NOVEL CLIMATE IMPACT ASSESSMENT TOOL FOR RURAL, URBAN, AND WATER INFRASTRUCTURE DEVELOPMENT IN CLIMATE-INDUCED COASTAL AREAS– A CASE STUDY

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ABSTRACT

Bangladesh is the seventh most vulnerable country to climate devastation. Resilient infrastructure is critical to a sustainable and functioning society. Infrastructure planning and design are highly complex processes encompassing the interests of numerous stakeholders while they are pressured by the uncertainty of climate change and societal transition. To address this issue, the Climate Resilient Local Infrastructure Centre (CReLIC), a Centre of Excellence established under the Local Government Engineering Department (LGED), developed Rapid Climate Impact Assessment Tools (RCIA) as part of the Climate Resilience Tool (CRT) Handbook for engineers to plan, design, and maintain infrastructure investments by providing a sequence of processes. Considering the high risk of climatic disasters in many districts in Bangladesh, it is necessary to evaluate the impact of climate change on the selected project across the country. Therefore, this study utilized the newly developed RCIA to assess the impact of climate change on the selected project in Satkhira Municipality, one of the most climate-induced districts among the 64 districts in Bangladesh. The RCIA was analyzed using Module I (desk-level analysis) and Module II (participatory approach). Apart from highlighting the present and future adaptation challenges, this study determined the necessary use of the Comprehensive Climate Impact Assessment (CCIA) tool to assess the selected project comprehensively, assuming that the project may not comply with the country's Environment Conservation Act (ECA) and Environment Conservation Rules (ECR). Based on the findings, the average rate of change in Extreme Climate Indices (the ECIs considered in the study included temperature, precipitation, dry days, and sea level rise) increased at regular intervals of about 8%, indicating worsening climate change in the study area. The Aggregate Hazard Baseline (AHB) was calculated at 73%, while the Aggregate Hazard Index (AHI) was determined for up to the year 2100. Additionally, the proposed tool identified the associated hazards and their current and future levels and helped to analyze the potential impact that could occur on the infrastructure, considering the location, preliminary design, and materials. Finally, the study identified the present and future adaptation challenges. Since the project does not meet all the necessary conditions, the study recommended conducting a CCIA to describe the terms of reference (technical specifications) for a more in-depth assessment of climate risks and impacts.

Keywords: *Climate change, climate resilience tool handbook, rapid climate impact assessment tool, adaptation challenges, climate-stress area*

1. INTRODUCTION

According to the 2018 United Nations Framework Convention on Climate Change (UNFCCC) report, agriculture, coastal infrastructure, water resources, and coastal erosion are all vulnerable to the impact of climate change (UNFCC, 2019). It was found that the population living in coastal areas is more vulnerable than those in other areas (Kamal et al., 2003). Scientists believe that the effect of increasing temperature, rainfall, and sea level rise is more pronounced in coastal regions, especially in terms of natural disasters, coastal inundation and erosion, salinity intrusion, deforestation, biodiversity loss, agriculture, and large-scale migration (DoE, 1997).

Being one of the most vulnerable countries to the effects of climate change, ranking in 7th place on Germanwatch's 2021 Climate Risk Index (Eckstein et al., 2021), Bangladesh recently ratified the Paris Agreement and its initial Nationally Determined Contribution (NDC). Bangladesh is located in the delta of the Ganges and the Brahmaputra in the northeastern part of the Indian Subcontinent, specifically between 23º34'N and 26º38'N and 88º01'E and 92º41'E. The country borders India to the west, north, and east while sharing a border with Myanmar to the southeast and the Bay of Bengal to the south (Masum, 2008). Bangladesh's Integrated Coastal Zone Management Plan (ICZMP) classified 19 of its 64 districts as coastal zones, which include Bagerhat, Barguna, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalganj, Jessore, Jhalokati, Khulna, Lakshmipur, Narail, Noakhali, Patuakhali, Pirojpur, Satkhira, and Shariatpur (Kamal et al., 2003).

The overall temperature in Bangladesh increased by 0.50 °C between 1976 and 2019 (Mahmud et al., 2021). It was projected that the temperature may increase by 1.4 °C by 2050 and 2.4 °C around 2100 (Mahmud et al., 2021). The country was also predicted to lose 17% of land and 30% of food production by 2050, and 30% of the population faces displacement (IMF, 2019). Moreover, climate change has caused successive natural disasters in the country, such as supercyclone Aila, Bijli, Mora, Nargis, Rashmi, Sidr, and Viyaru, resulting in catastrophic environmental damage and flooded vast coastal regions. The social environment was further hampered by the extreme impact of natural calamity, which was the ultimate cause of climate change (Shaibur et al., 2017). In short, the increased temperatures, erratic and irregular rainfall, drought, cyclones, salinity intrusion, and sea level rise adversely affect the country.

Satkhira, a coastal district in the southwestern coastal zone of Bangladesh, is highly exposed to various climatic factors, including variations in temperature, the erratic behavior of rainfall and sunshine hour, sea level rise, and cyclonic events. Satkhira is one of the most climate-induced coastal districts in the country. The district (between 21º36'N and 22º54'N and 88º54'E and 89º20'E) borders to the south by the Bay of Bengal and is part of the Khulna Division. The district covers 3858.33 km2 of land and has a population of over 2 million (Ahmed et al., 2003). Surrounded by a complex river network consisting of Kobadak, Sonai, Kholpatua, Morischap, Raimangal, Hariabhanga, Ichamati, Betrabati, and Kalindi-Jamuna, the district is the hotspot for various climate-induced hazards given its association with salinity intrusion, tidal inundation, waterlogging, cyclone and storm surges, and drought. Being a nature-based economy, most of the people of Satkhira depend on agriculture, fishing, and livestock for livelihoods. However, the climate-induced sudden and slow onset disasters disrupt the natural ecosystem in this district and make people's lives harder.

The climate of Satkhira: According to the Köppen Climate Classification subtype, Satkhira's climate is "Aw" (tropical savanna climate). Tropical savanna climates have a monthly mean temperature above 18 °C (64 °F) every month of the year and typically a pronounced dry season, with the driest month precipitation less than 60 mm (Weatherbase, 2023). The annual average maximum temperature of Satkhira reaches 35.5 °C (95.9 °F), while the minimum temperature is 12.5 °C (54.5 °F), and the annual rainfall is 1690 mm. **Table 1** shows the climate data of the Satkhira district.

