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ORIGINAL ARTICLE

Vulnerability of the power sector of Bangladesh to climate change and extreme weather events

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Abstract Rise in temperature and annual precipitation, changes in seasonal rainfall patterns, more frequent and severe extreme weather events, and increased salinity in river water have been observed in Bangladesh in the recent years. Rising temperature will elevate total power consumption and peak power demand especially during the pre-monsoon hot summer season, reduce power plant efficiency and transformer lifetime, and increase the transmission loss. More frequent and severe extreme weather events may cause more disruption in power generation and distribution, and more damage of power infrastructure. Lower river flow in dry season may cause water scarcity in power plants and hamper the production. Increased salinity in river water due to sea level rise may lead to corrosion and leakages in power plants located in the coastal region of Bangladesh. A diversified, decentralized, and climate resilient power system can reduce negative impacts of climate change on power sector of Bangladesh. Adaptation and mitigation strategies must be incorporated in the planning and development of new power systems and the reformation of existing power systems of Bangladesh.

Keywords Climate change · Extreme weather events · Power sector · Bangladesh

Introduction

The climate of Bangladesh has changed significantly in the recent years (Shahid and Khairulmaini 2009; Shahid 2010b, c). It has been observed that the annual rainfall and daily mean temperature of Bangladesh have increased by an amount of 5.2 mm/year and 0.9°C/decade, respectively (Shahid 2010c). According to the recent IPCC report (IPCC 2007), Bangladesh will experience 5–6% increase in rainfall and 1.9°C increase in temperature by 2030. Small changes in the mean and standard deviation values can produce relatively large changes in the probability of extreme events (Groisman et al. 1999; Rodrigo 2002; Chiew 2006; Su et al. 2006; Shahid 2011b). As the primary impacts of climate change on society result from extreme events (Rodrigo 2002), it might have severe negative consequences for Bangladesh. The impacts of more variable precipitation and extreme weather events are already visible in Bangladesh (Shahid 2010b, 2011b). Climate models predict more increase in extreme weather events in the near future (May 2004; Mirza 2002; Palmer and Raisanen 2002). Bangladesh is one of the most vulnerable countries of the world to climate change as the country has low capacity to address the devastating impacts (Shahid 2010a). Studies show that changing climate will have severe implications on the agriculture (Karim et al. 1999), water resources (Shahid 2011a), and public health (Shahid 2010a) of Bangladesh. The power sector of Bangladesh might be another severely affected sector due to climate change. The combination of higher temperature and potential increases in extreme weather events may create the conditions for higher power demand but lower efficiency in power generation.

Climate change and power research can be divided into two broad branches: (1) the emissions of greenhouse gases produced by power plants and (2) the impact of climate change on power infrastructure. Bangladesh has one of the lowest per capita carbon dioxide emissions (less than 0.2 ton/year) in the world (Sarwar 2005). This is due to a lower number of energy intensive industries and the use of natural gas (nearly 70%) as the primary sources of commercial

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energy. Therefore, the study greenhouse gas emission from power generation in Bangladesh is not meaningful. On the other hand, climate change and related extreme events can cause a number of significant impacts on power generation and transmission and consumption in Bangladesh especially in the context of the poor energy infrastructure of Bangladesh. Power structures have been designed during periods of relatively stable weather, which may be strained by changing patterns of climate and related extreme weather events. High system losses, low plant efficiencies, erratic power supply, blackouts, electricity theft, and poor management are the main problems in the power sector of Bangladesh. Variable climate and extreme weather events can pose another problem in power generation and transmission and distribution in Bangladesh. Impact of climate change and extreme weather events on the power sector can already be felt in Bangladesh. Peak demand of electricity in Bangladesh has increased dramatically in the recent years. Increased frequency and severity of floods and storms often cause disruption of power supply and tripping of power plants for varying durations (GOB 2008). Increased salinity of coastal river water due to sea level rise has compelled to relocate the power plants in the recent years (Mirza 1998). On-time attention can substantially reduce negative impacts of climate change on power sector of Bangladesh. The objective of the present paper is to summarize the present knowledge of possible direct and indirect effects of climate change on power production, transmission and distribution, and power consumption in Bangladesh as well as to identify the possible strategies to reduce the negative effects and increase the adaptive capacity. It is hoped that the study will help raise awareness among policy makers and agencies working in the power sectors in Bangladesh on climate resilience policy planning for future development of power infrastructure of Bangladesh.

Climate change impacts on power sector are analyzed based on historic changes and future projections of the climate and climate-related extreme events in Bangladesh. Literatures available on climate change in Bangladesh are thoroughly reviewed to identify the possible changes of temperature, rainfall, temperature- and rainfall-related extreme events, cyclones, floods, river discharges, river water salinity, etc. that can affect the power infrastructure of Bangladesh. In some cases, data are collected from corresponding departments or organizations for analysis and show the change. For example, historic rainfall and temperature data for the time period (1958–2007) are collected from Bangladesh Meteorological Department (BMD), and data related to floods are collected from Flood Forecasting and Warning Center; river water salinity data are collected from Soil Resources Development Institute (SRDI), and river discharge data are collected from Global River Discharge Database (GRDD 2010). These data are used to show changes in rainfall, temperature, river discharge, salinity, floods, and climate-related extreme events. Information about the power sector of Bangladesh is gathered from available literatures such published journal articles, annual reports, newsletters, booklets, and online database of various organizations responsible for power generation, transmission and distribution in Bangladesh such as Bangladesh Power Development Board, Power Cell of Bangladesh Ministry of Energy and Power, and Power Grid Company of Bangladesh, etc. Impacts of climate change on the power sector are identified through analysis of information gathered from above-mentioned sources as well as other published materials such as newspaper and magazine reports.

