences at the tectonic sources, which have the potential to generate an earthquake. They can be composed of subsidence, surfacing faulting or uplift, or other ground surface activities caused by earthquake induced tectonic deformation. Secondary effects are caused by shaking of ground, some examples of which are tsunami, landslide, liquefaction, displaced rocks, cracking of ground, destruction of trees etc. (Choudhury, et al., 2016)

#### 1.4.7.1 Primary effects

Primary effects occur as direct consequences of an earthquake. The occurrence of primary effects also depends on the intensity of the earthquake and the stress environment. Two earthquakes with the same energy dissipated, but having different focal depths and stress environments, cause different environmental effects. Therefore, the local intensity values of the two earthquakes may also be different. This variance of intensities is more pronounced in earthquakes with shallow focal depths (less than 4 kilometres) and low magnitude, such as in areas near volcanic hotspots. For this reason, some macro-seismic intensity scales such as ESI- 2007 consider lower intensity values for earthquakes with shallow depths, and use higher intensity values for earthquakes having high focal depths or located in volcanic areas. (Tatevossian, et al., 2009)

i. **Subsidence**
   The movement of the earth's surface from a higher position to a lower position relative to a certain reference point (for example, the mean sea level) is called subsidence of earth’s crust. Uplift is the opposite of subsidence, both of which are researched by engineers, geologists, and surveyors. Subsidence is measured in units of length. (Comerci, et al., 2007)

Some seismic observations indicate that the liquefaction of sand may also trigger subsidence, which can cause serious problems. (Konagai, et al., 2012) The subsidence and uplift caused by the earthquake can affect the rock structure and configurations, landforms and coastlines' development in tectonic active areas, thereby changing the coastal structure and configuration. (Mori, et al., 2012)

ii. **Surface Faulting**

Surface faults or surface ruptures are displacements that reach the surface of the earth due to the movement of faults inside the earth during an earthquake. This phenomenon usually occurs in earthquakes with shallow depths (depth below 20 km). (Kumar, et al., 2010) The impact of earthquakes on the environment, such as surface faults, surface cracks, landslides, etc., can be used to determine the earthquake epicentre area, damage intensity, and comparison with estimated values and historical data.

#### 1.4.7.2 Secondary Effects

The cascading effects that occur in the natural environment as a consequence of primary effects are called secondary effects.

i. **Liquefaction**

Soil liquefaction is a process in which saturated, partially saturated and non-cohesive soils lose their strength and rigidity in response to earthquakes or other rapid loads of shaking soil, resulting in changes in soil behaviour to fluid-like. In this process, the pore water pressure in the soil interior increases effective stress, thereby causing decrease in dynamic loading. Effective stress becomes insignificant when pore pressure equals total stress which caused suspension of soil particles in water, which leads to liquefaction. (Choudhury, et al., 2016)

Some factors which affect liquefaction of soil are –

- Seismic Conditions – The distance of a given area from the earthquake's epicentre affects the intensity of ground motion and the cyclic loads transferred to the soil. It was found that the risk of liquefaction increased as the cyclic loading increased.
- Pressure on Soil – Soils with high overlying ground pressure (such as roads, buildings, or other loading) are less likely to

liquefy than open areas (such as crop land or beaches with shallow alluvial deposits).

- Arrangement and Density of Soil Particles – A porous or loose layer has lesser liquefaction resistance as compared to closely packed soil. Liquefaction resisting strength is higher for soils that are denser.
- Ground Water Level – Supply of ground water is an essential factor to increase the pore pressure of soil, which in turn results in liquefaction. (Choudhury, et al., 2016)

**ii. Earthquake Induced Geological Hazards**

- **Tsunami**
  A tsunami is a series of huge waves that rise from the ocean or other bodies of water which force its way into the land and cause extensive damage and destruction. The wave height can reach more than 30m. While tidal waves are caused by the gravitational pull of the sun, moon, or other planets or wind, tsunamis are caused by huge instantaneous displacement in sea level caused by the primary effects of earthquakes, such as subsidence or uplift of the sea bed. Other reasons for the generation of tsunami may be meteorite impacts and underwater volcanic activities. (Choudhury, et al., 2016)
- **Landslides**
  Landslides or landslips are rocks, gravel, or topsoil that move along a slope in large quantities by the action of gravity. Landslides may be caused by earthquakes or other reasons, such as volcanic eruptions, or disturbance in the ground water table due to anthropogenic activities. When collecting information about the impact of landslides on the environment, it is also important to find out the accurate epicentre, location, magnitude, and possible types of errors involved. An earthquake can cause single or multiple landslides. In fact, the destruction and damage caused by landslides and other secondary effects is often greater than the damage caused by earthquakes. This lead to the development of models and methods for assessment of landslide risks. (Choudhury, et al., 2016)

### 1.4.8 Damage to Structures due to Earthquakes

The damage caused by an earthquake depends on many parameters, including the frequency, intensity, and duration of ground motion, soil and geological condition, quality of construction, etc. The design of buildings must ensure that the building has sufficient strength and high ductility, and maintains uniformity and integrity when subject to a very large deformation.

Historical seismic observations show that site conditions have a significant impact on building damage. Research on earthquakes almost always shows that the intensity of shock is directly related to the type of soil layers that supports the building. Structures constructed on firm soil and solid rock have better integrity and performance during an earthquake as compared to structure built on soft ground. This was demonstrated dramatically when the Mexico City earthquake occurred in 1985, where the epicentre was 400 kilometres away, the damage to the soft ground in Mexico City was significantly greater than the closer areas. (International Association for Earthquake Engineering, 2004)

For example, according to the study of the Mexico City earthquake on July 28, 1957, it has been observed that the damage to the soft soil in the city centre could be 5-50 times higher than that of the firmer soil in the surrounding area. Another instance showing similar observations, occurred in 1976 in Tangsgan, China, where 50% of the buildings built on thick soil were destroyed, while only 12% of the structures built on rock subsoil near mountainous regions were razed to the ground. On the contrary, examples of occurrences of earthquakes in North Yemen, 1980 and in Koyna, India, 1967 showed that rigid masonry structures built on rock were more severely damaged than the ones built on soil. (International Association for Earthquake Engineering, 2004)

The learnings from recent earthquakes indicate that the topography of a building site can affect the damages. Structures built on sites with open, uniform terrain tend to suffer less damage during an earthquake as compared to structures on separated high hills, strip-shaped hill ridges, and steep slopes. (International Association for Earthquake Engineering, 2004)

#### 1.4.8.1 Other Factors Affecting Damage

The degree of damage to a structure depends substantially on the integrity, strength, and ductility of the structure, as well as the stiffness of the underlying soil in a given intensity of seismic activity and motion. In an earthquake, buildings are mainly destroyed by horizontal forces acting on the structure which are usually designed to resist and contend with vertical stresses. The major factors that influence the damage of buildings and other man-made structures are –

i. **Building configuration**
Symmetry and regularity are important features in the overall shape of the building to maintain stability and integrity in the event on an earthquake. A box-shaped building with a rectangular floor plan and elevation is inherently stronger than a U-shaped or L-shaped building (such as a building with wings). A building with irregular shape will distort and increase damage when shaken.

ii. **Opening size**
Openings in the walls of buildings generally tend to weaken the walls, and the fewer openings, the less damage is suffered in the event of an earthquake. If large openings are necessary in a building, or if an open first floor is required, special measures must be taken to ensure structural stability and integrity. (International Association for Earthquake Engineering, 2004)

iii. **Rigidity distribution**
The stiffness of the building in the vertical direction must be evenly distributed. Therefore, changing the structural system of the building from one floor to the next will increase the possibility of damage and should be avoided. Shear walls or columns should run uninterrupted from foundation to the roof, without discontinuities or changes in material.

iv. **Ductility**
Ductility refers to the ability of a building to bend, sway, and deform significantly without collapsing. The opposite situation in buildings is called brittleness, which is caused by the use of inherently brittle materials and insufficient structural design of buildings using otherwise ductile materials. Brittle materials are known to crack under load. Examples of brittle material are bricks, mud bricks, and concrete blocks. It has been observed that buildings that suffered damage during earthquakes in the past comprised of masonry using brittle materials that were tie together insufficiently. Adding steel

reinforcements can increase the ductility of brittle materials. For instance, through the correct use of steel reinforcements and closely spaced steel ties, reinforced concrete can be made ductile. (International Association for Earthquake Engineering, 2004)

v. **Foundation**

Strong and durable earthquake-resistant buildings may sometimes collapse due to the insufficient foundation design. Cracking, tilting, and collapse of the superstructure may be caused by differential settlement of footing and soil liquefaction. Some types of foundations are more vulnerable to damage than others. For instance, isolated foundation may be subject to different settlement, especially when the supporting ground consists of soft soil or different types of soil. Differential settlement may also be experienced by buildings with mixed foundations. Very shallow foundations can be damaged due to weathering, especially when exposed to freezing and thawing in cold climates.

vi. **Construction quality**

Poor quality of construction, use of sub-standard materials, poor workmanship such as inadequate skill in bonding, improper and inadequate construction, absence of through stones or bonding units, etc. can lead to failure of buildings in an earthquake. (International Association for Earthquake Engineering, 2004)

## Categories of Damage

*Table 1 Categories of Damage due to Earthquakes*
*Source: (International Association for Earthquake Engineering, 2004)*

| S.No. | Damage category | Extent of Damage in General | Suggested Post-Earthquake Actions |
|---|---|---|---|
| **0** | **No Damage** | No damage | No action required |
| **I** | **Slight Non-Structural Damage** | Thin cracks in plaster, falling of plaster bits in limited parts. | Building need not be vacated. Only architectural repairs needed. |
| **II** | **Slight Structural Damage** | Small cracks in walls, failing of plaster in large bits over large | Building need not be vacated. Architectural |

| S.No. | Damage category | Extent of Damage in General | Suggested Post-Earthquake Actions |
|---|---|---|---|
| | | areas; damage to non-structural parts like chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably. | repairs required to achieve durability. |
| **III** | **Moderate Structural Damage** | Large and deep cracks in walls; widespread cracking of walls, columns, piers and tilting or failing of chimneys. The load carrying capacity of the structure is partially reduced. | Building needs to be vacated; to be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening are necessary after which architectural treatment may be carried out. |
| **IV** | **Severe Structural Damage** | Gaps occur in walls; inner and outer walls collapse; failure of ties to separate parts of buildings. Approx. 50 % of the main structural elements fail. The building takes dangerous state. | Building has to be vacated. Either the building has to be demolished, or extensive restoration or strengthening work has to be carried out before reoccupation. |
| **V** | **Collapse** | A large part or whole of the building collapses. | Clearing the site and reconstruction. |

#### 1.4.8.2 Impact on Complex Infrastructure Networks

Even as most of the casualties in the earthquake are caused by damage to urban housing, the economic impact is caused by the damage and failure of critical infrastructure such as energy, transportation, energy, and other utilities, and the consequent effects of disruption of their operations and functionality. There may also be significant interdependencies between infrastructure systems in urban areas, which implies that damage to one system may disrupt other critical infrastructure. Therefore, assessment and evaluation of financial risks due to earthquakes requires the development of robust methodologies to evaluate the physical vulnerability of various infrastructure elements and infrastructure systems, as well as the interdependencies between critical infrastructure systems functioning in urban areas. The demand in the financial industry is to better recognise the impact of complex and interdependent urban infrastructure systems designs in relation to investment volatility. There is currently no modelling of issues related to extreme natural disasters (such as earthquakes) in this context, hence giving rise to considerable uncertainties regarding loss potential. The ultimate goal is to support the international financial industry's strategy of creating smart financial tools for critical urban infrastructure. (Rinaldi, et al., 2001)

### 1.4.9 Economic Consequences of Earthquakes

Earthquakes have been recorded to cause extreme damage to economy of countries, states and individuals.

The economic impacts of a natural disaster can be categorised as –

i. **Losses to immovable assets (direct losses) -** these include the direct economic losses due to destroyed or severely damaged buildings and critical infrastructure
ii. **Losses to movable assets (direct losses) -** these consist of economic losses due to damaged or destroyed contents of buildings and other private property.
iii. **Economic losses due to business interruption**
iv. **Public sector economic costs -** public sector economic costs accrue because of loss of revenues and increases in expenses for the public sector.
v. **Household income losses due to death, injury, and job disruption** (Gokhale, et al., 2004)

Economic losses can be broadly classified into direct and indirect economic losses. The first two effects, losses to immovable assets and movable assets are direct losses, and the other three effects, i.e. economic losses caused by business interruption, public sector economic costs and household income losses are considered indirect economic losses. (Sinha & Kumar, 2017)

In addition, earthquakes ensue losses in income in the areas affected, thereby causing significant drop in sales. Consequently, the government faces the risk of losing sales tax revenue, which is a significant source of revenue for the government. However, the impact on revenue will depend on the speed at which reconstruction and recovery work begins. Although the loss of income in the region due to the direct impact of the earthquake can result in loss of revenue in the short term, the increase in reconstruction and new construction projects post disaster may generate additional revenue. A comparative study conducted by Sinha & Kumar (2017), on the economic consequences of earthquakes in cases of Latur earthquake (1993), Bhuj earthquake (2001) and Sikkim earthquake (2011), revealed the loss percentage are 0.13%, 1.00% and 0.13% of GDP of India respectively.

#### 1.4.9.1 Case of Bhuj Earthquake, Gujarat (2001)

The Gujarat earthquake of 2001 occurred on January 26 and lasted more than 2 minutes. The epicentre was about 9 km south-southwest of Chobri village in Bhachau Taluka of Kutch District. The earthquake caused approximately 20,000 fatalities, injured nearly 167,000 people, and damaged around 400,000 houses.

The extent of physical destruction was enormous: 1.2 million houses, 2,000 medical facilities, 12,000 schools, hundreds of public and other buildings, water supply systems, dams, energy infrastructure, roads, electricity and telecommunications systems, cottage industries, factories, and farms were destroyed, crippling the state's public, social, and municipal services in addition to the economy. The earthquake hit 12 districts, but Kutchh, one of the economically weakest districts in the state, was the most severely affected, with an average of 70% of all buildings ravaged. (Sinha & Kumar, 2017)

According to assessment conducted by World Bank, the total loss of public and private property was estimated at USD 4.97 billion, with the percentage of loss in GDP as 1% of India's GDP. The earthquake had an adverse impact on small and medium-sized enterprises in areas affected by the earthquake, causing lakhs of people (about 488000) to lose their jobs.

The revenue loss for Gujarat in April 2011 was estimated to be 40% of expected state revenue, excluding Bhuj Circle. For Bhuj, the loss of revenue accounted for 80% for the whole of 2001-2002. Reconstruction and rehabilitation programs were carried out in areas affected by the earthquake, including repairs and restoration of houses, basic infrastructure for irrigation and roads, and public buildings. (Sinha & Kumar, 2017)

#### 1.4.9.2 How Earthquakes Affect Economic Behaviour

In addition to the economic losses and impact on GDP, earthquakes have also been observed to alter economic behaviour in the affected regions. The population affected by earthquakes are affected not only physically, psychologically and emotionally, but are also known to experience changes in their thought process and decision-making, including economic decisions.

Most economic theories and assumptions believe that people “save for the rainy day”, that is, accumulate savings to help them through hard times, a process known as “consumption smoothing”. Hence, it is predicted that people who have experienced a disaster are more likely to safe-guard themselves economically against the next one. However, a study conducted by Kevin Chen, Mateusz Filipski and Xiaobo Zhang (2019), on “How do Earthquakes Shape Economic Behaviour?” made opposing revelations. The people affected in the Sichuan Earthquake in China (2008) were found to be living an epicurean way of life, and believed in “enjoying life while it lasted”. These people, although affected economically as well as psychologically, were still willing to take risks with their finances instead of saving them for the future. This expenditure and change in their consumption patterns may lead to a slight boost in the local economy. (Chen, et al., 2019)

The sectoral growth of the area at the local level was also affected. Since the affected areas received massive financial aid for relief and reconstruction activities, the prices of local services and local wages increased.

In this study, the authors found that the combination of response, recovery, rebuilding and coping strategies, such as extensive response measures, mobilization of external resources, and effective coordination with multi-level and cross-sectoral stakeholders, enhanced the resilience against natural disasters, thereby limiting the extent of economic fallout. (Chen, et al., 2019)

Even as the research by Chen, et.al. (2019) finds a significant contrast in the actual economic behaviour of people affected by the earthquakes as against the expected behaviour, it is important to establish that different communities respond and cope differently with natural disasters and their impacts. The cultural, economic and behavioural diversity of communities shapes their economic and psychological behaviour, and a “one-size-fits-all” theory or observation may not be generalised for all populations.

### 1.4.10 Psychological and Socio-Economic Aspects of Earthquake Occurrence

People affected by earthquakes experience long-lasting trauma and post-disaster stress and can adversely affect their growth and functioning. This also entails their interactions within the society and the impacts on socio-economic behaviour of the community and region.

The psychological effects of earthquakes can be divided into two categories: long-term effects and short-term effects. Short-term effects are stronger, have higher intensity, but its duration varies from one minute to one hour, depending on the person's psychological state. The number of victims is small, but it is dangerous because it can cause severe mental disorders and even heart failure. (Gokhale, et al., 2004)

The long-term effects last for more than an hour, and the intensity is relatively lesser, but its impact is more critical and important for the mental health of earthquake survivors. These effects depend on the age group and state of psychological health of the victims. Although the financial losses and economic conditions are also some of the aspects that affect mental state, it has been observed that the victims can develop Post Traumatic Stress Disorders, Acute Stress Disorders, Depression and Adjustment Disorders in many cases. The psychological impact of the earthquake on children under the age of 5 is not only directly related to their mental health, but in many cases is also related to their period of learning and growth. (Gokhale, et al., 2004)

The severity of economic and social impacts on society and its resilience depend to a large extent on socio-demographic characteristics, experiences with earthquakes, perception of earthquakes, and their overall response capacities.

Socio-economic impacts can be classified according to the level of development of different industries in developed countries, developing countries and underdeveloped countries. A study conducted by Spence (2007), compares the country's relative progress in reducing preventable deaths with public health campaigns and earthquake deaths in the same period. It was observed that countries with a high Human Development Index

(HDI) had a relatively stable decline in earthquake mortality from the baseline, but it was found that sufficient efforts were not made to detect earthquake death prevention in developing and underdeveloped countries.

The earthquake has been found to cause disproportionate effects on the economically weaker sections of the society. These socially vulnerable groups live in old, poorly constructed housing, which is more prone to damage during an earthquake and the necessary capital required to rebuild and recover is not readily available after the event. (So & Platt, 2014)

Further, a significant section of the population affected is the elderly, senior citizens, who are unable to respond to warnings and evacuate in time, or seek refuge. As a consequence of earthquakes, certain municipalities and towns observe a significant loss in population, which is exacerbated by young people leaving town due to severe damage to local economies.

The pre-existing socio-economic trends in an area may be amplified by a major disaster; the places that were shrinking before the occurrence of the disaster may further decline severely; the industries trying to survive may collapse, and young people may move elsewhere to find work. (So & Platt, 2014)

In contrast, places that were prosperous or economically favourable before the disaster, or where the economic situation was promising, may experience accelerated growth as opportunities arise and capital flows into the region.

Vulnerability and disaster risk have an uneven impact on people who are already physically and socio-economically underprivileged and have fewer resources that enable them to recover or 'bounce back' to a certain degree of normalcy. These include the elderly, poor, foreign nationals, ethnic minorities, persons with mental and physical disabilities, and women, especially the poor, pregnant, lactating or elderly. (So & Platt, 2014)

### 1.4.11 Loss Potential Ensuing Earthquakes

The potential impact of a major earthquake on urban communities can be reduced by promptly taking appropriate actions after a devastating earthquake. Modern technology makes it possible to measure strong earthquakes in earthquake-prone urban areas almost in real time. The distribution of severe ground movements, injuries, fatalities and damage in buildings can be assessed within a few minutes after the earthquake. The ground motion measurement and data processing systems designed to provide this information are called Earthquake Rapid Response Systems. (Erdik, et al., 2011)

If the information from the Rapid Response Systems can be used to rapidly assess the location and severity of the damage, the fatalities in urban areas can be reduced immediately following the earthquake. Emergency management centres in the private and public sectors that provide services immediately after the earthquake, allocate and prioritise resources to minimise loss of life. Through the rapid and effective deployment of emergency response measures and operations, emergency response capacities can be greatly improved to reduce the number of casualties and facilitate evacuation. To make it more effective, it can be helpful to link Rapid Response data to the incident command and emergency management systems. (Erdik, et al., 2011)

Ground motion data related to oil and gas pipelines, power transmission facilities, and transportation systems (especially high-speed trains) help in the rapid assessment of possible damages in order to avoid secondary risks. Waste-water, gas and water utilities can help in location of sites of hazardous and broken pipelines. Preventing gas-related damages needs understanding of damage to the pipeline networks and immediately shutting down the gas supply in critically damaged areas.

Earthquake Early Warning (EEW) systems are involved in the co-seismic phase, which includes the generation of maps for estimating real-time earth motion, as a product of real-time seismology and/or generating alarm signals directly from online instrumental data. Immediately after an earthquake, an estimate of the intensity distribution of the earthquake (called Shake Maps) and information on physical damage to buildings, injuries, fatalities, and economic losses can be produced by Rapid Response Systems. This rapid data on the consequences of the earthquake can help search and rescue teams reach areas in need and provide support to civil defence authorities in emergency situations. Therefore, governments and international agencies recognize and encourage the need for rapid earthquake loss assessment. (Erdik, et al., 2011)

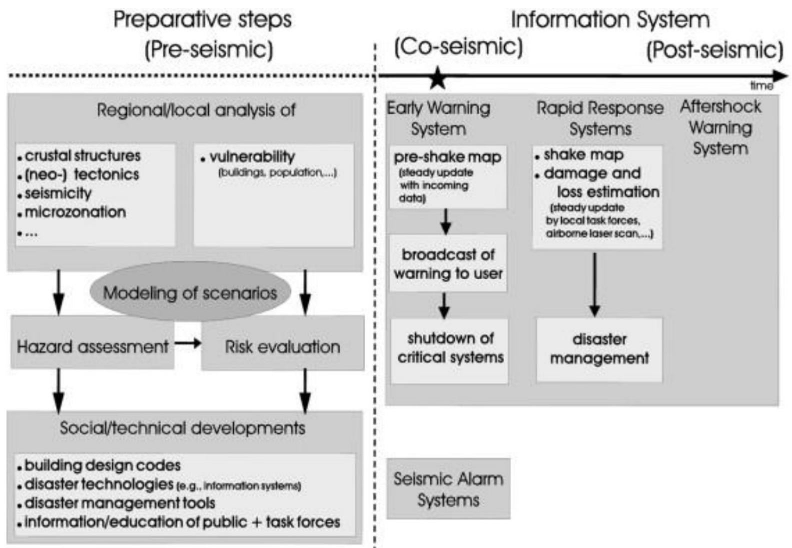


*Figure 5 Pre- co- and post-earthquake risk management activities*
*Source: (Erdik, et al., 2011)*

### 1.4.11.1 Earthquake Loss Estimation Softwares and Tools

With known building inventories, and in an environment where the earthquake risk can be quickly assessed based on the ground shaking distribution after the earthquake, the tools listed below can be adapted to rapidly estimate the losses. (Erdik, et al., 2011)

i. **HAZUS**
HAZUS-MH (FEMA and NIBS 2003) is developed by the United States Federal Emergency Management Agency (FEMA) for the forecasting and mitigating the losses due to earthquakes (HAZUS), hurricanes and floods. (Erdik, et al., 2011)

ii. **EPEDAT**
The EPEDAT (Early Post-Earthquake Damage Assessment Tool) is designed by EQE International, Inc. for post-earthquake loss approximation. The results include damages (buildings and lifelines) and casualties for California based housing and demographic data specific to the county. (Erdik, et al., 2011)

**iii. SIGE**

SIGE, developed by Italian National Seismic Service of the Civil Protection Department, is used for rapid approximate estimate of the damage. (Erdik, et al., 2011)

**iv. KOERILOSS**

Bogazici University devised a scenario-based building loss and casualty prediction model for assessing earthquake losses in Istanbul, Izmir, Bishkek, and Tashkent. The model's derivatives were applied in the EU's FP5 LessLoss project, as well as for estimating scenario earthquake losses in Amman. Both deterministic (scenario) and probabilistic forecasting techniques are taken into consideration in the methodology used. (Erdik, et al., 2011)

**v. ESCENARIS**

The software tool ESCENARIS was originally created for Catalonia. Giovinazzi's empirical fragility functions are used in the methodology, that is based on scenario-based seismic hazards and intensity-based empirical fragility functions (2005). The losses are calculated based on the building stock and social impact classes. (Erdik, et al., 2011)

**vi. CAPRA**

A Web 2.0 format based Earthquake Loss Estimation model for region-specific assessment is currently being developed by CAPRA Project (Central American Probabilistic Risk Assessment – www.ecapra.org).

**vii. LNECLOSS**

The Laboratorio Nacional de Engenharia Civil (LNEC) in Lisbon, Portugal created a software package called LNECLOSS, which is a GIS-based earthquake loss assessment tool that includes modules to calculate seismic scenario bedrock input, local soil effects, fragility and fragility analysis, and human and economic losses. (Erdik, et al., 2011)

viii. **SELENA**

SELENA (Seismic Loss Estimation Using a Logic Tree Approach) is an earthquake building damage evaluation programme created at NORSAR. SELENA computes confidence intervals using the capacity-spectrum approach (HAZUS methodology, ATC-55-ATC 2005) and a logic tree-based weighting of input parameters. (Erdik, et al., 2011)

ix. **DBELA**

The ROSE School/EU-Centre in Pavia is currently building DBELA (Displacement-Based Earthquake Loss Assessment), an earthquake loss estimation tool. The methodology is based on comparative analysis of the building stock's displacement capacity (grouped by structural type and failure mechanism) and the imposed displacement requirements from a given earthquake scenario. (Erdik, et al., 2011)

x. **EQSIM**

A rapid earthquake damage estimation component of the Disaster Management Tool (DMT) known as EQSIM (EarthQuake damage SIMulation), is presently being developed at the University of Karlsruhe. To reflect the European building standards, the loss estimation methodology is based on the adaptation capacity spectrum technique used in HAZUS. (Erdik, et al., 2011)

xi. **QUAKELOSS**

The Extreme Situations Research Centre, Moscow developed QUAKELOSS, a computer tool for assessing human fatalities and building damage due to earthquakes. The World Agency for Planetary Monitoring and Earthquake Risk Reduction (WAPMERR) uses the QUAKELOSS algorithm to produce near-real-time figures of injuries and deaths due to earthquakes anywhere on the world. (Erdik, et al., 2011)

xii. **NHEMATIS**

A robust automated system to enable risk management strategies to assess Canada's Emergency Preparedness by gathering and processing natural hazard information combined with demographic and infrastructure characterizations called as Natural Hazards Electronic Map and Assessment Tools Information System

(NHEMATIS). NHEMATIS, like HAZUS to enable for hazard impact assessment, integrates an expert system rule base, a geographic information system (GIS), relational databases, and quantitative models. (Erdik, et al., 2011)

xiii. **EQRM**

An event-based tool for scenario loss modelling and earthquake scenario ground motion, as well as probabilistic seismic hazard and risk modelling, called EarthQuake Risk Management (EQRM) has been created by Geoscience Australia. (Erdik, et al., 2011)

xiv. **OSRE**

The Open Source Risk Engine (OSRE), a multi-hazards open-source software that can assess the risk of a targeted place given a hazard and the fragility with the associated probability distributions, has been created by the Department of Urban Management, Graduate School of Engineering at Kyoto University. (Erdik, et al., 2011)

xv. **ELER**

A tool for evaluating earthquake impacts and fatalities across the Euro-Med Region, the program allows for loss estimation at three levels, each of which is tailored to the quality of the building inventory and demographic data available called Earthquake Loss Estimation Routine – ELER developed by The EU Project NERIES' Joint Research Activity 3 (JRA3). (Erdik, et al., 2011)

xvi. **MAEVIZ**

MAEviz, created by the University of Illinois' Mid-America Earthquake Centre, combines geographical data, statistics, and visual input to perform seismic risk assessment and analysis. With a built-in library of fragility relationships, it can estimate earthquake risk for buildings (structural and non-structural damage), gas networks and bridges. (Erdik, et al., 2011)

### 1.4.12 Fire and Chemical Hazards as Consequences of Earthquakes

The important themes of research in earthquake engineering include focus on earthquake-resistant engineering and design, analysis of earthquake hazards in terms of building collapse, impact on transportation, dam and bridge failures, etc. While structural safety is vital in mitigation of seismic hazards, post-earthquake fires also significantly contribute to damages and fatalities, and hence are substantially relevant. (Mohammadi & Alyasin, 1992)

### 1.4.12.1 Fire Hazards Associated with Earthquakes

Single or multiple ignitions may arise as a result of earthquakes, with the ability to spread to multiple buildings. The fires that followed after the 1906 San Francisco and 1923 Tokyo earthquakes were the two greatest urban infernos in history, with the latter culminating in around 140000 casualties. The 1995 Kobe earthquake, which spanned only 20 seconds and recorded a magnitude of 6.8 on the Richter Scale, triggered 148 distinct ignitions and devastated 6500 buildings across a total land area of 634,671 square meters. It has been observed that fires that follow earthquakes, can lead to significant damages, rather than the quake itself. Large post-earthquake fires have a low possibility of occurrence, but if they do occur, the effects are catastrophic. (Kim, 2014)

Several newly constructed structures are built to withstand earthquakes and fires in accordance with prescriptive building codes. Improved design methodologies have substantially reduced the risk of structural collapse and casualties in developed nations, where building codes address seismic hazards. However, the same may not hold true in relation to the performance of non-structural components and systems (NCS) in buildings during earthquakes. (Kim, 2014)

### 1.4.12.2 Chemical Hazards Associated with Earthquakes

Sites of chemical production, usage, and warehouses are susceptible to earthquake-related disruption and chemical discharge. Non-pressurized chemical reservoirs, pipes, and outdated gas and oil pipelines have been recorded to be highly vulnerable to rupture post-earthquakes. (World Health Organisation, 2018)

The following elements increase the likelihood of a chemical release in an earthquake posing a threat to the wider population –

i. Location –
    - Industrial establishments in earthquake-prone zones
    - Industrial sites with high population density in the vicinity

ii. Structures –

- Inadequate building and planning regulations
- Seismically non-resistant Structures

iii. Preparedness and warning systems –

- Inadequate warning systems
- Lack of public awareness about earthquake risks

Upon the occurrence of an earthquake, a decrease in response capacity could enhance the Natech risk. Search and rescue operations may be hindered in the event of release of hazardous materials. Disruption to on-site emergency equipment can delay response, as will disrupt critical infrastructure such as power, water, and telecommunication. (World Health Organisation, 2018)

**Mechanisms of Chemical Release**

Horizontal and vertical loads during an earthquake can cause structural damage, leading to failure of containment and consequent chemical release. The failure of containment can also be caused by falling debris, or soil liquefaction leading to collapse of the structure. A single location or a large industrial area could witness multiple and simultaneous chemical discharges.

Mechanisms of chemical release at industrial sites usually involve –

- Pipeline and connection flange rupture.
- Storage vessel buckling and breakage; liquid sloshing
- Power supply disruption
- Damage to storage vessels at petroleum facilities
- Fires started by the combustion of the contents of fuel storage tanks and the explosion of gas mains
- Fires can cause huge amounts of dust and fibres to release from asbestos and fibreglass insulation
- Turning and clashes of chemical tankers (due to transportation network disruption), resulting in breakage and chemical spill. Clean-up operations can result in the release of asbestos fibres from asbestos cement.
- Harmful and noxious smoke generated by the uncontrolled burning of post-disaster debris. (World Health Organisation, 2018)

**Potential Impacts of Natech Hazards on Human Health**

Chemical release caused due to earthquakes have harmful impacts on victims and rescuers who are subject to them directly, and can induce dermatological, bronchial, and systemic ailments. Environmental contamination, as well as fires and explosions, can cause toxic consequences and injuries. The rescuers, general public and persons involved in clean-up activities can be exposed to a variety of risks, which are classified as chemical-related and non-chemical related.

Chemical-related:

- Spilled corrosive chemicals that cause burns on exposure
- Exposure of noxious gases, combustion products, heavy dust, and fibres can trigger respiratory tract impairment
- Poisoning from exposure to spilled toxic chemicals
- Consuming contaminated water or food
- Improper use of petrol/diesel generators can cause carbon monoxide poisoning. (World Health Organisation, 2018)

Non chemical-related:

- Burns from fires
- Electrocution posed by collapsed power lines
- Building collapse, falling masonry, falls from buildings etc. that lead to fatalities and impairments
- Injuries during rescue and clean-up phases
- Evacuation consequences, such as increased risk of contagious illnesses at evacuation sites, amplification of pre-existing health complications during patient transfer, and overcrowding of healthcare institutions limiting the capacity to provide appropriate treatment, potential water supply, and sanitation issues, etc.
- Psychosocial effects such as post-traumatic stress disorder. (World Health Organisation, 2018)

Prevention of exposure:

The civil defence, fire, or other specialized services can be advised based on the risk analyses, on the necessity for:

- Techniques of quarantine/ containment
- Access restrictions to sites that are contaminated
- Need for Personal Protective Equipment (PPE)
- Shelter-in-place or evacuation advisories for affected communities

Further, it is essential that the persons involved in clean-up and rescue activities is properly equipped with PPE and are aware of the likelihood for chemical leaks. Chemically exposed people must have access to decontamination facilities. For the general public, comprehensive information on preventative measures must be provided. (World Health Organisation, 2018)

## 1.5 LANDSLIDES

The downward movement of a massive amount of rocks, earth, mud, and organic material is referred to as a landslide. Landslides are particularly prevalent in areas with mountain slopes, such as hilly regions. Most landslides are triggered by a combination of factors that coalesce to weaken the slope. The inadequate knowledge among residents in India about first aid, safety pathways, warning signals, and first response to a landslide emergency situation is the main cause of significant losses during landslides. Efficient and operative early warning systems and action taken at the prompt of early warnings can allow people to avoid or mitigate the potential risks.

The period between the moment when the occurrence of an incident becomes substantially certain and the moment when it actually occurs is known as lead time. In the event of landslides, the lead time is so short that radical risk reduction solutions are not feasible. Early warnings can only be used for extremely specific incidents, in such cases, or the warning signals must be sent well in advance, i.e. when the likelihood of occurrence is high but not certain. (Connors, 2019)

### 1.5.1 Landslide – Technical Definition

A landslide or a landslip is a geological occurrence that includes a series of ground motions. Rock falls, steep slope failures, and shallow debris flows are the common occurrences. Landslides can occur in different locations, such as coastal, offshore, and onshore. While gravitational force is the primary cause for the occurrence of a landslide, there are additional elements that contribute to the disruption in original stability of a slope. Usually, pre-conditioning factors create certain sub-surface conditions that render the area/slope susceptible to failure, whereas an actual landslide typically needs a trigger before its release.

Landslides occur due to movement of masses of earth, rock or debris down a slope. Mass ground movements, or landslides, are common natural disasters that can relay severe financial, social, and health implications. Landslides typically occur as individual events or in clusters, and are often a part of 'disaster' chains, occurring after or as a precursor to other disasters. (Werner & Friedman, 2010)

### 1.5.2 Causes of Landslide

The primary cause of landslides is the force of gravity acting on materials that are weakened and make up a steep or sloping area of land. While some landslides occur progressively over time (such as movement of land on order of a few metres per month), the most catastrophic ones occur immediately as response to a trigger such as severe rainfall or earthquake.

Since water is heavy and adds significant weight to the earth, it can trigger landslides, and is one of the most common triggers. Due to the excess weight, slope materials (soil, rock, etc.) are more likely to yield to gravitational force. (Connors, 2019)

Landslides can also be caused by other factors that undermine or weaken slope materials. These factors include natural occurrences such as soil erosion and geological weathering, as well as anthropogenic activities, such as changes in floe of groundwater and deforestation. The removal of vegetation after droughts, logging and fires can also increase the risk of landslide occurrences. (Connors, 2019) Landslides are triggered by a shift in the slope's stability, which can be caused by a number of variables operating together or separately.

The natural causes of landslides are –

- Destabilization of the slope due to the action of groundwater pressure
- Vertical vegetative structure, soil nutrients, and soil structure that are lost or absent following a wildfire
- Rivers or ocean waves causing erosion of the toe of a slope

- Snow melt, heavy rainfall, glaciers melting, causing saturation and thereby weakening of a slope
- Earthquakes contributing to loads to a slope that is barely stable
- Destabilisation of slope due to earthquake-caused liquefaction
- Volcanic eruptions
- Aggravation of landslides due to human activities such as –
  - Cultivation, construction and deforestation, which cause instability in already fragile slopes
  - Vibrations from machinery or traffic
  - Blasting
  - Earthwork altering the shape of a slope, or imposing new loads on an existing slope
  - Removing deep-rooted vegetation, which binds colluvium to bedrock in shallow soils (Connors, 2019)

### 1.5.3 Types of Landslides

i. **Debris flow**

A debris flow or mud flow can form when slope material becomes saturated with water. The consequent slurry of mud and rock may pick up cars, trees, and buildings, thereby blockading tributaries and bridges, causing floods in the path.

