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An Investigation into the Potential Impacts of Climate Change on Power Generation in Bangladesh

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Abstract: Most scientific studies report that the increasing concentration of greenhouse gases in the atmosphere is causing global climate change. Human induced emissions of carbon dioxide and other greenhouse gases, as well as deforestation and land-use change are the primary causes of increasing greenhouse gas emissions. Climate change is believed to be responsible for frequent and intense natural disasters, and the rise of sea level and its salinity. People from low lying countries are being affected most. The effects of climate change are numerous. Apart from social, environmental and demographical impacts, global climate change also affects power generation capacity. The main aim of this study is to identify the impact of climate change on existing power plants, assessing how those plants might be affected depending on current geographic locations across the country. The study used Bangladesh as a case study as the country is extremely vulnerable to climate change due to much it being not much above sea level and its large population size. The study identified several parameters affected by global climate change and showed how each parameter can influence the power generation capacities of existing as well as future power plants.

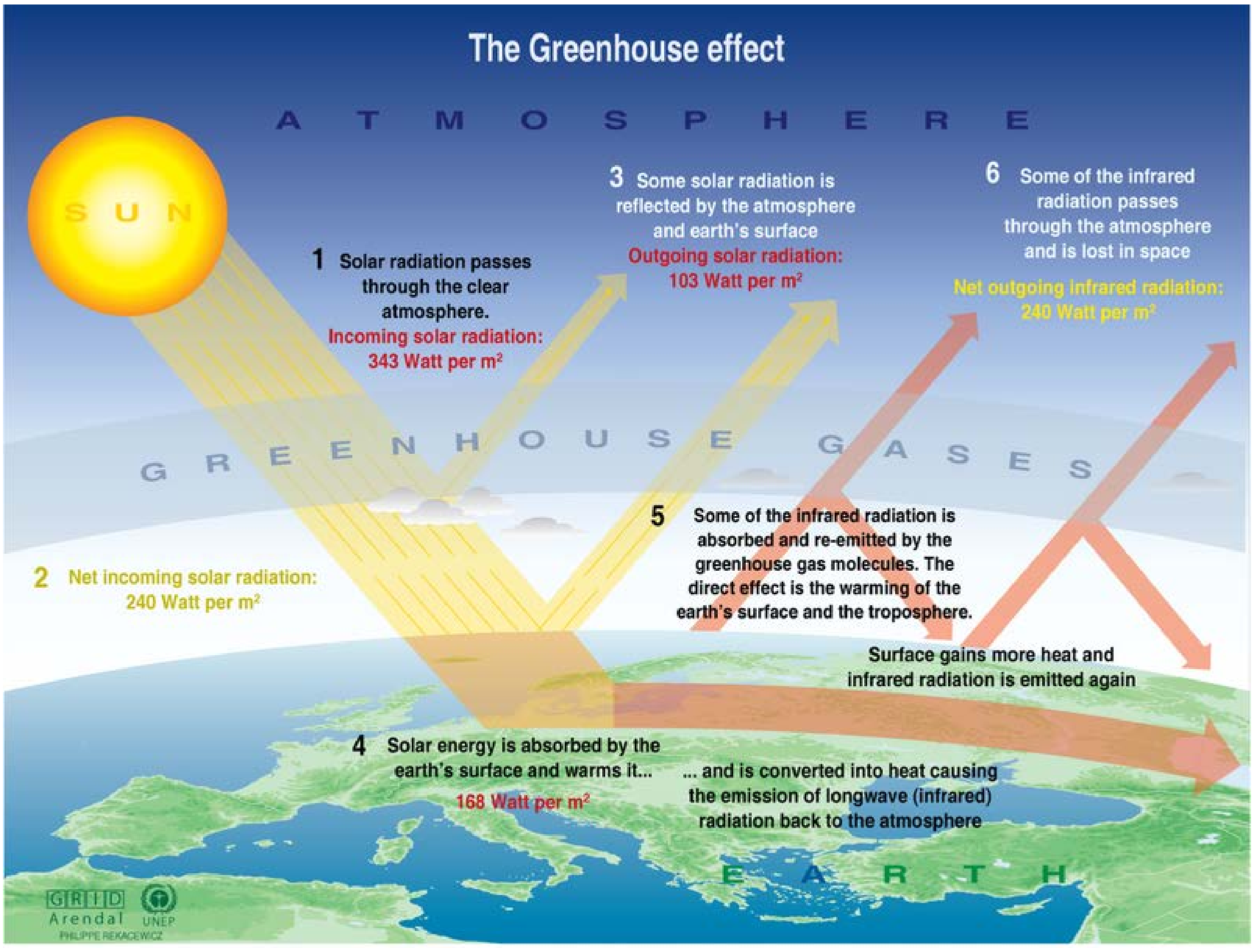
Keywords: Global climate change, impact on power plant, infrastructure, plant site, salinity, sea level rise.