In the next section of the paper, a review of climate change and related extreme weather events in Bangladesh is given. This follows a short description of power sector of Bangladesh. Possible impacts of climate change and related extreme events on power sector of Bangladesh are then discussed. Finally, the possible strategies to reduce the negative impacts and increase the adaptive capacity of the power sector are proposed.

Power sector of Bangladesh

The power infrastructure of Bangladesh is quite small, insufficient, and poorly managed. Electricity is the major source of power for most of the economic activities of the country. Bangladesh's installed electric generation capacity was 4.7 GW in 2009. At present only 47% of the population is served with electricity, and per capita electricity consumption is only 156 KWh, which is one of the lowest in the world (GOB 2010). Problems in Bangladesh's electric power sector include high system losses, delays in completion of new plants, low plant efficiencies, erratic power supply, electricity theft, blackouts, and shortages of funds for power plant maintenance. A recent survey reveals that power outages result in a loss of industrial output worth $1 billion a year, which reduces the GDP growth by about half a percentage point in Bangladesh (Temple 2002).

Power generation

The power plants in Bangladesh can be divided into hydro and thermal power plants. In the eastern zone of Bangladesh, five hydro-power plants are operating, having installed capacity of 230 MW of 3.36% of total generation (BPDB 2010b). With the exception of these units, the rest of the power generation is based on thermal sources. At present, there are 79 thermal power stations operating in Bangladesh. The thermal power stations include steam turbine, compression turbine, and combined cycle comprising of steam turbine and compression turbine. Power generation by using different technologies in Bangladesh is given by a chart in Fig. 1. About 2,638 MW or 48% of total power is generated by using steam turbine, followed by 1,359 MW or 24.7% using combined cycle, 997 MW or 18.2% by gas turbine, and the rest by diesel and hydro turbines (BPDB 2010b). All of the thermal power plants on the eastern side of Bangladesh are operating on gas. On the other hand, all of the power plants in the western region except one are operating on liquid fuel because of non-availability of gas in that area.

Renewable energy (excluding hydro) constitutes a very small percentage of the total energy production in Bangladesh. The government has taken a number of steps for the development of Renewable Energy in the recent years. Present capacity of renewable energy stands at approximately 3 MW with nearly 60,000 installed units. The total installed wind energy capacity is less than 1 MW (Hossain and Tamim 2006; BPDB 2010a).

Power transmission and distribution

Power generated from different power plants all over the country is transmitted through an integrated grid system through 230- and 132-kV transmission lines and substations. At present, there are 2,314.5 ckt km of 230-kV line and 5,533.6 ckt km of 132-kV line throughout Bangladesh for power transmission. Bangladesh's power system has a distribution network with over 15,230/132-kV grid substations with a total capacity of 6,850 MVA in 2009. The distribution network is comprised of 33-, 11-, and 0.4-kV lines. Total distribution lines in the country amounted to about 209,932 km, and the total number of consumers of different categories was about 1,922,361 at the end of 2009 (PGCB 2010; BPDB 2010a).

Many problems bar the power system from delivering its services reliably and effectively. One major concern is the performance of the distribution system. It is estimated that the total transmission and distribution losses in Bangladesh amount to one-third of the total generation, the value of which is equal to US $247 million per year (Alam et al. 2004). Among the losses, transmission loss is 7.62%, and distribution loss is 26.09%. Alam et al. (2004) concluded that the category of the power system in Bangladesh lies somewhere between strong and medium, and the system loss in distribution unit should always be lower than 10%. Therefore, among the total losses only about one-third is technical losses and the rest are non-technical losses. Pilferage, the main ingredient of non-technical loss in the distribution system of Bangladesh, is caused due mainly to theft in one form or another (Alam et al. 2004).

Power consumption and demand

Power consumed by different sectors of Bangladesh is given by a chart in Fig. 2. About 43% of total power generated in Bangladesh is consumed by the domestic sector, followed by large industry (32.4%), commercial (10.9%), small industry (8.4%), irrigation (2.7%), and other sectors (2.6%). Over the last decade, Bangladesh has experienced a net energy demand growth in the order of 8–10% per annum. Peak electricity demand is around 5,200 MW (BPDB 2010a), and available generation capacity is insufficient to satisfy the demand. At the same time, the demand for electricity continues to grow due to population growth, industrialization, additional connections, and rise in the use of modern electrical appliances.

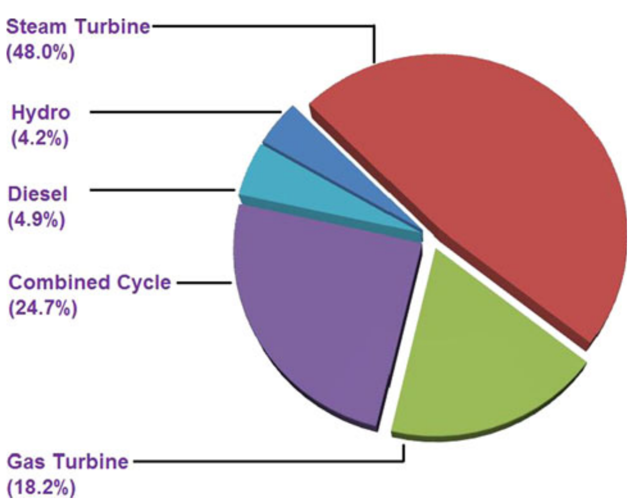

Fig. 1 Chart showing the power generation by using different technologies in Bangladesh (*Source:* BPDB 2010b)

