Assessment of Livelihood Adaptation Strategies to Climate Variability in a Coastal Area of Southwest Bangladesh

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Sabrina Mehzabin

Dedicated to

My Beloved Husband

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Abstract

Climate variability refers to fluctuation of rainfall and temperature around the average without causing the long-term average itself to change. Bangladesh was ranked as the 6th hardest hit country by climate calamities among 180 nations and its coastal zone is the most vulnerable area which is affected more by climate variability than climate change. Climate variability includes unexpected and untimely heavy or less rainfall events, extreme temperature, etc. which ultimately lead to unexpected floods, water-logging, drought, sea-level rise and salinity intrusion in the zone. To understand the recent scenario of rainfall and temperature variability, statistical analysis was performed. The analysis involved the use of Coefficient of Variation (CV), Standardized Precipitation Anomaly (Z) and Precipitation Concentration Index (PCI) from 1978 to 2017 (40 years). Furthermore, Mann-Kendall test is used to detect the time series trend and its significance. The impact of climate variability on livelihood is calculated by a Livelihood Vulnerability Index (LVI). This index is frequently used to identify and compare climate change-specific livelihood vulnerabilities. The extent of the impact of climate change and variability on livelihood depends on the level of vulnerability of farmers and people of other occupations to these impacts. The index consists of six major livelihood components under which there are several sub-components and they contribute equally to the overall index. Impact of climate variability is evaluated by comparing the present LVI with the past. Participatory approaches like transect walk, group discussion, structured questionnaire survey and key informant interview are used to develop LVI and also to assess the current adaptation practices and evaluate potential future adaptation strategies. The variability analysis shows that for both wet and dry seasons, anomaly of temperature has increased significantly with time but rainfall showed little anomaly over the study period. The trend analyses show that except January, the other months, the dry season and the monsoon season have a notably increasing trend in average temperature during the study period. Trend is significant for 99% level of confidence for average temperature of the months May to September, of the dry and the monsoon seasons and also for the annual average temperature. In case of annual temperature variability analysis, highest variation is seen in earlier years-that is 1979-1984. Variation then decreases a little with time, but then increases notably in recent years 1997, 2006, 2009 and 2010, meaning that the variation in temperature has become more visible recently. In case of rainfall, July has increasing trend and December has decreasing trend at 90% confidence, but the other months show non-significant rising or falling trend over time. The analysis of PCI values demonstrates that 1979, 1984, 2006, 2009, 2011, 2014 and 2015 had very high rainfall concentration having the PCI values of 21.50, 21.92, 20.44, 20.08, 21.84, 22.41 and 22.35 respectively. The Z values indicate that 1985, 1989, 1996 and 2010 suffered from severe drought with Z values of -1.54, -1.36, -1.15 and -1.49 respectively, whereas 1992 and 1994 witnessed extreme drought with Z values of -1.91 and -2.17 respectively. The resulting LVIs reveal that livelihood has become more vulnerable due to climate variability in the present decade (0.443) than the past (0.408). Except livelihood strategies, all other major components (socio-demographic profile, health, food, water and natural disaster and climate variability) depict greater vulnerability in the present decade in comparison with the past. All of these are impacting the livelihood aspects like agriculture, health, water, environment etc. Finally, current adaptation practices in response to climate variability are discussed and potential future adaptation strategies to combat upcoming climate threats are suggested.

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Abbreviations and Acronyms

AEZ	Agro Ecological Zone
AOGCM	Atmosphere-Ocean General Circulation Model
BASD	Bangladesh Association for Sustainable Development
BBS	Bangladesh Bureau of Statistics
BDRCS	Bangladesh Red Crescent Society
BMD	Bangladesh Meteorological Department
BRAC	Bangladesh Rural Advancement Committee (former name)
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CBACC-CA	Community Based Adaptation through Coastal Afforestation,
DFID	Department for International Development
DMB	Disaster Management Bureau
FAO	Food and Agriculture Organization
GBM	Ganges-Brahmaputra-Meghna
GD	Group Discussion
GDP	Gross Domestic Product
GO	Governmental Organization
IFRC	International Federation of Red Cross and Red Crescent Societies
IMDMCC	Ministerial Disaster Management Co-ordination Committee

IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
IWFM	Institute of Water and Flood Management
KII	Key Informant Interview
LVI	Livelihood Vulnerability Index
MoA	Ministry of Agriculture
MOEF	Ministry for Environment and Forests
NGO	Non-governmental Organization

Chapter 1

Introduction

1.1 Background of the Study and Present State of the Problem

One of the biggest problems that is threatening mankind is climate change, which is eventually working as a key factor for environmental degradation, water and food insecurity, pollution, natural disasters, etc. The Intergovernmental Panel on Climate Change (IPCC, 2013) Fifth Assessment Report concluded that "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century." Climate model projections summarized in the report indicated that during the 21st century, the global surface temperature is likely to rise a further 0.3 to 1.7 °C in the lowest emissions scenario, and 2.6 to 4.8 °C in the highest emission scenario, all these making livelihood more vulnerable to impacts of climate change.

While the climate tends to change quite slowly, that does not mean that we do not experience shorter-term fluctuations on seasonal or multi-seasonal time scales. Climate change is a long-term process, so its effects become visible gradually with time. But there are many reasons that can cause various climatic parameters to fluctuate around the average without causing the long-term average itself to change. This phenomenon is climate variability. According to IPCC (2013), "Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability)." If simply put, climate variability describes the way climate elements, such as temperature and rainfall, depart from the average value in given months, seasons, years, decades or centuries. Consecutive summers, for example, will not all be the same, with some cooler and some warmer than the long-term average. As climate variability is abrupt and cannot be predicted earlier, it is no less threatening than climate change at present. Difference between climate variability and climate change can be clearly understood from Figure 1.1.

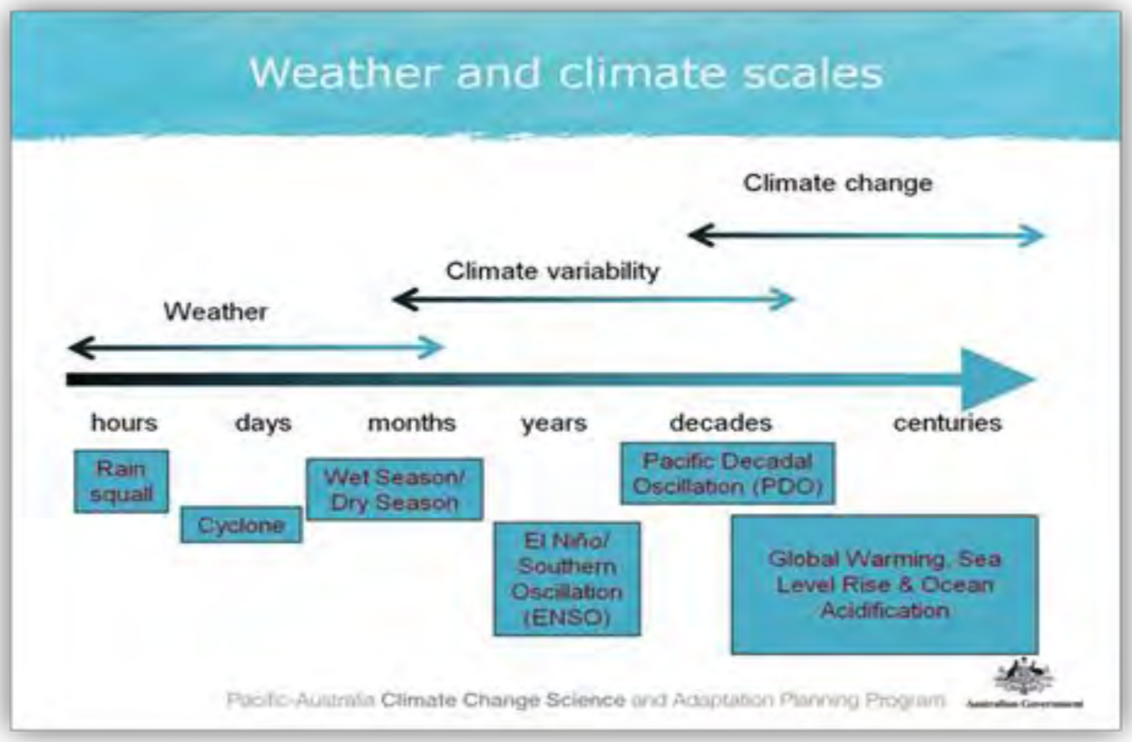


Figure 1.1: Climate change vs climate variability

Bangladesh lies at the bottom of the Ganges, the Brahmaputra and the Meghna (GBM) river system. Bangladesh is watered by a total of 57 trans-boundary rivers flowing to it: 54 from neighboring India and three from Myanmar. The geographical location of Bangladesh and its geomorphic conditions have made the country easily vulnerable to climate change, climate variability and natural disasters, such as tropical cyclones and accompanying storm surges, floods, tornadoes, droughts, etc. According to Global Climate Risk Index 2017, Bangladesh is ranked 6th in the list of mostly affected countries. Coupled with the high level of widespread poverty and increasing population density, limited adaptive capacity, and poorly funded, ineffective local governance have made the region one of the most adversely affected on the planet. Among all the areas, coastal area of Bangladesh is the most vulnerable and hazardous-prone to climate change and climate variability. The coastal areas of Bangladesh are different from the rest of the country not only because of its unique geo-physical characteristics but also for different sociopolitical consequences that often limit people's access to endowed resources and perpetuate risk and vulnerabilities. The potential impacts of climate change on coastal areas include progressive inundation from sea level rise, heightened storm damage, loss of wetlands and increased salinity from saltwater intrusion.

Bangladesh is an agrarian country and for the coastal communities, agriculture is one of the dominant livelihoods and a major driver of their socio-economic condition. According to BBS (2011), about 40 million people of the coastal region of Bangladesh directly or indirectly depend on agriculture. But situation has changed in the past few decades. The Polder 31 of Dacope Upazila in Khulna district has been suffering from the effects of climate variability for quite a long time. Local people mentioned that heavy rainfall events are more frequent nowadays. It results in water logging which leaves a large area of cultivable lands under water. In recent years, meteorological drought is occurring in some parts of the coastal region. These are hampering regular livelihood of local people. Cultivable lands are becoming unsuitable for agricultural production. Saline water intrusion is hampering crop irrigation and fish cultivation. Now people have to look for other occupations and take different adaptation strategies.

1.2 Objectives with Specific Aims and Possible Outcome

The proposed research will be carried out for the fulfillment of the following objectives:

1. To assess climate variability (rainfall, temperature) in the study area;
2. To assess the impacts of climate variability on local livelihood; and
3. To evaluate current livelihood adaptation strategies and to formulate future strategies in response to climate variability.

The outcome of this research will be a better understanding of the present scenario of climate variability in the study area. The current problems with livelihood adaptation to such variability will also be identified through the study. Policy makers and relevant local and national organizations will be able to devise better adaptation strategies based on the findings of the study.

1.3 Justification of the Study

This study was performed in a southwest coastal polder, Polder 31, in Dacope Upazila, Khulna District. Untimely rain, unusual heavy rainfall, high temperature, prolonged drought, natural disaster, etc. are disrupting local livelihood in the last few decades. An assessment of climate variability and its impacts on this area is needed and also modification of existing adaptation strategies and development of new strategies are important from local livelihood perspectives. Several works have been done on the impacts of climate change in the coastal region of Bangladesh (Karim et. al, 2008; Islam et. al., 2014; Ahsan et. al., 2014; Dasgupta et. al., 2015), but there are few regarding climate variability (Shahid et. al., 2010; Shameem et. al., 2015). So, this study was taken to fill up the knowledge gap.

1.4 Structure of the Thesis

This thesis has been organized in six chapters. The content of each chapter is outlined below:

The first chapter provides with relevant background information, objectives, justification of the study and expected outcome.

The second chapter reviews the existing literatures on climate variability, climate change and their effects on the coastal livelihood of Bangladesh. Also, relevant literatures on adaptation strategies to climate variability are reviewed.

The third chapter provides with the methodology of the study, including analysis of climate variability, collection of different primary and secondary data to develop LVI, etc.