1. Introduction

Energy is the key driving force for all economic activitiesand industrialization. For sustained economic growth, a continuous and secure energy and power supply is vital. Recently, some disruptions to power supplies were observed due to extreme weather conditions in some countries. Due to climate change, the frequency of extreme weather events has increased many times. For example, in 2009 Brazil's energy supply experienced severe blackouts due to extreme weather conditions. About 40% of the Brazilian National Power Grid System's load was disrupted [1]. Most power plants across the world are based on fossil fuels (coal, oil and natural gas). The efficiency of thermal power plants is severely affected by high ambient temperatures [2]. The scale and level of effect depend on the geographical location of the power plant and ambient conditions. Greis et al. [3] examined a specific conventional steam/gas power plant site in Germany and identified that by 2050 rising average air and water temperature levels will affect the gross power output of the power plant. A study by the Inter-Governmental Panel on Climate Change (IPCC) [4] reported that the frequency of periods characterized by water shortages and high water temperatures will increase in Europe and other parts of the world. For cooling purposes power plants require a constant supply of fresh water. Lower water temperatures generally ensures a higher efficiency of the cooling system and hence the efficiency of the power plant. Around 43% of the European Union's fresh water supply is used for the cooling of power plants [5]. Heat waves and droughts both reduce the cooling capacity of power plants. Power generation could be severely restricted by the increasing river water temperature and decreasing stream flow [6]. Figure 1 schematically shows the impact of global climate change and the causes of the greenhouse effect [7].

One of the most vulnerable countries to global climatic change is Bangladesh. It is located between the foothills of the Himalayan mountain range to the north and the Bay of Bengal (Indian Ocean) to the south. The entire country is almost all created by the sediment carried by two of Asia's giant rivers: the Ganges and the Brahmaputra. Most of the country's 145,000 km^2 is just a few meters above sea level. Sadly, Bangladesh is also one of the world's most densely populated countries. Due to frequent extreme climate events, Bangladesh is most vulnerable to natural disasters due to its low lying landmass and large population (approximately 150 million). The IPCC in their Fourth Assessment concluded that the continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century [8]. The impact of higher temperature, more variable precipitation, more extreme weather events, and sea level rise have already been felt in Bangladesh and will continue to intensify in the future. The impact will not only be from gradual changes in temperature and sea level rise but also, in particular, from increased climate variability and extreme events, including more intense floods, droughts, and cyclones. Some of these changes have already caused major economic problems, especially in the country's fragile power generation sector.

Power generation in Bangladesh is not capable of meeting existing demands. Only around 18% of the population (25% in urban areas and 10% in rural areas) has access to electricity, and per capita commercial power consumption is among the lowest in the world [9]. For sustained economic growth, the country needs an adequate supply of power for its industrial, agricultural and residential sectors. The government of Bangladesh is seeking foreign and local investments for its industrialization and infrastructural development. At this point in time, power generation supply is the key constraint. To eliminate this difficulty, the government has undertaken a long term plan for installing new power plants across the country. However, climate risk assessments of the installations, site selections and the design of power plants have not been undertaken. The adaptation to climate change in Bangladesh is in its early phase. A nationwide impact assessment due to climate change on different industries is yet to be undertaken. There is a lack of studies on which power plants are in high risk zones due to global climate change. The planning for future power plant construction, operation and maintenance has not yet considered the threat of global climate change. Therefore, a study on the impact of global climate change on power plants in Bangladesh is essential for the safe and sustainable economic future of the country.



Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Figure 1. The greenhouse effect and climate change [7].

2. Power Plants in Bangladesh

The current power generation and future planning are discussed in the next subsections.

2.1 Current Power Generation

There are a total of 54 power plants currently in operation across the country with a total power generation capacity of around 6,688 MW as of early 2011. The total number of power plants and their installed capacities throughout the country's seven administrative regions (Barisal, Chittagong, Dhaka, Khulna, Rajshahi, Rangpur, and Sylhet) is shown in Table 1. The table shows that a large number of power plants are built mainly in two regions of the country, Dhaka and Chittagong, the country's economic and political hubs. Table 2 illustrates the type of power plants based on fuel used. The table shows that natural gas is the main fuel source for almost 80% of Bangladesh's present power plants. The remaining power plants' fuel is mainly fuel oil (FO)/high speed diesel (HSD)/light diesel oil (LDO), coal and hydro-electric which constitute 13.14%, 3.64% and 3.35%, respectively (the country's lone hydro power plant is located in Kaptai, near Chittagong).

2.2 Power Generation for the Next Five Years

In order to meet the high demands for power, reduce the current shortages, and accelerate the country's rapid industrialization, the government of Bangladesh has undertaken massive initiatives and long term power generation plans [10]. Table 3 depicts new installations [planned] between 2011 and 2016 [10-12]. The tablealso shows the type of fuel which will be used for these power plants. Table 2 indicates that gas is the main source of fuel for existing power plants. Due to the shortage of gas supplies, the country has planned to reduce its dependency on gas fired power plants. In Table 3, we see that a significant amount of power plants using other fuel sources such as coal, fuel oil (FO), high speed diesel (HSD), diesel, wind and solar power will be installed from2011 to 2016. Another important fact is that a significant number of power plants will be duel fuelled using alternate fuel sources of gas and liquid fuel such as diesel, fuel oil(FO) and high speed diesel (HSD). In comparison to other fuel sources, there are few

Table 1. Power plants across Bangladesh as on December, 2010.

Region	Number of Power Plant	Total Capacity (MW)
Barisal	2	51
Chittagong	12	1862.5
Dhaka	17	3316.05
Khulna	5	505
Rajshahi	5	330
Rangpur	5	346
Sylhet	8	277
Total	54	6687.55

Table 2. Power plants by fuel type till December, 2010.

Type of Fuel	Number of Power Plant	Total Capacity (MW)	Percentage
Coal	1	250	03.64%
FO/HSD/LDO	14	902	13.14%
Gas	38	5480.55	79.86%
Hydro	1	230	03.35%

plans for the installation of renewable energy sources in Bangladesh. A 100 MW wind power plant will be installed in 2013 and a 12 MW solar power plant will be installed in 2012. Table 4 shows present power generation and undergoing installation plans between 2011 and 2016 in different districts of Bangladesh. Figure 2 illustrates the power generation capacity in different districts of Bangladesh by the year 2016.

Table 3. New installations of power plant based on fuel type (adapted from [10-12]).

Type of Power Plant	2011	2012	2013	2014	2015	2016
Gas	544	460	1114	1408	450	1500
Coal				550	1900	1300
Gas/FO	302	290	520	365		
FO	1248	1145				
Gas/HSD		150	150			
FO/Gas		100				
Gas/Diesel			290			
Diesel	100					
Wind			100			
Solar		12				

3. Effects of Climate Change on Power Generation

Due to global climate change, several natural environmental variables will be changed. These will intensify the frequency and time period of occurrence of natural calamities. Some of the changes which have direct impact on power plants are: (a) Global temperature increase, (b) Risk of inundation from the sea and salinity increase, (c) Risk of flood from storm surges and cyclones, (d) Risk of drought, and (e) Risk of river erosion.

In the following subsections, detailed analyses of their impacts on power generation for existing power plants of the country are given based on regional locations.

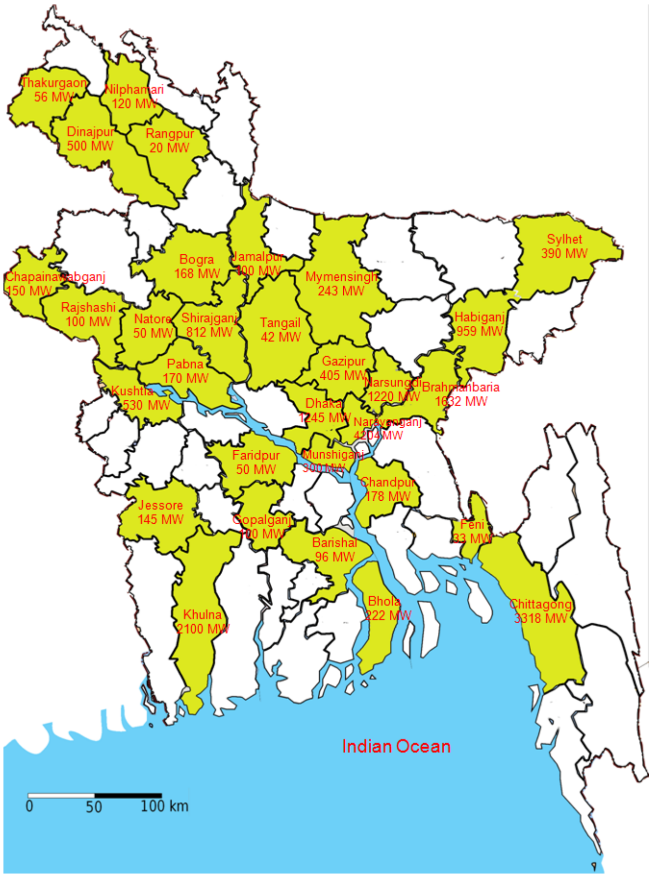


Figure 2. Power generation on different district of Bangladesh at the end of 2016.

Table 4. District wise current power generation and five year power generation plan in Bangladesh.

District	Installed Power Plant 2010	New Installation 2011	2012	2013	2014	2015	2016	New Installation Total	Total Power Plant Installed 2016
Barisal	46	0	50	0	0	0	0	50	96
Bhola	5	0	147	70	0	0	0	217	222
Bogra	18	50	100	0	0	0	0	150	168
Brahmanbaria	779	253	0	0	150	450	0	853	1632
Chandpur	0	0	178	0	0	0	0	178	178
Chapainawabganj	0	50	100	0	0	0	0	150	150
Chittagong	993	300	125	0	300	300	1300	2325	3318
Comilla	57.5	50	50	0	0	0	0	100	157.5
Dhaka	44.75	50	150	200	50	0	750	1200	1244.75
Dinajpur	250	0	0	0	250	0	0	250	500
Feni	33	0	0	0	0	0	0	0	33
Faridpur	0	50	0	0	0	0	0	50	50
Gazipur	105	50	250	0	0	0	0	300	405
Gopalganj	0	100	0	0	0	0	0	100	100
Habiganj	277	0	0	444	238	0	0	682	959
Jamalpur	0	0	100	0	0	0	0	100	100
Jessore	0	145	0	0	0	0	0	145	145
Khulna	335	115	200	0	150	1300	0	1765	2100
Kushtia	170	0	0	0	360	0	0	360	530
Mymensingh	243	0	0	0	0	0	0	0	243
Munshiganj	0	0	0	0	0	300	0	300	300
Narayanganj	1759	820	30	320	525	0	750	2445	4204
Natore	0	0	50	0	0	0	0	50	50
Nilphamari	20	0	100	0	0	0	0	100	120
Narsingdi	1142.3	78	0	0	0	0	0	78	1220.3
Pabna	0	70	100	0	0	0	0	170	170
Rangpur	20	0	0	0	0	0	0	0	20
Rajshahi	0	50	50	0	0	0	0	100	100
Sirajganj	312	50	150	0	300	0	0	500	812
Sylhet	0	240	150	0	0	0	0	390	390
Tangail	22	0	20	0	0	0	0	20	42
Thakurgaon	56	0	0	0	0	0	0	0	56

3.1 Risk of Global Temperature Increase

The cooling system of power plants (hence the productionefficiencies) will be greatly affected by climate change. In general, there are three kinds of cooling systems which are widely used in power plant cooling. One is a once through system which uses cooling water directly from a surrounding water reservoir such as a river and discharges it directly back into the water source. Another type of cooling is a once through cooling system with a cooling tower. After passing through the power plant the water goes to cooling tower where the temperature is reduced and then discharged to the river. Third type of cooling system is a closed circuit system where the water re-circulates in the system after condensation and heat reduction in a cooling tower. Figure 3 shows a schematic view of these three widely used cooling systems for power plants around the world. Due to global warming, the water temperature will also be raised. The lower the temperature of intake water, the higher the efficiency of the cooling system and hence the higher power production and reduced fresh water usage.

In order to assess the power plant performance incorporating the effect of water temperature rise and water salinity, Koch and Vögele [13] and Rübbelke and Vögele [14] derived a mathematical model. As presented in their study, the demand for freshwater for cooling purposes of a thermal power plant can be expressed using the following equation:

$$Q^F = \frac{KW \cdot h \cdot 3.6 \cdot \dfrac{1-\eta_{total}}{\eta_{elec}} \cdot \lambda \cdot (1-\alpha) \cdot (1-\beta) \cdot \omega}{\rho \cdot c \cdot AS} \cdot EZ \qquad (1)$$

Where,

Q^F = cooling water demand (m^3)
KW = installed capacity (kW)
h = operation hours (h)
3.6 = factor to convert kWh to MJ
η_{total} = total efficiency (%)
η_{elec} = electric efficiency (%)
α = share of water heat not discharged by cooling water (%)
β = share of water heat released into the air (%)
c = specific heat capacity of water (MJ/ton °K)
ω = correction factor accounting for the effects of changes in air temperature and humidity within a year [-] (usually between 0.7 and 1.25)
λ = correction factor accounting for the effects of changes in efficiencies [–]
ρ = water density (ton/m^3)
AS = permissible temperature increase of the cooling water (°K)
EZ = densification factor

Equation (1) illustrates the interrelation among energy conversation, fuel, waste heat generation and cooling water demand. Generally, power plants produce electricity from only 30% to 55% of the input energy. The rest of the energy is converted to heat, which is wasted through cooling water or air. The amount of total wasted heat can be calculated based on the electricity produced in a period (KWh) and from data on efficiency of the power plant. From equation (1), the amount of waste heat that thecooling water will remove from total waste heat equal to the totalwaste heat (*KW.h.* 3.6. $(1-\eta_{total})/\eta_{elec}$) multiplied by different factors (α, β, ω, λ).

Problems associated with the cooling of power plants arise for two reasons, such as a limitation of water availability and a limitation of water temperature. To heat up 1 liter of water by1ºC, requires 4.2 kJ. If the maximum allowable heating temperatureis 28°C and the intake water temperature is 18ºC, 1 m^3 of water is needed to dissipate 42 MJ of heat. If the intake water temperature increases to 23°C and the maximum allowable temperature is 28ºC, 2 m^3 of water is needed to dissipate 42 MJ of heat. The lack of fresh water will result in significant losses of power generation capacity. In the instance of limitation of cooling water temperature and cooling water shortage, the capacity of the power plant can be related to the equation (2).

$$KW = \frac{Q^F \cdot \rho \cdot c \cdot AS}{h \cdot 3.6 \cdot \dfrac{1-\eta_{total}}{\eta_{elec}} \cdot \lambda \cdot (1-\alpha) \cdot (1-\beta) \cdot \omega \cdot EZ} \qquad (2)$$

Equation (2) indicates that if the temperature of the cooling water increases or there is a limitation of intake cooling water, the power generation capacity will be reduced. This reduction is more clearly evident in once through cooling systems. In closed circuit cooling systems the amount of water required will also be increased due to the increased evaporation of discharge water at increased temperatures. The study conducted by Ahmed and Alam [15] showed that the average increase in air temperature in Bangladesh might be 1.3ºC by the year 2030 and 2.6°C by the year 2075. The National Adaptation Program of Action (NAPA) [16] predicts 1.0, 1.4 and 2.4ºC ambient air temperature rises by the years 2030, 2050 and 2100, respectively, due to global climate change. As the air temperature increases, the temperature of water also increases. In Rübbelke and Vögele [14] the relationship between air temperature and stream water temperature can be expressed as:

$$T_s = \mu + \frac{\alpha - \mu}{1 + e^{\gamma(\beta - T_\alpha)}} \qquad (3)$$

where, T_S is stream water temperature (ºC), $T_\alpha$is air temperature (ºC), μ is the estimated minimum stream temperature (ºC), α is the maximum stream temperature (ºC), γ is the steepest slope of the function; and β is the air temperature at the inflection point (ºC). The relationship expresses that with an increase of ambient temperature, the surface water temperature of the river will also be increased. This temperature rise of river water will increase the cooling water temperature and it will directly affect the cooling capacity of the power plant and hence power generation.

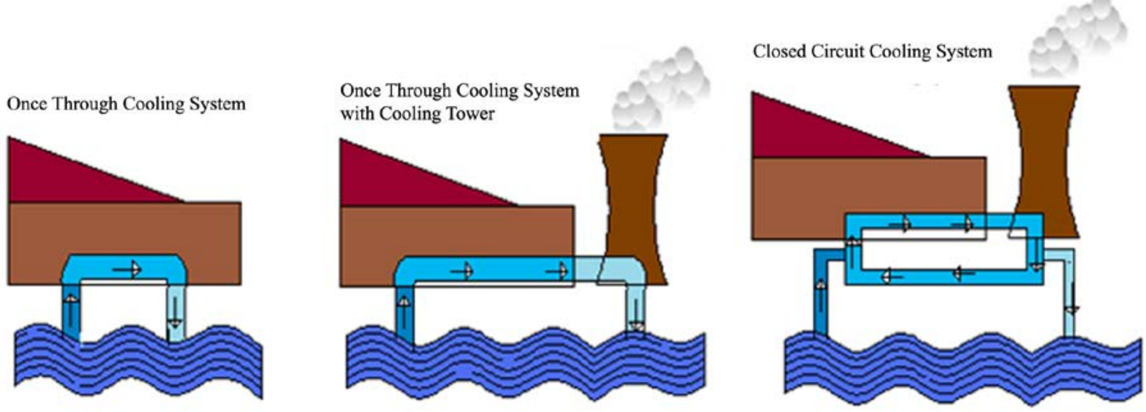


Figure 3. Schematic of three widely used different cooling system for power plant.

Table 5. Affected regions due to various natural calamities and threat to power plants.

Risk Type	Barisal	Bhola	Chandpur	Chittagong	Feni	Jessore	Khulna	Risk to Generation
Inundation	√	√		√	√		√	5769 MW
Salinity	√	√	√	√	√	√	√	6092 MW
Storm Surge	√	√		√	√	√	√	5914 MW
Tidal Wind	√	√		√	√	√	√	5914 MW
Cyclone	√	√	√	√	√	√	√	6092 MW

Table 6. Effects of Sea level rise (SLR), water temperature, wind speed & surge height (adapted from [19]).

Scenarios	Wind Speed (km/h)	Surge height (m)
Scenario-I. SLR (m) = 0, SST rise(ºC) = 0	225	7.6
Scenario-II. SLR (m) = 0, SST rise(ºC) = 2	246	9.2
Scenario-III. SLR (m) = 0, SST rise(ºC) = 4	274	11.3
Scenario-IV. SLR (m) = 0.3, SST rise(ºC) = 0	225	7.4
Scenario-V. SLR (m) = 0.3, SST rise(ºC) = 2	246	9.1
Scenario-VI. SLR (m) =0.3, SST rise(ºC) = 4	274	11.3
Scenario-VII. SLR (m) = 1, SST rise(ºC) = 0	225	7.1
Scenario-VIII. SLR (m) = 1, SST rise(ºC) =2	246	8.6
Scenario-IX. SLR (m) =1, SST rise(ºC) = 4	274	10.6

3.2 Risk of Inundation from the Sea and Salinity Increase

Bangladesh is one of the most vulnerable countries in the world to climate change. The Third Assessment Report of the IPCC [8] projected a rise of 9 to 88 cm from 1990 to 2100. The global-mean sea level will rise significantly within 21st century. The coastal zone of Bangladesh is low-lying with 62% of the land having an elevation of less than 3 meters and 86% less than 5 meters [17]. The country has over 710 km coastline facing the Bay of Bengal (Indian Ocean). The study of Mohal et al. [17] estimated that about 11% more land would be permanently inundated over the next century. The Sundarbans, a UNESCO listed world heritage site and mangrove forest, will be lost due to sea level rises and high salinity by 2100. Based on the third IPCC report, a National Adaptation Program for Action (NAPA) [16] has been formulated by the government of Bangladesh which predicts 14, 32 and 88 cm sea level rises by the year 2030, 2050 and 2100, respectively.

Mohal et al. [17] made a mathematical model of the Bay of Bengal to predict the invasion of sea water to the mainland river networks. Based on an 88 cm sea level rise in 2100, they used a one-dimensional model for inland tidal rivers and a two-dimensional model for the Meghna Estuary region to identify the inundation and salinity intrusion. The simulated results indicate that around 11% (4,107 km^2) of the coastal zone will be inundated by sea water. In addition, sea water will enter almost 80 km upstream to Chandpur region. Sarwar [18] showed that with a sea level rise of 1m, approximately 17.5% (25,000 km^2) of Bangladesh would be inundated, affecting almost the entire Patuakhali, Khulna and Barisal regions. If the sea level rises 32 cm (as predicted for year 2050), almost 84% of the Sundarbans will disappear and the entire Sundarbans will be under saline water in 2100 as predicted by the simulation. The affected areas would not only be the Sundarbans but also the power plants located in the coastal regions (e.g., Chandpur, Bhola, Khulna, Jessore, Barisal, Feni, and Chittagong).

The study by Mohal et al. [17] shows that the 5 ppt (parts per thousand) saline front will enter about 40 km inland with a sea level rise of 88cm. These rises will severely affect the fresh-water of the Tentulia River in the Meghna Estuary by increasing the water salinity. All the coastal areas including Jessore will experience high salinity due to the climate change. A total of 6,092 MW power generations would be affected by the year 2016 due to the increased salinity of the river water (as rivers are the main source of cooling water for all power plants) as shown in Table 5. It includes 13 existing power plants (out of a total 54 power plants) and 20 new power plants (that will be installed by the year 2016). The densification factor EZ is introduced in equation 1 and 2 for increase in salinity in cooling water due to the evaporation of cooling water at increased temperatures. With the increase of EZ the required fresh water will also be higher. As shown in equation 1, the densification factor due to increased salinity is directly proportional to the amount of fresh water. On the other hand, the salinity has a significantly larger effect on power generation. As shown in equation 2, with an increase of densification, the power production will reduce inversely. It shows that increasing salinity has a negative impact on power plant overall power production. Furthermore, increased salinity will increase the corrosion of the equipment and pipes of the power plant. It can reduce the cooling capacity of the power plant. Hence, 6,092 MW of power plants in coastal areas would experience great difficulties in adequate cooling and thereby power generation will be reduced.

3.3 Risk of Flood from Storm Surges and Cyclones

The coastal region is facing a high risk of cyclones and storm surges due to its geographical position and low elevation from the sea level. Recently, the country has been experiencing numerous devastating cyclones and storm surges which are believed to be due climate effects. The cyclones and storm surges have caused millions of human deaths and damage to infrastructure, resources and livelihoods. The intensity of cyclones and storm surges is expected to increase in the near future [19].

A study undertaken by Karim and Mimura [19] indicatednine climate change scenarios with respect to three sea level rises of 0 m, 0.3 m and 1 m and three sea surface temperature rises: 0ºC, 2ºC and 4ºC. The results for corresponding wind speed and the surge height are shown in Table 6.

In the study, Scenario I represents the base condition, while Scenario V is considered as an average climate condition by 2050. The study found that the storm surge height may increase as much as 21% if sea surface temperature (SST) rises by 2°C (Scenario II) and 49% if SST rises by 4ºC (Scenario III). The study predicted that bank flooding would occur as much as 69 km inland for a surge that corresponds to Scenario II, while the intrusion reached up to 78 km inland for a surge that corresponds to Scenario III. These intrusion lengths are 15% and 30% higher, respectively, than in Scenario I. The flooding area increases by 12.6% for a surge that corresponds to 2ºC temperature rise (Scenario II) and by 24.5% for a surge that corresponds to 4ºC temperature rise (Scenario III) if sea level remains unchanged. The estimated risk areas are 9,548, 10,988 and 11,628 km^2, which correspond to Scenario I, Scenario II and Scenario III respectively. An assessment was made to identify the flood risk for average - predicted climate condition by 2050 (i.e., Scenario V). Karimand Mimura [19] showed that for a storm surge at 2°C SST rise and 0.3 m sea level rise, the flood risk area would be

15.3% greater than the present risk area and the depth of flooding would increase by as much as 22.7% within20 km from the coastline. Within the risk area, the study identified 5,690 km^2 land (22% of exposed coast) as a high-risk zone where flooding to a depth of 1 m or more might occur. This high risk zone is 1.26 times the present coastal high risk zone of Bangladesh. It also found that the flooding depths, especially within 20 km from the coastline, are 30–40% higher with respect to previously estimated depths [19].

Therefore it is clear that the storm surge due to the climate change poses a severe risk to all currently installed power plants in coastal districts including Satkhira, Khulna, Bagerhat, Barguna, Patuakhali, Jhalokati, Pirojpur, Barisal, and Bhola. Table 5 illustrates the affected regions with a greater risk to existing and future power plants due to climate change in Bangladesh. The nation's 2nd, 3rd, 5th and 7th largest cities will be affected directly. The table also indicates that nearly 40% of country's electricity generation will be affected by climate change.

Islam and Sado [20], made a comprehensive study of flood risk on different regions throughout the country. Based on their study and the location of power plants, it is clear that the districts of Narayanganj and Sirajganj are at very high risk of flooding. They currently have a power generation capacity of 2,071 MW and will have 5,016 MW by the year 2016, as shown in Table7. Besides the high risk zone, Islam and Sado [20] also identified some other flood risk regions. Power generation capacity in ten districts is directly under threat, which currently constitutes 2,265 MW whereas the total capacity is forecasted to be 6,108 MW by 2016. According to IPCC [4], the flood intensity and time period of flooding will be increased due to climate change. Hence the power plants located in these regions will be affected.

3.4 Risk of Drought

Shahid and Behrawan [21] have undertaken a detailed study of the country's drought risk. They divided the western area of the country into four zones, namely very high, high, moderate and low risk zones. Figure 4 shows the power generation by 2016 in different districts that would face severe drought. Power plants located in Dinajpur, Natore and Nilphamari areas will face a very high risk of drought. About 270 MW of current power generation and about 670 MW power generation by the year 2016, are in very high risk drought zones. Other districts suchas Bogra, Jessore, Kushtia, Chapainawabganj, Rajshahi, Rangpur and Thakurgaon are also in high risk drought zones. In these seven regions, current power generation is 264 MW and about 1,169 MW power generations will be installed by the year 2016. It indicates that the shortage of fresh water for cooling purpose of these power plants will severely reduce power generation.

3.5 Risk of River Erosion

The river network in Bangladesh is changing rapidly. The reason for this rapid change is due to morphological attributes and the direct impact of climate change. The river channel dimensions will also be subject to change due to increased flooding which occurs due to an indirect effect of climate change. There is a great effect of flood discharge on the rate of river erosion. Increased flood discharge may increase the rate of river bank erosion. Climate Change Cell (CCC) [22] estimated the impact of climate change on monsoon flooding in the rivers Jamuna (Brahmaputra) and Ganges, and reported that the peak flood level in the river increased by 37cm in comparison to a moderate flood. In the river Ganges, the flood level has been found to be more than 50 cm. It is also reported in CCC [22] that the duration of flooding at its danger level increases from 10 days to 16 days. In the river Brahmaputra, the flood level duration increases from 3 days to 8 days, due to the impact of climate change.

In 1960s, the country's island district of Bhola had an area of about 6,400 km^2. At present, it has been reduced to only 3,400 km^2. Almost half of this island district has been lost due to sea level

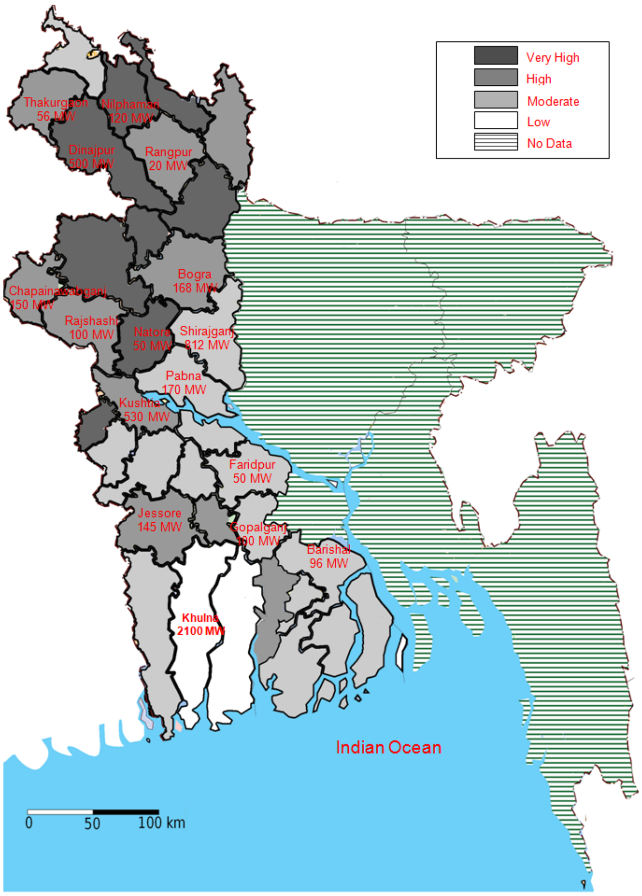


Figure 4. Power Generation in Drought Risk Region.

Table 7. Power generation in high flood risk regions.

High Risk	Power Generation at the end of 2010 (MW)	Power Generation at the end of 2016 (MW)	Very High Risk	Power Generation at the end of 2010 (MW)	Power Generation at the end of 2016 (MW)
Brahmanbaria	779	1632			
Dhaka	44.75	1244.75			
Gopalganj	0	100	Narayanganj	1759	4204
Habiganj	277	959			
Munshiganj	0	300			
Natore	0	50			
Narsingdi	1142.3	1220.3			
Pabna	0	170	Sirajganj	312	812
Sylhet	0	390			
Tangail	22	42			
Total	2265.05	6108.05		2071	5016

rise and unpredictable courses of the Ganges and Brahmaputra river systems. If this process continues, the entire district of Bhola will be under water within the next 40 years. In Bhola district, the power plants are in a great threat of river erosion and sea level rise. The power plants which are planned to be built in the Bhola district need to be carefully designed, incorporating all the predicted effects of climate change. About 30,868 m^3 of the costal estuaries and channels are filled with tidal water from the Bay of Bengal.

