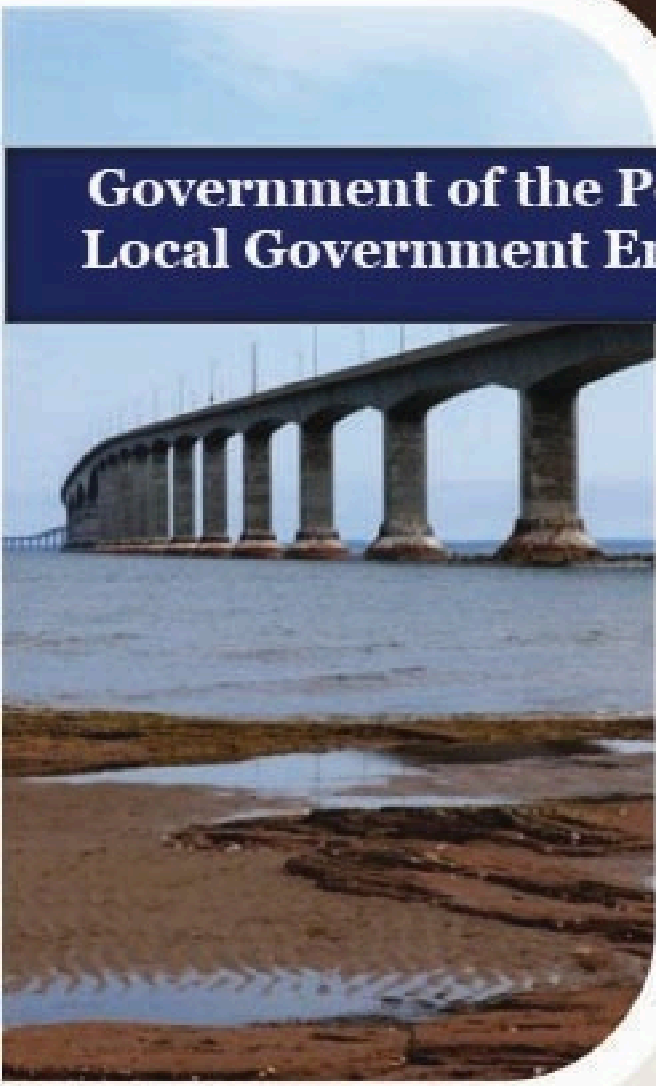
Government of the People's Republic of Bangladesh
Local Government Engineering Department (LGED)



Guidelines for the Planning Design and Implementation of Climate Resilient Rural Bridges

December, 2025

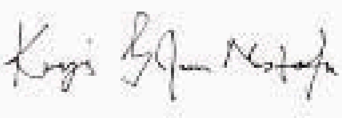
Message

It is a matter of great satisfaction that the "*Guidelines for Planning, Design and Implementation of Climate Resilient Rural Bridges*" have been developed under the Program for Supporting Rural Bridges (SupRB), jointly funded by the Government of Bangladesh (GoB) and the World Bank. These Guidelines mark a significant milestone in LGED's efforts to integrate climate resilience into rural bridge infrastructure, ensuring that future investments remain sustainable and adaptive to changing environmental conditions.

The Guidelines provide clear directions for engineers and planners to incorporate climate-resilient features in bridge design, construction, and implementation. They emphasize practical approaches to address climate risks such as flooding, riverbank erosion, and extreme weather events, thereby enhancing the durability, safety, and serviceability of rural bridges and culverts.

I am confident that these Guidelines will greatly benefit LGED officials at Upazila, District, and program levels in planning and executing climate-resilient bridge projects. They will also strengthen institutional knowledge and capacity, enabling LGED to safeguard rural connectivity and protect infrastructure investments against future climate challenges.

LGED reaffirms its commitment to building resilient infrastructure and ensuring that bridge asset management remains forward-looking, efficient, and sustainable in the face of climate change.



(Kazi Golam Mustafa)
Chief Engineer
Local Government Engineering Department

Message

It is a great pleasure to present the Guidelines for Planning, Design and Implementation of Climate Resilient Rural Bridges, developed under the SupRB project. These Guidelines represent a significant advancement in LGED's infrastructure development practices, providing systematic directions for integrating climate resilience into bridge planning, design, and implementation.

The Guidelines emphasize the fundamentals of climate-resilient bridge and culvert construction, offering step-by-step approaches to address climate risks such as flooding, riverbank erosion, and extreme weather events. They have been designed to complement LGED's Bridge Asset Management Framework and RuBIMS platform, making rural bridge development more adaptive, technology-driven, and accountable.

These Guidelines will serve as a practical tool for contractors, engineers, and LGED officials at all levels, helping them to adopt standardized practices, minimize vulnerabilities, and ensure the long-term durability and serviceability of rural bridge structures. They will also contribute to the future development and strengthening of LGED's Climate Resilient Infrastructure Policy.

I extend my sincere appreciation to the World Bank Task Team and subject matter experts for their valuable comments and feedback during the preparation of these Guidelines. Together, we reaffirm our commitment to building infrastructure that is not only climate-resilient and sustainable but also safe, responsible, and future-ready.

(Md. Belal Hossain)
Additional Chief Engineer &
Project Director
Program for Supporting Rural Bridges (SupRB)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS, ABBREVIATIONS AND KEY TERMINOLOGIES

ADB	Asian Development Bank
BCCSAP	Bangladesh Climate Change Strategy Action Plan
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
GHG	Green House Gas
IPCC	Intergovernmental Panel on Climate Change
MCA	Multi-Criteria Analysis
NAP	National Adaptation Plan
OPEX	Operational Expenditure
PPTA	Project Preparatory Technical Assistance
SLR	Sea Level Rise
SSH	Second Southern Highway
USAID	United States Agency for International Development

ADAPTIVE CAPACITY, as it relates to infrastructure and built assets, describes the degree to which the physical elements of a system can absorb, withstand, or respond to climate change impacts without incurring damage.

CLIMATE is an expression of the composite weather conditions (e.g., temperature, precipitation, wind), including both statistical averages and the occurrence of extreme events, over a given period of time. The World Meteorological Organization recommends a 30-year period to adequately describe the climate of a given area.

CLIMATE CHANGE refers to a statistically significant variation in climate data or patterns over a given period of time, due to either natural climate variability or as a result of human activity.

CLIMATE CHANGE ADAPTATION describes measures taken in response to actual or projected climate change in order to eliminate, minimize, or manage related impacts on people, infrastructure, and the environment.

CLIMATE CHANGE MITIGATION refers to actions that reduce the production of greenhouse gases that cause climate change. Although some adaptation strategies have mitigation co-benefits, they are not specifically referenced in this guide.

CLIMATE CHANGE IMPACTS on infrastructure are, for the purposes of this guide, the resulting influence of climate change effects on the structural form or function of an asset (e.g., the buckling of train tracks due to extreme heat).

CLIMATE CHANGE VARIABILITY is the short-term fluctuation in weather conditions, usually over a period of a year or a few decades.

CLIMATE DRIVER is the manifestation of a change in climatic conditions through one or more weather variables, such as a change in precipitation or sea level rise, to create an impact.

CLIMATE RESILIENCY is a concept to describe how well people or ecosystems are prepared to bounce back from certain climate hazard events. The formal definition of the term is the "capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance".

CLIMATE PROOFING is a process that integrates climate change mitigation and adaptation measures into development projects. It involves identifying climate-related risks and ensuring that development activities are resilient to those risks. Climate-proofing is the practice of reducing Greenhouse Gas (GHG) emissions released from the implementation of a certain investment, as well as increase its resilience to climate change impacts.

EXPOSURE refers to the extent to which a system comes into contact with a hazard.

LARGE-SCALE INFRASTRUCTURE SYSTEMS serve large populations and tend to be focused on urban areas.

RISK is the combined function of the likelihood that a hazard will occur and the resulting consequences.

SENSITIVITY is the degree to which a built, natural or human system is directly or indirectly affected by or responsive to changes in climate conditions or related impacts.

SMALL-SCALE INFRASTRUCTURE SYSTEMS service smaller populations, ranging from villages to clusters or communities of households, and are often more relevant to rural areas.

VULNERABILITY is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. It is often defined as a combined function of exposure and sensitivity to the effects of climate change, minus the adaptive capacity of a system.

SUMMARY OF RECOMMENDED BRIDGE DESIGN CONSIDERATIONS

"Guidelines for Bridge Design of Local Government Engineering Department" is one of the very important documents for LGED in proving guidance to the Designers on Bridge/Culvert design. This guideline provides guidance on the following Conventional considerations for Bridge Design:

- ✓ Site specific Requirements
- ✓ Traffic Volume and Traffic Safety
- ✓ Structural Requirements, Track/Axcel Loading, Earthquake & Wind Loading etc.
- ✓ Durability and Materials consideration
- ✓ Hydraulic, Hydrologic and Geo-morphologic requirements
- ✓ Constructability

As per the Bridge Asset Management Prospective; the following additional consideration may be included in the guideline for the Bridge Design and Construction:

- ✓ Constructability and Economic Requirements
- ✓ Geometric and Aesthetic
- ✓ Environmental and Climatic considerations
- ✓ Climate Change Impacts (Natural Disasters i.e. Cyclone/tsunamis, earthquakes, landslides, rise of sea level, extreme temperature etc.)
- ✓ Bridge Safety consideration (from Waterway traffic)
- ✓ Operation and Maintenance (including ensuring access to all elements for inspections and maintenance),
- ✓ Life Cycle replacement (including Bearing Assemble replacement) and disposal considerations
- ✓ Accessibility for all on the sidewalk

Recommended considerations for Climate Resilient Bridge Planning, Design and Construction:

Climate Hazards/Stressor	Impacts	Design Considerations
Increase of temperature	Bridge material excessive Thermal Expansion and contraction will impact bridges, culverts structures.	Following International best practices LGED can increase the design range for expansion joints up to 80-120 mm for 100-meter span bridges. LGED should adopt finger-type expansion joints for greater range of

Climate Hazards/Stressor	Impacts	Design Considerations
		movement
Increase of monsoon rainfall and intensity	Floods, erosion of embankments and road infrastructure. Early or frequent flash floods. Drainage problems in drainage structures, Sediment problems and Navigation problems	Bridge opening/horizontal clearance selection based on additional consideration of flooding. LGED can adopt high-capacity drainage systems and elevate critical bridges. Waterproofing materials i.e PTFE, or polytetrafluoroethylene (a synthetic fluoropolymer known for its exceptional chemical resistance, low friction, and high thermal stability). High-grade Neoprene to enhance durability against moisture. Protection of Approach-road and bridge foundations.
Sea level rise	Increasing normal tide levels will flood more lands of the coastal zone in terms both of extent and inundation time; navigation problems. In some areas the extreme tide will overtop the polders. The road and infrastructures will be affected and increased consequent salinity will impact reinforcing materials.	Bridge Design should include elevated platforms, additional navigation clearance/vertical clearance (additional 1 – 2 meter), Provisions for elevating bridge to address future navigation clearance. Use of corrosion resistant materials like stainless steel or coted alloys and additional clear covers of concrete. Special types of concrete etc.
High winds and Increase of the frequency of strong cyclones including storm surges.	Potential Impact by wind driven wave action on embankments, bridge abutments and super-structure etc.	Wind load should be considered in bridge design.

Note: Currently, there is no International Codes and Standards on Climate Resilient Bridge Design. LGED should consider adopting International Codes and Standards on Climate Resilient Bridge Design once they are available.

CHAPTER I: INTRODUCTION

1.1 Introduction

Bridges and culverts are the integral elements of the Rural Road transportation system and form a vital and vulnerable Rural Transportation link in connecting the Growth Centers (GC), Rural Markets, other small economic and services centers of Rural Bangladesh. Any damage caused to the same can not only affect the rural road network connectivity but also causes a major impact on the rural economy which can result in a slower GDP growth. Despite its importance, however, bridge and culvert are often the most neglected components of the road maintenance program, which accounts only 4% of the total road maintenance fund. Demands on limited resources, especially competitive roadway priorities for increased capacity such as rehabilitation and widening, and improved riding surfaces, often result in deferred maintenance for bridges. The consequences are obvious - bridges are deteriorating far faster than they are being repaired. Without adequate attention, many require replacement or closure long before they are obsolete, further adding to the demand for limited funds, impacting safety, and discouraging both users and transportation providers. Bridge construction requires a substantial amount of investment and its use involves public safety. A bridge failure can be catastrophic. It can cause injury or death and can be very expensive to restore. Typically, the bridges were designed and constructed considering Site specific Requirements, Traffic Volume, Structural Requirements, Hydraulic and Constructability requirements. Conventionally bridges are designed using design criteria that have been calculated from historical climate data under the assumption that the average and extreme conditions of the past will represent conditions over the future lifespan of the structure. In the context of climate change, these designs will need to be reassessed, and updated to reflect changing climate risks. In addition, the inherent uncertainty associated with projecting climate change is likely to bring about additional challenges to the design, construction, and operation of new infrastructure. As number of bridges failing every year; causes of these failures are identified and the causes are not only age factor or lack of maintenance but also among many other reasons including climate change impacts (natural forces and hazards) and time-related degradation of materials due to lack of durability of materials consideration during design and construction. So, its time for the Bridge Design, Construction and Bridge Asset Management professionals to consider the following general Factors for Bridge Design, construction and maintenance/rehabilitation:

- ✓ Site specific Requirements
- ✓ Traffic Volume and Traffic Safety
- ✓ Structural Requirements
- ✓ Durability and Materials consideration

- ✓ Hydraulic, Hydrologic and Geo-morphologic requirements
- ✓ Constructability and Economic Requirements
- ✓ Geometric and Aesthetic
- ✓ Environmental and Climatic considerations
- ✓ Climate Change Impacts (Natural Disasters i.e Cyclone/tsunamis, earthquakes, landslides)
- ✓ Bridge Safety consideration (from Waterway traffic)
- ✓ Operation (including inspections), Maintenance (maintenance access) and Life Cycle and disposal considerations
- ✓ Accessibility for all on the sidewalk

As part of the suitable tools for incorporating climate resiliency into engineering design, this particular guide focuses on bridge infrastructure, with the overall objective of supporting the consideration of climate change risks and adaptation in bridge infrastructure development and maintenance activities. All transportation infrastructure, including roads and bridges, are sensitive to weather and climate change. Climate change affects the planning, design, construction, maintenance, and performance of these structures throughout their service life. In this Guideline Impacts of Climate changes on bridges will be discussed in detailed and guideline/standards for mitigating measures are out lined for climate resilient Bridge Design, Construction and Maintenance. Therefore, this guide will be useful for those considering specific engineering design options to make bridge infrastructure more resilient in a climate altered future. It provides engineering and non-engineering development professionals with an overview of potential impacts on bridge activities and adaptation options, and guidance for utilizing a risk assessment methodology to determine appropriate design measures.

CHAPTER II: CLIMATE CHANGE

2.1 Introduction

Extreme weather events such as droughts, heat waves, dust storms, forest fires, floods, Cyclone/tsunamis, torrential rain and landslides, which already disrupt the lives of millions each year, are expected to increase in frequency and intensity with climate change. The impact of these sudden events, in addition to the gradual change in climate effects over time, will put added stress on vital water, sanitation, flood management, transportation, and energy infrastructure. Responding to the impacts of climate change presents a major challenge for developing countries lacking adequate resources, and it is therefore an important focus point for any infrastructure development.

2.2 Climate change - Bangladesh Contexts

Reference: National Adaptation Plan of Bangladesh (2023 – 2050), October 2022. Published by Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh.

2.2.1 General Climate

Bangladesh is a subtropical country with a warm and humid climate. and is situated in the heart of the South Asian monsoon region; with the Bay of Bengal and Indian Ocean to the south and the Himalayan and Arakan Mountain ranges to the north and east respectively.

The average temperature ranges between 15°C and 34°C around the year. Mean annual rainfall is about 2,400 mm; about 70 percent of rainfall occurs during monsoon (June to September). Rainfall varies significantly across the country, with the arid western regions receiving as little as 1,400 mm and the north-eastern region and eastern hills receiving over 4,300 mm. Bangladesh has been experiencing higher temperatures, erratic rainfall and extreme rainfall events in recent decades due to climate change. It also is highly vulnerable to climate change impacts due to its low-lying terrain (13 percent of its territory lies within two meters above the mean sea level), high population density, and location at the confluence of the Ganges, Brahmaputra and Meghna River basins. Observed climate trends, hazards, future projections, ensuing stresses and resultant risks will be elaborated further based different regions of the country that reflect hydrological and topographical variations.

2.2.2 Historical Climate Trends

Temperature rise

The average temperature in Bangladesh is rising sharply in the last three decades compared to previous three decades. The plot below illustrates the stark differences in temperature distributions between two consecutive periods. Whereas temperature variations were minimal (0.0067°C per year) during 1961-1990, the variations rose sharply (to 0.03°C per year) from 1991 to 2019 (CEGIS, 2022).

In recent decades, the mean temperature has been rising very rapidly. From 1991 to 2000, the mean temperature increased by 0.39°C, which further increased by 0.53°C during 2001-2010 and 1.06°C during 2011-2019 (CEGIS, 2022). The minimum temperature has risen by 0.45°C and 0.52°C for the winter and monsoon, respectively. As such, winters are becoming warmer with minimum temperature increase of 0.02°C per year. Even hotter summers during the pre-monsoon and monsoon have seen a maximum temperature increase of 0.022°C per year and 0.035°C per year, respectively, and minimum temperature rises of 0.024°C per year and 0.043°C per year, respectively (CEGIS, 2022).

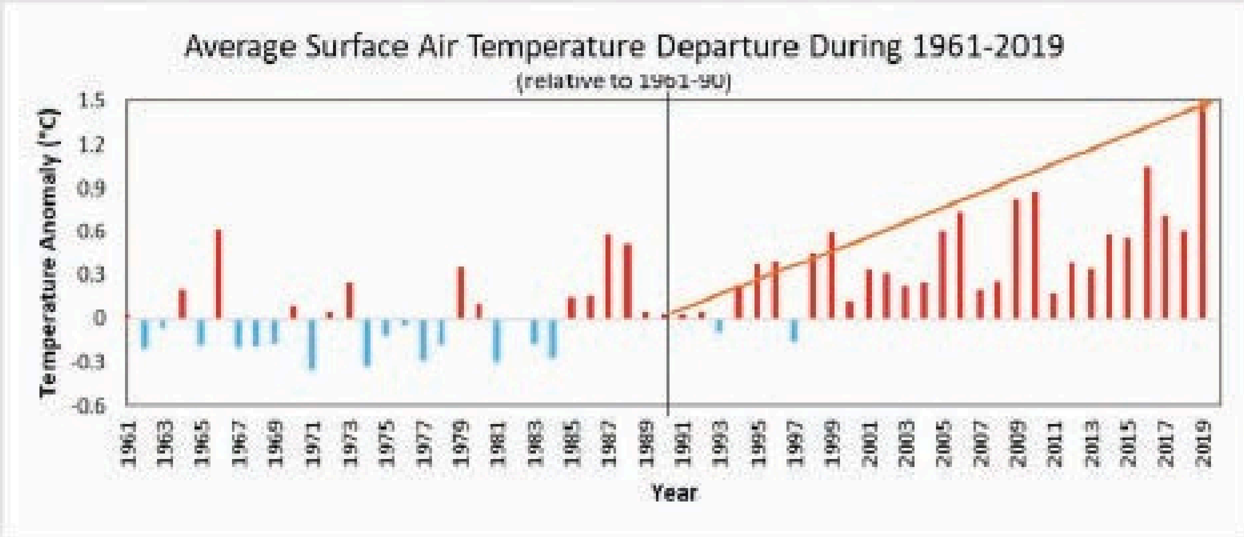


Figure 1: Departure of average annual temperature in Bangladesh relative to climate normal of 1960-1990

Source: CEGIS analysis based on BMD data.

Rainfall variability

Rainfall varies significantly across the different hydrological regions of the country, with lower rainfall ranging from 791-2,241 mm in the dry north-western Barind region to high rainfall (2,586-5,944 mm) in the north-eastern region. Rainfall increases nationwide are 8.4 mm per year (Roy et al., 2017). There is also temporal variation as average yearly rainfall distribution exhibits a skewed pattern. Rainfall is decreasing in the winter (December-February) and pre-monsoon (March-May) at 1.3 mm per year and 0.5 mm per year, respectively, while it is increasing for both the post-monsoon (October-November) and monsoon (June-September) at 0.05 mm per year and 4.5 mm per year, respectively. This indicates that winters are becoming dryer and monsoons are becoming wetter. Spatial variations in temporal rainfall distribution are erratic throughout the country, however (Rahman et al., 2015). The departure plot does not display increases as significant as those of temperature but it does illustrate the slightly increasing nature of rainfall in recent decades.

In recent years, the country has experienced several extreme rainfall events, e.g., 341 mm of rainfall occurred in 24 hours in Dhaka in 2004, 408 mm in 24 hours in Chattogram in 2007, 333 mm in 12 hours in Dhaka in 2009 and 433 mm of rainfall in 24 hours in Rangpur in 2020. The Rangpur rainfall was a record high in the last 60 years. Analysis of extreme rainfall indicates that consecutive dry days (CDD) is a significant increasing trend all over the country (Ezaz et al., 2021 and Islam et al., 2014). The simple daily intensity index (SDII) shows a decreasing trend in northern and central areas, while the coastal areas have an increasing trend (Ezaz et al., 2021). In addition, the difference in rainfall amount among regular and extreme events is increasing.

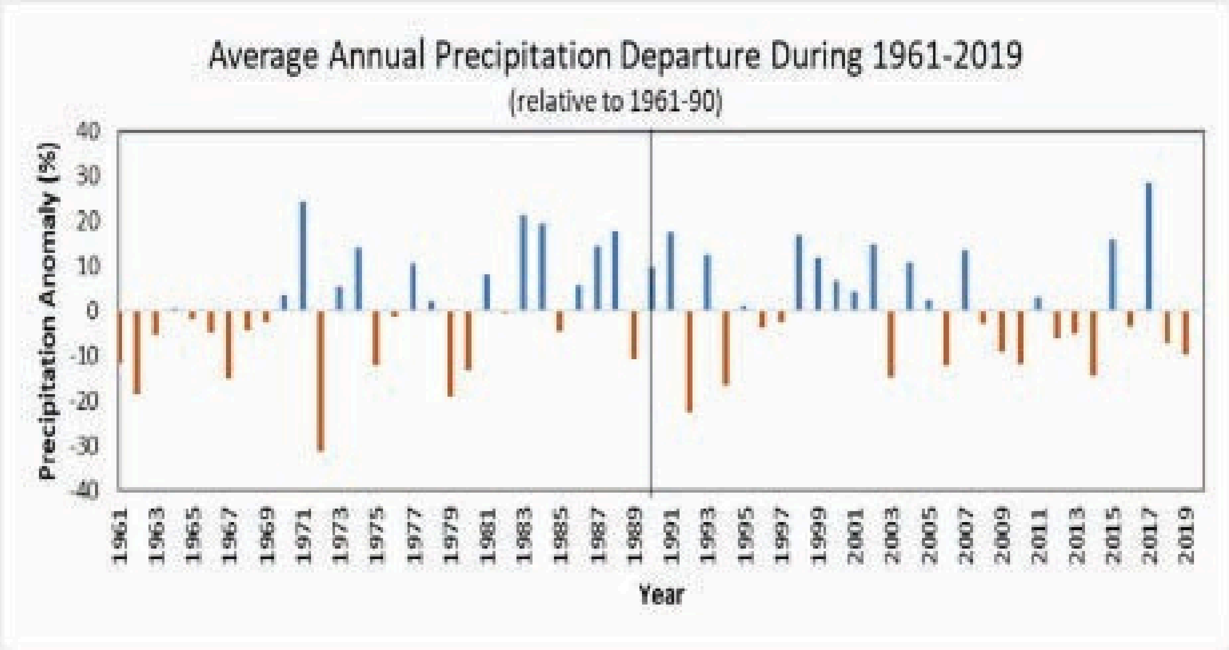


Figure 2: Departure of average annual precipitation in Bangladesh relative to the climate normal of 1961-1990

Source: CEGIS analysis based on BMD data.

Sea-level rise and ocean warming

Sea levels have risen adjacent to the Bangladesh coast due to both the geographic location and nature of the delta. Between 1901 and 2010, sea level rose at 1.7 mm per year, and from 1993 to 2010, it rose 2.8±0.8 mm per year. Satellite altimetry data analysis also supports this, showing a rising rate of 3.2±0.4 mm per year.

The Bay of Bengal is experiencing increasing sea surface temperature and subsequent changes in pH. A significant decreasing trend in pH is observed near the Bangladesh coast during the winter and fall seasons, indicating acidification of sea water (Sridevi and Sarma, 2021).

2.2.3 Climate Trends

The Sixth Assessment Report of the IPCC (IPCC, 2021) updated future climate projections with new shared socio-economic pathway (SSP) scenarios based on five narratives describing broad socioeconomic trends. These unfold the range of plausible future scenarios. According to the IPCC, SSP1-2.6 represents low future greenhouse gas emissions (GHG), while SSP5-8.5 is the very high emissions scenario. To capture the complete variation of future climate as presented in the IPCC Sixth Assessment Report (AR6), these two scenarios have been considered for Bangladesh. The SSP1 and SSP5 scenarios envision relatively optimistic trends for human development in the future. SSP5 assumes this will be driven by an energy-intensive, fossil fuel-based economy, while in SSP1, there is an increasing shift towards sustainable practices.

Temperature

IPCC AR6 (2021) projects a global temperature increase of 1.5°C to 1.6°C in the near term (2030s), 1.7°C to 2.4°C in the mid-term (2050s) and 1.8°C to 4.4°C in the long term (end of the century). Climate projections for Bangladesh based on a downscaled multi-model ensemble (following the IPCC AR6) for Bangladesh indicate a warming of 0.44°C to 0.69°C in the near term (2030s) and 1.3°C to 2°C in the mid-term (2050s) for the SSP1-2.6 and SSP58.5 scenarios, covering the potential range of future temperature rise. Interestingly, in the near term, SSP1-2.6 has a slightly higher temperature rise (0.69°C) than SSP5-8.5 (0.44°C) across Bangladesh. This changes in the mid-term with higher amounts of warming expected under SSP5-8.5

Future Projected Annual Average Temperature (°C)

Climate Stress Area	Base (1981-2010)	SSP1-2.6		SSP5-8.5	
		2030s (2016-2045)	2050s (2036-2065)	2030s (2016-2045)	2050s (2036-2065)
SWM	25.8	26.5	27.1	26.2	27.7
SEE	25.6	26.2	26.8	26.1	27.5
CHT	25.3	26.1	26.7	25.9	27.4
FPE	24.9	25.7	26.4	25.4	27.0
HFF	24.5	25.3	26.0	25.1	26.8
DBA	25.5	26.2	26.9	25.8	27.5
NNW	24.9	25.6	26.3	25.2	26.9
CBL	25.3	26.0	26.8	25.7	27.4
CHI	25.2	25.9	26.6	25.7	27.3
URB	25.3	26.0	26.7	25.8	27.3
BD	25.5	26.1	26.8	25.9	27.4
BoB*	28.3	28.7	29.0	28.7	29.4

°C: 24.5 25.5 26.5 27.5 28.5 29.5

Future Projected Annual Average Rainfall (mm)

Climate Stress Area	Base (1981-2010)	SSP1-2.6		SSP5-8.5	
		2030s (2016-2045)	2050s (2036-2065)	2030s (2016-2045)	2050s (2036-2065)
SWN	2129	2138	2210	2165	2215
SEE	3266	3300	3411	3374	3431
CHT	2912	2943	3040	3010	3069
FPE	2558	2579	2598	2647	2667
HFF	3653	3652	3688	3712	3783
DBA	1560	1588	1631	1638	1643
NNW	2157	2193	2191	2281	2255
CBL	1663	1692	1724	1745	1741
CHI	2606	2699	2750	2769	2800
URB	2759	2785	2840	2839	2882
BD	2579	2582	2640	2615	2669
BoB	1560	1353	1393	1628	1707

mm: 1300 1800 2300 2800 3300 3800

Figure 3: Future projections of temperature and rainfall for Bangladesh and different climate stress areas based on downscaled climate data

(Source: CEGIS analysis from the IPCC Sixth Assessment Report multi-model ensemble)

Note: *Sea surface temperature is used for future projections.