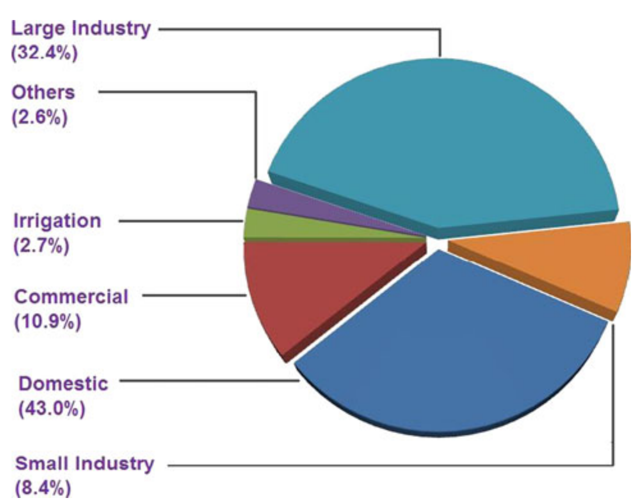

Fig. 2 Chart showing the power consumption by different sectors in Bangladesh (BPDB 2010a)

The increase in peak demand of electricity in the last 10 years is shown in Fig. 3a. It has been found that the demand for electricity continues to grow at the rate of over 500 MW a year in last 10 years (Sarkar and Singh 2010). Seasonal variation of electricity demand shows that the electricity demand rises to peak during pre-monsoon hot summer months (March–April) due to the increase in consumption in domestic sector for space cooling as well as in agriculture sector for irrigating rice field. The generation capacity deficits result in frequent power failures (load shedding) during peak load hours. The average load shedding pattern within a year is shown in Fig. 3b. Frequent load shedding hurts economic growth and industrial development and affects the quality of life in Bangladesh.

Climate change and its impacts on power sector of Bangladesh

Bangladesh has a sub-tropical humid climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity (Rashid 1991). The average temperature of the country ranges from 7.2 to 12.8°C during winter and 23.9 to 31.1°C during summer. January is the coldest month, and May is the hottest month in Bangladesh. Rainfall in Bangladesh varies from 1,400 mm in the west to over 4,400 mm in the east. More than 75% of rainfall in Bangladesh occurs during the monsoon, caused by weak tropical depressions that are brought from the Bay of Bengal into Bangladesh by the wet monsoon winds (Shahid and Khairulmaini 2009). Climate change in Bangladesh is likely to result in: (1) higher annual precipitation and daily temperature; (2) greater temperature and rainfall extremes; (3) increased flooding, both in terms of extent and frequency; (4) increased cyclone and storm surges both in terms of extent and frequency; (5) low river flow during dry periods; and (6) increased salinity intrusion in coastal rivers. The changes are visible from the trends of rainfall, temperature, and extreme events in Bangladesh (Shahid 2010b, c, d).

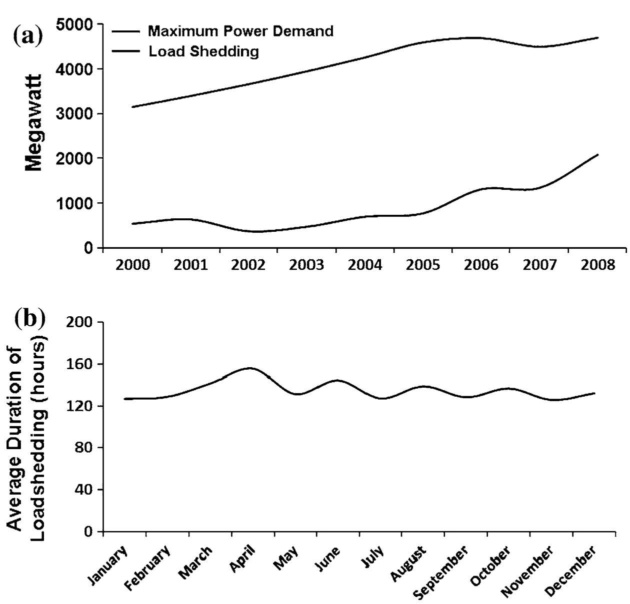

Fig. 3 **a** Changes in peak power demand and load shedding and **b** monthly variation of load shedding in Bangladesh (*Source:* BPDB 2010b; ADB 2009)

It has already been mentioned that high system losses, low plant efficiencies and a big gap between supply and demand are the main problems in the power sector of Bangladesh. More variable climate and extreme weather events can make some of these problems very severe. Climate change and extreme weather events may affect system losses, power plant efficiency, peak demand, transmission system, and power infrastructure in a number of ways. Recent trends and future projections of climate and extreme weather events in Bangladesh and their possible impacts on power generation, consumption and transmission and distribution in Bangladesh are discussed below.

Change in rainfall and temperature

The trend analysis of annual rainfall time series shows that the annual average rainfall of Bangladesh has increased at a rate of +5.53 mm/year during the time period 1958–2007 (Shahid 2010b, c). An increase in mean temperature of Bangladesh by 0.097°C/decade has also been observed at 95% level of confidence in the last 50 years (Shahid 2010c). Climate models predict more increase in rainfall and temperature in Bangladesh in the near future. The temperature and rainfall for the years 2050 and 2100 with respect to the base year projected by the General Circulation Models (GCM) run with the IPCC B2 SRES scenario are shown by graphs in Fig. 4a and b, respectively. Shahid (2011a) found that the out of seventeen GCM models available for the assessment of greenhouse gas-induced climate change, seven models can simulate temperature and eight models can simulate rainfall of Bangladesh with reasonable error. Therefore, those models are used for the projection of rainfall and temperature. The models are run with the IPCC B2 SRES scenario (IPCC 2000) that describes a world where emphasis is given on local solutions to economic, social, and environmental sustainability and lower greenhouse gas emission. Similar to B2 scenario, population of Bangladesh and surrounding region is projected to increase continuously but at a lower rate. GDP projection also represents the intermediate level of economic development like B2 scenario (Nair et al. 2003). Lower emission of green house gas close to B2 scenario is

