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Macro-Financial Stability Under Climate Shocks in Bangladesh: Time Series Evidence Using a Constructed Financial Stability Index

Mohammad Shahriar Siddiqui
Bhaskar Podder, Ph.D.
Soumen Chakravarty

Financial Stability Department
Bangladesh Bank

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Mohammad Shahriar Siddiqui, Bhaskar Podder, Soumen Chakravarty[1]

Financial Stability Department, Bangladesh Bank

Abstract

This study evaluates the adverse impact of climate-induced events on macro-financial stability in Bangladesh using annual time-series data spanning 35 years, from 1990 to 2024. Using Principal Component Analysis (PCA), we constructed a composite Financial Stability Index (FSI) that integrates six macroeconomic variables: exchange rate, foreign currency reserves, broad money, inward remittances, the share of private-sector credit in GDP, and the consumer price index (CPI). Using the Autoregressive Distributed Lag (ARDL) method, this study examines both the short- and long-run impacts of climate-induced variables, namely carbon dioxide (CO_2) emissions in million metric tons, the number of days with temperatures above 35 degrees Celsius in a year, and the number of consecutive dry days in a year, on FSI, controlling for several real, financial, and external sector variables. The results of the analysis suggest a statistically significant negative relationship between climate-induced events and Bangladesh's macro-financial stability. All our primary independent climate-induced variables have a detrimental impact on Bangladesh's financial stability. This study will enrich the existing literature on climate-induced financial stability by providing empirical evidence from one of the world's most climate-vulnerable countries. The findings of our study underscore the urgent need for practical, timely initiatives to recognize the impact of climate change on financial stability and to devise macro-prudential measures to address climate-change-induced deterioration in the financial sector in Bangladesh and other climate-vulnerable countries worldwide.

Keywords: Financial Stability Index, Climate Shocks, ARDL, Macro-Financial Stability, Bangladesh.

JEL: C58, E63, G21, Q54.

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1. Introduction

Climate change has posed diverse, consequential, and detrimental impacts across the global economy (Tol, 2018). According to a 2023 report published by the Intergovernmental Panel on Climate Change (IPCC), emissions of greenhouse gases, such as carbon dioxide from human-induced activities, including increased energy use from burning fossil fuels, have altered production and consumption patterns worldwide and have mainly contributed to global warming, an observed impact of climate change (Lee et al., 2023). The report also concluded that climate change has already impacted nature, people, societies, and economies and continues to do so. Across the world, vulnerable societies and economies that are less involved in climate change activities are disproportionately bearing the burden of its adverse impacts.

Bangladesh is also experiencing the adverse effects of climate change, despite being one of the least emitters of total greenhouse gases. In 2024 alone, global greenhouse gas emissions totaled 54.43 billion tons, whereas Bangladesh's emissions were only 241.06 million tons, accounting for approximately 0.40% of total emissions (Ritchie et al., 2023). Yet the country faces almost all the negative consequences of climate change, including rising temperatures, heatwaves, erratic rainfall, severe floods, droughts, river erosion, sea-level intrusion, salinity, and frequent tropical cyclones (Bangladesh Planning Commission, 2018). Additionally, Bangladesh has been ranked 13th on the long-term Climate Risk Index (CRI), indicating that it is highly susceptible to climate-related threats and vulnerabilities. Not only that, Bangladesh’s two neighbors, India and Myanmar, rank among the top ten on the CRI, suggesting that the entire region of South Asia and countries along the Bay of Bengal's coastlines also face threats and vulnerabilities associated with climate-induced events (The Daily Star, 2025).

Although Bangladesh has made some progress in socio-economic development over the past few decades, the benefits of this progress are being eroded by the adverse effects of climate variability (Roy & Haider, 2018). Climate change events can adversely affect economic outcomes by reducing agricultural output and weakening the capacity of critical economic resources, such as land and labor. From the perspective of central banks, it is now evident that the impact of climate change should be taken into account to ensure macro-financial stability (Batten, 2018). In the context of Bangladesh, the central bank must emphasize macroeconomic and core financial sector variables, including inflation, productivity, non-performing loan

(NPL) management, liquidity governance, credit quality amid climate change impacts, and financial stability.

Several studies have examined the impact of climate change on financial stability. Some studies use a model-based framework, such as an ecological DEFINE (Dynamic Ecosystem-Finance-Economy) macro model, which is further used to assert strain liquidity conditions and the probability of non-repayment induced by climate change events (Dafermos et al., 2018). Studies also address the encapsulation of climate change as a source of financial risk and articulate a theoretical model to mitigate this risk and ensure financial stability under climate risk (Fabris, 2020). Additionally, there have been demonstrations of strengthening climate change management policies to enhance financial stability (Meng et al., 2023). Furthermore, advanced country-level econometric analyses, such as one conducted in China, have examined the impact of temperature variations on China's Financial Stability Index and found that these variations affect financial stability (Wu et al., 2023).

Numerous studies have analyzed the broader socio-economic impacts of climate change in Bangladesh and across South Asia. These studies have demonstrated that extreme climate events and abnormal climate variability have already affected agricultural productivity and, in turn, food security across South Asia (Rehman et al., 2024; Kashem, 2025). Moreover, specific studies have estimated Bangladesh's economic losses and long-term GDP degrowth due to climate-related events (Huq et al., 2024).

Nevertheless, a research gap remains regarding the impact of climate events on financial risk and macro-financial stability. Our study is designed to fill this gap by constructing a Financial Stability Index (FSI) based on the modification of prior work by Wu et al. (2023). Here, we aim to construct the FSI by weighing the selected 35 years (1990-2024) of yearly time-series macroeconomic and financial sectors data of Bangladesh, and then conduct time series analysis by applying different climate variables over the same time frame with the FSI, while controlling for variables, including agricultural value, manufacturing value, capital formation, appreciation or depreciation of local currency, and non-performing loans. We found that climate-induced variables adversely affect financial stability.

Our aim is to quantify the impact of climate events on financial stability in Bangladesh, which will be instrumental in analyzing their effects on the financial sector and the broader macroeconomy. The findings of our study will provide policymakers and central bankers alike with valuable insights to devise policies, guidelines, and regulations for climate change governance in Bangladesh. Finally, we anticipate that our study will provide South Asian and other climate-vulnerable countries with a quantitative tool to identify their financial stability issues in response to climate events.

We structured our paper as follows. We begin with the Introduction, followed by the Literature Review, Theoretical Framework & Hypothesis Construction, and Methodology. We then present the Results, Discussion, and Recommendations. Finally, we conclude with Limitations, Policy Implications, and Conclusion.

2. Literature Review

The literature on the interactions between climate change impacts and macro-financial stability has been expanding, and there is growing recognition that climate risks adversely affect macroeconomic variables (NGFS, 2024). This literature review presents key theories, analyses, and findings on ensuring macro-financial stability amid intensifying climate change.

Macro-Financial Stability

In the context of macro-financial stability, an economy's financial system is closely linked to its macroeconomic environment, enabling effective and efficient economic activity and helping it remain resilient in the face of adverse shocks (IMF, 2024). Furthermore, macro-financial stability ensures that the financial institutions, markets, and infrastructure of an economy collectively mitigate disruptions arising from adverse economic scenarios, external shocks stemming from geopolitical or technological developments, and unfavorable climate events (European Central Bank, 2025). This also extends to mitigating setbacks in the financial intermediation process that could threaten real economic activity.

The International Monetary Fund (IMF) explains macro-financial stability through the lens of systemic risk, in which the possibility of disruption to the financial system can have severe adverse consequences for the economy, as measured by tail risks associated with forecasts of real GDP growth (IMF, 2024). For emerging markets and developing economies (EMDEs), the macro-financial stability concept emphasizes resilience to domestic and external shocks, including those stemming from climate-related vulnerabilities (BIS, 2022).

Table-1: Definitions of Macro-Financial Stability

Author(s)	Region	Key Contribution
IMF (2024)	Global	Conceptualize macro-financial stability through the lens of systemic risk.
European Central Bank (2025)	Euro Area	Macro-financial stability demonstrated the financial system's capacity to withstand shocks.
BIS (2022)	EMDE*	Macro-financial stability underscores resilience against financial and macroeconomic vulnerabilities in EMDEs.

*Emerging & Developing Economics

Source: Authors' compilation.

Composite Indices to measure Macro-Financial Stability

Various studies have been conducted to develop the Financial Stability Index (FSI). One notable work in this regard was conducted by Illing and Liu (2006). They designed an FSI to measure financial stress in Canada by collecting data on variables from the Canadian money, bond, equity, and foreign exchange markets. They constructed the FSI by conducting a Principal Component Analysis (PCA) of different variables to produce a single, measurable measure. Another FSI was developed by Al-Rjoub (2021) in Jordan. Here, FSI was constructed using indicators such as the NPL ratio, ROE, and ROA, and PCA was then applied to the indicators to derive financial stability measures. To evaluate the resilience and financial stability of Bangladesh's financial system, Ahamed and Chowdhury (2025) designed an Aggregate Financial Stability Index (AFSI) by combining indicators from the real, financial, monetary, external, and fiscal sectors. Nayn & Siddiqui (2014) also constructed an AFSI for Bangladesh by combining different indicators from the banking soundness index, financial soundness index, and the regional economic climate index.

Table-2: Review of composite Financial Stability Index (FSI)

Author(s)	**Region**	**Methodology & Key Contribution**
Illing & Liu (2006)	Canada	Considered 12 financial market indicators and developed the Financial Stress Index (FSI) for measuring systemic stress.
Nayn & Siddiqui (2014)	Bangladesh	Combined 7 indicators under the banking soundness index, 9 indicators (external, financial, real sectors) under the financial soundness index, and 2 indicators under the regional economic climate index to develop Bangladesh's Aggregate Financial Stability Index.
Al-Rjoub (2021)	Jordan	FSI was developed from several indicators, such as liquidity, profitability, and macro variables, to conduct PCA and subsequently compute the FSI to evaluate financial stability in response to External Shocks.
Ahamad & Chowdhury (2025)	Bangladesh	Compiled 19 indicators from different sectors (Real, Fiscal, Financial, and External) and developed the Aggregate Financial Stability Index (AFSI) for Bangladesh.

Source: Authors' compilation.

Impact of Climate Change on Financial Stability

According to Carney (2015), climate change affects financial stability through three channels. The first is physical risks, which underscore liability arising from insurance claims and damage to physical property caused by climate events. Second is liability risk, which may arise when victims of climate change seek compensation from the responsible parties. Third, transition risks arise from adjustments to a low-emission, low-carbon economy. Battiston et al. (2017) acknowledged that climate risks adversely affected the financial system. They stressed that early and stable policy adjustments to address climate risks would lessen their impact on the financial system. A late policy response to climate risk can have the opposite effect, potentially exacerbating systemic risks.

Table-3: Impact of Climate Change on Financial Stability

Author(s)	Region	Methodology	Key Findings
Carney (2015)	Global	Descriptive	Conceptualized climate events as a threat to financial stability as risk propagates through physical, transition, and liability risk channels.
Battiston et al. (2017)	Global/Euro Zone	Network model for Climate Stress Test	Climate change can generate systemic instability through asset degradation and spillover effects.
Chen & Zhao (2021)	China	Dynamic Panel GMM & Regression	Climate Policy ambiguity negatively impacts banking stability.
Liu et al. (2021)	China	VAR and NARDL	Climate shocks exert significant adverse effects on financial stability indicators.
D'Orazio et al. (2025)	Global (including Bangladesh)	Panel Data Analysis	Physical and transition risks increase NPLs and strain liquidity conditions. Effective climate policies can mitigate these effects.

Source: Authors' compilation.

Empirical studies show that climate-related events pose risks to financial systems. A recent study by D'Orazio (2025) shows that higher-level occurrences of physical and transition risks increase financial instability by affecting NPL ratios, liquidity conditions, and financial institutions' stability (Z scores). Similar conclusions are drawn by Chen and Zhao (2021), who argue that natural disasters directly affect financial stability by deteriorating profitability and increasing NPLs in financial institutions and the banking sector. A study by Liu et al. (2021) in China demonstrated that both negative and positive climate shocks trigger disruptions in the credit market and prolonged financial distress.

Climate Change and Financial Stability: In the context of Bangladesh

The literature indicates that Bangladesh's macroeconomic and financial sectors are vulnerable to climate change. According to the Global Center for Adaptation, Bangladesh ranks among the top 10 most vulnerable countries in the World Risk Index for 2023. It is estimated that the country may lose 17% of its land area to climate change-induced sea-level rise (Global Center on Adaptation, 2024), ultimately reducing the total agricultural land area by 30%. In addition, rising sea levels in coastal areas will induce mass migration from coastal areas to the plains and further diminish the country's core economic resources. In the financial sector, climate change vulnerabilities will further increase non-performing loans (NPLs) in climate-vulnerable sectors such as small and medium Enterprises (SMEs) and agriculture, whereas in the fiscal sector, adaptation and mitigation costs will rise to tackle climate vulnerabilities.

A recent Bangladesh Bank (2025) study involves climate stress testing using the Network for Greening the Financial System (NGFS) scenario and identified that without timely adaptation within Bangladesh's financial system in response to the climate vulnerabilities, it could increase the loan loss reserve and put pressure on achieving Nationally Determined

Contributions (NDCs) for Bangladesh. However, in the context of Bangladesh, the impact of climate issues on the macro-financial stability remains limited.

Table-4: Impact of Climate Change on Financial Stability: In the context of Bangladesh

Author(s)	Scope/Focus	Methodology	Key Findings
Global Centre for Adaptation (2024)	Global (including Bangladesh)	Assessment of Adaptation	Recommends immediate climate action.
Bangladesh Bank (2025)	Bangladesh	Climate stress testing model based on NGFS	Acknowledges climate impacts on the economy, including rising loan loss reserves and a decline in banking sector stability.

Source: Authors' compilation.

Research gap and contribution of the study

This paper aims to fill significant gaps in the Bangladesh literature despite the well-developed global and theoretical background on the relationship between climate factors and macroeconomic stability. First, there is limited empirical research on the dynamic relationship between climate factors and macro-financial stability, using a broad range of financial stress indices. Second, the literature in Bangladesh primarily focuses on research that offers limited exploration of dynamic relationships, using techniques such as cointegration or PCA. Third, there is limited research in the context of an extremely vulnerable country like Bangladesh that uses a range of variables to construct a single vector autoregression index. This paper aims to address these gaps in the context of the most vulnerable countries, like Bangladesh, by employing a range of techniques to develop a new composite financial stress index. The index includes variables such as banking-sector stability, macroeconomic factors, external factors, and climate factors. The paper aims to conduct the first empirical research on the relationship between climate factors and macro-financial stability in Bangladesh, a country highly vulnerable to climate change.

3. Theoretical Framework & Hypothesis Construction

The theoretical foundation for examining the interaction between climate change and macro-financial stability rests on the integration of three complementary conceptual frameworks. First, the systemic risk framework developed by the International Monetary Fund (IMF, 2024) emphasizes the interdependence between the financial system and the broader macroeconomic environment. Second, the climate risk taxonomy introduced by Carney (2015) identifies three primary transmission channels, namely physical risks, transition risks, and liability risks, through which climate change affects economic and financial systems. Third, the climate-augmented financial accelerator mechanism, which extends the seminal work of Bernanke et al. (1999) and is further developed by Dafermos et al. (2018), explains how climate-induced shocks propagate through financial systems and amplify systemic instability. Together, these frameworks provide a comprehensive lens for understanding how climate-related risks translate into the real economy and ultimately destabilize the financial system.

At the core of the systemic risk framework is the premise that a well-functioning financial system is inherently dependent on macroeconomic stability (IMF, 2024). Financial institutions play a critical role in efficient capital allocation and economic growth; however, they remain vulnerable to adverse shocks that can cripple financial intermediation. In Bangladesh, the economy is highly exposed to climate-sensitive sectors, including agriculture, employment, and overall economic growth (Bangladesh Bank, 2025; World Bank, 2022). Frequent climate-induced hazards, such as floods, cyclones, droughts, salinity intrusion, and heatwaves, erode the economy's productive capacity by damaging physical capital (e.g., infrastructure and farmland) and human capital through climate-induced migration and adverse health outcomes (World Bank, 2022).

These disruptions reduce household and firm incomes, which are transmitted to the financial sector through deteriorating asset quality, rising NPLs, and tighter liquidity conditions (Carney, 2015; Bangladesh Bank, 2025). As banks' balance sheets weaken, their lending capacity contracts, and they may be forced to sell assets to meet regulatory liquidity requirements. These dynamics reflect the ‘financial accelerator’ mechanism, whereby real-sector shocks, originating from climate events, are amplified through financial system feedback loops, intensifying economic downturns and systemic risk (Bernanke et al., 1999; Dafermos et al., 2018).

While physical risks are more immediate and visible in climate-vulnerable economies like Bangladesh, transition risks are increasingly significant in the evolving global policy landscape. International decarbonization initiatives, carbon pricing mechanisms, and regulatory shifts are spilling over into domestic economies, compelling a transition towards low-carbon development pathways. This transition may lead to the stranding of carbon-intensive assets, thereby reducing their value and exposing financial institutions to potential losses (Carney, 2015; Battiston et al., 2017). Additionally, liability risks arising from legal claims and compensation demands related to climate damages can further strain the firm's financial position and, indirectly, the balance sheets of lending institutions.

Traditional assessments of financial stability in developing economies, including Bangladesh, typically rely on macro-financial indicators such as GDP growth, inflation, interest rates, and bank-level performance metrics (Bangladesh Bank, 2025). However, these indicators often fail to capture the complex, non-linear, systemic effects of climate change on financial stability (Brunetti et al., 2024; D'Orazio et al., 2025). This limitation underscores the need for a more comprehensive empirical framework that explicitly incorporates climate variables into financial stability analysis.

Against this theoretical backdrop, this study posits that climate change is a significant and adverse driver of financial instability. Specifically, climate-induced shocks are expected to undermine financial stability, even after controlling for macroeconomic variables such as value addition in the agricultural and manufacturing sectors as a percent of GDP, gross capital formation as a percent of GDP, the appreciation/depreciation of the local currency, and the NPL ratio.

Hypothesis: Climate change negatively impacts financial stability in Bangladesh.

4. Methodology

Data

Our quantitative analysis relies on annual time-series observations of variables from 1990 to 2024. This period spans multiple economic liberalizations, financial, fiscal, and external-sector reforms, and extreme climate events in Bangladesh, including super cyclones SIDR, AILA, and AMPHAN in 2007, 2009, and 2020, respectively, to capture the effects of these events on macro-financial stability. All time-series data were collected from official and internationally recognized sources and cross-validated to ensure consistency, accuracy, and reliability.

Construction of the Financial Stability Index (FSI)

The outcome variable of our study is a composite Financial Stability Index (FSI) formulated by combining six macro-financial indicators with weights based on their relevance to understanding Bangladesh's macro-economic evaluations, including external sector vulnerability, liquidity conditions in the banking sector, and domestic credit channel transmission (Wu et al., 2023; Ahamad & Chowdhury, 2025). These indicators are:

- *Total Gross Foreign Currency Reserves (USD billion):* This variable is collected from the World Bank Data Bank and is used as a proxy for external buffers to assess import shocks arising from climate-induced agricultural and production shortfalls.

- *Broad Money (M2):* This variable is derived from the Bangladesh Bank data on both narrow money and time deposits of the financial sector of Bangladesh to assess the economy's monetary depth and liquidity condition.
- *Domestic Credit to Private Sector (percentage of GDP):* This variable is collected from the World Bank Data Bank to measure the extent and magnitude of the financial intermediary process, particularly the exposure of the agricultural and Small & Micro Enterprises (SME) credit portfolios that are vulnerable to climate risks.
- *Inward Remittances (USD in Billion):* We used inward remittance data because inflows from other countries cushion domestic consumption and build foreign reserves to help buffer against various disaster events.
- *Exchange Rate (BDT/USD):* This variable serves as a proxy for the stability of the external sector in the face of climate risks and events. Depreciation of the BDT rises import costs and, in turn, fuels cost-push inflation. It also makes foreign loans more expensive and reduces the country's ability to rely on them for climate adaptation and mitigation. Data for this variable are collected from the Bangladesh Bank web portal.
- *CPI:* The Consumer Price Index (CPI) is an economic indicator that quantifies the average change over time in the prices paid by consumers for a representative basket of goods and services. The CPI is typically assessed by calculating its percentage change from one year to the next. Macroeconomic stability is commonly linked to price stability, which is often evaluated using inflation measures.

We standardized each data series using ($X^*_{it} = (X_{it} - \bar{X}_i) / \sigma_i$) and then aggregated them using Principal Component Analysis (PCA), assigning objective weights to the variables based on each variable's importance for financial stability and its vulnerability to climate events. We then used the FSI as the primary dependent variable in our empirical model.

Independent Variables (Primary Climate Variables)

To capture the impacts of climate shocks, we incorporate four climate indicators that reflect both acute and chronic climate risks prevalent in Bangladesh. These indicators were selected based on IPCC guidelines (Lee et al., 2023) and prior studies on the relationship between climate and macro-financial stability (Liu et al., 2021; Wu et al., 2023). All climate indicator data were collected from the World Bank Climate Knowledge Portal:

- *CO_2 emissions (million metric tons):* This measures Bangladesh's CO_2 emission patterns over a time frame of 35 years. Emission patterns indicate the country's contribution to global warming and, most importantly, the physical risks associated with the CO_2 emissions.

- *Days with Heat Index (> 35°C):* This variable captures extreme heat events in a year, which can lead to adverse health impacts, labor market disruptions, reduced agricultural output, and sectoral vulnerabilities.
- *Consecutive Dry Days:* This shows the maximum number of consecutive days over the period with precipitation < 1mm. As Bangladesh is an agricultural economy, a higher number of consecutive dry days is a disaster for the economy. This adversely affects Bangladesh's overall productive capacity, particularly agricultural productivity, and has negative spillover effects on financial markets and financial stability.

Control Variables

We include several macroeconomic control variables to isolate the effect of climate variables on the FSI and to better understand how climate events affect financial stability.

Our dataset is carefully curated and structured to enable the application of time-series econometric techniques (ARDL). We present the methodology, descriptive statistics, unit-root test results, and econometric results in the subsequent section.

All the study variables are defined in Table 5.

Table 5: Variable description

Variable	Definition	Expected Sign	Data-Source	Reference
Dependent Variable				
FSI	A composite index constructed by considering the volatility of the six indicators (Exchange rate, Reserve, Broad Money, Remittance, Private Sector Credit to GDP, and CPI)			Wu et al. (2023); Ahamad & Chowdhury (2025)
Main Effects Regressors				
Primary Independent Variables				
Co2Emi	Carbon dioxide (CO2) emissions (Million metric tones)	−	World Bank Data Bank	Conlon et al. (2024)
Days35C	Number of days in a year when the temperature rose more than 35 degrees Celsius	−	World Bank climate change knowledge portal	Amo-Bediako (2024); Li et al. (2026)
Consecutive DryDays	The consecutive number of dry days in a year	−	World Bank climate change knowledge portal	Fuje et al. (2023)
Controls				
Agricultural Value	Agriculture sector value addition as a percentage (%) of GDP	+	World Bank Data Bank	Khalid et al. (2016)
Manufacturing	Manufacturing sector value addition as a percentage (%) of GDP	+	World Bank Data Bank	Ali & Pasha (2020)

Variable	Definition	Expected Sign	Data-Source	Reference
Capital Formation	Gross fixed capital formation as a percentage (%) of GDP	+	World Bank Data Bank	Dell'Ariccia et al. (2016)
AppDepLCY	$(Exchange\ Rate_{t-1} - Exchange\ Rate_t)/Exchange\ Rate_t$	−	Bangladesh Bank	Sein & Sah (2025)
NPL	Percentage of Non-performing loans to Total Loans (%)	−	Bangladesh Bank	Shahriar et al. (2022)

Source: Authors.

Empirical Framework

The ARDL model (Pesaran & Shin, 1995) is employed to test the hypothesis. This approach facilitates the investigation of long-run cointegrating relationships among the variables of interest and enables estimation of both long-run and short-run dynamics. Furthermore, incorporating sufficient lags in the model can address issues of serial correlation and endogeneity, while also permitting the selection of different optimal lags for distinct variables within the same model (Duasa, 2007).

An ARDL model specifies the dependent variable as a function of its own lagged values and the current and lagged values of other explanatory variables. This approach emphasizes exogenous variables and determines the optimal lag structure for both dependent and independent variables (Podder, 2024).

An ARDL model includes independent variables and their lags, as well as the lagged values of the dependent variable.

In general form, with p lags of y and q lags of x, an $ARDL\ (p,q)$ model can be expressed as –

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \cdots\cdots + \beta_p Y_{t-p} + \propto_0 X_t + \propto_1 X_{t-1} + \propto_2 X_{t-2} + \cdots\cdots + \propto_q X_{t-q} + \varepsilon_t \quad \cdots\cdots\cdots\cdots (1)$$

where ε_t is a random disturbance term. The model is autoregressive in the sense that Y_t is explained partly by its lagged values. It also has a distributed lag component in the form of successive lags of the 'X' explanatory variable.

For testing our specific hypothesis, based on equation (1), the mathematical equation for our model stands as follows:

$$
\begin{aligned}
FSI_t = {} & \beta_0 + \beta_1 FSI_{t-1} + \beta_2 FSI_{t-2} + \cdots\cdots + \beta_p FSI_{t-p} + \alpha_0 Co2Emi_t + \alpha_1 Co2Emi_{t-1} + \alpha_2 Co2Emi_{t-2} \\
& + \cdots\cdots + \alpha_p Co2Emi_{t-p} + \gamma_0 Days35C_t + \gamma_1 Days35C_{t-1} + \gamma_2 Days35C_{t-2} + \cdots\cdots \\
& + \gamma_p Days35C_{t-p} + \delta_0 AgriculturalValue_t + \delta_1 AgriculturalValue_{t-1} \\
& + \delta_2 AgriculturalValue_{t-2} + \cdots\cdots + \delta_p AgriculturalValue_{t-p} + \gamma_0 Manufacturing_t \\
& + \gamma_1 Manufacturing_{t-1} + \gamma_2 Manufacturing_{t-2} + \cdots\cdots + \delta_p Manufacturing_{t-p} \\
& + \theta_0 CapitalFormation_t + \theta_1 CapitalFormation_{t-1} + \theta_2 CapitalFormation_{t-2} + \cdots\cdots \\
& + \theta_p CapitalFormation_{t-p} + \vartheta_0 AppDepLCY_t + \vartheta_1 AppDepLCY_{t-1} + \vartheta_2 AppDepLCY_{t-2} \\
& + \cdots\cdots + \vartheta_p AppDepLCY_{t-p} + \mu_0 NPL_t + \mu_1 NPL_{t-1} + \mu_2 NPL_{t-2} + \cdots\cdots + \mu_p NPL_{t-p} \\
& + \varepsilon_t
\end{aligned}
$$

Time series data were processed and analyzed using Stata 19.5. In Stata, the data set was declared as a time series. Skewness and kurtosis tests were conducted to assess normality for each variable included in the models, and the results indicated that the variables were normally distributed. The variables used in a regression model must be stationary. A unit root test was conducted to determine whether the data set was stationary in levels or in first differences. To determine whether the data set is stationary at which level, the Augmented Dickey-Fuller test (Dickey & Fuller, 1979) was run, and the results were cross-checked with the Phillips-Perron test (Phillips & Perron, 1988).

Before conducting the cointegration test (Engle & Granger, 1987), it is necessary to determine the optimal lag length for the variables in the model, as time-series data are influenced, to some extent, by their past values. Based on the Akaike Information Criterion, Schwarz Bayesian Criterion, Hannan-Quinn, and Log Likelihood, the optimal lags were selected.

Then, the cointegration test was conducted to determine whether the variables had a long-run relationship. The ARDL bound test (Pesaran et al., 2001) was used to assess cointegration in the model.

Several diagnostic tests were conducted to assess the validity of each model. The variance inflation factor (VIF) was used to check for multicollinearity across all models. The Durbin-Watson test (Durbin & Watson, 1971) and the Breusch-Godfrey test (Breusch, 1978; Godfrey, 1978) were used to check for autocorrelation. White's test (White, 1980) was used to assess heteroscedasticity.

5. Results

Table 6 presents the results of unit root tests evaluating the stationarity of the time series data at both levels and first differences. The Augmented Dickey-Fuller (ADF) test and the

Phillips-Perron (PP) test were conducted at both the level and first-difference stages, using constant and constant-and-trend specifications.

Table 6: Results of ADF and PP tests for stationarity

Variable	Level				First Difference			
	Intercept		Intercept and Trend		Intercept		Intercept and Trend	
	ADF	PP	ADF	PP	ADF	PP	ADF	PP
FSI	0.10	0.21	−2.48	−6.38	−2.13***	−12.41***	−4.89***	−28.78***
Co2Emi	4.16	1.66	−1.77	−3.94	−1.77***	−14.83***	−4.55***	−38.76***
Days35C	0.99	0.54	−4.08***	−39.83***	−7.15***	−49.36***	−7.66***	−49.70***
ConsecutiveDryDays	−0.01	−0.15	−4.47**	−40.21***	−8.15***	−48.56***	−7.98***	−48.61***
AgriculturalValue	−5.04	−1.04	−2.94	−7.35	−3.13***	−26.66***	−7.03***	−38.36***
Manufacturing	1.67	0.50	−1.53	−5.22	−3.62***	−31.27***	−4.18**	−35.50***
CapitalFormation	1.91*	0.48	−1.21	−3.01	−3.62***	−31.28***	−4.18***	−35.51***
AppDepLCY	−2.76***	−14.48**	−4.26**	−26.59**	−3.62***	−31.27***	−4.18***	−35.50***
NPL	−0.60	-0.80	−1.17	−3.90	−3.62***	−31.28***	−4.18***	−35.50***

Note: Null Hypothesis: Series contains a unit root; significance at 1% ***, 5% **, and 10% *.

Source: Author with Stata 19.5.

Table 6 demonstrates that most variables are non-stationary at the level, as indicated by both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. In contrast, when first differences are considered, both tests reject the null hypothesis for all variables under both the 'constant' and 'constant and trend' specifications. These results indicate that all variables achieve stationarity in first differences. The results of the ADF and PP tests indicate that most variables are integrated of order one, thereby fulfilling the prerequisite for conducting the cointegration test.

Table 7 displays the optimal lag lengths. The Akaike Information Criterion, Schwarz Bayesian Criterion, Hannan-Quinn, and Log Likelihood are commonly employed to determine the appropriate number of lags. According to these criteria, the optimal lag length for each model has been established.

Table 7: Optimal lag length results

Variable	FSI	Co2Emi	Days35C	Consecutive DryDays	Agricultural Value	Manufacturing	Capital Formation	AppDep LCY	NPL
Optimal lag length	1	0	0	0	1	1	0	0	0

Source: Authors' calculation with STATA 19.5.

Then, we proceed with ARDL cointegration tests (F-bounds test). It becomes evident that our model exhibits a long-run relationship among the variables (Table 8).

Table 8: ARDL cointegration tests (F bounds test) results

F-statistic	F-critical value	t-statistic	t-critical value
3.275	2.79	−2.67	−2.57

Source: Authors' calculation with STATA 19.5.

As the F-statistic (3.28) exceeds the F-critical value (2.79) and the t-statistic (−2.67) is less than the t-critical value (−2.57), the null hypothesis of no cointegration can be rejected at the 1% level. This confirms the long-run relationship among the variables in the model.

After confirming a long-run relationship, the full ARDL estimation was conducted using the optimal lag length to assess the impact of climate variables on financial stability.

The model's Coefficient of Determination (R-squared and Adjusted R-squared) are 0.8611 and 0.7708, respectively (Table 9). These values indicate that the independent variables under consideration are strongly correlated with the dependent variable in our model. The variation in the dependent variable attributable to the independent variables is significant and not due to chance.

Table 9: ARDL estimation results
of the long-run and short-run impacts

Variable	Coefficient	Standard errors	P-values
FSI (L1)	0.872***	0.102	0.000
Long Run			
Co2Emi	−0.019***	0.005	0.000
Days35C	−0.005**	0.002	0.041
ConsecutiveDryDays	−0.012***	0.004	0.008
AgriculturalValue	0.179***	0.003	0.000
Manufacturing	0.094**	0.037	0.019
CapitalFormation	0.223***	0.045	0.000
AppDepLCY	−0.016**	0.007	0.029
NPL	−0.009**	0.004	0.028
Short Run			
Co2Emi (D1.)	−0.013*	0.006	0.058
ConsecutiveDryDays (D1.)	−0.01***	0.002	0.000
Manufacturing (D1.)	0.068**	0.03	0.036
NPL (D1.)	0.008	0.008	0.357
Constant	7.598***	1.47	0.000

Note: Significance at 1%=***; 5%=**; and 10%=*; In time series ARDL estimation, L1 indicates the lagged value of a variable based on its value in the previous period; D1 indicates level or zero lag.
Source: Author's calculation with STATA 19.5.

Table 10: Diagnostic Test results

Mean VIF	Durbin-Watson test	Breusch-Godfrey LM test (Prob>Chi2)	White's test (Prob > chi2)
2.25	d-statistic (12, 34) = 1.99	0.83	0.42

Source: Author's calculation with STATA 19.5.

The results in Table 10 indicate that there is no multicollinearity, autocorrelation, or heteroscedasticity in any of the models. This supports the reliability of the models.

6. Discussion and Recommendation

Our findings reinforce both the theoretical and empirical literature cited in the study, providing strong evidence that climate shocks are increasingly becoming a systemic macro-financial risk in Bangladesh. These results can be understood through the lens of the systemic risk framework, Carney's (2015) climate risk taxonomy, and the climate-augmented financial accelerator mechanism discussed earlier.

The confirmation of a long-run cointegrating relationship among climate variables, macroeconomic indicators, and the Financial Stability Index (FSI) is particularly important. This finding supports the IMF’s systemic risk framework, which holds that macroeconomic and financial systems are deeply interconnected and that persistent external shocks can undermine financial stability over time. The presence of cointegration indicates that climate shocks are not temporary environmental disturbances; rather, they exert structural, long-lasting effects on Bangladesh’s macro-financial system. This finding aligns with the work of Dafermos et al. (2018) and Liu et al. (2021), who demonstrated that climate-related shocks generate persistent disruptions in financial systems through macroeconomic transmission channels.

The negative and statistically significant effects of CO_2 emissions, extreme heat exposure, and consecutive dry days on the FSI strongly support the study’s main hypothesis that climate change adversely affects financial stability in Bangladesh. These findings are highly consistent with Mark Carney’s (2015) climate risk framework, which conceptualizes climate change as a source of systemic financial risk through physical, transition, and liability channels. In Bangladesh, the results suggest that physical climate risks are the dominant transmission mechanism. Extreme temperatures and prolonged dry periods reduce agricultural and labor productivity, disrupt supply chains, and lower household income. These shocks eventually transmit to the banking sector through rising default risk, deteriorating asset quality, and tighter liquidity conditions.

The significant negative coefficient on consecutive dry days is especially important for Bangladesh, where the economy remains heavily dependent on agriculture and climate-sensitive rural activities. This finding aligns closely with studies by Rehman et al. (2024) and Kashem (2025), which found that droughts and climate variability significantly reduce agricultural output and food security in South Asia. From a theoretical perspective, this result also supports the climate-augmented financial accelerator hypothesis of Bernanke et al. (1999) and Dafermos et al. (2018). Climate shocks initially affect the real economy by reducing production and income, but these effects are amplified through the financial sector as banks face higher loan defaults and weaker repayment capacity, particularly in agricultural and SME portfolios.

Similarly, the adverse long-run impact of CO_2 emissions on financial stability indicates that environmental degradation and unsustainable growth patterns can undermine macroeconomic resilience. This result aligns with the global literature, which suggests that environmental deterioration eventually translates into systemic financial vulnerabilities. The findings support the arguments of Battiston et al. (2017), who demonstrated that climate-related asset degradation can create spillover effects throughout the financial system. Higher emissions are often associated with inefficient industrialization, pollution-intensive growth, and rising climate exposure, all of which increase future adaptation costs and economic vulnerabilities.

The negative relationship between heat exposure (days above 35°C) and financial stability aligns with international empirical findings. Studies, such as Wu et al. (2023) found that rising temperatures negatively affect financial stability by lowering productivity and disrupting economic activity. In Bangladesh, where a large share of labor-intensive activities occurs outdoors and in climate-sensitive sectors, excessive heat can reduce labor efficiency, increase health expenditures, and lower overall production capacity. These effects weaken economic growth and, in turn, reduce the resilience of financial institutions.

Conversely, the positive effects of agricultural value added, manufacturing output, and capital formation on financial stability underscore the importance of economic diversification and productive investment for strengthening macro-financial resilience. These findings align with the broader macroeconomic stability literature, particularly the perspectives of the IMF and the BIS, which emphasize that stronger productive sectors and sustainable economic growth enhance the financial system's resilience to shocks. The positive effect of manufacturing GDP suggests that industrial diversification can partially offset climate-related vulnerabilities in agriculture. Similarly, higher capital formation improves infrastructure, productive efficiency, and adaptive capacity, thereby supporting financial stability.

The negative relationship between exchange-rate depreciation and financial stability is also theoretically and empirically meaningful. Exchange-rate volatility increases import costs, inflationary pressures, and external debt burdens, especially for an import-dependent economy like Bangladesh. This finding aligns with the macro-financial vulnerability framework discussed by the International Monetary Fund and the Bank for International Settlements, in which external-sector instability amplifies systemic financial risks in emerging economies. Climate shocks may further intensify exchange-rate pressures by reducing export earnings and increasing import dependence on food and energy.

The negative long-run impact of NPLs on financial stability aligns with both theory and prior empirical evidence. Rising non-performing loans weaken banks' balance sheets, reduce lending capacity, and heighten systemic fragility. This pattern is consistent with D'Orazio et al. (2025), who showed that climate-related risks worsen banking-sector asset quality and liquidity conditions. In Bangladesh, climate-sensitive sectors such as agriculture, fisheries, and SMEs are particularly vulnerable to repayment difficulties after climate disasters, which may eventually elevate NPL ratios across the banking system.

The strong significance of the lagged FSI variable indicates persistence and inertia in financial stability dynamics. This finding implies that current financial conditions are strongly influenced by past macro-financial performance, reflecting structural rigidities and delayed adjustment mechanisms within Bangladesh's financial system. Such persistence is common in macro-financial studies and underscores the importance of early policy intervention to prevent climate vulnerabilities from accumulating into systemic risks.

The diagnostic and stability tests further strengthen the credibility of the empirical findings. The absence of multicollinearity, autocorrelation, and heteroscedasticity indicates that the ARDL model is statistically robust and well-suited to examining the long-run relationship between climate variables and financial stability. This methodological robustness enhances confidence in the study's contribution to the emerging climate-finance literature.

Overall, the findings make a significant contribution to the growing global literature recognizing climate change as a macro-financial stability issue rather than solely an environmental challenge. The results support recent international discussions by the Network for Greening the Financial System and the Financial Stability Board, which emphasize integrating climate risks into central banking, financial supervision, and macroprudential regulation. For Bangladesh, the study shows that climate vulnerability directly threatens financial-system resilience through both macroeconomic and banking-sector transmission channels. Consequently, climate risk management should become an integral component of monetary policy, financial regulation, banking supervision, and long-term development planning.

Drawing from the empirical findings, the following policy recommendations are advanced to strengthen macro-financial stability amid climate shocks in Bangladesh:

(i) ***Integrate Climate Risks into Financial Sector Regulation:*** Bangladesh Bank should integrate climate-related financial risks into prudential regulations, stress-testing frameworks, and supervisory guidelines. Bangladesh Bank may conduct regular climate stress tests covering heat stress, drought, and transition shocks. The results will guide supervisory discussions, capital allocation strategies, and sector exposure thresholds.

(ii) ***Promote Green and Climate-Resilient Financing:*** Financial institutions should expand green financing initiatives, including renewable energy projects, climate-smart agriculture, sustainable infrastructure, and environmentally friendly industrial investments. Preferential refinancing programs and green credit incentives can support this transition. Bangladesh Bank might offer refinancing, reduce risk weights when appropriate, acknowledge sustainability ratings, and provide supervisory incentives for credible green and adaptation financing.

(iii) ***Strengthen Agricultural Risk Management:*** Given the pronounced impact of consecutive dry days on financial stability, policymakers should strengthen climate-resilient agricultural practices, improve irrigation systems, promote crop diversification, and expand agricultural insurance. These measures will enhance agricultural resilience, reduce credit risk, and safeguard rural financial systems.

(iv) ***Improve Banking Sector Asset Quality:*** The negative impact of non-performing loans underscores the need for robust credit risk management and enhanced loan monitoring. Banks should strengthen borrower risk assessments, particularly in climate-sensitive sectors, and maintain adequate provisioning for potential climate-related defaults. Concentration limits may be introduced for highly vulnerable geography or carbon-intensive sectors.

(v) ***Enhance Climate Data and Risk Disclosure:*** Regulatory authorities should adopt standardized climate-risk disclosure frameworks for banks and financial institutions. Banks should disclose climate-related exposures, green finance, carbon-intensive lending, climate risk governance, and stress test results.

(vi) ***Encourage Economic Diversification and Industrial Development:*** The positive impact of manufacturing and capital formation indicates that diversified economic growth strengthens financial resilience. Policies that promote industrial modernization, sustainable manufacturing, and infrastructure investment should be prioritized.

(vii) ***Strengthen Exchange Rate and Macroeconomic Stability:*** As exchange-rate depreciation undermines financial stability, maintaining external-sector stability through prudent monetary, fiscal, and foreign-exchange policies is vital. Effective foreign reserve management and export diversification can help mitigate vulnerability to external shocks.

(viii) ***Develop a National Climate-Financial Stability Framework:*** A coordinated national framework, involving Bangladesh Bank, the Ministry of Finance, financial institutions, and environmental agencies, should be established to comprehensively address systemic climate-related financial risks. A centralized climate-financial risk database should link loan-level data with geography, sector, borrower vulnerability, collateral location, and disaster history.

(ix) ***Expand Climate Adaptation Investment:*** Public and private investments in flood control, coastal protection, renewable energy, disaster preparedness, and resilient infrastructure should be increased to minimize long-term economic and financial losses from climate change. More credit should go to climate-resilient agriculture, renewable energy, water management, coastal protection, green buildings, resilient CMSMEs, and disaster-recovery finance.

(x) ***Mandatory climate risk assessment in lending:*** Climate vulnerability should be included in credit appraisal, especially for agriculture, CMSME, coastal industries, real estate, energy, textiles, and infrastructure. Environmental and Social Due Diligence should be strengthened under the Bangladesh Bank's sustainable finance framework.

7. Conclusion, Limitation, And Future Directions

This study examined the impact of climate shocks on macro-financial stability in Bangladesh using a constructed Financial Stability Index (FSI) and the ARDL modeling approach, with annual data from 1990 to 2024. The findings confirm that climate-related variables significantly affect financial stability in both the short and long run. Specifically, CO_2 emissions, extreme heat exposure, and consecutive dry days negatively influence the FSI, indicating that climate stress weakens economic productivity, increases financial vulnerability, and erodes banking-sector resilience. Among these variables, drought-related shocks showed particularly strong adverse effects, reflecting Bangladesh's dependence on climate-sensitive sectors such as agriculture.

The study also found that agricultural value added, manufacturing growth, and capital formation contribute positively to financial stability, suggesting that economic diversification and productive investment enhance resilience to climate risks. Conversely, exchange-rate depreciation and rising non-performing loans undermine financial stability over time.

Overall, the results demonstrate that climate change is not only an environmental challenge but also a critical macro-financial concern for Bangladesh. Therefore, integrating climate risks into financial regulation, monetary policy, and macroeconomic management is essential to ensure long-term financial stability and sustainable economic development.

While this study offers valuable insights into the link between climate shocks and macro-financial stability in Bangladesh, it has several constraints. The analysis relies on annual data from 1990 to 2024, limiting observations and potentially missing short-term climate and financial variations. The created Financial Stability Index (FSI) is comprehensive but includes only selected macro-financial indicators, which may not capture all aspects of systemic financial risk. Additionally, due to data limitations, key climate-related factors such as flood severity, cyclone strength, sea-level rise, and sector-specific financial losses were not included. Although the ARDL model effectively identifies long- and short-term relationships, it might not fully capture nonlinear dynamics or structural breaks related to major climate events or policy shifts. Finally, since the research focuses only on Bangladesh, its conclusions may have limited applicability to other nations with different economic systems and climate vulnerabilities.

Future research ought to improve composite indicators of climate-financial vulnerability and explore sector-specific risks. Continuous monitoring of the connections between climate and finance will support evidence-based policymaking and enhance Bangladesh's long-term financial resilience.

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