The downward tide imposes immense pressure and intense waves which cause erosion to the coastal areas. Due to global warming glaciers are melting at a faster rate. The amount of melt water from the Himalayas is increasing and speeding up through the Ganges and Brahmaputra and crashing into the coastal estuaries of Bangladesh. The mean annual flow of the Ganges and the Brahmaputra will increase by 2050s [23]. Furthermore, the collision between river water and uprising sea levels creates turbulence that causes erosion to the coast. Besides that, newly formed islands in the river will create changes in the river flow which will exposure more area to river erosion. Also changes in the tidal surge due to climate change and unplanned management of river bank and a lack of proper river control increases erosion of the river banks. The high risk of river erosion will threaten the installed and planned power plants on river banks. The cooling system of all of the power plants in Bangladesh is mainly river based. All of the power plants except the power plants in Chittagong region face a great threat from the river erosion. Historically, Chittagong region is less subject to river erosion due to its geographical location and soil structure. So in a total, 16,498 MW power generations by the year 2016, is threatened by river erosion.

4. Discussion

Low lying landmasses are will be affected most by global climate change. Being a low lying country, the social, environmental, demographical and economical losses will be unimaginable for Bangladesh. Its economy will be crippled by the impact of global climate change on current and future power production capacity. The power plants, plant sites, power transmission and distribution will all be directly and indirectly affected by increased ambient and water temperature, salinity, flooding, river erosion, prolonged drought which in turn will have a profound effect on people's livelihood, environment, and economic prosperity. Bangladesh's current and future power plants are not resilient to the effects of climate change. To minimize the loss of efficiency of power production, transmission and distribution, a contingency plan and design parameter adjustments for all existing and future power plants is urgently required. The impact of rising water temperature and ambient temperature, salinity, flooding, river erosion, prolonged drought on power plant design, site selection, installation, and maintenance needs to be studied and relevant corrections and measures are required to be undertaken. Failure to undertake such measures will affect all power plants thereby significantly reducing the country's industrialization, and social and economic progress. The lack of economic progress will have unprecedented consequences for the people of Bangladesh. In this study, it is clearly shown how the sea level and temperature (water and ambient air) rise, salinity, flooding, drought will influence the power production from existing as well future power plants across the country. All regions in Bangladesh will be affected differently. Therefore, mitigation of a single parameter will not be very effective for power plants across the country. Therefore, we propose the following recommendations for the mitigation of climate change risk on power plants in Bangladesh:

Region based study of river flow, river erosion and river management (administration);

(a) Development and application of localized and region based design parameters/factors instead of a generalized design factor for all power plants across the country;

(b) Special flood protection embankments must be constructed for power plants located in flood prone areas, for current and future power plants;

(c) Physical infrastructure development for power plants, transmission lines, distribution lines in coastal areas should account for increased wind speeds and wind gusts during storms and cyclones;

(d) Projected capacity and efficiency of the power plant must be considered carefully based on ambient cooling water temperature, salinity, and availability of fresh water;

(e) Drainage system of the power plant infrastructure should be designed to incorporate increased precipitation.

The sea level rise will cause power plants in coastal regions to experience increased salinity. Therefore, the design of cooling systems for power plants should not be affected by increased salinity. In drought conditions, an adequate fresh water supply for power plant cooling systems must be ensured by recycling water and/or installing a desalination plant on the site. Additionally, a corrosion allowance for the physical infrastructure must be considered in coastal regions.

Apart from power plants in Bangladesh, power generation capacities in all low lying countries such as the Maldives, Pacific Ocean countries (Marshall Islands and Samoa), Antigua and Barbuda, Costa Rica will be affected by climate change. In addition, some regions of Myanmar, Honduras, Vietnam, Nicaragua, Haiti, India, Dominican Republic, Philippines and China will also be affected. Similarly, many cities and regions of developed countries such as the USA, Italy, Portugal, Spain, Australia, UK and the Netherlands will experience inundation and salinity thereby affecting existing and future power generation capacities [24].

5. Conclusion

Although the extent of climate change impact is yet to be fully determined, vulnerable counties like Bangladesh must urgently develop strategies and plans to implement adaptation and mitigation activities. However, vulnerable developing countries have limited financial resources and technological knowhow. They need assistance from developed nations in development and implementation of climate change mitigation.

To achieve sustainable economic development and the Millennium Development Goals, vulnerable developing countries must integrate climate adaptation and mitigation into their short term and long term development policies.

Sectorial and multi-sectorial adaptations for existing and future power generation capacities as well as other industrial sectors are required to minimize the effects of rising water and air temperature, sea level, salinity, drought, flood and rainfall.

Bangladesh being a most vulnerable country to climate change, the effects of global climate change must be taken seriously in all current and future development activities especially power plants, site selection, power transmission and distribution.

Future studies should quantify the reduction of power generation efficiency due to temperature rise in water and air, salinity, drought, rain fall and flood especially which design parameters need to be incorporated to minimize the impact of climate change.

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