Severe damage is caused to infrastructure and buildings in alpine areas due to muddy debris flows, further causing casualties. Slope-related variables can cause muddy-flows, and shallow landslides can dam stream beds, causing temporary water obstruction. As the reservoirs falter, a 'domino effect' may occur, resulting in a significant increase in the volume of flow of mass, which picks up debris in the stream channel. The liquid-solid mixture can achieve densities of up to 2 tons/cum and speeds of up to 14 m/s. (Aseta, 2018)

ii. **Earthflows**

Earthflows are viscous downslope streams of saturated, fine-grained particles that move at low or high speeds. They have slower motion and are covered in solid material that is carried along by internal flow as opposed to fluid flows that occur at a faster rate. Earthflows can affect clay, fine sand and silt, and fine-grained, pyroclastic material.

The velocity of the earthflow is entirely determined by the amount of water in the flow itself: the more water content in the flow, the higher the velocity. High rainfall saturates the ground and adds water to the slope content, causing earthflows to occur more frequently. Such flows originate usually when a fine-grained mass has enhanced pore pressures, such that the pore water supports adequate weight of the material, which thereby reduces the internal shearing strength of the material significantly. (Aseta, 2018)

**iii. Debris landslide**

A debris slide is considered by the haphazard motion of soil, rocks, and debris in the presence of water and/or ice. The saturation of densely forested slopes, which leads in an inconsistent mixture of broken timber, smaller plants, and other debris, frequently triggers debris slides. Debris slides typically begin with large rocks at the top of the slide that break apart as they tumble down the bottom. (Aseta, 2018)

**iv. Sturzstrom**

A sturzstrom is a type of landslide, unusual and poorly defined, with a significant run-out. These slides, which are often rather huge, are exceptionally dynamic, run a long distance over a low slope, flat, or even slightly uphill ground. (Aseta, 2018)

**v. Shallow Landslide**

In a shallow landslide, the sliding surface is positioned inside the weathered bedrock or soil mantle (usually to a depth of a few decimetres to a few metres). Debris flow, debris slides, and road cut-slope failures are common examples.

Block glides are landslides that occur when a single enormous block of rock moves slowly down a slope.

Shallow landslides are common in regions where sloped have high permeable soils sitting on top of low permeable bottom soils. High water pressure in the topsoil is created when water is trapped in the shallow, high permeable soils by the low permeable bottom soils. Slopes could become exceedingly unsafe and unstable, and can slide over low permeable bottom soils, as top soils fill with water and become heavy. (Aseta, 2018)

vi. **Deep-seated Landslide**

These are landslides where the sliding surface is usually located deeply, under the maximum rooting depth of vegetation (mostly to depths more than ten metres). They are characterized by significant slope failures associated with complex, rotational or translational movement, and typically involve weathered rock, deep regolith, and/or bedrock. (Aseta, 2018)

### 1.5.4 Impact of Landslides on Population

Critical infrastructure, housing, fields and farms, railway lines and border roads, water supply installation and hydro-electric plants, aerial ropeways, transmission line projects, tunnels, open cast mines, monasteries and heritage buildings, tourist spots and pilgrim routes, are all at risk of damage and losses due to India's vulnerability to landslides. Unprepared communities living on slopes with a history of landslides are most vulnerable to landslides. Landslides affect at least 15% of the nation's land area. (National Disaster Management Authority, 2009)

As the world's population grows, people are becoming increasingly vulnerable to landslides. People have a tendency to migrate to new territories that were once regarded too dangerous, but are now the only places left for a rising population. Deficient or non-existent land-use regulations allow for the development of buildings and other structures on land that would be better suited for open-space parks, agriculture or other purposes than for houses and other structures. Communities are usually unprepared to control harmful building practices, and may lack the legitimate authority or knowledge to do so. (Highland & Bobrowsky, 2008)

The short-term and long-term impact of landslides on society and the environment have been stated below –

i. The short-term impact includes for the loss of life and property at the affected site.

ii. The long-term impacts include irreversible changes such as degradation of cultivable land and environmental consequences, such as soil loss and erosion, as well as population shifts and establishment relocation.

iii. Susceptible zones are populated by socio-economically disadvantaged members of society. They have limited means of income, which, if destroyed by a disaster, renders them without food or shelter. Further, the injuries and fatalities that have occurred add to the troubles of the communities who have been affected.

iv. Disruption to infrastructure and heritage structures, as well as loss of private and government property.

v. Landslides significantly limit the effective life of, and returns from multi-purpose and hydroelectric projects by loading reservoirs with a large amount of silt.

vi. Large upstream regions are flooded as a consequence of landslide dams. Further, in case of dam failure, flooding and widespread catastrophe can occur in downstream areas.

vii. The volume and density of the regular streamflow may be increased, causing channel blocking and diversions, thereby resulting in flooding and localized erosion as a consequence of the solid landslide debris.

viii. Landslides also can affect dams to overflow, leading in flash floods and/or reduced reservoir storage capacity. (National Disaster Management Authority, 2009)

**1.5.5 Impact of Landslides on Natural Environment**

Landslides can affect the natural environment in the following ways –

- The morphology of the Earth's sub-aerial and submarine surfaces
- Natural forests and grasslands covering the planet's surface significantly
- Quality of streams and other water bodies
- Natural animal habitats, both on the surface of the Earth and in its streams and oceans

Morphologic impacts are part of a common tendency of bulk waste and erosion degrading the Earth's surface. Some of the losses that occur due to landslides are large scale die-offs of fish due to the abundance of landslide material polluting water bodies, adversely harming riverine and marine sources of food that communities either consume or sell in local and/or national markets, destruction of forest roads leading due to ground failure, thereby hindering and/or disrupting locally-sustaining or commercial logging activity, and devastation of forest access roads and landslide dams which cause flooding of farmland, villages, and obstruct the normal flow of downstream water, in turn, cutting off sources of water for drinking and irrigation owing to ground faults. (Schuster & Highland, 2007)

Landslide triggered by wave action is a primary reason for the withdrawal of coastal cliffs. Coastal retreat has an impact on tourism, commercial fishing, housing, and sediment loading.

Submarine landslides, also known as sub aerial landslides, are common in many regions of the world, especially on volcanic islands like the Caribbean Islands, Hawaiian Islands, and Canary Islands. The threat posed by this type of landslide has been investigated in light of the potential for huge, destructive tsunamis caused by the rapid breakdown of unconsolidated materials in steeply positioned areas into oceans and inlets. Most sites that have widely suffered older or even ancient submarine landslides are at risk of a similar major failure in the future. (Schuster & Highland, 2007)

#### 1.5.5.1 Impacts on Forests

Landslides causing forest destruction are widespread in several regions of the world, especially in tropical climates, as a result of the combination of heavy rains and earthquakes. A number of cases were reviewed by Schuster and Highland (2007). In 1960, a massive earthquake in Chile triggered landslides that damaged about 250 sqkm of forest. Landslides wiped away 54 sqkm of tropical forests after the 1976 Panama earthquakes (M6.7 and 7.0) (12 % of the impacted area). In 1987, intense rains and earthquakes ravaged 25% of the forest from Reventador Volcano in Ecuador, while in 1994, destroyed 250 sqkm of forest and soil in Paez, Colombia. (Schuster & Highland, 2007)
Smith et al. (1986) found that forest cover was restored to landslide regions more gradually than to logged areas; forest productivity in landslide areas was reduced by around 70% as compared to similarly-aged logged areas. In

rare circumstances, large water waves triggered by high-velocity landslides have also damaged forests. (Smith, et al., 1986)

#### 1.5.5.2 Impacts on Streams

A summary of impact of landslides on streams has been developed by Schuster and Highland (2007). Debris flows, which can fill and/or degrade the stream channel over lengthy ranges, are the most common types of landslides that affect streams (usually 100 km or more). Debris flows serve as essential sediment transport linkages between alluvial channels and hill slopes, thereby acting as a key component of drainage-basin sediment budgets.

Additionally, deposition of material in the channels or deposits providing a source for increased sediment transport of material further downstream, are the impacts of debris flow on the temporal and spatial distributions of sediment in stream channels.

Low-level, long-term deposits of silt and big woody debris to channels are caused by slumps and earth flows, as are partial channel closures, local channel restriction below the point of landslide entrance, and variations in channel configuration. However, the large, short-term increases in sediment and large woody debris; channel scour; large-scale reallocation of bed-load gravels; channel damming and constriction; intensified channel erosion and bank eroding; and channel shape deformation due to flow interruption are consequences of debris avalanches and debris flows. (Geertsema, et al., 2009)

#### 1.5.5.3 Impact on Drinking Water Quality and Environmental Health

By introducing suspended organic and sediment elements, landslides can have a harmful impact on drinking water sources. Landslides in watersheds over drinking water reservoirs are anticipated to be associated to poor water quality.

In the aftermath of the earthquake, epidemics have been linked to elevated concentrations of airborne dust on exposed landslide surfaces. (Geertsema, et al., 2009)

#### 1.5.5.4 Landslide Generated Tsunami

Tsunamis caused by landslides occur in water bodies all over the world. A notable example is the 8000-year-old Storegga submarine landslide off the coast of Norway. Its tsunami wreaked havoc and inundated coasts as far as Greenland.

Extensive fan-delta fracture and translational sliding resulted in 75 million cubic metres of coastline in Valdez Harbour, during the 1964 earthquake in Alaska (Schuster & Highland, 2007). In 1958, a rock slide-caused tsunami in Lituya Bay, Alaska, produced the largest displacement wave in recorded history (Pararas-Carayannis, 1999). A massive crater was carved in the inlet's floor by the rock avalanche removing the forest from the mountainside up to a height 500 m. (Geertsema, et al., 2009)

#### 1.5.5.5 Landslide Dams

The flooding of valleys and the failure of dams devastatingly resulting in outburst floods are the two main problems caused by landslide dams. The dams either introduce a significant amount of new silt load or trap sediments to streams. Landslide dams may last anywhere from a few minutes to millennia. Flooded woodlands may be able to sustain if the dam is only temporary, otherwise the submerged forests perish. Additional landslides occur above the landslide dam in some cases, most likely as a result of quick drawdown caused by lowering water levels. (Geertsema, et al., 2009)

### 1.5.6 Damage to Structures due to Landslides

Man-made structures are affected by landslides, whether they are located on or in the vicinity of a landslide. Since landslides destabilise or ruin foundations, walls, adjacent land, and above-ground and subsurface utilities, residential dwellings built on unstable slopes may suffer partial to complete collapse. Residential areas may be affected by landslides on a larger regional basis (in which numerous houses are affected) or on an individual site basis (where only singular structures or parts of a structure are affected).

Disruption to one property's lifelines (such as water supply, trunk sewer, or electrical lines, common-use roadways) can also affect the lifelines and accessibility routes of nearby properties. Landslides affect commercial structures in a similar way as residential. If the commercial facility is a common-use structure, such as a market, the repercussions could be severe if landslide destruction to the physical structure and (or) damage to the access routes cause a business disruption. (Highland & Bobrowsky, 2008)

A fast-moving landslide, such as a debris flow, is the most damaging type, and can entirely demolish a structure, since it usually occurs without warning or signs, and does not allow sufficient time for mitigation measures to be carries out. Due to the fact that debris avalanches and lahars are exceptionally fast-moving, powerful forces, they can easily erode or damage the structures and lifelines of cities, towns, and (or) neighbourhoods. (Highland & Bobrowsky, 2008)

#### 1.5.6.1 Impact on Infrastructure Networks

The transportation industry faces one of the most significant potential repercussions of landslides, and it impacts a vast number of people all over the world. Some of the common problems are cut and fill issues around railways and roadways, and road collapse due to underlying weak and slide-prone soils and fill. Rock falls have the potential to harm or kill vehicle-bound people and pedestrians, as well as cause damage to buildings.

Owing to road or rail blockage by dirt, debris, boulders, landslides can result in the interim or long-term closure of critical arteries for trade, tourism, and critical operations. Even slow creep can wreak havoc on linear infrastructure, causing costly maintenance issues. Highways are frequently blocked by landslides across the world, and many of them can be bulldozed or shovelled away. Others may need extensive excavation and, at least a temporary traffic detour or a road shutdown. (Highland & Bobrowsky, 2008)

### 1.5.7 Economic Consequences of Landslides

The direct losses from landslides include replacement, repair, or maintenance due to damage to installations and property, included within the limits of landslides that are responsible for such damage, or landslide-triggered floods. (Schuster, 1996)

Some examples of indirect landslide losses are:

- Damage to facilities or land, or disruption in transportation systems, thereby causing losses in tourism, agricultural, industrial and forest productivity revenues.
- Reduction in value of real estate in regions vulnerable to landslides
- Loss of revenues from properties whose value was reduced due to landslide damage
- Mitigation and prevention measures and actions required against additional damage due to landslides
- Severely affected quality of water in irrigation facilities and streams
- Injuries, fatalities, trauma, psychological impact, and the resultant loss of productivity (Schuster, 1996)

Indirect costs are typically observed to be higher than direct costs. However, since most indirect costs are hard to quantify, they are frequently overlooked or conservatively estimated.

One of the most difficult aspects of assessing landslide losses is that they frequently occur in a multi-hazard context, and losses that are actual landslide losses are factored towards the triggering event, resulting in all losses getting combined into one numerical figure. Volcanic landslides, for example, are one of the most dangerous consequences of volcanic eruptions. Due to the extreme heat from lava and tension caused by debris avalanches, these volcanic landslides are characterised in certain situations by structure collapse, as well as fast melting snow and accelerated debris flows. (Kjekstad & Highland, 2009)

### 1.5.7.1 Case of Alaska Earthquake (1964)

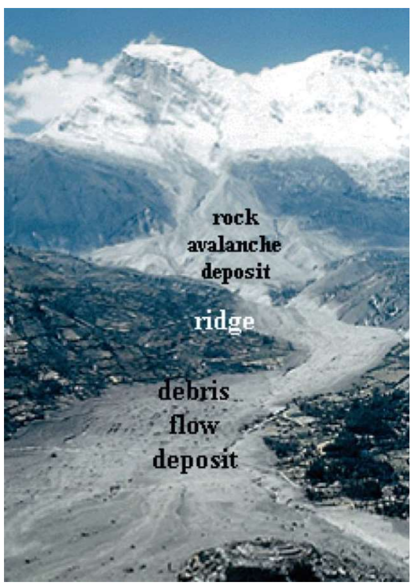


*Image 1 A photograph of the after-effects of a multi-hazard event.*

*It is an aerial view showing part of the Andes Mountains and Nevado Huascaran, the highest peak in Peru, South America. A massive avalanche of ice and rock debris, triggered by the May 31, 1970 earthquake, buried the towns of Yungay and Ranrahirca, killing more than 20,000 people. (Photograph by Servicio Aerofotografico National, graphics by George Plafker, U.S. Geological Survey).*

*Source: (Kjekstad & Highland, 2009)*

This earthquake triggered unprecedented occurrence of landslides, both in terms of number and intensity, as well as a landslide-generated tsunami that impacted not just the region around Anchorage, Alaska, but even the northern coast of California, causing casualties and property damage. Although the losses from landslides were substantially greater, the extensive damages have generally being attributed to losses from seismic shaking and faulting. The real nature of the event, as a complex, multi-hazard occurrence, was uncovered through extensive field work. (Kjekstad & Highland, 2009)

#### 1.5.7.2 Case of Northern Pakistan Earthquake (2005)

Another occurrence of a major hazard, a significant earthquake, in the October 8, 2005 earthquake in Northern Pakistan (M = 7.6), which triggered at least one catastrophic debris avalanche. The earthquake produced smaller regional landslides and severe ground cracking on sloped. A large debris avalanche created a landslide dam in a neighbouring river, in addition to burying an entire village. The landslide dam could not be removed due to a large amount of debris, and the obstruction triggered flooding upstream and slowed river flow downstream. A man-made channel was eventually built above the landslide dam to allow for the recovery of at least a portion of the river's original flow rate. (Harp & Crone, 2006)

*Image 2 Photograph of the Hattian Bala, Pakistan debris avalanche, resulting from an earthquake (M = 7.6) in 2005. The view is the impounded lake, created by a landslide dam.*
*Source: (Kjekstad & Highland, 2009)*

### 1.5.8 Social, Socio-Economic and Psychological Aspects of Landslide Occurrence

#### 1.5.8.1 Social Impacts

Natural disasters are anticipated to become more prevalent as the world's population expands, weather and climate become more dangerous, and anthropogenic triggers become more widespread. The social implicated of landslides are often misinterpreted and under-estimated. Loss of life, property, land, interruption of transportation, trapped communities with shortage of water, food and shelter, damaged communication infrastructure, loss of productivity and revenues from other departments such as tourism, psychological trauma, and mitigation costs are some of the crucial implications and losses. The economically weaker population generally bears the brunt of the social consequences, since they dwell in the most dangerous areas and have appalling housing conditions. (Kjekstad & Highland, 2009)

A destructive rockslide-debris avalanche transpired in a fractured, seismically active region with worn volcanic soils, in a thickly wooded area with a high population density in Leyte Island, the Philippines in 2006 called as Guinsaugon. Agricultural development at the bottom of the valley had a significant impact on the rock avalanches run-out. In terms of post-failure conduct, the run-out of the rockslide-debris avalanche was aggravated by un-emptied loading of rice paddy fields on the floor of the valley underneath the debris sheet, causing the debris to expand and flatten. The convergence of climatic, geological/tectonic, and cultural variables — a multi-faceted hazard condition – is assumed to be the cause of the exceptionally high number of casualties and damage of human habitat, including critically required cropland. (Evans, et al., 2007)

The potential risk involve in a landslide disaster can be lowered by reducing the hazard and/or vulnerability. Settlements in susceptible locations can be avoided with proper land use planning. It is possible to identify landslide hazard hotspots using suitable technology. Engineered solutions can help to alleviate threats. Preparedness for disasters has proven to be critical, and if well-planned, effective.

#### 1.5.8.2 Socio-Economic Impacts

Construction and engineering projects in the mountainous regions are often disrupted due to geo-hazards, the most common of which are landslides. A landslide not only ceases the work and poses critical risks to the structure under construction, but also jeopardises the safety of workers and movement of materials. Losses vary from damage to roads, electrical lines, and communication channels to housing. In areas that experience frequent landslide occurrence, geo-hazard prevention and control is advisable to perform a geo-hazard risk assessment before planning and construction processes commence. This can help decrease the losses considerably, thereby improving the social and economic efficiency.

(By Zhang Yongshuang, Zhang Chunshan, Shi Jusong, and Zhang, Jiagui, "*Consequences of Landslides on Infrastructure Development in China*" as a part of the World Landslide Forum Session on Socioeconomic Impacts of Landslides (Kjekstad & Highland, 2009))

Additionally, landslides and different mass movements are often times unexpected, and mapping of hazards can help in distinguishing areas that are potentially high-risk. However, only a few countries have enacted to put in place national hazard zonation mapping projects at any level. As a result, it is impossible to obtain lead time for taking preventative steps in potentially affected areas to avoid casualties or loss of property.

Landslide disasters are caused by risk factors (economic, social, and physical) that have not been addressed for a long period. The majority of landslides that have happened in the Asia Pacific region in the past have had a minor influence on urban centres, as their influence was concerted in rural areas. However, urban areas have been reported to have high susceptibility to landslides in recent events. Regardless of the triggering mechanism, landslides in metropolitan environments cause massive human and economic devastation due to the simultaneous failure of several slopes over a large region. It is caused by similarities in slope characteristics, land use patterns, sub-surface formations, and other factors, and it has the potential to damage a large population and substantial built infrastructure.

The rise of occurrences in urban areas is associated with a high degree of unsuitable construction practices, unregulated growth and development, and municipal planners' and engineers' reluctance to strictly implement land-use rules and regulated activities in disaster-prone locations. Landslide mitigation has been severely hampered as a result of this conduct. Although recent landslides in urban regions have increased pressure on authorities to implement land-use restrictions, improved construction practices, proper policy guidelines for urban hill slope redevelopment, and public awareness creation are yet to appear on the agenda of municipalities and urban local bodies.
(By N.M.S.I. Arambepola, "*Effective Land Use Planning Solutions for Landslide Risk Management in Urban Areas in Asia*" as a part of the World Landslide Forum Session on Socioeconomic Impacts of Landslides, (Kjekstad & Highland, 2009))

#### 1.5.8.3 Relocation of Communities

Once landslide-prone sites have been recognized, mitigation strategies will almost certainly be implemented. As a result, in these types of situations, communities with the greatest risk levels may need to be relocated. Relocation must be considered after a thorough examination of variables such as hazard awareness, landslide risk level, housing and structural condition, and livelihoods.

Following the determination of the risk level (high) and the occurrence of a disaster, affected communities are placed into two types of resettlement programmes. In this context, resettlement becomes an unavoidable need rather than a choice. One of the key concerns in this type of relocation, amongst other, is the effect on livelihoods. In these types of resettlement programmes, those with location-specific livelihoods are particularly vulnerable. As a result, identification of the socio-economic background, including occupations, livelihoods, occupation, etc. is critical in resettlement programmes.

(By Kishan Sugathapala, "*Impact on Livelihoods of Landslide Affected Communities due to Resettlement Programmes*" as a part of the World Landslide Forum Session on Socioeconomic Impacts of Landslides, (Kjekstad & Highland, 2009))

The World Bank along with a consortium of other organizations introduced a novel approach to accurately evaluate the socio-economic consequences of landslides on a worldwide scale in a mapped GIS format. In the publication, Global Hot Spots for Landslide and Avalanche Hazard (Nadim et al, 2006), the probability of occurrence of avalanche and landslide is evaluated by modelling physical processes and assimilating the results with statistics from previous experience. Topography and slope angles, seismic activity, extreme monthly precipitation, lithology, hydrological conditions and mean temperature in winter months (for use in snow avalanche conditions).

For risk assessment and evaluation, the calculations were based on human loss as documented in several natural disaster impact databases. The expected losses were estimated by first integrating the landslide frequency and the demographic exposed, to determine the physical exposure, and then performing a regression analysis using several uncorrelated socio-economical characteristics. (Nadim, et al., 2006)

The following geographical areas and countries have been identified as landslide hazard hotspots in the study –

- North-western South America
- Central America
- The Himalayan belt
- The Caucasus region
- Philippines
- Taiwan
- Italy
- Indonesia
- Japan

#### 1.5.8.4 Psychological Impacts

Landslide data and studies usually focus on financial losses and fatalities rather than psychosocial and social impacts and consequent losses. Nevertheless, numerous authors have looked into psychological issues such as psychosocial support and the moderating effects of family roles. Among these are studies on the frequency of psychiatric problems among victims and responsiveness to the needs of firefighters who intervene in the event and aftermath of a landslide for search and rescue activities. Some authors have also reviewed how landslides affect people's relationships and how this in turn affects their mental health. (Kennedy, et al., 2015)

It was observed that survivors were found to have post-traumatic stress disorder (PTSD), where 27.6% of them met the diagnostic criteria for PTSD. The symptoms were almost universal in the community under investigation the year after the disaster, with 90% of the study sample experiencing PTSD symptoms related to intrusive flashbacks. (Kennedy, et al., 2015)

It was also discovered that having additional disaster-exposure experiences, in addition to PTSD and major depression disorders, were directly connected to a higher risk of suicide among women. Suicide risk was found to be decreased in subjects who perceived high levels of family support. (Kennedy, et al., 2015)

Norris, et al. (2005) observed that people who survived mass movements had a deterioration of social support as compared to those who lived in flood-affected regions. The re-establishment of social support was delayed among those who had escaped landslides. (Norris, et al., 2005)

Post the landslides in Puerto Rico in 1985, researchers studied the role of family support in calamities. More number of cases were reported involving depression, alcohol abuse, and total psychiatric symptomatology in case of lower levels of emotional support from the family. (Solomon, et al., 1993)

During and after disasters, the mental health and psychosocial well-being of relief personnel, rescue workers and their families are also in jeopardy. A multitude of factors exacerbated the labour-intensive and dangerous emergency response, include exhaustion, dissatisfaction, worry for personal safety, prior knowledge of the victims, and media attention. (Kennedy, et al., 2015)

### 1.5.9 Loss Potential Ensuing Landslides

A detailed comprehension of the socio-economic and physical repercussions of landslides can help develop refined strategic planning, mitigation methods, and land use policies. The link between physical and economic exposure, as well as the likelihood of landslide occurrence in an area-weighted for its socio-economic exposure based on real-estate market values, plays a key role in hazard mapping and estimation of loss potential that could be incurred due to landslides. (Donnini, et al., 2020)

Landslide risk assessment is an uncertain and complex task that necessitates information of the following –

i. **The hazard (H)**, the probability of a landslide of given magnitude (for instance, area or volume) occurring in a given area (susceptibility) in a specified timeframe
ii. **The vulnerability (V)**, the potential damage or losses incurred due to a landslide
iii. The number and the type of the **elements at risk (E)**

Finally, the risk analysis can be utilised to calculate the potential economic losses resulting from occurrence of landslides. Nevertheless, the final result may be difficult to achieve because estimating the potential losses due to landslides is a complex process for the wide range of potentially exposed elements, which is especially significant when considering the urban context. Human interaction and anthropogenic activities have frequently resulted in unrestrained urban development, which magnifies the effects of natural disasters.

Donnini, et al. (2020) detailed a replicable measure for evaluating a wide area's tendency for landslide devastation and consequently, for assessing the associated potential economic losses. A streamlined method was presented, that integrates landslide susceptibility, or the likelihood of a landslide occurring in a given location due to local factors, with potential economic losses in terms of direct market values of real estate, which serve as a proxy for overall economic exposure.

This project attempted to develop an economic landslide susceptibility metric that can capture the likelihood of a landslide occurrence in a given area, weighted for its socio-economic exposure. This scale can be used to estimate the relative probable socio-economic costs of landslides in the area under consideration. The approach was tested in Umbria (Central Italy), a high-risk landslide-prone region known for its abundance of landslides in both urban and rural areas, and the lack of credible landslide hazard models. (Donnini, et al., 2020)

Batista, et al. (2019) did a second study for a Highway Domain Strip that included performing a vulnerability assessment for use in landslide risk assessment in the Serra Pelada Region (Brazil). The goal of the study was to develop methodologies for determination of (a) the economic value of slope landslides and (b) their susceptibility in areas affected. The economic measurement methodology devised in this study included both direct and indirect cost to assess the total costs. The direct costs include impacts connected to the rehabilitation or construction of highways, unpaved roads, infrastructures, commercial and residential buildings, vegetative cover, and agricultural lands. The indirect costs include economic losses borne by victims, agricultural area profitability, and highway interdictions. (Batista, et al., 2019)

The following steps were used in the economic risk evaluation: (i) identification of susceptible elements; (ii) collecting local data; (iii) production of the total costs measurement map, which included both direct and indirect costs in its composition; (iv) elaboration of the risk analysis map using loss indexes, ranging from 0 (no loss) to one (total loss), (v) creating a vulnerability assessment map that expresses the likelihood of a landslide occurrence, and (vi) economic landslide risk mapping – production and validation. (Batista, et al., 2019)

### 1.5.10 Multi-Hazards Associated with Landslides

Global climate change is evidence of how landslide hazards are strongly linked to another primary event, and may not be apparent in landslide data. The lateral slopes that held the ice in place are being destabilized as a result of glacial retreat, culminating in slope failure, including Glacial Lake Outburst Flood (GLOF). This type of hazard is becoming a greater threat to human settlement and infrastructure in Nepal, as well as Bhutan and India to a smaller extent owing to global climate change.

Because of the threats of GLOF occurrence, insurance policies for new hydroelectric power stations in these regions have grown expensive in some situations. Glacial regret also causes other forms of dangers. For instance, some glaciers are retreating in Alaska, causing slope destabilisation and collapse, which has resulted in massive tsunamis when the slope failure happens in inlets, bays, or other coastal areas where glaciers border these regions. (Wieczorek, et al., 2007)


*Image 3 The Gangotri Glacier, India where the glacial retreat from the Indian sub-continent has been about 18 m per year. This study was carried out by The International Centre for Integrated Mountain Development (ICIMOD), Nepal, in 2007, to understand the impact of climate change on glacier retreats in the Himalaya Mountains (Photograph from ICIMOD)*

*Source: (Kjekstad & Highland, 2009)*

Natural disasters such as earthquakes, floods, landslides and volcanic eruptions can take place simultaneously, or some of these disasters can trigger others. Landslides often occur due to floods, earthquakes, and volcanic activity, and consequently can lead to further hazards; for instance, an earthquake-induced landslide may further trigger a catastrophic tsunami if

sufficient landslide debris slides right into a water body, displacing a large amount of the water.
Another case example is a landslide caused by a volcanic eruption or earthquake that obstructs a river, causing water to back up behind the mound and flood the area upstream. If the dam fails, the water being held back will be released all at once, causing floods downstream. With fast saturation of slopes and undercutting of cliffs and banks, these floods can accelerate riverbank and coastal erosion and destabilization. Therefore, when assessing a region's susceptibility to landslides, it is vital to investigate the potential of other possible hazards. Currently, few maps exist, that depict multi-hazard vulnerabilities; in most locations, if natural hazards are mapped at all, only singular hazards are mapped. (Highland & Bobrowsky, 2008)

### 1.5.11 Post-fire Landslide Hazards

Landslides can result in broken electrical, gas and fuel pipelines, thereby increasing the risk of fire hazards post the disaster. However, landslide is also a consequent phenomenon to occur after wildfires and forest fires. Extension of anthropogenic activities and land development into forest cover has led to forest wildfires, landslides and flooding, which pose threat to life and property.

Landslide hazards post-wildfire involve the rapid movement of devastating debris flow that can happen in the years following wildfires as a response to high-intensity rainfall events, as well as extended flows along with root decay and depletion of soil strength. Post-fire debris flows are excessively dangerous because they can strike without warning, can strip vegetation, can exert large impulsive stresses on objects in their paths, obstruct drainage channels, destroy structures, and put human lives in danger. Wildfires have the capacity to result in disruption of pre-existing deep-seated landslides across extended periods of time. (U.S. Geological Survey, 2021)

Post-wildfire dangers can get activated as soon as an area has been extensively burned, and can to two years or beyond. However, debris flow and increased flooding risks in some excessively burned areas could persist for much longer. Reforestation and the breakdown of soil water resistance after two to three years indicates that the risk has reduced significantly. Hence, it is critical to ensure the execution of a post-wildfire risk assessment in order to determine the safety concerns to nearby residential areas. These kind of studies aid in determining the safety concerns to residential areas near wildfires. (Ministry of Forests and Range, 2011)

## 1.6 FLOODS

Floods occur when *an overflow of water submerges land that is usually dry. Floods are often caused by heavy rainfall, rapid snowmelt or a storm surge from a tropical cyclone or tsunami in coastal areas.*

Floods can result in massive destruction, consequently causing damage to critical public health infrastructure and property, fatalities, displacement of households and victims, etc. populations living in non-resilient buildings, or residing in floodplains, and have lack of access to warning systems and awareness of flooding, are the most susceptible to damages and losses. (World Health Organisation, 2020)

One of the most devastating hazards, floods affect humans and their livelihoods globally. When developing nations are struck by natural disasters of such magnitude as flooding, decades of investments and financial ventures can be wiped out, in addition to personal wealth of the victims, loss of life, trauma, injuries, and disease. (United Nations International Strategy for Disaster Reduction, 2004)

### 1.6.1 Classification of Floods

While different types of floods occur at different velocities, they are typically categorised among sudden onset phenomena. The classification of such floods are as follows –

- **Flash floods** are a result of intense and rapid rainfall, which causes water to rise in heights quickly, thereby overtaking roads, streams, rivers or channels.
- **River floods** are a result of constant rainfall of snowmelt, which causes surpassing of the river's capacity.
- **Coastal floods** are a result of storm surges, typically related to tsunami and tropical cyclones.

The factors that influence the severity of flooding disaster are – duration, depth of water, rate of rise, velocity, season and frequency of occurrence. (World Health Organisation, 2020)

### 1.6.2 Causes of Floods

The major causes of floods are as stated below –

i. Rivers bring down high flows from the upper catchment areas that occur due to heavy rainfall, and cannot restrict these high flows within their banks due to their insufficient capacity. This leads to flooding in the rivers.

ii. Accumulation of water due to heavy rainfall causes flooding of areas that have poor drainage services and infrastructure.

iii. The problems of water logging are accentuated by increase in the ground water levels as a result of seepage from irrigated agricultural fields and canals, and by excess irrigation water applied to command areas.

iv. Silting of riverbeds, reduced capacity of river channels to carry water, changes in river courses due to erosion of banks and river beds, hindrance in flow as a result of landslides, are some of the factors that exacerbate the flooding problem.

v. GLOFs caused as a result of sudden release of large quantities of bounded water in glaciers can cause severe floods.

vi. Tropical cyclones, well-marked lows, and depressions result in rainstorms, which subsequently cause flooding in river basins.

vii. Floods may also be a result of cloud bursts which lead to sudden unprecedented heavy rains within a short duration. (National Disaster Management Authority, 2008)

### 1.6.3 Flash Floods

Flash floods can be attributed to sudden rise and recession of water flow of high discharge and small volume. They can cause significant destruction due to their sudden nature. Flash floods are common in areas that are hilly and have sloping lands, where thunderstorms, cloudbursts and heavy rainfall are frequent.

Flash floods are also a result of cyclonic storms and depression, and usually occur in coastal areas of Andhra Pradesh, Odisha, Karnataka, West Bengal and Tamil Nadu.

Flash floods occurring as a result of cloudbursts affect areas such as Assam, Arunachal Pradesh, Himachal Pradesh, Uttarakhand, Odisha, Western Ghats in Maharashtra and Kerala.

Breaches in landslide dams, unexpected release of water from reservoirs upstream, breach in river bank embankments lead to sever floods, some examples of which are the floods in Arunachal Pradesh in 2000 and in Himachal Pradesh in 2000 and 2005. (National Disaster Management Authority, 2008)

### 1.6.4 Urban Flooding

With the development of civilisations along river courses and growth in towns, cities and their populations, floods plains have been encroached considerably, due to absence of land regulations and controls. Due to the insufficient capacity of the storm water drainage systems in such areas, the damages become more critical. As observed in the cities of Mumbai, Chennai, Bengaluru, Ahmedabad, Vadodara, Surat, Hyderabad, Kolkata, Vijayawada and Vishakhapatnam, urban flooding has become not only a nuisance but also a serious problem.

This implies that the cities and towns are being flooded not only because of excessive sudden rainfall, but majorly due to incessant encroachment of waterways, inadequacy of drains and poor maintenance of the infrastructure for drainage and storm water discharge. (National Disaster Management Authority, 2008)

### 1.6.5 Glacial Lake Outburst Floods – GLOF

Glacial Lake Outburst Flood (GLOF) can be defined as the sudden, unexpected release of a large amount of water that had been retained in a glacial lake, regardless of the cause. GLOFs are distinguished by extreme peak discharges, usually because of floods triggered by hydro-meteorological factors, carrying transport potential or excessive erosion material. As a result, these can also turn into GLOF-induced debris flow-type movements. (UN-SPIDER, 2021)

While the causes and mechanisms of GLOFs may be diverse, the specific causes are typically associated with specific mechanisms, and not all combinations lead to realistic scenarios. Some of the direct causes of GLOFs are stated below –

- Heavy snowmelt/rainfall
- Rapid slope movement into the lake
- Earthquakes
- Cascading processes (flood from a lake situated upstream)
- Blocking of subsurface outflow tunnels
- Melting of ice incorporated in dam/forming the dam
- Long-term dam degradation (UN-SPIDER, 2021)

It is common to find glacial lakes in the high elevation of glaciered basin. They are formed by impounding of water from moraines or glacial ice, in natural depressions. Such lakes are of different types, ranging from big lakes formed in side valleys and dammed by glacier in main valley, to ponds of melt water surface of glacier. The water from these lakes is usually drained through seepage from the front of the retreating glacier. Glacial lakes are also formed when melt water is accumulated in a topographic depression created by a moraine. These melt waters continue to accumulate when these lakes are watertight, until the overflow or seepage limited the lake level. (Central Water Commission, 2020)

The most common type of glacial lakes are the moraine-dammed lakes. The stored water may be released in large quantities, when the impoundment of the melt becomes unstable. Many examples of devastation caused by such ice or moraine dams have been observed globally.

