



# Challenges and Threats of Rising Sea Level: A Scenario Assessment on the Coastal Areas in Bangladesh

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## Abstract

This study aims to investigate the manner in which SLR significantly affects the social and ecological systems of coastal communities in Bangladesh on a regional and global level, as well as possible hazards, problems, and repercussions. The adverse effects of rising waters are especially worrisome because the Bay of Bengal is so close to the southern region of the country. Compared with the global SLR, this study will primarily concentrate on two geographical areas: the districts of Chittagong, Cox's Bazar, and Potuakhali in Bangladesh. For this study, a questionnaire, focus group discussions, and KII were used to examine the scenarios related to the local and global causes and effects of SLR using two different types of data sources: secondary and primary. The use of satellite altimetry for sea level measurement was also revolutionized. Bangladesh's islands could be submerged by 2100 due to a potential 0.4 - 1.5 m rise in sea level, according to the study's key findings. By 2050, increasing sea levels would force 20 million people to leave their homes as roughly 17% of Bangladesh will be under water.

## Subject Areas

Impacts of Climate Change for Sea Level Rise

## Keywords

Sea Level Rise, Climate Change, Coastal Area, Challenge and Impact

## 1. Introduction

Thirty years before, on August 10, 1992, a new satellite named TOPEX/Poseidon had been launched with the goal of comparing computer models of ocean circulation with real world observations and using the data to enhance climate predictions. For now, its objective was to measure the patterns of ocean circulation. NASA, the U.S. space agency, and CNES, the French space agency, deployed RADAR altimeter facility equipped subsequent satellites to monitor ocean surface topography as part of the TOPEX/Poseidon mission. The Jason-CS/Sentinel-6B mission, which will be launched in 2025, will continue sea level observations into a fourth decade after more than five missions were carried out from 1992 to 2020 for this purpose [1]. One of the most significant indicators of climate change driven by humans, these satellites will continue to track the increase in the oceans on a global scale. After combining historical data from the coast with satellite data, scientists have noticed that sea levels worldwide have been rising quickly. Since 1992, the rate of global sea level rise has increased by an average of 10.10 cm. Following the collection of tidal gauge and satellite data, it was discovered that the sea levels had risen by 21 cm to 24 cm over the previous 140 years. During the 20th century, the average annual rate of increase was 1.5 mm, but in the early 1990s, this rate was 2.5 mm, and it quickly increased to 3.9 mm in the last decade of the recent 21st century [2].

Though a few millimeters of sea level rise may seem insignificant, scientists have determined that every 2.5 cm of sea level rise results in an average 2.5 m disappearance of the sea coastline in coastal locations. The alarming rate of global sea level rise caused by humans is ten times more than that caused by natural sources, according to statistics from the past 30 years [3]. However, it does not clearly demonstrate how the rate of sea level rise in the world compares to the situation in our country with regard to sea level rise because the rate of sea level rise differs among the coasts of the world. The coastal regions of Bangladesh are neither static nor disproportionately high in comparison to other coastlines, because beaches around the world experience different rates of sea level rise [4].

Fizzy recently hosted a climate change-related International Forum meeting of the Conference of Parties (COP23) in Bun City, Germany. Among the multifaceted debates, various topics of security threats related to climate change were brought to light in preparation for the world's environmental challenges in the future. Security threats concerned with the Sea Level Rise are one of the most important issues of these. Those effects will be felt around the world as sea levels rise, and everything is very important for Bangladesh [5].

Human activities are mostly to blame for sea-level rise. Adopting a modern lifestyle, various human actions are directly and indirectly contributing to global warming [6]. According to science law, when the temperature rises, so does the volume of water. The melting of land-based ice (glaciers, ice sheets, etc.) and the thermal expansion of ocean water as it warms both accelerate SLR. SLR is a direct result of the increase in the earth's surface temperature, often known as "Global

Warming.” Sea level is expected to rise at an average pace of 3 mm/year due to rising temperatures melting glaciers and expanding oceans [7]. When oceans absorb heat, the thermal expansion of water accelerates sea level rise. According to Cazenave *et al.* [8], heat absorbed by ocean water causes thermal expansion, which contributes to sea level rise. Increased ocean warming threatens to unblock Antarctic glacier outlets, potentially resulting in fast sea level rise [9]. The retreat of non-polar glaciers also contributes to sea-level rise [10]. Although near-surface air temperature rises are the most commonly used gauge of global warming. It was discovered that over the last 50 years, 90% of the excess energy in the climate system has been stored in the ocean, warming it [11]. Data from satellite radar measurements show a 7.5 cm increase in sea level from 1993 to 2017 [12], which is mostly due to human-caused global warming [13]. Scientists predict that if the current pace of temperature increase continues, sea level rise could range from 11 inches to 38 inches. It may potentially be dangerous if cracks are discovered in Greenland and Western Antarctica. Rebecca Lindsey [14] noted that the average global sea level has risen since 1880 by 8 to 9 inches (21 to 24 cm). In **Table 1**, according to data from TOPEX/Poseidon, Jason-1, OSTM/Jason-2, and Jason-3, the average sea level worldwide reached a new peak in 2022, rising by 101.2mm (4 inches) over 1993 levels [15]. The 2023 Report of the World Meteorological Organization (WMO) by **Table 2** examines different scenarios of climate change and integrates SLR with respect to the global and Asian climates in 2022 [16] [17]. The temperature changes between 1961 and 1990 were minimal (0.0067°C each year), but from 1991 to 2019 they dramatically rose (to 0.03°C per year) [18]. The IPCC AR6 (2021) (**Table 3**) predicts increases in global temperature of 1.5°C to 1.6°C in the near future (2030s), 1.7°C to 2.4°C in the middle future (2050s), and 1.8°C to 4.4°C in the far future (20th century) [19] [20]. In contrast to both the global and Bay of Bengal rates, our data (**Table 4**) show that SLR increases at much greater rates along Bangladesh’s coastline [21]. By the year 2021, the IPCC studies an increase in sea level of 0.11 to 0.12 meters in the near future, 0.23 to 0.27 meters in the medium term, and 0.54 to 0.86 meters in the long term [22]. **Table 5**’s (RCP 2.6) vs. continuously increasing emissions (RCP 8.5) comparison shows 90% confidence intervals in parenthesis [23] [24]. The respondents’ demographic data is displayed in (**Table 6**). According to the required questionnaire, a total of 250 individuals were chosen for interviews. Of them, 200 individuals (or 80%) have engaged in the process. The effects of the salinity that had snowed beneath are difficult for the people to comprehend, but in the wake of the SLR, it has become one of their main sources of sorrow. In addition, the main way that humans create salinity is by causing saline water to stagnate on cultivable land due to the influence of that particular area, which makes it difficult to grow crops [24]. The respondents’ perceptions on the causes of sea level rise (SLR) were gauged in where (**Table 7**) shows that they have a relatively high level of awareness regarding sea level rise. **Table 8** and **Figure 1** present perception-based indicators of the socio-economic impacts and human interests related to Sea Level Rise (SLR). Of the 200