Table 1: Climate data for Satkhira, Bangladesh (Weatherbase, 2023)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high (°C)	25	28	33	34	34	33	31	31	32	31	29	26	30
Average low (°C)	12	15	20	24	25	26	26	25	25	23	18	13	21
Average precipitation (mm)	7.6	23	30	71	140	290	350	330	270	140	25	7.6	1690

The solution to addressing climate change issues, including mitigating Greenhouse Gas (GHG) emissions, is mainly associated with the root cause of climate change and the impacts due to the changes, which requires dramatic, rapid, and informed actions. The available options/steps in addressing climate change are: 1. Mitigation, 2. Adaptation, and 3. Resilience.

The Local Government Engineering Department (LGED) is one of Bangladesh's leading engineering agencies responsible for developing the country's rural economy through local infrastructure development. One of the goals of LGED is to achieve Sustainable Development Goals (SDGs) and manage climate-related issues in the country. In 2020, LGED established the Climate Resilient Local Infrastructure Centre (CReLIC), a Centre of Excellence under LGED committed to systematically integrating climate change adaptation into the decision-making and operation of local infrastructures. CReLIC conducts research and undergoes guideline revision, knowledge management, capacity building, and awareness-raising activities.

Recently, CReLIC developed the Climate Resilience Tool (CRT) Handbook as a guideline for engineers to plan, design, and maintain infrastructure investments by providing a sequence of processes. The CRT Handbook can be applied to any link of the project development chain of any infrastructure (such as rural, urban, and water) at any size. It can also be used to discuss the development of infrastructure master plans with officials and stakeholders at local, regional, or national levels.

The Rapid Climate Impact Assessment (RCIA) is a tool in the CRT Handbook that assesses the impact of climate change on infrastructure projects. The tool proposes a set of analytical forms and matrices to facilitate the rapid tracking, collection, and processing of secondary and empirical information. RCIA also facilitates identifying the hazards and challenges for resilient climate engineering and determining the feasibility of the project implementation based on climate-related hazard considerations. RCIA is analyzed using Module I (desk-level analysis) and Module II (participatory approach). Under certain conditions, RCIA focuses on technical specifications using the Comprehensive Climate Impact Assessment (CCIA) tool, assuming that the project may not comply with the country's Environment Conservation Act (ECA) and Environment Conservation Rules (ECR), possesses a high hazard level, has over ten years of life, contains four or more information gaps, are linked to critical infrastructures, and consider the vulnerability of the surrounding population.

Given the severe risk of climatic disaster in Satkhira, it is necessary to evaluate the impact of climate change on the selected project in Satkhira Municipality using the newly developed RCIA. Therefore, this study was conducted to identify the extreme climatic and hydro-meteorological hazards and their impact on the infrastructure project and provide a technical recommendation based on the RCIA results. Apart from highlighting the present and future adaptation challenges, this study also determined the necessary use of the CCIA to assess the selected project comprehensively.

2. METHODOLOGY

Engineering practices of infrastructure projects, planning, and design have taken a stationary viewpoint of the climate by considering "Business as Usual" (BaU), believing that historical trends will represent the future climate and overlooking the extraordinary changes in "extreme values of extremes." These key aspects, not considered in BaU engineering processes and projects, lead to increasing infrastructure vulnerability, especially those with longer service life, making forward-looking design, operation, maintenance, and rehabilitation essential.

The CRT Handbook is crucial for equipping decision-makers and stakeholders with the knowledge and resources needed to address the impacts of climate change effectively. The CRT process can be carried out by engineers from their headquarters (HQ), decentralized offices, or by a combined task force, in any case, with the participation of local stakeholders. Figure 1 shows the schematic diagram of the six-part CRT Handbook developed by CReLIC.

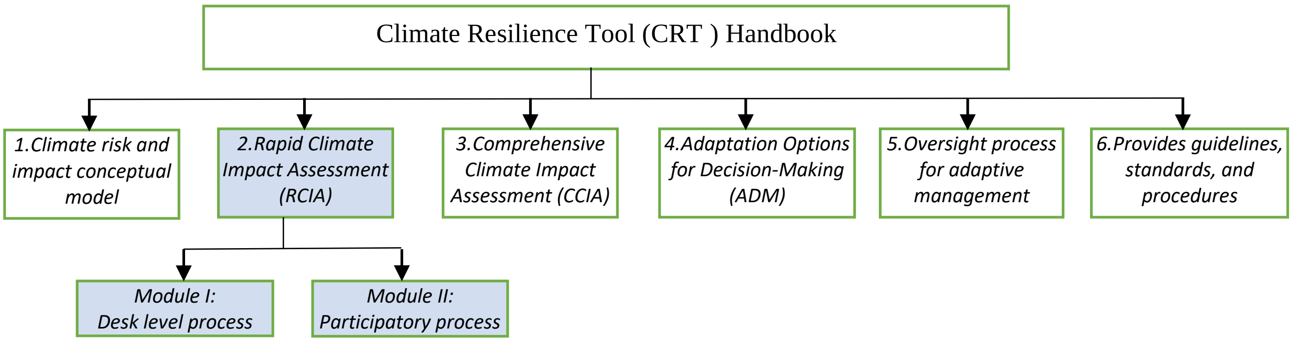


Figure 1: Schematic diagram of the CRT Handbook

RCIA is the second tool in the CRT Handbook, which assesses the impact of climate change on infrastructure projects. Based on climate-related hazards, RCIA determines the feasibility of the project for implementation using the following guidelines:

I. Estimate the level of hazard associated with climate signals and the aggregate impacts to which the project may be exposed now and throughout its lifetime.
II. Gather local knowledge of climate-related hazards and assess the conditions at the project site.
III. Identify adaptation challenges for the project by applying commonly used standard designs and materials and the selected site.
IV. Study findings and recommendations for improving the feasibility study process while defining technical adaptation specifications for design, materials, and possible site improvements.

The RCIA is a tool designed to be used in sub-project sectors for which the LGED is responsible, such as rural, urban, and water. Essentially, the RCIA formulates and conducts feasibility analysis of urban master plans or water resources development plans through I (desk-level analysis) and Module II (participatory approach).

The first phase of this study (Module I: Desk level study) was conducted in October 2022, while the second part (Module II: field level study) was in December 2022. A nine-person team was assembled by CReLIC, LGED, to carry out the study. The collected data were then analyzed and discussed. The following section presents the layout for Modules I and II. The study area is briefly described in **Form 1**.

2.1 Module I (Desk Level Process)

Module I is a step-by-step guideline for collecting and analyzing a preliminary assessment of secondary information extracted from various documents consulted and data management platforms found on the internet. Module I consists of 8 steps, as shown in **Figure 2**.

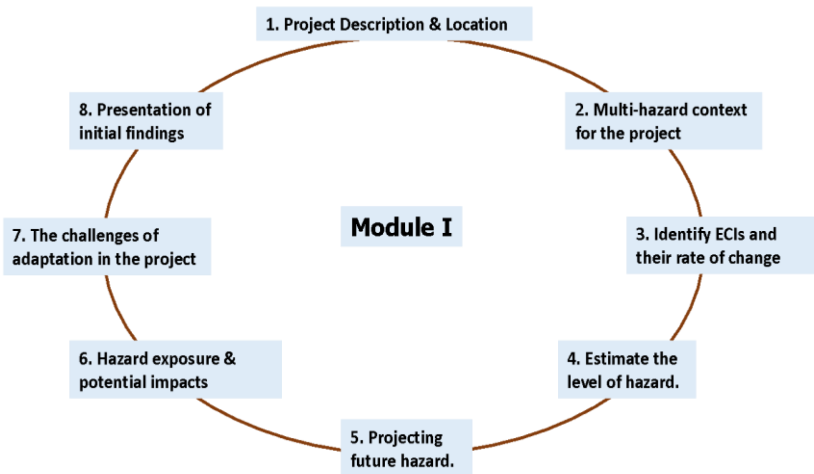


Figure 2: General procedures for climate impact analysis at the desktop level and with secondary sources

The first step involves a detailed description of the project or sub-project profile at the district level, and its likely location is requested to describe the initial design idea and materials for use (standard design). The second step is identifying whether the project site is in a hotspot or climate-stress zone. The general multi-hazard map of Bangladesh developed by the Center for Environmental and Geographic Information Services (CEGIS) (2021) highlights the spatial distribution of climatic hazards. A form is prepared that lists the climatic hazards and the affected districts.

The third step leads to the identification of Extreme Climate Indices (ECIs) and their rate of change. For this purpose, the technical guidelines were given for data collection on the "climate extremes of extremes" (90th-95th and/or 10th-05th percentiles) for the reference period, the historical period, and the projections to calculate the rate of change of the ECI of interest for civil engineering for 20 years and considering the emission scenarios of SSP2-4.5 and SSP5-8.5 (Shared Socioeconomic Pathway). Once the rate of change of the ECIs has been calculated, the fourth step is to collect documents, extract information, and calculate the aggregate hydro-meteorological hazard index (for the district of interest). This is followed by classifying the hazard levels in terms of Intensity, Duration, and Frequency (IDF) and establishing the proportional relationship between the ECIs and the Aggregate Hazard Index (AHI).

Once the proportional relationship between the ECIs and the hazard index is established, the fifth step involves calculating the Aggregate Hazard Baseline (AHB). The future hazard index is projected, and the hazard level can be classified for the same periods as the ECIs (from 20 years to 2100). Ultimately, it is vital to identify the most relevant hydro-meteorological hazard to the project or sub-project. In the sixth step, the hazard levels are projected into the future, considering the climate change scenarios (SSP2-4.5 and SSP5-8.5) for the same 20-year periods used to calculate the ECIs.

The seventh step analyzes the exposure and potential impact (loss probability and expected damage) corresponding to a specific type of infrastructure. This is the stage at which the knowledge and experience of the engineering team in charge of the sub-project comes into play. The objective is to enhance the resilience of the infrastructure and ensure that the development projects are designed to withstand the impacts of climate change. This step involves typical teamwork to identify the adaptation challenges that the sub-project will face, given the expected impacts of climate change.

Step eight summarizes the findings of the RCIA. The final report explains the analytical steps carried out, the results of each step, the conclusion, and the following steps to be taken. Assuming the project meets the exclusion criteria, the engineering team must prepare the required items from the Project Feasibility Study Report. Otherwise, the next step is to proceed with the CCIA, and the technical team shall propose the technical specifications for the scope of the CCIA.

2.2 Module II

Once the Module I process is completed, the next phase is Module II, which facilitates a participatory meeting and site assessment with local stakeholders. The stakeholder workshop discusses the hazards affecting the area's hazards potential impacts on the project and incorporates their knowledge of hazards, the experience of previous disasters, and suggestions for adaptation challenges.

Module I may have some data marked "unknown," which denotes insufficient information or poor comprehension of that aspect. In addition, certain misunderstandings or data omissions may occur in some form. Hence, various stakeholders, including local/regional LGEDs, government officials, non-governmental organizations, international cooperation agencies, and professional organizations, were bound to attend the participatory sessions to partially gather information and rectify the scenario from Module I.

The RCIA was oriented towards determining the technical specifications leading to the comprehensive climate impact assessment using the CCIA tool, particularly in certain situations, such as the size of the investment, environmental condition, the complexity of the infrastructure works, and/or the high level of hazard at the location of the proposed project. The modules' outcomes summarize the technical requirements should CCIA be required for subsequent action.

3. DISCUSSION

The study report was prepared based on Modules I and II. The study report discussed the project's exposure to extreme climatic and hydro-meteorological hazards, potential impacts, adaptation challenges, and technical recommendations based on the RCIA tool. The findings also outline the project's compliance with the Project Feasibility Study Report requirements and conclude with a technical recommendation.

3.1 Project Description and Hazardous Context

The project's brief description and the general contexts of hazards to which it may be exposed during its lifespan are presented. **Form 1** provides a comprehensive overview of the project's details, including the project type, location, duration, design, material considerations, and a brief description of the project site. **Figures 3** and **4** display the project maps to help readers better understand the project and its location, respectively.

<table>
<tr><th colspan="5">Form 1: Project general information at the feasibility stage</th></tr>
<tr><td>Project name</td><td colspan="4">Climate Resilient Infrastructure Mainstreaming Project (CRIMP)</td></tr>
<tr><td>Scheme name</td><td colspan="4">Improvement of RCC (Reinforced Cement Concrete)road from Golam Rahman VC's House to Rishirampur, Ward no-3, Chainage 0-1515 m</td></tr>
<tr><td>(a) Sponsoring ministry/division
(b) Implementing agency</td><td colspan="4">a) Local Government Rural Development and Cooperatives/Local Government Division
b) Local Government Engineering Department</td></tr>
<tr><td rowspan="2">Project brief description</td><td colspan="2">Problems to be solved:</td><td colspan="2">Project objectives:</td></tr>
<tr><td colspan="2">➢Pavement integrity/life
➢Waterlogging
➢Saline effect
➢Connectivity
➢Urban flood management
➢Drainage
➢Settlement issues
➢Construction materials quality/availability
➢Protection against soil erosion
➢Embankment stability
➢Accessibility throughout the year</td><td colspan="2">● Climate resilient road infrastructure improvement
● To provide better access to social and economic infrastructures (such as schools, cyclone shelters, rural markets, and households)
● Increase livelihood standards by providing better connectivity
● Increase economic activities
● Reduce the vulnerability of the coastal population to natural disasters through climate-resilient urban infrastructure</td></tr>
<tr><td>Sector and subsector</td><td colspan="4">Urban sector</td></tr>
<tr><td>Project category</td><td colspan="4">Orange category (Based on Environment Conservation Rules 1997)</td></tr>
<tr><td rowspan="4">Sub-project
What is the expected lifespan of the sub-project?</td><td colspan="2">Sub-project (Major components)</td><td>Area</td><td>Length</td></tr>
<tr><td colspan="2">RCC road construction</td><td>Ward 3</td><td>1515 m</td></tr>
<tr><td>> 10 years</td><td>> 30 years</td><td>> 50 years</td><td>> 70 years</td></tr>
<tr><td>☑</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td rowspan="3">What kind of sub-project is it?</td><td colspan="4">☑ New sub-project</td></tr>
<tr><td colspan="4">☐ Rehabilitation sub-project</td></tr>
<tr><td colspan="4">☐ Reconstruction sub-project</td></tr>
<tr><td rowspan="2">Sub-project geographic location</td><td>Division</td><td>District</td><td>Upazila</td><td>Others (City corporation or municipality)</td></tr>
<tr><td>Khulna</td><td>Satkhira</td><td>Satkhira Sadar</td><td>Satkhira Municipality</td></tr>
</table>

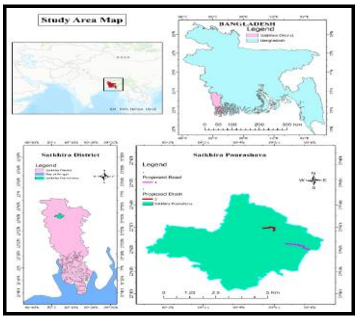


Figure 3: Map of the study area.


Figure 4: Existing scenario of the proposed road

Form 2 shows the corresponding prominence of climate hazards, and Figure 5 displays the multi-hazard risk map depicting Bangladesh's spatially climate-stress areas. The risk map segregates the country into 11 climate-stress areas and includes all hazards. Most areas face five or more disasters. With more frequent or intensified disasters due to climate change, the climate-stress areas would experience more significant risks in the future. Satkhira district belongs to the "South-western coastal area and the Sundarbans (SWM)" and "Urban areas (URB)" climate-stress area (NAPB(MoEFCC), 2022).

3.1.1 South-Western Coastal Area and the Sundarbans (SWM)

The SWM covers an area of 30,646 km2 and is home to 13.57 million vulnerable people. The area faces the most climate-related hazards, as summarized in Form 2. In recent years, many households have experienced severe damage due to cyclones, salinity, and lightning. Future climate change will intensify these stresses. While the Sundarbans is an essential part of Bangladesh's natural ecosystem and biodiversity, it is now under threat due to sea level rise (NAPB(MoEFCC), 2022).

3.1.2 Urban Areas (URB)

Satkhira district is one of 43 cities grouped under the URB. Climate change and associated urban risks substantially impact the overall economy of URB. As such, Satkhira City faces a high risk of urban flooding due to the changing rainfall patterns and has reported recurrent urban drainage problems. People who migrated to urban areas due to climate-induced disasters are the most vulnerable in society (NAPB(MoEFCC), 2022).

Based on **Figure 5** and **Form 2**, the most critical climate change-induced hazards in the study area (climate-stress area = SWM + URB) are rainfall variability, river floods, urban floods, sea level rise, salinity, cyclonic storm surges, droughts, extreme heat waves, extreme cold, riverbank erosion, and lightning.

3.1.2.1 The major climate signals and hazards and the potential impacts for the study project are summarized below (NAPB(MoEFCC), 2022):

1. *Excessive rainfall:* Urban drainage problem resulting in prolonged waterlogging, road damage, disrupted communication, recurrent investment losses, and loss of infrastructure.
2. *Extreme heat:* Drinking/construction water crisis, reduced work hours for marginalized people, and road and flexible pavement cracking and damage.
3. *Frequent river floods:* Houses, roads, and other infrastructure inundated and damaged, communications problems, investment losses, and severe water and sanitation problems.
4. *Early or frequent flash floods:* Houses, roads, and other infrastructure inundated and damaged, communication problems, and investment losses.
5. *Severe droughts/water scarcity:* Drinking water crisis in urban areas.
6. *Frequent landslides:* Damage to settlements, communication problems, and road and infrastructure damages.
7. *Increased salinity:* Severe drinking water crisis, corrosion of road and bridge materials due to salt, and the need for recurrent investment.
8. *Frequent cyclones and storm surges:* Loss of houses and damages to properties.
9. *Sea level rise:* Infrastructure damages, recurrent loss of investment, and increased drinking water crisis due to salinity intrusion.

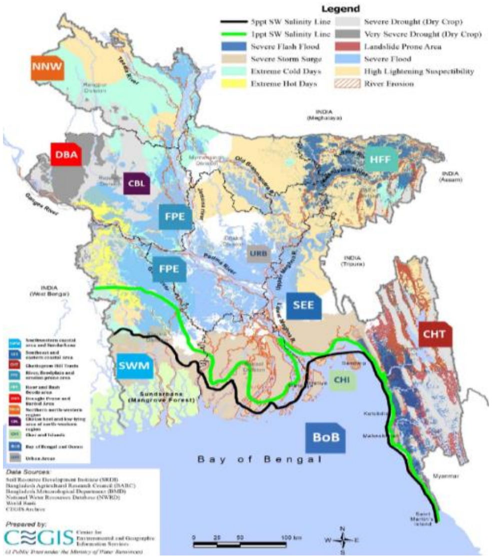


Figure 5: Climate-stress areas of Bangladesh. Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh in National Adaptation Plan of Bangladesh (2023–2050)

Form 2: Climate-stress areas and related hazards			
Climate-stress area	**Districts**	**The prominence of climate hazards**	**Mark the project location**
South-western coastal area and Sundarbans (SWM)	Satkhira, Khulna, Bagherhat, Pirojpur, Barguna, Barisal, Patuakhali, Jhalokhathi, Bhola, Shariatpur, Gopalganj, Jashore, Sundarbans	Rainfall variability, river flood, sea level rise, salinity, cyclonic storm surge, drought, extreme heat wave, extreme cold, riverbank erosion, and lightning	☑
Urban areas (URB)	43 cities	Rainfall variability, urban flood, sea level rise, salinity, cyclonic storm surge, drought, extreme heat wave, extreme cold, and lightning	☑

(Source: National Adaptation Plan of Bangladesh (NAPB(MoEFCC), 2022))

3.2 Hazard Exposure Context (Identify ECIs and their Rate of Change)

The extreme hydro-meteorological events and project predictions for the next few decades are primarily focused on the ECIs (Key Climate Signals of Hydro-meteorological Hazards) and identify the rate of change of hydro-meteorological events in the coming decades. An Aggregate Hazard Index (AHI) was then calculated, and the future hazard levels were plotted according to the AHI. Finally, the project's hazard exposure levels for 2020–2039, 2040–2059, 2060–2079, and 2080–2100 were estimated.

The main climate change signals of hydro-meteorological hazards' were temperature, precipitation, dry days, and sea level rise. The climate change signals of the ECIs and their average rate of change for the coming decades are illustrated in Form 3. Specifically, **Form 3** considers five time periods for the next ten decades, from 1995 to 2100. Each period/projection was considered for two decades. The relevant ECI data were collected from the Climate Change Knowledge Portal (CCKP) (CCKP, 2023) and IPCC (Intergovernmental Panel on Climate Change) Interactive Atlas platforms (IPCC, 2023). The median year was taken as the reference year for each period. The rate of change of ECIs was then calculated based on the 2004 median for 1995–2014, with the 90th percentile data considered.

According to **Form 3**, the temperature change rate for the projected year 2020–2039 (median year of 2030) was not remarkable. Although the people of Satkhira might not experience temperatures above 45 ºC up to 2079, the temperature (TX35) might regularly increase by about 10% every 20 years for the next six decades (from 2040), while the increasing rate might be 5 ºC and 3 ºC for TX40 and TX42, respectively. On the contrary, the cumulative precipitation change rate was higher than the TX index. The rate of change is approximately follows the same pattern.

Regarding "consecutive dry days," the rate of change of ECI for the currently projected decades was 4.53%, which might decrease in the next four decades. This trend does not indicate an improved climate condition because the population in Satkhira might experience heavy rainfall and high temperatures within the same period. The most alarming ECI was the Sea Level Rise (SLR), which showed an increasing trend of up to 70% by 2100 compared to 2004. For example, the sea level might rise 20 cm by 2050 compared to 2004. Overall, the average rate of change of ECIs increased with a regular interval of 5–8%, signifying that the climate change in the study area would worsen. Therefore, the potential hazards should be identified and categorized according to the CRT Handbook.

The damaging or disruptive potential of hazards is directly related to the IDF (Intensity, Duration, and Frequency) and vulnerability of extreme events. Note that this study focused only on the potential hazards. **Form 4** identifies the extreme hydro-meteorological events and their current magnitude in IDF and hazard level in the study area. Various recent documents were reviewed to identify potential hazards, such as Community of Practice documents, LGED's Project documents, EIA, and CReLIC documents (CReLIC, 2023). Then, the information obtained was complemented by reviewing "Disaster and Climate Risk Information Platform (DRIP)" (DRIP, 2023)and "Think Hazard" digital platforms (ThinkHazard, 2023). **Form 4** also normalizes hydro-meteorological hazard levels in three percentage ranges (high, moderate, and low) according to IDF, as used in disaster risk management. Subsequently, the Aggregate Hazard Baseline (AHB) (**Form 5**) was used to estimate the percentage change in hydro-meteorological hazards in the Satkhira District (**Form 4**, dependent variable) for future decades based on the percentage change in ECIs (**Form 3**, independent variable) in the same decades. Finally, future climate change scenarios of the hydro-meteorological hazards were linked.

The average rate of change of ECI (**Form 3**) and AHB (**Form 5**) were used to calculate the AHI (AHI = AHB + % ECI change) and reclassified for the four time periods. Form 6 shows the AHI and hazard reclassification projections based on the ECI projections, with a "High ≤ 9.5" for the hazard level from 68% to 92.70% throughout the period. Eventually, an analysis was conducted to determine the level of hazard exposure to the impact of future hydro-meteorological hazards. **Form 7** shows the projection of each hazard level for the subsequent decades by considering the color classification obtained from Form 6 with each hydro-meteorological event. **Figure 6** shows the team discussion at the field level during the data collection process.

Form 3: Annual Extreme Climate Indices (ECIs) and the projected percentage of change for selected emission scenarios through multi-model ensemble

Extreme Climate Index	Unit	Period 1995-2014	Projection							
			2020–2039		2040–2059		2060–2079		2080–2100	
		Value in 2004	Value in 2030	% change	Value in 2050	% change	Value in 2070	% change	Value in 2090	% change
Days with TX above 35 ºC (TX35)	Days	*101.19*	*104.47*	*0.90*	*136.07*	*9.56*	*173.9*	*19.92*	*223.89*	*33.62*
Days with TX above 40 ºC (TX40)		*33.65*	*35.75*	*0.58*	*49.66*	*4.39*	*65.54*	*8.74*	*83.85*	*13.75*
Days with TX above 42 ºC (TX42)		*20.38*	*21.80*	*0.39*	*30.86*	*2.87*	*45.26*	*6.82*	*55.04*	*9.50*
Days with TX above 45 ºC (TX45)		*0*	*0*	*0.00*	*0*	*0.00*	*0*	*0.00*	*30.80*	*8.44*
Largest monthly cumulative precipitation	mm	*613.4*	*647.04*	*5.48*	*712.38*	*16.14*	*758.3*	*23.62*	*758.24*	*23.61*
Maximum 1-day precipitation (RX1day)		*134.13*	*152.56*	*13.74*	*171.32*	*27.73*	*178.06*	*32.75*	*177.75*	*32.52*
Maximum 5-day precipitation (RX5day)		*312.37*	*332.2*	*6.35*	*360.04*	*15.26*	*375.77*	*20.30*	*394.37*	*26.25*
Maximum number of consecutive dry days	Days	*111.28*	*127.81*	*4.53*	*116.33*	*1.38*	*120.46*	*2.52*	*127.95*	*4.57*
Sea level rise (SLR)	Meter	0	0.22	22	0.47	47	0.78	78	1.2	120
Average rate of change (%)			**6.75%**		**15.54%**		**24.08%**		**30.25%**	

Form 4: Climate-related hazards that have occurred in the District during the reference period, rated by its IDF						
Hydro-meteorological events observed around the last 10 years	**Max value (IDF)**	Current hazard rating classification and its percentage of weights				**N/A**
		a	b	c	d	
		High ≤ 95%	**Moderate ≤ 65%**	**Low ≤ 35%**	***Unknown 40%**	
1. **Hw.** Heatwave	38º	√				
2. **Ec**. Extreme cold	------				√	
3. **Hr.** Heavy rain	56 mm/24 h		√			
4. **Cy.** Cyclone	High	√				
5. **Dg.** Drought	------	√				
6. **Ls.** Landslide	------					√
7. **Hs.** Hailstorm	------			√		
8. **Fl.** Flood/coastal flood	Very high					√
9. **Ff.** Flash flood	------	√				
10. **Re.** Riverbank erosion	Very high			√		
11. **Sd.** Strong sedimentation	Moderate				√	
12. **Wc.** Water scarcity	------	√				
13. **Lt.** Lightning	Insignificant			√		
14. **Ss.** Storm surge	No extremes		√			
15. **Es.** Extreme swell	------					√
16. **SLR.** Sea level rise	Insignificant	√				
17. **Si.** Salinity intrusion	Important process	√				
18. **Ce.** Coastal erosion	Seems important				√	
Aggregated Hazard Index (AHI) for the reference period		7	2	3	3	3
		$68\% = \frac{(665 + 130 + 105 + 120)}{(7 + 2 + 3 + 3)}$				

Note: Formula to calculate the Aggregated Hazard Index (AHI): $\boldsymbol{Hi} = [\boldsymbol{H}(\boldsymbol{\Sigma a}) + \boldsymbol{M}(\boldsymbol{\Sigma b}) + \boldsymbol{L}(\boldsymbol{\Sigma c}) + U(\boldsymbol{\Sigma} d)]/\boldsymbol{Nh}$
Hi = Aggregated Hazard Index; **Nh** = Number of hazards considered in column a, b, c, or d; **H** = High weight (95%); **M** = Moderate weight (65%); **L** = Low weight (35%); U = Unknown (40%); **Σa** = Sum column a; **Σb** = Sum column b; **Σc** = Sum column c; **Σd** = Sum column d

Form 4: Aggregated Hazard Baseline (AHB)		
ECIs	**Value**	**AHB**
− Days with extreme temperatures observed over the entire period	*20.38*	***68%***
− Millimeters of precipitation in the wettest month of the entire period	*613.4*	
− Millimeters of precipitation accumulated on the wettest day of the entire period	*134.13*	
− Millimeters of precipitation accumulated on 5 consecutive rainy days in the whole period	*312.37*	
− Consecutive days with no precipitation observed over the entire period	*111.28*	
− Millimeters of sea elevation for the entire period	*0*	

Form 5: Projections of the Aggregate Hazard Index (AHI) and the hazard level based on Form 3 (ECI projections) and Form 4				
Proportional Baseline Ratio (PBR) 1995–2014	**Hazard index 2020–2039**	**Hazard index 2040–2059**	**Hazard index 2060–2079**	**Hazard index 2080–2100**
68%	74.75%	83.54%	92.08%	98.25%

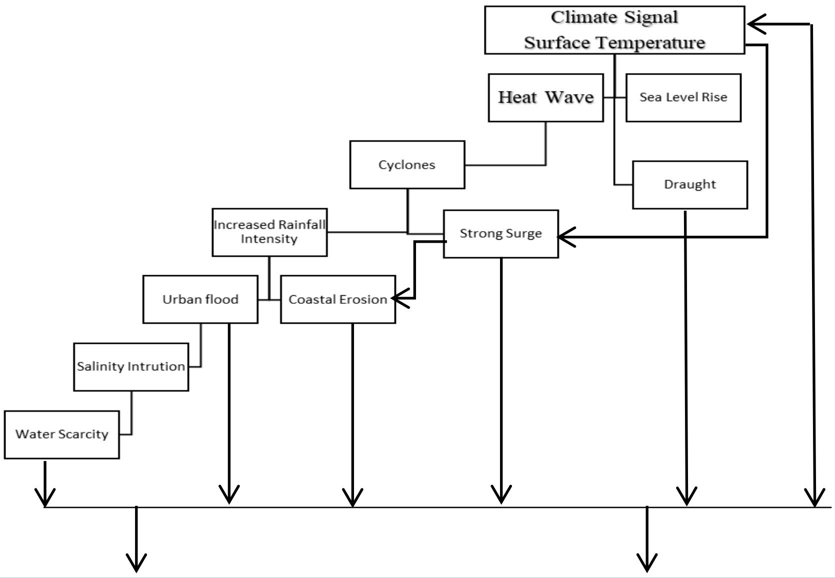
Form 6: Projections of the hazard level in the next decades																		
Period	**Hw**	**Ec**	**Hr**	**Cy**	**Dg**	**Ls**	**Hs**	**Fl**	**Ff/Uf**	**Re**	**Sd**	**Wc**	**Lt**	**Ss**	**Es**	**SLR**	**Si**	**Ce**
1995– 2014																		
2020– 2039																		
2040– 2059																		
2060– 2079																		
2080– 2100																		

Figure 6: Team discussion at the field level

3.3 Impact Chain

Form 7 shows the projection of each hazard level (from **Form 4**) for the subsequent decades by considering the color classification obtained from **Form 6** with each hydro-meteorological event. An impact chain was determined (**Figure 7**) to establish a chain of aggregate impacts for the physical components and services to be provided. After deciding the impact chain, **Form 8** was used to describe the physical components and services of the project that could be damaged, lost, or altered and the mechanism.

3.3.1 Impact Chain



In the road	In the service
➢Top layer damage ➢Shoulder damage ➢Different types of pavements (especially flexible pavement) cracking and damage ➢Loss of infrastructure ➢Iron cast occurs on RCC roads ➢Damage to different layers of the road ➢Corrosion of road and bridge materials due to salty water ➢Decreased life span of the roads	➢Communication disruption ➢Sanitation problems and inadequate drinking water ➢Recurrent investment losses ➢Drinking/construction water crisis ➢Sanitation problem ➢Salinity intrusion in nearby crop fields and road surfaces ➢Damage to settlements ➢Work hours reduced for the marginalized people ➢Spreading of waterborne diseases ➢Reduced economic growth

Figure 7: Impact chain of the project area

Form 7: Impact analysis
Question 1: What physical elements of the project could suffer loss or damage? Damage to the road surface, shoulders, and/or different layers may occur. Flexible pavements can show cracking and damage. Iron rust can be seen on RCC roads/structures. Temperature rise could lead to deterioration of pavement integrity, including softening and bleeding of asphalt from traffic-related rutting. As the temperature rises, the thermal expansion of steel structures, expansion joints in bridges, and paved surfaces could visibly grow. Saline exposure can cause corrosion of road and bridge materials. Therefore, the lifespan of a road/structure may be reduced. The formation of waterlogging due to heavy rainfall, urban flooding, inadequate drainage systems, and high elevation of outfall beds can spread waterborne diseases, sanitation problems, insufficient drinking water, and salinity intrusion in nearby crop fields and road surfaces. **Question 2:** What services could be interrupted or altered? In what way? Damage to road surfaces, shoulders, and/or different layers could disrupt economic activities and connectivity. Flooding could wash away or damage road surfaces, resulting in economic activity and communication loss. Other services could be disrupted due to waterlogging, flooding, and road/structure damage, such as: ➢ Sanitation problems and inadequate drinking water ➢ Recurrent investment losses ➢ Drinking/construction water crisis ➢ Salinity intrusion in nearby crop fields and road surface ➢ Damage to settlements ➢ Work hours reduced for the marginalized people ➢ Spreading of waterborne diseases ➢ Reduced economic growth

3.4 Project Adaptation Challenges

The potential adaptation challenges a project may face due to hazards and their potential impacts, ranking them based on the design, materials, and location and highlighting their importance and potential consequences. It provides a comprehensive understanding of the potential risks and their potential impacts.

Form 9 identifies the central problematic situations in three categories based on the three aspects: (1) standard design, (2) standard materials, and/or (3) project site. All three aspects of the project might have weaknesses that could lead to the project's eventual failure.

Form 10 shows the possible loss or damage due to weakness in the three aspects of the project. All three aspects are critically important to build a climate-resilient infrastructure, which are listed as follows:

1. Asphalt softening and bleeding may be observed on road surfaces, including traffic-related rutting, which can lead to pavement integrity deterioration if the hazards discussed in roadway design are not considered. The height of the road embankment, the highest and lowest water level, and the mean sea level should also be considered in standard design. Salinity intrusion would be an essential parameter in making a standard design.
2. Standard materials are another vital aspect of constructing a climate-resilient infrastructure. The lack of standard materials would expose the top layer and shoulder of the road and even the whole structure to damage. Since the Satkhira district is an area of high salinity, materials with strong resistance to salinity should be used.
3. The location and environment of the selected site is also a critical issue. A poor drainage flow system in this area can result in waterlogging. Additionally, authorities should pay attention to the outfall bed's higher elevation than the area's current drainage level.

Form 9: Adaptation challenges for the project		
Answer the question: **What aspects of the project design, the materials considered, and/or the site chosen could pose a problem leading to loss and damage?**		
Standard design problematics situation	**Standard materials problematics situation**	**Project site problematics situation**
•The proposed standard design did not consider the prediction of extreme events and climate-related hazards •The reduced level (elevation) of road design is a vital aspect that might generate problems with road life loss since the Reduce Level RL of the road must go to higher ground to avoid sea level rise •Another adaptation challenge is the type of vegetation to protect against soil erosion of the road embankment •Consideration of type/grade of bitumen while formulating road design as bitumen type/grade depends on rainfall patterns, heat waves, flood, and market availability **The following aspects could also lead to loss and damage to the project:** •Heat absorbent properties of the materials •Concrete's density (proportion of ingredients) •Clear cover •The use of standard or epoxy-coated reinforcement •The use of normal concrete or marine concrete •Consideration of safety factors during design •The size and number of engineering structures (hydraulic structures, high river crossings) during project design •Consideration of using "increased water holding capacity and slow infiltration through natural or bioengineered systems" during project design •Raising pavement and adding additional drainage capacity •Using materials that are less affected by seawater •Allowing for alternative routes in the event of a road closure •Include additional longitudinal and transverse drainage systems •Protecting embankments with suitable mangroves/indigenous vegetation or re-vegetating with drought-tolerant species •Increasing water retention capacity and slow infiltration through environmental measures and bio-retention systems to recharge aquifers and reduce surface flow runoff •Achieving optimal compaction to avoid subsequent settlement	•Local sand that is usually considered in the design for Satkhira district could be a significant problem in building climate-resilient roads •Bricks from local soil burned with firewood or coal can be another aspect •No provision in LGED specifications for the purchase of portable water for road construction, which is one of the major construction materials. As a result, contractors can use water from any available source •Specifications do not include parameters that can ensure water quality •No chemical composition parameters of cement in the LGED specification •Consideration of rainfall patterns, heatwaves, floods, and market availability to select the type/grade of bitumen •No data in LGED specification to phase out of bricks and brick chips •A guideline to ensuring the selection of materials with resistance to the effects of high dry conditions and salinity	•Uncertainty of the exact results and their spatial distribution is the key challenge in adapting to climate change •The ability to adapt is not equal in all areas and the population •A nature-based solution is needed to protect against soil erosion of the road embankment •Waterlogging due to the absence of a drainage system and drainage outfall •High elevation of outfall bed than existing drainage elevation •Shrimp cultivation at nearby locations is overflown during the rainy season •Integration of climate change adaptation in land use planning •Rehabilitation and restoration of rivers and floodplains •Adaptation of groundwater management •Drinking/Construction water crisis •Salinity intrusion in nearby crop fields and road surface •Settlement issues could be variable depending on the project site •Massive climate migrants are damaging the natural drainage system •Work hours reduced for marginalized people

Form 10: Possible loss or damage could be attributed to weakness in the three aspects of the project (1. Standard design, 2. Standard materials, and 3. Project site)		
Standard design	**Standard materials**	**Project site**
•Deterioration of pavement integrity, including softening and bleeding of asphalt from traffic-related rutting •Reduced connectivity in specific periods in a calendar year •Spreading of waterborne diseases •Sanitation problems and inadequate drinking water •Reduced economic growth •Salinity intrusion in nearby crop fields and road surface •Communication disruption •Top layer of road damage •Road shoulder damage •Different types of pavements (especially flexible pavement) cracking and damage •Loss of infrastructure •Iron cast at the RCC road	•Damage to the top layer of the road •Damage to road shoulder •Iron cast occurs at the top of the RCC road •Damage to different layers of the roads •Corrosion of road and bridge materials due to saltwater •Decrease the life span of the road	•Waterlogging due to the absence of a drainage system and drainage outfall •High elevation of outfall bed than existing drainage elevation •Shrimp cultivation at nearby locations, which overflows during the rainy season •Massive climate migrants are damaging the natural drainage system •Drinking/construction water crisis •Salinity intrusion in nearby crop fields and road surfaces. •Damage to settlements •Work hours were reduced for marginalized people

There are some columns in Module I forms that were marked "unknown," denoting a lack of knowledge or inadequacy. Some gaps were solved through the Module II process, although certain issues may still need to be addressed or fully understood. Form 11 summarizes all aspects that still need to be addressed or are insufficiently understood. The data were arranged based on the level of importance in descending order.

Form 11: Summary of information that has not been solved or insufficient understanding	
Aspects not found or with insufficient understanding and marked '*Unknown' in Form 4	**Comments and clarifications**
Ec. Extreme cold (**Form 9:** Hydro-meteorological events observed by the local stakeholders in the last 20 years)	"Extreme cold" (Ec.) is a hydro-meteorological event not considered a climate-related hazard in the study area. People in the study area reported that no Ec. has been observed in the last 20 years. However, the Urban Team feels the form should clearly state which temperature the Ec. refers to.
Sd. Strong sedimentation (**Form 9:** Hydro-meteorological events observed by the local stakeholders in the last 20 years)	"Strong sedimentation" (Sd.) is a hydro-meteorological event not considered a climate-related hazard in the study area. People in the study area said that they do not understand the Sd. problem enough. So far, they know Sd. has not been observed in the last 20 years. However, the Urban Team feels the form should clearly define Sd.
Ce. Coastal erosion (**Form 9:** Hydro-meteorological events observed by the local stakeholders in the last 20 years)	"Coastal erosion" (Ce.) is a hydro-meteorological event not considered a climate-related hazard in the study area. As a coastal district, Satkhira suffers from Ce, but the study area is very far from the coast (about 20 km). Therefore, people in the study area said Ce. has not been observed in the last 20 years.

4. CONCLUSION AND RECOMMENDATIONS

This section offers key comprehensive conclusions and critical recommendations for enhancing project resilience.

−**Significant hazards:** According to the multi-hazard risk map of Bangladesh, Satkhira district is located in SWM and URB climate-stress areas. Rainfall variability, river floods, urban floods, sea level rise, salinity, cyclonic storm surges, droughts, extreme heat waves, extreme cold, riverbank erosion, and lightning are the most dangerous climate change-induced hazards in the research area.

−**Main expected impacts:** The following are the elementary climatic signals, hazards, and probable impacts on the study area:

- *Excessive rainfall:* Urban drainage problem resulting in prolonged waterlogging, road damages, disrupted communications, recurrent investment losses, and loss of infrastructure
- *Extreme heat:* Drinking/construction water crisis, work hours reduced for marginalized people, and road and flexible pavement cracking and damage
- *Frequent river floods:* Houses, roads, and other infrastructure inundated and damaged, communications problems, investment losses, and severe water and sanitation problems
- *Early or frequent flash floods:* Houses, roads, and other infrastructure inundated and damaged, communication problems, and investment losses
- *Severe droughts/water scarcity:* Drinking water crisis in urban areas
- *Frequent landslides:* Damage to settlements, communication problems, and road and infrastructure damages
- *Increased salinity:* Severe drinking water crisis, corrosion of road and bridge materials due to salt, and the need for recurrent investment
- *Frequent cyclones and storm surges:* Loss of houses and damage to properties
- *Sea level rise:* Infrastructure damages, recurrent loss of investment, and increased drinking water crisis due to salinity intrusion

−**The core adaptation challenge:**

The three aspects of design, materials, and location were used to show the adaptation challenges that the project could face due to exposure to hazards and potential impacts. All three aspects are critically important to build a climate-resilient infrastructure, which are listed as follows:

1. Asphalt softening and bleeding may be observed on road surfaces, including traffic-related rutting, which can lead to pavement integrity deterioration if the hazards discussed in roadway design are not considered. The height of the road embankment, the highest and lowest water level, and the mean sea level should also be considered in standard design. Salinity intrusion would be an essential parameter in making a standard design.
2.
3. Standard materials are another vital aspect of constructing a climate-resilient infrastructure. The lack of standard materials would expose the top layer and shoulder of the road and even the whole structure to damage. Since the Satkhira district is an area of high salinity, materials with strong resistance to salinity should be used.
4.
5. The location and environment of the selected site is also a critical issue. A poor drainage flow system in this area can result in waterlogging. Additionally, authorities should pay attention to the outfall bed's higher elevation than the area's current drainage level.

−**Key comprehensive conclusions based on the previous points:**

This study employed the RCIA tool to determine the impact of climate change on the selected project in Satkhira Municipality, one of the highly exposed coastal districts in Bangladesh to various climatic factors, including variations in temperature, the erratic behavior of rainfall and sunshine hours, sea level rise, and cyclonic events. Based on the newly developed RCIA, hazards in hydro-meteorological systems include temperature, precipitation, dry days, and sea level rise. The average rate of change of ECIs showed an increasing trend with a regular interval of 5–8%, indicating that climate change in the study area was expected to worsen. The IDF (Intensity, Duration, and Frequency) and vulnerability of extreme events were found to influence the damaging or disruptive potential of these hazards directly. Furthermore, the Satkhira District's AHB estimated the hydro-meteorological hazards for future decades based on ECIs. The AHI calculated a 72–98% hazard level for all-time periods. The project's exposure to hydro-meteorological hazards was identified, and the level of exposure to future hazards was determined.

Additionally, an impact chain was established to determine aggregate impacts for physical components and services provided. The impact chain analysis demonstrates that the temperature rise can cause pavement deterioration, including softening and bleeding of asphalt and increased thermal expansion of steel structures, bridges, and paved surfaces. Besides, road surface damage, flooding, and infrastructure issues could disrupt economic activities, connectivity, communication, waterlogging, sanitation, investment, and water crises. These issues reduce work hours, spread diseases, and hinder economic growth for marginalized populations. Furthermore, the adaptation challenges step covers a project's design, materials, and location-based challenges, considering exposure to hazards and potential consequences.

Key recommendations to increase the project's resilience:

Six basic conditions were considered to develop key recommendations to improve project resilience. **Table 2** shows the conditions considered while formulating key recommendations. It can be seen that the project only met certain conditions. Therefore, conducting a CCIA to describe the terms of reference (technical specifications) for a more in-depth assessment of climate risks and impacts is necessary.

Table 2: Decision-making table

The following conditions are considered while formulating key recommendations to enhance project resilience:

Sl no	Conditions	Indicators to proceed toward the CCIA	Indicators do not proceed toward CCIA	Findings of this study	Remarks
1.	Conformity with Environment Conservation Act (ECA) and Environment Conservation Rules (ECR) of the country	→Orange and Red category projects →Road construction/ renovation of a minimum of 5 km →Bridge construction of a minimum of 100 m →Residential and commercial building (min 5000 m^2 built-up area)	'No' or 'minor' level of impact	Minor	Since the project does not meet all these conditions, it is necessary to conduct CCIA
2.	Level of hazard	The hazard level is high at any stage of the infrastructure lifespan	Moderate or low hazard level	Moderate	
3.	The useful life of the infrastructure	The lifespan is > 10 years	The lifespan is ≤ 10 years	10 years	
4.	Information gaps	There are 4 or more variables marked "*unknown" in Form 4	There are 3 or less variables marked "*unknown" in Form 4	Three are "*unknown."	
5.	Critical infrastructures	The project is directly linked to the energy, health, water, transport, communication, and food security sectors.	The project is linked to the energy, health, water, transport, communication, and food security sectors.	The project **is not directly linked** to the energy, health, water, transport, communication, and food security sectors.	
6.	Vulnerability of the surrounding population	High or very high vulnerability of nearby populations	Moderate or low vulnerability of nearby populations	Moderate	

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledges the Local Government Engineering Department, Bangladesh.

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