**Climate stress areas: SWM: south-western coastal area and Sundarbans; SEE: south-east and eastern coastal area; CHT: Chattogram Hill Tracts; FPE: river, floodplain and erosion-prone area; HFF: haor and flash flood area; DBA: drought-prone and Barind area; NNW: northern and north-western region; CBL: Chalan Beel and low-lying area of the north-west region; CHI: Char and islands; BoB: Bay of Bengal and ocean and URB: urban areas.

Rainfall

Rainfall variation due to future climate change for Bangladesh ranges between 0.1-1.4 percent in the 2030s and 2.4-3.5 percent in 2050s. The northeastern and eastern hills regions will receive higher rainfall, while the western part will see lower levels. Future annual rainfall will be slightly higher or similar in the 2030s across the country. In the 2050s, rainfall will increase all over the country. A higher amount of change is expected in coastal areas and the Chattogram Hill Tracts. Future projections indicate that winter rainfall is decreasing for most of the country except in the coastal and Chattogram Hill Tracts regions. In contrast, pre-monsoon rainfall will decrease in the Chattogram Hill Tracts and Bay of Bengal. Rainfall in the

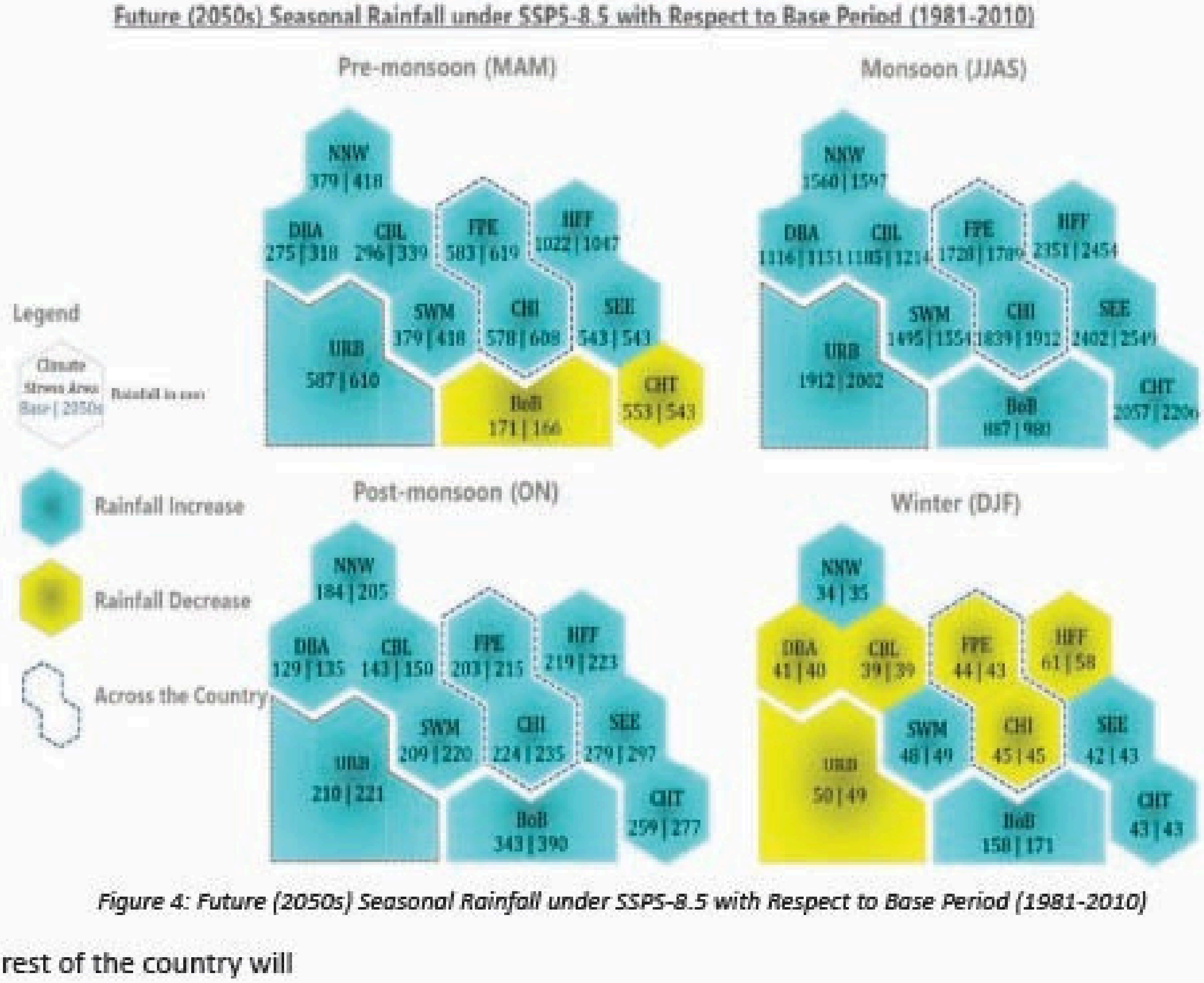


Figure 4: Future (2050s) Seasonal Rainfall under SSP5-8.5 with Respect to Base Period (1981-2010)

rest of the country will

increase during this season. Monsoon and post-monsoon rainfall all over the country will increase. The frequency of heavy rainfall events is projected to rise while that of light rainfall events will fall, inferring a shift towards a lower number of wet days with an increase in the intensity of rainfall on days with rain, entailing an increased risk of flash floods (Caesar and Janes, 2018).

Sea-level rise and Subsidence

Global warming is causing sea-level rise and increasing the vulnerability of low-lying coastal areas of Bangladesh. Future sea-level rise is projected to be between 0.11-0.12 m in the near term, 0.23-0.27 m in the mid-term and 0.54-0.86 metres in the long term (IPCC, 2021). There is, however, substantial uncertainty in the long-term projections near the Bangladesh coast, according to the IPCC. Some global models estimate an increase of up to 1.75 m.

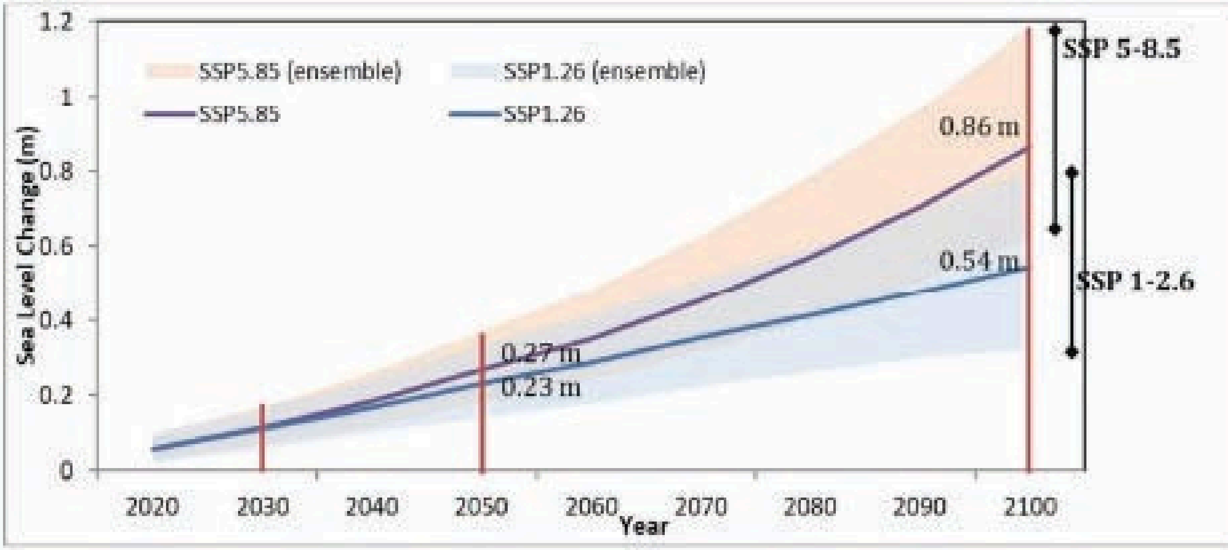


Figure 5: Sea-level rise projections near the Bangladesh coast in the Bay of Bengal

Note: The lines andshaded region represent the ensemble average of sea-level rise and the spread of ensemble results from the IPCC CMIP6 models, respectively.
(Source: Fox Kemper et al., 2021.)

2.3 Future Climate Change and Increased Extremities of Hazards

Due to climate change, most climate-related hazards will increase in frequency and/or intensity. The most critical climate change-induced hazards in Bangladesh are rainfall variability, river floods, flash floods, urban floods, sea-level rise, salinity, cyclonic storm surges, droughts, extreme heat waves, extreme cold, riverbank erosion, lightning, landslides, higher sea surface temperature and ocean acidification.

2.3.1 Drought

The dry regions of Bangladesh located along the western border are most vulnerable to meteorological droughts in pre- and post-monsoon periods. The mean annual rainfall in the dry zone is around 1,250-1,750 mm, mainly from May-June to September-October (Ahmed and Suphachalasai, 2014). Due to the combined effect of soils with low moisture-holding capacity (<200 mm available moisture), an increasing number of dry days (precipitation <0.5 Potential Evapo-Transpiration) and extreme summer temperatures of more than 40°C, the drought situation in the dry areas become extremely severe during April and May. Nineteen droughts occurred in Bangladesh between 1960 and 1991. The average occurrence is once in 2.5 years. Bangladesh experienced severe droughts in 1951, 1957, 1961, 1972, 1976, 1979, 1989 and 1997. On average, 2.32 million ha per year (Kharif seasons) and 1.2 mha per year (Rabi season) of agricultural lands are damaged during a typical drought event (CEGIS, 2013).

Future climate change projections outline an increase in daily temperature with more hotter days during the pre-monsoon and fewer rainy days. According to BDP2100 studies, Aus production would decline by 27 percent under a moderate climate change scenario while wheat production would fall to 61 percent. Under a severe climate change scenario (with 60 percent moisture stress), the yield of dry season or Boro rice might decrease by 55-62 percent. Moisture stress might force farmers to reduce Boro cultivation.

2.3.2 River flood

River flooding is a recurrent phenomenon in Bangladesh, occurring almost every other year. It generally takes place during the monsoon and inundates low-lying floodplain areas.

Major floods happened in 1987, 1988, 1998, 2004, 2007 and 2017. The area inundated during the 1987, 1988, 1998 and 2007 floods comprised 39 percent, 61 percent, 69 percent and 42 percent of the country, respectively. During the 1988 floods, embankments of 1,990 km (17.5 percent of the total), irrigation canals/drainage channels of 283 km (5.3 percent of the total), 1,465 structures (10 percent of the total) and protection works of 265 km (24.8 percent of the total) of the Bangladesh Water Development Board (BWDB) were partially or fully damaged. The 1998 flood caused the death of 1,100 people and damaged 4,500 km of embankments and 575,000 hectares of crop. During the 2004 floods, embankments of 3,158 km (27.7 percent of the total) and protection works of 178 km (16.6 percent of the total) were partially or fully damaged. The 2007 flood caused 405 deaths. The flood of 2020 was an alarming event. Around 5 million people were affected; 41 people lost their lives.

Estimated damages due to the flood events of 1988, 1998, 2004, 2007 and 2017 were $1.2 billion, $2.8 billion, $6.6 billion, $1 billion and $900 million, respectively. While flood-related fatalities are decreasing, economic losses have been increasing over the years. The Government has been developing and implementing various measures to reduce flood risks.

Due to climate change, the mean annual flow of the Ganges, Brahmaputra and Meghna River basins will increase by 17-28 percent, 2-5 percent and 1-4 percent, respectively, under the SSP5-8.5 scenario in the 2050s (CEGIS, 2021). The seasonal flow distribution in the 2050s will also increase substantially during the pre-monsoon in all three basins. The flow will increase significantly (18-30 percent) in the Ganges basin, while a smaller increase might occur in the Brahmaputra and Meghna basins. The higher increase in the Ganges basin is most probably attributed to additional flow from melting Himalayan glaciers. This will increase the flooding probability in the country. Winter flows will decrease in the Brahmaputra and Meghna basins under SSP5-8.5.

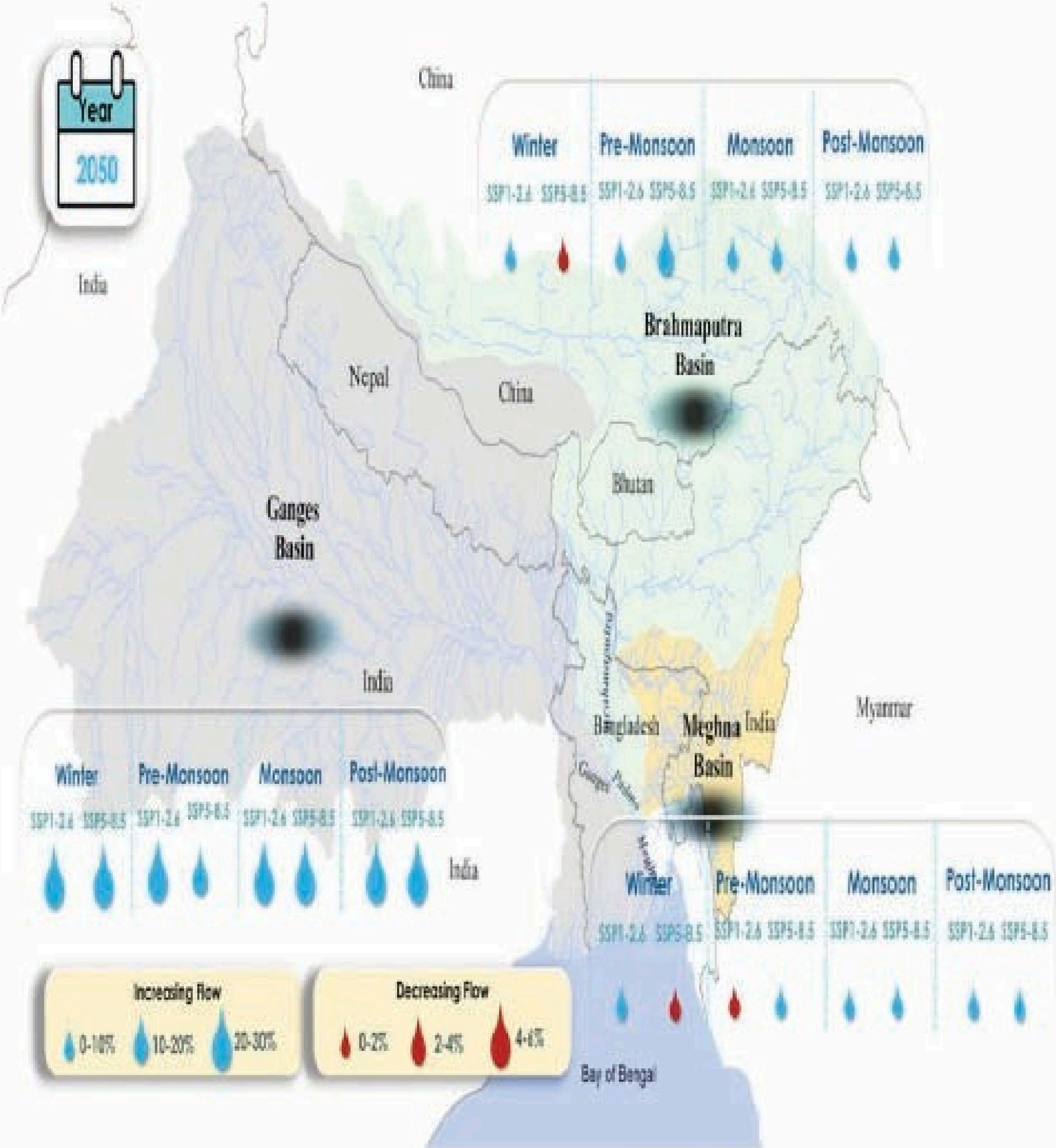


Figure 6: Future seasonal flow variation in the Ganges, Bhramaputra and Meghna basins

Source: CEGIS GBM Model (2021)

1.3.3 Riverbank erosion

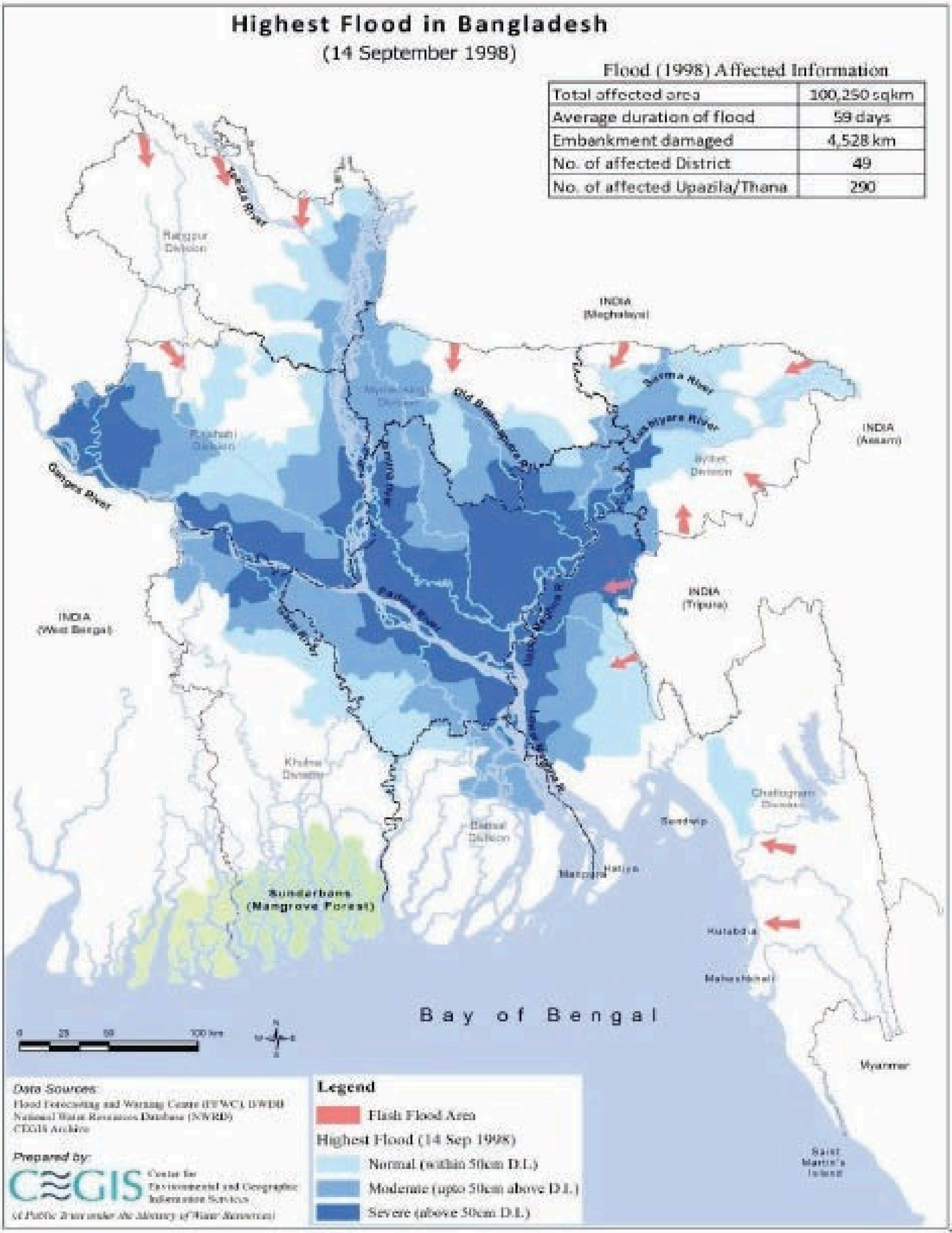
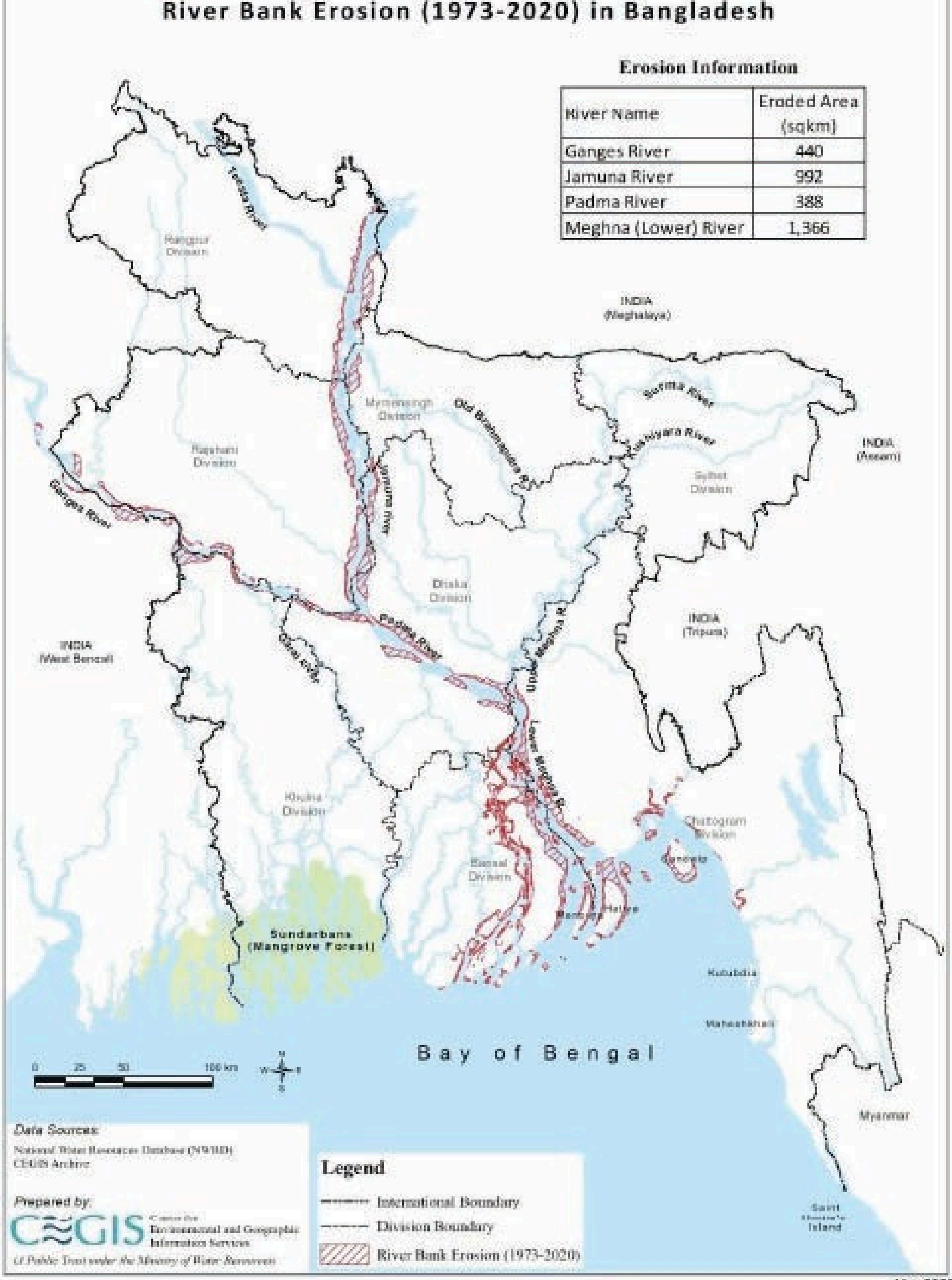


Figure 7: Highest Flood Map of Bangladesh (September 14, 1998)

Every year in Bangladesh, rivers erode around 10,000 hectares of land (NWMP, 2001). According to CEGIS estimates, between 1973 and 2021, erosion along the Jamuna River was 93,965 ha and accretion was 14,545 ha. During this period, erosion along the Ganges River was 30,300 ha while accretion was 29,100 ha. Along the Padma River, erosion was 33,585 ha and accretion was 5,485 ha.

In 2020, 725 ha eroded along the Jamuna, 460 ha along the Ganges and 780 ha along the Padma. Currently, on average, total erosion in Bangladesh is 3,000 ha per year, displacing approximately 25,000 people annually.

Changes in river flow and sediment transport due to the multifaceted impacts of climate change are expected to increase the dynamics of these rivers even more. Due to climate change, erosion might escalate further in the near term as high-intensity rainfall and peak flow in the major rivers will increase and carry more sediment from upstream catchments (CEGIS, 2010).



River Name	Eroded Area (sqkm)
Ganges River	440
Jamuna River	992
Padma River	388
Meghna (Lower) River	1,366

Figure 8: River Bank Erosion (1973-2020) in Bangladesh

2.3.4 Flash floods

Flash floods are caused by heavy or excessive rainfall or upstream flooding in a short period of time. Flash floods are most common from April to July and from September to October (WMO, 2003). The north-eastern areas of Bangladesh are more country. Boro rice is the only major crop in the north eastern areas. Almost 80 per cent of the area is covered by dry season rice from January to May (pre-monsoon), producing 18 percent of Bangladesh's total rice production (BHWDB, 2012). Flash floods suddenly inundate crops near the harvesting time, damage infrastructure and often cause losses of lives and properties. The flash flood event of 2017 was the most devastating early flash flood, disturbing roads and embankments and damaging pre-mature dry season crops worth $1.49 billion, which posed a threat to the overall food security of the country. The flash flood of 2022 severely affected 7.2 million people in nine north-eastern districts, damaging 1,133 sq. km of croplands, 44,254 water ponds and 49,885 sanitation facilities. Livestock losses reached $27.84 million. Around 3,600 schools suspended activities, and 480,000 people were displaced (UN RC Bangladesh, 2022). The Eastern hill regions are also very prone to flash floods. During 1985 to 2015, 12 flash flood events occurred in the region. These events have caused substantial damages to the local population and economy. The torrential rain event of 23rd June 2015 triggered a flash flood that affected approximately 1.8 million people in Chattogram, Bandarban, and Cox's bazar districts (Adnan, 2019). Future climate change will likely increase rainfall in the pre-monsoon and monsoon seasons in the north-eastern areas, resulting in more chances of flash floods.

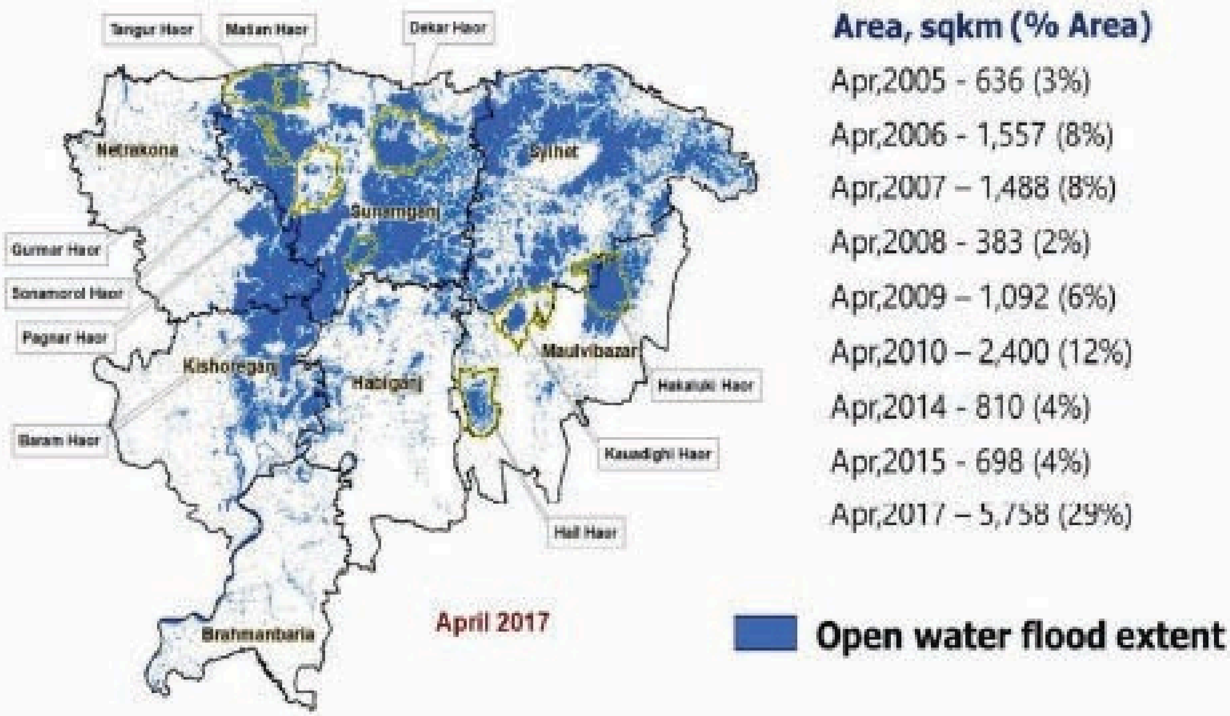


Figure 9: Flash flood-affected areas in north-eastern Bangladesh (Source: CEGIS analysis based on satellite images.)

2.3.5 Urban floods

Urban floods in Bangladesh have recently become an environmental and economic concern. In the last two decades, Bangladesh has experienced several significant urban floods (as elaborated in 2.1.2). In 2004, Dhaka saw record high daily rainfall causing widespread flooding. The event affected more than 80 percent of the city and over 5 million people. Combined with underdeveloped drainage infrastructure and the reduction of water bodies, these short-duration but high-intensity rains exert extreme stress on urban drainage management. With growing urbanization, more cities are prone to urban floods as many are located in low lying floodplains, and rainfall extremes are increasing. Climate change projections indicate an increasing trend of short-term heavy rainfall in urban catchments, which will intensify the risk of urban flooding and waterlogging.

2.3.6 Sea-level rise

Climate change will further aggravate historical sea-level rise and projections for the coastal areas. This will substantially affect coastal communities, infrastructure and livelihoods. Potential coastal inundation estimated by CEGIS (2021) for variable sea-level rise, incorporating the existing coastal polder set-up, shows that by the mid-term, around 18 percent of the coastal area might be inundated due to sea-level rise projections, based on the SSP5-8.5 scenario. The inundated areas are mostly behind the coastal polders in the south-central region and are low-lying. Some existing polders have flooded due to lower polder height caused by previous damage. In case of a breach or damage to the polder, which was not considered in the simulation, the inundated area will be much greater. This will impact the coastal population and livelihoods, exacerbate salinity intrusion, and damage crops and fisheries.

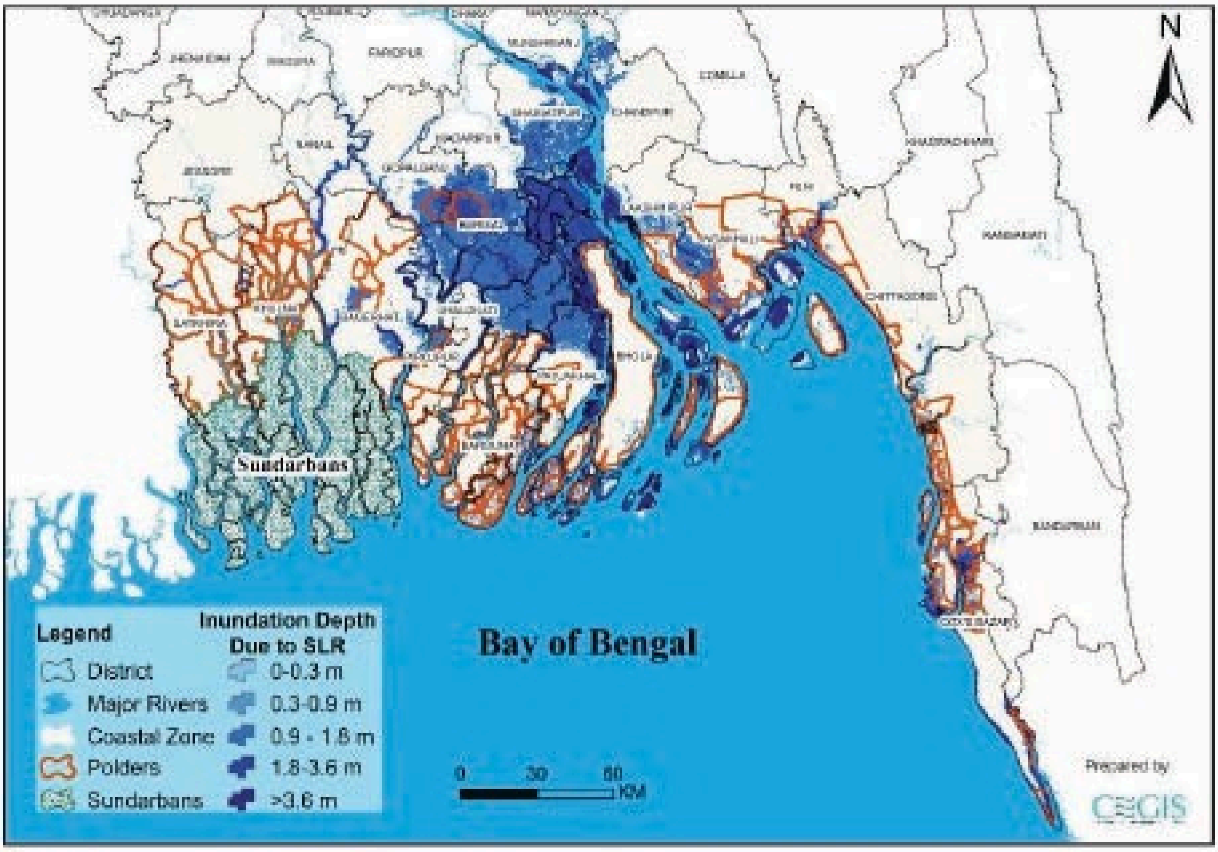


Figure 10: Potential inundation due to sea-level rise and cyclone storm surges in the coastal areas by the 2050s [26]

(Source: CEGIS Bay of Bengal Model, 2021)

2.3.7 Cyclone, tornado and storm surges

Twenty-one severe cyclones (winds between 87 to 117 km/hour) and severe cyclonic storm with hurricane intensity (winds >117 km/hour) struck the Bangladesh coast between 1960 and 2010 (MoEFCC, 2018b). Among them, 33 percent happened pre-monsoon and 67 percent post monsoon. In the three decades since 1990, Bangladesh has experienced category four cyclones with wind speeds of 209-251 km per hour.

Besides cyclones, Southern and central Bangladesh is very prone to tornados. Tornados in Bangladesh generally form during April and cause damage to lives and properties (Finch and Dewan, 2003). In 25 Mar 2013, a deadly tornado happened in Brahmanbaria, causing death of 31 persons and injury of 388 persons (DMIC, 2013).

Storm surge is a common phenomenon during and after a cyclone. The surges have devastating impacts on the local population and resources. Combined with sea-level rise, this will cause more devastation in low-lying coastal areas (DoE, 2020).

Numerous catastrophic cyclone events have taken place, especially in the last two decades. In 2020, Cyclone Amphan affected more than a million people in 26 districts and caused 26 deaths. It damaged 55,667 houses, 149,000 ha of agricultural lands, 1,80,500 hatcheries, 150 km of embankments, 200 bridges and culverts, and 100 km of roads, causing a total loss of BDT 11 billion (IFRC, 2021). Future 50 cm sea-level rise combined with a SIDR equivalent cyclonic storm surge could potentially inundate large parts (11%-12%) of the coastal area of Bangladesh (DoE, 2020).

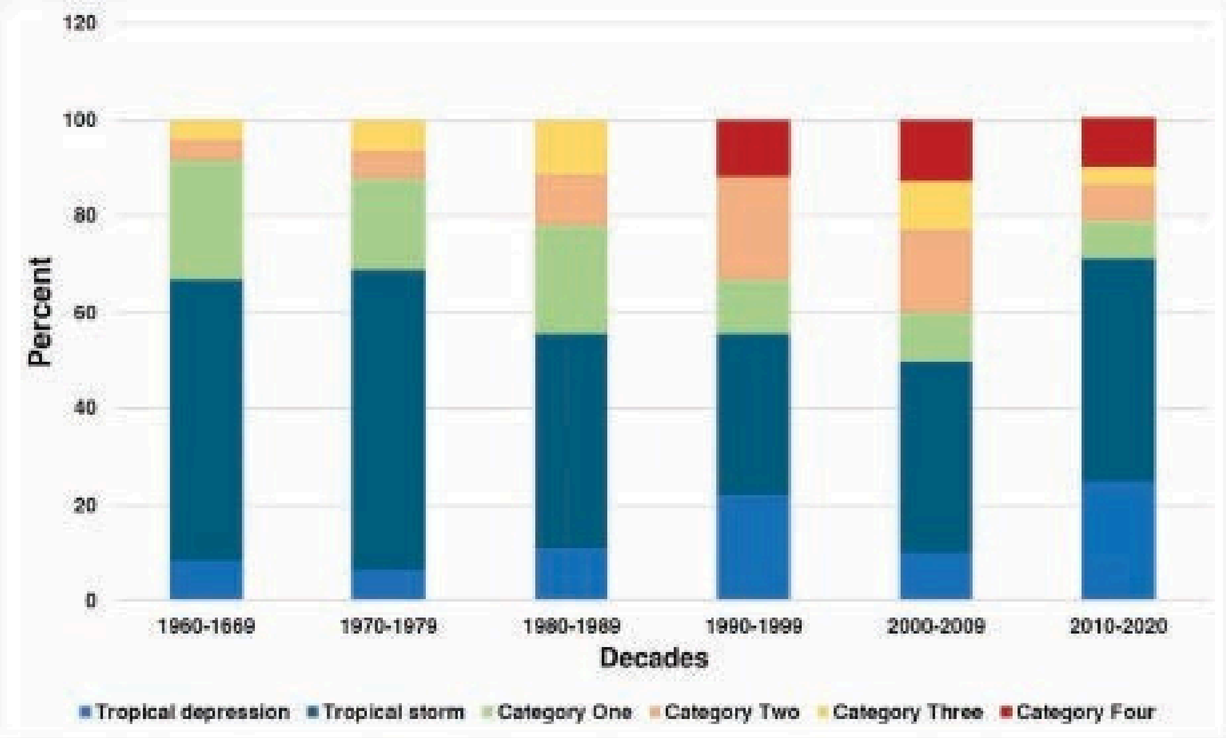


Figure 11: Distribution of different categories of cyclones, 1960-2020

(Source: CEGIS analysis based on BMD data)

2.3.8 Salinity

The coastal zone of Bangladesh covers about 20 percent of the country and more than 30 percent of cultivable land. The salinity level (surface water, ground water or soil) generally increases almost linearly from October to late May with the gradual reduction of upstream freshwater flows. Historic salinity data illustrate an increase of salinity in Khulna from 0.7 ppt to 16.8 ppt in the Rupsa River from 1962 to 2011. Low salinity (0-2 ppt) in the south-central zone, i.e., in much of the Barisal area for the whole year, results from the significant volume of freshwater flow from the Padma River and the Lower Meghna River. Salinity intrusion in the south-west region reduces the freshwater supported area, resulting in decreased agricultural production in many parts of the coastal zone, especially the Khulna and Patuakhali regions and small areas in Noakhali and Chattogram. Climate change-induced sea-level rise will significantly increase river salinity during the dry season which is further aggravated due to less water availability in the major rivers. Of 2.86 million ha of coastal and offshore lands, about 1.056 million ha are affected by different degrees of soil salinity. From 1973 to 2009, land affected by salinity in Bangladesh grew by about 26.7 percent, amounting to approximately 0.223 million hectares. Salinity increased in around 35,440 hectares of new land between 2000 and 2009 alone (SRDI, 2010). Future sea-level rise will push salinity further inwards in the near and mid-term (CEGIS, 2021). The 1 ppt salinity-affected areas will increase by 7.5 percent in the 2050s while the 5 ppt areas will increase by 9 percent under SSP5-8.5. The situation will be worse on the western coast.

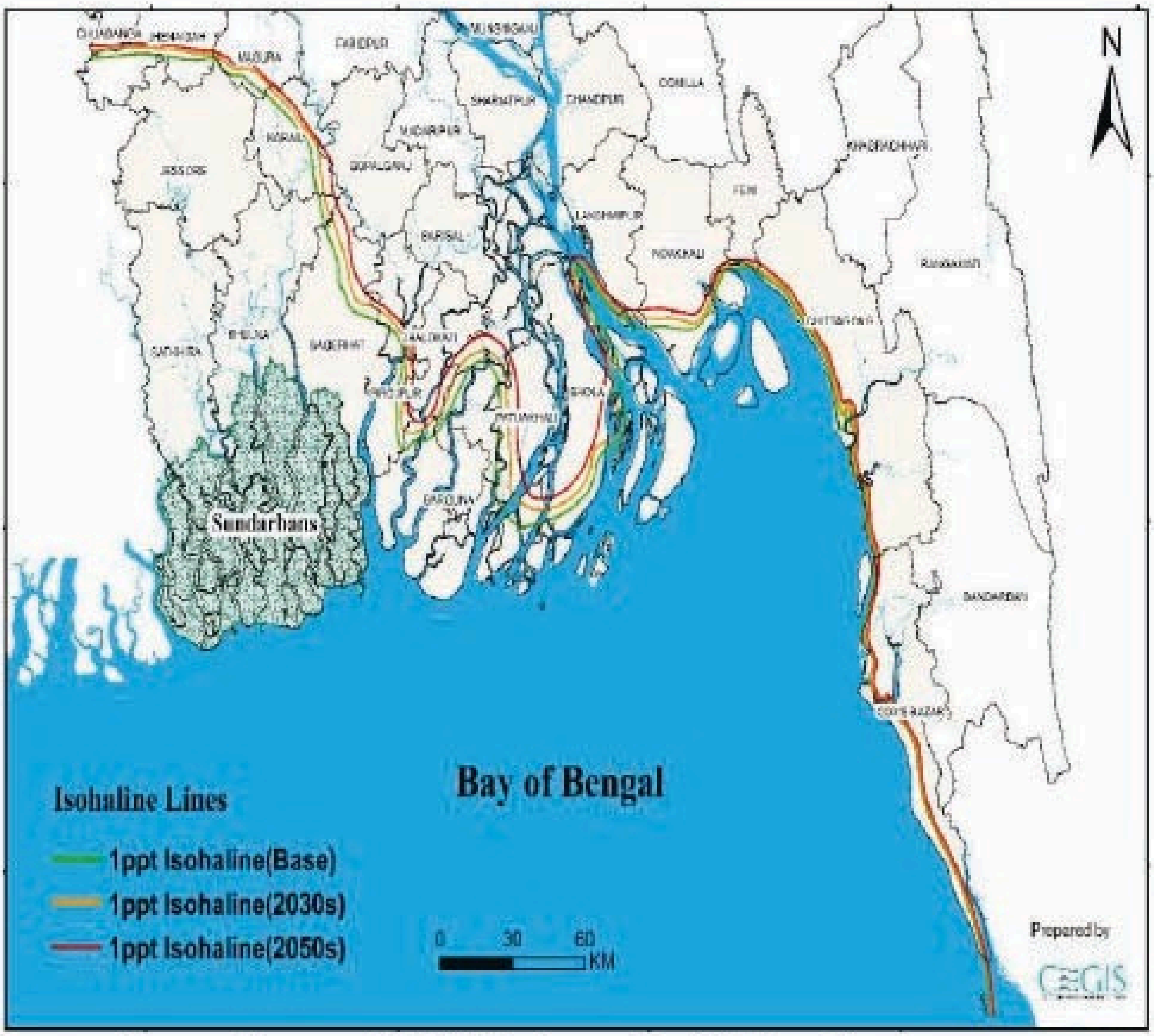


Figure 12: Surface water salinity distribution in coastal Bangladesh due to climate change

(Source: CEGIS Bay of Bengal Model)

2.3.9 Extreme heat waves

The seasonal trends in surface urban heat island intensity (SUHII) (◦C per year) from 2003 to 2019 in major Bangladesh cities exhibit significant increases during the pre-monsoon and winter seasons in most cities. Winter nights show a strongly increasing trend in central (Dhaka) and western cities. There is a significantly decreasing trend in north-east (Sylhet) and south-west (Khulna) cities.

Other urban areas of Bangladesh will face similar impacts in the future due to climate change extremes. Trends in land surface temperatures in recent years in Dhaka reinforce already evident surface heating over past decades. A similar situation is visible in other major urban concentrations in Bangladesh.

Extreme heat events impact people and animals in various ways. The productivity of labourers declines, disease outbreaks occur and heatstroke increases. Cattle, poultry and fish suffer heavily from extreme heat and their mortality increases. Crop production is very susceptible to extreme heat. As plants maintain all physiological processes wit hin t emp era tur e thr esh old s, s udd en temperature changes hamper important activities like flowering, germination, etc.

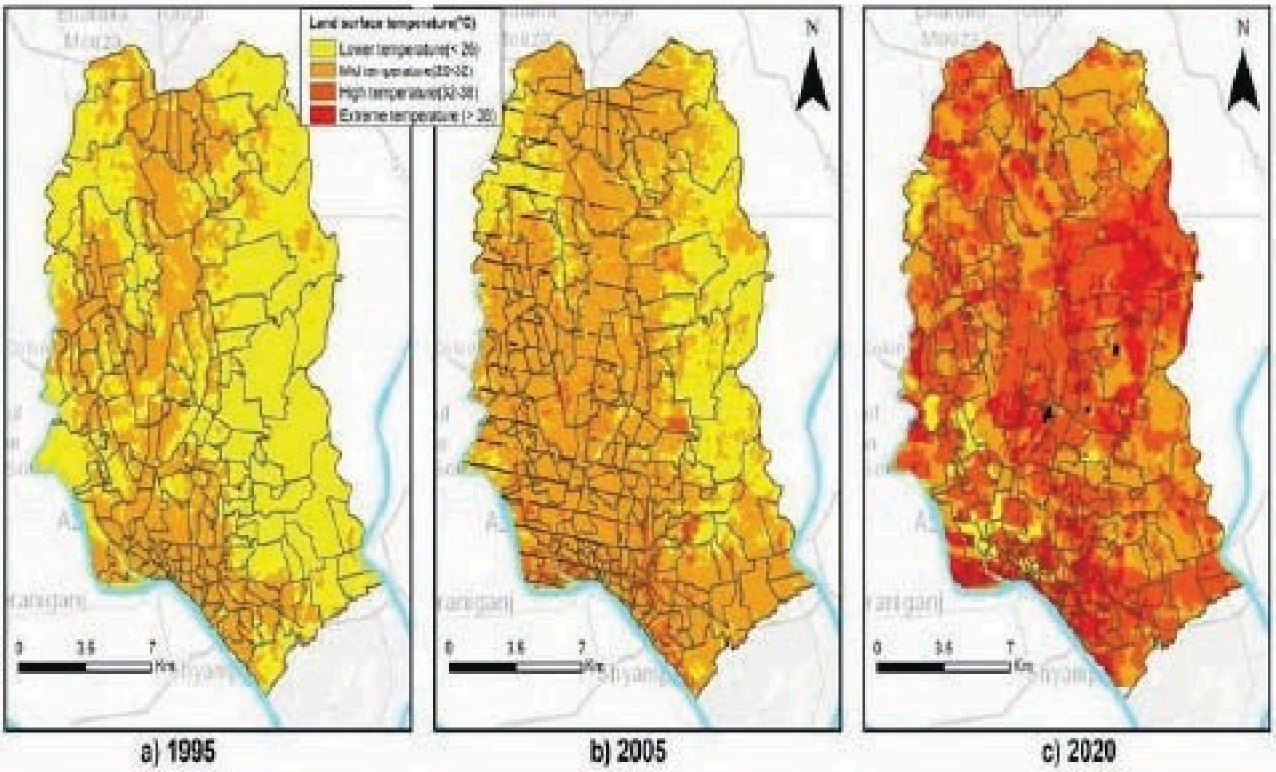


Figure 13: Land surface temperature changes in Dhaka

(Source: CEGIS analysis based on satellite imagery)

2.3.10 Extreme cold

Extreme cold is expressed as the days with temperatures below 10°C. During the winter, northern Bangladesh experiences cold waves regularly. Extreme cold occurred in 2001, 2003, 2011, 2013, 2017 and 2018, with extreme temperatures below 6°C in 2003, 2013 and 2018. The annual frequency of days with a minimum temperature of less than 10°C is increasing (0.035 more days per year) in Rajshahi and decreasing in Rangpur (0.123 fewer days per year) and Dinajpur (0.119 fewer days per year) (Karmakar, 2019). Such extreme weather events often have severe impacts, hindering the livelihoods of the most vulnerable people. For example, fog and winter rain can reduce cash crop yields and thus income. Cold waves can also have significant health impacts, contributing to acute respiratory infections (ARI), fever, pneumonia, asthma, coughs and skin diseases, especially among the elderly and children. Overall, future climate change is expected to increase the impact of extreme cold in Bangladesh.

2.3.11 Landslides

Since 1990, Bangladesh has experienced more than 30 landslide events in the hilly regions, with a death toll of approximately 200 people and massive economic and property losses. The causes of landslides are topography, weakening slopes through saturation by water, steeper slopes due to erosion, soil properties (sandy soil), torrential rain and high-velocity surface run-off. According to the geological timescale, the hilly area of Bangladesh developed in the tertiary age and is mainly composed of unconsolidated sedimentary rocks such as sandstone, siltstone, shale and conglomerate (Rashid, 1991). The areas are underlain by tertiary and quaternary sediments that have been folded, faulted and uplifted, and then deeply dissected by rivers and streams (Brammer, 1996). Future climate change is expected to increase the monsoon and post-monsoon rainfall in the hilly regions by 5-10 percent. This might further aggravate the landslide risk for vulnerable areas.

2.3.12 Sea surface temperature (SST) and ocean acidification

The historical record of SST in the Bay of Bengal demonstrates an increasing trend. The region near the Bangladesh coast shows a rising trend of 0.01°C and 0.058°C per year during the pre-monsoon and monsoon, respectively, while decreasing at a rate of 0.004°C and 0.021°C per year during the winter and post-monsoon, respectively (Sridevi and Sarma, 2021). Sea surface temperatures in the future are expected to increase by 0.6°C in the near term and 1°C to 1.4°C in the mid-term in the Bay of Bengal. The pH level trend mostly decreases at a rate between 0.0002 0.0025 per year during most seasons (Sridevi and Sarma, 2021). Only the monsoon pH rises at a rate of 0.0014 per year.

Increasing SST and acidity have harmful consequences, such as depressing metabolic rates in jumbo squid, depressing the immune responses of blue mussels and coral bleaching. This will impact the sea ecosystem and create low oxygen conditions for fish species. Along with future climate change-induced rises in sea surface temperature, ocean acidification will likely intensify in the Bay of Bengal.

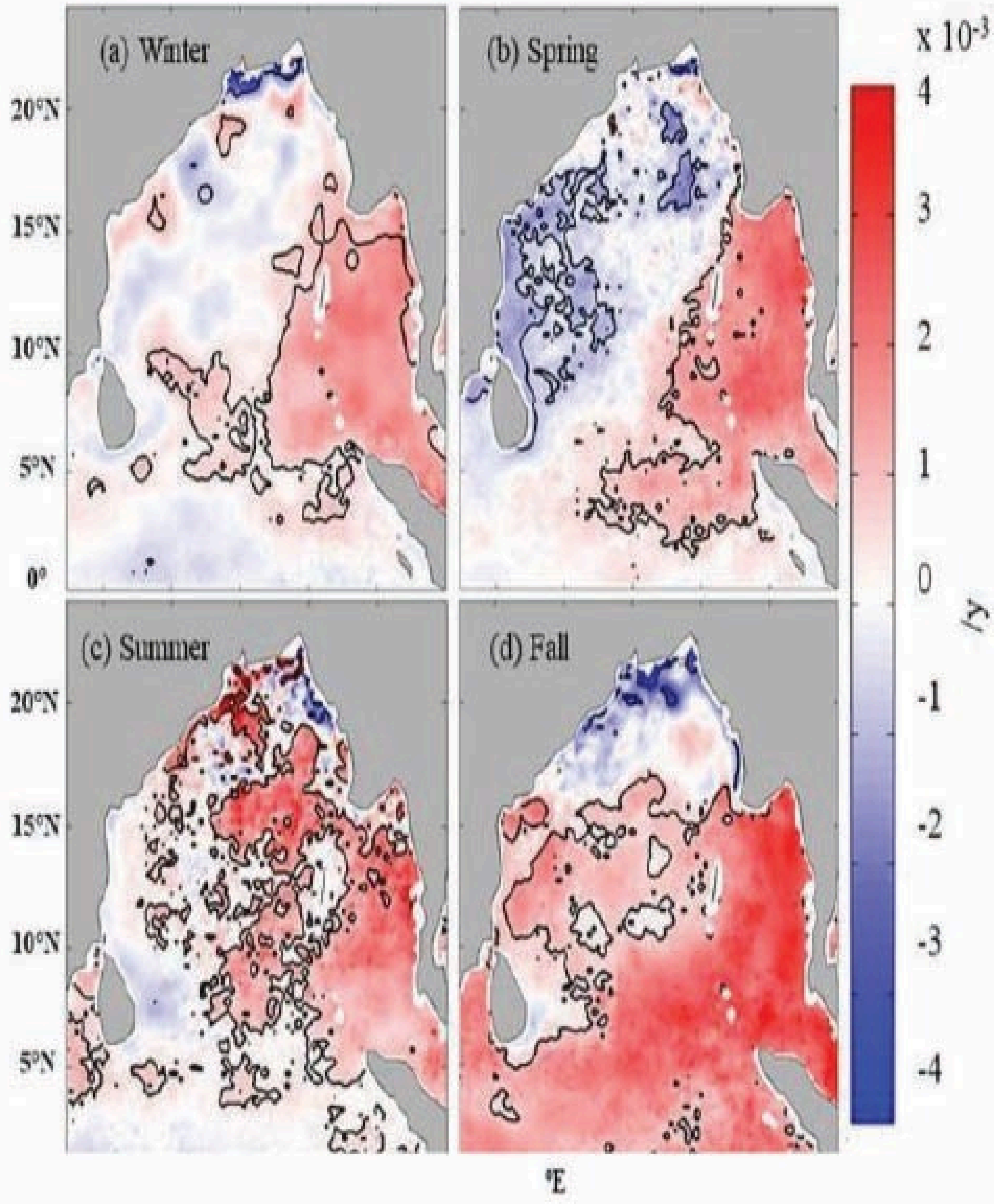


Figure 14: Trends in the seasonal mean rate of pH (in 10-3) in the Bay of Bengal

Source: Sridevi and Sarma, 2021

2.4 Future Climate Risks and Vulnerabilities

2.4.1 Climate stress areas

A Climate stress areas multi-hazards risk map for Bangladesh illustrates the spatial distribution across the country (CEGIS, 2021). The risk map includes all described hazards and segregates the country into 11 climate stress areas defined as follows:

Table 1: Climate stress area coverage and related hazards

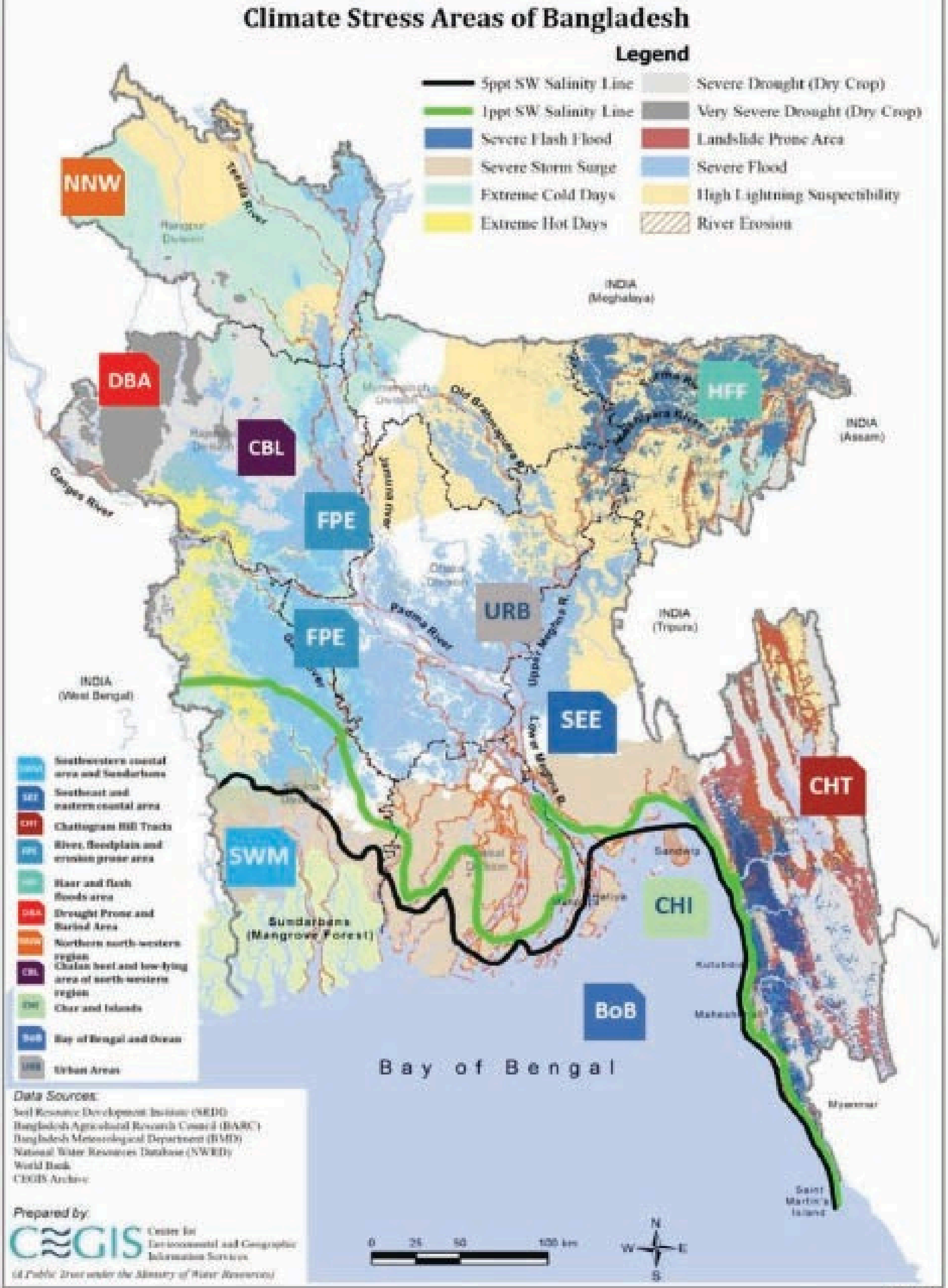
Climate stress area	Districts	Area (sq. km)	Vulnerable population, 2020 (millions)	Prominence of climate hazards
South-western coastal area and Sundarbans (SWM)	Satkhira, Khulna, Bagherhat, Pirojpur, Barguna, Barisal, Patuakhali, Jhalokhathi, Bhola, Shariatpur, Gopalganj, Jashore, Sundarbans	30,646	13.57	Rainfall variability, river floods, sea level rise, salinity, tropical cyclone, storm surges, drought, extreme heat waves, extreme cold, riverbank erosion and lightning
South-east and eastern coastal area (SEE)	Noakhali, Feni, Lakshmipur, Chattogram, Cox's Bazar, Chandpur	13,891	10.93	Rainfall variability, river floods, sea level rise, salinity, tropical cyclone, storm surges, drought, extreme heat waves, extreme cold, riverbank erosion, lightning and landslides
Chattogram Hill Tracts (CHT)	Rangamati, Khagrachari, Bandarban	13,294	1.33	Rainfall variability, flash floods, tropical cyclone, storm surges, drought, extreme heat waves, extreme cold, lightning and landslides

Climate stress area	Districts	Area (sq. km)	Vulnerable population, 2020 (millions)	Prominence of climate hazards
Rivers, floodplains, and erosion prone areas (FPE)	Nilphamari, Kurigram, Lalmonirhat, Gaibandha, Rangpur, Bogura, Sirajganj, Pabna, Rajshahi, Jamalpur, Tangail, Manikganj, Dhaka, Munshiganj, Mymensingh, Sunamganj, Netrokona, Habiganj, Kishorganj, Sylhet, Brahmanbaria, Narsingdi, Narayanganj, Rajbari, Faridpur, Madaripur, Gopalganj, Narail, Sariatpur, Barisal, Patuakhali, Bhola, Jhalokathi, Khulna, Chandpur, Cumilla, Noakhali, Lakshmipur, Cox's Bazar	58,010	12.72	Rainfall variability, river floods, tropical cyclones, tornado, extreme heat waves, extreme cold, riverbank erosion and lightning
Haor and flash floods areas (HFF)	Sunamganj, Netrokona, Habiganj, Kishorganj, Sylhet, Maulvibazar, Brahmanbaria	19,662	4.02	Rainfall variability, flash floods, tropical cyclone, tornado, extreme heat waves, intense cold, riverbank erosion, lightning and landslides
Drought-prone and *barind* areas (DBA)	Naogaon, Chapai Nawabganj, Rajshahi, Bogura, Joypurhat, Rangpur, Dinajpur, Meherpur, Chudanga, Kushtia, Jashore, Magura, Jhenaidah	21,512	3.85	Rainfall variability, tropical cyclone, tornado drought, extreme heat waves, extreme cold and lightning
Northern, north-western region (NNW)	Panchagarh, Thakurgaon, Nilphamari, Lalmonirhat, Rangpur, Kurigram, Dinajpur	9,917	6.32	Rainfall variability, river floods, flash floods, tropical cyclone, tornado, drought, extreme heat waves, extreme cold, riverbank erosion, lightning and landslides
Chalan beel and low-lying area of the north-	Pabna, Natore, Sirajganj, Rajshahi, Naogaon	5,027	5.70	Rainfall variability, river floods, tropical cyclone, tornado,, extreme heat waves, extreme cold,

Climate stress area	Districts	Area (sq. km)	Vulnerable population, 2020 (millions)	Prominence of climate hazards
western region (CBL)				riverbank erosion and lightning
Char and islands (CHI)	Nilphamari, Lalmonirhat, Kurigram, Gaibandha, Sirajganj, Jamalpur, Mymensingh, Manikganj, Munshiganj, Shariatpur, Chandpur, Bhola, Patuakhali, Feni, Noakhali, Lakshmipur, Chattogram, Cox's Bazar	3,976	8.51	Rainfall variability, river floods, sea-level rise, salinity, tropical cyclone, tornado, storm surges, extreme heat waves, extreme cold, river bank erosion, lightning, higher sea surface temperature and ocean acidification
Bay of Bengal and ocean (BoB)	Bay of Bengal (maritime boundary)	118,813	1.26	Rainfall variability, sea-level rise, tropical cyclone, tornado, storm surges, extreme heat waves, lightning, higher sea surface temperature, hypoxy and ocean acidification
Urban areas (URB)	43 cities	10,600	32.41	Rainfall variability, urban floods, sea level rise, salinity, tropical cyclone, storm surges, drought, extreme urban heat waves, extreme cold and lightning

* The area and population are tentative estimates based on hazard information, climate stress areas and BBS data (BBS, 2022b).

**Appendix I presents the alignment of climate stress areas with BDP2100 hotspot areas and hydrologic regions.



May 2022

Figure 15: 15a Climate Stress Areas of Bangladesh

The above map and table describe the geographic coverage of the hazards and potentially vulnerable populations across the climate stress areas. Most areas face five or more disasters. With all disasters intensifying or becoming more frequent due to climate change, the climate stress areas face larger risks in the future.

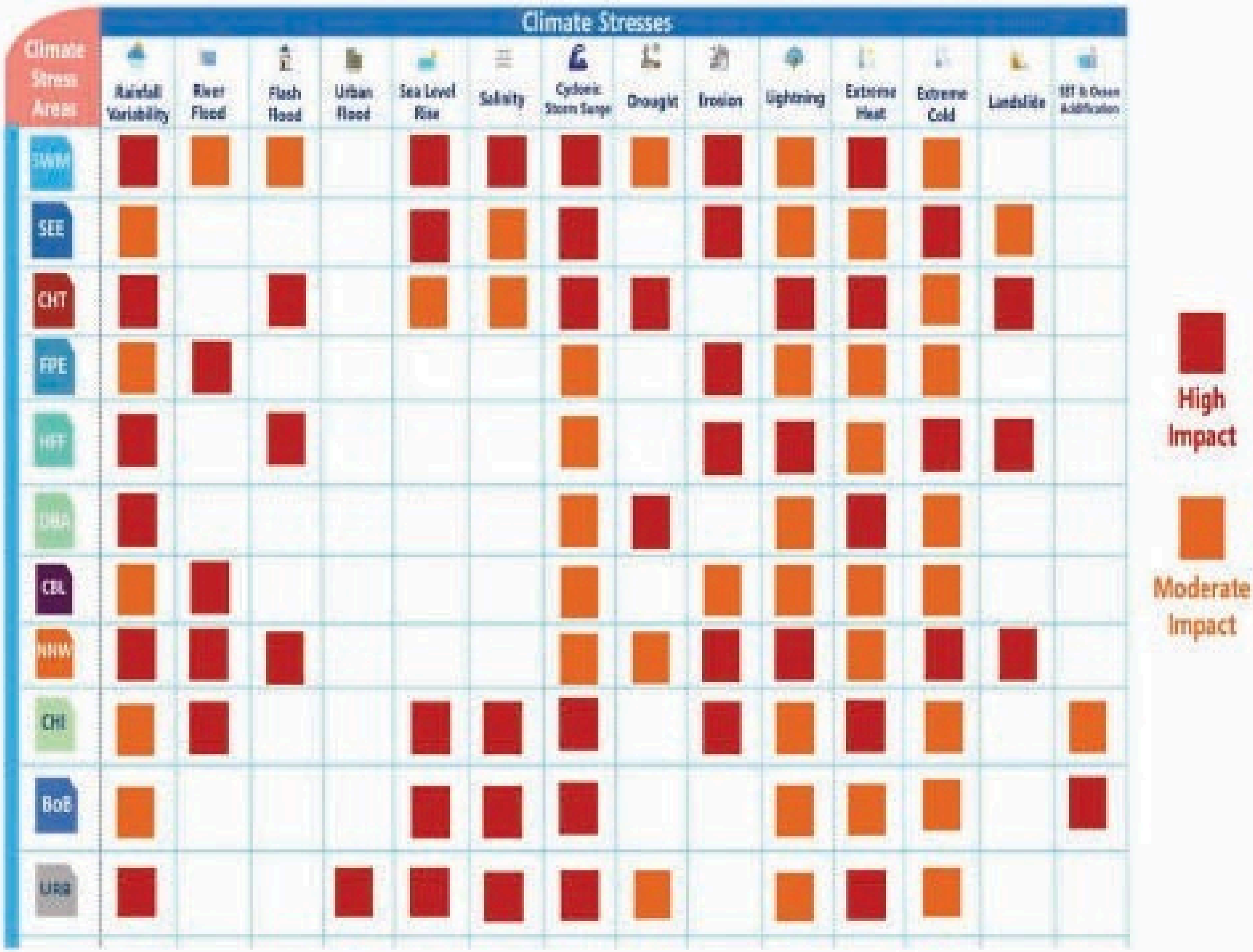


Figure 16: 15b Climate Stress Areas of Bangladesh

2.4.2 Risks and vulnerabilities of Water resources sector

Climate change impacts in Bangladesh mainly affect climatic patterns and disasters. These ultimately increase vulnerabilities and risks in major sectors like water resources, crop production, fisheries and aquaculture, livestock, ecosystems, biodiversity, etc. The NAP has identified the risks and vulnerabilities of major resources through the stocktaking and consultation process, which involved local sessions with different vulnerable communities dependent on various sectors. This information was combined with future climate change-induced vulnerability and risk information to summarize the potential risk levels of major sectors under different climate change scenarios. Tables 2.2-2.8 present the risk levels under two future climate scenarios (SSP 1-2.6 and SSP 5-8.5), expressed as low (+), medium (++) and high (+++). The estimation entailed aggregating all stakeholder consultation outcomes and finalizing them based on expert knowledge of risk. As the design of bridges are closely related to water resources The following section briefly discusses the Water resources sector-specific vulnerabilities and risks for different regions of Bangladesh.

Water resources

Being a lower riparian country, Bangladesh largely depends on freshwater availability from the country's transboundary rivers. Recent research on global freshwater storage depicts the area in and around Bangladesh as having a water deficit (Rodell et al., 2018). It is characterized by water depletion and less water reaching the groundwater layer.

Due to climate change, the average annual flow of the Ganges, Brahmaputra and Meghna River basins will increase, resulting in more frequent river floods. Additionally, flash floods might occur early and become more frequent, droughts during the dry season might become more severe and water scarcity will be aggravated. Due to sea-level rise and increased salinity, more coastal areas will face freshwater shortages and damage to agriculture, while extreme heat might cause a reduction in water bodies. The potential impacts and risks for water resources are presented in the following table for the two scenarios.

Table 2 : Potential impacts and risks for water resources

Climate signals and hazards	Potential impacts	Risk level	
		SSP1-2.6	SSP5-8.5
Excessive rainfall	• Waterlogging and drainage problems • Frequent erosion	++	+++
Extreme heat	• Decreases in perennial water bodies and wetlands	+	++
Frequent river floods	• Sediment problems • Prolonged waterlogging	+	+++
Early or frequent flash floods	• Drainage problems in drainage structures • Sediment problems • Navigation problems • Water management infrastructure becomes dysfunctional/damaged • Submersible embankment breaches	++	+++
Severe drought/water scarcity	• Lower water availability • Hampered water security • Dependency on groundwater increases and groundwater depletion	++	++
Increased salinity	• Less freshwater availability • Unfavorable water quality	+	++
Frequent tropical cyclones/ tornado and storm surges	• Polder or coastal embankment breaches • Water quality deteriorates • Salt water ingress	++	+++
Sea-level rise	• Salinity increases • Inundated land area increases with potential land loss	+	++

*Risk level: low (+), medium (++) and high (+++).

2.4.3 Risks and vulnerabilities in stress areas

South-western coastal area and the Sundarbans (SWM)

The southwestern coastal area and Sundarbans have an area of 30,646 sq. km and 13.57 million vulnerable people. The Sundarbans is the largest mangrove forest in Bangladesh. The area faces most climate-related hazards, as summarized in Table 2.1. A large percentage of households have experienced damage due to cyclones (53.3 percent), salinity (6.53 percent) and lightning (7.5 percent) in recent years (BBS, 2022a). Average damages and losses from disasters totaled BDT 30.2 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a). Future climate change will intensify these stresses. While the Sundarbans is an essential part of the natural ecosystem and biodiversity of Bangladesh, it is now under threat due to sea-level rise.

South-east and eastern coastal area (SEE)

The south-east and eastern coastal area (SEE) has an area of 13,891 sq. km and 10.93 million 42 vulnerable people. The region faces hazards similar to those in the south western coast. It includes the major industrial areas, ports and some forests. A large percentage of households have faced damages due to cyclones (29 percent), salinity (2.5 percent) and lightning (7.2 percent) in recent years (BBS, 2022a). Average losses and damages due to disasters were BDT 17.2 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a). Future climate change will intensify these stresses.

Chattogram Hill Tracts (CHT)

The Chattogram Hill Tracts (CHTs) region in the eastern hills area is a distinct part of Bangladesh with topographically different settings. It is inhabited by ethnic communities. The region has an area of 13,294 sq. km (about 10 percent of the country), with elevations ranging from 60 m to more than 1,000 m. A large part of the region is forest with a unique ecosystem. The region is underdeveloped and harder to reach than other areas, and the local population (around 1.9 million) mainly depends on hill resources and agriculture for livelihoods. As a result, people are highly vulnerable to climate change impacts and associated disasters. Households have faced damages due to landslides (2.4 percent), droughts (3 percent), and lightning (7.2 percent) in recent years (BBS, 2022a). Average losses and damages due to disasters were BDT 11.5 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a). Future climate change is expected to reduce pre-monsoon rainfall in the region and raise the annual average temperature by 1.3 to 2°C. The rise in temperature will be more for daily maximum temperature.

For ethnic communities, climate change is not simply a physical environmental change. It is also a threat to livelihoods and resources, and to their social life, traditional knowledge and culture. Climate change will continue to cause substantial damage to the CHT region by increased drought, water scarcity, landslides, desertification, flash floods, soil erosion and health issues due to water pollution. These will negatively affect the population, their hill and spring watershed dependent livelihoods and their unique ecosystems.

River, floodplain and erosion-prone area (FPE)

A large part of Bangladesh (58,010 sq. km) falls in the river, floodplain and erosion-prone area, which spreads across different regions. With the Bangladesh delta formed due to sediment deposits from three major rivers and their tributaries, this area is most fertile for agriculture but experiences floods, erosion and related hazards. It is home to about 12.72 million vulnerable people. They have faced damages due to floods (50 percent), droughts (3 percent), and lightning (5-9 percent) in recent years (BBS, 2022a). Average losses and damages due to disasters were more than BDT 100 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a). Managing water resources and associated hazards are major tasks to reduce vulnerability in this area.

Haor and flash floods area (HFF)

The north-eastern haor area has unique geographic features and is home to various ecosystems, flora and fauna. This area covers 19,662 sq. km with a vulnerable population of 4 million. Households have faced significant damage due to flash floods (56.5 percent), lightning (14.8 percent), droughts (7.2 percent) and landslides (0.2 percent) in recent years (BBS, 2022a). Average losses and damages due to disasters were BDT 26.8 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a).

Drought-prone and Barind area (DBA)

The north-western barind area is in the highlands with soils that have low moisture-holding capacity. The area experiences higher temperatures and low rainfall. It covers 21,512 sq. km. with a vulnerable population of 3.85 million. It is highly productive for various crops, including rice. The population faces damages due to droughts, floods, lightning and extreme heat. Average losses and damages due to disasters were BDT 1.7 billion during 2016 2021, mainly driven by climatic stresses (BBS, 2022a).

Northern and north-western region (NNW)

The northern and north-western region spans 9,917 sq. km with a vulnerable population of 6.32 million. It faces damages due to floods and flash floods (52 percent), droughts (1.7 percent), lightning (9.3 percent) and extreme heat and cold waves. Average losses and damages due to disasters were BDT 33.3 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a).

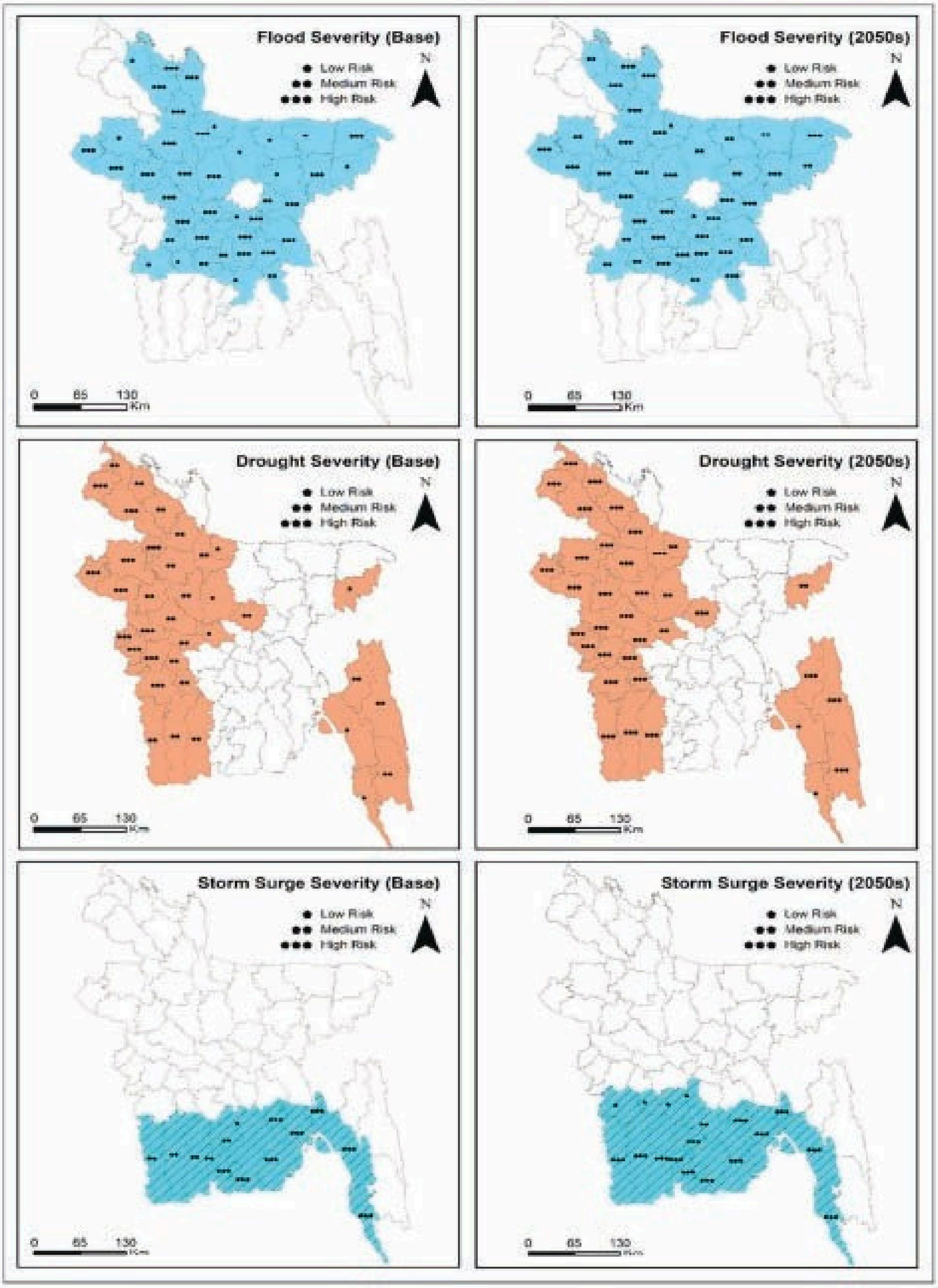


Figure 17: Flood, drought and storm surge severity in Bangladesh due to climate change

Source: CEGIS, 2021

Chalan Beel and the low-lying area of the north western region (CBL)

The chalan Beel and low-lying north-western area cover 5,027 sq. km. This area is very low-lying and faces damages due to floods and flash floods (34 percent), droughts (3 percent), lightning (17 percent) and extreme heat and cold waves. The area has a vulnerable population of 5.7 million. Average losses and damages due to disasters were BDT 16.7 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a). Char and islands area(CHI) - The char and islands area cover different parts of the country totaling a significant 3,976 sq. km. As major rivers intersect, they host large chars or islands that are continuously flooded and eroded each year. About 8.51 million vulnerable people experience these hazards, forcing them to live in a loop of poverty. Agriculture and livestock rearing are major livelihood activities in the chars and islands. The coastal islands confront almost all climate-induced disasters common to sea-facing locations.

Bay of Bengal (BoB)

The Bay of Bengal is part of the Indian Ocean, covering a large area. Bangladesh's extended economic zone is 118,813 sq. km. It is used for fishing and other economic activities by 1.26 million vulnerable coastal residents. An expansion in economic activities through blue economy initiatives is occurring as the ocean faces increasing SST and gradual acidification. This primarily damages the sea ecosystem and fish species and will affect coastal people.

Urban areas (URB)

The urban areas include 43 cities, with 2 (Dhaka and Chattogram) holding more than 1 million people, 6 (Rajshahi, Sylhet, Khulna, Gazipur, Narayanganj and Bogura) with between 0.5 million and 1 million people, 10 (Savar, Mymensingh, Barisal, Rangpur, Cumilla, Kushtia, Jashore, Cox's Bazar, Feni and Manikganj) with between 200,000 and 500,000 people, and 25 that comprise mostly the greater districts, district towns and *upazilla*level towns (such as Chowmuhuni, Bhairab, Sreepur, Saidpur, etc.) with between 100,000 to 200,000 people. The estimated total population of urban areas is 61.8 million.

Climate change and associated urban risks substantially impact the overall economy. Major cities are at high risk of urban flooding due to changing rainfall patterns and have reported recurrent urban drainage problems (CEGIS 2022a). Different city corporations and municipalities have also experienced these issues in unplanned urban developments that are intended to meet increased population demand but often take place without ensuring adequate drainage capacity.

Heat waves will affect human health adversely. As human bodies are not habituated to adjust to a sudden temperature rise, more heatstroke will occur. Vector-borne diseases will spread as well. Adverse impacts of climate change in rural areas may increase internal migration to urban areas. People migrating into urban areas as a result of climate induced disasters are the most vulnerable in the society. Table 2.7 summarizes potential impacts and associated risks in urban areas.

2.4.4 Actions and Achievements towards Climate Resilience

Actions - Bangladesh is considered one of the most climate vulnerable countries due to ensuing natural calamities and slow onset adversities. Despite seemingly insurmountable afflictions, Bangladesh has steadily progressed in making a mark on the global economy and pioneering efforts to address climate fallout through effective adaptation strategies. A rapidly escalating development trajectory in the last three decades has seen economic growth resulting Per capita income increased to $2,824 in 2021-2022 from $300 in 1973. Rice production grew from 12 million tons in 1973 to 37 million tons in 2021, fisheries has ranked third in open water capture production, and additional livestock production generated nearly 30 percent of employment. Consequently, food security has been ensured & livelihood security enhanced.

Such remarkable advances have been possible through prudentially management of climate change impacts and subsequent losses and damages under a strong legacy of adaptation. Bangladesh has been striving towards achieving climate resilience, mandated by the Constitution in its 15th amendment, Article 18A on the protection and improvement of the environment and biodiversity. The Government of Bangladesh presently spends approximately 6-7 percent of its annual budget on enhancing climate resilience through adaptation initiatives (MoF, 2021), among which seventy-five percent cost comes from domestic resources; despite the fact that Bangladesh contributes very little to rising global emissions.

Already a pioneer in the global arena, climate change adaptation got its first break in Bangladesh through formulation of the NAPA in 2005. The updated NAPA in 2009 and the subsequent formulation of the BCCSAP (also in 2009) further streamlined and reinforced climate adaptation efforts in the succeeding decade. The National Environment Policy was updated in 2018 with specific directives on climate change preparedness in its Section 3.19. Towards addressing long-term climate change uncertainties for water resources management and developing a more prosperous nation, Bangladesh recently formulated a strategic Delta Plan 2100. The Climate Prosperity Plan 2030 (CPP, 2021) has been drafted with Bangladesh as chair, for Climate Vulnerable Forum (CVF) countries. Also, policy initiatives such as the Climate Fiscal Framework (2014); National Disaster Management Plan (2021-2025); updated Standing Order on Disaster (2019) etc. highlights the strength of Bangladesh currently possesses in dealing with climate adversities.

However, the changing climate regime and the unique geographical setting is exerting considerable stress on Bangladesh's economy and the advancement towards sustainable development. Bangladesh suffered approximately $11.3 billion in losses in 2021 due to climate related natural disasters (WMO, 2021a) which is roughly 2.47 percent of total GDP of FY2021-2022. According to the 2021 global Climate Risk Index, Bangladesh ranks 7 in the top 10 most affected countries (2000-2019). Constantly aggravating climate-induced disasters, coastal tropical cyclones, monsoon flooding, flash floods, droughts, sea level rise, salinity intrusion, urban floods, etc., are causing catastrophic losses to many socio-economic sectors.

Despite the relentless efforts for climate adaptation, future is projected to be far more extreme and uncertain by the IPCC in its Sixth Assessment Report. The Bangladesh Delta Plan

(GED, 2018a) projects that the combined effects of climate change could range from a loss of 1.1 percent of GDP per year in a moderate climate change to 2 percent per year in extreme climate conditions. The BDP2100 also indicates the possible impact on overall rice production, predicting a declining rate of 17 percent by 2050, which would impede food and nutrition security. Tackling such unprecedented repercussions would bring unimaginable hardship for the country and serious threats to its development aspirations. Redemption can only be ensured through swift and effective climate adaptation practices, backed by promised enhanced climate finance mobilization from developed countries.

Effective medium- and long-term adaptation strategies are crucial to reducing negative climate impacts and providing a viable path towards resiliency. Planning for a future development trajectory necessitates addressing medium- and long-term climate simultaneous adversities and their mainstreaming into national planning. The current drive towards planning and implementation is thus more focused on medium- and long-term climate change adaptation along with concrete strategies for governance and climate financing.

Addressing medium- and long-term climate change impacts further requires a coordinated strategy document for implementing climate change adaptation. This would ensure collaborative efforts to reduce climate risks and vulnerabilities, increase resilience and minimize maladaptation, while paying heed to both soft and hard adaptation limits. This would increase capacity and resilience, bring about transformation and system transitions, take measures to uphold sustainable human and ecosystem health and gender-inclusive socio-economic well-being, and reduce losses and damages.

Achievements

As a global pioneer in climate adaptation, Bangladesh has advanced substantially in building adaptive capacity and resilience for coping with various climate change impacts across sectors and levels. Ministry of Environment, Forest and Climate Change (MoEFCC), Ministry of Disaster Management and Relief (MoDMR), Ministry of Agriculture (MoA), Ministry of Fisheries and Livestock (MoFL), Ministry of Water Resources (MoWR), Ministry of Local Government, Rural Development and Cooperatives (MoLGRDC), Ministry of Food (MoF) along with other relevant ministries/divisions and respective agencies, are working hard to make the country climate resilient. Over the last seven years, the climate relevant budgetary allocation has doubled, increasing from $1.44 billion in FY2015-2016 to $2.96 billion in FY2021-2022, which is 0.73 percent of GDP for FY2021-2022 (MoF, 2021). Some landmark initiatives and success stories are as follows:

Policy Response at National Level

Bangladesh has made commendable efforts in creating required policies and regulatory frameworks for enabling climate resilient sustainable development. The Parliamentary Standing Committee on MoEFCC is actively involved in accelerating adaptation and mitigation processes', mandated by separate resolution; joining the global declaration on 'Planetary Emergency' to counter climate adversities. Over the years, the Government has formulated policies, plans and programme including the National Adaptation Programme of Action (NAPA, in 2005 and later updated in 2009), Bangladesh Climate Change Strategy Action Plan (BCCSAP) in 2009, Bangladesh Climate Change Trust Act in 2010, Bangladesh Climate Change Gender Action Pan in 2013, Climate Fiscal Framework in 2014 & updated in 2020, Roadmap for formulating National Adaptation Plan in 2015, Nationally Determined Contribution (NDC) in 2015 and later enhanced & updated in 2021, Bangladesh Delta Plan 2100 in 2018, Climate inclusive National Environment Policy updated in 2018, updated Standing Order on Disaster in 2019, Climate Prosperity Plan 2030 (Draft) etc., which have paved the way for effective climate change adaptation and has propelled Bangladesh as a pioneer in the global arena.

Climate Prosperity Plan

Bangladesh has launched a program to develop "Climate Prosperity Plan" for Bangladesh for mobilizing financing, primarily international cooperation, for implementing renewable energy and climate resilience initiatives, thus contributing to both climate change adaptation and mitigation. The draft plan identifies several key initiatives, which focus on renewable energy, energy storage infrastructure, power grid modernization, establishing carbon market regime etc. for future-proofing locally-led adaptation outcomes, and enhancing MSMEs.

Bangladesh Delta Plan 2100

The Government has recently adopted the Bangladesh Delta Plan 2100, aimed at gradual, sustainable development through adaptive delta management approach. The plan identifies climate change as a significant future challenge and reaffirms Bangladesh's commitment to both reducing GHG emissions as well as lays the foundation for climate adaptation initiatives for the following decades. It specifically identified 52 climate change adaptation projects for enhancing climate resilience of the delta.

Food Security and Climate Smart Agriculture

A well-coordinated effort of MoA, MoFL, MoWR, MoFood, MoDMR, MoEFCC and others is facilitating to maintain the food system climate resilient for ensuring food & nutrition security. Agriculture researches have advanced impressively since independence and contributed a lot to the food and nutrition security of Bangladesh. In the early 1970s, Bangladesh was a food-deficient country with a population of about 75 million. Today, the population is more than 160 million, and Bangladesh is self-sufficient in rice production, which has tripled over the past three decades. Government is providing research grants that enabled creation of more than hundreds of high yielding modern rice varieties that are saline tolerant, submergence tolerant, less water intensive, cold tolerant and heat tolerant high yielding varieties. Multiple crops and year-round vegetable farming is now possible instead of cultivation in single season. Floating cultivation is being widely practiced specially in the southwestern, northwestern and northeastern regions of the country tackling recurrent floods but allowing integrated farming. Initiatives are undertaken by Ministry of Agriculture for extension of water saving technologies in drought prone areas, harvesting rainwater in canals or reservoirs for enhanced irrigation, increasing overall irrigation efficiency through improved distribution network, integrated farming of rice and vegetables in waterlogged coastal areas, extended use of solar powered portable irrigation pump, improved water management in haor areas, improvement of surface water & sprinkler irrigation, integrated organic and inorganic fertilizer management for increasing soil carbon, use of Unmanned Aerial Vehicle (UAV) technologies for drought monitoring and irrigation management etc. Furthermore, promotion of Climate Smart Agriculture such as Alternating Wetting & Drying (AWD) & Nature based Solutions such as floating cultivation agriculture practices are highly emphasized in development agenda to ensure food & nutrition security, environmental sustainability and societal development.

Ministry of Water Resources is playing pivotal role in improving the surface water irrigation system. Ministry of Fisheries and Livestock (MoFL) is striving towards making the fisheries and livestock production system resilient to climate change through extended climate research for stress tolerant fish species, conservation of Hilsa fishes, developing more resilient open water fisheries, extension of aquaculture, strengthening early warning and climate information system and advisory services, improvement of value chain & post-harvest facilities and capacity building of fishing communities with special emphasis on women. Ministry of Food (MoF) has undertaken initiatives for establishing 8 steel silos with modern facilities, renovating old food silos and ancillaries, capacity building and research on food safety, distribution of 55 kgs rice storage capacity 0.3 million household level silos for poor, ethnic community and vulnerable families of disaster-prone areas, improvement of distribution system etc.

Integrated Water Resources Management

Ministry of Water Resources is contributing to improve lives, livelihoods and environment for secured investment of the country through its adaptation initiatives. Implementation of integrated water resources management for climate resilient delta with conducive regulatory and planning tools like Bangladesh Water Act 2013, Bangladesh Water Rule 2018, Haor Master 4 Plan, Bangladesh Delta Plan 2100 etc. is given high priority by the ministry. Building 5,816 km of coastal embankment in 139 polders, 2,728 km submersible embankment in haor areas and 7,984 km flood protection embankment in the country, maintenance of total 16,528 km embankment, protection of 1,457 km river bank and 31 districts from erosion, increasing navigability and water storage through 4,375 km river dredging and excavation, restoration of wetlands ecosystem and biodiversity, basin wide management and freshwater flow increase, irrigation of 16.49 lac hectares of land & additional 1.15 crore MT additional food production through construction of 5,355 irrigation canal, 3,613 km canal dike and 4,502 km drainage canal, construction of 5 rubber dams, implementing 5 days' monsoon flood forecast in the country and 3 days' flash floods forecast in haor areas through community, SMS and smartphone apps, annual erosion prediction among stakeholders and communities, collection and monitoring of surface water and groundwater hydrology, river bank stabilization and 1,086.2 sq km of land reclamation, shadow water pricing etc. are noteworthy achievements made by the MoWR in last few decades. Engagement of community for integrated water resources management is being ensured through formulation of Integrated Water Resources Management Guideline (2020) and establishment of Water Management Organizations (WMO) at local levels. As a cross-cutting issue, managing the water resources in integrated manner is not only contributing towards achieving the sectoral development goals but also water & food security, enhanced DRR & livelihoods security, sustainable development goals and climate resilience.

Disaster Risk Reduction

Bangladesh has time and time again, demonstrated success in disaster preparedness and climate resilience. Cyclone Preparedness Programme (CPP) established by the Government of Bangladesh currently has 76,020 volunteers (of which around 50% are women) dedicated to Disaster Risk Reduction. Additionally, 46,000 urban volunteers are also working for urban safety and resilience. A total of 4,530 cyclone shelters have been constructed across the coast. The Ministry of Disaster Management (MoDMR) have constructed 340 flood shelters across the country with additional 393 shelters under construction. A total of 550 Killas, specially designed on raised land, have been constructed to provide shelter for the people and livestock in coastal regions during the cyclone/tidal surge, 60 multipurpose rescue boats have been built for persons with disabilities. Consideration for gender and persons with disabilities have been mainstreamed into new design guidelines of cyclone shelters. A total of 65 Disaster Relief Warehouse-cum-Disaster Information Center have been established along with 18 community radio (FM) networks for the coastal people and fishermen. The government has planted 5.4 million Palm trees to reduce the risk of death due to lightning. ICT based early warning and dissemination system has been strengthened through operating dedicated Interactive Voice Response (IVR), increasing flood forecast lead time from 3 days to 9 days, developing and piloting Dynamic Flood Risk Model (DFRM) etc. Coverage of social safety net has been increased for securing lives and livelihoods through blending traditional initiatives such as Employment Generation Programme for the Poorest (EGPP), Kabita (Cash for Works), KABIKHA (Food for Work), Test Relief (TR). Standing Order on Disaster is updated in 2019 and National Plan for Disaster Management (2021-2025) is formulated to reinforce these efforts. Gender gaps have been minimized in disaster risk management through implementing DRR activities focusing on person with disability, senior citizens, women, and children, gender responsive and inclusive budgeting. Decreasing human deaths during cyclone is one of the proven indicators for enhanced disaster preparedness. For instances, preparation of 6,816 cyclone shelters and keeping standby 1,343 emergency medical teams in 14 coastal districts for emergency evacuation and managing the "double trouble" severe cyclone 'YAAS', during the COVID19 pandemic, saved thousands of lives. Similarly, evacuating around 2.4 million people and half a million livestock in less than 5 days during super cyclone 'Amphan' in May 2020 and later managing flash floods in northern and haor region in the same year also reflects the long experiences of emergency disaster management, saving of lives of millions of peoples. Overall mortality rate has been reduced due to disaster, particularly from cyclone which is now single digit from 6 digits compared to 1970, 1991.

Ashrayan: Climate Resilient Shelter for Displaced People

Bangladesh had undertaken the Ashrayan project in 1997. Under the scheme, a total of 538,139 families have been rehabilitated since 1997, totaling 3,700,160 inhabitants. Specially designed Machang & houses for hilly and char areas are considered in this scheme along with housing for other vulnerable areas. The government is implementing "Khurushkul Special Ashrayan Project" launched in 2014-15, which is one of the world's biggest housing projects for climate refugees. Under this project, 139 five storied buildings with modern facilities have been set to be constructed in Cox's Bazar, with a capacity to rehabilitate 4,409 climate refugee families. Till date, 20 buildings have been constructed and a total of 640 climate victim families have been allotted a 406 sq. ft. flat each in its first phase. Training programmes and loan disbursements are going on to make the rehabilitated families financially self-reliant. The project also focuses on mitigation through plantation of 1.5 million trees, rainwater harvesting, the solar panel based alternate power sources, improved cook stoves etc. Besides this, 50,104 families have been rehabilitated under the "Guchchhogram" project, where 455,000 trees have been planted.

Climate Resilient Infrastructures, Improved Public Health and Urban Resilience - Transformation for climate resilient infrastructures, improved public health and urban resilience is going on with remarkable initiatives by the Ministry of Local Government, Rural Development and Cooperatives, Ministry of Road, Transport and Bridges, and Ministry of Housing and Public Works. In last 13 years, 4,407 km urban drainage construction, 11 urban cyclone shelters construction, 47 slum development and rehabilitation, 378.51 km water supply pipe construction, 92 women sections establishment in markets, 719 water resources related sub-projects implementation, 166 cyclone shelters construction or rehabilitation, 6569 km length of tree plantation. 16845 km bridges/culverts construction, highway side tree plantation, research for climate resilient houses and shelter development, research for innovating climate resilient WASH technologies and expansion of WASH infrastructures, rehabilitation of climate rural water & disaster management infrastructures etc. have been implemented to facilitate disaster risk reduction, improvement of public health and climate resilience.

Afforestation and Greenbelt Development

Ministry of Environment, Forest and Climate Change (MoEFCC) has developed capacity of its forestry sector to engage in adaptation and mitigation co-benefit via developing monitoring system and adopting National REDD+ Strategy for adaptation, reducing emission and enhance forest carbon stocks. Tree coverage once was only 7%, which has been increased to 22%. The National REDD+ Strategy further targets to restore all degraded forest and bring all newly accreted coastal lands under afforestation and thereby increase tree cover of Bangladesh from current 22% to 25% by 2030. Bangladesh completed its first National Forest & Tree Inventory in 2019 and assessed a carbon sequestration capacity of 1275.54 million tons (all five carbon pools, soil up to 30 cm). The Government planted 10 million trees in 2020. Coastal afforestation programme has been undertaken to stabilize the coastline and create 6 green belts through engaging community people. Coastal afforestation with suitable mangrove and non-mangrove species provides variety of useful ecological and bio-physical functions, protects inland habitats as a natural storm surge barrier, alleviates environmental degradation, acts as highly efficient carbon sink, offers habitat and breeding ground for wildlife and fisheries, and improves recreational value of coastal area. It also offers socio-economic benefits to the coastal community through widening the opportunities of harvesting non-timber forest products. Community people are getting chance to improve their livelihoods. For greenbelt development and afforestation around 11.5 million trees have been planted. This community-based adaptation technique is unique and can contribute in enhancing climate and disaster resilience of coastal islands.

National Climate Finance Mechanism-BCCTF

Government of Bangladesh established BCCTF under MoEFCC in FY 2009-10 from its own resources, establishing itself as a pioneer among the developing countries. The BCCT has undertaken more than 800 projects so far with the investment of around $480 million to implement strategic actions of the BCCSAP which mainly focus on adaptation, mitigation and climate change research. Noteworthy adaptation projects undertaken through BCCTF include construction of 231.40 kilometers of embankments, excavation/re-excavation of 590.60 km of canals, construction of 1,43,463 cubic meter water combined capacity reservoirs, construction of 14 schools cum cyclone shelters, construction of 483 rainwater reservoirs, establishment of 17 pure water supply systems, installment of 12 pond sand filters, training of 14,205 Volunteers and Coastal fisherman for Cyclone preparedness programme, production and distribution of 19,428 metric ton of stress tolerant seeds, construction of 8,529 climate resilient houses, establishment of 12,900 floating vegetables bed in 210 villages, building 3 rubber dams and reconstruction of 2 spars. Through research projects 12 heat and stress tolerant crop varieties were introduced. Approximately 71.15 million trees were planted and 6,921.7 hector of forest land was brought under afforestation, 2,451 water purification solar plants were established, 20 solar irrigation pumps were mounted and 7,901 biogas plants were installed at Household level along with 13 community biogas plants, 2 eco parks reconstructed and developed contributing to both mitigation and adaptation.

GCA Regional Center for South Asia

In recognition of the country's progressive role to address climate change, the Global Commission on Adaptation established a GCA Regional Center for South Asia in Bangladesh. Hon'ble Prime Minister of Bangladesh, H.E. Sheikh Hasina, and the 8th UN Secretary-General Ban Ki-moon jointly inaugurated GCA regional office at the Department of Environment in Dhaka on 8 September 2020. The center will exchange knowledge, experience, and best practices on adaptation among 8 (eight) South Asian Countries and support their efforts to accelerate climate adaptation.

CHAPTER III: CLIMATE CHANGE IMPACTS ON ROAD INFRASTRUCTURES

3.1 Climate Change Impacts – Global Prospective

Climate change will likely exacerbate existing roadway issues and further deteriorate the condition of bridges in both developed and developing countries. In 2014, the Intergovernmental Panel on Climate Change (IPCC) concluded the following:

- The effects of climate change will continue even if greenhouse gas concentrations were to stabilize at existing levels; average temperature increases and sea level rise will continue due to the timescales associated with climate processes and feedback effects.
- IPCC AR6 (2021) projects a global temperature increase of 1.5°C to 1.6°C in the near term (2030s), 1.7°C to 2.4°C in the mid-term (2050s) and 1.8°C to 4.4°C in the long term (end of the century).
- Future sea-level rise is projected to be between 0.11-0.12 meter in the near term, 0.23-0.27 meter in the mid-term and 0.54-0.86 meter in the long term (IPCC, 2021). In most regions, there will be more instances of hotter, and fewer instances of cold temperature extremes as global mean temperatures increases.

Transportation infrastructure, such as bridges, is vulnerable to extremes in precipitation, temperature, storm surges and salinity, which can damage the structure and roadway deck of bridges. For example, if soil moisture levels become too high with increased precipitation, the structural integrity of aged or weak bridges could be compromised. Gradual increases in extreme rainfall events and damaging storms increase the risk of flooding, causing bridge damages and closures, as well as the need for repair and reconstruction. Amplified extreme temperatures affect the thermal expansion and movement of joints, and therefore increase stress on bridges. The greater variability and range of maximum and minimum temperature can generate more thermal stressful conditions and damage bridge expansion joints. Any increase in the intensity of storm surges is likely to increase, causing more frequent or severe flooding of low-lying infrastructure and scouring bridge foundations due to eroding riverbeds. Salinity in some river water may increase due storm surges and accelerate the corrosive environment for bridges.

Future bridge structures will have to adjust for the direct and indirect impacts from climate change. If these risks are not carefully considered in new construction activities, they could prevent emerging countries from continuing their economic and social development.

Design guidance revision is necessary to provide more robust bridges in the future. Revising existing guidelines requires changes to design criteria, including considerations for new and higher traffic loads, stronger foundations, and greater freeboard between the water level and the bridge surface.

How does climate change affect bridges?

The Intergovernmental Panel on Climate Change (IPCC), created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), found out that intensity of precipitation, particularly the proportion of total precipitation that falls during heavy events, has increased and is very likely to continue to increase in the future.

Available research indicates a tendency for an increase in heavy daily rainfall events in many regions, including some in which the mean rainfall is projected to decrease. In the latter cases, the rainfall decrease is often attributable to a reduction in the number of rain days rather than the intensity of rain when it occurs.

The IPCC also found that higher precipitation intensity could increase the risk of flooding and they identified bridges as one of the infrastructures most at risk due to climate change.

Its conclusions coincide with the results of another study carried out by the World Road Association (PIARC). In collaboration with road administrators from thirteen states on five continents, they concluded that increased precipitation intensity and frequency can cause severe scour on bridge pier foundations and abutments due to increased river flow.

In order to assess the vulnerability of a bridge to climate change, other factors are identified that should additionally be considered. These significant effects could be:

Temperature changes that would cause expansion and contraction of the bridge's super-structure, leading to thermally induced stresses that can cause degradation.

Rise in sea level which can cause scour and a reduction of the bridge clearance. Sea Level Rise may also trigger salinity intrusion, which is causing detrimental effect to RCC and steel infrastructures.

Increased wind speed due to increased storm intensity that can become a threat, especially for tall bridges. Secondly, cyclone made speedy tidal surge associated with flow of debrides creates excessive lateral thrust to the piers and abutments, which may lead to collapse of the bridges.

Although climate change mitigation must be a priority and a global goal, it is expected to continue to create significant stress despite the efforts made; therefore, a new and more ambitious strategy for the adaptation of infrastructure to climate change is needed. The NAP vision has been conceptualized based on the plan's underlying aim, which is to reduce risk and vulnerability due to the adverse impacts of climate change, and to help fulfil Bangladesh's aspiration to become a climate-resilient nation. Ecosystem resilience in the face of climate change is core to achieving this aspiration, recognizing that ecosystems may be adversely impacted both by Anthropogenic impacts and by climate change results in potential risks to infrastructure particularly bridges.

The identified risks on bridges:

- Accelerated material degradation of construction materials due to projected higher temperatures increased precipitation, humidity, and higher carbon concentrations in the atmosphere, factors that can contribute to the faster deterioration of bridges;
- Higher flood levels and more frequent flooding, for example, a German study shows that increased flooding events could submerge some bridges;
- Damage to pavements and railways from heatwaves and increasing frequency and intensity of rainfalls. For example, heatwaves can cause lateral buckling of railroad tracks;
- The higher scour around the foundation of bridges due to fast-moving water that removes the sediments. Because climate change is projected to bring higher precipitation and runoffs this will increase the velocity of stream flows resulting to higher scour and sometimes affects lateral stability of piers and abutments.
- The sea level rise will increase salinity intrusion which will lead faster corrosion to the reinforcement of RCC structure as well as steel structure.

And there are still other risks on bridges influenced by climate change.

Such as increased temperatures and solar radiation which will require higher demands on deformation capacity, bushfires events, more violent storm surges and hurricanes that can damage bridge decks, and sea-level rise. Other studies even suggested that climate change can trigger tsunamis.

3.2 Climate Impacts on Coastal Area Infrastructure – Bangladesh Prospective

Current and future climate will impact the infrastructure, environment, ecology, agriculture, water resources and livelihood of the people of coastal Bangladesh. The increase in temperature has the potential to cause material expansion resulting in damage concrete structures such as buildings, bridges, and culverts and bitumen seals to roads may be susceptible to softening unless higher temperature resistant bitumen is used. Floods resulting from increased rainfall, cyclones and storm surges have the potential to damage road embankments, markets and housing. SLR will increase this potential risk.

Increasingly severe storm events will also increase the potential flood related damage as well as causing additional erosion damage from the over-topping of road embankments. High winds associated with storm events have the potential to damage buildings, as well as cause secondary damage from trees and other debris. Wind driven wave action can have a significant erosive effect on exposed road embankments and bridge abutments.

The severity of impacts will be a function not only of the scale of the climatic events but also the extent to which the resilience of individual infrastructure components has been compromised by poor construction and lack of effective maintenance and periodic rehabilitation.

Table 3 presents a summary of the information gathered from the field and desk studies.

Table 3: Climate Change Impacts on road Infrastructure

Climate Change	Impacts	Field Observations and Survey Interview Outcomes
Increase of temperature	Higher rate of evaporation of water bodies containing sweet water, leading to increasing scarcity of potable drinking water. The material expansion will impact structures, such as buildings, roads, embankments, bridges, culverts, sluices, etc.	Such impacts have already been evident particularly in the dry season over the coastal zone.
Increase of monsoon rainfall and intensity	Monsoon rain causes floods, erosion of embankments and road infrastructure and damage to market and housing. The rainwater accumulating within the polders will cause water logging and inhibit normal land-use practice and impact livelihoods.	The local inhabitants have advised that such impacts are already evident. The drainage problem causing water-logging is a regular phenomenon and permanent in some areas.
Sea level rise	Increasing normal tide levels will flood more lands of the coastal zone in terms both of extent and inundation time. In some areas the extreme tide will overtop the polders. The road and infrastructures will be affected and increased consequent salinity will impact land-use and local eco-systems. Overall increased risk to life and livelihoods.	The higher tidal levels due to sea level rise causes inundation of roads, houses, marketplaces, shrimp farms and agricultural crops during extreme high astronomical tides, already noted
High winds	Potential damage to buildings, ghats, etc. as well as secondary damage from trees and other debris.	These impacts are already observed

Climate Change	Impacts	Field Observations and Survey Interview Outcomes
	Impact by wind driven wave action on embankments, bridge abutments etc.	
Increase of the frequency of strong cyclones including storm surges	Cause damages to, environment, infrastructure, resources, economy and livelihood. Increased risk to life. Water bodies are contaminated causing scarce of drinking water and impacting on health. Roads are partially damaged when surge height is less than 1m, and more fully damaged when the depth of inundation exceeds 1m.	Confirmatory evidence from assessment of recent cyclones Aila, and Sidr.

The culmination of these impacts will be a rapidly increasing deterioration of the regional infrastructure, including a significant risk to road connectivity, particularly at times of when it may be most needed.

The vulnerability of infrastructure to monsoon and cyclone damage in some parts of Bangladesh is to a significant extent governed by protection offered by the polder system. In the 1960s, 139 polders and supporting infrastructure were constructed primarily to protect low lying coastal areas against tidal flood and salinity intrusion. Limited protection only was afforded against major cyclone events. The Bangladesh Coastal Embankment Rehabilitation Project (CERP) was approved in 1995 with the objective of rehabilitating 21 key coastal polders, and closed in 2003. The project only partially achieved its objectives and the outcome was rated as moderately satisfactory. Cyclone protection was provided - but not to the extent planned. Only 14 of the 21 polders targeted for rehabilitation were protected completely by new or renovated embankments, leaving 7 polders at risk of rapid inundation. Crucially the review report noted that a polder embankment is only as strong as its weakest link thus the "patch, mend, and upgrade" approach (while providing local protection) does not guarantee the integrity of the coastal polders and even at the time of the review report parts of the rehabilitated embankments were deteriorating.

The current Coastal Embankment Improvement Project (CEIP) is looking to upgrade only 17 polders and these will be designed to withstand a 1:25 year cyclone (both Sidr and Aila were larger events than this). The clear implication from the above is that there is limited and variable protection afforded to infrastructure within the polder system from the impacts of current and future monsoon and cyclone events and that the vulnerability of, for example, specific roads must be evaluated on a case-by-case basis.

3.2.1 Climate Impact Assumptions

As discussed in section 2.2.3 that Global warming is causing sea-level rise and increasing the vulnerability of low-lying coastal areas of Bangladesh. Future sea-level rise is projected to be between 0.11-0.12 meter in the near term, 0.23-0.27 meter in the mid-term and 0.54-0.86 meter in the long term (IPCC, 2021). There is, however, substantial uncertainty in the long-term (2100) projections near the Bangladesh coast, according to the IPCC. Some global models estimate an increase of up to 1.75 m.

The Coastal Embankment Improvement Project (CEIP) has adopted a figure of 500 mm SLR by the year 2050 (a rate of around 10 mm/yr). Although no detailed commentary is available on the selection of this figure given in the CEIP22 report, it is our assumption that a high Factor of Safety (FoS) has been incorporated due the regional importance of the protection and disaster mitigation functions of polders. This implied FoS is appropriate due to the regional importance of the proposed polder improvement works in this case. It would be difficult to justify such a high FoS for within-polder Upazila, Union and village roads and, based on a review of the relevant literature, a general relative SLR of 7mm/yr has been taken for assessment of the subprojects for CCRIP.

The "effective" SLR is actually a combination of relative SLR and land subsidence. This land subsidence has been estimated to be between 2 and 4 mm per year within the project region23. For CCRIP an on-going average land subsidence rate of 3mm/yr. has been adopted.