respondents, most reported that primary data indicated that more than 60% of respondents believed that coastal Bangladeshis were currently facing more challenges, including decreased agricultural land, declining soil quality, unemployment, damaged infrastructure, disrupted tourism, an increase in the number of climate refugees, problems with the health and education systems, and so on. **Table 9** on conducting qualitative KIIs and focus groups at each location involved semi-structured, in-depth interviews. Three coastal districts of Bangladesh were chosen to host the KII, and thirty individuals of high social standing were chosen from 12 Union Parishads and 6 Upazillas. Getting the many, widely-held viewpoints inside a group is a great use for focus group discussions (FGDs). Bangladesh's three coastal districts—Patuakhali, Chittagong, and Cox's Bazar—hosted eight focus groups, each with twenty members. **Table 10** and **Figure 2** show that during FGDs and KIIs, respondents in Patuakhali district (42.5 percent and 17.65 percent), Chittagong district (62.5 percent and 16.67 percent), and Cox's Bazar district (47.5 percent and 28.57 percent) mostly hear about SLR from radio and television. Moreover, it's clear that online learning has consistently ranked lowest across all parameters. The two main contributing factors to the Physico-Chemical Impacts Scenario sector of the coastal population are salinity intrusion and coastal erosion, as shown in **Table 11** and **Figure 3** & **Figure 4**. According to respondents in KIIs and FGDs, sea level rise (SLR) has caused coastal erosion and accretion as well as ecological declination. In light of the many local and worldwide observations and recommendations, **Table 12** examines the risks and challenges related to SLR in where the port city of Chittagong is expected to be totally submerged by the Bay of Bengal within the next 100 years, and 2.5 billion people would likely become climate refugees, according to NASA [25]. Ocean boundaries can shift dramatically when the ocean territory actually shifts slightly, which could lead to conflict between powerful nations trying to get into the deep water to seize a special economic zone or blue economy, according to the UN Convention on the Law of the Sea (UNCLOS) and other agencies and researchers [26].

## 2. Objectives

- 1) Determine the possible hazards, problems, and effects on the coastal population of Bangladesh by evaluating the broader regional and global context for SLR;
- 2) To investigate how the social and ecological systems of Bangladesh's coastal settlements are significantly impacted by SLR.

### 2.1. Materials and Methods

This study combines quantitative and qualitative methods in its application. Through field research, Key Informant Interviews (KII), Focus Group Discussions (FGD), and reviews of secondary data sources like books, government reports, international reports, journals, maps, and news articles that highlighted sea level rise-related issues. The study makes an effort to identify SLR scenarios and their implications in order to address this. Applications like Ms. Excel, SPSS, STATA, and MATHLAB have also

been used to add a fresh viewpoint to the study of the collected data.

### 2.1.1. Study Area

Around the world, coastal life is seriously threatened by sea level rise. It is challenging to forecast how much the water level will rise. However, it is a problem that needs to be closely watched so that coastal areas can be ready for the effects. In consideration of the world's SLR, the eastern and central coastal zones, including the districts of Chittagong, Cox's Bazar, and Potuakhali in Bangladesh, are the two main geographic regions that this study will focus on. Topography around the Bangladesh coast and the locations of the selected study sites. The Cox's Bazar station is located at 21.45° N and 91.95° E, Charchanga at 22.22° N and 91.06° E, and Khepupara at 21.85° N and 90.08° E.

### 2.1.2. Sources of Data

This study attempts to estimate future sea level rise in Bangladesh and its coastal deltas, which will be compared to global sea level rise and Bay of Bengal Sea level rise and its effects on local, regional, and global levels. For this study, two types of data sources—secondary and primary—have been taken into consideration when analyzing the scenarios pertaining to the local and global causes and impacts of SLR. The Bangladesh Meteorological Department (BMD), the authorized institution for the data records nearest to the research area, is the source of the secondary data, which includes daily maximum, minimum, and mean temperatures, rainfall, and sea-level data. In order to collect the first historical sea records, self-recording tide gauges (TGs) were used to monitor the sea level and its variations, especially in coastal regions. The three stations are Hiron Point in the Sundarbans mangrove forest region (southwestern Bangladesh), Char Changa in the Meghna estuary (central Bangladesh), and Cox's Bazar on the southeast coast. All three have provided data for roughly twenty years without significant disruptions. The Government of Bangladesh's Inland Waterways and Transportation Authority (BIWTA) collects and monitors the initial tide gauge data, while the Bangladesh Water Development Board (BWDB) provided the tide gauge data for the Ganges Delta. However, improvements in space-borne radar altimetry during the past two decades have given rise to fresh perspectives on sea level fluctuations worldwide. When the US/French mission TOPEX/Poseidon (CNES/NASA) was launched in August 1992, the use of satellite altimetry to measure sea level was revolutionized and National Oceanic and Atmospheric Administration (NOAA) of USA. In the three coastal districts of Bangladesh, a field survey using a questionnaire, FGDs, and KII were done to provide the socioeconomic impacts for SLR.

## 3. Results and Discussion

### 3.1. Global Perspective

The following **Table 1** shows the breakdown of sea level rise over the recent period (1993+) using only satellite data, and the long term, back to 1900, when tide gauges were the source.