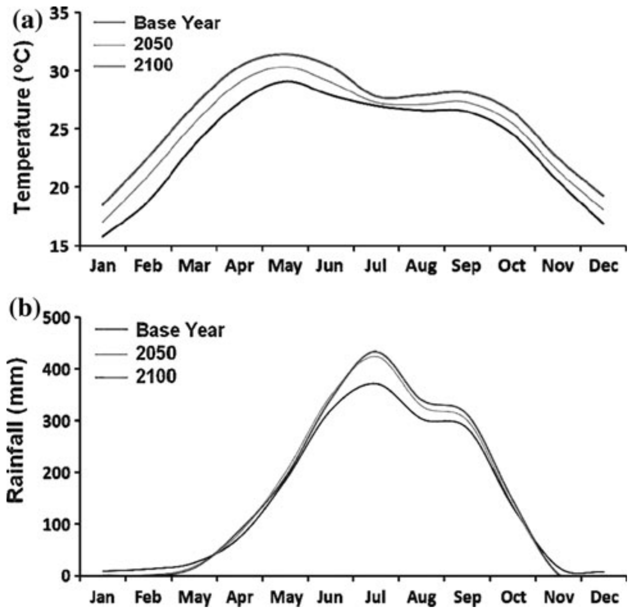

Fig. 4 Projected change in **a** temperature and **b** rainfall in Bangladesh obtain by General Circulation Models (GCM) with the IPCC B2 SRES scenario (Shahid 2011a)

the mid-to-long-term policy of the region (Hong et al. 2007). Therefore, projected climate under the B2 climate scenario is used in the present study. The climate models estimate a steady increase in temperature for Bangladesh. The models predict an average increase in temperature of 1.4°C in 2050 and 2.4°C in 2100. In case of rainfall, the models show an annual increase in rainfall. Most of the climate models estimate that precipitation will increase during the summer monsoon as the air over land will warm more than the air over oceans during summer. The models also show a decrease in precipitation in the winter months of December, January, and February. Maximum increase in rainfall is predicted for the month of August, about 1.2 mm/day in 2100, and a maximum decrease in rainfall in December, about 0.4 mm/day in 2100. Higher temperature can cause a number of negative impacts on power demand as well as power transmission and distribution system of Bangladesh. Some possible impacts are discussed below.

Rising temperature and power demand

With the rise of temperature, increasing trends in number of hot days has also been observed in Bangladesh (Shahid 2010d). Increased temperature and hot days will cause more consumption of power for space cooling. It will cause an increase in total power consumption as well as the peak demand of power. As the main cause of frequent power failures in Bangladesh is the power demand surge during peak load hours, it is more likely that there will be more power failures in Bangladesh due to climate change if no initiatives are taken to increase the generation with the increase in demand due to the rise of temperature.

Increased irrigation requirement and peak power demand

Groundwater is the main source of irrigation in most parts of Bangladesh especially during the dry season (Shahid and Hazarika 2010). Electric pumps are generally used to exploit groundwater and irrigate cultivated land. Ever increasing ground water extraction for irrigation during the dry season in the recent years has caused the ground water level to fall to the extent of not getting fully replenished in the recharge season. This causes overdraft in some parts of Bangladesh. It has been reported that the irrigation rate during the pre-monsoon rice-grown period will be increased from 8.5 mm/day in the base year to 8.9 mm/day in 2050 and to 9.3 mm/day in 2100 (Shahid 2011a). As there is a direct relation between groundwater level and pumping rate, pumping out of more water in less time to meet the irrigation demand will cause more declination of groundwater level. Consequently, more energy will be required to sustain the yield of groundwater for sufficient irrigation (Shahid 2011a). It will cause an increase in peak power demand and more load shedding during the pre-monsoon summer season in Bangladesh.

Temperature rise and transmission loss of electricity

Transmission loss is the major component of technical system loss in Bangladesh, which is equal to 7.62% of total electricity fed into the transmission line (Alam et al. 2004). Besides that about 5.17% of total electricity is lost in the distribution system, which includes primary distribution lines, distribution transformers, and secondary distribution lines, service drops to the individual consumers. Mainly copper wires are used for transmission of electricity in Bangladesh. The temperature coefficient for the resistivity of copper is 0.39% per °C. With an increase of 2°C, the losses in the lines and transformers will increase by about 0.8%.

Temperature rise and transformer lifetime

Transformers are the most important and critical equipment in the transmission line grid. Increased temperature will have important effect on the lifetime of a transformer. Transformers are designed for a certain load rating at an ambient temperature according to its operation environment. Transformers are often fully loaded in the grid of Bangladesh. Temperature rise may cause the outdoor temperature to reach levels above the rated temperature of the transformer in summer. Operation of transformers

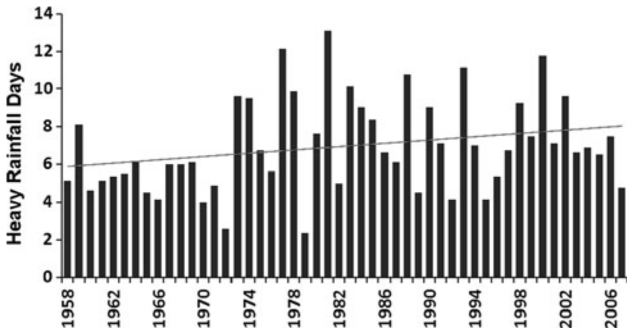

Fig. 5 Trends in heavy rainfall days in Bangladesh over the time period 1958–2007 (Shahid 2011b)

above the rated temperature for longer periods would accelerate the transformer aging rate. Therefore, probable increase in temperature by an amount of 2°C or more might cause a decrease in lifetime of transformers.

Extreme rainfall and temperature events

Analysis of daily rainfall and temperature data shows an increase in extreme rainfall and temperature events in Bangladesh. Figure 5 shows the trends in heavy rainfall days in Bangladesh over the time period 1958–2007. It has been found that the heavy rainfall days (>20 mm) in Bangladesh have increased significantly during the time period 1958–2007 by an amount of 1.2 days/decade (Shahid 2011b). Increased annual rainfall and heavy rainfall events can trigger more rain-related flood in Bangladesh. The trends in the number of hot days (maximum temperature > 30°C) and heat wave frequency (consecutive 3 days with maximum temperature greater than the 90th percentile) for the time period 1958–2007 are shown in Fig. 6a and b, respectively. It has been found that the hot days in Bangladesh have increased by 1.16 days/year at 99% level of confidence. The heat wave frequency has also increased significantly in some places (Shahid 2010d).

Climate models also predict a further increase in extreme weather events in Bangladesh. Through the simulation of variability and extremes of daily rainfall during the Indian summer monsoon, May (2004) predicts an increase in intensity of heavy rainfall events in Bangladesh. An examination of the frequency distribution of daily monsoon rainfall over Indian subcontinent in the model-simulated data suggests that the intensity of extreme rainfall events is likely to be higher in the future due to the increased convective activity during the summer (Lal and Aggarwal 2001).

Extreme temperature events often cause widespread power outages due to increased use of cooling system. Power outages reached to the worst-ever level in the

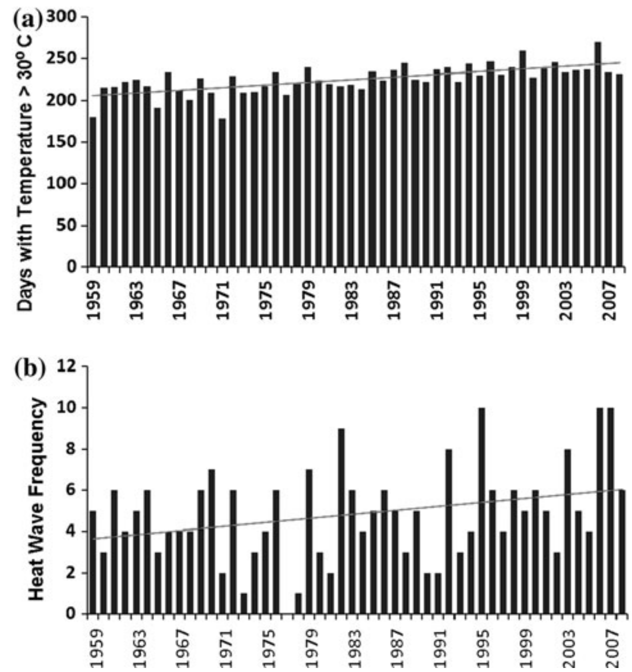

Fig. 6 Trends in **a** hot days and **b** heat wave frequency in Bangladesh over the time period 1959–2008 (Shahid 2010d)

history of Bangladesh during the extreme hot summer days in 2011 when the average temperature rises to 35°C. This caused 9–10-h load shedding in the cities and 15–18-h in the rural areas every day (Blitz 2011). Extreme temperature also reduces the supply as power plants may have to run on lower energy output because of the high temperature of cooling water taken from river during heat waves or extreme temperature days. Extreme rainfall can also cause widespread power outage. Dhaka city experienced 341-mm rainfall on August 14, 2004, and 333-mm rainfall on July 27, 2009, in 24 h, which caused havoc in the electricity supply creating power outage in the capital city of Bangladesh (Habib 2011).

Rising trends in extreme weather events

Extreme weather events such as floods, droughts, and storms have been found to increase in Bangladesh with the increase in rainfall and temperature. Floods in 1988, 1998, 2004, and 2007 and cyclones and tidal surges in 1991, 1998, 2000, 2004, 2007, and 2008 record the increase in extreme events both in frequency and severity. Super cyclone SIDR in 2007 exceeded previous records of its coverage and wind velocity. Bangladesh was flooded twice in a single year in 2007 (Mallick 2008). Trends in extreme weather events and their impacts on power sector of Bangladesh are discussed below.

Tropical cyclones

Bangladesh is highly susceptible to tropical cyclones. A total of 117 tropical cyclones hit the coast of Bangladesh from 1877 to 2003, of which 39 were tropical depressions, 52 were tropical storms, and 26 reached hurricane intensity (Islam and Peterson 2009). In the past century (1901–2000), the rate of tropical storms striking the coast is one storm per year. Since 1950, the rate of landfalling tropical storms has increased by 1.18 per year (Islam and Peterson 2009). Using a hydrodynamic model Karima and Mimura (2008) predicted more intensified-surge heights at the coast of Bangladesh due to climate change. They also predicted that flooded area, flooding depth, and surge intrusion length will be substantially larger under intensified surge conditions. Possible impacts of increasing frequency and severity of tropical cyclones on power infrastructures are discussed below.

Severe cyclones and power plants Bangladesh experienced the worst ever blackout in 2007, after the severe tropical storm SIDR. All major power plants tripped and failed for varying durations. It took 2 days to restore the full generation. Despite restoration of power generation in most of the power plants, electricity supply was hampered as the power lines and poles were severely damaged. It took 2–3 days to restore the full supply and many more days in severely affected southern districts.

Severe storms and renewable resources infrastructure of Bangladesh Bangladesh, being a sub-tropical country has a lot of wind flow at different seasons of the year. The coastal region of Bangladesh has good potential for wind energy generation. The location of Bangladesh is also ideal for tapping solar energy effectively. Tropical cyclones represent the biggest challenge in renewable energy, especially wind power generation, in Bangladesh. There is always a risk that the wind turbine might be affected in cyclones. The biggest wind power generation project of Bangladesh (1,000 kWp capacity Wind Battery Hybrid Power Project) in the coastal region of the southeast District was heavily damaged by tropical cyclones of the Bay of Bengal several times. During the project implementation phase, the Super Cyclone SIDR crossed the coastal areas of Bangladesh. There was a 10–15 feet higher tidal surge above the dam in front of the project. All equipment and materials were submerged by those high waters. Some 3-ton steel towers were washed away by strong waves. All completely ready civil constructions were fully damaged. After the SIDR, the implementation works started again and were completed by 2007. The Tropical Cyclone Nargis with winds of about 200–240 km/h again severely damaged the project. It took about 3 months to re-start the power generation (Rahman 2009). The first biggest solar photovoltaic system of Bangladesh installed at a coastal island of Bangladesh was completely destroyed in the 1991 cyclone (Islam 2002).

Severe storm and power distribution The power distribution system of Bangladesh was significantly affected by the recent cyclones. The impacts of the most recent five cyclones on the power distribution system of Bangladesh are given in Table 1. The strong winds of cyclone SIDR caused major destruction to the electricity transmission and distribution system of Bangladesh. Several transmission lines and substation components were damaged by high sustained winds and fallen trees. It caused disruption of electricity supply for the entire country for almost a full day. Full restoration of the distribution system took more than a month. Damage and loss to the power sector totaled US$ 13.4 million. Cyclone Bijli in April 2009 caused high waves and a tidal surge of up to three meters above the normal tide. The cyclone battered 14 southeastern coastal districts of Bangladesh with heavy rain and winds of up to 100 km/h. Hundreds of electricity poles were uprooted or damaged, leaving parts of the southeastern districts without power for a long time. Cyclone Aila in May 2009 uprooted numerous electric poles, downed power lines, and caused

Table 1 Impacts of recent storm events on power system

Storm events	Impact on power system
1991	The supply of electricity was cut-off for one to few days in several storm-hit cities including Chittagong, the main commercial city of Bangladesh
2007	Bangladesh experienced the worst ever blackout after the severe tropical storm SIDR. All of the 26 power plants had tripped and failed for varying durations. The power lines and poles have been severely damaged. It took 2–7 days to restore the full supply
2008 (April)	Cyclone uprooted electricity poles and damaged power line, leaving parts of the southeast areas without power
2008 (May)	Damaged the Wind Battery Hybrid Power Installation in the coastal region of Bangladesh. Three months were taken to resume the supply
2009	Caused numerous electric poles uprooted and power lines downed, causing widespread power outages in southwest costal area of Bangladesh

Source: National newspapers

widespread power outages in the southwest coastal area of Bangladesh (Sources: national newspapers). Increased frequency and severity of storms due to climate change may severely affect the power distribution system in Bangladesh in the near future.

Floods

The frequency of abnormal floods in Bangladesh has increased substantially in the past few years. Figure 7 shows the flood events in last 55 years in Bangladesh. It is clear from the figure that flood severity has increased in Bangladesh in the recent years. Future peak discharges under climate change indicate the possibility of more serious flooding in Bangladesh. Recent increases in mean peak discharge in the main rivers of Bangladesh indicate significant changes in the spatial as well as depth of inundation in Bangladesh (Mirza 2002; Mirza et al. 2003). Most of the climatic models project an increase in rainfall in monsoon in south Asia, which may cause more extreme floods in the region (IPCC 2007). The floods of 1998 that inundated nearly 70% of the country area and the floods of 2007 that occured twice in a single year indicate increasing flood severity in Bangladesh.

Recent floods in Bangladesh affected power distribution in Bangladesh in different ways. The impacts of most recent extreme floods on power distribution in Bangladesh are given in Table 2. All the extreme floods caused power supply to shutdown especially in urban areas. Eighteen electric power sub-stations were flooded in 1988. About 2,000 km of 11-kV power lines had to be de-energized due to severe floods in 1988 and 1998. Severe flooding in 2007 washed away electricity poles in some parts of Bangladesh, which caused disruption of electric supply (Sources: national newspapers).

Low river flow in dry season

Average river discharge in the Ganges River (Fig. 8) shows that discharge is less than 2,000 m^3/s for about 6 months (December–May). It is anticipated that changing rainfall

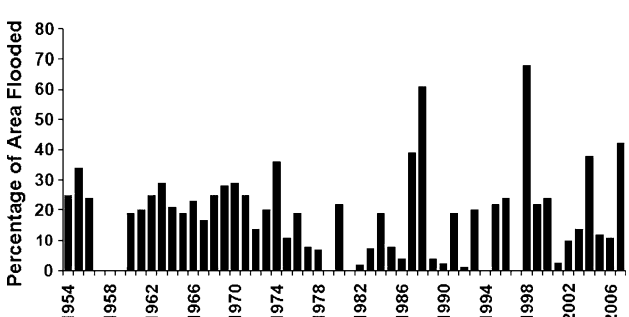

Fig. 7 Graph shows the percentage of area inundated in Bangladesh by peak floods over the time period 1954–2007 (FFWC 2010)

patterns may cause more seasonal variation in river discharge. It has been concluded in a recent research that there will be a lowering of river discharge during the low-discharge season (Kundzewicz et al. 2009). Examining the stream flow from 1948 to 2004, Dai et al. (2009) found that the Ganges, the lifeline of Bangladesh, is losing water because of climate change. They found that due to the effects from damming, irrigation, and other water use, these changes could add up to a threat to future supplies of food and water in the region. According to the climate forecast scenarios, dry season rainfall in Bangladesh and surrounding areas is expected to decrease (Shahid 2011a). Baas and Ramasamy (2008) reported that higher mean temperatures and potentially reduced dry season precipitation may exacerbate droughts and low river flow in west part of Bangladesh both in terms of intensity and frequency during winter and pre-monsoon seasons.

Water plays important roles in energy production, including generating steam that turns turbines, keeping power plants cool, removing pollutants from power plant exhaust, and flushing away residue after fossil fuels that are burned. The thermal power plant of Bangladesh draws cool water from the river and discharges the hot water into the river. It has been estimated that an average of 95 l of water is required to produce 1 KWh of electricity (Heiner 2010). Though most of the plants are located in an area that is influenced by significant tidal action during the dry season, low river flow due to climate change can cause water scarcity in power plants and hamper the production in future.

Sea level rise and salinity in river water

Figure 9 shows the change in salinity of a coastal river in Bangladesh between 1967 and 1997. A study by the Soil Resources Development Institute (SRDI 1998) shows that salinity in some parts of the coastal region of Bangladesh has increased by 124% in the last 30 years. It has been reported that the sea level in the coastal region of Bangladesh will increase by 1 m by 2100 (World Bank 2000; Frihy 2003). One of the major impacts of sea level rise on water resources will be the reduction in freshwater availability by salinity intrusion. Reduction in rainfall and low river flow during the dry season may aggravate the salinity levels in the coastal rivers of Bangladesh.

The water-cooled power plants located in the coastal zone of Bangladesh require thousands of gallons of freshwater daily to keep them operative. This process has turned into an odyssey, as freshwater becomes a rare commodity with tidal waters of the sea intruding further north everyday. The flow of freshwater from the Ganges River has been stemmed, especially during the lean months. As a result, tidal waters are spreading inland turning the coastal environment more saline. Sea level rise due to climate

Table 2 Impacts of recent flood events on power system

Flood events	Impact on power system
1988	Eighteen electric power sub-stations were flooded. About 2,000 km 11-kV power lines had to de-energize
1998	Prolong floods severely affect the power supply system of Dhaka. Power lines had to de-energize in different parts of Bangladesh, which affected over a million people
2004	Power supply was shutdown in some parts of Dhaka city for few days. Some southeastern sub-districts were out of power for more than a week
2007	Electricity poles were washed away by the flooded rivers in northwest and northeast Bangladesh, which caused disruption of electric supply in many parts of the country and paralyzed the normal life of people

Source: National newspapers

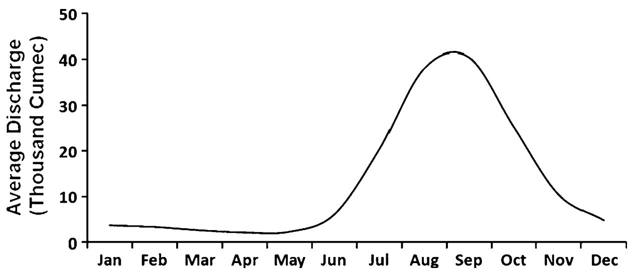

Fig. 8 Average monthly discharge (in cumec) of the river Ganges at a point in Bangladesh (GRDD 2010)

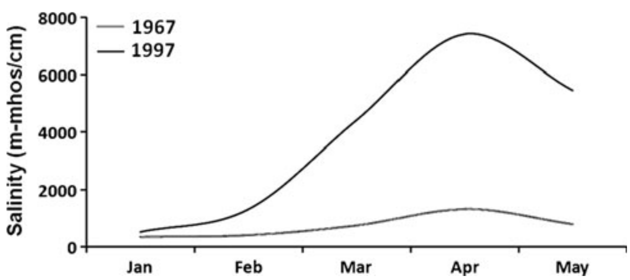

Fig. 9 Changes in salinity between the time period 1967 and 1997 in the river water of the coastal zone of southwest Bangladesh (SRDI 1998)

change will cause increased salinity in river water. Increased salinity in the river and use of saline water for cooling in the *Goalpara* barge-mounted power plant, the main power plant of the coastal industrial city of Khulna, has lead to corrosion and leakages. The power plant had to stop several times for various durations. Over the last one decade, the barge had to be moved further and further upstream to get suitably freshwater for cooling (Mirza 1998). Therefore, power plants situated in the coastal zone of Bangladesh will certainly be affected by salinity due to climate change induced sea level rise and lower freshwater runoff.

Adaptation measures

To make power system climate proof, adaptation and mitigation strategies must be assessed and incorporated in the planning and development of new power systems and in the reformation of the existing power systems. It is essential to consider the ways to adapt to possible adverse impacts. Medium and long-term cost-effective strategies are necessary to formulate to secure a diversified, decentralized, accessible, and affordable modern power system that is more resilient to climate change.

Understandable climate change and extreme weather events information and spatial distribution of their impacts (Islam and Sado 2000; Shahid 2008, 2010c, 2011b; Damen and Van Westen 2011; Shahid and Behrawan 2008) should be made available so that vulnerability can be identified easily. A spatial decision support system can be developed for this purpose. Geographic Information System (GIS) maintains the spatial location of sampling points and provides tools to relate the sampling data contained through a relational database (Shahid et al. 2000). Therefore, GIS can be used to develop a spatial decision support system to deliver climate change impact and vulnerability information in understandable format such as maps, reports etc. to help the development/planning authorities in policy formulation in terms of climate change vulnerability risk reduction in Bangladesh.

Climate change issues should be considered in development of all new power infrastructures in Bangladesh. Future power plant sites should be selected based on availability of water during dry season, salinity in river water, and potential increase in the severity of cyclones. To reduce the impact of non-availability of sufficient water for cooling specially during dry season, power plants should be designed with the capacity of water reuse for cooling and stream generation. Water recovery from condenser and heat exchangers, reduction in evaporation losses, and energy efficiency improvement in cooling equipment and in building envelopes can be used to reduce the amount of freshwater used for cooling and steam generation (CCSP 2007).

Power system structures in the coastal region should be designed and developed by considering impacts of increasing trends of storms, floods, and water levels. Strengthening of power supply structure is necessary considering more severe and frequent storms and floods in the future (CCSP 2007). Cyclones have often uprooted electricity poles and damaged power line in the coastal region of Bangladesh, which resulted in power outages in the region for long periods of time. Instead of centralized power systems, decentralized power systems should be considered especially for the coastal region. Currently, Bangladesh like most of the other countries generate most of the electricity in large centralized facilities and transmit electricity long distances through national grid. Disruptions in national grid due to natural disaster often cause widespread power outages. Decentralized power system generates electricity from many small energy sources and supply power to localized microgrid (Chambers 2001). Distributed power systems are very easy to maintain and much easier to modify, redesign, or replace and therefore may be an adaptation option in the context of increasing extreme events. Generation and distribution of power at local level in coastal zones can be helpful to resume supply soon after the disaster. Burge mounted plants can be planned for the coastal region, which can be moved to freshwater zone when salinity increases in river water. It can also be taken to safe location during severe storms or floods.

Severe storms and prolonged floods often affect the power supply system in the urban areas especially in the capital city of Bangladesh. Overhead power lines often need to be de-energized due to floods and storms which affect urban life and the economy severely. Underground distribution lines can be implemented to protect power distribution systems from cyclones and floods and reduce susceptibility to outages. Though the costs associated with it's installation as well as future expansion and repairs are very high, it has been reported that underground construction might be the least-cost approach in areas where overhead lines are susceptible to storms, because of the life-cycle cost of poles and their replacement might exceed the cost of underground construction (ESMAP 2000).

Among the power consuming sectors, the domestic and irrigation sectors are the most sensitive to climate change in Bangladesh. Power consumption will increase in the domestic sector due to the rise of temperature as more energy will be required for space cooling. Specially, there will be an increase in peak power demand in pre-monsoon summer season. Peak hour power plants can be developed to cope with the situation of peak demand. A strategy to reduce the dependency on electricity can be adopted to adapt to the situation. Gas supply should be extended all over the country to reduce pressure on electricity for cooking. Use of gas operated house hold utilities should be encouraged. As it has been mentioned that space cooling will be the main cause for the surging of electricity demand in the context of climate change in Bangladesh, energy-efficient cooling system, energy-efficient building construction, etc. should be encouraged. Reforestation and increased green areas to reduce the urban heat island effect can also be helpful to reduce the temperature rise and the demand of power for space cooling. Efficient power management system and load distribution planning should be implemented to balance between power generation and demand.

Increased demand for irrigation will be another factor for the rising of electricity demand in Bangladesh. Policies such as the application of restrictions to electricity supply for irrigation during peak hours, encouraging irrigation during night time, etc. can be helpful to adopt with the situation. Some other measures like encouraging water harvesting to reduce the use of electricity for pumping groundwater for irrigation, reuse of water in crops lands and increase crop water productivity, use of gas-operated pumps in irrigation can also be effective to reduce the impact of higher demand of power in irrigation.

Prospects of adaptive measures depend considerably on the level of knowledge of possible climate changes and their implications in power generation, distribution, and consumption. The current knowledge about climate change impacts on the power sector of Bangladesh is very limited to support such an awareness. Quantitative information about climate sensitivity of power consumption, power distribution losses, water use for cooling system in power plants, etc. is very limited. Analysis of historical data to simulate the effect of climate parameters on power systems and forecasting the impacts with quantitative values under the projected climatic conditions are essential. More research to expand the knowledgebase is therefore essential.

Conclusion

Due to its sub-tropical hot climate, the power sector of Bangladesh will not benefit from rising temperatures due to climate change. Rather climate change will cause a number of negative impacts on power generation and transmission and distribution in Bangladesh. Increased consumption of power especially during the pre-monsoon hot summer season, reduction in efficiency of power plants, more losses in transmission and distribution, and more damage of power infrastructure by tropical storms and floods are likely to happen in Bangladesh. The impacts may be much more severe and diverse as we still do not have any quantitative assessment of climate sensitivity of power generation, distribution, and consumption in Bangladesh. More research is needed to identify the climate sensitive sectors of the power system in Bangladesh. Research should also be undertaken to identify the adaptive measure to reduce the negative impacts. Though there exists a number of big problems in the power sector of Bangladesh, which need immediate attention, climate change issues should also be taken into consideration, specially in planning new power infrastructure development as well as in restructuring the old infrastructure. On-time attention can substantially reduce negative impacts of climate change on the power sector of Bangladesh.

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