3.2.2 The Infrastructure Environment

The in-service performance and hence the vulnerability of rural infrastructure and roads in particular to climatic impacts, may be considered to be a function of a series of impacting factors; collectively known as the Infrastructure Environment, Figure 17.

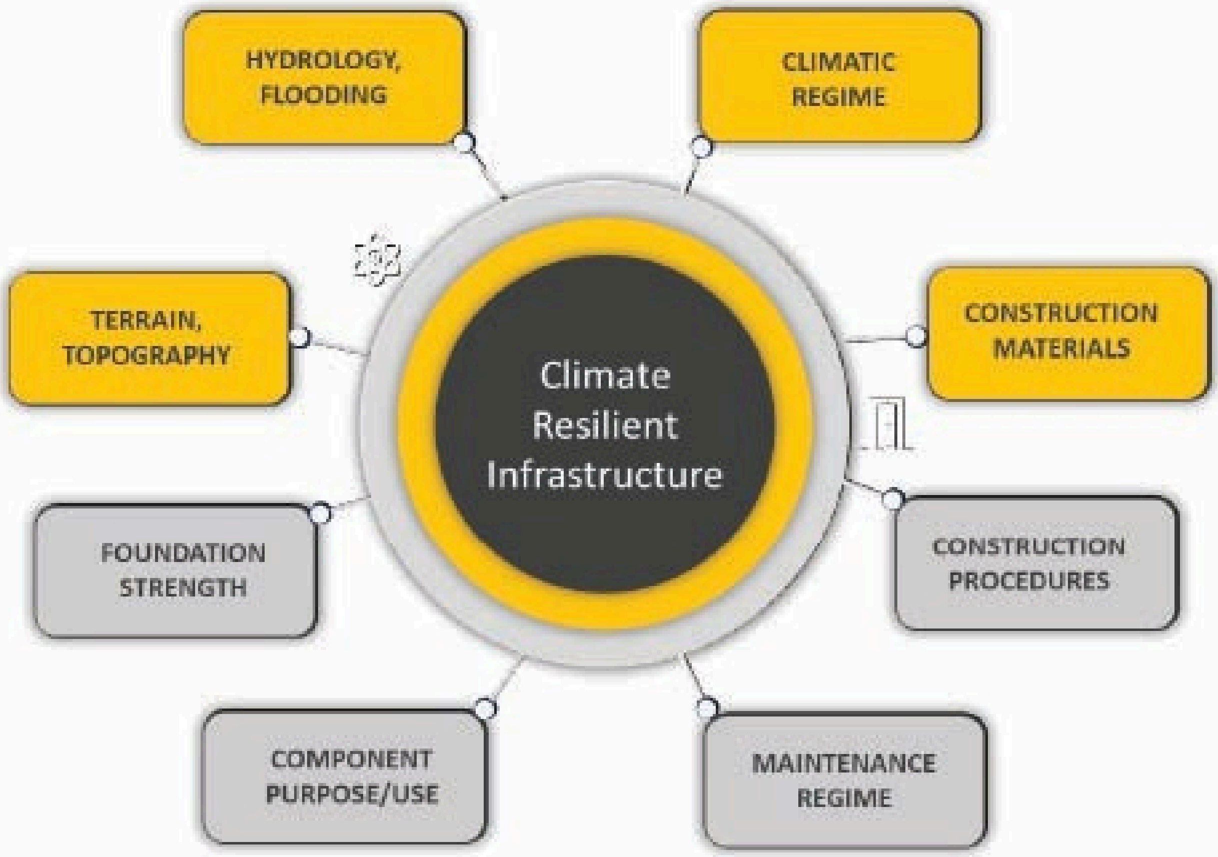


Figure 18: The Infrastructure Environment

Table 9 provides a generic summary of these factors as they apply to LGED roads within the Bangladesh coastal region.

Table 4: Engineering Environmental Factors

Impact Factor	Description
Construction Materials	Very limited options with respect to locally available natural materials–deltaic fine sediments with some sand for embankment construction and locally produced engineering quality bricks. Stone aggregate has to be imported from outside the region.
Climate/rainfall	As discussed in the above sections–a monsoonal climate with regular extreme cyclone events dominates the environment.
Surface and sub-surface hydrology	The relative protection afforded by the polder system is a crucial issue in deciding on the climate adaption measure. Saline flooding and consequent lack of suitably salt-free water is a significant factor in the use of concrete in construction.

Impact Factor	Description
Terrain	The flatter rain reflects the geological and geomorphological history and together with the climatic factors contributes to the high static and erosive flood risk for the region.
Sub-grade and foundation conditions	The natural sub-grade and foundation materials are weak and compressible. CBRs likely to be2-3%.
Road Task (Traffic)	Limited traffic data indicates a preponderance of light vehicles but consideration still needs to be given to the possibility of at least some heavy vehicles and the risk axle over loading.
Construction Regime	Evidence gained form site visits and in discussion with local engineers indicates a weak construction regime characterized by generally poor specification compliance, and in particular: Lack of adequate earthwork compaction Inadequate construction supervision Difficulties with appropriate plant availability Some modifications to specifications required
Maintenance Regime	Although the Government of Bangladesh is officially committed to the principles of routine and periodic maintenance, which for the rural road network is primarily handled through LGED, there is still an evident shortfall in funding.

CHAPTER IV: CLIMATE IMPACTS AND RISKS TO BRIDGES INFRASTRUCTURE DESIGN

4.1 Identifying Impacts to Bridges

Rural Bridges are an integral part of the transportation system of Bangladesh. Only with an efficient and well-connected road network, transportation services, and well - maintained bridges can maximize Bangladesh's economic potential. Investing in bridges and transportation systems make it easier for rural areas to transport goods, travel long distances, gain access to improved developments and services, such as education, health care, tourism, electricity and clean drinking water.

Better-quality bridges and road access also support advancement in social infrastructure. Positive impacts have been documented in developing countries including Bangladesh, where improved road access created safer traveling conditions, resulting in an increase of girl's attendance in school. Improved road access has also been shown to substantially increased health care facility use. Despite this value, reliable bridges and roadways with sufficient connectivity to jobs and community resources are still lacking in Bangladesh because of inadequate investment and maintenance.

The development of new infrastructure and the renewal and maintenance of existing assets will increasingly be impacted by climate change. Consequently, it will be critical that practitioners understand how natural hazards and the changing climate will likely impact infrastructure assets and services in order to assess risks and make informed decisions regarding asset design, construction, operation and maintenance. The primary climate drivers referenced in this guide are identified below. Additional natural hazards that are not explored in this guide but may affect infrastructure include tsunamis, earthquakes, volcanic eruptions, landslides and rockfalls. The following sections provide an overview of the risks that climate change may pose to bridges, and how to manage or minimize these risks in the development, maintenance or rehabilitation of bridge infrastructure. The range of risks discussed is not exhaustive; practitioners should conduct a detailed assessment at the project or program level to identify all relevant risks.

Extreme Heat / Heat Wave

Extreme temperatures are location specific. Heatwaves are prolonged periods of excessively hot weather. Likely increase in extreme air temperature and heat waves in most areas.

Drought / Drying Trend

A prolonged dry period in a natural climate cycle which results in a shortage of water. Likely increase in drought conditions in some areas through a warming of air temperature and decrease in precipitation.

Extreme Precipitation / Flooding

Extreme precipitation events are location specific and can cause flooding when down pours exceed the capacity of river or urban drainage systems. Uncertain climate projections, expected to intensify in some areas.

Storm Surge

The difference between the actual water level under the influence of a meteorological disturbance (storm tide) and the level which would have been attained in the absence of the meteorological disturbance (i.e. astronomical tide). Sea level rise exacerbates storm surge height.

Sea Level Rise

Anticipated Sea level changes due to the greenhouse effect and associated global warming. Leads to changes in erosion and accretion, long term inundation, exacerbate storm surge and tsunami height.

Damaging Storms (High Velocity Wind, Lightning)

Severe weather systems involving damaging winds and heavy rainfall downpour, including tornados, hailstorms, tropical cyclones and hurricanes. Uncertain climate projections.

It is recommended that LGED needs to capture historical data of damaged bridges caused by climatic factors (i.e. flooding, Flash Flooding Storms etc.). This could be the number or length (m) of bridges damaged/destroyed by each climate event or an estimated annualized life cycle cost increase if bridges are not made more resilient. These historical data will provide LGED with a clearer sense of the probability/severity of each climate risk, and so countermeasures can be appropriately targeted to maximize benefit/cost.

4.1.1 Key Consideration in Identifying Impacts to Bridges

Climate change is likely to impact bridge infrastructure assets through modification in the pattern of extreme climatic events, which includes storms and storm surge, floods, and drought; or through gradual changes in seasonal or annual patterns of temperature, solar radiation, precipitation, and sea level rise.

When evaluating the impact of climate change and risk to bridge infrastructure there are two overarching concerns the timeframe for the asset's productive lifespan and required capital costs. While engineering design always considers some measure of extreme weather conditions when designing or rehabilitating infrastructure, it is important to consider a temporal scale that is appropriate to the anticipated life of the asset as well as and cost-effectiveness of climate resilience options.

In Bangladesh, climate adaptation needs to reduce the over all life cycle costs and disruption caused by climate change. Keeping in mind the key aspects noted above, it will also be important when designing new bridges or rehabilitating existing bridges to follow certain principles that will help create greater resiliency by planning not just for the current climate, but for the climate scenario projected for the entire design life of the bridge asset.

Impacts are a function of current and future climate variability, location, asset design life, function, and condition. Many characteristics of the bridge asset and its location influence the likelihood and extent of climate impacts. These characteristics must be considered when establishing the context for the climate change risk and vulnerability assessment. Questions about the condition of the existing asset base (Has it been maintained? What is its current failure rate?) are important to evaluate as part of a comprehensive assessment. Climate change can cause direct physical impacts to bridge assets and indirect impacts including loss of service. Changes in the pattern of extreme events can directly impact the physical integrity of bridge structures in a variety of ways, causing loss of service. One way climate change impacts bridges are through flooding, washout of approach (in case of insufficient floodway) and scouring (due to high velocity of flood water) around bridge foundations due to increased intensity and frequency of heavy rainfall. Collapses of bridges due to flooding can also occur. In the future, flooding is expected to occur more frequently and be more destructive in many regions.

Current infrastructure design is based on historical data and professional experience. Most existing bridge assets were designed based on historical climate data, such as average rainfall and runoff in an area, or historic flood events. However, the pace of climate change means that historic data may no longer be relevant for longer-term infrastructure performance. Climate change may cause shorter asset life spans or require early rehabilitation as infrastructure degradation accelerates. These situations can be exacerbated for Rural bridges, where design standards and climate information may be out of date or nonexistent.

For new bridge assets, both the location of the asset and the functional classification of a bridge based on performance characteristics (e.g., traffic flow and performance of a bridge, as well as vehicular traffic and pedestrian usage) should take climate change into consideration.

The associated impacts of climate change on transportation infrastructure will vary regionally, reflecting differences both in the magnitude of climate change, and in environmental conditions. Asset location is particularly relevant in coastal areas and floodplains of Bangladesh. The capability of the asset to perform to its level of design may be impacted by changes in the environment. Uncertainty in climate projections should not prevent them from being considered in design. When considering the design of an asset, the question of how high or how big is critical and not easily answered with available climate projections. To help overcome this, designers must consider the implications of failure of a bridge. If it is critical that there be no interruption to service then consider the upper bounds of the possible risk (i.e. worst-case climate projections) would be prudent. Alternatively, consideration should be given to the marginal costs and benefits of a design decision. Sensitivity testing of a design's relative costs and benefits may show that the risk management benefits from a larger pipe, or higher asset, may significantly out-weigh the marginal cost.

Demand for services can shift as a result of climate change. Warmer temperatures and more frequent heat waves can lead to physical damage for some bridges and consequently increase usage for other undamaged bridges, if available. Demographic expansion or contraction, such as the relocation of coastal communities affected by flooding and sea level rise, may affect the demand for services as well. Indirect impacts and cascading consequences can be more difficult to identify than direct impacts, but they should be considered. For example, the location of population and human activity can be affected by climate change and alter the demand for bridges. If demand is likely to change, then the consequences need to be considered in future designs.

4.2 Potential Impacts on Bridges from different Climate Factors

4.2.1 Impacts on Small Bridges

Both small and large bridges are affected by climate change very similarly, although small bridges are generally much weaker and therefore more susceptible to climate change. Since small bridges are typically designed and built with local labor or materials, they are often subjected to lower standards, requirements, lower quality of construction and materials. The condition of this type of bridge may be relatively poor even without the effect of climate change. This is especially true in remote areas of Bangladesh, where there was challenging access during construction of the bridge. Impacts and risks associated with small bridges are described in further detail in this section.

Increased Frequency of Extreme Weather Event

A major concern for small-scale bridges is the predicted increased frequency of extreme weather events involving damaging winds and heavy downpours, including tornadoes, hailstorms and tropical cyclones.

Shorter But More Intense Precipitation Events Causing Flash Floods

Increased frequency of heavier short duration rainfalls is expected to cause more frequent and severe flash floods. If a bridge is built over a river, the depth of water passing under the bridge may raise to a height that has not been recorded before. Higher flow rates can create erosion and carry debris (large boulders and trees) that can create dams behind bridges or directly impact the footings of the bridge and cause it to collapse. The image below shows an example of a collapsed and washed-out river bridge due to a powerful flood event.

Increased Intensity of Cyclone and Tropical Storms

One of the direct results of more powerful hurricanes and tropical storms is stronger wind. As mentioned above, in most developing countries, existing small-scale bridges generally are structurally weak and in poor condition. These bridges may not withstand severe weather conditions. As the intensity of storms is expected to increase, these bridges are likely to be exposed to higher risk of failing and collapsing.

Table 5: provides examples of potential climate impacts on small bridges

Climate Drivers	Impacts and Consequent Risks
Increased frequency of extreme Precipitation events and floods	Similar to large bridges, small bridges, such as a pedestrian foot bridge, can be damaged by flooding caused by an extreme precipitation event. However, small bridges are more vulnerable since they are often not designed to withstand powerful floods or strong winds. Therefore, an increase in Frequency and intensity of storm events will pose a greater risk to small bridges, as compared to large bridges
Extreme heat and heat waves	Small bridges are less susceptible to changes in temperature (both extreme and gradual), than large bridges. They typically are short, made of local material and not built with expansion joints. Premature deterioration of materials can result from prolonged periods of extreme heat and drought

4.2.2 Impacts on Large Bridges

For large bridges, a major climate change risk is an increase in intensity and frequency of heavy rainfall, which can result in greater flooding and scouring around bridge foundations. Large bridges, especially those that span several hundred meters over a large water body, are very vulnerable to river flooding (if located inland) or storm surges and waves (if located in the coastal Area). The destructive energy, wind, precipitation and storm surges associated with hurricanes and typhoons are likely to increase in this century. Sea level rise, increased frequency of storm events, and increasing extreme temperatures, are a few of the climate drivers that can have serious impacts on large bridge structures.

Impacts from Increase in Average Temperature and Extreme Heat

Damage to Expansion Joints

Under current climate projections, extreme heat events and heat waves are likely to become more frequent and to last longer than in the past. Bridges are subject to many modes of heat transfer and variation in the average daily temperature can cause bridges to extend or shorten. Although the effect is minimal in the short-term, the impact can be cumulative and reduce the service life of a bridge, increase the costs of bridge inspection, maintenance and repair. Greater variability and range of maximum and minimum ambient temperatures will also cause an increase in freeze-thaw cycles, which can damage bridge expansion joints. However, the impact of increase in freeze-cycles is mostly relevant to colder climate regions.

Degradation of the Bridge Deck Material

Most large bridges are built with asphalt or concrete pavement surfacing bridge decks. One reason for using asphalt layers is to protect the bridge deck structures from water, dirt, de-icing agents, or other intrusions.

Asphalt pavement can experience softening and traffic-related rutting, as well as the migration of liquid asphalt to the bridge deck surface from older or poorly constructed pavements as well as resurfacing maintenance of the deck material. Asphalt rutting may become a larger problem during longer periods of summer heat on roads with truck traffic, whereas some bleeding or flushing could occur with older pavements or those with excess asphalt content. These problems should be avoidable with proper design and construction, but at a cost.

Impacts from Extreme Precipitation Events and Damaging Storm

Flash Floods

Flash Floods and Extended Flooding Conditions. When a swollen river passes under a bridge during a flood event, the high-water level can cause debris to come in contact with the bridge. If the impact doesn't damage the bridge immediately, the weight of the piled-up debris combined with the force of the flowing water pushing on it can cause the bridge to collapse.

Cyclone and Tropical Storms

Cyclone and Tropical Storms are Becoming More Powerful. As Cyclone are expected to increase in intensity (and frequency in some regions), bridges may encounter stronger and more powerful storm surges and waves causing direct physical damage.

Scour Approach Wash-out

Hydrologists and structural engineers have studied scour for decades, and it is a central consideration in bridge design. During past historical flood events (1998, 1988 etc), several bridges collapsed due to bridge scour in Bangladesh; these collapses occurred in different regions and under different hydrological conditions, highlighting the potential for scour to occur under many streambed conditions. Scour is a process involving the erosion of streambed or bank material due to flowing water at or around piers and foundations. Scour causes stabilizing material, (e.g. the streambed or bank) to move away from the bridge substructure, causing instability of the bridge's foundation. Climate change will likely increase the intensity of river flows and exacerbate bridge scour. Extensive damage associated with scour can cause a bridge to collapse.

Impacts From Sea Level Rise and Storm Surge

Climate change is expected to contribute to more rapid sea level rise. Although the rate varies globally and even different coastal points of Bangladesh, Sea levels have risen adjacent to the

Bangladesh coast due to both the geographic location and nature of the delta. Between 1901 and 2010, sea level rose at 1.7 mm per year, and from 1993 to 2010, it rose 2.8±0.8 mm per year. Satellite altimetry data analysis also supports this, showing a rising rate of 3.2±0.4 mm per year. Future sea-level rise is projected to be between 0.11-0.12 m in the near term, 0.23-0.27 m in the mid-term and 0.54-0.86 metres in the long term (IPCC, 2021). There is, however, substantial uncertainty in the long-term projections near the Bangladesh coast, according to the IPCC. Some global models estimate an increase of up to 1.75 m. Sea level rise impacts bridges through the increased frequency of flooding, which can worsen bridge scour and inundation of inlands with saline water creates aggressive corrosive environment for RCC and steel bridges. An increased rate of bridge scour and corrosion can weaken the structure and its service life, and lead to more frequent and extensive repair. Sea level rise also reduces the navigation clearance under the bridges.

Storm Surge and Waves

Storm surge is caused by strong winds and pressures, which lead to a rise in water surge. Storm surge during powerful storms or cyclone can reach over 20 feet in elevation3 and can cause significant damage to bridges. Additionally, waves are more powerful and have higher arches, which can cause considerable damage to bridges. Since most infrastructure design is based on historical data and experience, the asset design is not always capable of withstanding such impacts. For instance, Hurricane Katrina, one of the deadliest and destructive hurricanes in the history of the United States, damaged the Twin Span Bridge by lifting many of the 225-ton concrete bridge spans off of their piers.

Table 6 : Provides examples of potential climate impacts on large bridges

Climate Drivers	Impacts and Consequent Risks
Increased frequency of extreme Precipitation events and floods	Increased frequency of extreme precipitation events increases the risk for flooding, which can reduce the Service life of bridges by: Increasing the scouring rate of bridge foundation or pier, and build-up of sediments Increasing moisture levels in soil that may lead to loss of structural foundation integrity Increased intensity of storms can place additional stresses on bridges
Sea level rise, storm surge and waves	As sea level continues to rise, coast lines will change. Thus, infrastructure that was not previously at risk may be exposed to storm surge and wave damage in the future. Storm surge is caused by strong storm winds and pressures,

Climate Drivers	Impacts and Consequent Risks
	which lead to increases in water levels. Both sea level rise and storm surge scan: Damage bridges and connected road ways due to flooding, inundation, and erosion of land that Accommodates infrastructure Decrease expected life time of bridges Storm surges and waves can exceed more than several feet and can cause significant damage to the Structure of a bridge and connecting road ways Result in scour by eroding river beds and exposing bridge foundation sand piers. Sea level rise, storm surge and waves also enhances inundation in the coastal area with saline water causing corrosive environment for RCC and Steel bridges. Sea level rise also reduces the navigation clearance.
Increase of extreme temperature and heat waves	Higher temperatures and extreme heat can cause: Bridges to be stressed by thermal expansion and movement Premature deterioration of infrastructure During winter periods, the greater daily variability and range of maximum and minimum temperature can generate more frequent freeze-thaw conditions which may damage bridge joints

CHAPTER V: CLIMATE RESILIENT PLANNING, AND DESIGNING AND CONSTRUCTION OF BRIDGE INFRASTRUCTURE

5.0 Climate Resilient Planning and Design of Bridge Infrastructure

This chapter provides a step-wise methodology to enable practitioners to include climate change considerations in the design of new structures or the evaluation of existing ones (see Figure 18). The management of climate change risks in planning and design activities can be facilitated by the following five step process including:

STEP 1 Establishing the Context - establishes the context of the assessment defining the asset and the climate impacts that will be the focus of the assessment.

STEP 2 Vulnerability Assessment - considers the vulnerability (exposure, sensitivity, and adaptive capacity) of the assets screening those that require more detailed analysis.

STEP 3 Risk Assessment - identifies, analyzes and evaluates the subsequent risks (combining likelihood with consequences).

STEP 4 Development of Adaptation Strategies - develops adaptation strategies to address the most significant risks.

STEP 5 Implementation - guides the implementation, monitoring and evaluation of adaptation solutions.

In applying the methodology, the majority of the effort is focused on Steps 3 and 4. Risk assessment and adaptation to climate change impacts should be part of a multi-criteria decision-making process (along with other technical, socio-cultural, environmental, economic, and financial factors) that reviews solutions and options during engineering planning and design. While the capital costs of creating infrastructure assets that are more resilient to climate change impacts may guide the adaptation strategy selection and design, a proactive approach when possible and affordable is often more cost-effective than being reactive. It will ultimately be more economical to build stronger and better located assets than to rebuild or repair structures following a disastrous event, in addition to other costs such as healthcare and clean-up that may result from failure of an asset.

If a risk management process is already in place for infrastructure activities, the following framework can be used to assess the adequacy or identify gaps in the process. If there is no existing risk management process in place, this step-wise approach can be used to establish such a process.

Collectively, these steps establish a climate resilient design methodology to be used when determining appropriate engineering design actions for more climate resilient structures. This process will help establish whether or not an existing or future infrastructure asset is vulnerable and at risk from climate change impacts. Tools, in the form of checklists, worksheets, or matrices, can support practitioners in undertaking these steps and are provided in this chapter.

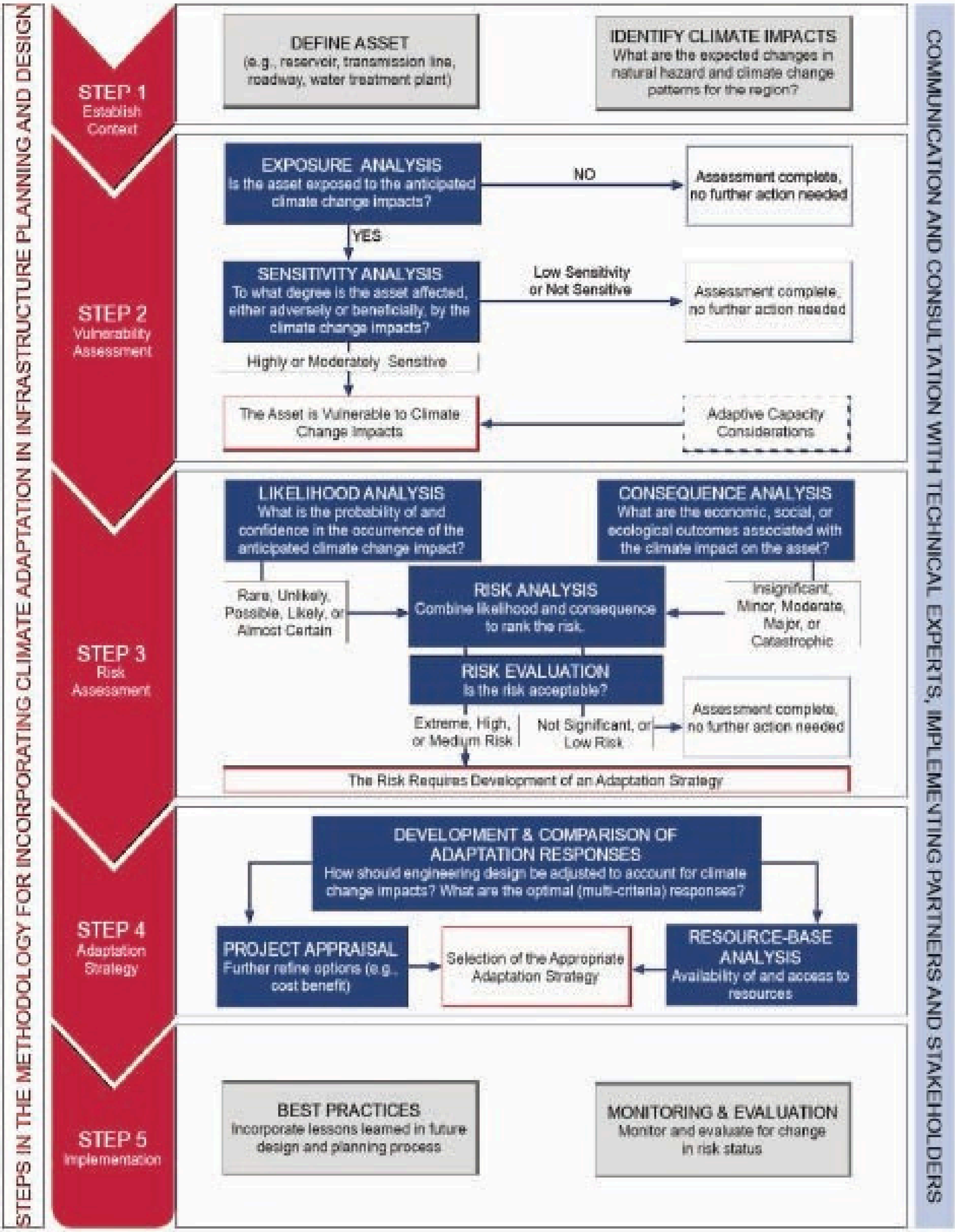


Figure 19: Climate Resilient Development Framework

Source: A guide for USAID Project Managers Bridges, incorporating Climate Change Adaptation in Infrastructure Planning and Design, November 2015

5.1 Establishing the Context

The first step in the overall approach is to define the service to be delivered by the infrastructure activity in the face of future climate change. Establishing the context notably includes defining the service to be delivered by the bridge infrastructure within the context of future climate change.

5.1.1 Defining Infrastructure Objective

For bridge infrastructure, establishing the context includes gathering research and information to understand baseline and projected traffic conditions, travel patterns, and mode share usage (automobile, truck, bus, bicycle, and pedestrian). Understanding projected use can assist in determining if any changes to the target level of service may be required. Climate change can represent one of a number of influences that may affect demand for a particular service or asset, and practitioners should therefore assess the potential for changes in demand as a result of climate change risks. For example, coastal erosion or flood events may cause a gradual shift in population over time away from an area at risk due to sea level rise, and anticipated travel patterns will change accordingly.

Consideration should also be given to the broader system that the assets are integrated with. Once the scope of the assets bridge infrastructure is defined, information about the assets is needed to inform the later stages of the assessment. Typically, an inventory or database is developed that contains information on each asset's criticality, function, condition, location, design and interdependences. This information may be sourced from existing asset management systems or operational staff. Site visits or physical surveys may also support this task.

5.1.2 Understanding and Identifying Climate and Non-Climate Stressor

Gathering data and information via research will also help practitioners understand current hazards, how they may be affected by climate change, and identify relevant internal and external factors that are within or outside the control of the project team or organization.

Internal factors include objectives and criteria governing investment decisions, engineering specifications, or service delivery targets. External factors include socio-economic (financial resources, economic activities, culture and traditions, education, and socio-demographic conditions); biophysical aspects (biodiversity, geomorphology, hydrology, and soils); and institutional arrangements (governance, regulations, and stakeholder relationships among public, private, and voluntary sectors).

Most of these factors will be reviewed as part of typical planning infrastructure development activities. The additional element that must be integrated involves climate science modeling for the region to understand what the likely changes in climate variables such as rainfall patterns, extreme temperature, or storm events might be. For coastal projects, projected sea level rise and storm surge must also be reviewed.

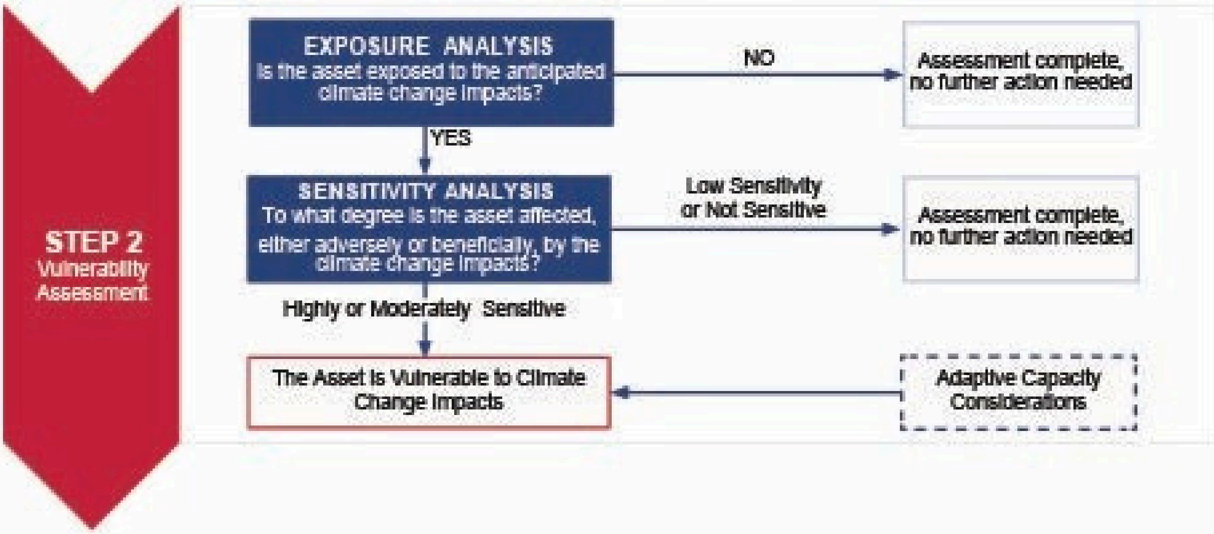
5.1.3 Sourcing Climate Data

LGED have been constructing Bridges in entire Bangladesh whose contexts involving floodplains, coastal atolls, hilly and relatively dry regions. When evaluating climate impacts and risks to infrastructure assets, understanding the context by collecting climate data and projected trends for specific geographic locations will be a critical first step. In Bangladesh, detailed climate observations and projections may be scattered, inaccurate, incomplete, or even not available. Lack of weather stations, difficulties in terrain, and inaccuracies from data collection (i.e., human error) are all factors that can create uncertainty. Practitioners can respond by making conservative estimates based on available data and source data at the regional and continental scales. Climate data sources should include government and non-government agencies, major publications, etc. where reliable data can be obtained and communication channels established. Lack of access to reliable climate data may be a major bottleneck for piloting/implementing guideline recommendations in practice.

In some situations, lack of specific climate data may be overcome by consulting available data in similar parts of the region, traditional knowledge and mapping, drawing from studies conducted under similar conditions or by conducting new studies.

As LGED is implementing its comprehensive Bridge Asset Management System. So, once the once the Rural Bridge Information Management System (RuBIMS) is fully operational with bridge inventory and bridge condition inspection data in the future, some of the needed data will be able to be sourced from RuBIMS bridge inspection and condition data.

5.2 Impacts and Vulnerability Assessment



- ✓ Analyze exposure of the asset to hazards using spatial information
- ✓ Analyze sensitivity of the asset using a sensitivity matrix
- ✓ Consider adaptive capacity

The second step in the overall approach considers the degree to which an infrastructure asset is susceptible when exposed to hazards identifying those that warrant more detailed investigation in Step 3. The vulnerability screening involves understanding an asset's vulnerability to specific climate change impacts over time. Climate-Resilient Development Framework for Understanding and Addressing Climate Change defines vulnerability as a function of an asset's exposure, sensitivity and adaptive capacity to a specific climate hazard.

5.2.1 Determining Asset Exposure

Exposure is the nature and degree to which a structure or asset is subject to a climate impact. For example, a bridge likely to be impacted by tidal flooding as a result of sea level rise at mid-century would be exposed to this climate impact, whereas a bridge that is not likely to be impacted by tidal flooding would be considered not exposed.

For each planned activity, determine whether or not it is likely to be exposed to the impacts identified in Step 1. Spatial information related to hazards will assist this process (e.g. flood hazard or other planning maps). Only those assets deemed to be exposed to particular climate change impacts identified in Step 1 should progress to the assessment of sensitivity. If an asset or project site is not exposed to climate change impacts, then the assessment is complete at this point.

5.2.2 Determining Asset Sensitivity

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate stressors. For example, a wooden bridge may be more sensitive to wildfire than a concrete bridge due to the potential damage that fire may cause to the wooden construction materials compared to concrete construction materials. Table 12 below outlines the levels of sensitivity ranging from Not Sensitive to High Sensitivity. Using this scale, project elements that are rated as having a Moderate or High Sensitivity would be deemed vulnerable to the climate impacts associated with the relevant climate hazard and be the focus of the risk assessment. To help inform sensitivity assessments, Table 13 below provides a summary of the likely sensitivity of different types of bridge infrastructure to different climate hazards. Noting, that the sensitivity of a bridge will be dependent on its construction materials, Table 14 below summarizes the sensitivity of different materials to various climate variables in temperate climates.

Table 7: Levels of Sensitivity to Climate Change Impacts

Definition/Description	Levels of Sensitivity
No infrastructure service disruption or damage	Not Sensitive
• **Localized infrastructure service disruption; no permanent damage** • **Some minor restoration work required**	Low Sensitive
• **Widespread infrastructure damage and service disruption requiring moderate repairs** • **Partial damage to local infrastructure**	Moderately Sensitive
Permanent or extensive damage requiring extensive repair	Highly Sensitive
Moderate or high sensitivity impacts are considered vulnerable and should be the focus of the risk assessment.	

Table 8 : Likely Sensitivity to Climate Change Impacts

Climate Factor	Impacts on Large Bridges	Impacts on Small Bridges
Extreme Heat	Moderately Sensitive	Low Sensitivity
Draught/Drying Trend	Low Sensitivity	Low Sensitivity
Extreme Precipitation/Flooding	Highly Sensitive	Highly Sensitive
Storm Surge	Moderately Sensitive	Moderately Sensitive
Sea Level Rise	Moderately Sensitive	Moderately Sensitive
Damaging Storms (wind, lightening)	Moderately Sensitive	Moderately Sensitive

Table 9 : Differential Impact of Climate Effects on Materials

Material	CO2	Cyclones & Storms	Sea Level Rise	Extreme Rainfall & Floods	Annual & Max Temp.	UV Radiation	Draught
Concrete	M	H	H	M	M	L	L-M
Metals	L	H	H	M	M	L	L
Mortar	L	M	M	M	L	L	H
Coatings	L	M	L	M	M	H	L
Polymers	L	M	L	L	M	H	L

Tested on commonly used materials in engineering designs for temperate climates only (AECOM – Climate sensitivity of materials research, S.E. Australia Region 2007)

L Low	M Moderate	H High	E

5.2.3 Assessing Adaptive Capacity

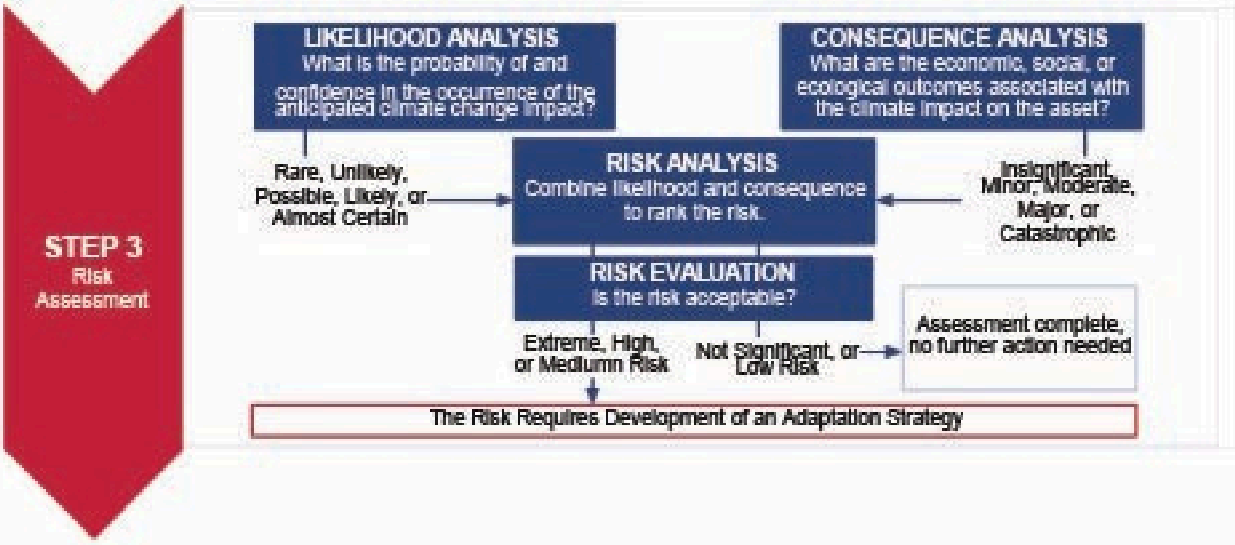
Following the determination of an asset as vulnerable, practitioners may also consider the adaptive capacity of the infrastructure system. This step is not critical to the vulnerability screening process; however, it may provide useful information to inform the consequence discussion in Step 3.

Adaptive capacity is generally considered as a social component when working with soft infrastructure. When working with built or hard infrastructure, adaptive capacity refers to the ability to anticipate, prepare and recover from climate impacts.

From a system perspective, this may be assessed by looking at core economic drivers in-country (or in similar contexts if not readily available), such as access to health services and education, resource strength in terms of wealth and human, strength of networks, institutions leadership, and disaster response mechanisms.

Focusing on specific infrastructure, consideration may be given to the potential for supplementary capacity (e.g. redundancy), likely duration of a disruption to service or the duration of repairs to return an asset to operation.

5.3 Risk Assessment



The third step of the approach enables practitioners to consider risks once the vulnerability of an asset or project has been established. In this step the following tasks needs to be performed:

- ✓ Define the likelihood of climate impacts occurring,
- ✓ Understand the consequences of climate impacts,
- ✓ Conduct a risk analysis and develop a risk rating matrix and
- ✓ Accept the appropriate level of risk and adaptation needs.

A risk assessment provides an analytical framework with qualitative descriptors for likelihood and consequences in a resulting risk matrix. Only those assets that have been identified as vulnerable in Step 2 need to be analyzed for risk. This approach is aligned with traditional risk management principles (e.g. ISO 31000:2009 Risk management— Principles and guidelines). Exposure and sensitivity data gathered in Step 2 can be used to inform the rating of likelihood and consequences.

Risks are often expressed as the combination of the consequences of an event and the associated likelihood of it occurring:

RISK = CONSEQUENCES x LIKELIHOOD

5.3.1 Likelihood of Climate Impacts

Table 15 provides examples of qualitative definitions that can be used to characterize the likelihood of a risk occurring. The probability of a risk occurring is often described in qualitative terms. Only when there is sufficient data and capability can a quantitative description of likelihood be made, where the time horizon is the life of the asset.

The level of certainty in determining the likelihood of a climate impact largely depends on the scale and certainty that the climate modeling exercise will yield (e.g., more frequent heat waves), changes in hydrological patterns (e.g., recurring floods), variations in coastal environments (e.g., sea level rise), and climate-driven gravitational hazards (e.g., higher frequency of rock falls, mudslides and avalanches).

Regional models will likely yield more precise results with a smaller range of projections, providing greater certainty. Assumptions regarding uncertainties associated with the model, or a hypothesis when modeling is not possible, should be clearly articulated.

Table 10 : Example of Qualitative Definitions of Likelihood

Level	Likelihood	Definition
5	Almost Certain	More likely than not, probability greater than 50%
4	Likely	As likely as not, 50 / 50 chance
3	Possible	Less likely than not but still appreciable, probability less than 50% but still quite high
2	Unlikely	Unlikely but not negligible, probability low but noticeably greater than zero
1	Rare	Negligible, probability very low, close to zero

5.3.2 Consequences of Climate Impacts

It is important to understand the consequences associated with an asset being impacted by a climate hazard. Defining consequences is ideally done in a workshop setting with key stakeholders to identify important criteria to be used to assess consequences. There may be one or several criteria used, depending on the project. Examples of consequence criteria which could be considered are listed below. Table 16 provides example definitions for rating each consequence criteria.

- ✓ **Asset Damage** - Damage requiring minor restoration or repair may be considered minor while permanent damage or complete loss of an asset would be considered to be a significantly higher consequence.
- ✓ **Financial Loss** - A high repair or capital replacement cost would be of major consequence compared to a cheaper repair or replacement cost.
- ✓ **Loss of Service** - As an example, a water system serving a largescale industry with high water use requirements would be of major regional consequence compared to one serving a small-scale industry using less water.
- ✓ **Health and Safety** - A system serving a large number of people would be of major consequence compared to a system serving a smaller number. Casualties or other acute public health consequences would weigh more heavily.
- ✓ **Environmental Considerations** - Damage to a wastewater system adjacent to a local drinking water source, for example, would be of major polluting consequence compared to a system isolated from a local water source.
- ✓ **Reputation** - Loss of service, health or environmental impacts may affect the reputation of the responsible agency.

Table 11: Example Description for Consequences

Level	Likelihood	Definition
5	Catastrophic	➤ Asset Damage - Permanent damage and / or loss of infrastructure. ➤ Loss of Service - Widespread and extended (several weeks) interruption of service of the agreed Level of Service; result in extreme contractual penalties or contract breach. ➤ Financial Loss - Asset damage > annual maintenance budget or 75% of CAPEX value. ➤ Health / Safety - Substantial changes to the health and safety profile; risk of multiple fatalities as a result of extreme events. ➤ Reputation - Irreversible damages to reputation at the national and even international level / Public outrage.
4	Major	➤ Asset Damage - Extensive infrastructure damage requiring extensive repair / Permanent loss of local infrastructure services. ➤ Loss of Service - Widespread and extended (several days) interruption of service for less than 50% of the agreed Level of Service; result in severe contractual penalties. ➤ Financial Loss - Asset damage 50%+ of annual maintenance budget or 25% of Capital Expenditure (CAPEX) value. ➤ Health / Safety - Marked changes in the health and safety profile, risk of severe injuries and even fatality as a result of extreme events. ➤ Reputation - Damage to reputation at national level; adverse national media coverage; Government agency questions or enquiry; significant decrease in community support.
3	Moderate	➤ Asset Damage - Damage recoverable by maintenance and minor repair / Partial loss of local infrastructure. ➤ Loss of Service: Widespread interruption of service for less than 20% of the agreed Level of Service; result in minor contractual penalties. ➤ Financial Loss: Asset damage > 10% but < 25% of annual maintenance budget or 5% of CAPEX value. ➤ Health / Safety: Noticeable changes to the health and safety profile, risk of severe injuries as a result of extreme events. ➤ Reputation: Adverse news in media / Significant community reaction.
2	Minor	➤ Asset Damage: No permanent damage / Some minor restoration work required. ➤ Loss of Service: Localized interruption of service for less than 10% of the agreed Level of Service. ➤ Financial Loss: Asset damage > 5% but < 10% of annual maintenance budget or 1% of CAPEX value. ➤ Health / Safety: Slight changes to the health and safety profile; risk of minor injuries as a result of extreme events. ➤ Reputation: Some adverse news in the local media / Some adverse reactions in the community.
1	Insignificant	➤ Asset Damage - No infrastructure damage. ➤ Loss of Service - Localized interruption of service for less than 1% of the agreed Level of Service (LoS). ➤ Financial Loss - Asset damage < 5% of annual maintenance budget or negligible CAPEX value.

Level	Likelihood	Definition
		➢ Health / Safety - Negligible or no changes to the health and safety profile or fatalities as a result of extreme events. ➢ Reputation - Some public awareness.

5.3.3 Conduct a risk analysis

Once the likelihood and consequence are defined, the risk level is determined by multiplying the likelihood value by the consequences value to result in a score from 1 (Low) to 25 (Extreme). Generally, the resulting score will be assigned one of five levels of risk: Not Significant, Low, Medium, High, or Extreme (Table 11).

Table 12 : Risk Rating Matrix

Level of Risk		Consequence Level				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Likelihood Level	Almost Certain (5)	Medium (5)	Medium (10)	High (15)	Extreme (20)	Extreme (25)
	Likely (4)	Low (4)	Medium (8)	High (12)	High (16)	Extreme (20)
	Possible (3)	Low (3)	Medium (6)	Medium (9)	High (12)	High (15)
	Unlikely (2)	Low (2)	Low (4)	Medium (6)	Medium (8)	Medium (10)
	Rare (1)	Not Significant (1)	Low (2)	Low (3)	Low (4)	Medium (5)

5.3.4 Determining Risk Acceptability and the Need for Adaptation

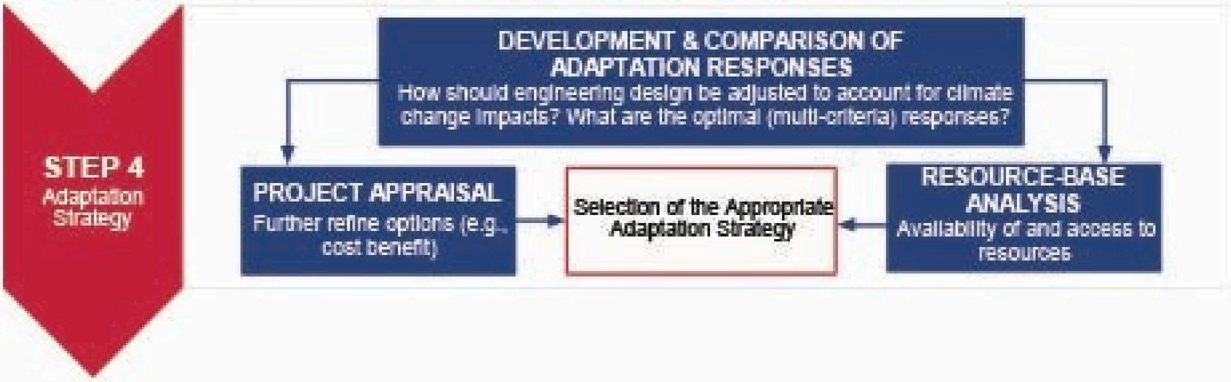
Based on the outcomes of the risk analysis, it is necessary to determine and prioritize those risks requiring treatment with appropriate adaptation measures. Risk acceptability criteria need to be defined (refer to Table 12) to guide the determination of which risks are determined to be acceptable and the most significant risks requiring treatment (i.e. adaptation planning).

Often the risk evaluation is led by a project funder or leader, rather than the technical staff who lead the risk analysis. Decisions on risk treatment should take into account the acceptability of external stakeholders that are likely to be affected.

Table 13: Risk Rating Matrix

Level of Risk	Definition
EXTREME > 20	➢ Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations. ➢ These risks are not acceptable without treatment.
HIGH 12-16	➢ High risks are the most severe that can be accepted as a part of routine operations without executive sanction, but they are the responsibility of the most senior operational management and reported upon at the executive level ➢ These risks are not acceptable without treatment
MEDIUM 5-10	➢ Medium risks can be expected to form part of routine operations, but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at the senior management level ➢ These risks are possibly acceptable without treatment
LOW ≤ 4	➢ Low risks will be maintained under review, but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe ➢ These risks can be acceptable without treatment

5.4 Developing and Selecting an Adaption Response



Under Step 4 the following Tasks needs to be performed:

- ✓ Identify potential adaptation solutions
- ✓ Conduct project appraisal (e.g., CBA) to further refine and generate a shortlist of adaptation options
- ✓ Consider the availability and access to resources, human and material
- ✓ Develop the adaptation strategy with the identified adaptation solutions

Once the degree of vulnerability has been established and the most critical risks have been identified, a decision can be made regarding how to address the risks. A range of appropriate adaptation strategies are available when preparing for and adapting to climate change impacts. Selection of a strategy is dependent on a number of factors, including location, temporal scale, and the specific impacts faced. Understanding the available resource base to implement the infrastructure activity will also be important. While some adaptation options may require little resources (e.g., training or monitoring) others may prove more cost-intensive.

Four generally accepted types of adaptation responses that can be implemented include: 1) accommodate and maintain; 2) harden and protect; 3) relocate; and 4) accept or abandon. These strategies can help categorize various adaptation responses for new and existing infrastructure (Table 13 below) and understand the various advantages and disadvantages of selected responses (Table 20 below).

Examples of adaptive engineering design options specific to bridge infrastructure are provided in Table 13 below, with additional detail provided in Chapter 6.

5.4.1 Short-Listing of Adaption Solutions

Once a range of possible adaptation options has been identified, they should be prioritized to create a shortlist of the most appropriate options for implementation. A number of approaches are available, including decisions strictly based on best judgment and not including detailed analysis and justification. Common approaches to shortlist options include the use of a Multi-Criteria Analysis (MCA) or applying an economic analysis, such as Cost-Benefit Analysis (CBA), to further refine and prepare for implementation.

Table 14 : Approaches to Adaption Strategies

Strategic Approach		Adaption Strategies	
		Existing Infrastructure	New Infrastructure
1	Accommodate and Maintain	➢ Extend, strengthen, repair or rehabilitate over time ➢ Adjust operation and maintenance	➢ Design and build to allow for future upgrades, extensions or regular repairs
2	Harden and Protect	➢ Rehabilitate and reinforce ➢ Add supportive or protective features ➢ Incorporate redundancy	➢ Use more resilient materials, construction methods, or design standards ➢ Design for greater capacity or service
3	Relocate	➢ Relocate sensitive facilities or resources from direct risk	➢ Site in area with no, or lower, risk from climate change
4	Accept or Abandon	➢ Keep as is, accepting diminished level of service or performance	➢ Construct based on current climate, accepting possibly diminished level of service or performance

Table 15 : Adaption Solutions with their Advantages and Disadvantages

	Strategic Approach	Advantages	Disadvantages
1	Accommodate and Maintain	➢ Less costly ➢ More pragmatic and flexible, allows adjustment over time as more climate change data becomes available	➢ Requires monitoring, possibly frequent repairs, adjustments, or more rigorous operations ➢ Necessitates design for more flexible or upgradeable structure
2	Harden and Protect	➢ Proactive ➢ Straightforward to implement and justify	➢ More costly ➢ Assumes reasonably accurate climate forecasts
3	Relocate	➢ Proactive	➢ More costly ➢ Sub-optimal location may decrease period of performance or service
4	Accept or Abandon	➢ No extra up-front cost	➢ Proper communications needed to inform decision-makers and beneficiaries to expect lower performance or service

Table 16 : Examples of Engineering Adaption Options for Climate Resilient Bridge Infrastructure

Climate Drivers	Adaptation Measures
Extreme Precipitation Events, Flooding and Damaging Storms	Adaptation strategies that address flooding and reduce its impacts on bridges fall under two broad categories: ➢ Protect bridges from damages caused by flooding by strengthening the bridge piers and foundations, or by increasing the hydraulic capacity of the bridge by raising the bridge deck ➢ Minimize the occurrence of flooding or reduce its magnitude by increasing infiltration within the catchment area draining through the bridge structure, or diverting high flows to drainage systems with a higher drainage capacity
Sea Level Rise and Storm Surge	➢ To protect bridges from powerful storm surges and waves, at-risk structures can be reinforced, particularly to protect against scouring of bridge piers, columns, or foundations ➢ Treat metal components of the bridge to resist corrosion due to increased exposure to salinity
Extreme Heat, Heatwaves and Wildfires	Extreme heat and increases in diurnal temperature variation can damage expansion joints and deck surface materials: ➢ Replace or reconstruct bridge deck expansion joints to mitigate the impacts of higher temperature ➢ Use paving materials that are more resistant to expansion in extreme heat conditions ➢ Small-scale bridged built with timber are at risk of destruction in extreme heat causing wildfires ➢ Build small-scale bridges with heat resistant materials or use coatings ➢ Maintain and implement vegetation management practices that aim to minimize fire risk

5.5 Implementation

Step 5 – Implementation involves the following activities:

- ✓ Provide on-going monitoring and evaluation to consider change in risk status.
- ✓ Identify and develop best practice examples to integrate into future design processes.
- ✓ Conduct consultation and transparent communication with all stakeholders involved to promote buy-in and better understanding of local context.

Implementation of climate change adaptation programs may be defined solely as an engineering program, but will likely be part of a larger program that includes planning and zoning, government and stakeholder buy-in, and many other complex factors.

5.5.1 Monitoring and Evaluation

Most projects and programs include monitoring and evaluation activities that can be adjusted to cover climate change risks. If feasible, embedding climate change risks in an existing monitoring and evaluation framework is the preferred approach, rather than developing a stand-alone climate change risk monitoring and evaluation framework.

Ongoing monitoring and evaluation activities can help consistently adjust the risk assessment and management approach, and support development of risk treatments that are effective, contribute to improvements in risk understanding, detect changes in external and internal conditions, and identify emerging risks.

Monitoring and evaluation should be based on robust and simple to measure quantitative and qualitative indicators. Careful consideration should be given to the cost efficiency and ease of measurement for the proposed measures. Information can be collected and analyzed through both participatory and external evaluation. Local communities can take a very active role in monitoring tasks.

5.5.2 Implementing Best Practices

Monitoring and evaluation provide organizations with an opportunity to identify assets susceptible to climate change impacts and better inform future asset planning. For example, asset condition deterioration profiles may change where assets are exposed to more extreme conditions.

Climate change adaptation is an emerging field, so implementation is also experimentation in some cases. Both successes and failures should be reported and documented to build a community of practice so that climate change adaptation strategies improve over time and practitioners become more conversant in implementing such strategies.

5.5.3 Communication and Consultation

Climate change risk communication activities should ideally form part of the overarching outreach and communications plan for each infrastructure asset.

Communication and consultation should ideally take place during all risk management activities. A robust and consistent communications plan including consideration of potential climate change risks and selected adaptation options should be developed in close collaboration with implementing partners and stakeholders. A communication plan should outline how the findings of the analysis will be made accessible to support decision making and general awareness raising for both technical and non-technical audiences.

Different target groups (e.g., government agencies, businesses, communities, and women and children) and different communication vehicles (e.g., workshops, reports, animations, summary sheets, and fact sheets) should be considered. Ongoing communication and consultation activities can support the development of appropriate objectives and understanding of the local context, help ensure that climate risks are correctly identified, and help build consensus among stakeholders on the findings of the risk assessment and the risk treatment selected for implementation.

CHAPTER VI: ADOPTATION OF THE CLIMATE RESILIENT DESIGN

6.1 Introduction

The perception that implementing climate resilient bridge design countermeasures increases costs is a barrier to widespread adoption of some high-value countermeasures.