The fourth chapter briefly discusses the geographic location, general information on demography, topography, literacy status, livelihood pattern, living standard and health profile of the polder people, river system, farming practice, climate, etc. of the study area.

Chapter five deals with the detailed results and discusses the findings of the study.

The final chapter six provides some conclusions and recommendations of the study.

Chapter 2

Literature Review

2.1 Climate of Bangladesh

Geographical location and physical settings govern the climate of any country. Bangladesh extends from 20°34'N latitude and from 88°01'E to 92°41'E longitude, surrounded by the Assam Hills in the east, the Meghalaya Plateau in the north, the lofty Himalayas lying farther to the north. To its south lies the Bay of Bengal, and to the west lie the plain land of west Bengal and the vast tract of the Gangetic Plain. It is located in the tropical monsoon region and its climate is characterized by high temperature, heavy rainfall, often excessive humidity and fairly marked seasonal variations. The most striking feature of its climate is the reversal of the wind circulation between summer and winter, which is an integral part of the circulation system of the South Asian subcontinent. From the climatic point of view, three distinct seasons can be recognized in Bangladesh- the cool dry season from November through February, the pre-monsoon hot season from March through May, and the rainy monsoon season which lasts from June through October.

2.1.1 Rainfall Pattern of Bangladesh

The single most dominant element of the climate of Bangladesh is the rainfall. Because of the country's location in the tropical monsoon region, the amount of rainfall is very high. During the early part of the pre-monsoon season, a narrow zone of air mass discontinuity lies across the country that extends from the southwestern part to the northeastern part. This narrow zone of discontinuity lies between the hot dry air coming from the upper Gangetic plain and the warm moist air coming from the Bay of Bengal. As this season progresses, this discontinuity weakens and retreats towards northwest and finally disappears by the end of the season, making room for the onset of the summer monsoon. The rainy season, which coincides with the summer monsoon, is characterized by southerly or southwesterly winds, very high humidity, heavy rainfall and long consecutive days of rainfall which are separated by short spells of dry days. Rainfall in this season is caused by the tropical depression that enters the country from Bay of Bengal.

However, there is a distinct seasonal pattern in the annual cycle of rainfall, which is much more pronounced than the annual cycle of temperature. The winter season is very dry, and accounts for only 2%-4% of the total annual rainfall. Rainfall during this season varies from less than 2 cm in the west and south to slightly over 4 cm in the northeast. The amount is slightly enhanced in the northeastern part due to the additional uplifting of moist air provided by the Meghalaya Plateau. As the winter season progresses into the pre-monsoon hot season, rainfall increases due to intense surface heat and the influx of moisture from the Bay of Bengal. Rainfall during this season accounts for 10%-25% of the total annual rainfall which is caused by thunderstorm or Northwester. The amount of rainfall in this season varies from about 20 cm in the west central part to slightly over 80 cm in the northeast. The additional uplifting (by the Meghalaya Plateau) of the moist air causes higher amount of rainfall in the northeast. Rainfall during the rainy season is caused by the tropical depressions that enter the country from Bay of Bengal. These account for 70% of the annual total in the eastern part, 80% in the southwest, and slightly over 85% in the northwestern part of Bangladesh. The amount of the rainfall in this season varies from 100 cm in the west central part to over 200 cm in the south and northeast. Average rainy days during the season vary from 60 in the west-central part to 95 days in the southeastern and over 100 days in the northeastern part. Geographical distribution of annual rainfall shows a variation from 150 cm in the west-central part of the country to more than 400 cm in the northeastern and southwestern parts. The maximum amount of rainfall has been recorded in the northern part of Sylhet district and in the southeastern part of the country (Cox's Bazar and Bandarban districts).

Kripalani et al. (1996) discussed on monthly rainfall patterns of Bangladesh to understand the inter-annual variability of the summer monsoon rainfall. Monthly rainfall may be described by considering four climatological periods. The rainfall distribution patterns for each month are similar and in general the isohytes display a gradient from east to west. The details of spatial distribution of rainfall as per Kripalani are given below:

(i) March-May: During March some areas, in particular the north-east, receive moderate rainfall (70-100 mm), although in most of Bangladesh, the rainfall is still below 50 mm. By April the eastern half of the country receives over 100 mm of rain and the north-eastern part receives over 300 mm. In May the whole country receives well over 170 mm with a maximum over the north-east region (more than 500 mm). On an average this season contributes 19% of the annual rainfall.

(ii) June-august: during this period the south-west monsoon is at its peak. During June the whole country receives over 300 mm of rain with a maximum over the north-east and south-east part of the country. The rainfall distribution patterns for July and August are similar to June. During this period rainfall is heavy especially in Chittagong region because it is exposed to the full force of the south-west monsoon and Cox's Bazar receives more than 700, 900 and 700 mm of rain during June, July and August respectively. These three months together contribute about 57% of the annual rainfall.

(iii) September-October: These are months of withdrawal of south-west monsoon and Bangladesh is practically dry during this period. Although the rainfall pattern remains similar as the pattern during the peak of the monsoon, the rainfall over the eastern parts of the country has become half that during the peak of the south-west monsoon. These two months contribute about 20% of the annual rainfall.

(iv) November-February: This is the season of the north-east monsoon and Bangladesh is practically dry during this period. In November the whole of the country receives well below 50 mm of rain, except the Chittagong region. During December and January the rainfall is around 10 mm over the entire country. During February the rainfall is between 20 mm and 30 mm. These four months contribute about 4% of the annual rainfall.

2.1.2 Temperature Pattern of Bangladesh

Though literature is available on the rainfall patterns and climate of Bangladesh (Ahmed & Karmakar, 1993, Shahid, 2009, Hussain & Sultana, 1996, Kripalani et al., 1996, Ahmed & Kim 2003, Islam & Uyeda 2008, Shahid 2008), studies on historical rainfall and temperature trends are very few (Jones, 1995, Rahman et al., 1997, Singh, 2001). Rahman et al., (1997) analyzed the trend of monsoon rainfall patterns and found that although the southeast part of the country shows a changing pattern of rainfall, the overall evidence does not suggest any changing pattern of monsoon rainfall. On the other hand, Singh (2001) reported that the monsoon rainfall over Bangladesh has increased during the period 1961–1991 with a maximum increase in September followed by that in July. The only work carried out so far on temperature trends in Bangladesh is by Jones (1995), who analyzed the monthly mean maximum and minimum temperatures over the period 1949–1989 and found no significant change in annual mean minimum and maximum temperatures. This contradicts the results obtained in the regions of India bordering Bangladesh (Rupa Kumar & Pant, 1997). A large amount of scientific literatures are available on the variability of rainfall and temperature of India (Mooley & Parthasarathy, 1984, Rupa Kumar et al., 1992, Pant & Rupa Kumar, 1997, Sinha Ray & De, 2003, Arora et al., 2005, Guhathakurta & Rajeevan, 2008) although similar studies for Bangladesh are very few. These studies show an increase in the annual mean temperature over India in the last 100 year, with a higher increase in winter temperature compared to pre-monsoon summer temperature.

2.2 Coastal Region of Bangladesh

The coastal region of Bangladesh (Figure 2.1) consists of a 700 km long coastal belt and an area of 47, 203 km^2 comprising 19 administrative districts (Khan and Awal, 2009). It covers 32% of the area of the country and 28% of the national population (Islam, 2004). The region is blessed with the world's largest mangrove forest the Sundarbans, one of the largest river systems of the world, i.e., the Ganges-Brahmaputra-Meghna (GBM) system which carries 2.4 billion tons of annual sediments, numerous small rivers and tributaries, canals and estuarine marshlands (PDO-ICZMP, 2002). This area is under a continuous process of active delta development and morphological changes by the GBM river system. There are 48 exposed upazilas in the 12 exterior districts in the southwest coastal region which have faced recurrent impacts of intense natural disasters like cyclone, storm surge, tidal flood, waterlogging, river erosion and salinity intrusion for a longer period, much more than the interior districts due to their close proximity to the ocean.

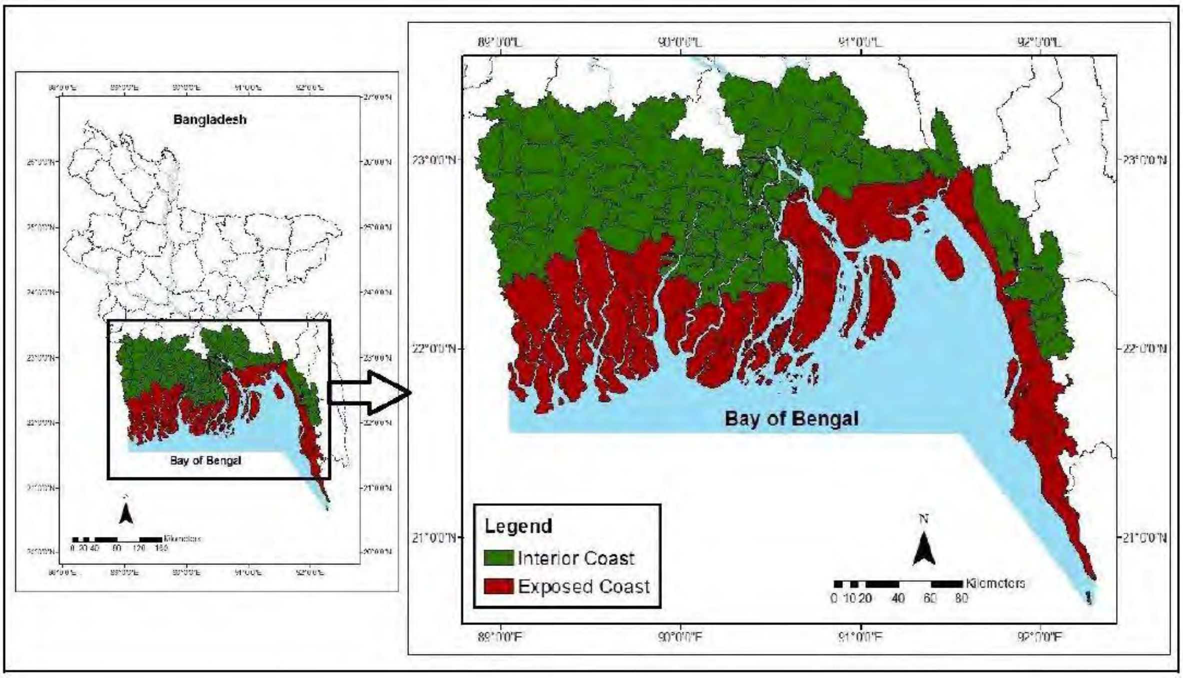


Figure 2.1: Coastal region of Bangladesh

Depending on the geomorphological features, coastal zone of Bangladesh can be broadly divided into three regions: the eastern region, the central region and the western region. Comprising of Satkhira, Khulna, Bagerhat, Jessore, Narail and Gopalganj districts and the great mangrove forest of the Sundarbans, the western region lies in the highly saline zone where the Sibsa and Passur river systems connect the area with the Ganges. The area is under tidal influence and the brackish water ecosystem depends on the upstream freshwater supplies. The vast resources and opportunities of the region have fascinated the community to live here though being in uncertainties of disaster impacts. The impacts of natural disasters in the area are no less than the other portions of the coastal belts, which for a long period have left the lives of the coastal people in perils. In an agro-based coastal economy, it is a notable fact that these disasters make the agriculture sector the worst sufferer (FAO, 2009).

Bangladesh is an agriculture-based country where about 80% of its 145 million people are directly or indirectly engaged in a wide range of agricultural activities (Islam, 2003). Rainfall is the most important natural factor that determines the agricultural production in Bangladesh. The variability of rainfall and the pattern of extreme high or low precipitation are very important for the agriculture as well as the economy of the country. It is well established that the rainfall is changing on both the global (Hulme et al., 1998; Lambert et al., 2004; Dore, 2005) and the regional scales (Rodriguez-Puebla et al., 1998; Gemmer et al., 2004) due to global warming. The implications of these changes are particularly significant for Bangladesh where hydrological disasters of one kind or another is a common phenomenon (Shahid and Behrawan, 2008). Bangladesh is one of the most flood-prone countries in the world due to its geographic position. Drought in northwestern part of the country is also a common phenomenon (Shahid, 2008; Shahid and Behrawan, 2008). The country experienced a number of extreme dry and wet periods in past 50 years. Heavy rainfall in the monsoon of 2007 together with the onset of flooding by Himalayan-fed rivers resulted in severe flood in Bangladesh which affected more than 9 million people in more than half of the districts of the country.