The GLOFs are common in Himalayas, where such moraine and glacial lakes are often formed due to landslides. Even with their immense potential to devastate downstream areas, not enough data and statistics are available, about the location of landslides, rainfall intensity, impounded volume and area, physical conditions of lakes, thereby making the consequences of such occurrences highly unpredictable. It is therefore, important to closely monitor the lakes and water bodies in the Himalayan regions. (Central Water Commission, 2020)

### 1.6.6 Impact of Floods on Population

#### 1.6.6.1 Factors of Vulnerabilities

Natural and man-made factors include –

- Non-resilient foundations and superstructures
- Settlements located on floodplains
- Low absorption capacity of land due to concrete paving or soil erosion
- Absence of warning systems and awareness of the flood hazard (World Health Organisation, 2020)

#### 1.6.6.2 Direct Impacts of Floods

- Fatal injuries and drowning
- Injuries, punctures and lacerations
- Electrical shock
- Transmission of communicable diseases
- Amplified risks of water and vector borne diseases (World Health Organisation, 2020)

#### 1.6.6.3 Indirect Impacts of Floods

- Inundation of critical infrastructure, especially health facilities
- Shortage of water, food and shelter
- Disruption of basic public health services
- Contamination due to chemical releases (World Health Organisation, 2020)

Apart from the damages and losses to property and lives, fear and a sense of insecurity prevails in communities that are prone to floods, and are residing in flood plains. Floods result in injuries and trauma to survivors, spread of epidemic, and lack of basic necessities, food, water, medicines, and loss of residence. (National Disaster Management Authority, 2008)

### 1.6.7 Impact of Floods on Natural Environment

The impacts of flooding on the natural environment are complicated and often not considered in policy making and decision making processes. Water management has shifted focus from domination over water resources, to harmonious philosophies of striking balance among the structural flow control which in turn supports and protects the environmental well-being.

However, in terms of political action and engineering/design interventions, there is a lack of understanding of environmental flood dynamics, and a constant need to be able to control floods, which thereby inhibits the implementation of the philosophical changes and the paradigm shift in water management. (Hickey & Salas, 1995)

Flooding has been found to impact the well-being of livestock and wildlife, cause dispersal of pollutant and nutrients, cause sedimentation in rivers and erosion of banks, in addition to impact of local landscapes, micro-habitats, and effects on surface and groundwater supplies.

It has also been found that flooding can sometimes affect the natural environment positively, by providing nourishment to the landscape. Annual floods occurring on a regular basis can help provide water replenishment and resources for irrigation, domestic usage and industrial usage. Floods can also benefit biological diversity in the ecological systems of the flood plains.

Further, rivers often carry nutrients and minerals that can help improve agricultural production in the flood plains. However, it is difficult to quantify these ecological consequences in terms of benefits, since these benefits may surface several months or years later, or may not even be apparent at all. (Svetlana, et al., 2015)

### 1.6.8 Geological and Hydrological Impacts of Floods

The risk of flooding may have increased, owing to several changes in land usage, which causes changes in hydrological and geological systems. A decrease in collection of water in the basins and increase in runoff has been observed due to excessive urbanisation, deforestation and reduction of wetlands. The risk of flooding increases due to urbanisation, primarily caused by increased impervious surfaces on roofs, roads, parking lots, sidewalks, etc. Concrete and asphalted surfaces cause rapid rainwater runoff, thereby causing the soil to dry up, reduced groundwater levels and climate change. The risk of local flooding is enhanced due to changes in drainage conditions as a result of these factors. (Svetlana, et al., 2015)

### 1.6.9 Damage to Structures due to Floods

Floodwaters exert physical forces on the structure, and these forces can be divided into three load cases. These are hydro-dynamic loads, hydro-static loads and impact loads. These loads can be intensified by effects of soil being washed away from around and under the foundation due to the floodwaters. Hydro-static forces are both vertical (buoyant) and lateral (pressures) in nature. The difference in exterior and interior water surface elevations result in lateral forces. With the increase in level of floodwaters, the higher levels of water on the exterior of the structure act inward against the walls of the building. (Rogers, 2008)

Excess lateral pressures can result in damage to structure elements and cause permanent deflections. Further, the basement wall may collapse inward if the lateral pressures from saturated soils around the structure exceed the structural capacity of the walls in the basement.

The displacement of water causes vertical uplift in the structure due to the presence of buoyant forces. The structure may float from its foundation if these buoyant forces exceed the weight of the components of the building. (Rogers, 2008)

Additionally, hydro-dynamic loads are exerted by the moving water around the structure. The lateral pressure exerted by the flowing water can collapse the floor systems and structural walls. Further, the building may get shifted from its foundation due to the net downstream force against the structure. (Rogers, 2008)

Impact loads can be induced by direct forces linked to the waves, usually encountered in coastal floods, or due to the impact of floating debris. These can cause severe destruction due to the high order of magnitude of the forces as compared to the hydro-dynamic and hydro-static forces. (Rogers, 2008)

#### 1.6.9.1 Impact on Infrastructure

Flooding can severely affect the critical infrastructure due to inundation and inaccessibility, thereby disrupting the functioning of the interdependent facilities. One of the most critical and most disrupted infrastructure systems is the energy sector. Disruption in power supply can cause failure in many functions and operations; however, most of the energy-dependent CI systems have backup power to enable uninterrupted functioning for 2-4 days (systems such as hospitals, communication, storm water, waste water, and drinking water plants). Road and rail transport systems can get affected by disrupted power supply due to interrupted functioning of traffic signals, traffic lights, bridges, tolls, etc. thereby leading to further delays. However, these backup systems need fuel supply, and the lack of accessibility to the fuel storage due to blockage and inundation can cause even the backup systems to get interrupted. (Bruijn, et al., 2019)

Facilities such as healthcare, airports, railway stations, power stations, etc. can be inaccessible for many days owing to the submerged and blocked roads, as a result of stagnant floodwater and debris, fallen power lines and uprooted trees. The inaccessibility of road networks can cause lack of access to supplies of food, water, shelter, in addition to hampered search and rescue activities. (Bruijn, et al., 2019)

### 1.6.10 Economic Consequences of Floods

Damages caused by floods can be categorised as direct and indirect. Damages that occur as a result of direct physical contact of floodwaters with property, humans and other objects are direct damages. Indirect damages are consequences of direct impacts, and can occur in different time or space outside the flood event. Further, both these types can be categorised into intangible and tangible damages, depending upon their feasibility of monetary assessment. (Merz, et al., 2010)

Damages that can be easily assessed in monetary terms, and occur to resource flows and man-made capital are tangible. Damages that are difficult to translate into monetary values, and occur to assets not tradeable, are intangible. While it is conventional to differentiate between direct, indirect, tangible and intangible damages, delineations and interpretations differ.

Some examples of the different types of damages are –

i. **Direct, tangible**: damage to infrastructure, buildings and its contents, agricultural losses, destruction of crop harvest and livestock, business interruptions, clean-up costs

ii. **Direct, intangible**: fatalities, injuries, distress, loss of memorabilia, damage to cultural heritage; negative impacts on ecosystems

iii. **Indirect, tangible**: cost of disruption to traffic, migration of companies post floods causing loss of tax revenue, disruption of public services outside the flooded area, induced production losses to companies outside the flooded area

iv. **Indirect, intangible**: loss of trust in authorities, psychological trauma

Direct losses can be assessed easily as compared to indirect losses. Indirect losses and impacts may have an added component of time scale of months or years. Further, cascading impacts of higher order can be estimated, such as long-term obstructions to development of flood affected areas. (Merz, et al., 2010)

#### 1.6.10.1 How Floods Shape Economic Behaviour

The frequency and severity of floods and droughts have been on an increase nationally in India. These two natural hazards accounted for 51% of the natural hazard occurrences and around 76% of the damages related to natural disasters in the country between 2000 and 2020. Between the months of June and October, the southwest monsoon rains account for more than 70% of the precipitation annually in the states located along the large river basins, such as Ganges, Indus and Brahmaputra. These river basins produce significant runoff during the monsoons, thereby causing significant flooding in the plains. This leads to around 43% of the population of the country vulnerable to recurrent flooding. 30% of the population is dependent on agriculture for their livelihoods, which are also susceptible to losses due to recurrent flooding and droughts. (Amarasinghe, et al., 2020)

To indicate the extent of inundation, FLEA, or the FLood-Exposed Area, is used to determine the maximum area exposed to flooding in a year. The total area of flood exposed pixels in a state is the FLEA value of that state. However, some areas can experience multiple floods during the monsoons, such as the regions located in the lower reached of Brahmaputra and Ganges. Such waves of flooding can cause heavier damages as compared to a singular flooding event.

However, such massive and recurrent floods do not have significant impacts on the Human Development Index (HDI) and the Gross State Domestic Product (GSDP) of the states affected, which are located downstream of the river basin of the Ganges. The HDI and GSDP values of these states are uplifted by the huge financial investments towards flood adaptation and mitigation. Additionally, such floods spread in a larger area and therefore help in groundwater recharge, which acts as a significant source of irrigation during the dry periods of the non-monsoon months. (Amarasinghe, et al., 2020)

### 1.6.11 Psychological and Socio-Economic Aspects of Floods Occurrence

Victims who have been exposed to the catastrophic eventualities have been consistently found to face severe psychological consequences. The most common disorder founds in these victims in PTSD. The symptoms of PTSD include emotional numbness, re-experiencing of the trauma, and exaggerated arousal. (Mason, et al., 2010)

The risk of psychological conditions consequent of a previous injury or disease is increased on exposure to flooding. People and communities who were victims of severe flooding and were force to evacuate were found to be almost twice as likely to experience PTSD, depression and anxiety, in contrast to the people who did not need to evacuate from their dwellings. Therefore, the increase in possibility of showing symptoms of psychological distress can also be a consequence of dislocation or relocation. Additionally, victims who had experienced floods previously showed increased symptoms of anxiety and PTSD due to fear of re-occurrence. (Mason, et al., 2010)

Further, another risk factor for symptoms of depression, anxiety and PTSD was self-reported physical health. Victims who were in poor health conditions were observed to be 2 to 4.2 times more likely to have symptoms of psychological distress and trauma, as compared to victims in good health conditions. An increase in PTSD was observed in children who were exposed to floods, and has been associated with the use of coping strategies. (Mason, et al., 2010)

The psychosocial resilience of people may be challenged due to their exposure to flooding. Further, floods can cause significant social and welfare disturbances, which can continue for long periods of time. This is because of primary stressors such as the fear of drowning and possessions being flooded, and secondary stressors such as those which are linked to the initial occurrence indirectly (for instance, the financial distress linked to re-building the houses). (Mason, et al., 2010)

**1.6.11.1 Socio-Economic Aspects**

The stability of a society is critically endangered by extreme events such as floods. The communities are affected more intensely when there is an increased number of dwellers and businesses in vulnerable regions. More occupants imply more buildings, leading to an increased number of such buildings to be evacuated. Emergency accommodation would be needed for all the evacuees, flooding will causes more workers to lose their livelihoods. The production of many more companies would be needed to be ceased abruptly, thereby halting the provision of their services, and causing unexpected shortfalls in the revenue and tax receipts. This can further result in causing municipal budgets to run out of balance and consequent ill-funding of public services. Also, repair of infrastructure also exerts strain on the already dipping economy. (Svetlana, et al., 2015)

On an individual level, the natural disasters can affect the low-income households disproportionately, thereby forcing them to give up expenditure on preventative healthcare and education to be able to sustain basic consumption. In the aftermath of disasters, the low-income households may experience financial distress for a long period of time, and struggle to live with the foregone income. Even as disaster recovery and financial aid programs are oriented towards appropriate compensation for damages to property and houses, the amount may not be sufficient to support the requirements of the people struggling with impacts that are unaccounted for. Post-disaster assessments often overlook or exclude the wider socio-economic implications, thereby having significant repercussions on the response and mitigation policies and decision making processes. (Allaire, 2018)

**1.6.12 Loss Potential Ensuing Floods**

Flooding can impact the society and economy in two major ways – (a) partial or complete damage to physical assets, and (b) the consequence of damages being losses or changes in economic flows in the region affected (including the disruption in services). In concept, there is an essential difference of comprehension between flood losses and flood damages. The term *flood damages* refers to the structural or physical damage inflicted on private and public property and assets, like housing, infrastructure, vehicles, etc. as a consequence of coming in contact with the floodwater. The term *flood losses* refers to short-term changes in the economic flows between the time of the occurrence of the disaster, until the time of full reconstruction and economic recovery. (World Meteorological Organization and Global Water Partnership, 2013)

The time taken for economic recovery and reconstruction can last up to several years in some cases. Such losses usually include a short-term decline in productivity, output, and higher costs of production in sectors of livestock, agriculture, fishery, tourism and trade. The losses also include higher cost of operating services such as healthcare, communication, education, electricity, water supply and sanitation, transport) with lower revenues, the humanitarian assistance requirements in the emergency phase that incur unexpected expenditures. Losses are typically shown in current values.

It is therefore, of utmost importance to develop an in-depth understanding of the economic, financial and social repercussions of natural and man-made disasters so as to be able to mitigate the vulnerabilities of the communities, infrastructure, and built and natural environment. The DaLA (Damage and Loss Assessment) methodology introduced in 1972 has been further developed to obtain the nearest approximation of losses and damages caused by disasters, and identify the resources of financing that can help attain full recovery and reconstruction. This tool has been recognised and applied across the globe for quantification of losses and damages. Using the DaLA methodology consistently aids the identification of the socio-economic impact of flooding and the exposure of physical and infrastructural assets. It also promotes the ideology of 'build back better', in recovery and reconstruction efforts, thereby also enforcing resilience. The post-disaster assessments leading to estimated needs for recovery and reconstruction are facilitated by the Global Facility for Disaster Reduction and Recovery (GFDRR). (World Meteorological Organization and Global Water Partnership, 2013)

#### 1.6.12.1 Actual and Potential Losses

A major aspect of assessment of damages and losses based on previous experiences of flooding or synthetic stage-damage relationships is the assumption that the communities or households that will be affected would not have taken any preparatory actions. These preparatory activities include clearing out storage from the ground floor and basement, moving vehicles to higher ground, and sealing the openings such as doors and windows in the buildings. While such assumptions assist in the assessment of potential losses, the level of actual losses is significantly influenced by flood awareness and preparedness of local households and communities. Therefore, to establish an integrated methodology for flood management, the project appraisals should account for the benefits of structural measures and flood defences, as well as the benefits of flood preparedness, risk awareness among the communities, and measures of mitigation undertaken. (World Meteorological Organization and Global Water Partnership, 2013)

#### 1.6.12.2 Economic and Financial Assessment

*"The intention of economic analysis as part of a flood loss assessment is to assess the deviation from likely economic activity as a result of the flood, not to take into account the financial losses to individual enterprises. This is not always easy to do, and you will commonly have to make approximations to this ideal."*

(Emergency Management Australia, 2002)

Financial assessment includes the losses suffered by households, property or businesses due to flooding. The following example illustrates the difference between financial assessment and economic assessment. Due to blockage of roadways as a consequence of flooding, a facility for food production was unable to transport goods to its consumers. However, a competitor benefitted from this situation by substituting goods from its own inventory, thereby gaining an increase in income as an indirect impact of the flooding. Hence, this incident would not impact the economic effects of flooding. (World Meteorological Organization and Global Water Partnership, 2013)

#### 1.6.12.3 Flood Loss Assessment Process and Methods

*i.* ***Rapid assessment during the flood***

The intent of conducting as assessment during a flood occurrence is primarily to obtain a factual basis for coordination of relief measures and arrange for emergency response systems, in addition to achieving a detailed understanding of the overall situation of flooding, the consequences and effects, and therefore, to devise a set of policy recommendations for the post-disaster phase, that deal with the attendant problems such as rise in sea levels or global warming. The most significant activity in the post-disaster phase is to emphasize on minimising the impact on affected communities and population, avoid further loss of life, and mitigate secondary disasters and cascading effects. (World Meteorological Organization and Global Water Partnership, 2013)

*ii.* ***Early recovery assessment***

The early recovery period post the peak of flood occurrence is one to three weeks. The purpose of assessment in the early recovery period in the immediate aftermath of the occurrence is to guide the process of recovery and provide early suggestions for reconstruction, keeping note of the following –

- The design of financial mechanisms is facilitated for rapid recovery
- Setting priorities and laying foundation for allocation of recovery assets
- Providing recommendations for repair and reconstruction of critical infrastructure and the coping capacity of the government for this purpose
- Identify the mistakes in planning and development practices in the past that need to be taken note of, during reconstruction and planning. (World Meteorological Organization and Global Water Partnership, 2013)

***iii. In-depth assessment 3 to 6 months after the flood***

It is only after three to six months post the event that a detailed assessment of the total economic impact can be conducted reliably. By this time, the direct and indirect losses are more apparent and can be analysed and estimated with sufficient accuracy and consistency. (World Meteorological Organization and Global Water Partnership, 2013)

### 1.6.13 Fire and Chemical Hazards as Consequences of Floods

#### 1.6.13.1 Fire Hazards

Flooding can lead to fire outbreaks in relation to gas leaks, damage to gas pipelines and damage to electrical works, in addition to increased risk of structural fire. Damage to structures due to flooding and its impacts can enhance the vulnerability. Additionally, compromised safety on account of affected or damaged appliances can lead to fire hazards.

However, it has also been recorded that the forest fires can make forests more vulnerable to flooding, thereby increasing the risk of post-fire flood hazards.

#### 1.6.13.2 Floods after Fire

Forest wildfires on a large scale have been observed to alter the soil conditions and terrain significantly. While forests and vegetation absorb rainfall and reduce the water runoff, wildfires render the ground and soil burnt, eroded and incapable of absorbing rainfall, thereby making the ground vulnerable to mudflow and flash flooding.

Only a few minutes of rainstorm can trigger such flash floods. Changes in landscape due to widespread fire induce vulnerability to regions that are not traditionally prone to flooding. The risk of flooding remains extremely high up to 5 years post a wildfire event – or until forest cover/ vegetation is restored. Further, damage caused by floods after fire are devastating, since the ash and debris remains from the fire can contribute to mudflows. The rainwater, moving across barren land, can pick up this debris, soil and sediment, and carry it downstream with floodwaters, which can cause subsequent damage. (FEMA, 2020)

While the burnt lands can experience flooding related to wildfire and increase in runoff for many years to follow, typically debris flows after the fire rarely occur beyond the second season of rainfall. Triggering debris flows due with rains is much easier from burned land as compared to unburnt land. There are various factors affecting the triggering and occurrence of debris flow, but post-fire, the debris flow is typically triggered due to two factors – (a) land-sliding due to seepage of rainfall into the soil, and (b) surface erosion due to runoff from rainfall. (United States Geological Survey, 2020)

#### 1.6.13.3 Chemical Hazards

A natural disaster can cause chemical releases indirectly or directly. The small releases include washing away of household chemicals from storage to floodwaters, and the large releases involve chemical spills in thousands of litres from a storage tank that has been ruptured due to flooding. These large-scale releases are especially possible when pipelines and storage vessels are involved, in addition to fixed chemical installations, and connecting flanges and pipes. (Krausmann, et al., 2011)

Storage tanks containing flammable materials struck by lightning accompanying cyclones can get ignited, causing widespread fires. Also, disruption in power supply can cause interruption in chemical processes or changes in pressure and temperature control valves and monitors, thereby causing blowdown and runaway chemical reactions. Tankers containing chemicals can get overturned or derailed because of damage to roads and railways as a consequence of flooding. (Hasegawa, et al., 2016)

Drinking water sources can get contaminated due to flooding, due to remobilisation of chemicals already present in the environment, or due to released chemicals. Chemicals such as disinfectants and reagents can be released in case of damage to laboratories and hospitals. Pipes can freeze and burst due to expansion of melting chemical contents, when exposed to long period of intense cold or very low temperatures. Equipment can suffer structural damage due to heavy ice. (Cruz & Krausmann, 2013)

#### 1.6.13.4 Risk factors for chemical release

From the analysis and records of previous flooding events, it has been observed that pipework and storage tanks are significantly susceptible to damage due to floods. Further, some of the factors that enhance the susceptibility of any region to chemical release and consequent health damage include –

- Inefficient building and planning regulations
- Industrial facilities located in areas that are prone to floods
- Non-resilient structures
- Grounds that do not have efficiency or capacity to absorb rainwater, due to deforestation, erosion, or impervious flooring materials
- Unsatisfactory warning systems
- Deficient emergency planning and safety measures
- High density of population around industrial sites
- Lacking community/public awareness about risks of floods (World Health Organisation, 2018)

#### 1.6.13.5 Potential impacts on human health

Release of chemicals as a consequence of flooding can expose the victims and rescuers to chemicals directly, thereby resulting in respiratory, systemic and dermal toxic effects. Explosions, fires and environmental contamination can also lead to toxic injuries and implications. Further, clean-up operations can put the rescuers and public at the risk of exposure to chemicals. (World Health Organisation, 2018)

## 1.7 CYCLONES

Tropical cyclones are *warm-cored, intense cyclonic, atmospheric vortices that develop over the warm tropical oceans* and have a horizontal scale typical of 100-1000 km and extend throughout the depth of the troposphere.

An intense mature tropical cyclone usually consists of an eye with weak subsidence near its centre. The centre is surrounded by rapid swirling flow, where deep convective ring slopes radially outward with height. (Wang, 2012)

Recurring cyclones often result in for significant fatalities, loss of private and public buildings, loss of livelihood opportunities, and severe damage to infrastructure. (Arya, 2010)

7% of the world's cyclones are generated in the North Indian Ocean (NIO) Basin, which also includes the Indian coast. However, when these cyclones strike, especially on the coasts along the North Bay of Bengal, their impact is considerably steep and destructive. Specific to the region, the frequency of cyclones in the NIO basin in bi-modal. The occurrence of cyclones is typically in the months of May-June and October-November, with the primary peak achieved in November and secondary peak achieved in May. These tropical cyclones originate typically in the NIO basin's eastern side, and move towards the west-north westerly direction initially. More number of tropical cyclones are originated in the Bay of Bengal as compared to those in the Arabian Sea, with a ratio of 4:1. (National Disaster Management Authority, 2008)

Tropical cyclones are usually accompanied by storm surges, heavy rainfall and destructive winds, which can wreak havoc on livestock and humans. Storm surges have been recorded to cause 90% of the fatalities in a cyclone disaster.

The Eye of the cyclone refers to the centre of a cyclone. The wind at this point rotates in counter-clockwise direction, and is slight or calm, and cloudiness/rainfall is light or nil.

Gale refers to the wind having a speed between 34 and 40 knots (Beaufort scale wind force 8). A knot is a unit of speed, and is used for aviation and maritime purposes globally. 1 international knot = 1 nautical mile per hour = 1.852 kilometres per hour.

Landfall of the cyclone is the point of land where the cyclone just crosses the coast.

Storm Surge refers to an uncharacteristic increase in the level of water along the coast, essentially as a consequence of low pressures and high winds originating with cyclones. Storm surges mostly affect only areas along the coast, but can sometimes intrude inland to some extent. (National Disaster Management Authority, 2008)

**1.7.1 Cyclogenesis**

Cyclones are atmospheric and oceanic phenomena. Scientific studies and observations have helped identify some of the favourable circumstances for formation of cyclones, which have been listed below –

i. Sea surface which is warm, with conducive temperature in excess of 26º–27ºC, and related warming ranging up to a depth of 60m, along with sufficient water vapour in the overlying air (by evaporation)
ii. The atmosphere having high relative humidity up to a height of around 5,000 metres
iii. Formation of huge vertical cumulus clouds, as a result of atmospheric instability and condensation of rising moist air
iv. Vertical wind shear between the higher and lower levels of the atmosphere is low; this does not allow the heat produced and released by the clouds to  of the atmosphere that do not allow the heat generated and released by the clouds to get carried from the area (vertical wind shear is the rate of change of wind between the higher and lower levels of the atmosphere)
v. Cyclonic vorticity (rate of rotation of air) being present, which generates and assists rotation of the air cyclonically
vi. Location above the ocean, at least 4–5º latitude away from the equator. (National Disaster Management Authority, 2008)

Contained in the cyclone field, intense winds circulate around the centre having low pressure centre; in the Northern Hemisphere, they circulate in anti-clockwise direction, and in the Southern Hemisphere, the winds circulate in clockwise direction. The wind at the eye of the cyclone is negligible and does not usually have rain and clouds. Winds gain speed quickly, and reach the peak (typically exceeding 150 km/h) at around 20-30 km from the eye, and thereafter lose speed slowly to become normal about 300-500 km away. Cyclones usually have a diameter in the range of 100-1000 km, but their effect prevails for thousands of square kilometres over the ocean and along the coast. Within a 100 km radius from the eye of the cyclone, is the powerhouse, a location of significantly strong winds, sometimes emceeing

250 kmph, and can be originated in a narrow zone beyond the eye diameter. (National Disaster Management Authority, 2008)

### 1.7.2 Classification of Cyclones

The Indian Classification of Cyclonic Disturbances in the North Indian Ocean (Bay of Bengal and Arabian Sea) is presented in the table below –

*Table 2 Indian Classification of Cyclonic Disturbances in the North Indian Ocean*
*Source: (National Disaster Management Authority, 2008)*

| S.No. | Type | Wind Speed in kmph | Wind Speed in Knots |
|---|---|---|---|
| 1. | Low Pressure Area | Less than 31 | Less than 17 |
| 2. | Depression | 31-49 | 17-27 |
| 3. | Deep Depression | 50-61 | 28-33 |
| 4. | Cyclonic Storm | 62-88 | 34-47 |
| 5. | Severe Cyclonic Storm | 89-118 | 48-63 |
| 6. | Very Severe Cyclonic Storm | 119-221 | 64-119 |
| 7. | Super Cyclone | 222 or more | 120 or more |

### 1.7.3 Nomenclature of Tropical Cyclones

To facilitate simplicity of identification and elimination of confusion in the presence of multiple systems in an individual basin simultaneously, tropical cyclones are provided with nomenclature. The names also help people to recognise the system, from which threat is most imminent. Usually the names of tropical cyclones are same for throughout their life, but sometimes they may be renamed while active under special circumstances. The cyclones are given names from lists pre-prepared lists that differ in various areas, and are shortlisted a few years prior. The authorities involved in the forecast of cyclones decide upon the list, and the decision-making is dependent on the region. The authorities are usually national weather offices (such as IMD in India), or committees of the World Meteorological Organisation (WMO). Every year, the names of highly devastating cyclones are 'retired', and are replaced by new ones. (National Disaster Management Authority, 2008)

### 1.7.4 Storm Surge

One of the inherent disastrous characteristic of tropical cyclones is the coastal phenomenon called storm surge. The extent of destructive potential depends on the amplitude of the storm surge related to the cyclone at the time of landfall, phases of tides, characteristics of the coast, and susceptibility of the community and the region.

When a cyclone advances towards the coast, the right forward sector of the cyclone encounters wind from ocean to land (on-shore wind), which thrusts the ocean water towards the coast, which eventually appears as the storm surge. The left forward sector of the cyclone encounters wind from land to ocean (off-shore wind), which thrusts the ocean water from the shore towards the sea, thereby generating even negative surge.

While the effect of tropical cyclones is very destructive around the coastal areas of Odisha and West Bengal, along the North Bay of Bengal, the impacts are also significant in the states of Tamil Nadu, Andhra Pradesh and the UT of Pondicherry. Gujarat is the most susceptible state on the west coast. (National Disaster Management Authority, 2008)

### 1.7.5 Damage to Structures due to Cyclones

Cyclones have been recorded to incur severe damages to structures such as power supply, houses, communication towers, food storage facilities, hospitals, bridges, roads, crops, etc. due to the high speed winds.

Excessive rainfall accompanying cyclones can cause flooding. Additionally, storm surges can flood low-lying areas near the coast, causing fatalities, devastation of property, eroding embankments and beaches, spoiling vegetation and soil fertility. (National Disaster Management Authority, 2008)

#### 1.7.5.1 Damage Risk Levels Due to Windstorms/ Cyclones

IS 875 (Part 3): 2015 – 'Indian Standard Code of Practice for Design Loads (other than earthquakes) for Buildings and Structures, Part 3 Wind Loads' has formulated and published macro-level wind speed zones of India. There are six basic wind speeds 'Vb' considered for zoning, namely 55, 50, 47, 44, 39 and 33 m/s. From wind damage view point, they have been depicted in Table 3 -

*Table 3 Damage Risk Levels Due to Cyclones; Source:* (Bureau of Indian Standards, 2015)

| S.No. | Basic Wind Speed | Zones | Damage Risk Levels to Housing |
|---|---|---|---|
| 1. | 55 m/s (198 km/h) | Very High Damage Risk Zone - A | Generally similar to "High Risk" but damage is expected to be more widespread as in the case of cyclonic storms. |
| 2. | 50 m/s (180 km/h) | Very High Damage Risk Zone – B | Generally similar to "High Risk" but damage is expected to be more widespread as in the case of cyclonic storms. |

| S.No. | Basic Wind Speed | Zones | Damage Risk Levels to Housing |
|---|---|---|---|
| 3. | 47 m/s (169.2 km/h) | High Damage Risk Zone | Boundary walls overturn, outer walls in houses and industrial structures fail, roofing sheets and tiles or whole roofs fly, large-scale destruction of lifeline structures such as lighting and telephone poles, a few transmission line towers/communication towers may suffer damage and non-engineered/ semi engineered constructions suffer heavy damage. |
| 4. | 44 m/s (158.4 km/h) | Moderate Damage Risk Zone – A | Loose tiles of clay fly, roofing sheets fixed to battens fly, moderate damage to telephone and lighting poles, moderate damage to non-engineered/ semi-engineered buildings. |
| 5. | 39 m/s (140.4 km/h) | Moderate Damage Risk Zone – B | Loose tiles of clay fly, roofing sheets fixed to battens fly, moderate damage to telephone and lighting poles, moderate damage to non-engineered/ semi-engineered buildings. |
| 6. | 33 m/s (118.8 km/h) | Low Damage Risk Zone | Loose metal or fibre cement sheets fly, a few lighting and telephone poles go out of alignment, signboards and hoardings partially damaged, well-detailed non-engineered/semi-engineered buildings suffer very little damage. |

### 1.7.5.2 Impact on Infrastructure

Cyclones can cause physical destruction to buildings, thereby resulting in disruption of infrastructure and services. These are often followed by cascading impacts on other infrastructures that are interdependent. Such interdependencies exist between infrastructure such as water, electric power, communication, transportation and healthcare. Further, substantial damage can be caused to infrastructure systems by winds and floods accompanying the cyclones. The danger to infrastructure networks depend on the location of the natural hazard and the geographical network layouts. (Mitsova, et al., 2019)

Some of the highly vulnerable infrastructure systems are telecommunications and energy, due to their assets exposed above the ground, such as telegraph poles and power lines, which are usually destroyed by cyclone winds. Winds can also affect the radio communications necessary for use in emergency services, due to damage to transmission towers. Sewerage systems and water supplies can be impacted consequently because of loss of power supply to pumping stations, or due to direct exposure to riverine flooding or storm tide. Further, transport infrastructure, especially road and railways are susceptible to storm tide, riverine flooding and landslides. (Middelmann, 2007)

The effect on transportation networks due to cyclones can be categorised into functional or physical damages. Functional damage involves disruption in connectivity, and delay in travel inducing extra costs, and can result in heavier costs that physical damage, especially in the case of railways and heavy-traffic highways. (Yang, et al., 2015)

### 1.7.6 Impact of Cyclones on Population

Cyclones cause destruction and fatalities as a consequence of three main forces – (a) winds higher than 155 mph, (b) storm surge when the sea level rises higher than 10 m and moves ashore, and (c) flooding caused by intense rainfall. The primary causes of fatalities in cyclone occurrences are floods and storm surges. Further, the susceptibility of the infrastructure and population is higher because of urbanisation, population growth, changing weather patterns and increase in settlements along the coastline. (Doocy, et al., 2013)

**Mortality** – the direct fatalities associated with cyclones are caused primarily due to drowning and trauma. In case of indirect fatalities, the causes often go unreported; however, the casualties have been recorded to be caused indirectly by trauma, poisoning by carbon monoxide, vehicular accidents, electrocution, and burns/fires. The risk of mortality has been observed to increase with age, with both elderly and children encountering disproportionate mortality. Other factors of risk causing fatalities include inability to reach to shelter, type of dwelling, flood level, geographic location and deforestation. (Doocy, et al., 2013)

**Injury** – the most common types of injuries include wounds, lacerations, blunt trauma, concussions, vehicular injuries and insect/animal bites. Several studies have observed injury rates to be highest among middle-aged adults. The risk of injury was found to be higher for males. Other risk factors for injury include location or administrative unit relative to the path of the storm, within a city, or being outdoors.

In developing and less developed countries, sufficient information is not available on the epidemiology of cyclone mortality and morbidity, other than simple counts of fatalities. However, a major disparity of cyclone mortality has been observed between developing and developed nations. 29 developing nations and 4 developed nations were identified by the United Nations Development Program (UNDP), which are prone to cyclones. However, it was observed that 42% of the fatalities due to cyclones have occurred in Bangladesh, while 27% of the casualties have occurred in India in the past two centuries. It was also observed that most of the high-fatality cyclones occurred in the latter half of the 20th century, but none of the developed nations faced more than 1000 fatalities from any cyclone during this time frame. (Doocy, et al., 2013)

However, significant improvements in early warning systems, forecasting, evacuation and shelter measures, especially in developed countries, have reduced fatalities related to storm surge and increased the proportional morbidity and mortality in the period of post-impact.

### 1.7.7 Impact of Cyclones on Natural Environment

Cyclones cast a significant devastating impact on the natural environment of the affected area, including the ecosystems and biotic environment.

Effect of Cyclones on Ecosystems:

- Soil Resources –
    - Salinization in presence of higher intensity of cyclone
    - Common and private land washed out, embankments and bunds breached
    - River surge causing water logging, standing crops in private lands damaged
- Water Resources –
    - Pollution and salinization of water bodies in private and public lands in case of sea surge

  - Surge in streams and rivers, increase in silt deposition
  - Lack of access to potable water
- Vegetation – old and new trees uprooted, devastation of horticultural plants (Nanda, 2014)

Effect of Cyclones on the Physical Environment:

- Coastal erosion, bathymetric changes due to turbulence in ocean and by tides, changes to granulometry of beaches
- Changes in geographic attributes
- Landslides, erosion and avalanches due to rainfall
- Invasion of salt water into sub-surface and surface water bodies

Effect of Cyclones on the Biotic Environment:

- Migration and fatalities in animals
- Falling and splitting of trees caused by high-speed winds
- Damage to coral reefs
- Damage to marine plant life
- Damage to mangroves
- Loss of coastal vegetation

Effect of Cyclones on the Perceptual Environment:

- Alternation of coastline and changes to landscape
- Flooding and cascading effects thereof

(Economic Commission for Latin America and the Caribbean, 2003)

### 1.7.8 Geological and Hydrological Impacts of Cyclones

#### 1.7.8.1 Geological Impacts

The speeds related to cyclones include the vortex winds, which are counter-clockwise, to flow around the eye of the cyclone, and the regional winds, which are slower, to steer cyclone in the forward direction. Cyclone tracks that are parallel to the coast help to keep the weaker left side of the cyclone against the coast, while cyclone tracks that are normal to the coast generate significant destruction as the more powerful right side of the cyclone inland. Cyclones incur geological changes such as dune erosion, beach erosion, landscape changes due to destruction of trees, inlet formation due to flood and ebb surge, and sedimentation and near shore channelling as a consequence of ebb surge. Other effects of cyclones also include storm surge, or elevation sea level, extensive erosion of shoreline, and geological impacts leading to loss of life and property. (Coch, 1994)

### 1.7.8.2 Hydrological Impacts

With the landfall of a tropical cyclone, the water level in the sea rises at the coast, inundating low-lying areas and causing severe impacts. The storm surge is minimised due to the distribution of effects of the wind stress over the depth, and due to the generation of counter currents in deep water. In response to deep water, the primary water surface elevation response is the deficit in atmospheric pressure, which further causes the 'inverted barometer' effect. This effect involves the rise of 1 cm for each hPa pressure drop. A reduction in the bathymetric depths, as the storm passes of the shelf, causes a set-up of the surface of water because of the currents caused by surface wind stress. The coastline, bathymetry, inundation barriers and topography can modify the surge. (Dube, et al., 2010)

## 1.8 Vulnerability Atlas of India, Third Edition, 2019

The occurrence of natural and man-made disasters causes severe damage and collapse to structures, and has been found to be the primary cause for fatalities and trauma. Hence, it is imperative to formulate and implement mitigation strategies in order to minimise the damages and mitigate the impacts of the disaster, in addition to ensure the safety of the structures and their occupants.

The first step towards the preparation of a functioning risk mitigation strategy is mapping of areas that are vulnerable to hazards, and analyse the risk of damage suffered by the structures due to disasters. Hazard maps have been prepared by the Vulnerability Atlas of India for all states and union territories of the Indian subcontinent, such as the wind hazard maps, earthquake hazard map, and flood prone area map. These maps illustrate the boundaries of the hazard zones of different intensities, in addition to the district-wise areas located in the various intensities. (BMTPC, 2019)

The Building Materials and Technology Promotion Council (BMTPC) was founded in 1990, and was committed to promote disaster reduction techniques through preparedness. The first Vulnerability Atlas of India was introduced in 1997. The data was collected from several government nodal agencies, such as the Geological Survey of India (GSI), Indian Meteorological Department (IMD), Census of India, Survey of India (SOI), Central Water Commission (CWC) and the Bureau of Indian Standards (BIS), and assimilated to prepare the natural hazard maps up to the district level for all states in the country.

The Vulnerability Atlas of India carries the following information for all states and union territories –

i. Cyclone and wind hazard map
ii. Seismic hazard map
iii. Flood prone area map
iv. Landslide hazard map
v. Housing stock vulnerability table for each district, which indicates the type and level of risk exposure involved for each house (BMTPC, 2019)

**1.8.1 Development of the Vulnerability Atlas**

The updated third edition of the Vulnerability Atlas is based on the premise of increased frequency of extreme weather events, impacts of the natural disasters, awareness of the losses caused, and the economic and social implications of these disasters over the decades. Post the release of the second edition of the atlas in 2006, the information and knowledge of disaster management and risk mitigation has progressed. The government nodal agencies, therefore, added new datasets, aligned with the advancement of technical and scientific knowledge, with respect to occurrences of cyclones, landslides, earthquakes, thunderstorms, wind storms, and failure of railways and roadways due to disasters. Further, the occurrence of some severely damaging disasters in the period of revision of the atlas added new statistics and observations to the previous data, as a result of which, the peer group set up by the ministry in 2019 initiated the revision of the atlas. (BMTPC, 2019)

**1.8.2 Purpose**

The atlas helps in identifying the existing hazard scenario of the entire country. It is an important tool for utilisation by the urban managers, state and national authorities that deal with disaster management and risk mitigation, as well as the public. The third edition of the atlas includes the following –

- District and state boundaries in line with the digitised data from the Survey of India, thereby increasing the accuracy
- Inclusion of national highways, railways, expressways and water bodies in hazard maps

- Inclusion of population and housing data aligned with the Census 2011 in hazard maps
- Inclusion of digitised maps for thunderstorms, cyclones and landslides, with details on effects and occurrences
- Inclusion of map that depicts the frequencies of thunderstorms at various stations, with corresponding details on causes and effects
- All data sets in the maps have been digitised (BMTPC, 2019)

The district-wise housing Vulnerability Risk Tables have also been included in the atlas, with the information based on roof and wall types as per the Census Housing data of 2011. Some information at the macro-level, has been included in the atlas, to be used by authorities involved to program for preparedness, mitigation and preventative actions. Some of this information has been stated below –

- Preventative actions such as retrofitting, upgrading existing structures, and disaster-resilient construction
- Mitigation of extent and intensity of a disaster
- Installation of warning system and conducting mock drills for its testing and usage
- Establishing a hierarchical structure to ensure preparedness down to village level
- Training of manpower for various emergency tasks and activities
- Implementation of building bye-laws with disaster-resistant features in urban and rural areas
- Implementation of land zoning regulations in coastal areas and flood plains (BMTPC, 2019)

**1.9 Summary and Further Reading**

The chapter is a critical anthology of the devastation caused by disasters, man-made, natural, multi-hazards, and bio-hazards. Some of the most significant natural disasters that affect mankind and environment, namely earthquakes, landslides, floods and cyclones, have been described in detail, and extend to use strong references of studies carried out by various authors to establish the severity and loss potential that these hazards pose. In addition to the important discourse on damage to structure, populations and natural environment, pivotal observations and inferences are drawn by these authors on vital subject matters such as the socio-economic and psychological impacts on the affected communities and their response to these disasters.

Various cases across the globe have been observed and discussed in detail to highlight the consequences and successive repercussions of the disasters and multi-hazards.

It is important to note that the disasters and extreme weather events threaten not only the micro-climate, ecology and infrastructure, but have significant menacing impacts to the lives and livelihoods of people who are directly affected. In addition to the disruption of their daily functioning for a long period of time, the loss of loved ones, the trauma of facing the disaster and the process of recovery can be gruesome and can affect the persons in more serious ways than expected. It is, therefore, necessary that the vulnerable communities are well-informed, aware, prepared and resilient to these disasters. Hence, it is recommended that the readers delve deeper into the preparedness offered by the states/ countries, the resilient measures, the gaps and how these can be implemented to ensure minimal loss of life and property.

**NOTES**

# CHAPTER 2 - CASCADING IMPACTS OF NATURAL DISASTERS AND EXTREME WEATHER EVENTS ON CRITICAL INFRASTRUCTURE

## 2.1 Learning Objectives

This chapter a culmination of selected case examples that depict the impact of natural disasters and extreme weather events on critical infrastructure. These cases have been used to develop a comprehensive overview of major extreme weather events and the cascading effects that are observed due to climate change.

The chapter covers extreme events such as landslides, cyclones, floods and extreme air mass to illustrate the severity of the major calamities. However, it does not encompass earthquakes, owing to the extensive studies carried out by various organisations. The typology of events covered in this research are relatively less studied and sometimes go unnoticed.

It is qualified that the data presented below is collected from various sources and may be approximate. However, the intent is to present the scale and magnitude of the problems entailed by these extreme weather events.

## 2.2 ARCTIC AIR MASS, USA, 2021

### 2.2.1 Introduction

A potent arctic weather system caused frigid weather in many cities of the USA in the middle of February 2021, breaking the records of low temperatures mid-country. Millions of people were left without energy and power supply owing to the ice and snow storms and extreme cold. Texas was reported to have limited power generation due to shortage of natural gas before the storm struck. After the polar air mass struck on 13 February, the energy/power demand surged, and the state was rendered powerless and dark due to controlled outages of power. 4 million consumers were reported by The Houston Chronicle to have power shortages on 15 February, most of which also followed to the next day. (Hansen, 2021)

News reports showed low temperatures in Dallas down to 4°F (-16°C) on 15 February, which is the coldest temperature recorded in the city since 1989. More areas such as Houston International Airport were recorded to be colder than Maine and Alaska. (Hansen, 2021)

### 2.2.2 Causes of Extreme Artic Air Mass

A cold air mass (polar or arctic) can be understood as an air mass whose temperature is lower than the temperature of the surface underneath. This is usually associated with high atmospheric turbulence and instability. The centre of this cold air mass is associated with high pressure on surface weather maps. Such air mass usually has denser and heavier cold air, which pushes itself under warmer air, thereby by forcing it upward at a sharp angle, which results into steeper wedge than a warm front.

Typically, these Continental Arctic air masses are formed near the poles in both hemispheres, over large areas of ice and snow. Arctic air masses are usually formed during June to September in the Southern Hemisphere and December to March in the Northern Hemisphere, when the Poles are cold and without much insolation. (Mishra, 2017)

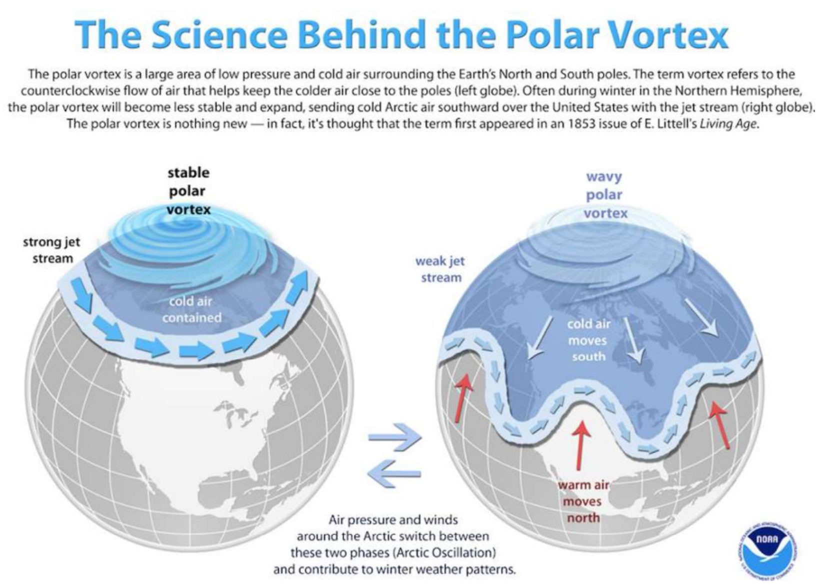


*Figure 6 The Science behind the Polar Vortex*
*Source: (World Meteorological Organisation, 2021)*

### 2.2.3 Geology

The Arctic acts as a heat sink for the global system, which also includes the ocean currents and atmospheric winds. A spectrum of variability is exhibited by the meridional cells and the atmospheric waves, combined with the deep-ocean and near-surface currents. This phenomenon occurs in concurrence with the redistribution of excess heat from tropics to higher latitudes. (Intergovernmental Panel on Climate Change, 2013)

Secondly, it is noted that an attribute of greenhouse gas or radiative forced climate change is that areas that have low temperatures display higher warming phenomena as compared to areas that have high temperatures. This differential sensitivity manifests into polar amplification, in addition to increased likelihood of stronger warming phenomena of the Arctic's coldest air masses relative to the rate of global warming. The air masses bring in cold air outbreaks from the Arctic to middle latitudes. (Intergovernmental Panel on Climate Change, 2013)

### 2.2.4 Chronology of Events and Cascading Impacts

*Table 4 Chronology of Events and Cascading Impacts*

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| **February 13, 2020** | • deeply entrenched arctic air mass expected to bring widespread below normal temperatures (25-45 degrees below normal) | • near or record-breaking low maximum temperatures expected<br>• any winds expected to exacerbate the very cold air mass |
| **February 14, 2020** | | • winter storm warning issued |
| **February 15-17, 2020** | • frigid air escaped its usual confines above the Arctic | • Cold air descended from Arctic and covered major parts of North America |
| **February 18-19, 2021** | • An anomalous cold spell persisted throughout Ohio Valley, most of the Plains, and Middle Mississippi Valley. | • Record breaking overnight lows<br>• Warmer temperatures across the Great Plains and Mississippi Valley could be observed after February 20 |

### 2.2.5 Extent of Damage and Effect on Population

The arctic air mass and the high speed chilly winds caused dangerously low temperatures and cold wind chill values. Such extreme cold can cause frostbite and hypothermia to people who get exposed to the chilly winds and temperatures. Adaptation of livestock and domestic animals also caused significant problems since the basic shelters for animals are not sufficiently effective against cold and winds of such severity. This also caused increased stress on calving operations.

Prolonged cold also caused an increase in the frost depth penetration in the soil, thereby causing freezing in pipes and heavy frost deposition on roads and buildings. Apart from increased demand in power consumption and production, car batteries may require double the current to start the engine as compared to normal conditions. Such low temperatures for extended periods of time can also cause rivers to freeze and thickening of the river ice, which could further cause localised flooding. (CR-ROC, 2021)

### 2.2.6 Impact on Critical Infrastructure

Significant impacts on critical infrastructure were reported due to the Arctic Air Mass. These were primarily associated with energy and electricity, water supply, transport and agriculture.

#### 2.2.6.1 Energy and Electricity Infrastructure

Texas faced heavy demands of energy, leading to excessive pressure on its energy infrastructure. The power outages hit the grid operators who struggles to provide electricity to the millions of residents. This incident confronted the power sector of the state on its inability to cope with the surge in demand of power supply. The root cause of the shortage of power supply was the deficiency in supply chain of fossil-fuel infrastructure. As a result, this rare event force the grid operators of the state to impose rotating blackouts, leading to around 4 million residents coping with electricity shortage. (Gabbatiss & McSweeney, 2021)

According to reports, out of the state's wind power capacity of 25 GW, 12 GW were affected, which was later denied as being the main reason of mass power outages. The wind shutdowns comprised less than 13% of the 30-35GW of total power shortage observed in Texas. It was claimed that the major role played in power shortage was of frozen instruments at coal, natural gas and nuclear facilities, in additions to limited supplies of natural gas. The cold wave also affected northern Mexico, where power outages affected around 4.7 million people, as claimed by the authorities. However, this power services were restored to almost 2.6 million of them within a span of 12 hours. (Gabbatiss & McSweeney, 2021)

#### 2.2.6.2 Water Supply

Around 7 million residents of Texas had to deal with unsafe drinking water due to lack of power to run water-treatment plants. With the utilities struggling to restore the water pressure back to acceptable levels of safety, around 12 million people were given boil water notices. To ensure distribution of safe and potable water across the state, emergency agencies and utilities began operations of water distribution centres for the communities.

Such conditions prevailed in the state due to power shortage and bursting of pipes. While the state asked the water utilities to issue boil water notices, these were not lifted until the water samples were tested to safety. (Chappell, 2021)

#### 2.2.6.3 Transport

The cold air mass and chilly winds caused heavy snowfall and perilous ice, thereby causing deposition of snow on roads. This led to dangerous transport conditions across the country, also causing a 100-vehicle traffic pileup in Texas. It was reported that cars were piled up on ice-coated roads and trucks slid off highways. Forecasters suggested minimal use of transport network and careful driving in Nashville.

The drivers were warned by the Texas Department of Transportation, for a 'marathon of historically cold air' which could make driving dangerous. Accidents were reported in the West of Odessa in Texas, where numerous vehicles including eighteen wheelers were involved in crashes. A pileup in Oklahoma City led to fire in several semi-trucks. A pileup on Interstate 35 led to six fatalities and numerous injuries involving more than 100 vehicles. (Rojas & Fazio, 2021)

### 2.2.7 Economic Losses

Owing to the demand surge of energy and extreme conditions causing generating units to trip, the price of wholesale electricity spiked by more than 10000% on the Texas power grid. Some electricity providers encouraged consumers to switch to other providers in lieu of the prospects of sending very heavy bills. (Gabbatiss & McSweeney, 2021)

Judah Cohen, the director of seasonal forecasting at Atmospheric and Environmental Research, a company that provides information to clients about weather and climate-related risk called the storm "*one of the most costly natural disasters of the year. Texas, which is known for hurricanes, is not known for snow and cold damage such as burst water pipes, and it's not in spite of climate change, but related to climate change*." (Rojas & Fazio, 2021)

### 2.2.8 Inferences/ Conclusions

It is evident that the Arctic Air Mass is a consequence of climate change, and can be classified as an extreme event. Such low temperatures were not recorded in the city since 1989. The air mass occurred at the time of the COVID-19 pandemic, and caused lockdowns and isolation for the citizens. The event posed hazards to not only water safety and electricity supply, but also caused freezing temperatures which led to deaths among the residents. Some were victims of road crashes, due to slippery roads covered with thick ice. Since this event is not frequent, the Texas state was not prepared for the extremely low temperatures and snowfall, thereby causing loss of electricity supply and safe water provision. Water freezing and pipe bursts were also noted to occur at many places, thereby posing a safety hazard and financial implications.

Even as the event did not devastate landscape and environment physically, as compared to other natural disasters, it is alarming to realise the implications of global warming and climate change. This air mass is a strong signal to ensure preparedness, and continue to strive to stop and even undo the global warming as much as possible.

## 2.3 CYCLONE AMPHAN, 2020

### 2.3.1 Introduction

Super Cyclonic Storm Amphan, a strong and fatal cyclone, caused severe damage and destruction in Bangladesh and West Bengal in May 2020. It was recorded to be the strongest tropical cyclone that struck the Gangetic Delta since Cyclone Sidr in 2007. The cyclone was also the first super cyclonic storm that struck in the Bay of Bengal since the Super Cyclone of 1999 caused widespread devastation in Odisha. Amphan has been recorded to be the most costly cyclone in the North Indian Ocean, inducing more than US$13 billion of damage, a record previously held by Cyclone Nargis of 2008.

The cyclone worsened the plight of the communities, considering the COVID 19 pandemic raging during that period. Equivalent to a category-3 hurricane, Amphan made landfall on the coast across Sunderbans, tearing through thickly populated areas of Southern Bengal. It sustained wind speeds of 170 km per hour, with gusts of up to 190 kmph and storm water surges of up to 16 feet. The cyclone made landfall on the coastal belt of West Bengal near Digha and Sundarbans and completely disrupted essential services and livelihoods across the southern part of West Bengal and even in some of the northern districts of the state. The combined effect of COVID 19 and Amphan put a huge challenge in rescue work and made the situation even more complicated. (State Inter Agency Group West Bengal, 2020)

### 2.3.2 Causes of Cyclone

Cyclogenesis of the Amphan ensued with the formation of a convective low pressure system in the south eastern Bay of Bengal on 13 May 2020 that showed potential for development of a mighty tropical cyclone. It rapidly turned into a depression on 16 May 2020, and within 12 hours transformed into a deep depression with maximum sustained (3-min average) wind speed of 56 km/h. The 'eye' of the storm initially shifted generally in N32°W direction till 17 May 2020, and thereafter started to move towards N24°E, and was positioned around 665 km east of Chennai as an extremely severe cyclonic storm on 18 May 2020. Subsequently, the system headed N22°W and strengthened into a super cyclonic storm on 18 May 2020 at with sustained wind speed of 222 km/h. The sustained wind speed reached the maximum of 241 km/h on the same day. (Das, et al., 2020)

### 2.3.3 Geology

The districts affected by Amphan include South 24 Parganas, North 24 Parganas, Purba Medinipur, Kolkata, Howrah and Hooghly. North 24 Parganas, the most populated district in West Bengal, lies in the Brahmaputra-Ganges delta. The river Ganges flows along the western border of the district. The largest district in West Bengal, South 24 Parganas, is surrounded by remote riverine villages of the Sunderbans on one side, and the urban fringe of Kolkata on the other. Kolkata, the capital of West Bengal, is located on the eastern bank of the river Hooghly, a distributor of the river Ganges. Purba Medinipur, is surrounded Hooghly River and South 24 Paraganas on East, Bay of Bengal in the south, and Howrah district to the north-east. (State Inter Agency Group West Bengal, 2020)

Cyclone Amphan left a devastating impact on the Lower Deltaic West Bengal (LDWB), coastal districts of Odisha and some parts of Bangladesh. It made its landfall as a very severe cyclonic storm close to the Saptamukhi Estuary of West Bengal coast, 100 km south of Kolkata.

In India, the area worst hit was the LDWB, which is delineated on the basis of northern limit of tidal intrusion through estuaries and streams, and includes the districts of Purba Medinipur, South 24 Parganas, North 24 Parganas, Kolkata, Howrah and Hooghly. The southern parts of the adjacent Purba Bardhaman and Nadia districts were also affected. (Das, et al., 2020)

### 2.3.4 Chronology of Events and Cascading Impacts

*Table 5 Chronology of Events and Cascading Impacts*

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| May 13, 2020 | • formation of a convective low-pressure system in the south-eastern Bay of Bengal (BoB) | • showed potential for development of a mighty tropical cyclone<br>• First press release was issued on 13th May, when the system was a low pressure area, and daily updates were released |
| May 16 to 17, 2020 | • concentrated into a depression over southeast BoB in the early morning<br>• intensified into a deep depression on the same afternoon<br>• moved north-westwards and intensified into Cyclonic Storm over southeast BoB in the evening<br>• intensified into a Severe Cyclonic Storm (SCS) over southeast BoB in the morning of 17th May | • Pre-cyclone Watch for West Bengal-north Odisha coasts was issued<br>• warnings were further upgraded and Cyclone Watch<br>• Cyclone Alert (Yellow Message) was issued on 17th May |
| May 17 to 18, 2020 | • underwent rapid intensification during subsequent 24 hours and accordingly intensified into a Very | • Cyclone Warning (Orange Message) issued on 18th May |

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| | Severe Cyclonic Storm (VSCS) by the afternoon of 17th,<br>• Extremely Severe Cyclonic Storm (ESCS) in the early hours of 18th<br>• Intensified into a SuCS around noon of 18th May, 2020 | |
| May 19, 2020 | • maintained intensity of SuCS over west-central BoB for nearly 24 hours, before weakening into an ESCS over west-central BoB around noon | • weakened slightly and crossed West Bengal – Bangladesh coasts as a VSCS, across Sundarbans<br>• Post landfall outlook (Red Message) for interior districts of Gangetic West Bengal, Assam and Meghalaya was issued of 19th May |
| May 20, 2020 | • lay over West Bengal as a VSCS, gradually moving north-eastwards during late evening to night<br>• It moved very close to Kolkata during this period.<br>• Moving further north-eastwards, it weakened into an SCS over Bangladesh & adjoining West Bengal around mid-night of 20th May | • Amphan's passage through the seafront occurred during low tide, hence, the storm surge elevations were not exceptional, and saved the region from further damages<br>• Accompanied by torrential rainfall (236.3 mm in Kolkata on 20 May 2020), Amphan pounded LDWB with complete disruption of civic facilities and large-scale storm inundation.<br>• From 20th morning onwards, hourly updates were issued and sent to disaster managers by email, uploaded on websites, and posted on social media. |
| May 21, 2020 | • Weakened into a CS over Bangladesh in the early hours into DD | • 12.3% of the affected area was inundated by storm waters of Amphan. |

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| | over Bangladesh around noon of 21st May and into a D over north Bangladesh in the evening of the same day.<br>• further weakened and lay as a well-marked low pressure area over north Bangladesh and neighbourhood around mid-night of 21st May | • Maximum waterlogging can be identified around the Hugli Estuary region, and in the reclaimed areas of the Sunderban<br>• The runways and tarmac of Netaji Subhas Chandra Bose International Airport of Kolkata were completely flooded and damaged by the cyclone<br>• Some recovery of the flooded areas was seen during the weeks following the event and before the onset of the monsoons, as the breached coastal embankments were repaired and accumulated waters drained |

### 2.3.5 Extent of Damage and Effect on Population

The cyclonic storm along with heavy rain coincided with the astronomical tide, resulted in storm surges with waves up to 15 ft. in height and devastated Kolkata and many districts of West Bengal. The cyclone left behind a trail of destruction, uprooted electric posts and trees, and destroyed numerous houses and swamping low-lying areas. Amphan hit the state on 20$^{th}$ May 2020 and caused 86 deaths as recorded in June 2020. It affected more than 10 million people only in West Bengal. The storm further caused significant destruction to thousands of trees, standing crops, in addition to the disruption in water and energy supply across the state. Several households lost their assets, moveable property, water and sanitation provisions etc. (State Inter Agency Group West Bengal, 2020)

The following 10 districts were affected, including 3 Coastal districts -

- Kolkata
- North 24 Parganas
- South 24 Parganas
- West Midnapore
- East Midnapore
- Hooghly

- Howrah
- Nadia (Partly)
- East Burdwan (Partly)
- Murshidabad (Partly)

The damages observed up to June 2020 as per the Joint Rapid Need Assessment Report on Cyclone Amphan, 2020, have been enlisted below.

- 86 fatalities
- 384 blocks / municipal corporation / municipality affected
- Estimated 21,560 sqkm of area affected
- 13.6 million people affected / 28.56 lakhs households affected
- 0.618 million people evacuated
- 5136 relief camps
- 1500 Gruel Kitchens
- Around 5 lakh trees uprooted
- Severe damage to education related infrastructure
- Around 17 lakhs hectares of agriculture land crop (including paddy and vegetables) loss reported from various districts mainly paddy and vegetables
- Approximately 250556 hectares of Betel vine, Litchi and Mango orchards lost
- Around 21.22 lakhs animal lost
- Fishing community faced heavy losses
- Electric poles uprooted in the severely affected districts (State Inter Agency Group West Bengal, 2020)

### 2.3.6 Impact on Critical Infrastructure

#### 2.3.6.1 Healthcare Infrastructure

Disasters cause degradation in public health directly as well as through the disruption and failure of health services, facilities and systems. People are left without healthcare access in times of emergency. Primary healthcare system plays a critical role to help build response mechanisms, local capacity, immediate responsiveness and action in case of a disaster or public health emergency. They also help build and enhance the resilience of communities. In addition, they aid easier access to basic infrastructure such as safe shelter, safe water supplies.

It was recorded that affected people were suffering from both communicable and non-communicable diseases after the disaster. 16% of the affected population was suffering from water-borne diseases.

Many health facilities were not functioning, the reasons for which were noted as lack of staff, supplies, medicines and medical equipment. (State Inter Agency Group West Bengal, 2020)

### 2.3.6.2 Education and Child Protection

With the COVID 19 pandemic spreading aggressively, the schools and colleges were shut down across the country. National, state and school level exams were also postponed owing to the pandemic and lockdown. A large number of children dropped out and were engaged in various kinds of labour, once the lockdown was relaxed. Only 13 percent of the households had access to online learning.

The cyclone affected temporary school structures, while the permanent and structurally sound school structures were used as relief shelters during and after the occurrence of the cyclone. Appropriate social distancing was ensured and COVID 19 safety protocols were followed.

Additionally, due to loss of shelter due to the cyclone, children faced lack of meals and proper diet. Loss of books, belongings and communication with peer caused distress. Chances of domestic violence were increased, and children were susceptible to suffer from neglect.

These compounded situations directly resulted in increased child labour, child trafficking, sexual abuse, exploitation, substance abuse and social malpractices 15% of the affected children faced sexual abuse. 4% of the affected children faced caste based and gender based violence.

26% children faced harmful traditional practices, including female genital mutilation (FGM), forced feeding of women, early marriage, nutritional taboos and traditional birth practices. (State Inter Agency Group West Bengal, 2020)

### 2.3.6.3 Mangroves of Sunderbans

Mangroves are one of the critical components of the Sunderban ecosystem, which help sustain livelihoods of the people of Sunderbans. The mangroves also protect the fragile earthen embankments that shield the villages from daily tides.

The Mangrove trees above the water level turned pale in some areas of Patharpratima block but were green on just the opposite bank of the river. In Jharkhali areas, root displacement of mangroves has been observed.

The brick/concrete embankments, with 2-3 layers of mangroves as shield, were intact. Salinity intrusion over the embankments happened in a few places where the villages are exposed directly to Bay of Bengal. (State Inter Agency Group West Bengal, 2020)

The Sunderbans cover an area of over 9630 sqkm, south of the Dampier Hodges line. Out of this, 4263 sqkm area is the mangrove forest. As per the initial estimate, about 1,600 sqkm area in the Sunderbans suffered damage. The mangroves act as a natural shield for Kolkata from the impact of cyclones like Amphan. It has been reported that around 28% of the Sunderbans were affected and devastated due to the cyclone. Some trees were found to turn red and yellow after the storm, which was claimed to be mainly due to salinity. It has been noted by experts that the mangroves in the Sunderbans not only diminish the wind speeds of the cyclone, but also help to break the waves when there is a storm surge due to a cyclone.

Nearly 17,800 hectares of agricultural lands have been estimated to be damaged because of saline water from seas entering the farms. Apart from erosion, opening up of creeks might have led to overflow of saline water into villages. (Sen, 2020)

#### 2.3.6.4 Water Supply and Management Infrastructure

83% toilets were either been fully or partially damaged and therefore there was no access to sanitation facilities. As a result, open defecation was prevalent among 54% of the population as recorded. The remaining people were using households or community toilets.

Average distance of water sources from toilets ranges between 25m in South 24 Parganas to 200m in North 24 Parganas. Due to absence of access to safe drinking water and no water containers for safe storage of drinking water, the affected people were dependent on ponds and hand-pumps for drinking water.

It was recorded that 91% water was contaminated and the remaining 9% was at risk in the affected districts of West Bengal. Water sources were inundated due to the intrusion of storm surges inland, which led to the contamination of safe drinking water.

Further, due to power disruption and damages, the water supply through the Public Health Engineering could not be restored for weeks.

Due to the high tides and low tides, the affected coastal districts river water rose thrice a day, causing hindrance to repair work on the embankments and to check intrusion of saline water that contaminated the sources of fresh water bodies. (State Inter Agency Group West Bengal, 2020)

#### 2.3.6.5 Agriculture and Food Infrastructure

Standing crops worth tens of millions were destroyed in millions of hectare fields in Bengal, on the point of being harvested, especially ridge guard, bitter gourd, pointed guard, okra, elephant foot, arbi, cauliflower etc.. Farmers faced huge losses as almost all vegetable fields were destroyed due to the cyclone. Managing to maintain physical distancing under such circumstances was even more difficult.

The crop fields for paddy, vegetable gardens, and betel vineyards, traditional paddy store houses, in addition to Orchards like lemon, mango, jack fruit, litchi, and jamuns were recorded to face significant destruction.

A total of 1350 and 170 hectare of crop area was affected in the assessed areas of the 2 districts of North and South 24 Parganas respectively. The food availability was for only 1-3 weeks, and the affected population faced food shortage and unavailability for more than a week after the downfall of Amphan. (State Inter Agency Group West Bengal, 2020)

#### 2.3.6.6 Housing and Shelter

Almost 24% of the houses were fully damaged in North 24 Parganas district and 69% houses were fully damaged in South 24 Parganas district. Alost 24% of total affected households fully lost their shelters in East Medinipur, and 32% of total households partially lost their shelters.

Due to the breakdown of power infrastructure, the relief camps did not have electricity supply. This increased the risk of exposure to wild animals, snake bite and insect bite.

As observed, 6% of the affected population had blankets, 7% had hygiene materials, 8% had fuel, 9% had bed sheets, 12% had Chula, 14% had kitchen utensils and 16% had emergency kits (torch, solar charger, etc.) with them as a source of light. However, a significant number of the affected population was in the need of the non-food essentials. (State Inter Agency Group West Bengal, 2020)

### 2.3.7 Economic Losses

It was recorded that cyclone Amphan was more economically damaging as compared to the earlier cyclones due to its passage ravaging the densely populated areas and urban setups and their critical infrastructure. However, owing to the spreading pandemic COVID 19, the regular economic activities and movement were restricted, which significantly helped in controlling the fatalities. While the Super cyclone of 1999 recorded 9887 fatalities, and losses were estimated to be around $4.44 billion, the cyclone Amphan had 86 fatalities and losses worth approximately $13.2 billion. For recovery and restoration activities and efforts, a high priority financial aid worth ₹10 billion and ₹5 billion was directed to West Bengal and Odisha respectively. As financial aid and for relief efforts, the European Union (EU) also declared an initial funding of €0.5 million to India. (Bhowmick, 2020)

As recorded by State Inter Agency Group, West Bengal, up to June 2020, the following losses were observed.

*Table 6 Damages and Losses due to Cyclone Amphan*
*Source: (State Inter Agency Group West Bengal, 2020)*

| S. No. | Sector | Extent of Assessed Damage (Up to June 2020) | Quantum of Damages (In INR Crores) |
|---|---|---|---|
| 1. | Dwellings | 28.56 lakh houses damaged | 28560 |
| 2. | Agriculture | 17 lakh ha agricultural land crops | 15860 |
| 3. | Horticulture | Area – 250556 Ha | 6581 |
| 4. | Fisheries | Boats – 8007, Huts – 1.48 lakh | 2000 |
| 5. | ARD | Animals Lost – 21.22 lakh | 452 |
| 6. | Drinking Water | Piped Water Schemes affected – 1192 | 2060 |
| 7. | Roads including rural roads and culverts/ bridges | Roads – 2148 km, bridges and culverts – 355, rural roads – 10091 km | 2237 |
| 8. | Irrigation Canals/ Ponds | Embankments – 245 km, sea dykes – 3.6 km | 2944 |

| S. No. | Sector | Extent of Assessed Damage (Up to June 2020) | Quantum of Damages (In INR Crores) |
|---|---|---|---|
| 9. | Power | Power sub-stations damaged – 273, poles – 449174 | 3230 |
| 10. | Forest | Forest Area affected – 1.58 lakh hectares | 1033 |
| 11. | Education Infrastructure | 14640 schools, 301 colleges | 793 |
| 12. | Health Infrastructure | PHC-563, BPHC/RH-169, Sub-centre – 5142, SDH/SGH – 37, DH-24 | 1270 |
| 13. | Anganwadi Infrastructure | ICDS Centre Damaged – 12678 | 342 |
| 14. | Urban Infrastructure | Municipal Roads, Street Lighting, Underground Sewerage System, Storm, Water Drainage, Water Supply Schemes, etc. | 6750 |
| 15. | Industries including MSME | Industrial Warehouse/ Raw Material/ Industrial Infrastructure/ Sheds | 26790 |
| 16. | Miscellaneous | Transport, Fire and Emergency Infrastructure, Godowns, Housing, Correction Homes, BCW, etc. | 1540 |
| | **TOTAL LOSSES** | | **102442** |

### 2.3.8 Inferences/ Conclusions

The occurrence of Cyclone Amphan coincided with the onset of the COVID-19 pandemic. While the country was in a lockdown and trying to control the spread of the virus, it was of utmost importance to maintain social distancing and stay indoors. However, the cyclone forced many communities and families to move out of their temporary shelters and take refuge in the Cyclone safety shelters provided by the government. These shelters were only able to accommodate approximately 40% of their actual capacity, owing to the requirements of social distancing. The devastating cyclone not only caused death, damage to property and environment, but also had a significant impact on the ecology, due to the damage of the Sunderbans. The Sunderbans acted as a shield for the villages against storms and also provided livelihoods to communities.

In addition to the massive economic losses, the housing, primarily temporary shelters, were entirely devastated and personal belongings and possessions were lost. The quantum of reconstruction for these families is momentous, and even as aid was provided to these in terms of shelter, money and food, the families faced psychological and emotional distress, which led to illnesses, increase in dropping out from schools, and a surge in domestic violence and violence against women.

## 2.4 CYCLONE FANI, ODISHA, 2019

### 2.4.1 Introduction

On 3 May 2019, Cyclone Fani, a rare summer cyclone, struck Odisha, affecting 16.5 million people in approximately 18,388 villages across 14 of the state's 30 districts. Khurda, Puri, Jagatsinghpur, Cuttack, and Kendrapara were among the worst-affected districts. A total of 1.55 million individuals were displaced and relocated to 9,177 shelters. Fishing operations were halted, and public awareness efforts were launched. Additionally, the Ministry of Home Affairs sanctioned an advance financial aid of INR 340.87 crore. The total damage was estimated to be INR 16,465 crore, and the total loss was worth INR 7,712 crore. Estimated recovery needs were worked out to be INR 29,315 crore. (Government of Odisha, 2019)

The Indian Meteorological Department (IMD) reported a maximum sustained surface wind speed of 175–180 kilometres per hour (kmph) gusting to 205 kmph during landfall at Satpada.  Even as the fatalities were lower as compared to the Super Cyclone of 1999, cyclone Fani caused 64 fatalities. (Government of Odisha, 2019)

### 2.4.2 Causes of Cyclone

Cyclone Fani was an unusual occurrence. As identified by the Indian Meteorological Department (IMD), the cyclone began in a low-pressure area on 25 April 2019. Over the next 48 hours, it was predicted to intensify into a cyclonic storm. The forecast of the path of the cyclone was revised 9 times. Fani was observed to have the longest ever lifecycle for a cyclone over the Bay of Bengal, since it meandered over the Bay of Bengal for 11 days.

The cyclone made its landfall in Odisha on 29 April 2019, even as it was not expected to affect Odisha in its initial days. Fani marked the second time when a cyclone made landfall in Odisha in the month of May since 1891. (Government of Odisha, 2019)

### 2.4.3 Geology

Odisha is highly vulnerable to disasters owing to its geographic and socio-economic condition. The location of the state on the east coast of India makes it count in one of the six most cyclone prone areas in the world. Odisha's coastline has been recorded to be most prone to cyclone landfall. It was recorded that in the last century, 1019 cyclonic disturbances occurred in the Indian subcontinent. Out of these, 260 had their landfall along the coast of Odisha, and 890 were along the eastern coast.

In Odisha, flooding is caused at regular intervals due to its ten major river systems. 1.40 lakh hectares (out of a total geographical area of 15,571 lakh hectares) are prone to floods. Vulnerability of the state to landslides, tsunami, flash floods, and earthquakes is also high. (Government of Odisha, 2019)

### 2.4.4 Chronology of Events and Cascading Impacts

*Table 7 Chronology of Events and Cascading Impacts*

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| April 25 to 27, 2019 | • low-pressure area was identified by the Indian Meteorological Department | • predicted to intensify into a cyclonic storm over the next 48 hours |
| April 29, 2019 | • Cyclone was confirmed to make its landfall in Odisha | |
| April 30, 2019 | • IMD issued a cyclone-watch message for the Odisha coast | • Vulnerable populations evacuated and shifted to safe shelters<br>• Availability of sufficient food stuff, drinking water and essential medicines was ensured<br>• Livestock and domestic animals in vulnerable areas evacuated<br>• Operationalise the DEOCs round the clock |
| May 03, 2019 | • Cyclone Fani made landfall at about 8.30 AM on 3 May 2019 between Satapada and Puri as an Extremely Severe Cyclonic Storm | • Evacuated around 15.5 lakh people towards 9,177 shelters, including 879 multipurpose cyclone/flood shelters and other safe |

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| | • A sustained surface wind speed of 170–180 kilometres per hour (kmph) gusting to 205 kmph was observed during landfall.<br>• Nine districts received more than 100 millimetres (mm) of rainfall within 24 hours of landfall | shelters like schools and public buildings.<br>• Around 25,000 tourists were also evacuated from the vulnerable areas by mobilising 23 special trains and 18 buses. |
| May 03 to 04, 2019 | • Very severe to severe cyclonic storm, winds speeds reaching 145-155 kmph gusting to 170 kmph<br>• heavy to very heavy rainfall at a few places with extremely heavy falls (>20 cm) at isolated places over coastal areas | • Extensive damage to all types of kutcha houses, some damage to old badly managed Pucca structures.<br>• Extensive uprooting of communication and power poles.<br>• Disruption of rail/road link at several places.<br>• Extensive damage to standing crops, plantations, orchards. Blowing down of Palm and coconut trees.<br>• Extensive evacuation from coastal areas.<br>• Diversion or suspension of rail and road traffic. |
| May 05, 2019 | • Maximum sustained surface wind speed, 50-60 gusting to 70; changes to deep depression<br>• Depression weakened into a Well-Marked Low Pressure Area over central Assam & neighbourhood. | |

### 2.4.5 Extent of Damage and Effect on Population

Total houses damaged were 361743, out of which rural houses were 295703 and urban houses were 66,040. 1031 health facilities were affected, 5735 schools were damaged, 107 universities and colleges suffered extensive damage. Approximately 113 monument sites were affected, and 6441 public buildings were damaged. Around 48.61 lakh workers were impacted by the cyclone, and approximately 19734 Ha of perennial crops, 50 fishing settlements, and 90 lakh poultry and cattle/ animals were affected/ killed.

Further, 272 km of National Highways, 5240 km of state highways and 6251 km of rural roads were affected. Distribution transformers, LT lines, high tension poles electrical lines and towers were extensively damaged. Around 22 lakh trees were uprooted/ suffered damages. (Government of Odisha, 2019)

### 2.4.6 Impact on Critical Infrastructure

#### 2.4.6.1 Healthcare Infrastructure

- **Health Infrastructure and Physical Assets**
  The cyclone affected more 1031 health facilities. Majorly, the structure, electricity and water supply, and air-conditioning systems were affected. Elements of the buildings, like false ceilings, doors and windows, roofs, outdoor units of ACs suffered damages of varying degrees. Even boundary walls of various healthcare buildings were destroyed, in addition to the blown off tin and asbestos roofs. It was noted that the structures did not following design codes and standards designated for hospital buildings. (Government of Odisha, 2019)
- **Health Service Delivery and Access to Services and Goods**
  Due to disruption of power infrastructure, health services' provision was severely interrupted. Access roads to the hospitals were blocked due to broken trees on the roads. Even as the backup diesel generators were put to use, they could not power the equipment that needed more power supply (such as X-Ray and CT scan machines). However, the routine functioning and services were continued, like IPD, OPD, deliveries, surgeries and emergency. (Government of Odisha, 2019)

#### 2.4.6.2 Transport Infrastructure

While the roads were not severely damaged, transportation was affected due to blockages caused by uprooted trees, collapsed compound walls and blocked footpaths. However, the road furniture was significantly damaged.

The State Works Department coordinated with the associated authorities to ensure the development of design specifications for gantries, traffic signs and other structures that could withstand high wind speeds. It was also proposed to develop a road tree plantation strategy to focus on species of trees that are resilient to cyclones, and also configurations of the plantations to reduce the wind speed and minimise damage (such as pre-cyclone pruning and lateral stiffening of plantation blocks). Nevertheless, it is important to build resilient road designs that are weather-friendly and adapt construction practices that ensure adequate storm water drainage. Further, the overall institutional capacity must be enhanced in order to implement such practices. (Government of Odisha, 2019)

#### 2.4.6.3 Energy Infrastructure

The cyclone induced heavy damages to the energy infrastructure. Infrastructure of 14 districts were affected, comprising of approximately 110000 distribution transformers and 500 substations. These were connected with a total of around 190000 km of distribution lines and 14000 transmission lines. Even as the transmission system was not severely affected, the distribution system incurred major damages including around 202 distribution substations, 80600 km of distribution lines, and 13400 transformers.

#### 2.4.6.4 Telecommunication & Information Technology Infrastructure

11 districts were most affected in terms of telecommunication services in coastal Odisha. Telecom infrastructure was damaged and mobile and internet services were disrupted. Restoration of telecom services and infrastructure were included in the immediate recovery needs. Medium and long-term recovery and reconstruction needs included adoption of higher design specifications and standards for mobile towers in order to sustain wind speeds up to 250 kmph. Further, it included resilience strengthening by encouraging the use of underground cabling ducts instead of aerial cables. Enhancing the reliability and redundancy within the telecom infrastructure and services, ensuring last-mile connectivity by deploying alternative communication systems for emergencies and testing them frequently with SOPs at community, block, and district levels was also included in the long-term recovery plan. (Government of Odisha, 2019)

#### 2.4.6.5 Water Supply and Management Infrastructure

The water supply system of both urban and rural areas was affected by Cyclone Fani. Structural, electrical and mechanical damages were recorded in 1088 piped water supply schemes in rural areas (49%). About 7,758 (1.4%) toilets constructed under Swachh Bharat Mission (Gramin) were completely damaged in the districts of Bhadrak, Khurda and Puri, while 100926 (18.9%) were partially damaged due to the cyclone.

Different ULBs were also affected, including 337 urban water supply systems. Losses were estimated at INR 28.65 crore (USD 4.12 million), while the overall damages of the urban Water, Sanitation and Hygiene facilities reached about INR 167.47 crore (USD 24.12 million). Many of the damaged water supply systems were repaired temporarily, but had to be redone in a permanent manner and resilience measures needed to be added.

#### 2.4.6.6 Agriculture and Food Infrastructure

The cyclone ravaged the agriculture sector, including cash crops and horticulture, leading to 55% of total loss and damages in this sector. Additionally, perennial crops were destroyed, causing loss of employment, livelihoods and agriculture related income. As a result, the government expenditure for post-disaster recovery increased, to compensate for losses in crops and livelihoods. It also led to prolonged losses in production up to many years, with a depression in the rural household income for a long duration.

The farming system also includes livestock rearing as an integral element. The cyclone affected 10 lakh small animals, 24.5 lakh large animals, and 54 lakh poultry birds. As a result, a total loss of estimated 1206 Cr was seen in livestock, which comprised of around 39.7% of the total loss estimated in the agriculture sector. A decline in milk production and eggs, death of animals and production losses was also recorded. Further, the marine and coastal fishery was also affected, with high damages to districts of Cuttack, Puri, Khurda and Jagatsinghpur. (Government of Odisha, 2019)

#### 2.4.6.7 Housing Infrastructure

The housing sector was severely affected by the cyclone. 2.96 lakh houses were affected in rural areas, and 66,040 in urban areas, making it a total of 3.62 lakh houses that were damaged. 95% of these houses were in Cuttack, Khurda and Puri. The urban slums, rural areas, and houses in settlements along the coastline were the worst affected. Most of these houses were temporarily built, thereby offering low resilience to cyclonic winds.

While the evacuation processes were carried out by the government promptly, and the vulnerable people shifted to safe cyclone shelters, numerous elderly people, persons with disabilities and other people from economically and socially vulnerable groups were affected. The total costs for recovery and reconstruction for the housing sector were estimated to be INR 8,996 crore (USD 1,285 million), which also included 'build back better' features and resilient techniques.

#### 2.4.6.8 Education Infrastructure

Infrastructure of higher education institutions and schools were affected by Cyclone Fani. While most school and college buildings are used as temporary shelters during cyclones, it was the old and dilapidated structures that collapsed due to their inability to withstand higher wind speeds. Ancillary buildings of these structures were also damaged, such as the kitchens and verandahs. He newer structures faced failure of elements that were mostly non-structural, such as unsecured equipment and gadgets, windows, false ceilings, doors etc. Uprooted trees also caused damage to the boundary walls. It was estimated that the education sector faced losses worth INR 814.48 crore (USD 116 million), with the total recovery needs estimated at INR 503.28 crore (USD 72 million). (Government of Odisha, 2019)

### 2.4.7 Economic Losses

#### 2.4.7.1 Healthcare Infrastructure

The healthcare infrastructure incurred damage costs of about INR 73 crore or USD 10 million in the 14 districts that were affected. Disruption of health services which also included shortfall of governance and associated risks incurred total losses of about INR 232 crore or USD 33.1 million. The 14 districts affected were estimated to need an amount of INR 165 crore or USD 23.7 million for total recovery needs. The nutrition sector incurred damage of INR 55 crore or USD 7.8 million to the institutions. The total losses were estimated to be around INR 30 crore or USD 4.3 million, while the approximate total amount for recovery needs was INR 291.79 crore or USD 42 million.

#### 2.4.7.2 Transport Infrastructure

Road furniture and road signs incurred a total estimated damage of INR 326.2 crore (USD 46.6 million), which includes state roads, rural roads, ULB roads and national highways. The amount for overall recovery was assessed to be approximately INR 425 crore (USD 60.7 million).

#### 2.4.7.3 Energy Infrastructure

With the energy infrastructure heavily damaged, the total requirement to 'bring back the system to the pre-cyclone level' was estimated at INR 8,139 crore (USD 1,163 million). Further, the damages and consequent outages of power supply caused a loss of revenue to the utilities of approximately INR 253.5 crore (USD 36 million).

Three options were considered and estimates were drawn to create and rebuild resilient and robust energy infrastructure –

- The overhead system is used with existing equipment, installation of poles, equipment of improved specifications and strict quality control, amounting to total cost of recovery at INR 9,747 crore (USD 1,393 million)
- The overhead system is used with H poles and spun poles, stricter quality control, amounting to total cost of recovery at INR 11,357 crore (USD 1,622 million)
- A new underground cable system is built for distribution network, amounting to a total cost of INR 25,920 crore (USD 3,703 million) (Government of Odisha, 2019)

#### 2.4.7.4 Telecommunication & Information Technology Infrastructure

The estimated loss and damage in the telecommunication sector due to the cyclone was INR 447 crore, with the corresponding recovery needs estimated to be INR 482 crore, which included BSNL and private operators. This was assessed on the basis of discussions held with the line departments.

#### 2.4.7.5 Agriculture and Food Infrastructure

One of the most severely affected sectors, the agriculture, fisheries and livestock sector, the losses and damages encountered were approximately INR 3033 crore. The corresponding recovery needs amounted to INR 2615 crore. Further, the fisheries sector faced losses worth INR 158.35 crore (USD 23 million), including damages to infrastructure and aquaculture. This amounted to 5% of the total loss and damage in the sector.

#### 2.4.7.6 Water Supply and Management Infrastructure

The cyclone caused INR 99.04 crore (USD 14.3 million) worth of damage to rural water and sanitation infrastructure in seven districts. The estimated losses were INR 100.4 crore (USD 14.35 million). (Government of Odisha, 2019)

### 2.4.8 Inferences/ Conclusions

Located on the east coast of India, Odisha is one of the most multiple-disaster-prone states in the country. Adding to the vulnerability is its poverty and deficit socio-economic profile, with sub-standard housing structures, densely populated islands close to the coast, large settlements located in areas that are extremely vulnerable to tidal surges. Further, the depletion of tree shelter belts and the mangroves, lack of proper access to villages near the coast, highly hazardous industries located in cyclone-prone areas, and climate change further exacerbate the risks.

It can be observed through damage assessment that critical infrastructure and human settlements suffered extensive losses, socially, economically and physically. Sectors such as housing, education, cultural heritage, transport, power infrastructure, animal husbandry, health infrastructure and ecology were severely affected.

The cyclone was also found to impact the marginalised groups and socially vulnerable populations differently and relatively more severely. These includes children, elderly, women and adolescent girls, persons with disabilities, members of the ST and SC communities, fishermen groups, small traders, urban slum dwellers, artisans and daily wage earners.

Some factors that further compounded the vulnerabilities of these marginalised groups even before the cyclone had struck included their location of residence, gender discrimination, poverty and inequality.

On a macro-economic scale, the damage and losses estimated were at 5% of the GSDP of the state. Damages worth INR 539 crore (USD 78 million), were suffered by about 6,441 public buildings. More than INR 21000 crore (USD 3 billion) were required for infrastructure needs across all the affected sectors.

## 2.5 KERALA FLOODS (2018-19)

### 2.5.1 Introduction

Kerala was struck by severe floods in July 2018, owing to unusually high rainfall in the monsoon season. The floods, recorded to be the worst flooding in almost 100 years, killed 483 people. All the 14 districts of the state were set on red alert.

The heavy rainfall was almost 256% more than the usual rainfall in the state in the monsoon season. This led to dams being filled to their capacity on the evening of $8^{th}$ August. 310 mm (12 inches) of rainfall was received within the first 24 hours. As a result, 35 of the 43 dams had to be opened, due to the rising water level close to heavy rainfall. This caused flooding in the low-lying areas around. (Cochin Herald, 2018)

The Government of Kerala claimed that$1/6^{th}$ of the total population had been directly affected by these floods and consequent incidents. The flow of water in some stretches of the Periyar was 1,800 cubic metres — or about one swimming pool of water — per second, almost equal to that in 1924 as recorded by the colonialists. The Government of India declared it as a Level 3 Calamity, or "calamity of a severe nature".

The extreme and persistent rainfall that occurred in Kerala in August 2018 had severe impact on the socio-economic conditions, human lives and livelihoods, infrastructure, transportation and agriculture. It was estimated that the flood caused economic damage of more than USD 3 billion. (News18, 2018).

### 2.5.2 Causes of Flooding

The Kerala High Court appointed an amicus curiae, Jacob P. Alex, who, in his report mentioned that the floods were resultant of the inefficient dam management by the State Government. The state had 79 dams, which were purposed for irrigation and generation of hydroelectricity. None of these dams were used or operated to control or moderate floods. The report quoted "*Sudden release of water simultaneously from different reservoirs, during extreme rainfall aggravated the damage*". In addition, blue, orange and red alerts had been issue, but they were not in accordance with the EAP guidelines. It was also highlighted in the report that no precautions or follow-up actions were taken to evacuate people and move them to safer locations, even after the red alert was issued. Noted engineer, E Sreedharan, also blamed the Kerala government, claiming that the Kerala Flood was a man-made disaster. In the Supreme Court, however, the Government of Kerala argued that the water was release very suddenly by the Tamil Nadu Government, from the Mullaperiyar Dam, stating that as one of the reasons that caused the devastating floods. (Firstpost, 2019)

### 2.5.3 Geology

The geographical location of Kerala, in addition to the high population density and weather patterns makes it vulnerable to various natural and man-made hazards. These include floods, coastal erosion, lightning, drought, earthquakes and landslides.

The state is vulnerable to lightning, specifically in the months of April, May, October and November. About 70 people are estimated to die every year due to lightning. Further, almost 14.8% of the state's area is vulnerable to floods. Additionally, the mountainous regions suffer numerous landslides in the monsoons. Kerala also experiences 12 years of moderate drought between 1871 and 2000. The coastline of Kerala, 570 km long, is also vulnerable to sea level rise, storm surges during the monsoons, and erosion. It has also been noted recently that soil piping and tunnel erosion have posed to be a slow hazard, causing land subsidence in the state. (Kerala State Disaster Management Authority , 2010)

### 2.5.4 Chronology of Events and Cascading Impacts

The state of Kerala began receiving unusually high levels of rainfall since May 2018. As recorded on 30th August, the number of fatalities came to 483. The devastation caused by the floods was similar to the Great Flood of 1999.

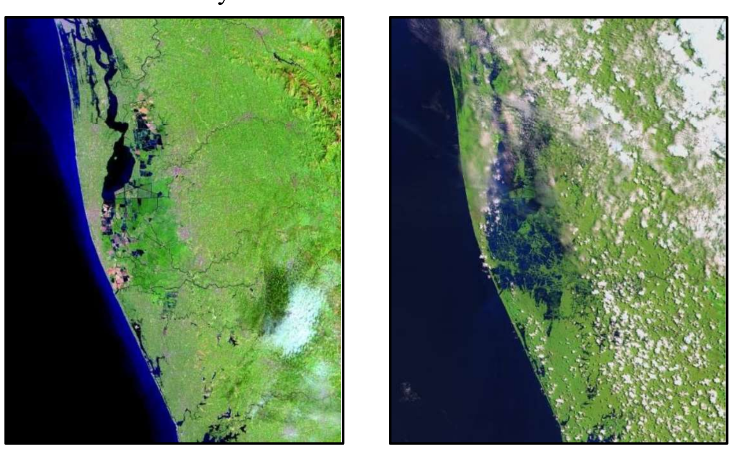

*Image 4 Kerala before (left) and after (right) the floods, released by NASA. The images are false-colour, which makes flood water appear dark blue and vegetation*

*Table 8 Chronology of Events and Cascading Impacts*

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| June 1 to 14, 2018 | • Monsoon hits 3–days three days before schedule on May 29, 2018.<br>• Warning of flash floods after the southwest monsoon hit Kerala. | • 8 of 14 districts reported floods and landslides, mostly in the hilly areas of the state. |
| June 15 to July 6, 2018 | • Heavy monsoon continues.<br>• No new flood reports. | |
| July 7 to 13, 2018 | • 7 more districts report heavy rains. | • Landslides and flash floods, again in the hilly and central parts of Kerala. |
| July 14 to 20, 2018 | • Heavy monsoon continues.<br>• National Disaster Management Authority declared 13 districts affected.<br>• Only Kannur District unaffected. | • Landslips, flash floods, people drowning and roads and bridges crumbling under the intensity of water. |
| July 21 to 27, 2018 | • No new flood reports.<br>• Kottayam and Alappuzha districts were officially declared flood-affected | • Rain-battered state sees at least 1.17 lakh people displaced to relief camps. |
| July 28 to Aug 3, 2018 | • Gates of the Idukki dam opened for the first time in 25 years | • |
| Aug 8 to 14, 2018 | • Kerala received rainfall of 310 mm within 24 hours | • Shutters of Neyyar dam rose to 5 inches from 4.<br>• Chalakuddy River overflowed.<br>• Over 20 landslides reported in Kannur district. Hundreds of families left isolated |

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| | • Gates of 24 dams across the state opened.<br>• Shutters of Idamalayar dam opened for the first time in 5 years. | • Landslides reported in Malappuram, Idukki, Wayanad, Kannur, Kozhikode and Palakkad districts.<br>• Red Alert issued in Wayanad.<br>• Parts of Nilambur were evacuated, and situation worsens in Kuttanad. |
| | • All 5 gates of Idukki-Cheruthoni dam opened.<br>• Kochupampa dam also opened. | • 10,000 people evacuated.<br>• ATMs and banks closed in flood-hit areas.<br>• Drinking water crisis in Kochi, as the supply from Aluva was down by 20%.<br>• Thiruvananthapuram airport geared up, as Cochin International airport shut down |
| | • Banasura Sagar dam opened<br>• Upper Kuttanad experienced heavy downpour | • IMD issued Red Alerts across 8 districts |
| | | • Number of houses destroyed reached 20,000 |
| | • All gates of Idukki dam opened | • Landslides reported in 5 districts |
| | • Walayar and Mattuppetti dams also opened. | • State government granted Rs 1,000 crores for first phase reconstructions. |
| | • Pampa River experienced its worst floods in half a century. | • Munnar town isolated. |
| Aug 15 to 20, 2018 | • Gates of 35 dams in the state opened | • Kochi airport shut until August 29<br>• Idukki district administration relocated over 4,000 people to relief camps<br>• At least eight people killed in Malappuram owing to a house collapsing |
| | • Neyyar dam opened for the first time in decades | • Landslides in 87 places across the state leaving hundreds isolated<br>• 130 fishermen, in 60 boats, reached flood-hit areas from Vizhinjam |

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| | | • Upper Kuttanad flooded<br>• Wayanad Churam blocked<br>• Public transport system halted in several parts of the state<br>• Southern Railways and Kochi Metro suspended operations due to floods<br>• Kochi Metro Rail (KMRL) also ceased its operations following flooding of its yard in Muttom |
| | • Chalakkudy River reached 16 feet. | • 150,000 homes abandoned in Kuttanad<br>• 142,000 people were in 416 relief camps in Ernakulam district<br>• 80,757 people placed in 500 relief camps in Alappuzha district<br>• Kerala State Electricity Board switched off almost 4,000 transformers across the state, disrupting power supply over past 24 hours<br>• Temporary health centers opened in all affected areas<br>• Kochi Naval Airport opened for civil aviation<br>• 5 units of NDRF made their way to Thiruvananthapuram for rescue operations |
| | • Mullapperiyar dam reached 141 feet<br>• Idukki dam stood at 2,402 feet | • 58,506 people rescued, however, 388 individuals were reported missing<br>• 14 deaths reported each in Alappuzha and Ernakulam<br>• PM declared an urgent relief of Rs 500 crore for rescue ops<br>• Water Authority opened 24/7 emergency water supply<br>• Ernakulam-Ankamaly road blocked, and district borders between Ernakulam and Thrissur washed off<br>• Fisheries Ministry opened control room in Chengannur |

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| | | • Situation in Chalakkudy, Paravur, Mala, Aluva, Kalady remained critical |
| | • Rainfall weakened across the state. However, IMD predicted strong winds by the coasts, and rough seas over the south, central and northwest Arabian Sea<br>• For the first time since the 1924 floods, water level at Vembanadu lake touched 90cm | • Red Alerts withdrawn from all districts where it was in place<br>• 8 deaths reported in Thrissur district<br>• 90% of Kuttanad residents evacuated<br>• Road and rail transportation services resumed<br>• Water receded in Ranni, Konni, Kozhancherry and parts of Pathanamthitta district |
| | • IMD declared that rainfall intensity should decline | • Community kitchens popularized in all 3,272 camps<br>• In total, 11,000 houses and 46,000 hectares of crops were destroyed |

### 2.5.5 Extent of Damage and Effect on Population

In August 2019, due to excessive rainfall, the water level in the water bodies rose, which affected close to 2 lakh people directly. Close to 2000 houses were fully damaged while around 15000 houses were partially damaged. Similarly the 2018 Kerala Floods led to a total loss of properties worth Rs. 40000 crore. Around 15600 houses were fully damaged. More than 36000 people displaced and 450 people lost their lives.

### 2.5.6 Impact on Critical Infrastructure

#### 2.5.6.1 Transport Infrastructure

The devastating floods caused the public transportation system to collapse in various parts of the state. All flights at the Cochin International Airport were suspended for 2 weeks. This caused losses of almost INR 300 crore. Similarly, services of the Kochi Metro Rail were suspended, since the metro yard got flooded. Operations of the metro were resumed on 16 August, offering free rides to people who were affected by the flooding. The floods had also impacted the bus services to Kochi, due to submerged sections of the national highways. The train services were affected and suspended, thereby having more than 25 trains rescheduled or cancelled. (Cochin Herald, 2018)

*Image 5 Aerial view of a flooded area of Northern Kochi, August 18, 2018. Source: cbsnews.com*

*Image 6 Kochi International Airport, 15 Aug 2018 Source: deccanchronicle.com*

Certain parts of the state also faced landslips, thereby cutting off hill stations like Nelliyampathy. The Main Central, or the MC Road, was among the worst affected arterial roads in the state. Numerous village roads were incarcerated, especially in the hilly districts of Idukki and Wayanad.

### 2.5.6.2 Healthcare Infrastructure

The floods affected numerous people, causing a surge in patients in the hospitals. Further, some hospitals were waterlogged and inundated, in addition to sever shortage of staff. Due to this, their patients were shifted to other hospitals, which had to cancel their routine operations and OPD in order to accommodate this surge. While most of the hospitals recorded 80-90% bed occupancy, the staff strength was only 30-35%. The major concerns of hospital authorities included liquid oxygen supply for patients on ventilator, surgeries and ICU. The hospitals also had to cope with the limited stock of diesel to run the generators, since the power shut down in the state. (Nair, 2018)

Most of the major hospitals in the state have a minimum capacity of 11000 litres of liquid oxygen, which they get from Bengaluru, and is refilled once in 7-8 days. However, due to roads affected by the floods, the vehicles carrying liquid oxygen were stuck in Thrissur. Many patients of Aster Medcity and CIMAR were shifted to neighbouring hospitals to ensure safety. Medical and surgical patients at the Amrita Institute of Medical Sciences were consolidated to one floor, while some patients were discharged and moved to the hospital guest house. Selected surgeries at the Lisie Hospital were postponed since the hospital was short of liquid oxygen. (Nair, 2018)


*Image 7 One Floor of TVM Cosmopolitan Hospital inundated, 15 Aug 2018; Source: thenewsminute.com*

### 2.5.6.3 Telecommunication & Information Technology Infrastructure

Telecommunication services at Idukki, Alappuzha, Ernakulam, Pathanamthitta, and Thrissur districts were among the worst affected. 190 optical fibre cable cuts were found out due to the impact of floods. Out of 85,900 Base Transceiver Stations (BTS), 23,552 were affected. The same was confirmed by P.T. Mathew, chief general manager, Kerala circle, BSNL about the telecom services in the low-lying areas. About 10% of the telecom services of Kerala were impacted. (Cochin Herald, 2018)

*Image 8 Collapsed telecom tower erected on top of a two-storey building, Thoppumpady Source: timesofindia.com*

**2.5.6.4 Water Supply and Management Infrastructure**

A study by the Central Water Commission (CWC), New Delhi, concluded that the Kerala floods of 2018 occurred due to severe storms, while the release of excess water from the dams and reservoirs did not have a major role in the augmentation of floods. The report, which was prepared by the Hydrology (South) Directorate, Hydrological Studies Organisation of the CWC, stated that the flood was due to severe storm occurrences during August 8 to 9 and 15 to 17. (Central Water Commission, 2018)

It was also recorded in the report that the volume of floods absorbed by the Idukki reservoir was almost 60 MCM (million cubic metres) in the period of August 15 to 17. Hence, even with the conditions of the reservoir being 75% filled, the flooding could not have been mitigated, since the rainfall occurrence in one day was more than 200 mm in majority of the areas. This severe rainfall continued for 3-4 days. The report also stated that the volume of water released was almost the same as the volume of inflow of water. (Central Water Commission, 2018)

Kerala floods also affected the availability of safe drinking water in the state. The Kerala Water Authority (KWA) was forced to stop pumping the water in the state from major treatment plants, due to power failure and very high rise in water levels. The worst affected plants in terms of the supply of drinking water were the ones at Ernakulam, like Chovara, Aluva, Pathanamtitta and

Ma. Additionally, supply of drinking water was affected in most places in the northern districts except Kasargode. Around 31 water schemes stopped functioning, and almost 90% of the supply of water Malappuram was affected, owing of the flood and power failure. Similarly, in Palakkad and Kozhikode, 60% of the water supply was affected. (Cochin Herald, 2018)

The state faced a shortage of fresh drinking water supply, and was also threatened by the onset of water-borne diseases such as typhoid, cholera, leptospirosis and hepatitis. The Indian Railway sent a special train on 17 August, carrying 2.9 lakh litres of drinking water, to help meet the fresh water demand.

### 2.5.7 Economic Losses

#### 2.5.7.1 Transport Infrastructure

The highway network in the state of Kerala is more than 2 lakh km, of which almost 60% is surfaced. Almost 10,000-12,000 km of these roads under the Public Works Department were estimated to be destroyed, damaged or affected. Additionally, rural roads, which comprise about 60% of the total surfaced road network, were also affected or damaged. (Cochin Herald, 2018)

*Table 9 Economic Losses of Road Network*

| | |
|---|---|
| Total Length of state highway network (Km) | 2,00,000 |
| Estimated damaged or destroyed roads (PWD) (Km) (60% is only surfaced) | 12,000 |
| Estimated expenditure for restoration of these roads | ₹8,00,00,00,000 |
| Estimated expenditure for restoration of rural roads | ₹ 3,00,00,00,000 |
| **TOTAL** | **₹ 11,00,00,00,000** |

Roughly around Rs. 10, 000 Cr. Was needed to restore and repair the damages to the road network immediately in the state.

*Table 10 Economic Loss of Air Network*

| | |
|---|---|
| Percentage of international passengers affected | 55% |
| Number of passenger traffic affected in 12-15 days | 4,00,000 |
| Estimated Revenue Loss | ₹ 3,00,00,00,000 |
| Additional Losses (Operations, Services, damages etc.) | ₹ 10,00,00,000 |
| Loss Due To Airport Disruption | ₹ 3,10,00,00,000 |

#### 2.5.7.2 Healthcare Infrastructure

About 75 lacs doxycycline tablets were disbursed in the State, of which 18 lakh capsules were provided by the Centre. Doxycycline is a drug that is used for treatment of leptospirosis and for prophylaxis. These drugs were used for water-borne illnesses that can typically be expected during and after floods, and were arrested effectively in the state. The situation was also monitored by The National Centre for Disease Control. The strategic operation centre of the state was activated. Further, reporting on daily basis was followed from August 21$^{st}$, to keep a check on epidemic-prone diseases.

In terms of the numbers of communicable diseases, it was only cases of leptospirosis that had shot up in the wake of the floods. Overall, there were 1,213 cases of confirmed leptospirosis and 2,427 cases of suspected leptospirosis reported after August 15 in the State. There were 48 deaths due to leptospirosis while 89 died of suspected leptospirosis. So, roughly a loss of around Rs. 150 Cr. was estimated. (Nair, 2018)

#### 2.5.7.3 Telecommunication & Information Technology Infrastructure

A review meeting chaired by Telecom Secretary Aruna Sundararajan pegged the losses to different telecom service and infrastructure providers at Rs 350 crore. More than 20 percent of the state's telecom network was affected due to floods and landslides.

### 2.5.8 Inferences/ Conclusions

The unexpected precipitation which caused the floods began 3 days before schedule on May 29th, 2018. The rainfall was 27% higher than expected affecting one sixth of Kerala's population directly. Transportation sector was the first to get it as roads and bridges started crumbling down under the intensity of water from 14th to 20th July, 2018. Kochi International Airport also had to be shut down around 10th August, 2018 till the end of the month. Damages were reported from the power sector as well as the Kerala State Electricity Board had to switch off almost 4,000 transformers across the state, disrupting power supply over past 24 hours. Water supply infrastructure was also affected as Kochi faced drinking water crisis because the supply was cut down by 20%. The healthcare infrastructure could not cater to the surge in number of patients and hence temporary healthcare camps had to be set up in different parts of the state. It is clearly visible the critical infrastructure of the state got adversely disrupted further adding to the miseries of the affected population.

Apart from the disruption, the damage to critical infrastructure incurred huge economic loss. The healthcare infrastructure alone estimated a loss of around 150Cr. while the damaged road network required immediate restoration of worth Rs. 10,000Cr. The power sector reported a loss of around Rs. 850Cr, with the telecommunication network estimated a loss of around Rs. 350Cr. The huge figures of economic loss for each sector of the critical infrastructure indicate the severity of extreme weather event of floods, which hit Kerala in 2018.

## 2.6 KOTRUPI LANDSLIDE, 2017

### 2.6.1 Introduction

Himachal Pradesh holds plenty of mountains and hills, which are vulnerable to landslides as a result of high intensity earthquakes and monsoons. Unsuitable activities, such as road cutting, deforestation, terracing, changed agricultural patterns, etc. has increased the vulnerability of unstable, steep and geologically young slopes in the Himalayan Ranges, in the recent decades. (Himachal Pradesh State Disaster Management Authority, 2020)

One of the most common hazards in Himachal Pradesh, landslides can pose severe risk to property and life. The state is affected by landslides in different regions almost every year, which causes damage to houses, loss of life, injuries, disruption of communication infrastructure, loss of agricultural land, disruption of energy infrastructure, etc. Unsuitable anthropogenic activities, climatic conditions and fragile rocks forming mountains have rendered the state vulnerable to frequent landslides. (Planning Commission - Government of India, 2005)

#### 2.6.1.1 History of Landslides in Himachal

- Maling (1968): Damage caused to 1 Km NH-22; landslide is still active.
- Kinnaur (Dec.1982): Collapse of 3 bridges and 1.5 km of road; occurred at Sholding Nala.
- Jhakri (March 1989): Damage caused to around 500 m road at Nathpa; landslide is still active.
- Luggarbhati (12 Sept.1995): 39 people as per official record but 65 people as per actual count buried alive due to the landslide.

- Prominent landslides in Beas valley: Bhang, Marhi, Mandu, Chhyal, in upper catchment of the Beas River. (Himachal Pradesh State Disaster Management Authority, 2020)

### 2.6.2 Causes of Landslide

The natural phenomenon of landslides has also been found to be triggered by anthropogenic activities. Similar to other parts of the Himalayas, Himachal Pradesh also has varying landslide activity depending on the geology, altitude, and topography. Other natural factors that influence the occurrence of landslides include saturation by heavy rains, steepness of slopes, rock vibrations, melting snow and ice, change in water content, exceeding loads from landfills, waste, embankments, debris dumps, frost, toe cutting by streams and rivers, and change in vegetable cover. (National Disaster Management Authority, 2009)

Various developmental activities in the hills and mountains have increased the vulnerability of landslides manifold. Some of the areas affected by landslides that have also affected the NH-22 in Satluj Valley are Pangi, Jhakri, Urni, Powari, Nichar, Sholdan, Thangi, Khadra Dank, and Barua. The increase in the frequency and intensity of landslides can also be attributed to anthropogenic factors such as terracing, unplanned and under-designed construction of roads, deforestation, encroachment on steep slopes of hills and agricultural practices that are water intensive.

It has also been emphasised by experts that the slopes in towns and cities like Shimla have neem overloaded and are therefore getting destabilised due to unplanned expansion of urban areas and unscientific land use. Such overloading may cause minor landslides initially, and lead to larger landslides in the future. Also, due to continuous excavation of slopes for infrastructure development and construction, Shimla has also been found to be sinking at various places. (National Disaster Management Authority, 2009)

#### 2.6.2.1 Factors Leading to Occurrence of Landslide

The slope wasn’t completely stable as there were earlier recorded landslides in the year 1977 and 1997 around the same time of the year. Due to this, the debris of the previous landslides were present, and there existed a fault line. Cracks had formed on the slope which allowed rainwater to percolate into the slope which consisted colluvium material and compacted debris from the previous landslides. Due to change in rainfall patterns attributing to climate change, the phenomena of cloudbursts was seen more and more. Rainfall of the current monsoon season and cloudburst caused the landslide to occur as the slope had become unstable due to excess moisture and led to the failure of weathered rock. (Singh, et al., 2020)

#### 2.6.2.2 Incidents in the past

Villagers had reported that deep cracks appeared on the hilltop around five years ago. The authorities did not take the development of the crack seriously. This was a negligence that put the condition of the slope to deteriorate further as time went by. It only made the slope more and more vulnerable to landslides as the region receives a good amount of rainfall every monsoon.

Well compacted debris of old slides that occurred in August 1977 and August 1997. (As per 41-parametric inventory sheet of the Kotrupi landslide, No. 16) Since there was newer material on the surface of the slope, the slope was not as stable as the surrounding slopes of the surrounding hills.

The area affected is geologically in a thrusted contact between the Shali Group of rocks (that contain brick red shale, dolomites, purple clay, micaceous sandstone and mudstone) and the Shiwaliks. Due to these rocks being subject to deformation by the thrust in the concerned area, in addition to the generally low hardness, these rocks are increasingly vulnerable to landslides. (Singh, et al., 2020)

### 2.6.3 Geology

The complex geological structures of Himachal Pradesh are rich with complicated topography of hills, valleys and mountain ranges. The Shiwalik hills are made up of rocks such as shale, sandstone, clay and recent Alluvium. The central part between Spiti, Lahaul and parts of Kinnaur districts, and Kullu, eastern Shimla is bordered by unclassified granites. The Triassic formation, found in the Kaza tehsil of the Spiti Lahaul district, are presented by the eastern greater Himalaya. The granites found at Bandel and Jeori-Wangtu near Largi in the Kullu district have the oldest rocks. (National Institute of Disaster Management, 2016)

### 2.6.4 Chronology of Events and Cascading Impacts

*Table 11 Chronology of Events and Cascading Impacts*

| Event Timeline | Event Description | Cascading Impact |
|---|---|---|
| 1977 | • Scarp had already started developing due to slope failure on 13 August 1977 (GSI 2017).<br>• After two decades, on 13 August 1997, the landslide reactivated, and scarp widened in dimensions. Again, on 13 August 2007, slide reactivated, but the slope failure was not large and did not affect people, hence not much attention given. | • Landslide event in August 2017 was most devastating.<br>• People residing in the area of landslide zone (near toe and run off zone) lost houses, vehicles, occupations and lives. |
| August 13, 2017 | • Massive landslide occurred near Kotrupi village in Mandi district during early hours (01:00-02:00 AM local time). | • Debris from landslide killed more than 50 people when two HRTC (Himachal Road Transport Corporation) buses (i.e. Manali-Katra and Chamba-Manali)<br>• Other private vehicles were swept away and buried under the debris<br>• Approximately 300 m of road stretch of national highway (NH-154) completely buried under debris, thus disrupting communication on an important route.<br>• Immense quantity of debris released from landslide blocked the drainage up to 1 km in the downstream. |

| | | |
|---|---|---|
| | | • The area was subsiding due to presence of nullahs, which made the region swampier. |
| 2018 | • The slide reactivated but since the slope failure was not sufficiently prominent, not much attention given. | |

### 2.6.5 Extent of Damage and Effect on Population

#### 2.6.5.1 Impacts on Human Lives and Livestock

The catastrophic event resulted in loss of 47 human lives. After the search operation, 46 bodies were found buried under the debris. One body was found in mutilated and unidentifiable condition. About 40+ passengers were travelling by HRTC Bus from Chamba - Manali and about 6 passengers were on HRTC Katra - Manali Bus. With reference to the first interaction with SDM, Padhar, Police personnel deployed at site and Local residents from nearby villages, there was no information about any other fatalities. However, the villagers claimed that a few more people may have been trapped, especially pedestrians and daily need vendors. Several cattle got buried under the debris. (Pradhan, et al., 2019)

#### 2.6.5.2 Impacts on Buildings and Land

In Kotrupi Village Settlement Upslope, about 3-4 Nos. of hutments and cattle shades were damaged as per local residents. Many local residents left their houses to save their lives. None of the local residents of 3-4 houses nestled in mid-slope lost their lives as they vacated their homes before the incidence, due to a crude idea about possible slope failure. A resident had reported a loss of two-storey house, cattle and 37 bigha agricultural land. (Pradhan, et al., 2019)

#### 2.6.5.3 Impacts on Surrounding Villages

The landslide wiped out one village, while five nearby villages were under threat because the flow of Rupi Nullah had been blocked after the disaster and a lake formed. The Mandi administration got five villages evacuated near Kotrupi after the lake had been formed in the upper side of villages. Badwan, Ropa and Kotrupi residents were very close to the landslide-prone area. The administration had distributed tarpaulin among the villagers for them to set up tents in safe places. The evacuated villages for safety concerns were: Saraj, Bagla, Badvaan, Ropa, Sharsti and Jagehad. (Pradhan, et al., 2019)

### 2.6.5.4 Impact on Water Bodies

Since tonnes of debris had blocked Kotrupi nullah, the excessive collection of underground water had made the region boggy, and Pharka had directed officials to dig both sides of the spilled debris to give way to water and bind its edges with proper channelization. The flow of Rupi Nullah had been blocked after the disaster and a lake had been formed which posed a threat to the villages below. (Pradhan, et al., 2019)

*Image 9 Google Satellite Images from before and after the landslide occurred*
*Source: (Himbus, 2021)*

## 2.6.6 Impact on Critical Infrastructure

### 2.6.6.1 Transport Infrastructure

At Road Level: Road stretch of about 350 m and Bridge (25 to 30 m in length). The landslide damaged the road up to a stretch of 350 metres. After the incident there was no trace of the national highway NH 154 at Kotrupi up to 350 metres so the traffic was diverted to other roads. A large number of JCBs, tippers, dodgers along with manpower worked on a war footing to restore the highway.

The Pathankot - Manali highway was reopened 12 days after the incident with allowance for the traffic to move on the patch only during the day time from 7am to 7pm. Police parties were deployed on both sides of the damaged patch to regulate the traffic. Several villages were cut off from the district headquarters due to breaching of road and bridge. Also work was done to clear and widen the narrow stretches of the bypass roads in the area where traffic flow has been diverted. (Pradhan, et al., 2019)

#### 2.6.6.2 Impact on Vehicles and Equipment

During the incident, 2 Nos. HRTC Buses, a few bikes and vegetable-carrying vehicles were buried under the debris and damage was caused in the area. It was reported in the news that when the landslide had occurred, a little later than midnight, both the buses had halted for a break. These buses got buried in the debris, after they were swept 800 m down the slope.

#### 2.6.6.3 Impact on Tourism, Commercial and Social Activities

The landslide had disrupted the tourism, commercial as well as social activities. This was due to the stretch of damaged road that cut off link routes to Manali and other tourist places.

### 2.6.7 Economic Losses

The data for landslide losses can be categorized as indirect or direct. Losses can occur in different forms. They can happen collectively in one geographic region, or they can happen as an isolated event that has an effect on only a small area, like residential structures or highways. Direct costs of damages due to landslides include the reconstruction, replacement, repair or maintenance, as a consequence of damage to installation or properties. These need to be within the boundaries of the landslide occurrence. Direct losses also include the damages caused due to floods, which in turn are caused by breach in a natural dam, which has been formed because of an obstruction in natural drainage due to sliding. (National Disaster Management Authority, 2009)

Indirect losses due to landslides include – loss in tourism revenues, interrupted transport system, loss of agricultural, industrial and forest productivity, reduction in value of real estate, losses in tax revenues on land or property whose value has sunk due to landslide, and mitigation measures. In addition to this, the indirect losses also include effect on water quality in irrigation facilities and streams, loss in animal or human productivity, death, injury, and psychological trauma. Other secondary physical effects include landslide-induced flooding. The indirect losses may exceed the direct losses. (National Disaster Management Authority, 2009)

However, indirect costs and losses are tough to estimate and assess, and hence, are not included in the final estimation. If included, they may be superficial and conservative. Nevertheless, since the financial information of this nature is often discreet, the details of the losses may not be completely revealed.

### 2.6.8 Inferences/ Conclusions

The landslide had been found to be recurring every 2 decades due to existing fault lines and changing rainfall patterns. Further, cracks had formed on the slope, which allowed rainwater to percolate into the slope. The landslide caused extensive damage to the road network and transport infrastructure, in addition to the (47) lives of bus passengers that were lost. The debris caused blockage in the Kotrupi nullah, thereby creating a lake due to ceased water flow. This was seen as a threat to the villages below owing to the increased chances of flooding.

In terms of economic losses, the costs included repair, replacement, or maintenance resulting from damage to property or installations, and loss in agriculture, tourism, real estate, injuries, deaths and trauma.

## 2.7 CHENNAI FLOODS (URBAN), 2015

### 2.7.1 Introduction

An unmitigated and unexpected calamity, the floods that occurred in Chennai in 2015 devastated life and property immensely. Emergency evacuations caused people to abandon their houses, located on the banks of Adyar River and other low-lying areas.

It has been observed that the flooding was primarily manmade disaster. Firstly, the opening of the Chembarambakkam reservoir during heavy rainfall without prior adequate warning acted as a significant factor in causing the deluge. Secondly, illegal constructions, unplanned development in urban areas and corruption in development permits without conducting an environmental impact assessment also played a major role in the flooding. (Gaitonde & Gopichandran, 2016)

### 2.7.2 Healthcare

Flooding can cause significant impacts on the health sector as well as infrastructure. The threats may be direct, such as flash floods causing fatalities and destruction, or indirect, such as closing of a hospital building due to inundation. It is important to have redundancy and surge capacity, in addition to immediate management and action, so as to reduce the pressure on medical practitioners, doctors, paramedics and nursing staff. The preparedness for flash floods for public health must include having a backup inventory of medical supplies, water, tools and equipment, contingency planning, standby arrangements for information and communication management, establishing and maintaining emergency services, and coordinating arrangements of mock drills, community level planning and personnel training. (TARU, 2016)

During the floods that occurred in Chennai in 2015, medical personnel in the functioning medical facilities were under tremendous pressure, working endlessly for 2-3 days to provide critical services to people. The availability of backup inventory of medicine, IV fluids, injections and equipment helped to provide continued medical care to the victims and patients. Emergency cases, patients who needed special care, deliveries and surgeries were given priority in the facilities. Paramedical staff and ESIC staff who had residences in the staff quarters donated their water and food supplies for staff on duty and the victims. Hospitals where the ground were was inundated, had their patients shifted to upper floors. (TARU, 2016)


*Image 10 Source: Hindu Newspaper, 2015*

### 2.7.3 ICT

Due to inundation, power losses and shortage of water and food supply, major companies in Information Technology (IT) located in Velachery and Tiruvanmiyur areas had to close down. Further, due to the loss of power, services and operations in the information and communication sector came to a halt and was not available to public. (Deccan Chronicle, 2015)

### 2.7.4 Transportation

#### 2.7.4.1 Impact on Transportation

Due to the unexpected deluge, all modes of transportation remained suspended, such as air, rail, suburban rail and road services. As a result, numerous passengers were stranded at rail terminals and airports. (The Hindu, 2018)

#### 2.7.4.2 Situation

The operations of the conventional systems of transport were stalled due to the flood waters and inundation. This caused hindrance in access to health services and evacuation activities from the inundated areas. (TARU, 2016)

#### 2.7.4.3 Challenges

Volunteers, rescuers and general public faced several challenges such as absence of route planning, management of priority tasks, absence of mechanism of mitigation of impacts. Direct impacts of flooding that also posed challenges included lack of coordination with fishermen community, lack of access to fuel, notifications of road closure, absence of emergency detour routes, absence of warning signs or traffic control, etc.

#### 2.7.4.4 Response

To rescue the people in distress and stuck in the deluge, fishermen and professional rowers were hired. They also supported the rescue operations conducted by the fire department. About 240 people were rescued in a day, with each boat rescuing 4-6 persons in one trip.

Role of Private Transportation Agencies: the floods affected all modes of transport, including air, road and rail networks, which were affected in Chennai in 5 out of 15 zones. In some areas, rescue operations on foot were extremely difficult due to the increase in water levels up to 10-12 feet. Private organisations such as Ola cabs offered significant services for rescue; they established boat services for evacuation and restoration of supply chains of water, food and other critical needs. Further, community based organisations, NGOs and other government agencies also followed the same and established boat services of their own for rescue and help. Based on the existing road network, the private agencies prioritised seven routes. In a day, every boat provided service to and fro, about 40 to 60 times. Further, these agencies maintained close contact with the fire department, in order to integrate their services and support with that of the government, in addition to the support and planning from the government agencies. The process brought to light, the significance of flood plain mapping, with different sets of precautions for day and night, especially for identification of roads that may be flooded or inundated. (TARU, 2016)

### 2.7.5 Water Sanitation and Hygiene

The status of sanitation facilities and drinking water in the state of Tamil Nadu, as assessed in the census 2011, finds approximately 80% of the households dependent on tap water. 13% of the households access the water through tube wells and hand pumps, and the rest access water through covered and open wells. Further, 48% of the households have access to toilet facilities, and 41% of the households have water closets within the toilets.

The flooding disaster severely affected the infrastructure and serviceability of the water, sanitation and hygiene facilities. The following observations were made:

- Lack of Safe Drinking Water
- Lack of Access to Water for Sanitation
- Lack of sanitation facility
- Poor Waste Management
- Poor Menstrual Hygiene Management system (Joint Needs Assessment Report, 2015)

### 2.7.6 Agriculture and Food Supply

Many of the districts affected by the floods had agriculture as their backbone for livelihood and economy. The districts of Thiruvallur and Kancheepuram, despite being located close to Chennai, have more than 50% of the workforce earning through agriculture. The floods destroyed crops such as pulses, millets, paddy, sugarcane, cotton, oilseeds, in addition to the horticulture plantations and crops.

The state recorded a loss of livestock at 9992 as on 15th December 2015. Additionally, due to heavy rains, 5223 poultry birds died. (Joint Needs Assessment Report, 2015)

## 2.8 BIHAR FLOODS, 2008-2020

### 2.8.1 Bihar Kosi Flood, 2008

#### 2.8.1.1 Overview

The Kosi River in Bihar flooded on 18th August 2008, bursting out through its eastern embankment, about 8 km north of the Indian border, and around 13 km upstream of the Kosi Barrage in Nepal. While the regular intensity of water force in the river in 25744 cusec (cubic feet per second), it went up to 166000 cusec at its peak, running through a new course straight down south, 150 long north to south and 15-20 km wide. This increase in water force caused major flooding in Bihar and Nepal. It was recorded that around 3.3 million people were affected in Bihar. Further, about 1100 culverts and bridges were destroyed due to the floods, in addition to 800 km of unpaved and paved roads. Districts of Madhepura, Supaul and Saharsa reported the maximum damages. (Government of Bihar, 2010)

#### 2.8.1.2 Scale of devastation

The flooding occurred in Northern Bihar, in the Kosi River valley, covering the districts of Araria, Madhepura, Supaul, Bhagalpur, Saharsa, Purnea and Khagaria.

250 people were killed and around 3 million people were rendered homeless. At least 840000 acres of crops were recorded to be damaged, and about 3 lakh houses destroyed. Villagers were forced to eat raw rice and flour mixed with polluted water, due to lack of food and water supply. The floods caused widespread disease and hunger. In the district of Supaul, the flooding caused swamping in 1000 sqkm of farmlands, destroying crops, thereby making it the worst hit district.

In Nepal, the floods affected 53800 citizens and 11572 households in 6 districts, according to the Government of Nepal. The floods also severely affected the Koshi Wildlife Reserve, its biodiversity and wildlife.

#### 2.8.1.3 Roads & Bridges

The floods damaged numerous roads and bridges. The breach in the embankment caused formation of new streams in places where no cross-drainage works existed before. The cross drainage structures faced an excess flow of design discharge, thereby damaging/ collapsing around 1100 culverts and bridges. Around 79% (1830 km) of the total roads in the five affected districts were severely affected, partially or fully.

The rural roads were disproportionally affected, due to the large rural concentrations in the affected districts. About 70% (1635 km) of the rural roads were damaged or destroyed. It was estimated that the total cost of damages to bridges, roads and culverts was approximately INR 5.7 billion (US$129 million). (Government of Bihar, 2010)

### 2.8.2 Needs Assessment

The state undertook minimal reconstruction of the damaged roads and bridges on priority basis since the disaster occurred. The Needs Assessment Team observed that temporary diversions were made to restore all damaged culverts and bridges. While most of the paved roads were restored, the unpaved roads still lacked substantial repairs.

The total estimated amount required for reconstruction of road infrastructure, including culverts and bridges, was about INR 13.9 billion. The estimate was drawn considering the need for multi-hazard resilient construction, enhanced quality of construction to 'build back better' after disasters occur, and the amount of time elapse post the disaster. (Government of Bihar, 2010)

The following was considered for estimation of costs for the reconstruction of bridges and roads –

- Cost of reconstruction would be around 50% above the value of damage. Around 30% was taken extra to incorporate 'build back better' features, and around 20% was accounted for inflation.
- Regardless of the extent of damage, all bridges and culverts would be constructed anew.
- The new construction of culverts and bridges to be located corresponding to new channels and water streams created after the disaster.
- The culverts and bridges would be designed for a life expectancy of 50 years, and accommodate for increase in traffic in this period. Further, they would be designed with a minimum of two lanes, regardless of the current traffic.
- All new road constructions would be all-weather/ bituminous roads. (Government of Bihar, 2010)

### 2.8.3 Post Flood

#### 2.8.3.1 Introduction

The Kosi floods of Bihar were declared a national calamity by the Prime Minister on 28$^{th}$ August. US$ 230 million were assigned as immediate aid for rescue and relief efforts for the region. The National Disaster Response Force (NDRF) and the Indian Army carried out rescue operations. Relief supplies were dropped for victims in most affected districts by Indian Air Force helicopters. A disaster management team of 22 members was sent by the Mumbai fire department for help in relief work.

### 2.8.3.2 Resources

The initial search and rescue operations were carried out by 28 NDRF teams, with 118 boats and 1152 personnel. Additionally, 7 army teams were deployed, comprising of 280 boats and 2228 personnel. Cooked food was distributed to the victims and affected people by 1765 community kitchens. College and school buildings were used as relief camps (360 in number) to set up the evacuees. During the peak of the disaster event, the camps had more than 440000 people living in them. (Government of Bihar, 2010)

### 2.8.3.3 Planning

The analysis process was categorised according to occupational and social groups to assess the impact on households. The occupational groups included agricultural labour, services, artisan work, business and cultivation. Some cases were difficult to assess due to different occupations held by multiple members of the family. The social groups included OBC I, OBC II, STs, SCs, and others. (United Nations Development Programme, 2009)

### 2.8.3.4 Process

- Immediate response to the disaster, rescue and relief to the people.
- Management of the causality and the area.
- Rehabilitation

### 2.8.3.5 Rehabilitation

The Bihar Kosi Recovery Project, prepared and financed by World Bank, aimed at supporting recovery post floods as well as risk mitigation efforts for the future. The objectives of this programme were –

i. To strengthen the flood management capacity of the Kosi Basin
ii. To reconstruct the road infrastructure and damaged houses
iii. To improve the emergency response capacity of the state and the agencies in the event of future natural disasters
iv. To enhance the livelihood opportunities of the people affected

The following changes were made by this restructuring –

- The Department of Economic Affairs, Ministry of Finance, Government of India requested cancellation of Special Drawing Rights (SDR) - INR 32.4 million of the credit (US$ 50 million)
- Reduction of the beneficiaries in the component of housing reconstruction
- Reduction of the scope in the component of flood management
- Consequent reduction of the component of project management and implementation support
- Modifications in withdrawal schedule
- Revision of project performance targets and indicators in order to match with the allocations and revised scope of the components (Bihar Kosi Flood Recovery Project, 2010)

The primary goal of the project was social and environmental management framework. It has the following six components:

i. Owner Driven Housing Reconstruction
ii. Re-construction of Roads and Bridges
iii. Sustainable Flood Management
iv. Improving Emergency Response Capacity
v. Livelihood Restoration and Enhancement
vi. Project Management, Implementation Support and Technical Assistance (Bihar Kosi Flood Recovery Project, 2010)

**2.8.4 Recurrent Flooding in Bihar post 2008 –**

Bihar has experienced recurrent floods every year, and despite the World Bank investment through the World Bank Bihar Kosi recovery project, the causes of the flood have not been addressed. The challenges faced by the communities and government still persist, and have not been reduced or eradicated in proportion to the investments or need. The state of Bihar is far from prepared for the flooding events, and the critical infrastructure has been observed to be continually inundated or failing or being rendered non-functional post disaster every year until 2020.

The losses occurred in Bihar floods from 2008-2020 have been tabulated in Table 12.

*Table 12 Losses in Bihar floods from 2008-2020*

| Year | Human Lives Lost | Persons Affected | Live-stock affected | Villages Affected | Houses Affected | Total losses (in Rs.) |
|---|---|---|---|---|---|---|
| 2020 * | 43 | 74 lakh | | 1232 | | |
| 2019 | 116 | 119 lakh | | 1846 | | |
| 2017 | 253 | 126 lakh | 12967 | 3641 | 2341 | 93.6 Cr |
| 2016 | 243 | 85 lakh | 5383 | 2403 | 1.3 lakh | |
| 2014 | 13 | 16.5 lakh | | 1691 | 2861 | 56 Cr |
| 2013 | 201 | 44 lakh | 3 lakh | 3768 | 1.6 lakh | |
| 2011 | 143 | 64 lakh | 5.98 lakh | 3588 | 28067 | 220 Cr |
| 2009 | 32 | 12 lakh | 15 lakh | 915 | 2509 | |
| 2008 | 493 | 10 lakh | 15,500 | 2,585 | 2.3 lakh | 11630 Cr |

* - Data for 2020 is provisional, official report not released as on 12-Oct-2020.

**2.8.4.1 References for yearly flood data –**

- Bihar Kosi Flood (2008) Needs Assessment Report, Government of Bihar, World Bank, Global Facility for Disaster Reduction & Recovery, 2010.
- Situation Report - Bihar Floods, World Health Organisation, 2009
- Flood Report 2011, Flood Management Improvement Support Centre, Water Resources Department, Government of Bihar, 2011
- Rapid Assessment Report, Bihar Flood 2013, 2013
- Bihar Floods Rapid Joint Needs Assessment Report Part – I, Bihar Inter Agency Group, 2014
- Joint Rapid Needs Assessment Report - Bihar Floods 2016, Bihar Inter Agency Group, 2016
- Flood Situation Report, PGVS & Christian aid, 2017
- Bihar Floods 2017 - Immediate Needs Assessment and Inclusion Monitoring of Responses towards affected Dalits, Minorities & Adivasis in Araria and Kishanganj, NCDHR, 2017
- Damage to crops due to Heavy Rains and Floods, Press Information Bureau, Government of India, Ministry of Agriculture & Farmers Welfare, 2019

- Joint Rapid Needs Assessment, Bihar Urban Floods, Bihar Inter Agency Group, 2019
- India - Landslides and floods, NDMI, IMD, Bihar State Disaster Management Department, media, ECHO Daily Flash, 2020
- Bihar Floods JRNA, Disaster Management Department, Bihar, 2017
- A Report on Bihar Floods 2016, Bihar State Disaster Management Authority, 2016

### 2.9 Summary and Further Reading

The case examples entailed in the chapter are evident consequences of climate change and the effects of global warming on arctic pole, water bodies and landmasses. The frequency and intensity of such events has only increased, and with the expected surge in future, the vulnerability of the communities and infrastructure enhances exponentially. It is, thus, imperative that an inherent resilience and preparedness is incorporated to ensure the reduction of losses of lives and built & natural environment.

This headway has been observed in the state of Odisha, that has been victim of sever cyclones on an annual basis. It can be recognised through the statistics that each year the numbers of losses in terms of fatalities and financial aid drop, with the Cyclone Fani (2019) noticeably dropping fatalities to double digit numbers. With the help of aid from global organisations such as the World Bank, Asian Development Bank and World Health Organisation, the finances have been put into appropriate channels thereby encouraging the safety and security of population, infrastructure and ecology. On the other hand, the case of Bihar floods is a strong example of how uninformed channelization and impaired usage of funds and investments can lead to severe devastation year after year. The statistics display a steady increase in the number of fatalities from 2008 to 2020, and the affected population due to annual floods only escalates. Mismanaged funds and a lack of well-placed intentions have compelling consequences, which may only look like numbers to authorities and by-standers, but have unsparing and grim impact on the victims. It is encouraged that the reader studies more cases of extreme events, where noticeable reforms and transformations were made, leading to safety and security and reduced number of fatalities when the event repeated. The methodologies and application of the reforms, corrective actions, resilience and preparedness plans are important in such cases, since they act as major takeaways that can be applied to more vulnerable locations.

**NOTES**

# CHAPTER 3 - POST-DISASTER NEEDS, RESILIENCE AND RECONSTRUCTION OF BUILT INFRASTRUCTURE

## 3.1 Learning Objectives

This chapter brings focus on the need and benefits of disaster risk reduction and resilience. The national and international organisations have extensive mechanisms in place for relief, rescue and recovery operations, and additionally post disaster needs assessment processes that lead to reconstruction and redevelopment. Even as these processes are in place, the idea of education and awareness of the concepts of risk reduction and resilience is to ensure significant markdowns in losses and reduced need for rescue, relief and reconstruction activities.

The intention of introducing risk reduction and retrofitting is to ensure that investments ahead of imminent disasters to ensure resilience save expenditures and need for reconstruction after the disaster occurs. This not only saves the economy, infrastructure and finances, but also safeguards the lives of inhabitants and minimises trauma.

## 3.2 Disasters and the Built Environment

The recent years have seen a rising acknowledgement and recognition of the architecture and construction industry and associated built environment professions. These professionals have been seen to play an important role in terms of their contributions to the enhanced resilience of the communities and society to natural disasters. Consequently, an inter-disciplinary and multi-sectoral approach to disaster risk reduction is called for. While sustainability movements and efforts are constantly being made to restore and protect the natural environment, it is important to note that humans also have significant direct interaction with the environments and products that are produced by human-initiated processes, thereby making it important to divert attention to these also. (Haigh & Amaratunga, 2010)

The terminology 'built environment' emerged in the 1980s as a medium to collectively define these processes and products led by human creation. The significance of this built environment in the circumstance of disasters is best demonstrated by probing its attributes. It is important to note that the built environment plays a vital role in the service of human endeavours, thereby implying that when its elements or operations are disrupted, the society's ability to function and operate in an economic and social fashion is severely interrupted. It can be safely stated that disasters have the capacity to disrupt the growth of the economy, and encumber a person's ability to seek better opportunities and move upwards in the financial ladder. Hence, it is important that the built environment is safely constructed and resilient, to ensure that it's protective attributes and functionality can continue to provide a safe milieu for the society and economy to function, by offering resilience and reduced exposure to disasters. (Haigh & Amaratunga, 2010)

However, the organic, individualised and localised nature of the built environment, modelled according to the context, makes it challenging to apply generic solutions of reconstruction, resilience and mitigation. Nevertheless, it is important that it is the responsibility of the construction industry professionals to ensure safe structures by incorporating effective disaster planning and resilience. (Haigh & Amaratunga, 2010)

### 3.2.1 Disaster Risk Reduction and the Built Environment

Disaster management, as a process, is usually visualised as a two-phase cycle, where pre-disaster risk reduction and resilience inform post-disaster recovery and reconstruction, and vice versa. It is the function of the disaster management cycle to demonstrate the ongoing processes, which can help the businesses, governments and civil society to plan for and thereby mitigate the impact of disasters. This cycle also helps decrease the reaction time for post-disaster relief and recovery. This concept signifies the ability of the disaster management cycle to encourage a holistic approach, in addition to demonstrating the relationship between development and disasters. (de Guzman, 2002)

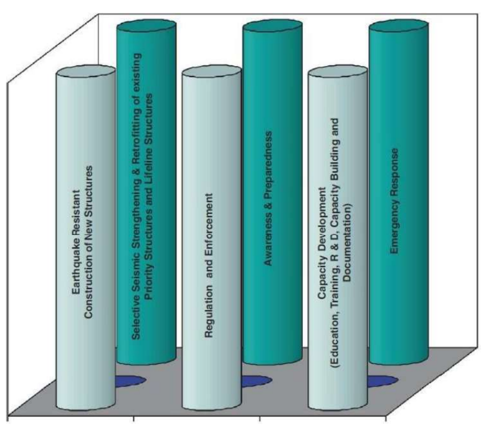


*Figure 7 The six pillars for earthquake management in India; Source: (National Disaster Mangement Authority, 2007)*

The most common stages of the disaster management process, as identified in various literature are – **pre-disaster, disaster and post-disaster.**

In the '**pre-disaster**' phase, the activities such as preparedness and mitigation are employed. This phase refers to the timeline before the occurrence of the hazard. It involves major activities such as risk reduction strategies, hazard assessment, preparation of response mechanisms, and minimisation of losses post-disaster. The '**disaster**' phase refers to the timeline of the duration and aftermath of the occurrence of the disaster. This phase involves short-term relief and response activities, such as evacuation, search and rescue, and medical care. The '**post-disaster**' phase involves the timeline of recovery until the community bounces back to relative or 'new' normalcy. Often, sustainable development is associated with long-term recovery, which essentially aligns with the widely defined term of resilience, whereby the vulnerable or affected community reduces its vulnerability by maximising its capacity of adaptation and shift their focus on long-term growth. (Haigh & Amaratunga, 2010)

The contributions of activities carried out in the '**pre-disaster**' phase are significant and varied. Structures are designed, engineered and constructed using resilient measures, thereby minimising the risk of damage and fatalities associated with disasters. This is a well-documented and vital section in the domain of hazard mitigation. (Mileti, 1999)

While enhanced strength and robustness in construction processes does not necessarily eliminate the dire consequences of disaster occurrences, it has been widely recognised that the engineering community plays a vital and significant role in identifying and implementing balanced, rational solutions to what can be seen as an unbounded threat. (Sevin & Little, 1998)

Extensive research has been carried out, aiming at development of knowledge and enabling the construction of structures that are safer and more robust. Real estate and urban planning strategies can help inform the management and land-use planning to regulate settlements in vulnerable areas, which can also promote the assessment of overall urban and regional vulnerability. Additionally, business continuity planning, evacuation and similar activities related to preparedness link strongly to facilities management. Building information modelling (BIM) has been found to have potential and add value to the rescue and search operations in the immediate aftermath of a disaster.

Further, providing temporary shelters, emergency shelters and temporary housing is a significant component of the relief and rescue efforts. The disciplines associated with the built environment profession are capable of informing the decision making processes and development of appropriate solutions to shelter the evacuees and displaced persons. Similarly, inputs from these professionals can help in temporary and permanent repairs and help restore the essential services at the earliest. (Haigh & Amaratunga, 2010)

The **recovery phase** involves the property and construction sector, more specifically the reconstruction in the post-disaster scenario. This has been a subject of potential and significant research, particularly emphasising on developing countries that may not be well-equipped to handle and mitigate the causes and impacts of such disasters. Hence, there is a need for developing countries to be equipped to manage the post-disaster recovery and reconstruction. (Ofori, 2002)

Post-disaster reconstruction usually involves restoration of critical infrastructure and activities as the top priority – such as healthcare facilities, water supply, communication infrastructure, schools, energy, state administration and environmental infrastructure. In the aftermath of a disaster, often the affected regions need to enhance their capacity for resilience and reconstruction, using skilled and experienced resources that can effectively manage the projects. Further, experience in the field of project management is also necessary in addition to the technical and construction expertise. Smaller and developing countries may not necessarily have these skill sets or appropriate professionals with time-critical and large-scale management experience and understanding. (Rex, 2006)

Reconstruction also has a significant economic and social impact on the areas under study and work, which helps focus on the use of local designs, construction techniques and markets, hence, acting as an engine for economic and social growth of the community affected. Similarly, it is important that the local population participate in the reconstruction activities, which can also help involve and empower the affected and vulnerable communities through the processes. (Haigh & Amaratunga, 2010)

### 3.2.2 Post Disaster Temporary Shelters

Shelters can be understood as a place to stay in the immediate aftermath or duration of a disaster that is likely to damage temporary housing and suspend daily activities. While the housing sector gets recovered, repaired and reconstructed in order to resume daily routine and household responsibilities, temporary shelters provide an interim space to sustain. Quarantelli (1995) defines the four stages of post-disaster housing reconstruction as below –

a. **Emergency shelter -** it is a place where the evacuees and survivors can stay for short durations, which is mostly during or immediately after the disaster strikes. A public shelter or a friend's house can act as an emergency shelter. Public buildings can also be used as emergency shelters.
b. **Temporary shelter -** it is a place for a short stay, usually extending to a few weeks after the disaster has struck. A public mass shelter or a tent can act as a temporary shelter. Public buildings can also be used as temporary shelters.
c. **Temporary housing -** it is a place for temporary residence of the survivors, and the timeline can range from 6 months to 3 years, depending on the availability of their housing. The household can return to its routine and daily activities. A rented house or a pre-fabricated house can act as temporary housing.
d. **Permanent housing -** it is the return to the recovered, repaired or reconstructed house to re-settle and live permanently. (Quarantelli, 1995)

## 3.3 Role of Public Buildings in Developing Earthquake Resilient Communities

### 3.3.1 Command and Operational Centres of Search and Rescue

In the aftermath of an earthquake, it is important that the command centres and stations become operational in a very short duration of time, in order to aid, assist and assume responsibilities for emergency management. Hence, these centres need to be resilient to earthquakes, and the structures must be designed and constructed using appropriate seismic codes and guidelines. Further, these centres should not be constructed adjacent or near to any structures that are vulnerable to potential man-made hazards or geological hazards, since they can affect the performance of the centres after the earthquake. (Hosseini, et al., 2008)

Such facilities, if damaged or destroyed due to the earthquake, can impact the emergency response activities in the aftermath of the disaster, during the golden hours. Hence, it is important that these structures are retrofitted on high priority basis. Also, the centres need efficient access to the areas that would be affected due to the earthquake, and should be placed along the emergency roads, having proper road with and specifications in line with the requirements of the rescue operations. The roads should be clear, without any obstructions, debris or geological/ man-made instability. (Hosseini, et al., 2008)

### 3.3.2 Emergency hospitals

One of the most important facilities during and after a disaster are healthcare facilities and hospitals. In the cycle of emergency medical care, when the essential medical treatments are required at the earliest, hospitals play a vital role, and hence, they must be well equipped to handle the same efficiently. Therefore, it is crucial to ensure effective planning, design, and development of the capacities of these facilities in disaster prone areas and seismic zones. (Hosseini, et al., 2008)

While it is important for the hospital infrastructure to be structurally sound and resilient to the disaster events that the location is vulnerable to, it is important that the structure is also resilient to earthquakes. Any hospitals that are accessed in times of emergency must be able to bear the seismic loads and not collapse. Also, any non-structural elements and movable assets must be arranged to minimise the damage in case of an earthquake. However, various case examples of earthquakes in India are evidence of the lack of basic structural and seismic safety. (Hosseini, et al., 2008)

Hosseini, et al. (2008) have also highlighted in their study, the significance of the architecture of these healthcare facilities and hospitals. In cases of emergency, the relevant functioning spaces must be placed with easy access. Additionally, hospital buildings must be equipped with backup infrastructure systems to avoid disruption of services. Systems like water and fuel supplies, power generators, emergency telecommunication systems, and oxygen backup, etc. must be operational for at least a few days following the earthquake. These facilities must also be able to adapt to a surge in the patient load, in terms of space, staff, beds and medical supplies. If possible, helicopter operation and frequent service of the ambulance can also be supported in order to transfer victims of the disaster more efficiently.

Another solution proposed by Hosseini, et al. (2008) is the establishment of field hospitals at sites that have been affected by the earthquake. This can help the medical care to reach to the victims faster, thereby reducing the delays in emergency treatment. Large open spaces have been found to be suitable for setting up of field hospitals, mainly in vicinity of other existing hospitals and emergency supply system of power and water. They can also be an extension of the existing hospitals.

It is also important to note that hospitals must be able to perform effectively in case of surge in number of victims. It has been observed in the past that hospitals lose their surge capacities due to a lack or collapse of ICS (Incident Command System) and due to inefficient planning and preparedness. Hence, hospitals must devise a preparedness and response plan to cater various levels of disasters and facilitate emergency medical services. This includes resource management, supply chain management, receiving patients in the time of emergency, cooperation and alliance with other healthcare facilities, forms of leadership, etc.

The methods by which patients are received by the hospitals in emergency conditions is one of the most critical challenges. Many patients and victims may not need hospitalisation after they have received first aid and initial medical care. It has been observed that around 10-15% of the mass casualty victims who have been evaluates and treated at local medical stations would need to be hospitalised for their illnesses or injuries. Therefore, triage posts can be helpful to check if the victims needs to be hospitalised. (Hosseini, et al., 2008)

### 3.3.3 Need for Seismic Strengthening of Existing Structures

The Seismic Zones III, IV and V in India have around 12 crore buildings. Most of these structures are not resilient to earthquakes, and have the vulnerability to collapse if a high-intensity earthquake occurs. Since it is not feasible practically and financially to retrofit all existing structures, the National Disaster Management Authority (NDMA) has recommended a retrofitting and structural safety audit of the critical infrastructure and high priority structures. The selection of these buildings takes into consideration the potential loss of life, degree of risk, estimation of financial implications for the structures, specifically in high-risk areas, which are Seismic Zones III, IV, V. (National Disaster Mangement Authority, 2007)

A cluster approach has been recommended by NDMA for selection of critical lifeline infrastructure and various building typologies (like stone masonry, brick and mortar, RCC, adobe, etc.). These buildings would be in adjoining districts, which will enhance demonstrations, mutual consultations, and possible replication in other areas and districts. Hence, the process selects buildings such as primary health centres, offices, block offices, post offices, primary schools, panchayat offices, etc. in Zones III, IV and V, and assesses the ability of these structures to withstand high intensity earthquakes. The buildings, where found to be expedient, will be selected as per priority, and will be subject to retrofitting and seismic strengthening. These retrofitted structures are expected to demonstrate the efficiency of retrofitting and seismic strengthening in similar structures. (National Disaster Mangement Authority, 2007)

Retrofitting and seismic strengthening are useful for structural as well as non-structural elements of a buildings. Seismic strengthening and retrofitting are specialised technical tasks that need to be processed and managed by engineers and professionals who have proficiency in the task. It is important to have technical supervision to ensure that any operations, maintenance or repair procedures carries out in the building are safe and do not add to the vulnerability of the structure. (National Disaster Mangement Authority, 2007)

### 3.3.4 Criteria for Retrofitting

It is important to determine the expected performance needs of a structure when it has to be evaluated for its resilience to multiple hazards. The adequacy in performance of a building depends on both structural and non-structural components. Performance Levels specify the combined performance of structures, commonly used to evaluate the safety against seismic loads and shaking. These performance levels have been defined below. (National Disaster Mangement Authority, 2007)

### 3.3.5 Performance Levels

While under force-type loading, it is expected that the structures remain elastic, it is under displacement-type loading that the structures enter the inelastic range, in conditions like earthquake shaking. To ensure that the structural and non-structural components of the building are safe during earthquake shaking, Performance Based Design and Assessment needs to be carried out. Typically, four levels of performance are outlined in Performance Based Design and Assessment, which have been described below in brief.

i. **Fully Operational (FO) Level**
The earthquake does not affect or disrupt the functioning or structural contents of the building; even as the utilities, contents and non-structural elements are shaken, they do not face any damages.

ii. **Immediate Occupancy (IO) performance level**
The occurrence of the earthquake shakes the utilities, contents and non-structural elements of the building predominantly within their linear range of behaviour; they incur minor damages but the building's functioning is not affected or restricted; the functions can be resumed immediately after the occurrence of the earthquake.

**iii. Life Safety (LS) performance level**
The occurrence of the earthquake shakes the utilities, contents and non-structural elements of the building severely, in the non-linear range of behaviour; the elements are damaged severely, but the building uses its redundancy and reserve capacity and does not collapse. However, the functioning of the building cannot be resumed until a thorough structural safety assessment has been performed and the building is found suitable for retrofitting, after which the building is subject to seismic retrofitting.

**iv. Collapse Prevention (CP) performance level**
The occurrence of the earthquake shakes the utilities, contents and non-structural elements of the building severely, in the non-linear range of behaviour; the elements face major damages. The building has reached its state of imminent collapse and does not have any additional reserve capacity or redundancy, and cannot be used after the impact from the earthquake. (National Disaster Mangement Authority, 2007)

### 3.3.6 Critical Lifeline Buildings

It is expected that the critical infrastructure, or the critical lifeline buildings can perform their services and functions immediately after the occurrence of the earthquake. Therefore, the performance levels described below are considered desirable when these buildings are subject to strong shaking due to the earthquake.

**i. Critical Lifeline Buildings**
These structures are expected to achieve the Immediate Occupancy (IO) level of performance. This helps ensure that the building can be

used immediately after the earthquake occurrence without being a threat to the users and the contents, even in the case of aftershocks.

ii. **Contents and Utilities**

The utilities, contents and non-structural element in these buildings are expected to achieve Fully Operational (FO) level of performance. This aids significantly in the continuity of services in critical infrastructure and can be used to serve the persons affected due to the earthquake efficiently. (National Disaster Mangement Authority, 2007)

**3.4 Prioritization of Structures**

The process of structural safety auditing and retrofitting focusses primarily on public and government structures. To conduct similar assessments for private structures, the necessary capacity can be developed by suitable professionals in the private sector. The technical guidance details for conducting the structural safety auditing, retrofitting and strengthening of critical infrastructure will be provided by the nodal agencies in the public domain, which is useful for suitable professionals and general public in the private sector.

Below is a brief of the Priority List for Structural Safety Audit, Seismic Strengthening and Retrofitting.

i. Structures of National Importance – such as Parliament House, Raj Bhavans, Rashtrapati Bhavan, the Supreme Court of India, High Courts, Legislatures, Central and State Secretariats, museums, water works, historical monuments, heritage buildings, vital installations and strategic assets like water supply and energy infrastructure.

ii. Critical infrastructure and lifeline buildings – such as academic institutions, colleges, schools, healthcare facilities, hospitals, and tertiary care centres.

iii. Structures of public utility – such as flyovers, bridges, dams, reservoirs, airports, harbours, ports, bus station complexes, railway stations, etc.

iv. Structures of importance that ensure business continuity and governance – such as offices of the superintendent of police, office of the district collectors financial institutions, stock exchange structures, Reserve Bank of India, etc.

v. Structures that are multi-storeyed, having five or more storeys in offices, residential apartments, commercial complexes. (Desai, 2011)

## 3.5 Comparative Analysis of the National and International Reconstruction Policies and Standards

### 3.5.1 The Reconstruction and Rehabilitation Policy 2072 (2016) - A case of Nepal

This policy provides an instrument for steering rehabilitation and reconstruction.

*Table 13 Framework for Reconstruction; Adapted from:* (National Reconstruction Authority - Government of Nepal, 2016)

| **Framework for Reconstruction** | |
|---|---|
| Promoting the use of local material, furnishing and skills of Local labours to restore traditional architecture | Re-establishing and strengthening functional maternal, new born and child health care |
| Promoting the principles of Owner Driven Reconstruction and Build Back Better | Providing youth and children with access to quality and safe learning environments |
| Promoting collective settlement | Strengthening the risk reduction capacity and preparedness of the education system |
| Ensuring access to livelihood support and settlement location | Mainstreaming social inclusion and gender Equity throughout the reconstruction and recovery process |
| Developing national capacity and skills to ensure overall recovery | Establish enabling environment for tourism |

The Reconstruction and Rehabilitation Policy was drafted during second half of 2015, and the broad policy objectives devised by NRA are:

- To retrofit, restore and reconstruct completely and partially damaged government, community and residential structures and heritage sites, and make them resilient and resistant to disasters with the use of local technologies as required;
- To reconstruct and restore damaged ancient villages and cities to their original formations, in addition to improvement in the resilience of the structures and the communities;
- To enhance resilience in the vulnerable population and communities;

- To create and develop new livelihoods and opportunities by revitalizing the production sector;
- To research and conduct in-depth studies in the science of earthquakes, the impacts, effects, damage potential, and recovery in the aftermath of the earthquake, including repairs, resettlement, reconstruction, risk reduction and rehabilitation; and
- To help recover and resettle the communities and populations affected by the earthquakes using identification of appropriate sites. (National Reconstruction Authority - Government of Nepal, 2016)

#### 3.5.1.1 Key Characteristics of the Reconstruction and Rehabilitation Policy:

- Reconstruction of cultural heritage sites and housing
- Engaging the population, communities, volunteers, private sector in reconstruction
- Relocation and land use
- Providing financial assistance
- Integrating principles of 'Build Back Better' and disaster risk reduction
- Restoring employment and livelihoods (National Reconstruction Authority - Government of Nepal, 2016)

### 3.5.2 Relief, Rehabilitation and Reconciliation (RRR) Framework- A case of Sri Lanka

The Government of Sri Lanka initiated the Relief, Rehabilitation and Reconciliation Framework process in July 1999. The objectives of the framework are directed towards strengthening the country's capacity –

- To ensure that people who have been affected by conflict are provided for their basic needs;
- To rebuild livelihoods that are productive;
- To facilitate reconciliation across ethnic lines.

The procedure is aimed to produce outputs in the form of revised guidelines, mechanisms, strategies and policies that provide a common direction and basis to support the devastated communities and populations effectively. (Government of Sri Lanka, 2002)

With the involvement of locals in working groups, district workshops and steering groups, deliberations were held on distinct policy choices, which helped the RRR Framework process to evolve. These policies are related to human rights, rights of the displaced, need for peace-building and reconciliation, and development of the relationship between development and relief.

- **Policy on the Application of International Humanitarian Law (IHL):** The basis of conduct of the parties in conflict must adhere to the International Humanitarian Law (IHL). The law is final and binding, for both insurgent groups as well as governments, without the contending parties being conferred upon with any legal status.

- **Policy on Maximizing Rehabilitation and Development**: The policy addresses the need to pursue development interventions and rehabilitations to the maximum extent as permitted by the local conditions. These interventions must contribute vitally to the peace-building process.

- **Transparency and accountability**: Establishment of an independent humanitarian ombudsman system in the interest of accountability and transparency, to channelize the grievances and complaints from the beneficiaries. This also includes the community based organisations that have been affected, in addition to private and public bodies concerned with reconciliation, rehabilitation and relief.

- **Policy on the Movement of Persons and Goods**: To ensure the basic security of the citizens of the country, and in order to minimise hardship among the populations and communities affected, appropriate demeanour must be devised to apply security-related restrictions on the movement of goods and people.

- **Policy on the Transition to Peace and Recovery**: Many national institutions are challenged by the interventions made to ensure the transition to recovery and peace. However, these organisations should not wait for forcing these post-conflict issues on them. They need to plan and equip themselves in advance to manage the challenges and problems associated post any violent conflicts. (Government of Sri Lanka, 2002)

### 3.5.3 Reconstruction and Rehabilitation Policy Framework – A case of Gujarat

The Gujarat Earthquake Rehabilitation and Reconstruction Project Framework (December 2001) developed by the Gujarat State Disaster Management Authority (GSDMA), is a multi-sector comprehensive program, which has been directed at the rehabilitation of the communities and people affected by the earthquake. This involves provision of social amenities, livelihood support, housing, infrastructure, based on sustainable ecology and economy.

The mandate of this program involving rehabilitation and reconstruction not only focuses on the redevelopment and reconstruction of structures of immediate priorities post earthquake, but also pursues larger issues of economic and social nature, that impinge on the empowerment and development at community level as well as household level. The following principles are to be implemented by this program –

- Involvement of representative institutions and people in the process of decision making, to reflect on the aspirations and priorities of the participants, through program deliverables.
- Application of principles of empowerment and equity to ensure that appropriate mechanisms are in place to make the voices of the poor and the weak heard.
- Introduction of non-structural and structural rehabilitation measures, which merge with the climate, lifestyle of the communities, and culture, in addition to being affordable and feasible.
- Ensuring the highest levels of accountability and transparency in implementation of the program. (Gujarat State Disaster Management Authority, 2002)

### 3.5.4 Comparison of the Reconstruction and Rehabilitation Policy Framework

*Table 14 Policy Framework - Comparison*

| Policies | Nepal | Sri Lanka | Gujarat |
|---|---|---|---|
| **Health Safety** | Ensure health, safety and well-being of the affected population. | Review the emergency needs of displaced and affected population; Ensuring that effective support is provided by other agencies to the | Provision of health support to the persons who have been injured by the disaster on a long term basis and |

| Policies | Nepal | Sri Lanka | Gujarat |
|---|---|---|---|
| | Restore health facilities.<br>• Address psychological and mental health needs of the earthquake affected population | Ministry of Resettlement, Rehabilitation and Refugees in order to maintain food, shelter, adequate health, education, water and sanitation facilities to the displaced in welfare centres | psychological counselling for the people traumatized.<br>• Provide support for the children affected, and alleviate social deprivation through integrated nutrition and education strategy. |
| **Housing /Resettle -ment** | • Provide shelter on Site, maintain and restore local livelihoods, culture and tradition<br>• To resettle the affected communities by identifying appropriate sites. | • In the resettlement or relocation of displaced families, continuity and progression is essential between grant assistance for resettlement and the longer-term poverty alleviation programme;<br>• In relocation sites, in particular, the needs of host communities should also be catered in the interest of social harmony between resettling and host communities;<br>• The progress of integration of relocated and resettled displaced families, and assessments of the socio-economic environment created, to be continuously monitored and followed up with appropriate interventions. | • Build, retrofit, repair and strengthen houses for the people, and the public buildings affected by the disaster.<br>• Debris removal, salvage and recycling<br>Construction of temporary facilities |

| Policies | Nepal | Sri Lanka | Gujarat |
|---|---|---|---|
| **Infrastr-ucture** | To retrofit, reconstruct, and restore the completely and partially damaged residential, community and government buildings and heritage sites, to make them disaster resilient using local techniques as needed;<br>Reconstruct social infrastructure in a disaster resilient manner | Assemble in systematic fashion information collected at the district level; Devise a first inventory of the required repair of infrastructure, of road and railway links, tanks and irrigation systems, power supply networks, of damaged health centres, school buildings, or other municipal facilities. Identification and recommendation of technical studies for priority works wherever necessary and compilation of preliminary estimates of the volume of resources needed for reconstruction and rehabilitation. | Repair and strengthening of bridges, roads, and culverts in earthquake- affected area.<br>Reconstruction and repair of urban and rural water supply schemes<br>Reconstruction of district hospitals, community health centres. Primary health centres and primary health sub-centres. |
| **Social** | Maintain national unity, harmony and resilience. Enhance Social Cohesion | The universally accepted rights of the internally displaced - to protection, to security and liberty of person, to humanitarian assistance and to their return, resettlement and integration in society | Upgrade social services in the sector of health, education and women's development.<br>Upgrade and rebuild social and community infrastructure, improve health and education system, and strengthen social protection measures for weaker sections of the population. |

| Policies | Nepal | Sri Lanka | Gujarat |
|---|---|---|---|
| **Environ -ment** | Protect environment and forests in improving DRR and Climate-resilient sustainable development | Rehabilitation is more than just a matter of restoring as things were before; as the prolonged conflict has modified the development context radically, rehabilitation and restoration becomes a significant part of development, and there should in the transition to peace be a continuing focus on opportunities to alleviate poverty, to promote gender equality and to protect the rural environment. | Reduce vulnerability through long-term programs of mitigation aimed at drought mitigation and watershed management, and improve resilience of the people, enhance food security through diversification of sources of income generation and asset building. |
| **Finance** | Providing financial assistance | Ensure that uniform strategies, programmes and procedures are adhered to by all stakeholders, that sufficient resource of finance are made available and that the overall humanitarian situation is regularly assessed.<br>Adequate facilities should be provided to co-operative societies and private sector institutions supplying rations and other essential items to the un-cleared areas. They should be granted financial assistance not only to procure the necessary food and other essential items but also to maintain the fleet of trucks required to ensure uninterrupted supplies. | Short term recovery assistance including provision of loans and subsidies, financial assistance for construction of temporary work sheds.<br>Long term assistance including permanent construction for houses which were fully destroyed, creation of revolving funds, subsidies and loans for institutions. |

### 3.6 Summary and Further Reading

The aftermath of a disaster can lead to severe disruption and damage, in the absence of preparedness and resilience. Preparedness involves awareness of the impending disaster, provision and movement to shelters, availability of food and water, evacuation and availability of emergency medical care to ensure safety and response preparation when a disaster occurrence is expected. However, resilience, when built in the structures and community, helps and saves more significantly than just preparedness. Redundancy of infrastructure helps them expand in case of surge in demand, saves the structural impact, and gives sufficient time for warning and evacuation when needed. Risk reduction and resilience help the structures and communities to bounce back to relative normalcy faster, minimise the disruption and loss of lives.

The investments, however, are often diverted towards the recovery phase of the disasters, and since they are not resilient, houses and infrastructure face damages, and are unable to cope with the impacts and surge in the aftermath of a disaster.

Nevertheless, post-disaster reconstruction is a considerable opportunity to incorporate resilience and redundancy when re-building infrastructure and housing that have lost their structural integrity or have collapsed. As also observed in Chapter 1, often the financial aid that is received for affected regions acts as investment that enhances the socio-economic growth of the affected communities.

Through comparison of the reconstruction and rehabilitation policies across three regions of Nepal, Sri Lanka, and Gujarat, it was found that healthcare infrastructure was prioritised, and the physical and mental health of the affected populations was addressed across all policies. These also pressed focus on housing, critical infrastructure, social and financial status of the affected regions. It is important to note that most reconstruction and rehabilitation policies include these aspects of improvement. However, it is important to read into their patterns of budgeting and investment, to realise what proportion of finances is allocated towards resilience and risk mitigation. Often, the investment for resilience seems overwhelming to spend ahead of the disaster, but it is this investment that saves the expenditure for rescue, recovery, relief and reconstruction, owing to the significant reduction in damage.

**NOTES**

**NOTES**

# CHAPTER 4 - QUANTITATIVE CALCULATION OF ECONOMIC LOSSES

## 4.1 Learning Objectives

Natural Disasters and Extreme Weather Events (EWEs) are characteristic of their impacts on the economy and the losses caused, not only to human lives and daily functioning, but also to the infrastructure and public emergency facilities. These losses can render organisations dysfunctional, and add to their existent financial liabilities. Further, the non-functioning of any structure also results in unemployment, loss of service, and extra costs incurred to those who would need to go to other buildings in case their nearest service fails. Also, these severely affected non-functional buildings cease to provide much-needed shelters in case of the aftermath and emergencies of extreme weather events. It is, therefore, essential to have a conservative estimate of the imminent and potential losses to structures, which helps the organisations insure themselves financially. If recognised in the design and pre-construction stages, these losses can be reduced extensively using measures enlisted in codal provisions and technical frameworks.

## 4.2 Framework for Calculation of Tangible and Intangible Losses Due to Floods

### 4.2.1 Floods and Flood Losses

Floods are among the most devastating EWEs due to the enormous losses caused by its recurrence in some parts of the country. Floods have various aspects –spills over the banks that cause inundation, poor drainage characteristics that cause drainage congestion, and changes in water courses that cause erosion. The most challenging issue in flood analysis is to determine the potential losses because of floods. The losses are divided into two categories, namely tangible and intangible losses. These depend on whether or not the losses can be evaluated in financial values. These losses can be further categorised as direct and indirect damages. (Dassanayake, et al., 2015)

Direct damages ensue immediately after the flood event as a consequence of the physical contact of the flood waters with damageable property and humans. Indirect damages are generated by the direct impacts and may occur immediately or late, outside the flood event. (Dassanayake, et al., 2015)

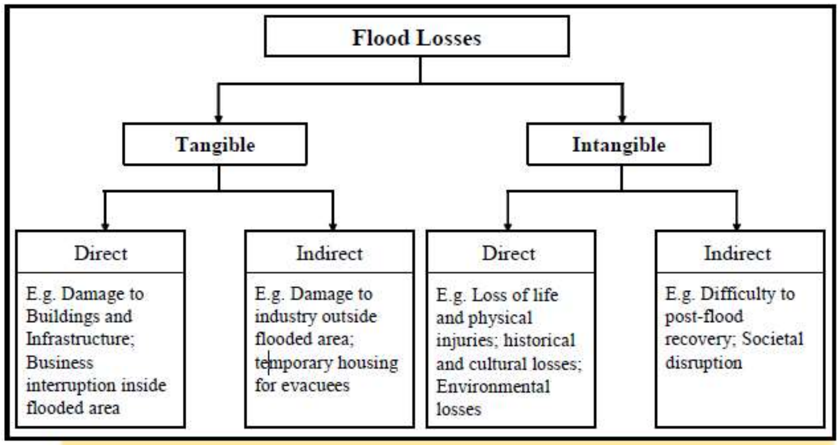


*Figure 8 Classification of Flood Losses; Source: (Dassanayake, et al., 2015)*

### 4.2.2 Calculation of Tangible Flood Losses

Tangible losses can be specified in monetary values and are therefore, often integrated in the flood risk analysis. The most severe tangible loss is the loss to property, infrastructure and the elements associated with it.

The key elements required for calculating tangible flood loss are:

a) Susceptibility of assets to flood damage
b) Value of assets that are at risk
c) Key variables that affect the extent of damage, which can differ in varying circumstances of flooding.
d) Flood probability (for conversion of event losses and damages into annual average losses and damages)
e) Level of aggregation of data required. (Messner, et al., 2007)

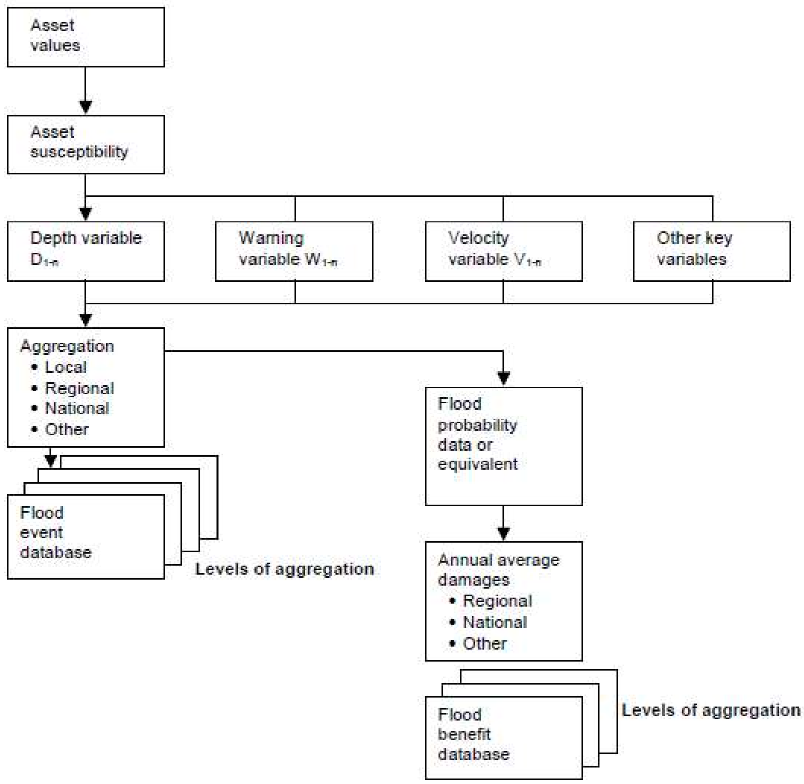


*Figure 9 Framework for Calculation of Tangible Losses; Source: (Messner, et al., 2007)*

### 4.2.3 Components of Framework for Calculating Tangible Flood Losses

a) **Asset Value**

Asset Value is the market value of the assets at risk, which includes buildings, contents of the buildings and the land. These can be characterised by field survey and secondary sources. It can also include other infrastructure facilities like water facilities, telecom utilities and electricity and gas systems. The asset value establishes the maximum potential damage endured by the property or facility that is at risk. It is determined by summation of the total value of each component within the building (inventory values and building repair operations). (Ramsbottom, et al., 2003)

b) **Asset Susceptibility**

Most floods do not damage buildings entirely. This means that the total asset value may be over-estimated to determine the flood damage potential, unless susceptibility values are suitably defined. 'Susceptibility' means the reduction in value or percentage loss due to immersion by flood water. It is determined by quantity surveyors and loss adjustors. (Ramsbottom, et al., 2003)

c) **Key Determining Variables**

i. **Flood Depth**
If the depth differential between the inside and outside water levels exceeds 0.5 metres, it can cause moderate damage to structures. If the differential of 0.5 metres occurs in combination with high flow velocity (greater than about 3m/s) or the differential becomes one metre, severe damage can occur. Structures of light construction may begin to float with the increase in depth of floodwater. In such conditions, the structures can be damaged severely when they settle unevenly in receding floodwaters. (Ramsbottom, et al., 2003)

ii. **Velocity Variable**
Buildings may be destroyed and the components swept away when the flood velocity is significant. More severe conditions can lead to irreparable damage. For instance, a differential depth of two metres and a flow velocity of 3m/s, or a differential depth of one metre and a flow velocity of 6m/s). (Ramsbottom, et al., 2003)

iii. **Warning Variable**
**Score for flood warning- 3- (P1x(P2+p3))**
Where -
P1= % of Warning Coverage Target Met
P2= % of Warning Time Target Met
P3= % of Effective Action Target Met (Ramsbottom, et al., 2003)

d) **Level of Aggregation**

The aggregated data contains information at different levels. Some data may be acquired for individual buildings, while other may be a sum those values for regions, localities, or a nation. Aggregated data usually needs to be put together from more detailed assemblages of information, comprising individual characteristics from which higher level averages can be derived. (Ramsbottom, et al., 2003)

e) **Flood Probability**

To gauge the full exposure of land or property to a range of flood events that are likely to be experienced at a specific location, flood probability is required to be measured. This implies that a property which was exposed to a flood with a reoccurrence period of 1 in 10 years will also be exposed to the flood that occurs once in 100 years. The probability data of flood damage is used to calculate annual average damage value. (Ramsbottom, et al., 2003)

f) **Aggregation of Weighted Annual Average Damage**

This is determined by knowing the proportions of properties within different classes in the appropriate regions or areas involved. This is required for application at regional or national level.

### 4.2.4 Calculation of Intangible Flood Losses

Intangible flood losses are the losses caused by floods which cannot be evaluated in monetary terms. They are divided mainly into two categories. First category is the category of social losses, which are experienced by individuals, families and the overall society including loss of life, health impacts and cultural losses. Environmental losses, which are the damages occurred to ecosystems are the second category. These losses are generally measured in terms of lives lost or the number of injuries. The main intangible impact due to flooding, loss of life and health effects.

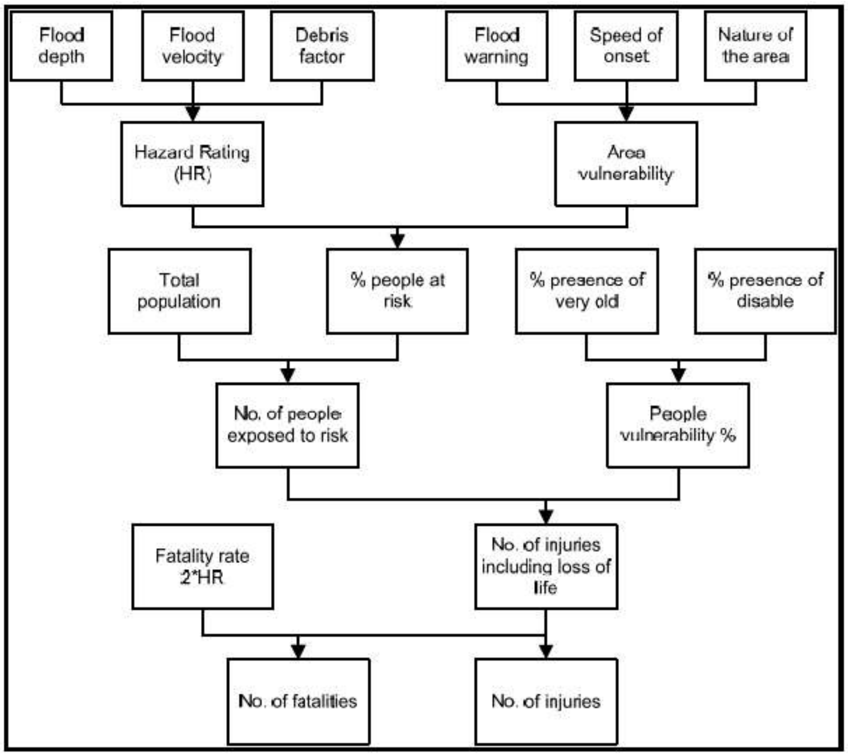


*Figure 10 Framework for calculation of Intangible Flood Losses; Source: (Wallingford, 2006)*

### 4.2.5 Key Elements for Calculating Intangible Flood Losses

- **Flood Hazard**
  A combination of velocity, flood depth, and presence of debris.
- **Area Vulnerability**
  Describes the attributes of an area of the floodplain that affect the likelihood of being exposed to the flood hazard.
- **People Vulnerability**
  Describes the attributes of the people affected by flood and their response capacity to ensure their own safety as well as the dependant members.

#### 4.2.6 Components of Framework for Calculating Intangible Flood Losses

i. **Flood Hazard**
   - Depth of flood water (m)
   - Velocity of flood water (m/s)
   - Debris factor (score)

ii. **Area Vulnerability**
   - Speed of onset of a flood (score)
   - Flood warning- % of at-risk properties covered by the flood warning system; % of warnings meeting the two-hour target; and % of people taking effective action (score)
   - Nature of area: typical residential/ commercial/industrial properties; multi-storey apartments; bungalows, schools, mobile homes, campsites, etc. (score)

iii. **People Vulnerability**
   - % residents aged 75 years or over
   - % residents suffering from long term illness

#### 4.2.6.1 Flood Hazard Rating

The flood hazard rating is calculated using the following equation:

**HR = d x (v + 0.5) + DF**

Where –

HR- Flood Hazard Rating

d- Depth of flooding (m)

v- Velocity of floodwaters (m/s)

DF- Debris Factor

*Table 15 Guidance on debris factors for different flood depths, velocities and dominant land uses*

| Depths | Pasture/Arable | Woodland | Urban |
|---|---|---|---|
| 0 to 0.25 m | 0 | 0 | 0 |
| 0.25 to 0.75 m | 0 | 0.5 | 1 |
| d>0.75 m and/or v>2 | 0.5 | 1 | 1 |

#### 4.2.6.2 Area Vulnerability

*Table 16 Area Vulnerability*

| Rating | Speed of Onset | Nature of Area |
|---|---|---|
| 1 | Onset of flooding is very gradual (many hours) | Multi-storey apartments |
| 2 | Onset of flooding is gradual (an hour or so) | Typical residential area (2-storey homes); commercial and industrial properties |
| 3 | Rapid flooding | Bungalows, mobile homes, busy roads, parks, single storey schools, campsites, etc. |

#### 4.2.6.3 People Vulnerability

The People Vulnerability score (Y expressed as a percentage) is simply:

**Y = %residents suffering from long-term illness + %residents aged 75 or over.**

The number of deaths/injuries is calculated using the following equation:

**N(I) = N x X x Y**

Where:

N(I) is the number of deaths/injuries

N is the population within the floodplain

X is the proportion of the population exposed to a risk of suffering death/injury (for a given flood). The value of X is based on the Flood Hazard and the Area Vulnerability.

Y is the proportion of those at risk who will suffer death/injury. The value of Y based on People Vulnerability.

## 4.3 Quantification of Loss to a Hospital Building due to EWE

### 4.3.1 Introduction

Extreme Weather Events have an ability to bring to the forefront vulnerabilities of structures, systems, people and processes, which can consequently cause large scale damages; hospitals are no exception in this matter. In the previous two decades, various countries have suffered enormous economic losses due to damages incurred to hospitals during and after these extreme weather events.

In India, experiences from the Kashmir Earthquake of 2005, the Indian Ocean Tsunami of 2004, and Gujarat earthquake of 2001 have shown that disasters affect not only the population but also health facilities. This has been seen particularly when the Children's Hospital in Jammu collapsed, and in the city of Bhuj, where thousands of people died and the civil hospital was reduced to a heap of debris when it was needed most. Quantification of such significant tangible and intangible losses are generally done on the assumption and based on the available data. The ripple effect is often left and not considered. Many intangible losses and their adversarial effects are left untouched and unconsidered.

### 4.3.2 Calculating the Socio Economic Vulnerability

#### 4.3.2.1 Introduction

Various terms are used by environmental experts in the field of disaster cost estimation, to describe the impacts of disasters, but these are not always consistent. It is therefore important to define the terminology:

i. The impacts of a disaster in broad terms include

- **Market Based Effect** – these include reduction in income and sales, and destruction to property.
- **Non-market-based Effect** – these include psychological effects and environmental outcomes involved in a disaster. (National Research Council, 1999)

ii. The losses due to disasters represent market-based negative economic impacts. These consist of:

- **Direct losses -** these result from the physical destruction of buildings and natural resources.
- **Indirect losses -** these represent the consequences of physical destruction, such as business interruption and temporary unemployment.

The costs of disasters typically refers to cash pay outs by governments and insurers to reimburse some or all of the losses suffered by businesses and individuals and. Losses suffered by the people or businesses whose losses do not make them eligible for insurance payments, those who are uninsured, those who do not receive government relief should be counted in for a complete compilation of the impacts of a disaster—but usually these losses are not included as 'costs'.

The damages caused by disasters include physical destruction, which are assessed by using physical indicators, such as the numbers of injuries and deaths, or the number of buildings destroyed. Damages are considered as direct losses when valued in monetary terms. The impacts include displacement of families, homelessness, death, and environmental losses. (National Research Council, 1999)

#### 4.3.2.2 Calculation of Human Impact loss

The documentation of impacts of extreme weather events and natural disasters on humans (in a comprehensive and standardised way) is a challenging task mainly due to the lack of common terminologies for human loss indicators, measurement methodologies, and perils.

**Primary Human Impact**

i. Deaths

   - The number of deaths (mortality) registered in a database for disaster losses refers to the numbers when the reporting by original sources of data is stable and does not change anymore.
   - The total number of deaths is the sum of direct and the indirect immediate deaths. The number of delayed indirect deaths is usually excluded.
   - The total number does not include missing persons.

ii. Missing

   - The number of people whose whereabouts are unknown post the disaster, and who are presumed dead based on official statistics.
   - The total number includes people who are presumed dead, although there is no physical evidence (e.g., human remains, death certificate). (Integrated Research on Disaster Risk, 2015)

iii. Injured

- Persons suffering from trauma, physical injuries, or illnesses that require immediate medical attention and assistance as a direct consequence of a disaster.
- The number of injured (morbidity) includes persons who were sick and sought medical attention.

iv. Exposed

- Number of people who temporarily or permanently reside in the hazard area before or during the disaster event.
- The figure represents the number of people who are potentially exposed to the adverse effects of the event. (Integrated Research on Disaster Risk, 2015)

**Secondary and Tertiary Human Indicators**

Additional indicators that are useful in defining human impacts and are beyond the disaggregation or improvement of primary indicators. These are -

a) the homeless
b) populations that have relocated
c) persons who have been evacuated
d) populations that are affected

It may be noted that 'homeless,' 'evacuated' and 'relocated' are not mutually exclusive, and they may involve repeated counting. For instance, some of the persons who were evacuated may become homeless later (post the initial return to their houses), and some of the homeless may be relocated (some may return after a period of time or rebuild in the same place). These three indicators correspond to the three stages of the disaster cycle:

a) Before and during a disaster (evacuated);
b) Immediate aftermath of a disaster (homeless); and
c) At the recovery and reconstruction stage (relocated). (Integrated Research on Disaster Risk, 2015)

**4.3.2.3 Economic Loss Indicators**

**Primary economic loss**

Definition: "*The amount of damage to property, crops, and livestock and to the flow of goods and services expressed in monetary terms*."

- The sum of indirect and direct losses = Economic loss
- The monetary value of structural damage to capital assets is direct loss.
- The damages to the flow of services and goods.
- As compared to indirect losses, direct losses are countable, comparable, concrete, verifiable and easier to measure. (Integrated Research on Disaster Risk, 2015)

**Secondary and tertiary economic loss**

Further, the damages can be divided into -

- Insured – Damages that are encompassed within the insurance sector and are directly paid to the owner of the damaged property.
- Uninsured – Damages and losses not encompassed by insurance policies. (Integrated Research on Disaster Risk, 2015)

### 4.3.3 Calculating the Tangible Losses

#### 4.3.3.1 Introduction

Structural failure of buildings in the aftermath of a disaster can lead to injuries, deaths, and damage to structure, damage to functionality, destruction of contents and damage to the environment. These consequences can be direct or indirect, which depends on the system boundaries. At the commencement of any consequence analysis, these should be clearly defined. Once these are outlined, identified and quantified, the values can be used to assess the structure's robustness. (Janssens, et al., 2011)

The after-effects of structural failures can vary considerably in different structures, and usually depend on the factors listed below –

a) Properties of the structure
b) Nature of the hazard
c) Location
d) Use/occupancy
e) Time frame over which the consequences are assessed
f) Meteorological conditions
g) Scope of consequences considered (in a socio-economic context). (Janssens, et al., 2011)

Structural failures can be divided into two categories -

- **Direct consequences** – Consequences that result from state of damage to individual components. They are limited to the effects of immediate damage ensuing the occurrence of a disaster. These are related to the vulnerability of the building.
- **Indirect consequences** – Consequences that are related to the robustness of the structure, in terms of loss of system functionality, as a result of local failure. Indirect consequences can be understood to occur as an outcome of direct consequences. (Janssens, et al., 2011)

#### 4.3.3.2 Factors Affecting the Consequences of Failure

- Nature and magnitude of hazard
- Vulnerability, robustness, materials, and type & quality of construction of the structure
- Occupancy
- Time of the day
- Time frame (in days/weeks/years) (Janssens, et al., 2011)

#### 4.3.3.3 Classification of Consequences

It is divided into 3 categories – Human, Economic and Environmental, as detailed in Table 17.

*Table 17 Classification of Consequences Source: (Janssens, et al., 2011)*

| | DIRECT CONSEQUENCES | INDIRECT CONSEQUENCES |
|---|---|---|
| **Human** | Injuries<br>Fatalities | Injuries<br>Fatalities<br>Psychological Damage |
| **Economic** | Repair of initial damage<br>Replacement/repair of contents | Replacement/repair of structure<br>Replacement/repair of contents<br>Loss of functionality/production<br>Temporary relocation<br>Clean up costs<br>Rescue costs<br>Regional economic effect<br>Investigation/compensation<br>Loss of reputation |
| **Environmental** | $CO_2$ Emissions<br>Energy use<br>Toxic releases<br>Environmental Studies/Repair | $CO_2$ Emissions<br>Energy use<br>Toxic releases<br>Environmental Studies/Repair |

#### 4.3.3.4 Classification of Damage Severity

The level of damage to a structure can help determine the root causes for structural and non-structural consequences. This can be achieved using a consistent scale of measurement for damage severity. Several such scales and models have been developed, one of which has been included below. The EMS consists of proposed damage grades with proposed classification system for damage resulting from accidental factors. (Janssens, et al., 2011)

*Table 18 Different Degrees of Partial Collapse; Source: (Janssens, et al., 2011)*

| Grade | Damage level | *Percentage of horizontal area collapsed* |
|---|---|---|
| **D0** | **No Damage** | *0%* |
| **D1** | **Negligible to slight damage**<br>No structural damage, slight non-structural damage | *<1%* |
| **D2** | **Moderate damage**<br>Slight structural damage, moderate non-structural damage | *1-10%* |
| **D3** | **Substantial to heavy damage**<br>Moderate structural damage, heavy non-structural damage | *10-50%* |
| **D4** | **Very heavy damage**<br>Heavy structural damage, very heavy non-structural damage | *50-80%* |
| **D5** | **Destruction**<br>Very heavy structural damage | *80-100%* |

#### 4.3.3.5 Economic Consequences

The economic consequences of failure of the structure include the following (direct) factors –

- Replacement/ Repair
- Temporary Relocation
- Loss of Functionality
- Clean-up Costs
- Rescue Cost
- Cost of Investigations/ Compensation
- Loss of Reputation

#### 4.3.3.6 Environmental Consequences

Environmental consequences due to the failure of a structure include -

- $CO_2$ Emissions/ Energy Use
- Environmental Studies/ Repair
- Toxic Releases (Janssens, et al., 2011)

### 4.3.4 Framework for Calculating Tangible Losses

For making the framework the different types of tangible assets are considered along with the above mentioned put in the consideration. The final list of frame work of calculating the losses has been narrowed down to the following:

i. Structural/ Civil/ Architectural Losses
ii. Equipment Losses
iii. Inventory Losses
iv. Machinery Losses
v. Land Losses
vi. Employment Losses
vii. Vehicle Losses
viii. Operating Data
ix. Reserve Funds

#### 4.3.4.1 Structural/ Civil/ Architectural Losses

Structural Losses include the structural elements that are prone to get damaged in an extreme weather event. These include foundations, columns, beams, slabs, structural steel, load bearing walls, shear walls.

Non-structural elements include doors, windows, non-load bearing walls, staircases and fire doors.

Interior/ architectural elements include false ceiling, cupboards, furniture, railings, signage, flooring and other finishes.

This category also encompasses all infrastructure and services' components losses, which include Electrical services, HVAC, Plumbing and Sanitation, Fire services, STP, WTP, Elevator and Dumbwaiter system, IT and Communications, Bio-hazard Management System, Medical Gas Pipeline System (MGPS), and Fuel Storage.

Further, the losses also depend on the age of the structure. The older the structure, the more vulnerable it is to deterioration and damage after getting struck by an extreme weather event.

For a structure whose age is less than 15 years, an extra of 2% losses must be included in the loss estimate. A structure which is between 15 and 30 years old, 2.5% extra losses must be incorporated. For a structure older than 30 years, an extra component of 3.5% must be included.

#### 4.3.4.2 Equipment Losses

All the equipment and machinery present in the hospital are unique in nature. Due to the multi-diversity in usage, all equipment & machinery have different properties and some require additional attention, care and support or foundation. Some have harmful emissions, and usually need special design and finishes of the containing room.

The equipment considered have been listed below –

- X ray Unit
- CT Scan
- MRI
- Linear Accelerator
- Modular Operation Theatre
- Non-modular Operation Theatre
- Minor OT
- Ventilator
- CSSD Plant
- Laundry Plant
- Laboratory Instruments
- IT Services Infrastructure
- Lifts
- Dumbwaiter
- ICU Equipment
- Pharmacy Equipment
- Eye Unit
- ENT Unit
- Dental Unit
- Physiotherapy Equipment

- Mammography Unit
- Laminar Flow
- Refrigerators
- OPD Equipment
- Blood Bank Instruments
- Maternity Ward Instruments
- Orthopaedic Instruments
- Maintenance Kit
- Kitchen Equipment
- Medical Equipment
- Mortuary Equipment
- Generators

**4.3.4.3 Inventory Losses**

This can be calculated from the following:

i. **Medicines**
The inventory of Medicare items and all medicines dealt with and traded by the hospital are valued at cost. This include all the medicines stored in a hospital. In case of any EWE, all the medicines are destroyed and not usable causing a huge economic loss to the hospital.

ii. **Furniture**
All furniture items, including hospital furniture such as beds, stools, panels, storage carts, equipment carts, stretchers, etc. are also vulnerable to damage by EWE.

iii. **Linen**
Bed sheets, covering sheets, covers, towels, curtains, aprons, etc. are also stated at cost.

iv. **Hospital Equipment**
Any hospital equipment, heavy or light, that has been bought and stored, for later usage, or awaiting installation, is prone to damage and loss.

v. **Blood Bank**
Blood bank storage of donated blood, or other organ donations/ organ banks, are significantly prone, and may cause heavy losses to both patients and hospital.

vi. **Crockery/ Cutlery**
These items are not perishable and if recovered after a disaster, can be used again by sterilizing. The economic loss may not be equivalent to replacing the items.

vii. **Surgical Instruments**
Syringes, Masks, Gloves etc. Surgical instruments are valued at cost. These are subject to $1/3^{rd}$ write off wherever applicable using the FIFO method.

viii. **IT Records/ Store**
All records of patients, staff, other paperwork, bills, etc. are significantly important documents and may get severely damaged/ lost due to a EWE.

ix. **Miscellaneous**
Lab Materials, Stationaries, Housekeeping Items, Stock of provisions, stores are stated at cost. They are accounted for at the applicable exchange rates prevailing on the date of the transaction.

#### 4.3.4.4 Machinery Losses

Any equipment or machinery that may be vulnerable to damage, needs to be repaired, replaced or serviced again so as to bring it back to functioning.

#### 4.3.4.5 Land Losses

A plot is defined as land parcel owned by someone or group of people or company or government of the country. It is considered as immovable property in some countries. During any disaster, land is the primary resource affected. This also includes the development cost of services and other infrastructure elements.

This category includes External Development, Destruction to flora/ fauna, Damage to Boundary Wall, Contamination of Groundwater, Silt Aggregation, Deposition of Debris, Damage to recreational/ scenic sources/ landscape, Dilution and Spillage of Sewage, Disruption of Contours (also leading to exposure of foundation), Damage to Retaining Structures, Soil

Erosion, Triggering of Landslide Activities, Site Infrastructure like roads, footpath, street lights, fire hydrants, etc.

#### 4.3.4.6 Employment Losses

Employees are prone to lose work hours or days, and may be expected to work more than the regular hours due to EWE affected patients. These include Medical Staff, Technical Staff, Administrative Staff, Maintenance Staff, Temporary Staff and Miscellaneous Staff.

#### 4.3.4.7 Vehicle Losses

Any vehicles owned or rented by the hospital may get severely damaged/ lost in an extreme weather event. These could be Ambulances, Mobile Vans, Mobile Pharmacy, etc.

#### 4.3.4.8 Operating Data

Operating data includes loans, outstanding liabilities, pending payments, other commitments, ongoing works, installations, inventories received but unpaid, etc. These components, in addition to loss of revenue to the hospital, add to pending liabilities.

#### 4.3.4.9 Reserve Funds

These losses can be estimated from the following:

- **Loan Principal Payment**

  It is the amount of money that has been loaned out to others by the hospital. The loan will have to be returned to the hospital after a certain fixed period and has the capacity to earn regular interest on it and acts as a source of income.

- **Capital Purchases**

  This category would include all the purchases made by the Hospital for a period for time of more than one year, and such purchases which would be considered as assets for the hospital. These assets are prone to depreciation in their value and there reduce their worth over time.

- **Other New Building/ Start-up Costs**
  Expansion of hospital on the same land or new location needs grant of certain amount to its sister concerns for new construction or expansion, till they become operational.

- **To Reserve Account**

  This is the Balance that is left or used up, after all Revenues have been paid and all dues have been cleared. The reserve account helps to serve as the buffer in case of adverse situation for the bank where it can resort to the wealth stored in the reserve account.

- **Advances taken by patients, security deposits that need to be paid off.**

### 4.3.5 Calculating the Intangible Losses

The 'non-market' or 'intangible' losses are the costs of hazards which are not easily measurable or not measurable at all in monetary terms. For instance, cultural heritage, impacts on health, or the environment are intangible effects. These are often not included in costs assessments, thereby leading to incomplete and biased cost assessment for natural hazards. Consequently, the optimum allocation of finances and appropriate resilience designs for reduction of damage cannot be ensured. It is, therefore, necessary that the intangible impacts and the costs ensued are considered in the assessment to ensure an integrated risk assessment and management. (Markantonis & Schwarze, 2012)

Intangible losses vary for different natural hazards and their severity. These intangible characteristics of losses can be incorporated in decision support frameworks either in a non-monetary form in a multi-criteria analysis framework or in monetary form in a cost-benefit analysis framework.

*Table 19 The intangible effects of natural hazards*

| | |
|---|---|
| **Environment** | Soil contamination & pollution |
| | Biodiversity loss |
| | Soil erosion |
| | Water depletion |
| | Water pollution |
| | Loss of wetlands |
| | Loss of soil nutrients |
| | Aesthetic environment impacts |
| **Health** | Mental illnesses, e.g. post-traumatic stress, depression |
| | Infectious diseases |
| | Fatalities/injuries |
| | Malnutrition |

#### 4.3.5.1 Review of Intangible Losses

i. **Injuries and Loss of Life**

Coastal flooding and cyclones pose catastrophic damage to human life. Cyclones (with subsequent floods) and flooding can cause significant devastation to the community and infrastructure. The factors determining the fatalities due to these destructive events are as follows –

**a) Societal characteristics**

- Timely receiving and understanding of warning
- Presence of sufficient places as shelters
- Quality of houses
- Age and disability of individuals exposed to hazard
- Population density of the affected area
- Availability and quality of medical facilities (Markantonis, et al., 2013)

**b) Flood characteristics**

- Water depth
- Collapse of buildings caused by high flood velocities and water discharges
- Day and time of the occurrence of the event (Markantonis, et al., 2013)
- Flood related injuries can occur before, during or after the occurrence of flood

ii. **Cultural losses**

Cultural complexes, such as architectural, archaeological and artistic sites of cultural value are vulnerable to risk from extreme weather events. This can be attributed to events such as floods that can introduce contaminated water to these complexes, thereby disrupting their soil, foundations and the equilibrium between soil and the artefacts. The stray water can also damage cultural landscape elements, functioning and deposition of debris.

Such assets of cultural value can generate societal concern due to the strong affinity and characterisation. Also, archaeological sites are limited in number and non-renewable. Further, these complexes usually attract visitors and tourists, and any damage to these sites can impact the tourism of the area.

The flood risk analysis finds the estimation of damages to historical and cultural as a significant concern. However, there is no clear demarcation of categorisation of attributes to the cultural and historical categories, in addition to the estimation and presentation of the damages (in terms of the number of places, the damage percentage to each structure and its contents, and the monetary value of such damages) in previous studies. (Markantonis, et al., 2013)

iii. **Environmental losses**

The investigation of impacts of floods on the ecosystem and the environment has limited research and documentation. Assessment of the environmental losses is often not considered, thereby leading to a lack of impact assessment that is scientific and systematic. Hence, there is a lack of such scientific investigation, recording and publishing. The impact of floods on environment, however, is significant and wide-ranging. This includes damage to natural recreational resources, destruction to flora and fauna, and damage to endangered and rare resources. (Markantonis, et al., 2013)

Environmental impacts depend mainly on the water depth, magnitude of water flow, duration of inundation, in combination with land-use attributes. The assessment of effects to the floods to the environment can be carried out by using the assessment proposed by Markantonis, et al. (2013), to separate and qualitatively assess the effects of its components: biotic medium (flora, fauna, and human beings), physical medium (water, air, climate, and soil), and perceptual medium (scientific, cultural and landscape resources), and interactions among these three. Two assessments can be performed: hydrological impacts and ecological impacts. (Markantonis, et al., 2013)

#### 4.3.5.3 Intangible Losses in Healthcare Infrastructure due to EWE

Losses to a hospital due to extreme weather events can be categorised in the following way.

**Intangible Losses to Hospital**

*Table 20 Intangible Losses to Hospital due to Extreme Weather Events*

| S.No. | Intangible Losses |
|---|---|
| 1. | Disruption of education processes (if any) |
| 2. | Lengthening hospital waiting lists |
| 3. | Effect on commerce/ business of hospital |
| 4. | Disruption of research processes (if any) |
| 5. | Contamination of water |
| 6. | Silt aggregation |
| 7. | Deposition of Debris |
| 8. | Destruction to flora/ fauna |
| 9. | Damage to recreational/ scenic sources |
| 10. | Impact on fuel supply |
| 11. | Impact on energy supply |
| 12. | Chemical pollution/ hazard/ contamination |
| 13. | Dilution of sewage |
| 14. | Exposure of bio-hazard |
| 15. | Potential loss of communication |
| 16. | Traffic congestion in the hospital’s main halls |
| 17. | Water and food shortage |
| 18. | Loss of Memorabilia |
| 19. | Evacuation |
| 20. | Efficiency losses due to interruption of hospital network services like laboratories or blood banks |

### Intangible Losses to Patients

*Table 21 Intangible Losses to Patients due to Extreme Weather Events*

| S.No. | Intangible Losses |
|---|---|
| 1. | Psychological Distress |
| 2. | Loss of life |
| 3. | Movement of patients to other healthcare facilities |
| 4. | Spread of diseases |
| 5. | Physical injuries |
| 6. | Reduced access to healthcare |
| 7. | Disability-Adjusted Life Years (DALY) defined by the World Health Organization (WHO) as *"the sum of years of potential life lost due to premature mortality and the years of productive life lot due to disability".* |
| 8. | Mental Health Disorders |
| 9. | Nutritional Deficiency |
| 10. | Electrocution |
| 11. | Loss of access to essential care |
| 12. | Loss of access to and failure to obtain continuing health care |
| 13. | Unavailability of toilet and sanitation facilities |
| 14. | Sexual/ Non-sexual assault |
| 15. | Infant and maternal mortality |
| 16. | Potential loss of communication |
| 17. | Injury due to falling of heavy overhead objects |

### Intangible Losses to Staff

*Table 22 Intangible Losses to Staff due to Extreme Weather Events*

| S.No. | Intangible Losses |
|---|---|
| 1. | Loss of Employment/ Income/ Livelihoods |
| 2. | Spread of diseases |
| 3. | Physical injuries |
| 4. | Damage to households/ personal belongings of staff (if available) |
| 5. | Mental Health Disorders |
| 6. | Unavailability of toilet and sanitation facilities |
| 7. | Sexual/ Non-sexual assault |
| 8. | Potential loss of communication |
| 9. | Injury due to falling of heavy overhead objects |

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### 4.3.6 Framework for Calculating Intangible Losses

#### 4.3.6.1 OPD – Loss to Patients

OPD services include Medicine, Surgical, Mother-Child, Cardiac, Dental, and Miscellaneous.

If a hospital is rendered dysfunctional due to an extreme weather event, patients in OPD need to be directed towards other hospitals that may be farther away than the hospital in consideration, which may cost extra in terms of the card registration system and other infrastructure. Further, due to the extreme weather event, the OPD will have more patients, injured, diseased or in need of medical assistance at the earliest. Apart from the trauma caused to the patients, which may be difficult to quantify, the patients are also subject to further deterioration of their condition due to delay in treatment. While some medical conditions may not suffer much deterioration (such as regular dental treatments), others may cause excessive damage, which may result in higher costs or longer durations of extended medical supervision/ care (such as cardiac conditions).

As a result, the impact of this deterioration has been categorised as –

a) High Impact – Impact Factor 5
b) Medium Impact – Impact Factor 2.5
c) Low Impact – Impact Factor 1.5

This impact factor is multiplied with the overall costs to the patients, to get an estimate of the total losses in value of treatment to the patients.

**4.3.6.2 Diagnostic – Loss to Patients**

Diagnostic Services include X-Ray, CT scan, MRI, Ultrasound, Blood Testing, Stool Testing, Urine Testing, Swine Flu, H1N1, etc.

These losses are evaluated in the same manner as the previous category. Diagnostic services may become unavailable due to inundation or spoilage of the required equipment. These services are necessary so as to provide emergency as well as regular services to the patients and may be sought from other labs or hospitals if not available at the hospital in consideration.

**4.3.6.3 Day Care – Loss to Patients**

Day care Services include Chemotherapy, Brachytherapy, Dialysis, Thalassemia, etc. These services can be completed in the same day and the patient does not need hospitalisation. As a result of the EWE, these services may get severely affected due to unavailability of staff and equipment and other infrastructure. Delay in these services may result in adverse consequences for the patient, hence, the need to consider the impact factor.

**4.3.6.4 Emergency – Loss to Patients**

A percentage of patients that arrive at OPD are considered as Load for Emergency Services. Emergency patients increase manifold in case of a EWE, and need urgent medical assistance in order to save lives and reduce the impact of trauma and injury. If the hospital is unable to serve the patients due to dysfunction, the patients need to be transported to other facilities.

#### 4.3.6.5 IPD – Loss to Patients

In-patient services and hospitalised patients need to be evacuated from a hospital that has been severely struck by a EWE. The hospital may get inundated, or its structure may give way, among various critical consequences of EWE. Hence, these patients need to be moved to other healthcare facilities so as to be able to receive continued medical treatment in order to avoid deterioration of their conditions.

#### 4.3.6.6 Surgeries – Loss to Patients

Scheduled surgeries may get severely affected owing to damage after an extreme weather event. The operation theatres and surgical instruments may get damaged and be rendered dysfunctional. As a result, these patients, who are in urgent need of surgical procedures, would need to be shifted to other medical facilities for earliest assistance. The losses to the patients depend on the varying costs of surgeries, and number of days of post-operation hospitalisation.

This category also includes deliveries, and mother-child post operation care. While the value loss calculation uses the same formula, it is assumed that 20% of these deliveries are C-section, and therefore, are counted as an additional loading in the surgeries section.

#### 4.3.6.7 Staff – Loss to society due to absence of staff

While the loss of income of the staff has been incorporated in the Tangible losses framework, the value of the work that the staff does for the society is a multiple of the actual emoluments. Hence, a significant value of service is lost, if the hospital is rendered dysfunctional, and does not serve in the aftermath of the extreme weather event. The usual multiplier of the work done by the income, when discussed with medical specialists and healthcare planners, is 3 times the income of the staff.

#### 4.3.6.8 Intangible Value Losses to Hospital

The value losses to hospital in terms of the opportunity cost are taken into account under this category. The loss primarily depends on the number of days for which the hospital is non-functional, and the usual costs of each service per day.

These losses can be calculated separately for each of the above categories: OPD, Diagnostics, Day Care Services, Emergency, IPD, Surgeries and Deliveries.

The total loss is the product of the number of patients, the number of days of non-functioning and the cost per day of the above services.

In case of surgeries and deliveries, the total loss is the product of the intangible value loss of surgeries (from section 2.6.6) and the number of operation theatres in the hospital.

**4.3.7 Inferences and Takeaway from Study**

The framework that has been established using various techniques, data and through adaptation of knowledge from specialists and medical practitioners helps develop an insight into the kind of losses and the quantum when an extreme weather event strikes. While in the case of a cyclone or flood, the hospital building has a higher tendency to get inundated, in case of a landslide, the structure of the hospital may be highly vulnerable, especially in mountainous regions. These extreme weather events have been observed and recorded to cause heavy damages and losses to all building typologies, in addition to the fatalities and trauma to humans and settlements.

It is important to note that in case of a EWE, healthcare facilities are heavily sought, owing to the injuries, spread of diseases and emergency functions. However, if this critical infrastructure gives way, it implies severe value losses, apart from the tangible losses that have been enlisted. Value losses may vary in different cases, but an estimate can be derived at, using the framework developed in this study. This estimate will not only help in the preparedness of the hospital and community in case of a predicted EWE, but will substantially help in the investments towards achieving resilience in the pre-construction, design and construction phases. Resilience is the key to drastically reduce not only the consequences of the disaster, but also to lessen rescue, relief, recovery and reconstruction costs as well as loss of value and opportunity costs of the land and the critical infrastructure.

Additionally, some intangible factors may not be quantifiable, even as they have significant value to the community as well as the healthcare institutions. These characteristics may be considered, nevertheless, in pre-construction and design stages, to ensure avoiding these losses.

## 4.4 HAZUS - Tool for Estimating Potential Losses: Development, Purpose and Applicability

### 4.4.1 Introduction

HAZUS is a natural hazard analysis tool which is based on Geographic Information System (GIS). The tool has been developed and is distributed by FEMA (Federal Emergency Management Agency) for free, and is used as a loss estimation software/ tool for general purposes by agencies relevant to mitigation and decision making for natural hazards. (FEMA, 2020)

The HAZUS tool as a loss estimation software helps in the quantification of social, financial, property and human impacts under existing conditions and the possible mitigation measures. Quantification of these losses under prevailing conditions helps to understand and communicate the importance risks from natural hazards and other factors that contribute to the risks (such as quality of construction, land use zoning, location, etc.). (Scawthorn, et al., 2006)

HAZUS is currently equipped to measure and model for hurricanes, floods, tsunamis, coastal surges and earthquakes. The risk is modelled in three steps. The first step includes calculation of the exposure of the selected area. The second step involves characterisation of the intensity or level of the natural hazard that the selected area is exposed to. The third step uses the area of exposure and intensity of hazards to determine the potential losses (like economic and structural losses, etc.) (FEMA, 2020)

### 4.4.2 Benefits of HAZUS-MH

- Identification of vulnerable areas that may need planning considerations.
- Assessment of the preparedness to respond to a disaster before its occurrence.
- Estimation of potential losses due to specific hazard events (before or after the occurrence).
- Allocation of resources to ensure effective response and recovery.
- Prioritisation of mitigation measures to be implemented to ensure reduced future losses. (Mickey, 2004)

### 4.4.3 HAZUS MH Models

*Table 23 HAZUS MH Model. Source:* (FEMA, 2020)

| | |
|---|---|
| **Earthquake model** | Evaluation of probability of damage to infrastructure and buildings using the ground shaking data from the U.S. Geological Survey (USGS) ShakeMap website. Robust analyses must also take into account the ground failure data from state geological surveys. |
| **Flood model** | Calculation of economic loss and physical damage and economic loss owing to the riverine/ coastal inundation. The functions relating the type of flooding and its depth to the degree of damage for different typologies of structures are used to calculate the losses. |
| **Tsunami model** | Estimation of physical damage and economic loss to buildings due to the force and depth of tsunami waves in five high-risk states (Washington, California, Washington, Hawaii, Alaska, and Oregon) as well as U.S. territories in the Caribbean and Pacific. These estimation statistics can be combined with earthquake loss estimations to quantify additive impacts from near-source tsunami events. |
| **Hurricane model** | Estimation of physical damage and economic loss to buildings due to wind and windborne debris. At the census tract level, the wind hazard data are generated. This process can be combined with an internal storm surge model or user-supplied surge data to estimate the damage to buildings caused by coastal flooding driven onshore by hurricane winds. (FEMA, 2020) |

### 4.4.4 Mitigation Planning Process

#### 4.4.4.1 Overview of Mitigation Planning

Hazard mitigation planning primarily involves the assistance to communities for identification of the most effective policies, actions, and tools to reduce the potential risks of any losses that occur in the future. Risk assessments involve the estimation of economic and social impacts of hazards on infrastructure, services, buildings, facilities and people of a community. The effectiveness of this risk assessment depends directly on the appropriateness and quality of the data acquired and incorporated. (FEMA, 2004)

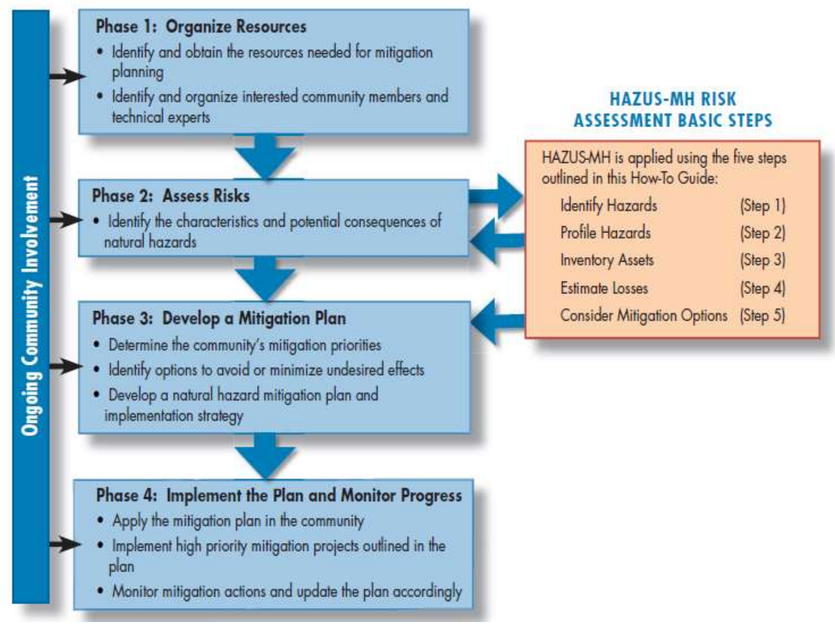


*Figure 11 The Hazard Mitigation Planning Process; Source:* (FEMA, 2004)

**In case of mitigation measures for floods,** the purpose is to minimise or avoid the exposure to flooding. This can be achieved by (1) engineering measures that address existing conditions and (2) actions that regulate new development and redevelopment. The following measures describe the above 2 points.

- Regulatory Measures
- Rehabilitation of Existing Structures
- Protective and Control Measures
- Construction of these protective measures
- Decreasing Runoff
- Increasing Discharge Capacity
- Containing, Diverting, or Storing Floodwater (FEMA, 2004)

**4.4.5 Risk Assessment and Mitigation Process Using HAZUS-MH**

During field visits, a specific risk assessment process is documented for using HAZUS-MH too, which identifies the tasks, steps and subsequent outputs involved in applying HAZUS-MH for risk assessment (as per requirement). Generally a risk assessment process involves four steps and is completed at loss estimation. However, a fifth step, known as 'Consider Mitigation

Options' has been added to this process. This extra step helps in the planning, identification, review and evaluation of the mitigation measures. (FEMA, 2004)

**4.4.6 Application Methodology**

**HAZUS-MH Levels of Analysis:** this consists of three levels –

- **Level 1** analysis produces a draft estimate using the nationwide database as its basis. This is considered to be a useful methodology to kick start the risk assessment process and for prioritization of high-risk communities.

- **Level 2** analysis uses the input of refined/ additional and hazard maps in order to produce more precise loss and risk estimation results. This assessment may need assistance from city planners, local emergency management personnel, GIS professionals, etc.

- **Level 3** analysis generates the most accurate estimation of losses and damages. This type of assessment and analysis usually needs involvement and inputs of technical experts such as geotechnical and structural engineers (who, based on the specific conditions of the community under study, can help modify the loss parameters). The analysis conducted at this level allows the users to provide their own techniques to study special conditions such as tsunamis and dam breaks. Expertise and Engineering is required at this level. (FEMA, 2004)

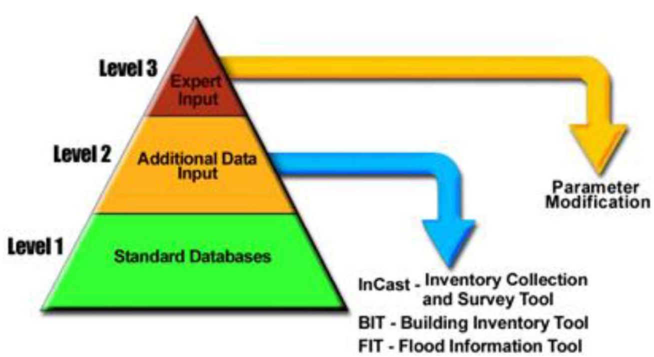


*Figure 12 HAZUS Analysis Levels; Source:* (FEMA, 2004)

To support data collection for the risk analysis and assessment, three data input tools were developed. The Inventory Collection and Survey Tool (InCAST) assists the users to collect and manage local building data for detailed analysis, as compared to the results using the data available with the National level datasets accompanying HAZUS. HAZUS-MH also includes an enhanced Building Inventory Tool (BIT) which allows users to import building data. This is helpful in handling large datasets (over 100,000 records). The Flood Information Tool (FIT) aids the users in manipulating the flood data into the format needed by the HAZUS flood model. (FEMA, 2004)

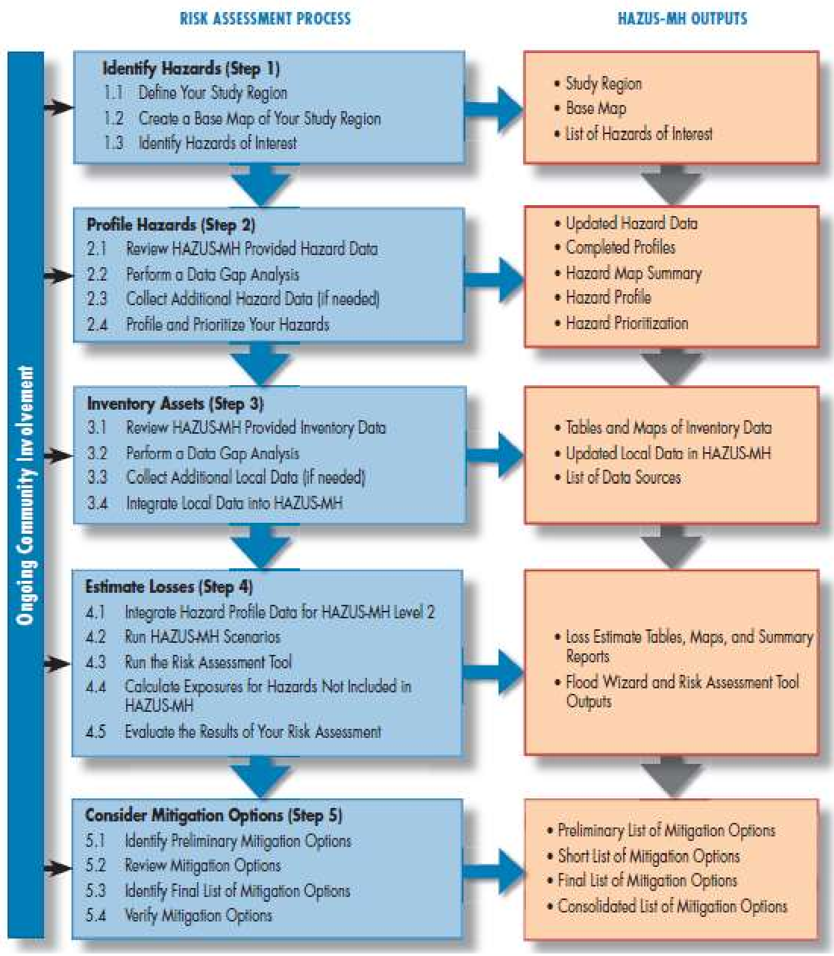


*Figure 13 HAZUS-MH Risk Assessment Process and Outputs; Source:* (FEMA, 2004)

### 4.4.7 Demonstration of Application of HAZUS for Indian Floods

The following are processes undertaken for analysis of hazard using HAZUS MH:

- vulnerability assessment
- built environment
- social impact
- hazard identification
- business interruption
- economic impact

Built environment consists of the background data on the building inventory. In case of Indian Flood example, this can be correlated with the following information for the any affected costal city:

- Demography details or the details of population, employment, housing
- building stock or categories of building such as residential, industrial or commercial properties
- essential facilities or facility of hospitals, schools, police stations and fire stations
- transportation or highway systems, bridges, railway infrastructure, airports
- utilities or the system of waste water, portable water, oil, gas supply lines, electric power and communication lines
- high potential loss facilities such as dams, nuclear facilities, site with hazardous material and military installation

For assessment of damage to buildings, the data pertaining to building inventory could be provided such that information related to occupancy type, number of stories, height of ground floor, type of foundation and value of the built structure and its content is provided to the software.

Since the software works with ArcGIS, locations for essential facilities such as hospitals, police station, and fire station in the vicinity are marked.

A hydrology model is provided to the software that allows us to assess the direction of water based on the existing terrain based on the 8 direction pour point model. Stream network is mapped in a similar manner. The level of flood for analysis of stream reach of the selected stream would be then undertaken along with discharge value sources. The input data also includes 'n-value' or Manning's Examples for assessment of ground cover where the smoother cover has a lower value of n and rough cover is associated with a higher value of n.

The output provided pertains to the structural flood loss on HAZUS. The software indicates the damage of property using specific occupancy depth damage functions taking the inputs of flood depth along with data such as occupancy type, number of stories, first floor height, foundation type and building value. It categorises the loss into four components a) direct damage (related to loss of general buildings, essential facilities, high potential loss facilities, transportation systems, utility systems), b) induced damage (generation of debris), c) direct loss (cost of subsequent repair, loss of income, damage to crops, casualties and requirement of shelter) and d) indirect losses (shortage of supplies, decline in sales, opportunity costs, economic loss)

### 4.4.8 Summary and Further Reading

Losses due to disasters are inevitable and cause damage at various levels. Disasters expose the vulnerability and unpreparedness of infrastructure, housing and communities, in addition to the lack of the country and states' proactive measures to minimise losses. As a result, communities bear losses not only on economic and health grounds, but also face longer periods of recovery and life 'back-to-normal'. Losses, hence, can be tangible and intangible, the quantification of which is difficult but necessary to arrive at an estimate of anticipated losses to the community and infrastructure in case the disaster strikes. While the calculation of tangible losses is more precise and quantifiable in terms of definitive parameters, the intangible losses have varied consequences in terms of damage severity, economics, social losses, ecology and health among many more interdependent variables relating to the typology of disaster and the community affected.

Loss of life cannot be quantified, even though many organisations offer financial aid and reimbursements to kinship. Similarly, losses to sites that hold cultural, artistic and archaeological value are very difficult to quantify owing to the invaluable nature of loss. Nevertheless, equations, spreadsheets, formulae, methodologies and new software tools have been designed by various authors and developers to arrive at more accuracy in terms of the losses incurred in the event of a disaster.

**NOTES**

# CHAPTER 5 - CONCLUSION AND WAY FORWARD

Extreme weather events and natural disasters affect the society and ecology in a complex, disoriented conundrum. The study conducted in this book is a congregation of after-effects that occur when a disaster strikes. The consequences are articulated in the form of detailed theory for earthquakes, landslides, floods and cyclones, for the purpose of dissemination. Correspondingly, the case studies categorically substantiate the theory with the help of actual numbers and tangible chronology of events, which not only validate the fundamentals, but also bring home the seriousness of the increasing problems caused by natural disasters.

Every disaster or extreme weather event has definitive characteristics and unfound peculiarities; however, the repercussions of these can be different than expected. A deeper investigation into the outcomes of the four disasters under study found varied consequences and reactions of communities and affected regions. The impact on population, structures, infrastructure, economics, psychology, socio-economics, and the fire and chemical hazards have been examined in detail, which brings to light the eclipsed effects of disasters. The spectrum ranges from triggering of multi-hazards to fire breakouts and chemical releases that exacerbate the impacts on affected population and infrastructure.

While some extreme weather events and natural disasters are unexpected, others assume stronger forms as they advance. The Cyclone Tauktae is one such example of an extreme weather event that struck the West Coast of India in May 2021, which was expected to be contained within wind speeds of 115-125 kmph as a ‘Very Severe Cyclonic Storm’, and transformed into an Extremely Severe Cyclonic Storm with winds speeds going upto 180 kmph.

Every year India’s coasts are struck by tropical cyclones of varying severity. Cyclone Fani struck the East Coast in 2019 as an unusual occurrence of an Extremely Severe Cyclonic Storm, Cyclone Amphan again struck the East Coast in 2020 as a Super Cyclonic Storm and hit Odisha, West Bengal and Bangladesh severely. On the West Coast, Cyclone Nisarga of 2020 hit Mumbai and Gujarat as a severe cyclonic storm, and was comparable to only two other cyclones of this intensity in the past. However, 2021 again saw Cyclone Tauktae devastating the West Coast, including Maharashtra and Gujarat as an Extremely Severe Cyclonic Storm.

Similarly, states such as Bihar, Assam, Kerala are struck by recurrent floods, causing severe destruction to life and property. It is important to note here that the intensity and frequency of extreme weather events has been increasing in the recent decades. As consequences of climate change, these events are expected to escalate in the future. While states are prepared with relief and recovery mechanisms and have National Disaster Response Forces for emergencies, it is crucial to avoid losses to life and infrastructure. An effective approach is the incorporation of resilience in the society. Communities and infrastructure that have inherent and built-in resilience have been found to repel the impacts of disasters effectively and 'bounce back better' and faster. Redundancy and risk reduction act as 'virtues' to enhance resilience and safety of critical infrastructure.

The study conducted in this book, therefore, extends the investigation to the realms of resilience, risk reduction, retrofitting and reconstruction. Even as emphasis is laid on resilience in the pre-disaster phase, it is equally important to ensure that reconstruction incorporates the attributes, guidelines and techniques for integrated resilience in the buildings. The infrastructure networks are complex and interdependent, and collapse of one of these during or after a disaster can lead to disintegration of other critical infrastructure in terms of both structure and functioning. The duration and aftermath of disasters are crucial and need effective operation and responsiveness of critical infrastructure for sustenance and feeling of relative safety.

To explore the provisions of resilience and risk reduction in reconstruction guidelines, three policy frameworks of three different countries were examined. A critical review and comparison of these policies reveals the eminence of quality and resilient methods of reconstruction, sustainable and local resourcing of construction materials, and ensuring transparency. However, it was observed that these policies indicate a lack of methodology for implementation of these guidelines at ground level. While the key elements and frameworks have been deliberated upon, there is also a deficiency of financial implications and investment frameworks that are involved to ensure resilience and risk reduction. International organisations such as the World Bank, Asian Development Bank and World Health Organisation release extensive financing and implementation frameworks towards rescue, relief and reconstruction, and a significant component of these frameworks are the methodologies to ensure that these finances are directed to ensure incorporation of structural and community resilience, to enable populations and buildings to withstand the next disaster. However, not only are these financing channels unclear in the state and national reconstruction policies, the external organisations' financing, additionally, is not effectively managed in most regions, thereby leading to increased losses after every 'anticipated disaster'. The policies also fall short in terms of the economic viability, investment opportunities and benefits of financing resilient reconstruction of structures.

Even as structures and communities need focussed resilient transformations, the possibility of extensive losses in the aftermath of a disaster cannot be ruled out. While resilience and risk mitigation can ensure minimised losses, the vulnerable regions must be examined for potential losses of infrastructure, livelihoods, personal commodities and intangible effects. This examination is more important in regions and cases that do not have inherent resilience or preparedness for disasters. The book delves into the typologies of losses, analyses the cascading effects and intangible consequences, and derives a conceptual estimation network across the fourth chapter. The building typology under scrutiny is a hospital, where the socio-economic, environmental and structural losses are considered, and the direct and indirect consequences are translated in terms of financial implications. Some of these intangible losses, such as loss of life, mental trauma, loss of limbs/ body parts, lengthy social-life disruptions, environmental degradation, among others listed in the chapter, cannot be quantified monetarily. Some cases may involve ex-gratia and compensations in the form of financial aid to kinship and affected families.

The economic ramifications can partially portray the quantum of losses post-disaster. Other aspects such as loss of infrastructure and communications, casualties, etc. depict the critical nature of the extreme weather event or natural disaster. The book, therefore, can be followed by analytical nature of study, involving the readers to scrutinise case examples that incorporated resilience and risk mitigation. The objective of the forward research is to examine and later, apply methodologies, frameworks and practices that were implemented in regions or cases with recurrent disasters. The approach to this forward study can be aligned with the ground reality of implementation and therefore, documentation and application of the fundamentals of such resilience practices. The research may also draw comparisons with the policies and guidelines in place, and check for the presence and implementation methodologies of these in the cases studied.

The purpose of the study conducted in this book is to enhance awareness and draw attention of practitioners in the construction and planning industry to the increasing nature of disasters and their extreme impacts. While the root cause of the extreme weather events can be pointed at climate change, it is a very tedious, long and utopian process to execute the reversal of the effects of global warming and consequent climate change. The practitioners can, however, administer their contributions in infrastructure and housing, to ensure minimum losses and disruptions in the affected regions.

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