While it is true that these countermeasures increase capital cost, they often reduce life cycle costs and reduce the risk of loss of bridge connectivity (which comes with serious economic and social impacts). A clear understanding of the life cycle costing concept would help LGED decision makers to appreciate the benefits of climate resilience countermeasures.

It would be useful to show i) the relative capital cost increase vs. life cycle cost reduction for each listed countermeasure (e.g. low/medium/high), ii) an explanation/discussion on life cycle costs, and iii) an example of life cycle costing with and without countermeasures (a detailed value engineering on different options) for a specific bridge.

Climate change practitioners, engineers, and other stakeholders will find the components to develop a preliminary cost estimate that is valid for a proposed project. Other aspects, such as technical feasibility and schedule, are also discussed in this Chapter. It is recommended that an in-depth inspection and load rating analysis be conducted for a bridge as part of preliminary design considerations. Most international standards require an engineer's report for the basis of design.

There are many comprehensive solutions and adaptation options that address climate change. Some involve technology or innovative design, while others involve the use of different materials. All options have their advantages and disadvantages, for instance: concrete is less sensitive to climate change effects, but harder to maintain. Some adaptation options may involve a substantial one-time, capital expenditure (CAPEX), other solutions require incremental increases in normal business operational expenditures (OPEX). Nonetheless, all strategies are intended to assist with decision-making for building bridges that are climate-proofed. It is important to note that schematic designs and graphic illustrations should be prepared at the start of a project to convey the concept or intervention to decision makers and community stakeholders.

Not all adaptation strategies that make bridge structures more resilient to climate can be applied to existing infrastructure. Some solutions involve modified design, such as raising the elevation of the structure, and cannot be applied simply to existing bridges. However, when a bridge is destroyed after a major weather event or near the end of its service life, it will be important for practitioners to take opportunities to incorporate climate-proof designs into the repair and reconstruction activities.

Climate change adaptation is an evolving field, with best practices and as-built case study examples being refined globally in multiple environments and contexts. This Chapter is not intended to be exhaustive. If there is a strategy or approach that the designer thinks merits and would like to consider effective, they can be incorporated in this Chapter in the next revision of the guideline.

6.2 Infrastructure Design and Materials

6.2.1 Use of Concrete Materials

Concrete is a commonly used construction material that has many benefits, which include the ability to resist high temperatures. Concrete is able to withstand extreme hot climatic condition, and generally has the advantages of being durable and having a long service life. The rehabilitation of bridge deck pavement slabs should consider greater use of concrete and reinforced concrete depending on the structural basis of the bridge. Though porous reinforced concrete is susceptible to marine environment because of salinity, sulphur and chloride affect.
Advantages of Concrete:

- Ability to resist high temperature
- Longer service life
- Require less maintenance and repair compared to asphalt, which results in lower operational cost

6.2.2 Marine Concrete

Bridge structures near salt water can be affected by salt in many ways. Wind carries salt particles that can affect concrete structures. Seawater and salt cause a chemical reaction with the cement in the concrete which will result in damage to the structure. The breaking down of concrete by seawater is mostly because of leaching or expansion of the concrete, or a mix of both. When seawater gets inside the pores of concrete, corrosion will occur and it will affect the durability of structure.

Marine concrete can be used for bridges those are near sea water and on corrosive soil. Marine concrete can also be used for bridges and buildings that are near the ocean, as well as aquariums that hold sea water. Marine concrete is mainly used in sulphate-rich environments where salt will be an issue for existing concrete structures.

When concrete for a bridge project is going to come in contact with salts or salt-like solutions, analytical surveys must be completed. By using Marine cement, concrete bridge structures will be more durable and long lasting. The composition of marine cement is created specifically to withstand the harsh environment created by that environment.

To improve the durability of Marine concrete, there are a few things that could be done. These bridge projects need to consider using concrete with low water to cement ratio. Concrete with low water to cement ratio will minimize the size of the pores which will prevent expansion. Also, ensuring that the mix used for the concrete contains no chloride to reduce the likelihood of corrosion.

Another way to improve the durability is to ensure that there is good compaction in the concrete. This helps the concrete withstand against expansion as well. Using Pozzolanic materials while preparing the concrete is also good protection against salt water. Lastly, washing aggregates with fresh water to reduce any salt concentration from building up is important.

6.2.3 High Performance Concrete

Conventional concrete designed on the basis of compressive strength using Portland cement concrete is found deficient in respect of durability in severe environments where it does not meet many functional requirements such as impermeability, resistance to thermal cracking etc. High performance concrete (HPC) successfully meets these requirements.

HPC is an engineered concrete possessing the most desirable properties during fresh as well as hardened concrete stages. HPC is far superior to conventional cement concrete as the ingredients of HPC contribute most optimally and efficiently to the various properties. HPC is a specialized series of concrete designed to provide several benefits in the construction of concrete structures that cannot always be achieved routinely using conventional ingredients, normal mixing and curing practices. In the other words a high-performance concrete is a concrete in which certain characteristics are developed for a particular application and environment, so that it will give excellent performance in the structure in which it will be placed, in the environment to which it will be exposed, and with the loads to which it will be subjected during its design life.

6.3 Cathodic protection for marine / saltwater areas

The principle of cathodic protection system is based on reversing of the flow of existing electrical currents that create the corrosion. The main principal acts as an external anode that introduced to the system. This external anode provides the source for positively charged ions rather than the reinforcing steel. The cathodic protection system favours the cathodic element and discourages the anode. In this way the anodic reaction that once took place on the reinforcement steel is stopped (Transportation Research Board 2009). The installation cost of cathodic protection system is equal to approximately 10-15% of the total construction cost of a bridge. Nevertheless, this cost can be increased due to expenses to maintenance and management of the system during its life span (Bright, 1991).

Nowadays, two types of cathodic protection are used in construction sector: 1) galvanic anode cathodic protection (GACP);2) impressed current cathodic protection (ICCP). In galvanic anode cathodic protection systems, the electrical flow is produced by metals due to different electro-chemical potential. Thus, this type of system does not require power supplies. In galvanic anode cathodic protection systems, a Zinc is used as a sacrificial metal. The main disadvantage of this CP system is relatively short time period of protection. Life span of the system depends on environmental conditions, type of structure and design of certain CP system. For most cases it is around 10 – 15 years. Impressed current cathodic protection systems need to be connected to an external low voltage supplier. However, it is possible to use solar panel and battery as a voltage supplier. But in this case alternating current has to be converted to direct current. Usually, inert materials are used as anode in this type of CP systems (Sohanghpurwala et al. 2007).

6.4 Use of Epoxy Coting Reinforcing Steel

In the ever-changing construction industry, innovation is key to making concrete structure more durable and lasting. One notable advancement is the use of epoxy coating on reinforcement bars.

Epoxy coating is a protective layer applied to reinforcement bars, typically made from steel. Composed of epoxy resin and a hardening agent, this coating forms a resilient barrier against corrosion, moisture, and chemical degradation. By shielding the reinforcement bars, epoxy coating ensures the longevity and structural integrity of concrete structures.

Epoxy Coating made of 1. Epoxy resin for adhesion and strength, 2. Curing agent to initiate the curing process. 3. Fillers to enhance mechanical properties and reduce costs. 4. Corrosion inhibitors to prevent steel oxidation. 5. Adhesion promoters for better bonding. 6. Modifiers for adjusting properties like flexibility and impact resistance and 7. Solvents (if used) to adjust viscosity for application.

Epoxy Coating Used in Reinforcement bars, or rebar, are essential components in concrete structures, providing tensile strength and structural support. However, steel rebar is prone to corrosion when exposed to moisture and harsh environmental conditions. Epoxy coating serves as a safeguard, mitigating the risk of corrosion and extending the lifespan of reinforced concrete structures. By enhancing durability and reducing maintenance needs, epoxy-coated rebar contributes to sustainable construction practices.

6.5 Use of water Proof Painting Materials

Concrete structures in environments with adverse geomorphic and climatic conditions such as severe ground and ambient salinity and high temperature-humidity regimes are prone to early deterioration. Such aggressive environments induce several deterioration problems, and the most frequent and damaging one is the corrosion of reinforcing steel, which causes early deterioration of concrete structures. Several measures have been tried to combat this problem and extend the service life of concrete structures. One such measure is the application of a waterproofing coating on the external surface of concrete structure. The main function of a waterproofing system is to prohibit water and any soluble salts from penetrating the concrete to cause corrosion, leaking, and other problems. In addition, waterproofing materials can be very effective in minimizing the rate of corrosion once it has initiated by preventing access of moisture and oxygen to the steel surface.

There are several generic types of waterproofing materials, which are commonly used for protecting concrete structures, such as cement-based, epoxy resin, polyurethane resin, acrylic resin, and silane/siloxane. These generic types have considerable variations in terms of the price, durability performance, and method of application.

Al-Dulaijan et al. investigated the performance of five resin-based surface coatings. The results showed that the adhesion of all the epoxy-resin- based coatings, to the concrete substrate, was better than that of the acrylic- resin-based surface coatings. The adhesion values of the resin-based surface coatings ranged from 1.25 to 2.03 MPa. The chloride permeability in the concrete specimens coated with the selected resin-based surface coatings ranged between 12 and 233 C.

Al-Dulaijan et al. investigated the performance of four cement-based surface coatings. The results showed that the adhesion of the tested coatings ranged between 1.10 and 1.60 MPa. The chloride permeability was also evaluated and the values ranged between 552 and 1113 C.

6.6 Replacement of Bridge Expansion Joints

This method is primarily designed for existing structures. Bridge expansion joints can be damaged as a result of prolonged and extreme daily temperature variation occurs. There are several joint types used in bridges that are part of the bridge and foundation design.

- ✓ Armor Joint (AJ);
- ✓ Sealed Expansion Joints (SEJ);
- ✓ Fabric Joint Under seal;
- ✓ Header Type Joint;
- ✓ Asphalt Plug;
- ✓ Finger Joint; and
- ✓ Modular Joint.

Bridge expansion joints allow thermal expansion and contraction, translation and rotation of the deck. They also assist in keeping water off of the substructure and protect exposed concrete edges. During extreme conditions, such as extreme hot days, expansion joints prevent bridges from bending out of place and allow enough vertical movement to permit bearing replacement.

Stresses on bridge expansion joints can be exacerbated by fatigue from heavy loading by vehicle sand increased frequency of extreme weather conditions. Their failure could cause damage to a bridge substructure and superstructure.

Advantages

- ✓ Prevent more severe damages in the future
- ✓ Further protect against extreme weather conditions

- ✓ Preserve the expected life of bridges
- ✓ Reduce the need for emergency repairs

Disadvantages

- ✓ Traffic disruption since repair requires full or partial closure

6.7 Avoid Flooding by Raising the Elevation of the Bridge

An option to protect bridges is to increase the elevation of the structure by raising it to protect against flooding and accommodate changes in higher tides and storm surges, associated with sea level rise. This strategy allows roads to be built and located in vulnerable and exposure areas, with a low risk of flooding or susceptible to mud flow, geological collapse, or foundation deterioration.

Since the design of most structures utilizes historical climatic data, including documented peak flows, the new design elevation should be above the historical peak and projected future high-water level to offset the alteration brought by changes in precipitation. If raising the structure and associated approach roadways is feasible, this option can be effective in protecting against flooding.

Advantages

- ✓ A protective measure against increased frequency of flooding, mudslides, or physical deterioration of bridge structural systems due to climate or severe weather
- ✓ Allow infrastructure to be built on low-lying or vulnerable areas

Disadvantages

- ✓ Raising the elevation of the structure can pose a design challenge to engineers
- ✓ Notable increase in Capital cost; substantial amount of material needed to raise the structure

6.8 Deepen Bridge Foundation

The flow of water can turn from slow to rapid in a short amount of time that can exert a strong force on a bridge foundation. A stronger foundation can protect a bridge from collapse due to the effects of the stronger flows associated with extreme precipitation events.

For new bridge projects, engineers can deepen the bridge footings – the enlarged portions of bridge foundations that rest directly on soil, bedrock, or piles – to protect against the effects of changes in the flow of rivers. Designing and constructing deeper bridge footings can provide a stronger, more resilient foundation.

Advantages

- ✓ A protective measure against unanticipated changes in the flow of rivers
- ✓ Protect a bridge from collapsing due to incapability of withstanding unexpected force–resulting in potential savings due to avoided damages

Disadvantages

- ✓ May encounter design challenges if geological conditions are complex
- ✓ Higher Capital cost that often involves all elements of a bridge (e.g. deck, foundation, approach roadway, and utilities)

6.9 Infrastructure Protection and Drainage Improvement

6.9.1 Improve Stormwater Management System

Increased frequency and duration of intense precipitation events creates a greater amount of storm water runoff coming in contact with the different components of a bridge structure, thereby creating conditions for deterioration and instability. Insufficient capacity of the drainage system can cause water to remain either on or within the bridge structure. Damage may be minimized by improving or upgrading the storm water drainage system in the catchment draining through the bridge structure to increase water infiltration and reduce excess runoff. Improvements to bridge-related storm water management also can reduce bridge deck runoff pollutants that flow into a receiving river and landscape.

Advantages

- ✓ Can be integrated into existing bridge system

Disadvantages

- ✓ Increase in both the Capital and Operational cost due to costs associated with assessment, prioritization, design, and installation of retrofit opportunities for storm water system, bridge deck drainage, and the conveyance network
- ✓ Need careful planning and may not be suitable in all locations
- ✓ Maintenance is required and necessary in maintaining proper drainage

6.9.2 Stabilize Stream Banks and Beds to Prevent Erosion and Scour

Bridges those are located near stream banks or traverse across streams or water ways are exposed to severe erosion that can deteriorate foundations and eventually damage a bridge. Extreme weather events can cause erosion to occur more frequently as they can generate flash floods.

Stabilized stream banks can prevent erosion and protect against bridge scour. Bridge scour is one of the main causes of bridge failure and collapses; protecting bridges against scour is very important when evaluating adaptation options. Protection against bridge scour and stabilization of stream banks can be done by installing revetments, gabions, riprap or other measures such as an increase in vegetation.

Advantages

- ✓ Could be implemented in the near-term as a generally cost-effective and efficient measure
- ✓ Stream bank stabilization can have numerous positive impacts on the environment
- ✓ Minimizing erosion can indirectly reduce the risk of flooding

Disadvantages

- ✓ Some level of maintenance needed to ensure objects installed (culvert, gabion, etc.) are not damaged after rainstorms and are maintained in good working order
- ✓ Additional cost of material, landscaping and professional design services

6.9.3 Adoption Options to Protect Against Sea Level Raise and Storm Surge

Sea level rise along with combined threats from strong storm surges pose a greater risk to coastal bridges. Several measures should be considered and used individually, or in combination, on future bridge projects to protect against these climate stressors. LGED can integrate numerous adaptive measures into the new bridge design to increase the structure's resilience. A sample list of measures include:

- ✓ Open-faced railings–to reduce wave forces and distribute water flow on a bridge deck. Railings need to adhere to testing and crash-worthiness standards;
- ✓ Raising piers – to elevate the structure above historic and future peak wave height and water levels. Ideally, a new structure should be constructed above historic and future peak levels; however, depending on the bridge structure and its footing design along with other components like location and expected life of the bridge, the new elevation can vary and feasibility challenges may prohibit implementation;
- ✓ Lengthening piles – depending on the bridge type and compressive loads on a bridge, to accommodate large anticipated wave loads, longer columns can be used and driven deeper into the soil and bedrock, in order to provide a stronger support to the structure;
- ✓ Use more rigid connections made of formed concrete to prevent decks from floating off bridge piers when strong storm surges and waves exert extreme force on bridge decks; and
- ✓ Site-specific protective structural or soft armoring measures applied around the base of a bridge including scour apron or blanket.

The design for these types of protective measures can be challenging and very costly. LGED need to consider the volume of traffic including future utilization, scale, expected service life of the structure, and cost-effectiveness before applying these protective measures.

Advantages

- ✓ If installed, these protective measures can be very effective inbuilding resilience against storm surge, wave and water forces
- ✓ If elevated above historical peak or future heights, bridges could operate during extreme event sand provide a safe evacuation route
- ✓ Possibly reducing or avoiding costs to implement future remediation
- ✓ Longer service life for bridges compared to those without protective measures

Disadvantages

- ✓ Significant increase in Capital Investment–variable depending on whether one or more type of measure is selected. High upfront cost, specific cost will be dependent on the type of protective measure implemented and design factors

6.10 Increased Frequency of Bridge Inspection and Repair

LGED have been adopting the comprehensive Bridge Asset Management Program which uses the increased frequency of bridge inspection and repair which is another adaptation option. With the help of Bridge Inspection and Assessment Guideline and RuBIMS LGED inspects bridge defects and develop programing for Bridge maintenance and rehabilitation. The inspection also includes identifying climatic conditions and defect types. Once the bridge inspection and data collection (using RuBIMS) are complete and continues as part of LGED's Bridge Asset Management program it will help enhancing/developing its systematic and data-driven planning and programming of bridge maintenance, rehabilitation and life-cycle replacement work.

While some damages caused by climate stressors can cause bridges to collapse, other damages are minor in nature and would not pose an immediate threat to the structure or safety of travelers, but could build up over time and ultimately result in bridge failure.

Conducting bridge inspections and repairs more frequently can ensure that incremental damages do not worsen and are repaired before causing substantial damages to the bridge.

Advantages

- ✓ Prevent minor damages from becoming severe
- ✓ Protect against extreme weather conditions
- ✓ Preserve the expected life of bridges

- ✓ Eliminate the need for emergency repairs

Disadvantages

- ✓ Disruption to traffic during inspection and repair; disturbance to traffic can be minimized by scheduling maintenance at low traffic hours or weekends
- ✓ Higher Operational cost – need additional workers to conduct inspections

6.11 Administrative Policy on Traffic and Loading Management

Regardless the type of adaptation strategy selected to improve the resiliency of a bridge to climate change, it needs to be accompanied by traffic (multi-modal and pedestrian in some cases) and truck load management. Climate change is likely to intensify severe storms, storm surges and intense precipitation, and require more frequent emergency response from LGED officials. Therefore, LGED officials should take a pro-active approach in dealing with climate extremes, for instance:

- Mapping, rating and prioritization of vulnerable transportation routes, such as those that are becoming more susceptible to flooding that is combined with route statistics (usage, infrastructure type, access to travel markets, etc.);
- Establish emergency plan in coordination with Roads and Highway Department, Zila and Upazila Authority to divert traffic to alternative routes when primary route becomes in accessible due to climate-related events, safety or security concerns; and
- Create and maintain an emergency operation budget that can immediately be used for emergency response purposes.

Having emergency response plans established before a disaster occurs can improve the preparedness of officials to deal with the impacts of such climate extremes. In addition, traffic management policies can be applied to further protect bridges from damage from climate extremes, including:

- Apply a loading restriction, that manages the incidence of heavy traffic traveling on a bridge structure during the time of a day when bridge usage is the highest. This action can reduce bridge fatigue and maintain expected service life of bridges; and
- Increase frequency of temporary road closure to perform maintenance on road and repair minor damages before damages worsen the condition of the bridge.

References

1. National Adaptation Plan of Bangladesh (2023 – 2050), October 2022. Published by Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh.
2. Climate-resilient infrastructure: Getting the policies right by Lola Vallejo, Michael Mullan.
3. Coastal Climate-Resilient Infrastructure Project (RRP BAN 45084)
4. Climate-Resilient Infrastructure Officer Handbook, (Knowledge Module on Public-Private Partnerships for Climate-Resilient Infrastructure)
5. Climate-resilient Infrastructure, POLICY PERSPECTIVES, OECD ENVIRONMENT POLICY PAPER NO.14
6. A GUIDE FOR USAID PROJECT MANAGERS BRIDGES, INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN, November 2015
7. California DOT (Caltrans), Guidance on Incorporating Sea Level Rise for Use of the Planning and Development of Project Initiation Documents, 2011. www.dot.ca.gov/ser/downloads/sealevel/guide_incorp_slr.pdf
8. FHWA, Highways in the Coastal Environment Hydraulic Engineering Circular (HEC) No. 25, 2008. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/07096/07096.pdf
9. FHWA, Highways in the Coastal Environment: Assessing Extreme Events Hydraulic Engineering Circular (HEC) No. 25 – Volume 2, 2014. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/nhi14006/nhi14006.pdf
10. Kopp et al., Probabilistic 21st and 22nd Century Sea-Level Projections at a Global Network of Tide-Gauge Sites, 2014. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2014EF000239
11. NASEM, TRB Special Report 290 - Potential Impacts of Climate Change on U.S. Transportation, 2008. http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf
12. NASEM, Review of the Draft Fourth National Climate Assessment, 2018. https://www.nap.edu/catalog/25013/review-of-the-draft-fourth-national-climate-assessment
13. NOAA, Technical Report NOS CO-OPS 083 - Global and Regional Sea Level Rise Scenarios for the United States, 2017. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios__for_the_US_final.pdf
14. TRB NCHRP Report 750 Series, Informing Transportation's Future http://www.trb.org/Resource.ashx?sn=n20-83B_IntroductiontotheReportsWEB2
15. Climate-resilient bridges, June 15, 2020 by Juan José Gil Olmos, https://www.idvia.es/en/climate-resilient-bridges

Appendix-01: Case Studies

Case Study 1 - Confederation Bridge Canada – Consideration of sea level rise

The information for this case study has been drawn from "https://www.cakex.org/case-studies/sea-level-rise-and-construction-confederation-bridge-gulf-saint-lawrence"

Project Summary

The Confederation Bridge crosses the Northumberland Strait in the Gulf of Saint Lawrence and connects Prince Edward Island to the Canadian mainland in New Brunswick. The structure, completed in 1997, was designed to facilitate transportation needs and accommodate a one-meter rise in sea levels over 100 years.

Background

The Confederation Bridge is one of the most frequently cited examples of incorporating adaptation into infrastructure. The bridge connects Borden, Prince Edward Island to Cape Tormentine, New Brunswick. It spans eight miles (12.9 kilometers) and is approximately 165 feet (50 meters) high; the bridge was designed to accommodate travelers, ocean vessels, and an expected one meter in sea level rise that could undermine the integrity of the structure and increase erosion along coastlines.

Implementation

Planning for the bridge began in 1985 in order to replace the seasonal, infrequent ferry service that facilitated travel between Prince Edward Island and the Eastern Canadian mainland. Climate change and sea level rise were considered from the very beginning in the proposal, siting, and design of the bridge. Fluctuations in public perception of the amount of sea level rise that Eastern Canada could expect led to debates about the extent to which sea level rise should be considered in the bridge's construction. Planners ultimately used climate scenarios to determine an appropriate height to account **for a one-meter rise in sea level and appropriate spacing between support beams to allow for ice blocks** that float down the Northumberland Strait to pass safely underneath.

Case Study 2 - Climate Resilient Bridge Design – CAO Lanh Bridge, Vietnam – consideration of downstream flooding and sea level rise

The information for this case study has been drawn from "A Guide for USAID Project Managers" Bridges – Incorporating Climate Change Adoption in Infrastructure Planning and Design.

Climate change poses a challenge, worsening the risks associated with large infrastructure projects within their lifespan. The Mekong Delta has been identified as one of the world's most vulnerable regions to climate change. Predicted changes to the climate of the delta could increase both the magnitude and frequency of floods and storms and induce greater seasonal variability in weather patterns. This increases the risks to, and potentially reduces the design life of, large infrastructure works. To mitigate such risk, climate proofing of the infrastructure to be financed by the investment project is necessary.

The Cao Lanh Bridge project is a flagship investment worth US$150 million, included technical assistance funds, and falls under Hanoi Post's economic integration pillar. The objective of the Central Mekong Delta Connectivity Project is to encourage the economic and social development of the Cao Long Delta area.

The Cao Lanh Bridge is one of the first large infrastructure investments to integrate climate change in the region. The objective of the Cao Lanh Bridge was to build resilience to climate-driven disasters and damage, particularly downstream flooding and sea level rise, and the focus was therefore on technical specifications for risk management.

The Cao Lanh Bridge project has been developed with the support of the Asian Development Bank (ADB) and the Government of Australia who financed the Project Preparation Technical Assistance (PPTA) grant. The purpose of the grant was to develop the project to a level suitable for ADB financing.

Project Components

There are three components to the Central Mekong Delta Connectivity Project:

1. The Cao Lanh bridge including the approach bridges and the approach road for a total length of 7.8km. The Cao Lanh Bridge itself will be a cable stayed bridge with a central span of 350m and a maximum clearance above high water of 37.5m. Including the approach spans, the overall length of the Cao Lanh Bridge is approximately 2km and will be 6 lanes wide crossing a branch of the Tien River.
2. A connecting road between the Cao Lanh and Vam Cong bridges will be approximately 15.7km long and will be designed to 6 lane expressway standards but will be constructed initially to 4 lanes.
3. The Vam Cong cable stayed bridge which has a central span of 470m. With the approach structures the total length will be 2.9km. This is designated component 3A. Component 3B is the approach road to the West of the bridge and is approximately 2.9km long.

The Cao Lanh Bridge project generally will be supported by soft ground, which will require special methods to reduce settlements to acceptable limits. The interface area between bridges and culverts, which will be supported on concrete piles and thus subject to minimal settlement, and the adjacent highway embankments, which will be subject to settlement over time, will require special examination to determine an economic method of reducing the 'step' between the embankments and bridges to acceptable limits.

The impact of climate change on the Mekong Delta is expected to be significant and was taken into account in the bridge and road design. The hydraulic analysis took into account:

- Changes in peak water levels due to changing fluvial flows and sea level rise;
- Changes in velocity;
- Possible long-term geomorphological impacts of sea level rise on channel geometry and regime width; and
- Possible impacts of climate change adaptation measures, such as raising of banks for protection.

The available guidance on expected and extreme scenarios of climate change for Vietnam and for regional changes in flow were used in the modeling and sensitivity tests carried out. The regional model of the Mekong delta was used so that changes at the coast could be transferred to give expected changes at the Cao Lanh Bridge and road locations.

Climate change is projected to affect the frequency and intensity of natural disasters, and funding was contingent on the incorporation of climate risk projections in the bridge's design.

The ADB, the coordinating development partner for the project, funded consultants to conduct a climate risk study. The study found that increasing the bridge's design height by 0.75m would strengthen its resilience up to 20-year flooding events, and this specification was adopted by the bridge design team.

The climate change consultants to the project also recommended that the associated road network be raised by 0.6m, twice the Ministry of Natural Resources and Environment's 'official' climate scenario which projects a sea level rise of 0.3m by 2050. An incremental approach will immediately raise the height of the road by 0.3m, with plans to raise it by a total of 0.6m over the course of the next decade as the road is upgraded to an expressway.

The groundbreaking ceremony for the Cao Lanh Bridge, held on 19 October 2013, was attended by senior officials from the Vietnamese and Australian Governments and the ADB. The bridge is expected to be completed after 43 months in mid-2017.

Lessons Learned

The following were the broad lessons learned from project design and implementation:

- Include climate change considerations in funding criteria; and
- Having climate projections and risk reduction recommendations prior to the design phase helped to increase buy-in from the Ministry of Transportation and other key stakeholders, and strengthen their capacities for understanding and managing uncertainties in climate projections.

The Government of Viet Nam was cautious of the increased costs resulting from climate proofing the project. Raising the road could have had cost implications for the wider road network by potentially introducing a new engineering standard, which would affect other roads, both existing and planned. As loans replace grants with Viet Nam's transition to middle income status, there are questions of who will pay for the incremental costs of upgrading existing infrastructure to be climate-resilient. This is a broader issue that donors and governments need to confront, but it also has implications for expectations of integration in certain projects, and how it is negotiated.

Guidelines for the Planning Design and Implementation of Climate Resilient Rural Bridges

Program for Supporting Rural Bridges (SupRB)
Local Government Engineering Department (LGED)