**Table 1.** Variables contributing to sea level rise and their recurring situations.

Indicators	Short-Term/Recent		Long-Term	
	Period	Scenario	Period	Scenario
Total Sea Level	(1993-2020)	3.34	(1900-2018)	1.56
Steric Sea Level (Thermal Expansion)	(2005-2019)	1.10	(1900-2018)	0.52
Ocean Mass* (Ice/Water added)	(2002-2020)	2.10	(1900-2018)	1.00
*Greenland	(2002-2020)	0.78	(1900-2020)	0.44
*Antarctic Mass Loss	(2002-2020)	0.41	(1900-2020)	0.08
*Glacier Mass Loss	(2002-2016)	0.57	(1900-2018)	0.70
Land Water Storage	(2002-2016)	-0.33	(1900-2018)	-0.21

Source: This is the Global Mean Sea Level (GMSL) obtained from the Integrated Multi-Mission Ocean Altimeter Data for Climate Research. The GMSL is a time series of globally averaged Sea Surface Height Anomalies (SSHA) from TOPEX/Poseidon, Jason-1, OSTM/Jason-2, and Jason-3.

Total sea level rise is calculated by adding steric sea level, which is essentially thermal expansion, plus ocean mass, which comes from melting Antarctic and Greenland ice sheets as well as mountain glaciers, and subtracting any land-based water storage or capture. Long-term sea level rise since 1900 has been averaging 1.56 mm/year, of which a third was caused by thermal expansion and a second two-thirds by the addition of water. The short-term pattern has not changed since 1993 or later, despite the fact that the rate of SLR has increased to 3.34 mm/year, or more than twice as much. Global sea levels have increased by an average of 21 - 24 millimeters since records began to be kept in 1880. The rate of SLR has been rising. One third of the rise throughout this 140+ year span has happened in the last 25 years. SLR increased from 1.4 mm/year for the most of the 20th century to 3.6 mm/year in a recent decade 2006 to 2015 (NOAA 2014). Sea levels rose by a record 91.3 millimeters above 1993 levels in 2020. This scenario demonstrates that the oceans' thermal expansion has made a sizable contribution to SLR, though not as much as the additional water brought about by ice melting (NOAA 2018).

**Table 2.** Scenario matrix of SLR integration with the 2022 global and asian climates.

Indicators in relation with the Climate Change and SLR	Scenarios for Global, Regional and Local	Global Effects	Regional and Local Effects
Atmospheric attentions of the three major greenhouse gases (CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O)	The gases reached new measured record highs in 2021, and according to real-time data, levels continued to rise in 2022.	In 2022, the yearly average global temperature was around 1.15°C ± 0.13°C higher than the pre-industrial average between 1850 and 1900. Global mean sea level rose to a record high in 2022 as a result of ocean warming and rapid ice mass loss from ice sheets.	The estimated mean temperature over Asia in 2022 was 0.73°C [0.63 - 0.78] above the average for the period of 1991 to 2020, making it the second or third warmest year on record. The continent has had warmer trends than the average for the world.

## Continued

Glacial Mass Balance	<p>Between October 2021 and October 2022, the average thickness of reference glaciers for long-term observations changed by more than 1.3 meters. Compared to the average loss over the previous ten years, this loss is significantly bigger. Since 2015, six of the top 10 most adverse mass balance years (1950-2022) have taken place.</p> <p>In the High Mountain of Asia region have seen mass loss during the last 40 years, with an accelerated trend in the 21st century.</p>	<p>Globally, glaciers lost more than 6000 Gt of ice between 1993 and 2019, according to the IPCC. This is similar to 75 lakes the size of Lac Leman, better known as Lake Geneva, which is the largest lake in Western Europe.</p>	<p>Due to a combination of limited winter snow, an influx of Saharan dust in March 2022, and heat waves between May and early September, the European Alps broke records for glacier melt. In Switzerland, 6% of the glacier ice volume was lost between 2021 and 2022, and 33% between 2001 and 2022.</p> <p>Preliminary data from the High Mountain Asia region show that mass changes will continue to be negative for the glaciological year 2021-2022.</p>
Changes in sea surface temperature	<p>Sea surface temperature variations have a significant impact on regional and global circulation patterns as well as marine ecosystems.</p> <p>With regional warming that is 5 - 7 times greater than the average worldwide warming, the Barents Sea is recognized as a hotspot for climate change.</p>	<p>A key contributing factor to the observed sea-ice retreat is sea-surface warming, which acts as a feedback mechanism to accelerate ocean warming.</p>	<p>The sea surface is warming at rates of more than 0.5°C per decade in several regions encircling Asia, which is roughly three times faster than the pace of global warming. The north-west Pacific Ocean experienced the warmest area-averaged SST anomalies—more than 0.6°C—in 2022.</p>
Ocean Heat Content	<p>The ocean absorbs about 90% of the energy that greenhouse gases trap in the climate system, which helps to moderate even higher temperature increases but puts marine ecosystems at risk.</p>	<p>In the last 20 years, ocean warming rates have been exceptionally significant. In spite of the ongoing La Nia, at least one marine heat wave occurred in 2022 on 58% of the ocean's surface.</p>	<p>Since 1993, the majority of Asia's marine region has seen an increase in the heat content of the ocean's top layer (0 - 700 m). The region's upper ocean layer experienced its fifth warmest year on average in 2022.</p>
Sea ice extent	<p>The overall volume of Arctic Sea ice is shrinking Following 2020 and 2021, 2022 is predicted to have the third-lowest volume since 2004. Antarctica's sea ice reached its lowest point ever and is now almost 1 million km<sup>2</sup> below the long-term (1991-2020) average.</p>	<p>Another essential measure of climate variability is the amount of the sea ice. Sea ice has an impact on local and planetary climates. The sea ice loss is significantly greater than the average of the previous ten years.</p>	<p>Approximately 15 million km<sup>2</sup> of sea ice reached its greatest extent in the Arctic on February 21-22, 2022, two weeks sooner than usual. On February 25, 2022, the Antarctic Sea ice area shrank to 1.92 million km<sup>2</sup>.</p>
Sea Level Rise	<p>The satellite altimeter record (1993-2022) shows that the global mean sea level (GMSL) increased once more in 2022, setting a new high. The worldwide mean sea level rise rate doubled between the first decade of the satellite record (1993-2002, 2.27 mm/yr) and the last (2013-2022, 4.62 mm/yr). The average annual increase in sea level between 2013 and 2022 was 4.6 mm.</p>	<p>Total land ice loss from glaciers, Greenland, and Antarctica contributed to the rise in the global mean sea level (GMSL) by 36% from 2005 to 2019; ocean warming (via thermal expansion) was responsible for 55% of the rise. Less than 10% of the variation came from variations in land water storage.</p>	<p>Most of Asia is experiencing a higher rate of sea level rise than the world average rate (GMSL) of 3.4 0.3 mm per year between 1993 and 2022. Even greater rates, exceeding 4 mm year, are present in the western tropical Pacific and the north-east Indian Ocean.</p>