2.3 Climate Change and Variability in Coastal Zone of Bangladesh

2.3.1 Climate change

Global climate has been changing due to adverse natural forces as well as anthropogenic activities, especially emissions of greenhouse gases and aerosols like carbon-dioxide, methane, nitrous oxide, etc., and change in land use for the past few decades (IPCC, 2007). Increased emission of greenhouse gases and consequent increase in global temperature is changing the climatic conditions. According to IPCC Fifth Assessment Report, temperature extremes have increased, strong variability of rainfall trends has been observed and rate of sea level rise has been higher than the average for the past 2000 years (CDKN, 2014). The IPCC warns that, continual emission of greenhouse gases at current rates will cause rising of average global temperature up to 2.6-4.8°C by 2100. Global mean sea level rise by the last two decades of the 21st century will likely be in the range of 26-55 cm under a low emissions scenario, and it can be 45-82 cm for a high emissions scenario with total sea level rise of up to 98 cm by 2100 in South Asia (CDKN, 2014). Being in the South Asian region, this fact is of great concern to Bangladesh. Though Bangladesh is not a major contributor of greenhouse gases compared to the developed countries of the world, but this country is one of the most vulnerable to climate risks and global climate change phenomenon. Climate variability and climate change bear potential risk of different hazards for all over the country. But, multiple vulnerabilities to periodic cyclone and storm surges, salinity intrusion, erosion and fragile coastal embankments make the coastal zone of Bangladesh different from rest of the country (PDO-ICZMP, 2004). According to Dasgupta et al. (2010), vulnerability of Bangladesh to cyclonic storm surges may increase even more as a result of climate change and increased sea surface temperature. A number of studies have been carried out on the trends of climatic parameters in the context of

Bangladesh in recent years (e.g., Karmakar and Srestha, 2000; World Bank, 2000; Debsarma, 2003; Karmakar, 2003; Mia, 2003; Basak et al., 2009; CCC, 2009; Yu et al., 2010; Mondal et al., 2012; Saha and Islam, 2015) assessing the changes in temperature and precipitation pattern which showed evidences of climate change. Changes in climate and consequent sea level rise is expected to force the salinity front further inward of the coastal belt thus aggravating the salinity problem in the coastal areas, particularly in southwest coastal zone. Also, temperature and rainfall inconsistency will continue to intensify and cyclonic storm surges will become more frequent (Sikdar, 2010). Thus, the people of the coastal region and their livelihood practices are under the threat of severe climate change impacts.

2.3.2 Climate Variability

Although a number of studies have been carried out on rainfall patterns (Ahmed and Karmakar, 1993; Hussain and Sultana, 1996; Kripalini et al., 1996; Rahman et al., 1997; Ahmed and Kim, 2003; Shahid et al., 2005; Islam and Uyeda, 2008; Shahid, 2008, Shahid, 2011), only very few works have been found on rainfall and temperature trends, extremes and variabilities in Bangladesh. The study done by Sanderson and Ahmed (1979) considered pre-monsoon rainfall and its variability in Bangladesh. A trend surface mapping technique was used to show the rainfall distribution of the variable of the pre-monsoon season. It helped to explain the regional trends and local effects on the distribution of pre-monsoon rainfall in Bangladesh. Although the trend surface mapping technique was found to be satisfactory for mapping the pre-monsoon rainfall, it was not satisfactory in explaining the variability of this rainfall monthly or seasonally.

Ahmed (1989) estimated the probabilistic rainfall extremes in Bangladesh during the pre-monsoon season. Karmakar and Khatun (1995) repeated a similar study on rainfall extremes during the southwest monsoon season. However, both the studies were focused only on the maximum rainfall events for a limited period. Rahman et al. (1997) used trend analysis to study the changes in monsoon rainfall of Bangladesh and found no significant change. May (2004) reported that the frequency of wet days has noticeably increased over the tropical Indian Ocean. He predicted that intensity of heavy rainfall events in Bangladesh will be increased in the future. Hossain et al. (2014) analyzed temporal variability of rainfall for the coastal region of Bangladesh for the period 1940 to 2007. Bari et al. (2017) analyzed rainfall variability and seasonality in northern Bangladesh using Mann-Kendall test and seasonality index (SI) respectively.

Rahman, Kamal and Billah (2017) used linear regression model to understand the variation, trend and prediction of rainfall for annual and various climatic seasons such as pre-monsoon, monsoon, post-monsoon and winter. Finding reveals that, the trends of mean rainfall of annual, pre-monsoon and winter have decreased, whereas rainfall remained unchanged in monsoon season and has increased in post-monsoon. Data predicts lesser rainfall in the period 1975, 1989, 1992, 1994, 2004, 2009, 2012, 2013 and 2014 years. These results indicate lesser precipitation in future over Bangladesh. The predicted rainfall amount from the best fitted model was compared with the observed data.

Kabir and Golder (2017) studied on rainfall variability and its impact on crop agriculture in southwest region of Bangladesh. They found significant decreasing trend (Mann-Kendall) of annual rainfall over the region is found (-4.5 mm/year at Mongla, -9.14 mm/year at Jessore, -15.71 mm/year at Madaripur) except Khulna, Satkhira and Khepupara, where the trend is positive over the long period (1948-2014) but it exhibits a decreasing trend during the recent period i.e., after 1980s. The trend is more intense at the upper southwestern part, i.e., places like Jessore and Madaripur but most wide annual deviation is observed in Khulna from 48.6% to -35.5%.

In case of temperature variability, Warrick et al (1994) studied the variation of temperature and rainfall over Bangladesh. In this study, mean-annual temperatures have been expressed as departures from the reference period 1951-1980. It is evident that, on this time scale, Bangladesh region has been getting warmer. Since the later part of the last century, there has been, on average, an overall increase in temperature by 0.5°C which was comparable in magnitude to the observed global warming.

2.4 Natural Disasters in Coastal Region

Natural disasters are common phenomena in Bangladesh due to its dynamic geographical settings. The impacts of natural disasters have been so widespread in this country that since 1970 to 2009, almost 39 million people were displaced by major natural events (Akter, 2009). The southwestern coastal region also faces the common disasters like the rest of the coastal area. Among them, cyclones and associated storm surges have been the most detrimental. Historical evidences show that the southwest coastal region of Bangladesh has been struck by a number of cyclonic storm surges over the last few decades.

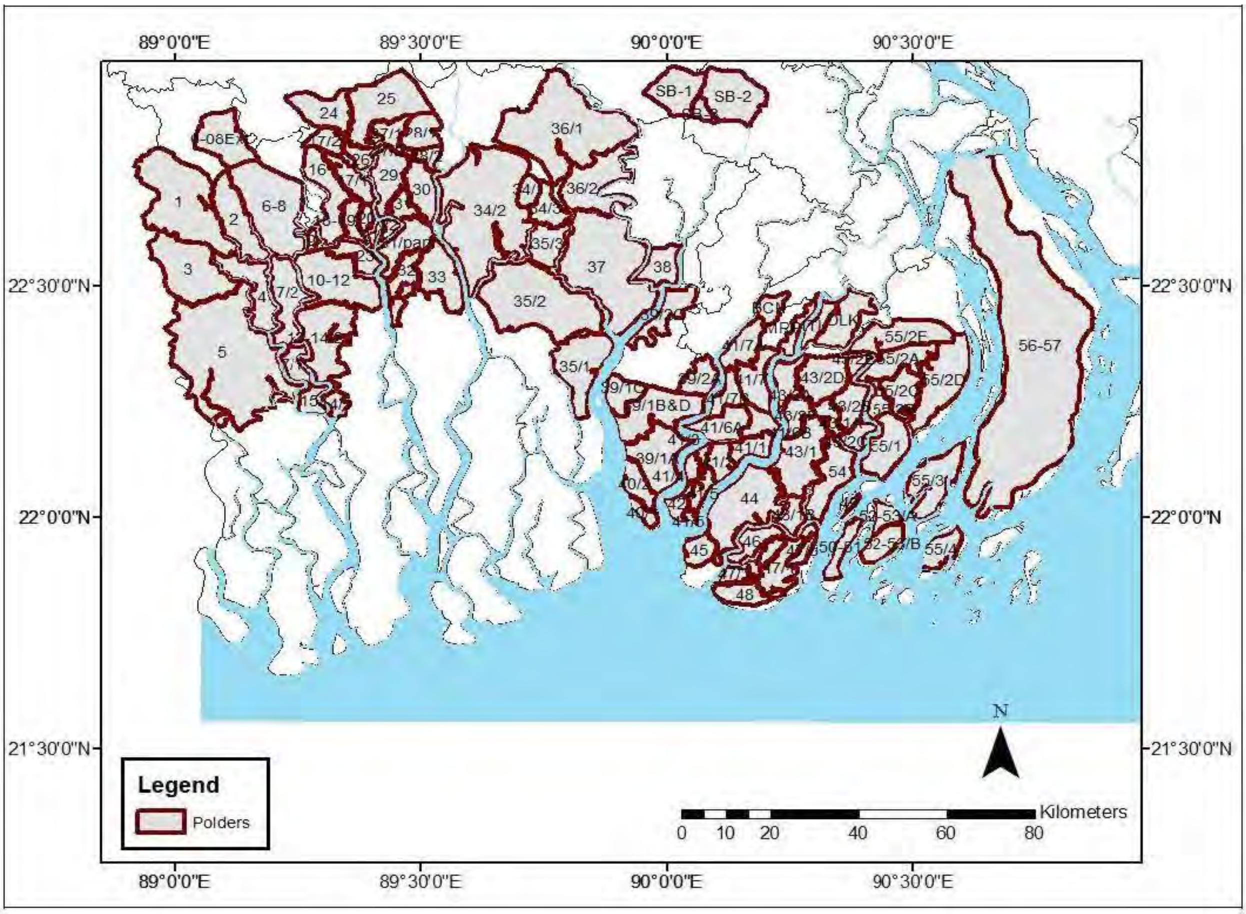


Figure 2.2: Coastal polders of south-west and south-central regions

Since 1970, the country has experienced 36 cyclonic storms resulting in over 450,000 deaths and a huge economic loss (UNDP, 2010). Since 1960s, a total of 139 polders have been constructed by Bangladesh Water Development Board (BWDB) in the coastal region of Bangladesh as a line of defense from cyclonic storm surges (Figure 2.2) (Khan, 2014). But regrettably, these polders could not serve well in protecting from coastal disasters and their impacts. Severe cyclone events have damaged the coastal polders many times, thus affecting the lives of the people inside the polder. Especially the super cyclones Sidr in 2007 and Aila in 2009 have aggravated the situation in the region. Though, the deadly cyclone Sidr was classified as 'Category 5' due to its high wind force, but the immediate and prolonged impacts of cyclone Aila were more detrimental than that of Sidr (250 km/hr) (Kabir and Azad, 2007). On 25 May 2009, at the time of landfall at Bangladesh coast, the sustained wind pressure of

Aila was 120.7 km/hr, which was much less than Sidr, but due to the economic cost and long term sufferings, the impacts of Aila outweigh the impact of any cyclone in the past in this region (Kumar *et al*., 2010). About 2.3 million people were affected by this event and many coastal inhabitants were stranded in the affected area, as they had no safe alternatives to survive. At many points the surge had risen almost three to four meters, which caused overtopping of embankments, breaching at some points, and inundation of households and croplands (Kumar *et al*., 2010). Both long and short term inundation and salinity ingression from polder damages affected the lives and livelihoods of the people up to a damaging extent. The agricultural lands were severely affected due to this super cyclone. Damage of 130,962 hectares (ha) of agricultural lands was reported (IRIN, 2009) and the food cycle throughout the coastal region was paralyzed. 96% of the livelihood bases in the southwest region were devastated. Farmers and local community had to wait two years before any vegetables could grow and six years before any fruit trees come to normal productive condition (Kumar *et al*., 2010). Figure 2.3 shows the areas which are under the risk of cyclone and storm surge.

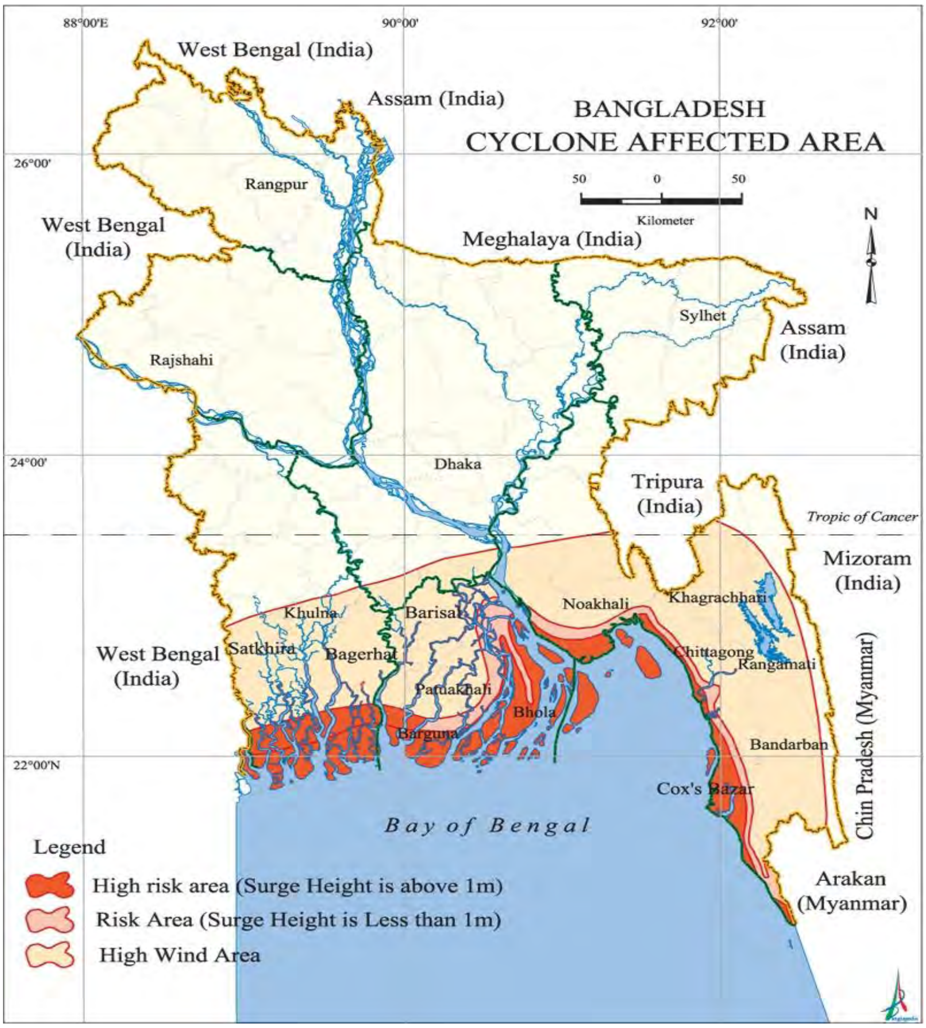


Figure 2.3: Cyclone affected areas of Bangladesh

2.5 Impacts of Climate Variability on Coastal Livelihood

According to International Federation of Red Cross and Red Crescent Society (IFRC), 'A livelihood is a means of making a living. It encompasses people's capabilities, assets, income and activities required to secure the necessities of life'. The coastal zone of Bangladesh is the most vulnerable to climate variability and change Bangladesh experiences different types of natural disasters almost every year because of the global warming as well as climate change and variability impacts. The impact of climate change will be felt by different parts of the world and by different people; poor countries like Bangladesh are going to be the worst hit. For example, research by Furberg et al. (2011) on Sami population shows that rapidly changing unstable weather patterns affect their living patterns. Furthermore, studies by Guha-Sapir et al. (2012) and Adebo and Sekumade (2013) suggest that women and children tend to be the worst affected. Additional studies by Devkota et al. 2014), Kendrovski and Spasenovska (2011), Davies et al. (2009), and Bhuiyan and Khan (2011) also show how these groups are suffering from health problems because of climate change. In disaster times, children and babies lack the capacity to escape from the hazard. In a study of 1991 Bangladesh cyclone, for example, children and older people died more disproportionately than others in the population (Chowdhury et al., 1993). About 71% of respondents mentioned that children suffer most due to the adverse effects of climate change and variability and this was closely followed by elderly people and women at 63%, respectively (Nesha et. al, 2014). This shows that women are the most vulnerable group who are the worst victim of the climate change followed by children and the elderly population. Other pieces of research show that the elderly populations suffer the most adverse health conditions due to changes in weather conditions (Grundy, 2006; Mortreux and Barnett, 2009 and Filiberto et al., 2009 Hansen et al., 2013).

Bangladesh is already evidencing the adverse impacts of global warming and frequent climate variability. The following impacts have been observed: hotter summers, irregular monsoons, untimely rainfall, heavy rainfall over short periods (causing water logging and landslides), very little rainfall in dry periods, increased river flow and inundation during monsoon, increased frequency, intensity, and recurrence of floods, crop damage due to flash floods and monsoonal rain, crop failure due to drought, prolonged cold spells, salinity intrusion along the coast (leading to scarcity of potable water and redundancy of prevailing crop practices), coastal erosion, river bank erosion, deaths due to extreme heat and cold, increasing mortality and morbidity, and prevalence and outbreak of dengue, malaria, and diarrhea (UNDP, 2010).

Also, there is growing scientific evidence from the literature that a changing climate is responsible for influencing all kinds of natural disasters and these natural disasters are affecting human lives. Almost one fourth of the total population of the country live in the coastal areas of Bangladesh, where majority of the population are somehow affected (directly or indirectly) by coastal floods / tidal surges, river-bank erosion, salinity, tropical cyclones etc.

With the rise of sea-level up to one meter only, Bangladesh could lose up to 15% of its land area under the sea water and around 30 million people living in the coastal areas of Bangladesh could become refugees because of climate change impacts. Agriculture, industry, infrastructure (school, hospitals, roads, bridges and culverts etc.), Livelihoods, marine resources, forestry, biodiversity, human health and other utility services will suffer severely because of the same. Salinity intrusion from the Bay of Bengal already penetrates 100 kilometers inside the country during the dry season and the climate change in its gradual process is likely to deteriorate the existing scenario to a great extent. Since most of the country is less than 10 meters above sea level and almost 10% of the population of the country is living below 1 meter elevation - the whole coastal area is highly vulnerable to high tides and storm surges. Moreover, the Bay of Bengal is located at the tip of the north Indian Ocean, where severe cyclonic storms as well as long tidal waves are frequently generated and hit the coast line with severe impacts because of the shallow as well as conical shape of the Bay near Bangladesh.

The combination of higher temperatures and potential increases in summer precipitation could create the conditions for greater intensity or spread of many infectious diseases. However, risk in the human health sector is low relative to climate change induced risks in other sectors (such as water resources) mainly because of the higher uncertainty about many of the health outcomes. Increased risk to human health from increased flooding and cyclones seems most likely. Changes in infectious disease are less certain. The causes of outbreaks of infectious disease are quite complex and often do not have a simple relationship with increasing temperature or change in precipitation. It is not clear if the magnitude of the change in health risks resulting from climate change will be significant compared to current risks. It is also not clear if increased health risk will be apparent in the next few decades. On the whole climate change is expected to present increased risks to human health in Bangladesh, especially in light of the poor state of the country’s public health infrastructure. Life expectancy is only 61 years, and 61% of children are malnourished (World Bank, 2002).

Being an agrarian country climate change risk to the agriculture sector of Bangladesh stands out to be the most important. The challenge of enhancing agricultural productivity with growing population can be highly affected by changed climatic condition. Long term changes in temperature and rainfall pattern have direct impact on evaporative demands and consequently on agricultural yields (Yu et al., 2010). Sea level rise and salinity intrusion are major concerns for coastal agriculture. Drainage congestion and resultant waterlogging also hinder crop agriculture in the coastal region (Roy, 2004, 2017). So, it is very important to assess climate variability influences on costal agriculture for developing and formulating necessary adaptation strategies for the survival and future development of agriculture sector in the coastal region of Bangladesh. In Bangladesh, few literatures including Nasrin (2009), Mondal et. al. (2012), Madhu (2012), Saha and Mondal (2016), etc., have studied the changes in future climate and their impacts on agriculture in the Khulna and Satkhira districts.

2.6 Adaptation to Climate Variability and Change in Coastal Region

Adaptation is defined as adjustments in human and natural systems, in response to actual or expected climate stimuli or their effects, that moderate harm or exploit beneficial opportunities (IPCC 2001b). From this main definition, three types of adaptation are distinguished:

- Anticipatory adaptation – Takes place before impacts of climate change are perceived. It is also defined as proactive adaptation.
- Autonomous adaptation – Adaptation that does not occur from a conscious response to climatic stimuli but is produced by ecological changes in natural systems and by market or welfare changes in human systems. It is also defined as spontaneous adaptation.
- Planned adaptation – Adaptation that is the result of a policy decision, based on knowledge that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

In Bangladesh, Autonomous Adaptation is practiced by local people and Planned Adaptation is taken by various institutions and GOs and NGOs in collaboration with root level communities in light of their practical experience and knowledge.

Adaptation in agriculture is how perception of climate change is translated into the agricultural decision-making process (Bryant et al., 2000). Farmers have experienced that climate change and variability have directly affected the agriculture sector, especially crop, fish and livestock production. That situation led the people to adaptation strategies to mitigate the risk. Based on their experiences, knowledge and resources, they looked for adaptation strategies to cope with the changing climatic situation. It is also reported that these factors affect the choice of method for adaptation (Deressa et al., 2008)

A handful of selected publications mentioned adaptation practices to climate variability and change in the southwest and other parts of Bangladesh. Those papers referred to very few of adaptation practices in agriculture, fisheries and livestock, water, health and sanitation, infrastructure, biodiversity and forestry sectors. Some good adaptation practices are identified in agriculture sectors against flood, drought and salinity. Saline tolerate rice varieties like Bina dhan-8, Bina dhan-10, BRRI dhan-47, BRRI dhan-55 are cultivated by more than one million farmers in Bangladesh. Bina dhan - 8 and Bina dhan-10 have been cultivated by farmers in districts of southwest coastal region in boro season. These varieties have the salt tolerate capacity to survive up to 10-12ds/m. Farmers cultivate BRRI dhan-47 variety that requires less water and tolerance capacity to dry soil is quite high (Alam et al., 2013). Bangladeshi and Chinese species or tilapia (Oreochromis niloticca, O.mossambica), Lates calicarifer, Eleutheronema tetradactylum, Glossogobius giuries and Mystus menoda are well accepted species. Moreover, salt resistant Aman paddy is cultivated in Shatkhira, Khulna, Bagherhat of Southwest coastal region of Bangladesh (Karim, 1986).

Coastal green belt is one of the best adaptation practices to protect local, coastal and regional areas from storms, cyclone and tidal surges. It is essential to reduce the wind speed by planting appropriate tree species, which can withstand the high speed of wind and break the wind speeds. Naturally grown halophytic plants have the special adaptation for withstanding in the littoral zones with clayey alluvial soil, tides and strong salinity and winds. There are several palm species and swamp grasses having soil binding capacity to control erosion. They also reduce the speed of tidal surges (Alauddin and Rahman, 2013).

Because of this extraordinary susceptibility to climate change, the Government of Bangladesh, with the support of development partners, has invested more than $10 billion over the last 35 years to manage disaster-related risks. These investments have included flood management schemes, coastal polders, cyclone and flood shelters, and the raising of roads and highways above flood levels (Government of Bangladesh 2009: xvii). However, as a response to the country's increased vulnerability and the severity of cyclone Sidr in 2007, the government for the first time developed and implemented an integrated climate change strategy and action plan in 2008. A local fund of $100 million was established exclusively for adaptation and mitigation efforts.

Currently, the Ministry of Environment and Forests is tasked with monitoring and managing climate change affairs. The government has established an inter-ministerial committee on climate change headed by the Ministry for Environment and Forests (MOEF) composed of relevant government ministries and departments as well as key nongovernmental organizations and research institutions. The Department of Environment under the MOEF has also set up a Climate Change Cell to act as Secretariat for climate change related work within the government. There is also a National Environment Committee to determine environmental policies chaired by the Prime Minister and with representation from Members of Parliament as well as government and civil society.

The national climate change adaptation plan espouses a "pro-poor climate change management" strategy, prioritizing adaptation and disaster risk reduction. It aims to address national concerns with respect to climate change including food security, social protection and health, comprehensive disaster management, infrastructure, research and knowledge management, mitigation and low carbon development, and capacity building and institutional strengthening (Government of Bangladesh, Ministry Environment and Forests 2009: 27–29). To further bolster national efforts, the Global Environment Facility and United Nations Development Program partnered with the government of Bangladesh to manage a project entitled "Community Based Adaptation through Coastal Afforestation," or CBACC-CA. The Executing Agency of the project is the MOEF and other implementing partners include the Forest Department, Bangladesh Forest Research Institute, Department of Agricultural Extension, Ministry of Fisheries and Livestock, and Ministry of Land. The project aims to reduce the vulnerability of coastal communities to the impacts of climate change by afforestation in four upazilas in the coastal districts of Barguna and Patuakhali (Western region), Chittagong (Eastern Region), Bhola (Central Region) and Noakhali (Central Region). The total value of the project, expected to run from June 2010 to 2013, is $5 million, with core support coming from the Global Environment Facility and United Nations Development Program as grants. In addition, the Government of Bangladesh has in kind contributed about

$1 million. In essence, the CBACC-CA project seeks to promote adaptation to climate change through more climate aware development and better risk management.

The project is based on four components. First is enhancing the adaptive capacity of coastal communities and protective ecosystems through community-led interventions focusing on coastal afforestation and the diversification of community livelihood. Second is strengthening national, sub-national, and local capacities of government authorities and sectorial planners so that they better comprehend climate risk dynamics in coastal areas and implement appropriate risk reduction measures. Third is reviewing and revising coastal management practices and policies with a view on increasing community responsiveness. Fourth is developing a functional system for the collection, distribution and internalization of climate related knowledge.

So, it can be concluded that in order to develop best adaptation strategies for future, help and knowledge of root level people and community and organizations should be taken into consideration besides government initiation.

Chapter 3

Methodology

In the first section of this chapter, methodology for the variability analysis of the climate parameters (rainfall and temperature) is discussed. After that, methodology to analyze the impact of climate variability is described elaborately. Similar methodology is used to assess the current adaptation practices.

3.1 Climate variability analysis

A number of techniques have been developed for the analysis of rainfall and temperature, which generally fall into variability and trend analysis categories. For analysis, the whole year is divided into two seasons: dry season from November to May and monsoon season from June to October. In this study, rainfall and temperature variability have been computed using CV, standardized anomaly and PCI. Furthermore, MK is used to detect the trend of rainfall and temperature with Sen's slope estimator. Data analysis is undertaken using SPSS software and excel spreadsheet.

CV is calculated to evaluate the variability of the rainfall. A higher value of CV is the indicator of larger variability, and vice versa which is computed as:

$$CV = \frac{\sigma}{\mu} \times 100$$

Where CV is the coefficient of variation; σ is standard deviation and μ is the mean precipitation. According to Hare (2003), CV is used to classify the degree of variability of rainfall events as less ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$). Similar analysis can be done for temperature and CV will indicate whether the variability is less, moderate or high.

Different indices have been used for this purpose and among these the Precipitation Concentration Index (PCI) is recommended (Oliver, 1980), as it provides information on long-term total variability in the amount of rainfall received (Michiels et al., 1992; Apaydin et al., 2006; Luis et al., 2011). PCI is used to examine the variability (heterogeneity pattern) of rainfall at different scales (annual or seasonal). The PCI values were computed, as given by Oliver (1980) and modified by Luis et al. (2011), as:

$$\text{PCI}_{\text{annual}} = \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} \times 100$$

Where: Pi = the rainfall amount of the ith month.

The precipitation concentration index can also be calculated on a seasonal scale and the formula can be modified accordingly (Luis et al., 2011). If we divide a year into two seasons, i.e. dry season (Nov-May) and monsoon season (Jun-Oct), then the formulae will be

$$\text{PCI}_{\text{dry}} = \frac{\sum_{i=1}^{7} P_i^2}{(\sum_{i=1}^{7} P_i)^2} \times 58$$

$$\text{PCI}_{\text{monsoon}} = \frac{\sum_{i=1}^{5} P_i^2}{(\sum_{i=1}^{5} P_i)^2} \times 42$$

According to Oliver (1980), PCI values of less than 10 indicates uniform monthly distribution of rainfall (low precipitation concentration), values between 11 and 15 denote moderate concentration, values from 16 to 20 indicates high concentration, and values of 21 and above indicate very high concentration.

On the other hand, standardized anomalies of rainfall have been calculated to examine the nature of the trends, enables the determination of the dry and wet years in the record and used to assess frequency and severity of droughts (Woldeamlak and Conway, 2007; Viste et al., 2013; Gebre et al., 2013) as:

$$Z = \frac{X_i - \overline{X_\iota}}{S}$$

Where, Z is standardized rainfall anomaly; Xi is the annual rainfall of a particular year; $\overline{X_\iota}$ is long term mean annual rainfall over a period of observation and 's' is the standard deviation of annual rainfall over the period of observation. The drought severity classes (Chappel and

Agnew, 1999) are extreme drought ($Z < -1.65$), severe drought ($-1.28 > Z > -1.65$), moderate drought ($-0.84 > Z > -1.28$) and no drought ($Z > -0.84$).

Trend analysis is performed through parametric and non-parametric tests. The advantage of non-parametric statistical test over the parametric test is that the former is more suitable for non-normally distributed, outlier, censored and missing data, which are frequently encountered in climatic time series. As a result, Mann-Kendall (MK) test is widely used to detect trends of meteorological data. MK test is a nonparametric test, which tests for a trend in a time series without specifying whether the trend is linear or non-linear (Yue et al., 2002). Normality and homogeneity of a variable throughout the series may be adversely affected by outliers and missing data in parametric tests.

MK trend test is a non-parametric test commonly employed to detect monotonic trends in series of environmental data, climate data or hydrological data. MK test has been used to detect the presence of monotonic (increasing or decreasing) trends in the study area and whether the trend is statistically significant or not. Since there are chances of outliers to be present in the dataset, the non-parametric MK test is useful because its statistic is based on the (+ or -) signs, rather than the values of the random variable, and therefore, the trends determined are less affected by the outliers (Birsan et al., 2005). Trend analysis has been carried out on annual bases, as well as for dry and monsoon seasons. This enables us to see the trend especially for the onset and cessation months. The MK test statistic 'S' is calculated based on Mann (1945), Kendall (1975) and Yue et al. (2002) using the formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i)$$

The application of trend test is done to a time series Xi that is ranked from i = 1, 2…n-1 and Xj, which is ranked from j = i+1, 2…. n. Each of the data point Xi is taken as a reference point which is compared with the rest of the data point's Xj so that:

$$\text{Sgn}(X_i - X_j) = \begin{cases} +1 \; if \; (\text{Xi} - \text{Xj}) > 0 \\ 0 \; if \; (\text{Xi} - \text{Xj}) = 0 \\ -1 \; if \; (Xi - Xj) < 0 \end{cases}$$

Where Xi and Xj are the annual values in years i and j (j > i) respectively. It has been documented that when the number of observations is more than 10 (n≥10), the statistic 'S' is approximately normally distributed with the mean and E(S) becomes 0 (Kendall, 1975). In this case, the variance statistic is given as:

$$\text{Var(S)} = \frac{n(n-1)(2n+5)-\sum_{t=1}^{m}(t_1-1)(2t_1+5)}{18}$$

Where n is the number of observation and ti are the ties of the sample time series. The test statistics Zc is as follows:

$$Z = \begin{cases} \frac{S-1}{\sigma} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sigma} & S < 0 \end{cases}$$

Where Zc follows a normal distribution, a positive Zc and a negative Zc depict an upward and downwards trend for the period respectively. Sen's Slope estimation test computes both the slope (i.e. the linear rate of change) and intercept according to Sen's method. The magnitude of the trend is predicted by Theil (1950) and Sen (1968) slope estimator methods. A positive value of β indicates an 'upward trend' (increasing values with time), while a negative value of β indicates a 'downward trend'. Here, the slope (Ti) of all data pairs is computed as (Sen, 1968). In general, the slope Ti between any two values of a time series x can be estimated from:

$$T_i = \frac{x_j - x\text{i}}{j-i}$$

Where xj and x_i are considered as data values at time j and k (j > i) correspondingly. The median of these N values of Ti is represented as Sen's estimator of slope which is computed as Qmed = $T_{(N+1)/2}$ if N appears odd, and it is considered as Qmed = [$T_{(N+1)/2}$+($T_{(N+2)/2}$)/2] if N appears even. A positive value of Qi indicates an upward or increasing trend and a negative value of Qi gives a downward or decreasing trend in the time series. In the MK test, parameters like Kendall's tau, S statistic, and the Z statistic were considered to identify the increasing or decreasing trend in the time series of climatic parameters. In this study p-value is used to detect the significance of a trend at different confidence levels.

Mann-Kendall test is conducted using SPSS. Steps of this procedure (with photos from 3.1 to 3.4) are given below:

- Monthly data are given as input in the 'Data view' of SPSS. Then name of the variables are changed switching to the variable view window as the following image. Also decimals are changed according to data type.

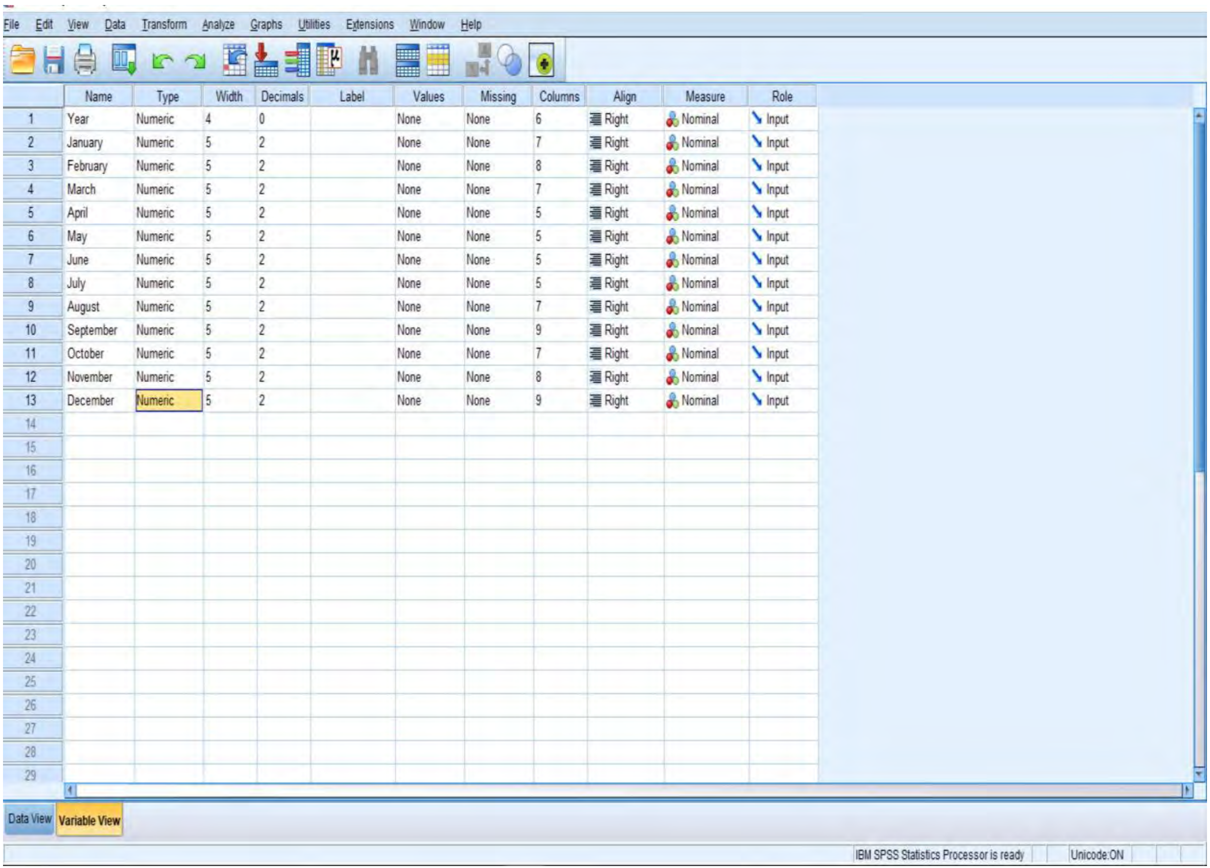


Photo 3.1: A view in SPSS after the input of data

- After changing the name of the data set, the 'Data view' looks like the following image.

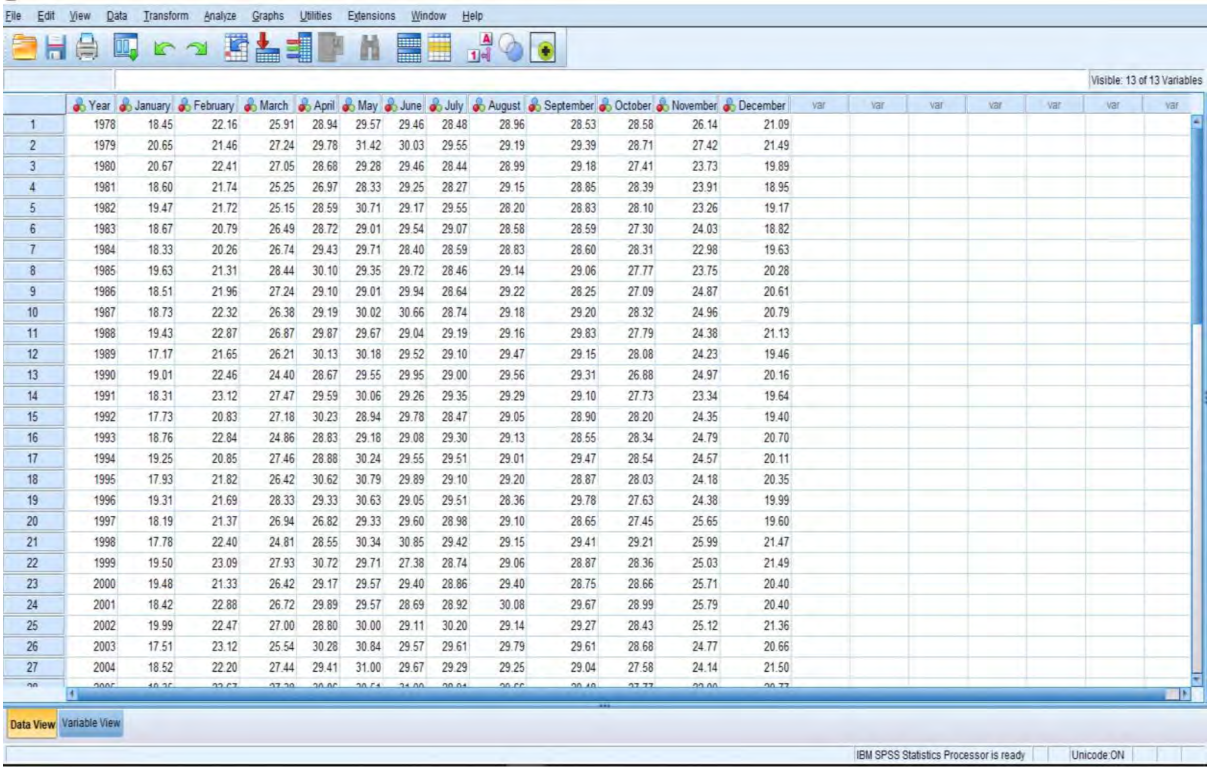


Photo 3.2: A view of all the data in SPSS

- From the 'Analyze' option on top bar, bivariate correlation is selected and the following window appears. All the variables are selected and 'Kendall tau-b' option is marked.

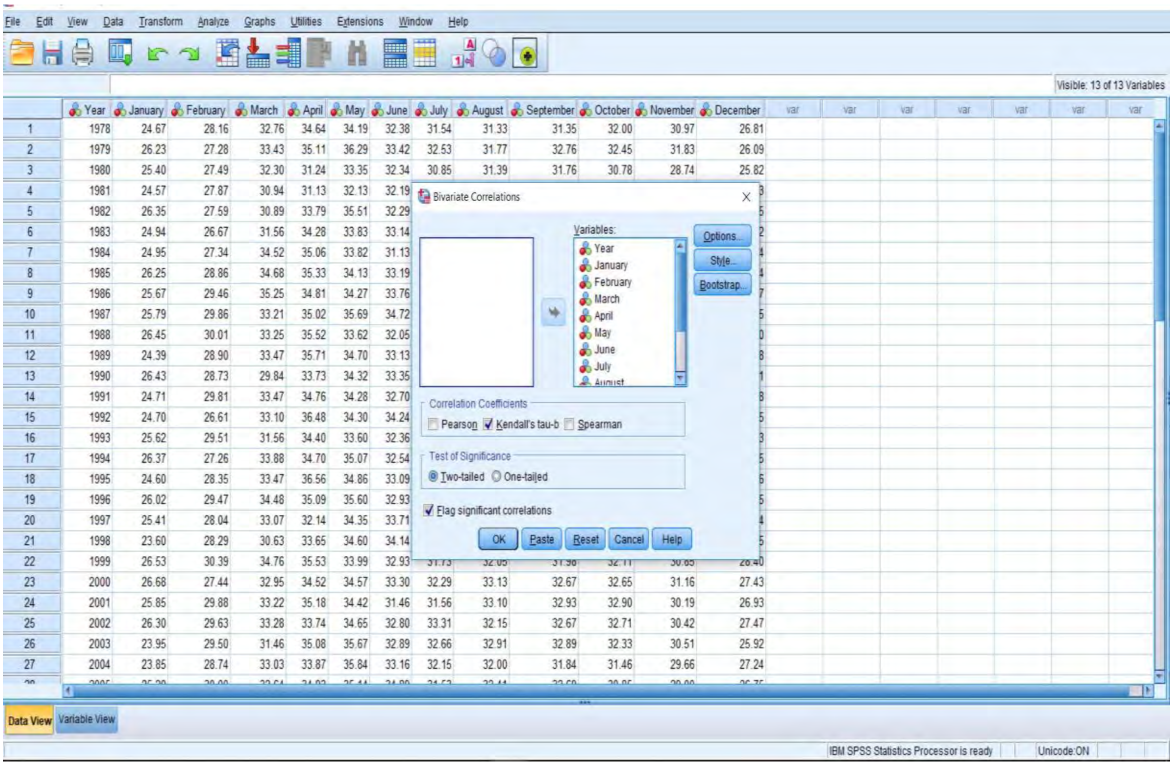
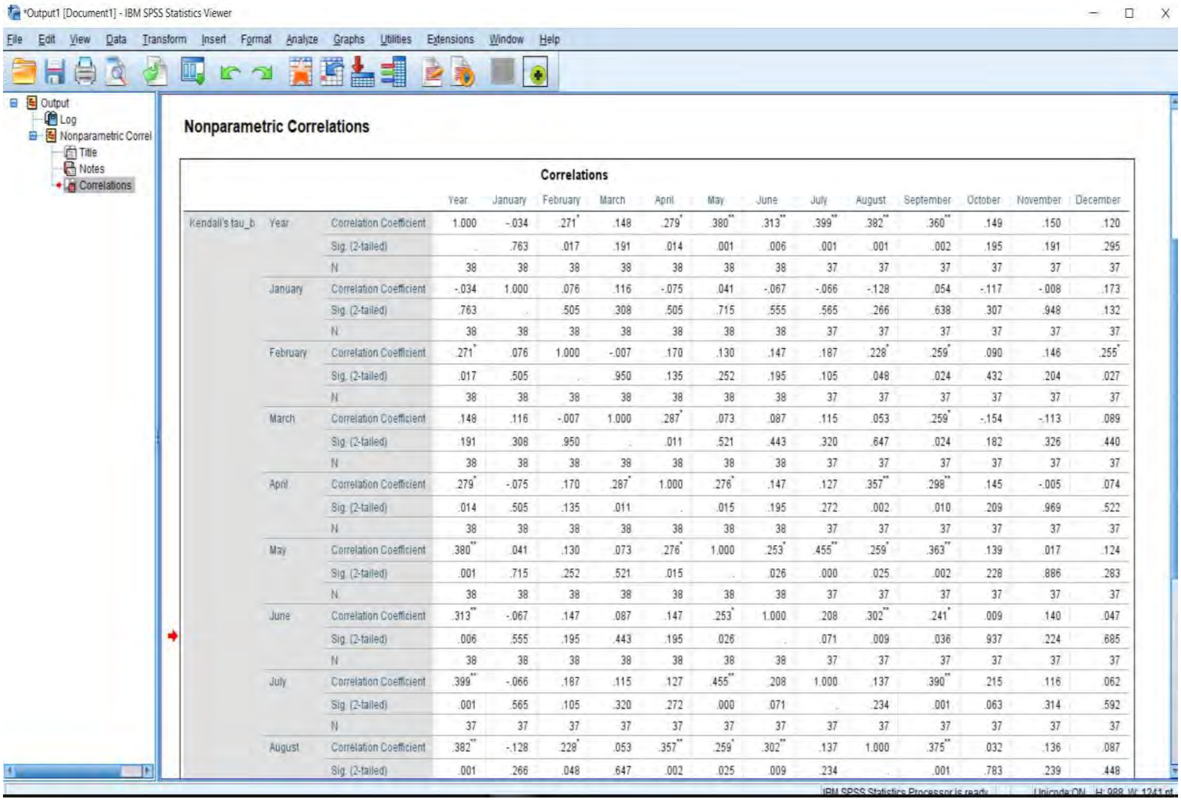


Photo 3.3: Analyzing with Mann-Kendall test in SPSS

➢ The output window then displays the result showing p-value and correlation co-efficient.



			Year	January	February	March	April	May	June	July	August	September	October	November	December
Kendall's tau_b	Year	Correlation Coefficient	1.000	-.034	.271*	.148	.279*	.380**	.313**	.399**	.382**	.360**	.149	.150	.120
		Sig. (2-tailed)	.	.763	.017	.191	.014	.001	.006	.001	.001	.002	.195	.191	.295
		N	38	38	38	38	38	38	38	37	37	37	37	37	37
	January	Correlation Coefficient	-.034	1.000	.076	.116	-.075	.041	-.067	-.066	-.128	.054	-.117	-.008	.173
		Sig. (2-tailed)	.763	.	.505	.308	.505	.715	.555	.565	.266	.638	.307	.948	.132
		N	38	38	38	38	38	38	38	37	37	37	37	37	37
	February	Correlation Coefficient	.271*	.076	1.000	-.007	.170	.130	.147	.187	.228*	.259*	.090	.146	.255*
		Sig. (2-tailed)	.017	.505	.	.950	.135	.252	.195	.105	.048	.024	.432	.204	.027
		N	38	38	38	38	38	38	38	37	37	37	37	37	37
	March	Correlation Coefficient	.148	.116	-.007	1.000	.287*	.073	.087	.115	.053	.259*	-.154	-.113	.089
		Sig. (2-tailed)	.191	.308	.950	.	.011	.521	.443	.320	.647	.024	.182	.326	.440
		N	38	38	38	38	38	38	38	37	37	37	37	37	37
	April	Correlation Coefficient	.279*	-.075	.170	.287*	1.000	.276*	.147	.127	.357**	.298**	.145	-.005	.074
		Sig. (2-tailed)	.014	.505	.135	.011	.	.015	.195	.272	.002	.010	.209	.969	.522
		N	38	38	38	38	38	38	38	37	37	37	37	37	37
	May	Correlation Coefficient	.380**	.041	.130	.073	.276*	1.000	.253*	.455**	.259*	.363**	.139	.017	.124
		Sig. (2-tailed)	.001	.715	.252	.521	.015	.	.026	.000	.025	.002	.228	.886	.283
		N	38	38	38	38	38	38	38	37	37	37	37	37	37
	June	Correlation Coefficient	.313**	-.067	.147	.087	.147	.253*	1.000	.208	.302**	.241*	.009	.140	.047
		Sig. (2-tailed)	.006	.555	.195	.443	.195	.026	.	.071	.009	.036	.937	.224	.685
		N	38	38	38	38	38	38	38	37	37	37	37	37	37
	July	Correlation Coefficient	.399**	-.066	.187	.115	.127	.455**	.208	1.000	.137	.390**	.215	.116	.062
		Sig. (2-tailed)	.001	.565	.105	.320	.272	.000	.071	.	.234	.001	.063	.314	.592
		N	37	37	37	37	37	37	37	37	37	37	37	37	37
	August	Correlation Coefficient	.382**	-.128	.228*	.053	.357**	.259*	.302**	.137	1.000	.375**	.032	.136	.087
		Sig. (2-tailed)	.001	.266	.048	.647	.002	.025	.009	.234	.	.001	.783	.239	.448

Photo 3.4: Display of results in SPSS

3.2 Analyzing Impact of Climate Variability

Based on the purpose, a research can be either exploratory or evaluation type or a combination of both. A study needs a systematic and logical methodology which reveals the entire process to achieve the ultimate goal and objective of the research in which various stages or steps of collecting data are explained and the analytical techniques are defined (Kothari, 1996).

Impact of climate variability is analyzed developing a Livelihood Vulnerability Index (LVI). This index is frequently used to identify and compare climate change-specific livelihood vulnerabilities (Hahn et al., 2009; Shah et al., 2013). The extent of the impact of climate change and variability on livelihood depends on the level of vulnerability of farmers and people of other occupations to these impacts (Etwire et al., 2013). Livelihood will become more vulnerable if climate variability impacts negatively. The index value ranges from 0 to 0.5, 0.5 being the highest vulnerability. The LVI is developed for the last two decades and compared.

Difference between the values will indicate whether vulnerability due to climate variability has increased in the present decade than the past. The LVI for analyzing the impact of climate variability on livelihood is developed following the participatory approaches and reviewing related literature. Participatory approaches are also used to assess the current adaptation practices and evaluate potential future adaptation strategies.

3.2.1 Data collection

Both qualitative and quantitative data are used in this study. Qualitative data basically consist of information on the study area and livelihood of its people. To collect such data, three field visits were made to the study area. The 1st visit was made in March 2016, the second visit was made in July 2016 and the third visit was made in April 2017. Quantitative data is collected from secondary sources for the analysis of trend and variability of climate parameters.

Data are collected for two purposes. One is to develop the LVI to assess the impact of climate variability on livelihood and evaluate possible adaptation strategies in response to that.

3.2.1.1 Primary Data Collection

Primary data are collected using some participatory tools, such as Transect Walk, Key Informant Interviews (KIIs) and Group Discussions (GDs), and a social investigation technique, called structured questionnaire survey.

During field visit, several transect walks were conducted to get an overview of the study area and its people. Transect walk enabled us to see the impacts of climate change and variability on the environment and livelihood of the people in person. Also, information on area and geographic condition, socio-economic condition of the people, climate, livelihood patter, etc. of the study area were acquired from transect walk.

Guidelines to conduct GDs were developed on the basis of objectives of the study. GDs were conducted to gather information about past and present conditions of livelihood and also for identifying the impacts of climate variability and ways of resolving existing problems.

GDs were done within the study area with farmers, fishermen, wives of farmers and fishermen, and people from other professions. Structured checklist was formulated to collect data necessary for the development of LVI.

During GD, participatory tools were used for documenting local knowledge, technology and practices related to coping and adaptation strategies. Gender, age, social position and income of respondents were considered during the process because socio-demographic profile of the people of this study area is needed for the formation of LVI. Collected data were validated through key informant interviews. Some probable simple adaptation options were presented to the community for their opinions in the light of their knowledge and experiences. The probable adaptations were selected based on the experiences of some farmers of southwestern part of Bangladesh, and observing some innovative examples established by a few innovative farmers which may be further improved. Some of the probable options were common for the villages and some were location specific.

KII is an important method for collecting information on the overall aspects of the study based on observation and experience of the local people and officials. KIIs were conducted to gather both qualitative and quantitative information on their livings and how their livelihood has changed due to climate change and variability over time. A list of interviews conducted is shown in Table 3.1 and a view of Key informant interview with Senior Agriculture Officer of Dacope Upazila is shown in Photo 3.5

Table 3.1: List of interviews with the key informants

<table>
<tr><th>Date</th><th>Location</th><th>Respondent</th></tr>
<tr><td rowspan="3">March 2016</td><td rowspan="3">Tea stall, Pankhali village, Dacope Upazila, Khulna</td><td>Sluice Gate Operator</td></tr>
<tr><td>School Teacher</td></tr>
<tr><td>Community Leader</td></tr>
<tr><td rowspan="4">July 2016</td><td rowspan="4">Ashroy Foundation Office</td><td>Manager, Ashroy Foundation</td></tr>
<tr><td>Community Leader</td></tr>
<tr><td>Farmer</td></tr>
<tr><td>Land Owner</td></tr>
</table>

April 2017	BWDB Office, Khulna	Assistant Engineer, BWDB
	Agriculture Extension Office, Dacope Upazila	Senior Agriculture Officer
	Agriculture Extension Office, Dacope Upazila	Deputy Director
	Paankhali, Dacope Upazila	Local Farmer Community Leader

Photo 3.5: View of a Key informant interview with Senior Agriculture Officer of Dacope Upazila

In this study, a survey was conducted in the study area for the collection of necessary information. Sample households included poor farmers, medium farmers, rich farmers, fishermen, local businessmen and women. To develop the LVI, a structured questionnaire survey was prepared to collect information from local people. People were asked questions needed to construct the sub-components which eventually compose the major component. For example: to calculate the value of dependency ratio of socio-demographic profile, the question asked was: 'How many people of age under 15 and over 65 years are living in your house? How many of such people lived with you in the past decades?' the survey result was then converted into an index value using Eq (1). The procedure is discussed in section 3.2.4 and the survey questions are provided in Table 3.4.

3.2.1.2 Secondary Data collection

Related publications (books, journals, researches, reports, etc.) are studied for collection of relevant secondary data. Beyond this, secondary data are collected from different government sources like Department of Agriculture Extension office and Bangladesh Water Development Board (BWDB) office of Khulna. Climate data on rainfall and temperature at Khulna for a period of 1978-2017 are collected from Bangladesh Meteorological Department (BMD). Both statistical and historical secondary data are collected from the UNO office and Dacope Agriculture Office about the historical and present practices in the area. Then using the information, notable historical events and their associated dates are analyzed for evaluation of changes in traditional agricultural activities and associated factors.

3.2.2 Timeline Analysis of Polder 31 livelihood

To determine the changes in livelihood due to climate variability and factors behind those changes, essential information was gathered from several visits to different wards of Polder 31, as a ward is considered as the lowest administrative unit. The PRA tools were used in a manner so that representative data can be collected from the whole area for further analysis. During the transect walk in the study area, the present resources and their uses were observed. There were fallow lands, agricultural lands with existing dry season crops, on-farm reservoirs, shrimp farms, and small and medium canals which have been observed during the transact walk along the polder boundary.

Also, there were some establishments including village markets and local gathering places, community shelters, governmental and non-governmental organizations. A timeline is an expression of aggregation of landmark events in an area depending on the perception of the community. It provides the evidence of critical events in a chronological order. It involves the analysis of notable historical events, changes in natural, socio-economic and environmental aspects along with community responses to those occasions (Callens et al., 1999). The purpose of this tool is to learn about important events in the community's past, identify their trends, understand the impacts of these events from community perspective and define the transformation in their lives and livelihoods (SEPP, 2007). The process of analyzing information using timeline analysis is provided in the following (SEPP, 2007):

- Selection of community people from different livelihood groups and variable social statuses to perform the exercise and initiation of the discussion;
- Letting the community people address their present situation, current livelihood practices, challenges and opportunities in the area, etc.
- Asking the community about earlier events in history and associated activities
- Enquiring about the key events and the years of occurrences which played crucial roles in perception alteration of the local community
- Adding dates and time to the events in chronological order and confirming them with the local knowledge
- Facilitation of discussion among the community people about the impacts of any event in their lives to gather all relevant information for future analysis and decision making

Though there are some limitations of the timeline analysis tool, as sometimes people lose focus from the actual facts and start discussion in an indiscreet manner. Also, if the participants cannot recall the past events and reasoning, then the analysis remains incomplete. Despite that, the tool is advantageous for analyzing facts from socio-economic perspective as it involves community participation and it prioritizes the contribution of the local people. Also, to understand the trend of the livelihood practices in an area this tool is suitable.

For the specific analysis of this study, super cyclone Aila of 2009 was taken as the benchmark as local people considered it as a critical event. This was also the event that triggered a major shift in the lives of the local people and in their livelihood practices. Information about the present and historical livelihood practices, existing cropping pattern and crop agricultural activities, types of agricultural crops, notable natural and anthropogenic events, changes in their perception and associated factors, profitability and willingness behind the practices and sustainability of the present livelihood practices were collected from the local people of the study area.

3.2.3 Livelihood Vulnerability Index development

The Livelihood Vulnerability Index (LVI) was constructed to estimate the differential impacts of climate change in two consecutive decades in the study area. The LVI includes six major components: Socio-Demographic Profile, Livelihood Strategies, Health, Food, Water, and Natural Disasters and Climate Variability. Each is comprised of several indicators or sub-components. These were developed based on a review of the literature on each major component. Table 3.4 includes an explanation of how each sub-component was quantified, the survey question used to collect the data, the original source of the survey question, and potential sources of bias.

The LVI uses a balanced weighted average approach (Sullivan et al., 2002, Hahn et al., 2009) where each sub-component contributes equally to the overall index even though each major component is comprised of a different number of sub-components. Because we intended to develop an assessment tool accessible to a diverse set of users in resource-poor settings, the LVI formula uses the simple approach of applying equal weights to all major components. This weighting scheme could be adjusted by future users as needed.

Because each of the sub-components is measured on a different scale, it was first necessary to standardize each as an index.

$$\text{Index} = \frac{S_{(t)} - S_{min}}{S_{max} - S_{min}} \qquad \text{Eq (1)}$$

Where S(t) is the original sub-component for a decade, and Smin and Smax are the minimum and maximum values, respectively, for each sub-component determined using data from both decades.

For variables that measure frequencies such as the 'percent of households reporting having heard about conflicts over water resources in their community,' the minimum value was set at 0 and the maximum at 100. Some sub-components such as the 'average agricultural livelihood diversity index' were created because an increase in the crude indicator, in this case, the number of livelihood activities undertaken by a household, was assumed to decrease vulnerability. In other words, we assumed that a household who farms and raises animals is less vulnerable than a household who only farms. By taking the inverse of the crude indicator, we created a number that assigns higher values to households with a lower number of livelihood activities. The maximum and minimum values were also transformed following this logic and Eq (1) was used to standardize these sub-components.

After each sub-component was standardized, the sub-components were averaged using Eq (2) to calculate the value of each major component:

$$M = \frac{\sum index}{n} \qquad \text{Eq (2)}$$

M = One of the five major components for a decade
n = The number of sub-components in each major component.

Once the values of the six major components for a decade were calculated, they were averaged using Eq. (3) to obtain the LVI:

$$LVI\ (t) = \frac{W(SDP)*SDP+W(LS)*LS+W*(H)+W(F)*F+W(w)*w+W(NDCV)*NDCV}{W(SDP)+W(LS)+W(H)+W(F)+W(w)+W(NDCV)} \qquad \text{Eq (3)}$$

Where LVI (t), the Livelihood Vulnerability Index for decade (t), equals the weighted average of the six major components. W represents the sub-components that make up each major component. Socio-Demographic Profile, Livelihood Strategies, Health, Food, Water and Natural Disasters and Climate Variability are denoted by SDP, LS, H, F, W and NDCV, respectively. The weight of each major component is determined by the number of sub-components that make up each major component. In this study, the LVI is scaled from 0 (least vulnerable) to 0.5 (most vulnerable).

The LVI is designed to provide development organizations, policy makers, and public health practitioners with a practical tool to understand demographic, social, and health factors contributing to climate vulnerability at the district or community level. It is designed to be flexible so that development planners can refine and focus their analyses to suit the needs of each geographic area.

Table 3.2: Major components and sub-components comprising the Livelihood Vulnerability Index (LVI)

Major components	Sub-components	Explanation of sub-components	Survey question	Source of question
Socio Demographic profile	Dependency ratio	Ratio of the population under 15 and over 65 years of age to the population between 19 and 64 years of age.	Could you please list the ages and sexes of every person who eats and sleeps in this house? If you had a visitor who ate and slept here for the last 3 days, please include them as well.	Adapted from Domestic Household Survey (DHS) (2006). Measure DHS: Model Questionnaire with Commentary
	Percent of households where head of household has not attended school	Percentage of households where the head of the household reports that they have attended 0 years of school.	Did you ever go to school?	Adapted from DHS (2006)
Livelihood Strategies	Percent of households with family member working in a different community	Percentage of households that report at least 1 family member who works outside of the community for their primary work activity.	How many people in your family go to a different community to work?	Adapted from World Bank (1997). Household Questionnaire: Survey of Living Conditions, Uttar Pradesh and Bihar
	Percent of households dependent solely on agriculture as a source of income	Percentage of households that report only agriculture as a source of income.	Do you or someone else in your household raise animals? Do you or someone else in your household grow crops? Do you or someone else in your household collect something from the forest or lakes and rivers to sell?	Adapted from World Bank (1997)

	Average Agricultural Livelihood Diversification Index (range: 0.20–1)	The inverse of (the number of agricultural livelihood activities +1) reported by a household, e.g., A household that farms, raises animals, and collects natural resources will have a Livelihood Diversification Index = 1/(3 + 1) = 0.25.	Same as above	Adapted from DHS (2006)
Health	Percent of households with family member who are chronically ill	Percentage of households that report at least 1 family member with chronic illness.	Is anybody in your family chronically ill (they get sick very often)?	Adapted from DHS (2006)
	Percent of households where a family member had to miss work or school in the last 2 weeks due to illness	Percentage of households that report at least 1 family member who had to miss school of work due to illness in the last 2 weeks.	Has anyone in your family been so sick in the past 2 weeks that they had to miss work or school?	Adapted from World Health Organization/Roll Back Malaria (2003).
Food	Percent of households dependent on family farm for food	Percentage of households that get their food primarily from their personal farms.	Where does your family get most of its food?	Developed for the purposes of this questionnaire.
	Average number of months households struggle to find food (range: 0–12)	Percentage of households that get their food primarily from their personal farms.	Does your family have adequate food the whole year, or are there times during the year that your family does not have enough food? How many months a year does your family have trouble getting enough food?	Adapted from World Bank (1997)
	Average crop diversity index (range: >0–1)	The inverse of (the number of crops grown by a household +1).	What kind of crops does your household grow?	Adapted from World Bank (1997)

	Percent of households that do not save crops	Percentage of households that do not save crops from each harvest.	Does your family save some of the crops you harvest to eat during a different time of year?	Developed for the purposes of this questionnaire
	Percent of households that do not save seeds	Percentage of households that do not have seeds from year to year.	Does your family save seeds to grow the next year?	Developed for the purposes of this questionnaire
Water	Percent of households reporting water conflicts	Percentage of households that report suffering from or having heard about conflicts over water in their community.	In the past year, have you heard about any conflicts over water in your community?	Adapted from DHS (2006)
	Percent of households that utilize a natural water source	Percentage of households that report a tube well, well, river or pond as their primary water source.	Where do you collect your water from?	Adapted from DHS (2006)
	Percent of households that do not have a consistent water supply	Percentage of households that report that water is not available at their primary water source or delivered to them everyday	Is this water available every day?	Adapted from World Bank (1997)
Natural Disaster and Climate Variability	Average number of flood, drought and cyclone events in the past 20 years	Total number of floods, droughts, and cyclones that were reported by households in the past 20 years.	How many times has this area been affected by a flood/cyclone/drought in 1998–2017?	Adapted from Williamsburg Emergency Mngmnt (2004).
	Percent of households that did not receive a warning about the pending natural disaster	Percentage of households that did not receive a warning about the most severe flood, drought, and cyclone event in the past 20 years.	Did you receive a warning about the Flood /cyclone/drought before it happened?	Adapted from Williamsburg Emergency Mngmnt (2004).

	Mean monthly standard deviation of daily maximum temperature	BMD data	Standard deviation of the average daily maximum temperature by month between 1998 and 2017 was averaged for each decade	Instituto Nacional de Estatistica (2007)
	Mean monthly standard deviation of daily minimum temperature	BMD data	Standard deviation of the average daily minimum temperature by month between 1998 and 2017 was averaged for each decade	Instituto Nacional de Estatistica (2007)
	Mean monthly standard deviation of daily rainfall	BMD data	Standard deviation of the average monthly precipitation between 1998 and 2017 was averaged for each decade	Instituto Nacional de Estatistica (2007)

Chapter 4

Study Area

4.1 Introduction

Dacope upazila of Khulna district was selected as the study area. Khulna district is one of the 19 coastal districts of Bangladesh which is situated in the southwestern coastal region. The district consists of nine upazilas and Dacope is one of them which faces the common natural disasters of coastal Bangladesh such as cyclone, salinity intrusion, river erosion, water logging, seasonal flood, etc. It is the second largest upazila of Khulna district in respect of area. Dacope Upazila consists of three different polders namely polders 31, 32 and 33. Among them, Polder 31 was selected for the study. There are two unions and one pourashava in Polder 31 which are: Pankhali union, Tildanga union and Chalna pourashava. Polder 31 of Dacope Upazila was selected as the study area because negative impacts of climate variability and change are more visible here than the other two polders of the upazila. Also, adaptation measures practiced in this union are very effective and can be introduced to other parts of the coastal region. That's why Pankhali is taken as the representative of Dacope Upazila.

4.2 Geographical Area and Location

The total area of Polder 31 is about 67 km^2. Pankhali union covers an area of about 22 km^2, Tildanga union has an area of about 45 km^2 and the area of Chalna pourashava is about 23 km^2.

Dacope upazila is situated at the southeastern side of Khulna district at 22.5722° N latitude and 89.5111° E longitude. The upazila is bounded by Rampal and Mongla upazilas of Bagherhat district on the east, Paikgacha and Koyra upazilas of Khulna on the west, Batiaghata upazila on the north and Pashur river on the south (Figure 4.1). The Sundarbans is situated at the southern part of the upazila. Dacope upazila falls under Agro-ecological zone (AEZ) 13 which is the Ganges River Floodplain. Most of the lands of the area are medium highland having inundation depth of 0.30-0.90 m. In some parts of the area, there is medium low to low land which is affected by inundation during the monsoon more than the medium high land areas.

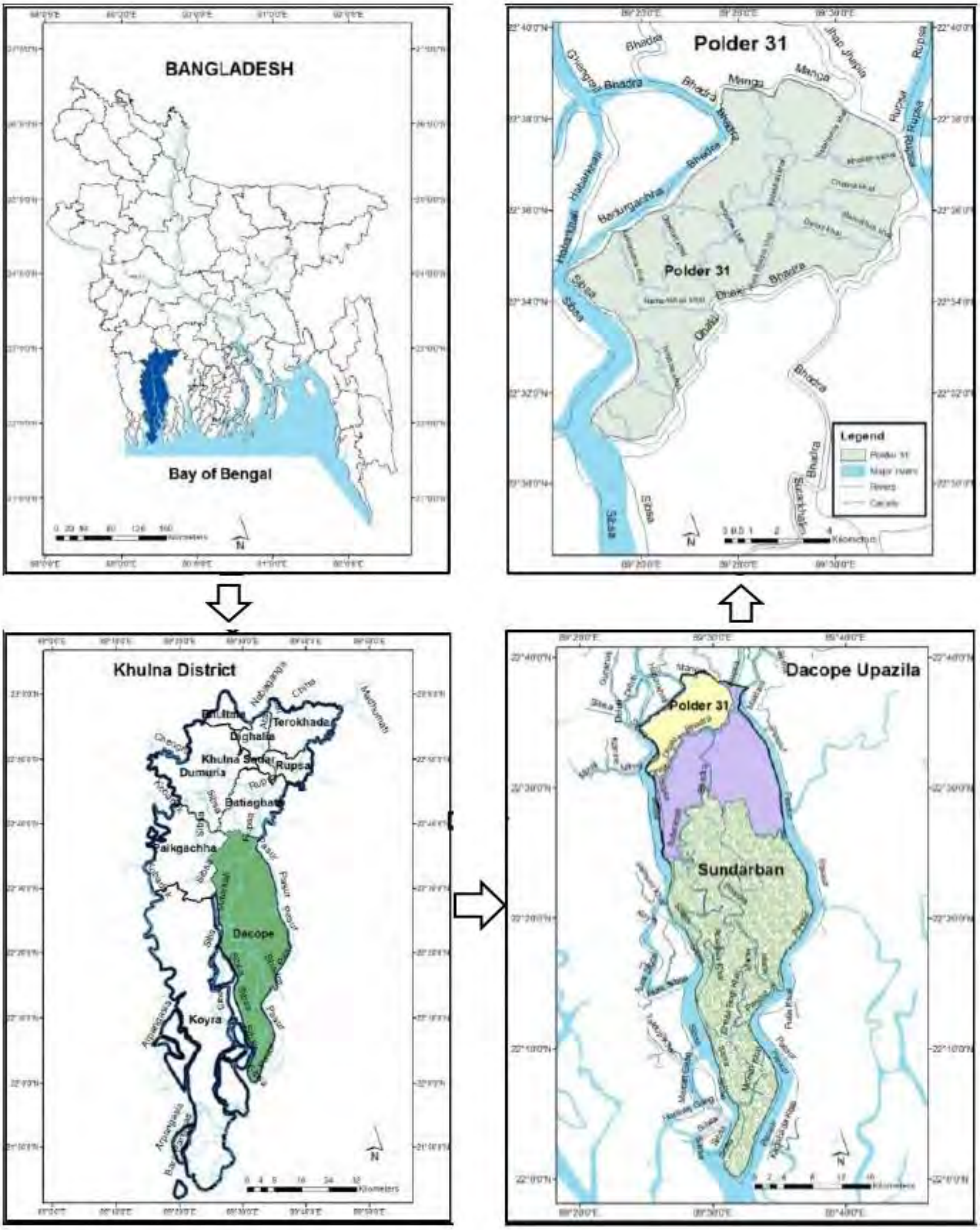


Figure 4.1: Location maps of the study area

4.3 Physical Environment

4.3.1 Major river systems

The total study area is enclosed by a number of medium and small rivers (Figure 4.2). The Sibsa river lies to the west of the area and the Bhadra river lies to the east coming as a tributary from the Rupsa river in the upstream which meets the Sibsa river at the downstream. The Bhadra river also flows through the middle of the polder with different local names. Some small rivers namely, the Manga, the Jhapjhapia lie to the north, while the Dhaki river lies to the south marking the boundary between polders 31 and 32. Pankhali union of Polder 31 is mainly surrounded by the Bhadra river while Tildanga union is at the banks of the Dhaki and Sibsa rivers. Apart from these rivers, there are a number of large and medium canals inside the polder area some of which are used for rainwater storage during the monsoon season and also for fish culture. Among these canals, Batbunia khal, Deloti khal, