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Stern review on the economics of climate change: implications for Bangladesh

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Abstract

Purpose – The purpose of this study is to investigate the impact of climate change on economic development in Bangladesh. More specifically, the research aims to figure out the influence of climate change on gross domestic product (GDP) growth rate related to different sectors such as agriculture, forest, water, health and infrastructure. It also attempts to explore the effect of climate change on the coastal economy of Bangladesh.

Design/methodology/approach – A set of statistical and econometric techniques, including descriptive and correlation analysis and time series regression model, was applied to address the objective of the research. Sector-wise time series economic data were collected from the World Bank for the period between 1971 and 2013. Climate data were received from the Bangladesh Agricultural Research Council online database for the period between 1948 and 2013.

Findings – The results from the statistical analysis show that climate variables such as temperature and rainfall have changed between 1948 and 2013 in the context of Bangladesh. The econometric regression analysis demonstrates that an increase by 1°C of annual mean temperature leads to a decrease in the GDP growth rate by 0.44 per cent on average, which is statistically significant at the 5 per cent level. On the other hand, the estimated coefficients of agriculture, industry, services, urbanization and export are positively associated with GDP growth rate, and these are statistically significant at the 1 per cent level. Sector-wise correlation analysis provides statistical evidence that climate change is negatively associated with various sectors, such as agriculture, forest, human health and arable land. In contrast, it has a positive relation to water access and electricity consumption. Analysis of coastal regions shows that climate change negatively affects the local economic sectors of the coastal zone of the country.

Originality/value – Although this study has received significant insight from the world-renowned research publication "The Economics of Climate Change: The Stern Review", there is a dearth of research on the economic impact of climate change in the context of Bangladesh. The findings of the paper provide deep insight into and comprehensive views of policy makers on the impact of climate change on economic growth and various sectors in Bangladesh.

Keywords Bangladesh, Climate change, Economic development, Coastal zone, Stern review

Paper type Research paper

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1. Introduction

1.1 Background

This research initiative is inspired by the world-renowned and widely accepted research publication, "The Economics of Climate Change: The Stern Review", led by Sir Nicholas Stern in 2007. We are indebted to that publication and express our heartfelt gratitude to the authors involved therein.

At present, climate change is one of the largest challenges in the world, especially in developing and least developed countries (Adedeji *et al.*, 2014; Arndt *et al.*, 2012; Korman and Barcia, 2012; Timsina and Shrestha, 2014). It is not a future phenomenon; rather, it is happening right now. Despite some disagreement, the reality of climate change accelerated by human activities is now unambiguously accepted (Basak *et al.*, 2013; McGowan, 2013; Oreskes, 2004). Anthropogenic climate change has become a prime concern for humans because of its socioeconomic impacts (Arnell *et al.*, 2016). There was a significant rise in temperature in the past century. It will continue to rise unless the emission of greenhouse gases (GHGs) declines substantially (Sillmann and Roeckner, 2008). To estimate the global economic cost of climate change, research has been done by renowned scholars. Fankhauser was acknowledged for carrying out the first serious study of the global welfare effects of climate change in 1994, although it was started by Cline in 1992, Nordhaus in 1991, and Titus in 1992 (Tol, 2009). The Stern Review offered pioneering approaches to the issue of the economics of climate change in 2007. It has brought about a new dimension in the conventional analysis of climate change by creating debates about climate economics (Ackerman *et al.*, 2009). The Stern Review emphasizes immediate decisions and early action to stabilize emission of GHGs to reduce the cost of climate change. The conclusion of the Stern Review is based on two basic strands. The first is a formal aggregative model based on low discount rate. The other is an intuitive argument suggesting potential for avoiding possible large uncertainties (Weitzman, 2007).

The Stern Review covers several topics in six broad parts. Part one includes two chapters covering the background and different aspects of climate change. In part two, the impacts of climate change on growth and development are discussed. Part three discusses the economics of stabilization and the projection of growth of GHG emission. It also analyses the challenges, identification of mitigation cost and structural changes and competitiveness of climate change policy. The policy responses for mitigation are discussed in part four. This part also explains the reduction of emissions, carbon pricing and acceleration of technological innovation. In part five, adaptation policy responses are discussed to explain the economics of adaptation and the role of adaptation in sustainable development. Part six concludes with an international collective action framework for climate change and international support for adaptation.

The root of the present research is underlined in part two of the Stern Review. This segment of the review discusses the potential impacts of climate change on people's lives, the environment and growth and development in different parts of the world. The review predicts some negative impacts of climate change on several essential components of people's livelihoods, such as water supply, food production, human health, availability of land and ecosystems. It also argues that economic growth can be severely affected by the extreme change in climate variables for developing countries. As one of the least developed Southeast Asian countries, Bangladesh is one of the top ten nations that are most vulnerable to climate change. The adverse effects of climate variability have already worsened the overall economic development of the country (Alauddin and Rahman, 2013; Mahmood, 2012).

2. Related literature

In the past few decades, climate change has drawn a great deal of scientific, political and public attention (Pasgaard and Strange, 2013). It incorporates several events, such as increase in temperature, changes in precipitation pattern (Mobeen *et al.*, 2017), rise in sea level, intrusion of saline water and higher possibility of extreme weather events (Bates *et al.*, 2008). Climate is an interactive and complex system. It can be changed naturally, as a result of change in the sun's energy, Earth's orbital changes, ocean currents or volcanic eruptions. Alternatively, it can be changed through persistent anthropogenic forcing, such as the addition of GHGs to the atmosphere by industries, sulfate aerosols or black carbon. It can also be changed by a combination of both (Azar and Johansson, 2012; Filho, 2009; Onoja *et al.*, 2011).

There is a strong link between climate change and economic development (Huq *et al.*, 2006). Evidence from empirical studies shows that ignoring climate change will eventually disrupt economic growth and development in the long run (Stern, 2007). Human-led emission of GHGs is assumed to be responsible for increasing concentration of GHGs in the atmosphere. Such GHGs might cause a rise in average global temperature, which negatively affects the aggregate output and the marginal product of capital (Gregory *et al.*, 2005). The impact of climate change on economic growth in the poorest countries is substantial. It has been found that poor countries that make the least contribution to climate change are the worst victims of climate change (Tol, 2009). These countries suffer in terms of declining economic growth rates. More specifically, poor countries face a reduction in agricultural production, industrial output and aggregate investment compared to rich countries (Dell *et al.*, 2008). The Stern Review observes that if action is not taken on time, the overall costs and risks of climate change will be equivalent to losing at least 5 per cent of global gross domestic product (GDP) each year, now and forever. This loss could rise to 20 per cent of GDP or more. The Review also warns that climate change could affect basic elements of life for people around the world. Changes in climate variables could affect access to water, food production, health care, environment and soil productivity (Stern, 2007).

The impact of climate change on the water sector can be understood by people in terms of water distribution around the world (Kiparsky *et al.*, 2006). Climate change is considered to be responsible for worldwide water scarcity (Elenwo and Akankali, 2014). There is strong evidence that freshwater resources are highly vulnerable to climatic change (Calow *et al.*, 2011). There might be a reduction of institutional resources, which may accelerate local and transitional conflicts due to scarcity of fresh water (Zakar *et al.*, 2012). Surface water and groundwater are the primary natural sources of domestic, agricultural and industrial usages in many countries. However, global groundwater reserves would be threatened by human activities and the uncertain consequences of climate change (Treidel *et al.*, 2011).

There is a complex interrelationship between climate change and agriculture. The agriculture sector is highly vulnerable to climate change. Changing global temperature and increasing weather-related disasters in the past few decades have reduced the potential for agro-product growth and export (Alboghdady and El-Hendawy, 2016; Fazal and Wahab, 2013; Joshia and Chaturvedib, 2013; Kakumanu *et al.*, 2016; Parry *et al.*, 2009). Countries situated in the tropical and subtropical zones, known as developing economies, are expected to face a loss in agricultural output. For example, rice production is supposed to be affected by climate change in Southeast Asian countries as they are in the tropical belt (Dewi, 2009). On the other hand, developing economies in the temperate zones are expected to gain (Vien, 2011). Hence, the global impacts of climate change on agriculture vary significantly from region to region. As a result, global food security problems will become more acute and complex (Ji-kun, 2014).

Industrialization is one of the fundamental ways to achieve economic development for low-income countries (Haraguchi *et al.*, 2017). In recent times, the negative impacts of climate change have been perceived in various industries in many parts of the world. For instance, industries related to rice and wool, tourism, seed, ski, etc. are being affected by changes in climatic variables (Gilaberte-Búrdalo *et al.*, 2014; Hall and Clayton, 2009; Harle *et al.*, 2007; Mushtaq, 2016; Singh *et al.*, 2013; Tapsuwan and Rongrongmuang, 2015). In addition, electricity, construction, insurance and forestry industries are highly sensitive to climate change.

Urbanization is an essential part of the process of economic development (Castells-Quintana, 2017). Urban areas have been the center of all economic activities over time. Urban regions are now facing the negative consequences of human-led climate change. Research findings indicate that urban areas will face extreme heatwaves, blockage of sewerage, over-flooding, etc. in the near future (Bi *et al.*, 2017; Liu and Hua, 2014). Extreme environmental changes would negatively affect the smooth expansion of urban areas and consequently impede sustainable economic development.

In the twenty-first century, climate change has become the most visible environmental concern. It will increase the global death caused by malnutrition and heat stress (Stern, 2007). Variations in climate have both direct and indirect impacts on human health (Pillay and Bergh, 2016; Rahman, 2008). Direct health impacts include heatwaves or injury due to flood or storm. Indirect health impacts include infectious and vector-borne diseases and water and air quality decrease, which contribute to human mortality and morbidity (Brown *et al.*, 2011; Kurane, 2009). Climate change is expected to affect coastal communities around the world by destroying land, infrastructure and coastal resources. It will also increase the risk of submergence, coastal flooding and coastal erosion because of relative sea level rise and extinction of flora, fauna and micro-organic resources in most developing countries (Amosu *et al.*, 2012; Dolan and Walker, 2006).

The negative consequences of climate change would be observed all over the world, including Bangladesh. Major impacts of climate change on the country would include frequent and uncertain occurrence of natural disasters, increase of salinity in coastal areas, coastal erosion, drought in the northern region, scarcity of drinking water, prolonged water-logging, heavy rainfall, irregular monsoon, inundation during monsoon, crop damage due to floods, riverbank erosion and outbreak of dengue, malaria, cholera and diarrhea (Haque, 2006; Zaman and Islam, 2012). The agriculture sector of Bangladesh is extremely vulnerable to disaster and risks related to climatic changes (Ahmed, 2000). Crop production, especially rice production, is highly affected by major climatic hazards such as the frequent occurrence of floods and droughts, soil and water salinity, cyclones and water surges. Climate change is also forcing smallholder farmers out of cereal production or agricultural activities (Rahman *et al.*, 2014). Smallholder farmers account for about 80 per cent of food production in Bangladesh. Predictions from different models reveal that rice production will decline by 17 per cent and wheat production by 61 per cent if the temperature increases by 4°C (Mondal, 2010). Changes in climate will be a threat to both the surface water and groundwater in the country. It is assumed that water-dependent activities such as irrigation, fish cultivation and navigation will be seriously disrupted because of changes in water resources and hydrology (Biswas, 2013). Simulated projections estimate that the cost to the agricultural sector will amount to US$26bn in terms of agricultural GDP during the period from 2005 to 2050. In the past 50 years, Bangladesh has experienced about 20 drought conditions, and in the 1990s, a loss of 3.5 million tons of rice production occurred in the northwest part of the country because of drought conditions (Faroque *et al.*, 2013). Besides, it is projected that there will be about a 3.1 per cent annual decline in the overall agricultural growth of Bangladesh because of climate change (Yu *et al.*, 2010).

The geographical location of Bangladesh makes the country susceptible to water-related problems such as flood, erosion, drought and storm surges (Hossain and Alsdorf, 2010). This also makes the country a vulnerable disaster-prone area. From time to time, different types of natural and human-induced disasters have happened in the country, causing a serious loss of life and assets and threatening the natural progress of economic development (Sabur, 2012). The impact of climate change on the health sector is putting pressure on the existing socioeconomic problems of Bangladesh. It has been found that malaria incidence increased from 1,556 to 42,012 during the period between 1971 and 2004. Climate change will accelerate the transmission of new infectious diseases alongside existing ones (Mahmood, 2012). In the coastal region, sea level rise is constantly increasing the risk of diarrhea, malnutrition and skin diseases (Rahman, 2008).

The coastal region of Bangladesh is assumed to be the worst sufferer of climate change because of its low-lying deltaic landscape (Hossain and Roy, 2012; Mahmood, 2012). Because of the threat of climate change, this region is expected to face great danger. For instance, if the sea level rises by 27 cm by 2050, about 33 million people will suffer from water surging. A 1-m-rise in sea level would submerge around 18 per cent of the total land area in Bangladesh (Minar *et al.*, 2013). About 53 per cent of the total land in the coastal regions of the country is saline (Haque, 2006). As a result, a huge amount of cultivable land is affected by salinity in these regions (Roy *et al.*, 2009). Because of the intrusion of saline water into the canal, Boro rice production has reduced from 5-5.5 tons to 2-2.5 tons and Aus rice production from 4-4.5 tons to 2-2.5 tons in this region (Khanom and Salehin, 2012).

Research on climate change and its impact on economic growth, along with the different economic sectors of Bangladesh, is unavailable in the existing literature. Hence, this research intends to analyze the impact of climate change on economic growth and economic sectors in the coastal regions of Bangladesh.

3. Methodology

3.1 Description of data and data sources

The necessary and relevant data for this research have been collected from secondary sources published by the World Bank (WB), Bangladesh Agriculture Research Council (BARC), Ministry of Finance and Bangladesh Bureau of Statistics (BBS). A brief description and details of the data are presented in Table I.

In Table I, a list of variables used to address the research objective has been provided. The table is divided into three parts. The first part includes the variables used in the growth model. The second part incorporates the variables used to analyze the sector-wise economic impact of climate change in the country. The last part covers the variables used for understanding sector-wise local influences of climate change in the coastal zone of Bangladesh.

The sector-wise impact of climate change has been analyzed by observing the degree of association between climate variables and different economic sectors in the context of Bangladesh. These sectors are agriculture, forest, water, human health and infrastructure. As agriculture is highly sensitive to climatic change, a change in climate variability is expected to affect this sector in the country. Similarly, the forest sector is also vulnerable to climate change. For various climatic reasons, freshwater sources have been skewed in this region. As such, changes in climate have effects on access to water. As many human diseases are directly influenced by climatic factors, a rise in temperature causes breakouts of these diseases. Climate change also affects the infrastructure of an economy. Two proxy

Variable name	Symbol	Measurement unit	Data range and source
GDP Growth Rate	*Y*	Annual GDP growth rate in %	1971-2013 WB (2014)
Agriculture Sector Growth Rate	*AG*	Annual growth of agriculture in %	1971-2013 WB (2014)
Industry Sector Growth Rate	*IND*	Annual growth of industry in %	1971-2013 WB (2014)
Services Sector Growth Rate	*SERV*	Annual growth of services in %	1971-2013 WB (2014)
Gross Saving	*SAV*	Gross saving in current US dollars	1971-2013 WB (2014)
Urbanization	*UR*	Urban population per year	1971-2013 WB (2014)
Net Income from Abroad	*IA*	Net income from abroad in current US dollars	1971-2013 WB (2014)
Export of Goods and Services	*EXP*	Exports of goods and services (annual % growth)	1971-2013 WB (2014)
Annual Mean Maximum Temperature	*MaxT*	Annual mean maximum temperature is calculated using year-wise monthly data	1971-2013 BARC (2015)
Annual Mean Minimum Temperature	*MinT*	Annual mean minimum temperature is calculated using year-wise monthly data	1971-2013 BARC (2015)
Annual Mean Rainfall	*Rain*	Annual mean rainfall is calculated from year-wise monthly average data	1971-2013 BARC (2015)
Sector-wise national data			
Agriculture Sector	*Agriculture*	Value addition of agriculture (% of GDP)	1971-2013 WB (2014)
Forest Sector	*Forest*	Forest rents (% of GDP)	1971-2013 WB (2014)
Water Sector	*Water*	Improved water source (% of population with access)	1990-2012 WB (2014)
Human Health Sector	*Human Health*	Total health expenditure (% of GDP)	1995-2012 WB (2014)

(*continued*)

Table I. Description of the variables

Table I.

Variable name	Symbol	Measurement unit	Data range and source
Infrastructure	*Arable Land*	Arable land (% of total land area)	1971-2012 WB (2014)
	Electricity	Electric power consumption (kWh)	1971-2012 WB (2014)
Sector-wise coastal zone data			
Agriculture sector	*Agriculture*	Gross value addition of agriculture sector at current price in million BDT	1977-1998 BBS
Crop sector	*Crop*	Gross value addition of crop sector at current price in million BDT	1977-1998 BBS
Forest sector	*Forest*	Gross value addition of forest sector at current price in million BDT	1977-1998 BBS
Livestock sector	*Livestock*	Gross value addition of livestock sector at current price in million BDT	1977-1998 BBS
Fisheries sector	*Fisheries*	Gross value addition of fisheries sector at current price in million BDT	1977-1998 BBS
Industry sector	*Industry*	Gross value addition of industry sector at current price in million BDT	1977-1998 BBS
Construction sector	*Construction*	Gross value addition of construction sector at current price in million BDT	1977-1998 BBS
Transport sector	*Transport*	Gross value addition of transport sector at current price in million BDT	1977-1998 BBS

Source: WB (2014), BARC (2015), BBS (1982), BBS (1986), BBS (1994) and BBS (1999) variables, arable land and electric power consumption, have been used to ascertain their relationship with climate variables.

Apart from the national level, especial attention has been paid to the impact of climate change on the various economic sectors of the coastal areas of Bangladesh. There are 19 districts in the coastal zone of the country. District-level economic data, in terms of different sectors, have been gathered from the various publications of the BBS. These sectors are agriculture, crop, forest, livestock, fishery, industry, construction and transport.

3.2 Theoretical background

Economic estimation of the impact of climate change requires various tools and econometric approaches, as climate change is a global phenomenon. Over time, researchers have introduced different models and approaches to assess the impacts of climate change. Among these, two popular and widely used approaches for estimating the impacts of climate change on economic growth are the enumerative approach and the dynamic approach (Akram, 2012). The first approach applies the sector-by-sector technique to identify the impact of climate change on economic growth. After that, the separate effects of climate change are summed up to figure out the total impact of the change. However, the limitation of the approach is that it concentrates on only one period of climate change effect, ignoring the intertemporal effects. Scholars such as Nordhaus (1991), Tol (1995) and Cline (1993) have applied this method. The dynamic approach, meanwhile, incorporates different specifications of growth models, including damage function. Notable models under this approach are the Solow-Swan model, the Ramsey-Cass-Koopmans model, the Mankiw, Romer and Weil model, etc. These models are used to analyze the impact of climate change on economic growth. The present study applies both approaches to some extent to assess the impacts of climate change on economic growth in the context of Bangladesh.

3.3 Theoretical framework

Several models have been used by the researcher to estimate the impacts of climate change. Among them, the Integrated Model (climate economy), the Regional Integrated Model of Climate and the Economy (RICE), the PAGE95 model, the PAGE2002 model, the Global Impact Model (GIM), the DICE model, the Integrated Assessment Models (IAM) and the SWOPSIM model are remarkable. The Stern Review has used the PAGE2002 model (an integrated assessment model) to estimate the impact of climate change on output and growth in the future (Stern, 2007). However, it requires a lot of assumptions to make the model function. Even so, the Stern Review acknowledges that these models are highly aggregative and simplified, which means that its results can be seen as illustrative only.

This paper adopts different approaches to estimating the effects of climate variables, such as temperature and precipitation on a single aggregate measure, economic growth (rather than identifying them step by step and then summing up).

The following empirical framework of the research is derived from the production function used by Dell *et al.* (2008). They have included climatic variables in the growth model that provides evidence to incorporate climate variables into growth functions. They direct ways to identify the impact of climate variations on economic growth:

$$Y_{it} = e^{\alpha Tit} A_{it} L_{it} K_{it} \tag{1}$$

$$\frac{\Delta Ait}{Ait} g_i + T_{it} \tag{2}$$

where Y is GDP, L is labor force, A is technology (can be referred to as labor productivity), T is impact of climate, g is growth rate of GDP and K is human capital. Equation (1) captures direct effects of climate change on economic growth, for instance, impacts on labor productivity. Equation (2) captures the indirect (dynamic) effect of climate, for example, the impact of climate on other variables that indirectly influence GDP. After taking logs of the equation (1) and differencing with respect to time, the following equation (3) can be derived:

$$g_{it} = g_i + (\alpha + \beta)T_{it} - \alpha T_{it-1} \tag{3}$$

where g_{it} is the growth rate of output, direct effects of climate change on economic growth appear through α and indirect effects appear through β, while g_i denotes the fixed effects.

Scholars have shown empirical and practical pieces of evidence for impact of climate change on GDP growth in different countries. Using a basic cross-country growth regression model, Abidoye and Odusola (2015) provided estimates of the impact of climate change on GDP growth in 34 African countries. Using a similar model, Barrios *et al.* (2010) estimated the impact of rainfall on GDP growth in an empirical economic growth framework of sub-Saharan African nations compared with other developing nations.

3.4 Empirical model

In line with the theoretical explanation, the following economic growth model has been specified in equation (4):

$$\begin{aligned} Y_{it} = \alpha_0 + \alpha_1 AG_{it} + \alpha_2 IND_{it} + \alpha_3 SERVs_{it} + \alpha_4 SAV_{it} + \alpha_5 UR_{it} + \alpha_6 IA_{it} \\ + \alpha_7 EXP_{it} + \alpha_8 MaxT_{it} + \alpha_9 MinT_{it} + \alpha_{10} Rain_{it} + \varepsilon_{it} \end{aligned} \tag{4}$$

where Y represents the GDP growth rate and AG, IND, SERV, SAV, UR, IA, EXP, MaxT, MinT, and Rain denote annual growth rate of agriculture, annual growth rate of industry, annual growth rate of services, gross saving, urbanization, net income from abroad in current US dollars, annual growth rate of exports of goods and services, annual mean maximum temperature, annual mean minimum temperature and annual mean rainfall, respectively.

Justification for using economic variables in the growth model is that since the liberation war in 1971, several factors have contributed to fostering economic growth in Bangladesh. These factors are agriculture, industry, service, gross investment (private and public), foreign direct investment, remittance, exports and imports of goods and services, human capital, urbanization, gross domestic savings and gross national savings (Mujeri, 2004; Rahman and Yusuf, 2010). The reason for using annual temperature and precipitation as an approximation of climate change has been referred to Deschênes and Greenstone (2012), who estimated the impact of climate change on US agricultural land by annual variation in temperature and precipitation. Furthermore, the relationships between economic growth and climate variables, for instance, temperature and precipitation, were established in the works of Dell *et al.* (2008) and Parry (2007).

3.5 Test of stationarity

To test the stationarity of the data, the Augmented Dickey–Fuller (ADF) test has been used (Gujarati, 2009). The ADF test is formulated with lagged difference terms in the following equation (5):

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta \gamma_{t-1} + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-1} + \varepsilon^t \quad (5)$$

where β_1 is a constant, β_2 is the coefficient on a time trend, m is the lagged difference term and the error term is ε^t. The error term is assumed to be homoscedastic. Here, the null hypothesis specifies H_0: Y = 0 and the alternative hypothesis indicates H_1: Y < 0. The ADF test examined the null hypothesis that a time series Y_t is I(1) against the alternative that it is I(0) (Uddin *et al.*, 2016).

The ADF test statistics are presented in Table II for all series. The results indicate that there is no scope to accept the null hypothesis. The variables have no unit root, and all the variables are integrated of order zero, i.e. I(0).

3.6 Correlation analysis

The value of the correlation coefficient indicates the strength of the relationship between variables (Aczel and Sounderpandian, 2008). Correlation analysis has been applied to find the degrees of association between various economic sectors (national and coastal) and climate variables (annual mean maximum temperature, annual mean minimum temperature and annual mean rainfall).

4. Results and discussion

4.1 Evidence of climate variability in Bangladesh

There are some hydro-geological and socioeconomic factors that act as catalysts for increasing vulnerability to climate change in Bangladesh. It is projected that in the coming decades, both temperature and sea level will rise annually. Precipitation will decrease in the winter season and correspondingly increase in the wet season.

The climate variability of Bangladesh is shown in Table III for the period between 1948 and 2013 by using climate variables, average annual maximum temperature, average

				Interpolated Dickey–Fuller			
Variable	Obs	Integration of order	Test statistic Z(t)	Critical value (1%)	Critical value (5%)	Critical value (10%)	MacKinnon approximate *p*-value for Z(t)
Y	42	I (0)	−4.62	−3.63	−2.95	−2.61	0.00
AG	42	I (0)	−6.58	−3.63	−2.95	−2.61	0.00
IND	42	I (0)	−7.80	−3.63	−2.95	−2.61	0.00
SERV	42	I (0)	−4.57	−3.63	−2.95	−2.61	0.00
SAV	35	I (0)	−7.38	−3.63	−2.95	−2.61	0.00
UR	42	I (0)	−6.48	−3.63	−2.95	−2.61	0.00
IA	34	I (0)	−4.50	−3.63	−2.95	−2.61	0.00
EXP	42	I (0)	−10.01	−3.63	−2.95	−2.61	0.00
MaxT	42	I (0)	−3.89	−3.63	−2.95	−2.61	0.00
MinT	42	I (0)	−4.98	−3.63	−2.95	−2.61	0.00
Rain	42	I (0)	−6.79	−3.63	−2.95	−2.61	0.00

Source: Author's compilation based on data collected from WB (2014) and BARC (2015)

Table II. ADF test of economic and climate variables

Climate variable	Statistics	1948-2013	1948-1979	1980-2013
Average annual maximum temperature (°C)	Mean	33.40	33.21	33.57
	SD	0.39	0.36	0.35
	CV (%)	1.17	1.07	1.04
	Min	32.44	32.44	32.73
	Max	34.35	34.01	34.35
Average annual minimum temperature (°C)	Mean	17.73	17.57	17.87
	SD	0.40	0.43	0.31
	CV (%)	2.27	2.45	1.76
	Min	16.85	16.85	17.09
	Max	19.05	19.05	18.51
Average annual rainfall (mm)	Mean	2,352.77	2,254.17	2,445.57
	SD	259.55	253.23	232.72
	CV (%)	11.03	11.23	9.52
	Min	1,640.00	1,640.00	1,937.06
	Max	2,810.75	2,772.18	2,810.75

Notes: SD = standard deviation; CV = coefficient of variation; Min = minimum; Max = maximum
Source: Author's compilation based on data collected from BARC (2015)

Table III.
Climate variability in Bangladesh

minimum annual temperature and average annual rainfall. It can be seen that mean annual maximum temperature has been 33.40°C and mean annual minimum temperature has been 17.73°C over the past 65 years in Bangladesh. Mean annual rainfall has been 2,352.77 mm for the same period. To get a clear picture of climate variability in Bangladesh, the data set has been split into two segments. The first segment covers the years from 1948 to 1979, and the second segment includes data from 1980 to 2013. Table III shows that both the mean annual maximum and the mean annual minimum temperature increased by 0.36°C and 0.30°C, respectively, and the mean annual rainfall increased by 191.40 mm from the first segment to the second segment.

4.2 Impact of climate variables on economic growth in Bangladesh

This section discusses the statistical analysis regarding the impact of climate variability on annual GDP growth rate during the period from 1971 to 2013 in Bangladesh. The results of the ADF test show that the economic and climate variables are stationary at an integrated order of zero, implying no unit root in variables under consideration.

The estimated regression results regarding the impact of climate change on GDP growth rate (Y) in Bangladesh are shown in Table IV. The value of R^2 is 0.97, which means that about 97 per cent of variation in GDP growth rate is explained by the considered explanatory variables in equation (4). It can be seen in Table IV that the estimated coefficients of AG, IND, SERV, UR and EXP are positive and statistically significant at the 1 per cent level. This result is consistent with the empirical evidence that the economic growth of Bangladesh depends mainly on the agriculture sector (AG), industry sector (IND), service sector (SERV), urbanization (UR) and export of goods and services (EXP). The results of the regression model also indicate that a 1 per cent increase in the annual growth rate of AG, IND, SERV, UR and EXP leads to an increase in the GDP growth rate of Bangladesh by 0.24, 0.14, 0.37, 2.13 and 0.02 per cent, respectively.

The estimated coefficient values of average maximum temperature (MaxT) and average minimum temperature (MinT) have been found to be negative, but the estimated coefficient of rainfall (Rain) has been found to be positive. Among them, only the estimated coefficient

Explanatory variables	Results of regression analysis Coefficients	Standard error	t-value	p-value
Y = dependent variable				
AG	0.24*	0.02	10.48	0.00
IND	0.14*	0.03	4.13	0.00
SERV	0.37*	0.12	3.14	0.00
SAV	−0.85	0.73	−1.16	0.26
UR	2.13*	0.61	3.48	0.00
IA	−0.51**	0.21	−2.36	0.02
EXP	0.02*	0.006	3.16	0.00
MaxT	−0.008	0.24	−0.03	0.97
MinT	−0.44**	0.19	−2.28	0.03
Rain	0.00003	0.0002	0.15	0.89
Constant	−16.47	9.20	−1.79	0.09
R^2	0.97			
F	99.18			
Model summary				
Mean VIF		10.37		
Durbin–Watson d-statistic		1.44		
Breusch–Pagan/Cook–Weisberg test for heteroskedasticity		$\chi^2(1) = 0.46$ Prob > $\chi^2 = 0.4964$		

Notes: * = Significant at 1% level; ** = significant at 5% level
Source: Author's compilation based on data collected from WB (2014) and BARC (2015)

Table IV. Impact of climate variables on economic growth in Bangladesh

of average minimum temperature has been found to be statistically significant at the 5 per cent level. This implies that a 1°C increase in mean minimum temperature causes an 0.44 per cent decrease in the GDP growth rate of Bangladesh. On the other hand, the coefficient of average maximum temperature is negative, implying a negative relation with the GDP of Bangladesh, although it has been found to be statistically insignificant. The underlying reason for the negative relation between average maximum temperature, average minimum temperature and GDP growth is that when minimum temperature increases, there are changes in climate and weather behaviors. As a result, there is a disruption in the normal economic activities of different economic sectors of the country. The leading economic sectors such as agriculture, industry and services are heavily climate-sensitive and climate-dependent. Rainfall plays a vital role in the development of agriculture, industry and other sectors, and it has a positive association with the GDP growth of Bangladesh.

Results from the post-regression estimation show that the mean variance inflation factor (VIF) is 10.37, implying tolerable multicollinearity among the explanatory variables. In addition, the Durbin–Watson d-statistic value is 1.44, indicating no serial correlation in the model. The test of heteroskedasticity provides evidence that there is an absence of heteroscedasticity in the model.

It can be inferred from the above analysis that climate change has significant influences on GDP growth in Bangladesh. Among all the economic variables, agriculture, industry, services, urbanization and exports have statistically significant positive effects on the GDP growth rate. The findings of this research are also supported by numerous researchers (Akram, 2012; Sun *et al.*, 2017; Tesfamariam and Hurlbert, 2017). Among the climate variables, the annual mean minimum temperature has a significant negative impact, the annual mean maximum temperature has an insignificant negative impact and the annual mean rainfall has an insignificant positive impact on the GDP growth of Bangladesh over the given period.

4.3 Impact of climate change on economic sectors in Bangladesh

In this section, attempts have been made to investigate the correlation between different economic sectors in the context of national and coastal zone perspective and climate variables, such as annual mean maximum temperature, annual mean minimum temperature and annual mean rainfall of Bangladesh. Results from the correlation analysis (Table V) indicate that average maximum temperature is negatively associated with the agriculture, forest and arable land of Bangladesh, and it is statistically significant at the 1 per cent level. The results indicate that the value addition of agriculture sector, forest sector and the amount of cultivable land decreases with an increase in annual maximum mean temperature for the given period. Tesfaye and Seifu (2016) have suggested that an increase in temperature and rainfall leads to decreasing agriculture and forest recourses respectively.

The coefficient values of average maximum temperature and average minimum temperature in relation to water access imply a strong positive relationship, and they are statistically significant at the 5 and 10 per cent level, respectively. The results imply that increase in temperature forces people to use more water than normal. In addition, average maximum temperature and average minimum temperature are positively related to electricity consumption, and this is statistically significant at the 1 per cent level. A possible explanation for this positive relationship is that because of the increase in temperature, more electricity is consumed for cooling purposes. On the other hand, climate variables have a negative association with economic sectors in the coastal regions of Bangladesh. Average maximum temperature and average minimum temperature have been found to be negatively associated with the agriculture, crop, forest, livestock, fishery, industry, construction and transport sectors. Among them, the agriculture and fishery sectors have a significant negative correlation with the average minimum temperature. Moreover, average maximum temperature has a significant negative relation to the construction sector in this region. However, the industry and transport sectors are

Table V. Correlation matrix of economic sectors and climate variables in Bangladesh

		Correlation matrix		
Region	Sector name	Max temp	Min temp	Rainfall
All region of Bangladesh	*Agriculture*	−0.65*	−0.21	−0.21
	Forest	−0.47*	−0.08	−0.06
	Water	0.46**	0.35***	−0.16
	Human Health	0.06	−0.07	−0.57**
	Electricity	0.53*	0.44*	0.07
	Arable Land	−0.54*	−0.31**	0.07
Coastal region of Bangladesh	*Agriculture*	−0.19	−0.53**	0.21
	Crop	−0.29	−0.32	0.13
	Forest	0.06	−0.009	0.09
	Livestock	−0.11	−0.26	0.33
	Fisheries	−0.17	−0.50**	0.19
	Industry	−0.23	0.23	−0.42**
	Construction	−0.48**	−0.03	0.06
	Transport	0.03	0.05	−0.46**

Notes: * = Significant at 1% level; ** = significant at 5% level; *** = significant at 10% level
Source: Author's compilation based on data collected from WB (2014) and BARC (2015)

found to be statistically negatively correlated with rainfall. The results presented in Table V clearly prove that both the national- and regional-level economic sectors of Bangladesh are threatened by changes in climate variables. Hence, to ensure sustainable development, it is imperative to take immediate active measures to reduce the negative impacts of climate change.

5. Concluding remarks

In this research, attempts have been taken to identify the impacts of climate change on the economic development of Bangladesh. It has been found that climate variables such as temperature and rainfall have increased over the past few decades. Annual maximum and minimum temperatures have negative impacts on the growth rate of the country. Besides, major economic sectors, both at national and regional levels, are negatively associated with these climate variables.

To cope with the impacts of climate change on the economy, practical measures should be taken as soon as possible. The following recommendations will be useful for policy implementation.

- The findings of the researchers emphasize that the economic growth of Bangladesh will reduce if the problem of climate change is not taken care of immediately. As the country can do very little to combat climate change because of a lower share in GHG emission compared to developed countries, an international joint effort is required to lessen the effects of climate change.
- The agriculture sector is found to be the most vulnerable to climate change, and it is imperative to introduce effective adaptation techniques to reduce the negative impact of climate change in the near future.
- Sector-wise specific adaptation policies have to be prepared and implemented at national and regional levels to minimize climate change-induced risk and losses. Furthermore, effective and efficient collaborations with different organizations in activating climate change adaptation measures have to be ensured.

A collective national and international effort to minimize the risk and vulnerability of climate change could be a promising way to avoid climate change and its impact on the economy of Bangladesh.

In recent years, climate change has gained more significant attention in the scientific community than previously. The impact of climate change cannot be perceived within a specific region or sector. Hence, it is crucial to identify the impact of climate change on all aspects to ascertain the real scenario. Therefore, research on climate change and its economic impact should be carried out in the context of Asian countries. In addition, further research regarding climate change vulnerability on different economic activities should be conducted in different regions of Bangladesh.

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