### 3.2. Bangladesh's Perspective on Historical Climate Trends

20 physiographic units, based on agro ecology, soil physiographic, and climatic conditions, encompass Bangladesh. Bangladesh's main physiographic units are hills, terraces, and floodplains. The Ganges Tidal Floodplain (saline), Ganges Tidal Floodplain (non-saline), Meghna River Floodplain, Meghna Estuarine Floodplain (Charland), Chittagong Coastal Plains, and St. Martin's Island can be further split into six sub-regions based on physiographic units. According to Brammer (2014). The Bay of Bengal has one of the slowest rates of sea level rise (2 - 2.5 mm/year). Recent data, however, indicates that these rates are increasing because the Arctic and Antarctic ice is melting quicker than anticipated by prior models. Daily minimal and maximum temperature, and rainfall data recorded at the Potuakhali, Cox's Bazar and Chattogram inside the coastal belt of eastern and central coastal zones of

Bangladesh for 33 years from 1985 to 2017 by the Bangladesh Meteorological Department (BMD) have been retrieved here for the present research.

### 3.3. Temperature Rise Scenarios in Bangladesh

When compared to the previous three decades, Bangladesh's average temperature has increased dramatically. The temperature distributions between two successive periods differ dramatically, as shown in the plot below. Temperature fluctuations were negligible ( $0.0067^{\circ}\text{C}$  per year) between 1961 and 1990, but they increased significantly (to  $0.03^{\circ}\text{C}$  per year) from 1991 to 2019 (CEGIS, 2022). The average temperature has been rapidly increasing in recent decades. The average temperature increased by  $0.39^{\circ}\text{C}$  between 1991 and 2000,  $0.53^{\circ}\text{C}$  between 2001 and 2010, and  $1.06^{\circ}\text{C}$  between 2011 and 2019 (CEGIS, 2022). The winter and monsoon minimum temperatures have risen by  $0.45^{\circ}\text{C}$  and  $0.52^{\circ}\text{C}$ , respectively. As a result, winters are getting warmer, with an average annual temperature increase of  $0.02^{\circ}\text{C}$ . Even hotter summers during the pre-monsoon and monsoon have seen annual maximum temperature increases of  $0.022^{\circ}\text{C}$  and  $0.035^{\circ}\text{C}$ , respectively, and annual minimum temperature increases of  $0.024^{\circ}\text{C}$  and  $0.043^{\circ}\text{C}$ , respectively (CEGIS, 2022).

**Table 3.** Using down scaled climate data, further research on Bangladesh's temperature in various climate stress zones.

Climate Stress Area	Future Studied Annual Average Temperature ( $^{\circ}\text{C}$ )				
	Base (1981-2010)	SSP 1-2.6		SSP 5-8.5	
		2030s (2016-2045)	2050s (2036-2065)	2030s (2016-2045)	2050s (2036-2065)
<b>SWM</b>	25.8	26.5	27.1	26.2	27.7
<b>SEE</b>	25.6	26.2	26.8	26.1	27.5
<b>CHT</b>	25.3	26.1	26.7	25.9	27.4
<b>FPE</b>	24.9	25.7	26.4	25.4	27.0
<b>HFF</b>	24.5	25.3	26.0	25.1	26.8
<b>DBA</b>	25.5	26.2	26.9	25.8	27.5
<b>NNW</b>	24.9	25.6	26.3	25.2	26.9
<b>CBL</b>	25.3	26.0	26.8	25.7	27.4
<b>CHI</b>	25.2	25.9	26.6	25.7	27.3
<b>URB</b>	25.3	26.0	26.7	25.8	27.3
<b>BD</b>	25.5	26.1	26.8	25.9	27.4
<b>BoB</b>	28.1	28.7	29.0	28.7	29.4

Source: CEGIS analysis from the IPCC Sixth Assessment Report multi-model ensemble. Note: \*Sea surface temperature is used for future study. \*\*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.

### 3.4. Studied Temperature Rise

The IPCC AR6 (2021) forecasts global temperature increases of 1.5°C to 1.6°C in the near future (2030s), 1.7°C to 2.4°C in the middle future (2050s), and 1.8°C to 4.4°C in the future (20th century). According to climate studies for Bangladesh based on a downscaled multi-model ensemble (IPCC AR6), the potential range of future temperature rise is between 0.44°C and 0.69°C in the near term (2030s) and 1.3°C and 2°C in the mid-term (2050s) for the SSP1-2.6 and SSP5-8.5 scenarios. Surprisingly, in Bangladesh, SSP1-2.6 shows a near-term temperature rise that is 0.69°C higher than SSP5-8.5, which rises by 0.44°C. Mid-term warming is anticipated to be greater under SSP5-8.5.

### 3.5. Regional Sea Level Rise Time Series of Satellite Altimetry

The Laboratory for Satellite Altimetry at NOAA provided the satellite radar altimeter data that were used to calculate sea level rise estimates. Time series are available for the altimeters launched in 1991, including TOPEX/Poseidon (T/P), Jason-1, Jason-2, and Jason-3 (all launched in 1992), as well as ERS-2, GFO, and Envisat [76 - 78]. Sea level increase in the Bay of Bengal is greater than in other areas, according to the satellite radar altimeter data in **Table 4**. Our findings indicate significantly higher rates of SLR increase along Bangladesh's coast than either the global rate or the Bay of Bengal rate. The IPCC (2021) predicts a sea level increase of 0.11 to 0.12 meters in the immediate future, 0.23 to 0.27 meters in the medium, and 0.54 to 0.86 meters in the long term by the year 2100. But the IPCC warns that there is a lot of uncertainty in the long-term studying near the Bangladeshi coast. According to some worldwide models, the height could reach 1.75 meters. [National Adaptation Plan for Bangladesh (P-20, 21)].

**Table 5** indicates the scenarios which are studied for the land and population exposure in 2050 and 2100 considering high tide line (MHHW) or the mean annual maximum flood level (MAM), given sharp carbon cuts (RCP2.6) vs. continued rising emissions (RCP8.5) 90% confidence intervals in parentheses. The total national land area is roughly 136,000 km<sup>2</sup>, and the total population is about 1561 lakhs.

**Table 4.** Regional sea level rise time series.

Region—TOPEX and Jason-1, -2, -3 Seasonal Signals Retained	MSL Trend mm/yr (1992-2022)
Pacific Ocean	2.8 ± 0.4
North Pacific Ocean	3.0 ± 0.4
Atlantic Ocean	3.1 ± 0.4
North Atlantic Ocean	2.7 ± 0.4
Indian Ocean	3.3 ± 0.4

## Continued

Adriatic Sea	2.2 ± 0.4
<b>Global Sea</b>	<b>3.0 ± 0.4</b>
Baltic Sea	3.8 ± 0.4
<b>Bay of Bengal</b>	<b>3.9 ± 0.4</b>
Bering Sea	1.8 ± 0.4
Caribbean Sea	3.0 ± 0.4
North Sea	2.8 ± 0.4
Mediterranean Sea	2.3 ± 0.4
Sea of Japan	3.0 ± 0.4
South China Sea	3.8 ± 0.4
Yellow Sea	2.7 ± 0.4

**Table 5.** Anticipated national exposure to land and population in 2050 and 2100.

Scenario/ Water Reference	Land (Thousands km <sup>2</sup> )		Population (Lakh People)	
	2050	2100	2050	2100
<b>RCP2.6, MHHW</b>	0.6 (0.5 - 0.6)	0.8 (0.6 - 1.2)	4.7 (3.9 - 5.5)	7.2 (5.1 - 9.9)
<b>RCP8.5, MHHW</b>	0.6 (0.5 - 0.7)	1.0 (0.8 - 1.8)	4.9 (4.1 - 5.7)	8.6 (6.4 - 15.6)
<b>RCP2.6, MAM</b>	1.1 (1 - 1.4)	1.8 (1.2 - 2.3)	11.2 (9.5 - 13.9)	17.0 (11.0 - 22.2)
<b>RCP8.5, MAM</b>	1.2 (1 - 1.4)	2.2 (1.5 - 3.1)	11.9 (9.9 - 14.4)	20.7 (15 - 31.6)

Source: Bangladesh and the Surging Sea [P-11].

### 3.6. Perception, Human Interests & Socio-Economic Risk, Challenges and Impacts for Sea Level Rise (SLR) in the Selected Areas

This section's design was enhanced by the inclusion of a survey questionnaire for the general public and FGD and KII for a focused group of people. This portion of the study was primarily created with the intention of comprehending actual knowledge regarding dangers, obstacles, and repercussions as well as the general socioeconomic situations in connection to the SLR of their location.

### 3.7. Demographic Information of Respondents

Based on the specified questionnaire, a total of 250 individuals were chosen for interviews. Of these, 200 (or 80%) have engaged in the process. The responders' demographic data is displayed in **Table 6**. In this study, the percentage of female participants (28.3%) was much lower than that of male participants (71.7%). The majority of responders (38.0%) are in the 31 - 40 age range, followed by

26.8% in the 21 - 30 age range, and 3.4% in the 61 years or older age group. Study data reveals that a significant number of respondents (13.7%) had no education while 30.7% completed their primary education, followed by 21.5% who completed graduation, 17.6% who were able to complete high school education, 12.2% earned post-graduation degree and the tiniest group (4.4%) completed college education. People from different categories in terms of their occupation were the respondents of this study where 19.5% each came from the farmer, student, and day laborer categories, followed by 9.8% each from teacher, businessman, housewife, and shopkeeper categories, and the remaining 2.4% consisted of others.

**Table 6.** Demographic information of respondents (N = 200).

Variable	Percentage (%)	
<b>Gender</b>	Male	71.7
	Female	28.3
<b>Age</b>	≤20	10.7
	21 - 30	26.8
	31 - 40	38.0
	41 - 50	13.2
	51 - 60	7.8
	≥61	3.4
<b>Level of Education</b>	No Education	13.7
	Primary Level	30.7
	Secondary Level	17.6
	Higher Secondary Level	4.4
	Bachelor Level	21.5
	Master's or above Level	12.2
<b>Occupation</b>	Teacher	9.8
	Farmer	19.5
	Businessman	9.5
	Housewife	9.7
	Student	25.5
	Shopkeeper	20.5
	Others	6.5

Source: Field survey.

### 3.8. Perception on Sea Level Rise

This section measured the respondents' perception about the perception of reasons for Sea Level Rise (SLR). From the table above we can observe that their awareness level about sea level rise is comparatively high. In matter related to perception-based questions 8.6% of respondents replies low against the parameter SLR caused by naturally created global warming and melting glacier and 9.4% of respondents' conception is low against the parameter SLR caused by human induced global warming and melting glacier. Similarly, mean symbolizes the general average of responses provided by the respondents, while standard deviation specifies the variance of replies provided by the respondents to a query differ or diverge from the mean. In most of the cases, standard deviation's value is close to 1, as displayed in **Table 7** which indicates each question's response not far from the average.

**Table 7.** Perception on sea level rise.

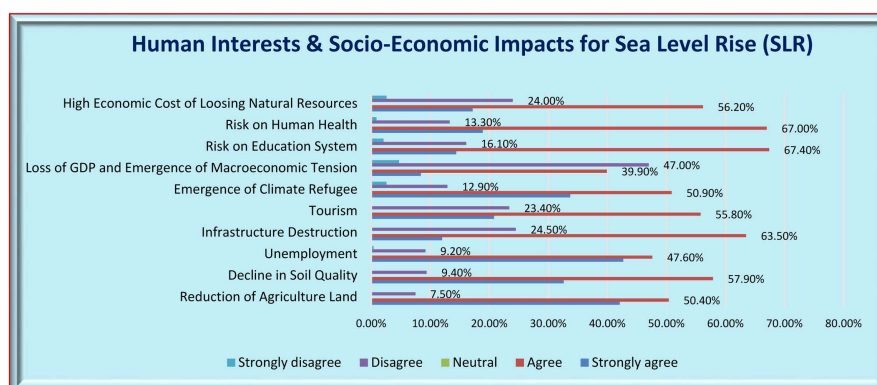
Opinion N = 200	Very High	High	Neutral	Low	Very Low	Mean	SD
SLR caused by naturally created global warming and melting glacier.	23.4%	51.9%	16.1%	8.6%	0.0%	3.90	0.854
SLR caused by human induced global warming and melting glacier.	10.5%	56.4%	23.6%	9.4%	0.0%	3.68	0.786

### 3.9. Human Interests & Socio-Economic Impacts for Sea Level Rise (SLR)

Regarding the perception-based indicators of the socio-economic impacts and human interests related to Sea Level Rise (SLR) in **Table 8** and **Figure 1**, the majority of the 200 respondents stated that primary data showed that over 60% of respondents thought that coastal Bangladeshis were currently facing more challenges, such as reduced agricultural land, declining soil quality, unemployment, infrastructure destruction, tourism disruption, increased numbers of climate refugees, and issues with the education and health systems, among other things. In answer to the inquiry on Bangladesh's Reduction of Agricultural Land for SLR. On this issue, over two-fourths of all respondents (50.4%) indicated agreement. Furthermore, more than 60% of respondents agreed on this point in response to the indicators of infrastructure destruction, risk to the educational system, risk to human health, and high economic cost of losing natural resources. The associated indicators' Standard Deviations (SD) show that they are all positive and remain at a considerable level.5 and above. Therefore, the socioeconomic level would have a very significant impact on both the GDP of our nation and the coastal population.

**Table 8.** Human interests & socio-economic impacts for sea level rise (SLR).

Opinion N = 200	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Mean	SD
Reduction of Agriculture Land	42.1%	50.4%	0.0%	7.5%	0.0%	4.27	0.806
Decline in Soil Quality	32.6%	57.9%	0.0%	9.4%	0.0%	4.14	0.829
Unemployment	42.7%	47.6%	0.0%	9.2%	0.4%	4.23	0.885
Infrastructure Destruction	12.0%	63.5%	0.0%	24.5%	0.0%	3.63	0.982
Tourism	20.8%	55.8%	0.0%	23.4%	0.0%	3.74	1.039
Emergence of Climate Refugee	33.7%	50.9%	0.0%	12.9%	2.6%	4.00	1.024
Loss of GDP and Emergence of Macroeconomic Tension	8.4%	39.9%	0.0%	47.0%	4.7%	3.00	1.181
Risk on Education System	14.4%	67.4%	0.0%	16.1%	2.1%	3.76	0.961
Risk on Human Health	18.9%	67.0%	0.0%	13.3%	0.9%	3.90	0.888
High Economic Cost of Loosing Natural Resources	17.2%	56.2%	0.0%	24.0%	2.6%	3.61	1.104

**Figure 1.** Human interests & socio-economic impacts for sea level rise (SLR).

### 3.10. Stakeholder Status

To achieve the study's goals, we conducted qualitative KIIs and focus groups at each location. Those with "great knowledge" who can throw light on the topics under investigation are known as key informants. For this study, important informants will be interviewed in-depth and in a semi-structured manner. Thirty individuals of distinguished social standing were selected from 12 Union Parishads and 6 Upazillas to conduct the KII in three coastal districts of Bangladesh. FGDs are quite useful in eliciting the diverse and widely held opinions within a group. Focus group discussions (FGDs) are a valuable method for gathering ideas from relatively homogeneous groups or from individuals who have common experiences, such as depression. Eight focus groups were held, with 20 participants each, in the three coastal districts of Patuakhali, Chittagong, and Cox's Bazar, Bangladesh. My goal is to bring together

a diverse sample of stakeholders with a range of perspectives in order to create a comprehensive picture of the phenomena and processes being studied. I thus pursued the help of important parties, including law-abiding residents who are knowledgeable but also experience SLR. Primary stakeholders' experiences are shaped by the settings they create, and secondary stakeholders will be chosen from among socio-ecological institutions and systems. Among these are decision-makers, teachers, therapists, medical professionals, and social workers.

**Table 9.** Concerning KII and FGDs, stakeholders.

Stakeholders	Patuakhali (Frequency)		Chittagong (Frequency)		Cox's Bazar (Frequency)	
	FGD	KII	FGD	KII	FGD	KII
Local Govt. Service Provider	04	05	02	01	03	01
Local Policy-makers	36	03	25	01	19	02
Researchers and academics	02	04	01	01	06	01
School/ College teachers	09	02	02	01	03	01
Social workers/NGO	12	02	05	01	05	01
Responsible person	17	01	05	01	04	01
<b>Total</b>	<b>80</b>	<b>17</b>	<b>40</b>	<b>6</b>	<b>40</b>	<b>7</b>

### 3.11. Source of Learning of the Stakeholders about SLR

The stakeholders are mainly aware of sea level rise, as shown in **Table 10** & **Figure 2**, which illustrate the sources of learning about sea level rise (SLR). Seven variables were developed in order to identify the source of learning on SLR. Radio and television were mentioned by the majority of participants in the three districts' FGDs and KIIs. Radio and television are the primary ways that respondents in Patuakhali district (42.5 percent and 17.65 percent), Chittagong district (62.5 percent and 16.67 percent), and Cox's Bazar district (47.5 percent and 28.57 percent) learn about SLR during FGDs and KIIs. Furthermore, it is evident that among all metrics, online learning has continuously come in last.

**Table 10.** Sources of information for stakeholders concerning SLR.

Source of learning	Patuakhali				Chittagong				Cox's Bazar			
	Frequency of FGD	Percentage (%)	Frequency of KII	Percentage (%)	Frequency of FGD	Percentage (%)	Frequency of KII	Percentage (%)	Frequency of FGD	Percentage (%)	Frequency of KII	Percentage (%)
Radio & TV	36	45.00	3	17.65	25	62.50	1	16.67	19	47.50	2	28.57
Newspaper	17	21.25	1	5.88	5	12.50	1	16.67	4	10.00	1	14.29
Internet	9	11.25	2	11.76	2	5.00	1	16.67	3	7.50	1	14.29
Workshop	12	15.00	2	11.76	5	12.50	1	16.67	5	12.50	1	14.29
Books & Journals	2	2.50	4	23.53	1	2.50	1	16.67	6	15.00	1	14.29
Others	4	5.00	5	29.41	2	5.00	1	16.67	3	7.50	1	14.29

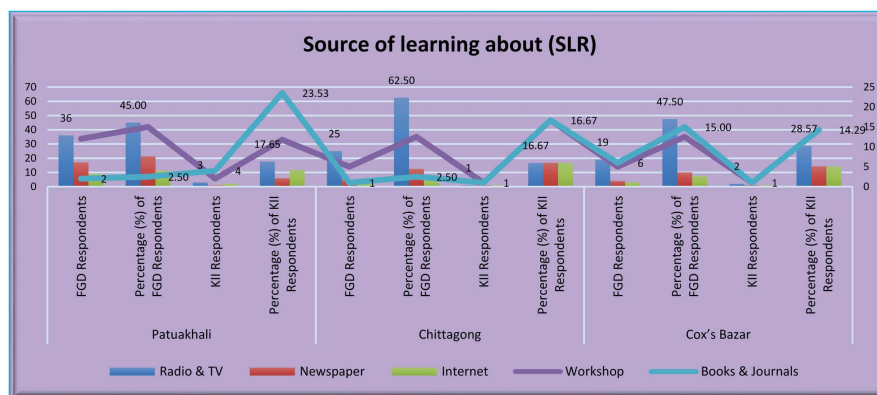


Figure 2. Sources of information for stakeholders concerning SLR.

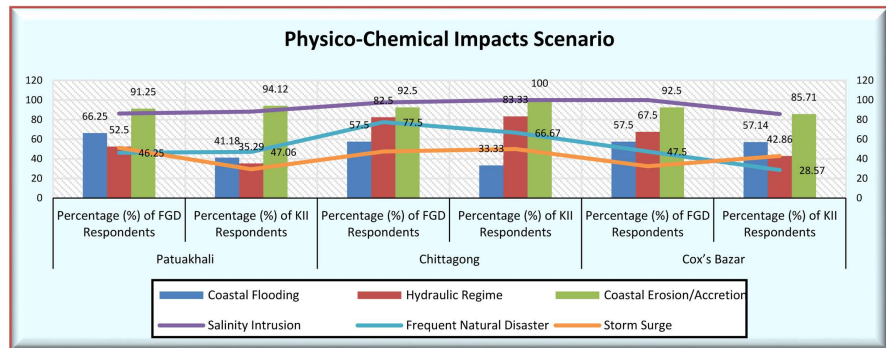
### 3.12. Identified Impacts for Sea Level Rise (SLR) to Face in the Coastal People

The Physico-Chemical Impacts Scenario and the Ecological Impacts Scenario, two sets of facts used to examine the consequences of the FGD and KII on society and the environment, each took into account nine characteristics, as shown in Table 11. Coastal flooding, hydrology, erosion and accretion, saline intrusion, frequent natural disasters, storm surges, deforestation, extinction of aquatic species, and extinction of wildlife were among these characteristics.

Table 11. Types of effects on coastal population for sea level rise (SLR).

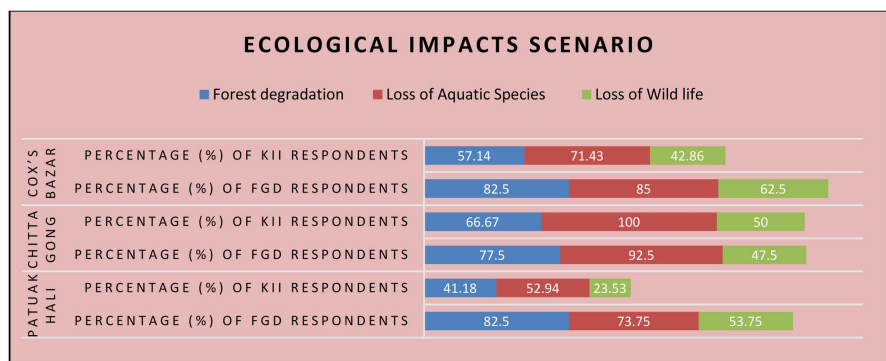
Type of impacts	Physico-Chemical Impacts Scenario											
	Patuakhali				Chittagong				Cox's Bazar			
	FGD Respondents	FGD Respondents' (%)	KII Respondents	KII Respondents' (%)	FGD Respondents	FGD Respondents' (%)	KII Respondents	KII Respondents' (%)	FGD Respondents	FGD Respondents' (%)	KII Respondents	KII Respondents' (%)
Coastal Flooding	53	66.25	7	41.18	23	57.5	2	33.33	23	57.50	4	57.14
Hydraulic Regime	42	52.5	6	35.29	33	82.5	5	83.33	27	67.50	3	42.86
Coastal Erosion	73	91.25	16	94.12	37	92.5	6	100.00	37	92.50	6	85.71
Salinity Intrusion	69	86.25	15	88.24	39	97.5	6	100.00	40	100.00	6	85.71
Frequent Natural Disaster	37	46.25	8	47.06	31	77.5	4	66.67	19	47.50	2	28.57
Storm Surge	41	51.25	5	29.41	19	47.5	3	50.00	13	32.50	3	42.86
Type of impacts	Ecological Impacts Scenario											
	Patuakhali				Chittagong				Cox's Bazar			
	FGD Respondents	FGD Respondents' (%)	KII Respondents	KII Respondents' (%)	FGD Respondents	FGD Respondents' (%)	KII Respondents	KII Respondents' (%)	FGD Respondents	FGD Respondents' (%)	KII Respondents	KII Respondents' (%)
Forest degradation	66	82.5	7	41.18	31	77.5	4	66.67	33	82.50	4	57.14
Aquatic Species Loss	59	73.75	9	52.94	37	92.5	6	100.00	34	85.00	5	71.43
Wildlife Loss	43	53.75	4	23.53	19	47.5	3	50.00	25	62.50	3	42.86

The coastal population’s sectoral inclination towards Sea Level Rise (SLR) is depicted in **Figure 3: Physico-Chemical Impacts Scenarios**. These figure’s outstanding high response indicators include salinity intrusion, indicated by the top yellow line, and coastal erosion and accretion, indicated by the grey-marked rectangular plot boxes. The respondents stated that they believed that coastal erosion and accretion, along with saline intrusion and 94.12% of KII participants in Patuakhali District, 92.50% of FGD and 100% of KII participants in Chittagong District, and 92.50% of FGD and 85.71% of KII participants, were the causes of sea level rise (SLR).



**Figure 3.** Physico-chemical impacts scenario.

However, **Figure 4** indicates that the primary reason of the decline in aquatic ecology due to sea level rise is the loss of aquatic species when compared to the Ecological Impacts Scenario. According to responses from 73.75% of FGD and 52.94% of KII participants in Patuakhali District, 92.50% of FGD and 100% of KII participants in Chittagong District, and 85% of FGD and 71.43% of KII participants, the primary cause of aquatic ecological imbalance brought on by sea level rise (SLR) is the loss of aquatic species.



**Figure 4.** Ecological impacts scenario.

### 4. Conclusions

Bangladesh is among the nations that are under threat from the increasing sea level. A large portion of Bangladesh is already underwater. A little over 3.5 million

**Table 12.** Numerous local and global observations and suggestions matrix of Some risks and challenges related to SLR.

Observation Indicators	Recommendations on Risk Factor for Local and Global
<b>1-meter (39.37 inch) SLR</b>	Our nation will experience a 17% to 20% land area inundation, and 2.5 billion people will become climate refugees. The majority of those who live within 100 km of the sea are at risk of becoming landless, making up two thirds of the world's population.
<b>Warn by NASA</b>	Within the next 100 years, it's likely that the Bay of Bengal will completely submerge the port city of Chittagong. Several island nations, including the Maldives, Papua New Guinea, and certain Pacific Ocean archipelagos, will be submerged by the sea. Additionally, the majority of the Middle Eastern, East Asian, and Northern African nations are under risk.
<b>SLR and the Ocean Boundaries' Challenges</b>	Conflict between the regional nations could develop in an effort to seize control of the expanding maritime zone. The UN Convention on the Law of the Sea (UNCLOS) designated ocean boundaries can change significantly when the ocean territory does, in fact, slightly. Getting into the deep water to seize a special economic zone or blue economy can cause conflict between powerful nations.
<b>SLR may pose a threat to fuel and energy infrastructure</b>	Due to the availability of large amounts of water for reactor cooling, the majority of nuclear or atomic power stations have been constructed along the seashore. SLR has the potential to harm nuclear reactors and result in nuclear explosions (i.e., The Fukushima Nuclear Power Plant in Japan was impacted by a tsunami in 2011).
<b>SLR might be dangerous for both national and international economies</b>	Local and global infrastructures, including the sea ports of various nations, would be impacted by SLR. The international trade is hampered and a state's economy will collapse if national or international sea ports are damaged or destroyed by SLR.
<b>Agriculture and faunal biodiversity are at risk due to SLR</b>	The entry of saline water into coastal land hinders grain production and changes crop quality. Large agricultural fields could be submerged by SLR, and saline water intrusion would reduce the capacity for production.
<b>SLR damages livelihoods and jeopardizes food security</b>	According to the Bangladesh Food Security Investment Framework Report 2010, the nation's rice production rate is at risk and could decrease by 3.9% by the year 2050.
<b>"Salt aggression" refers to the harm that SLR poses to fresh drinking water</b>	Due to SLR, there has been a serious influx of saline water into the plains, which poses a risk to local and global water security. Saline water will have an impact on the water source, and sweet water will become contaminated by it. As a result, dependence on groundwater will increase, leading to a shortage of clear drinking water that could potentially contain arsenic.

people, or 32% of Bangladesh's total land area, reside in coastal areas. Changes in the hydrodynamics of flow due to possible sea level rise and increase in river discharge will cause significant effects on the physical system, ecology, and human interests. The most significant impact would be on the agricultural sector. Global migration is being brought on by rising sea levels, and this is now a global rather than regional issue. The Directorate of Geological Survey of Bangladesh reports that it is possible to slow down climate change, especially the rate of sea level rise, because 1.2 billion cubic feet of sediment accumulate annually along Bangladesh's coast in the Bay of Bengal. This study was actually carried out to examine the ecological and socioeconomic effects on the coastal communities that are next to the

Bay of Bengal and how those issues may be resolved. The findings show that saline intrusion and coastal erosion are the two primary factors that contribute to the Physico-Chemical Impacts Scenario sector of the coastal population. According to 91.25% of FGD and 94.12% of KII participants in Patuakhali District, 92.50% of FGD and 100% of KII participants in Chittagong District, and 92.50% of FGD and 85.71% of KII participants, sea level rise (SLR) has caused coastal erosion and accretion. However, the loss of aquatic species is the main factor contributing to the aquatic ecological imbalance brought on by sea level rise (SLR), according to responses from 73.75% of FGD and 52.94% of KII participants in Patuakhali District, 92.50% of FGD and 100% of KII participants in Chittagong District, and 85% of FGD and 71.43% of KII participants. There is a risk to local and global water security because of the significant migration of saline water into the plains caused by SLR. Saline water entering coastal areas reduces grain yield and modifies crop quality. Saline water infiltration would lower the potential for production and cause large agricultural areas to be buried by SLR. As per the 2010 Bangladesh Food Security Investment Framework Report, the country's rice production rate is vulnerable and may decline by 3.9% by 2050.

Various studies have been conducted regarding the rising sea level and its effects in Bangladesh. However, the majority of the studies that I have come across regarding Bangladesh's sea level rise are either social science-based or strictly scientific in nature. However, this research's unique selling point is its application of a blend of social and scientific sciences. Thus, I believe that the outcomes of this work will provide a fresh perspective in contrast to the previous efforts, making them more useful to Bangladesh's coastal residents and policy-makers.

### **Acknowledgements**

This study will primarily focus on the eastern and central coastal zones of the world's SLR, which are located in the districts of Chittagong, Cox's Bazar, and Potuakhali in Bangladesh. As a result, it is proper to thank everyone who contributed to this endeavor, including all of the data sources and focus group and interview participants. Special recognition is given to Dr. Md. Humayun Kabir, Professor, Department of Geography and Environment, University of Dhaka, Dr. Debasish Kumar Kundu, Associate Professor, Department of Sociology, University of Dhaka, and Professional Vice Chancellor of BUP, and World Class Professor Dr. Khondoker Mokaddem Hossain for their technical guidance in preparing the paper.

### **Conflicts of Interest**

The authors declare no conflicts of interest.

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## Appendix

### Abbreviations and Acronyms

AR6, BMD, BoB, BIWTA, BWDB, CBL, CHI, CMIP6, CNES, CHT, CH<sub>4</sub>, CO<sub>2</sub>, COP, DBA, FGD, FPE, CEGIS, GMSL, HFF, IPCC, KII, MATHLAB, MHHW, MSL, MAM, NGO, N<sub>2</sub>O, NOAA, NASA, NNW, OSTM, RCP, SD, SLR, SST, SPSSA, STATA, SSHA, SSP, SWM, SEE, TOPEX, T/P, TRM, TG, URB, U.S., WCRP, WMO.

### Units

°C, cm, Gt, km<sup>2</sup>, m, mm, mm/yr.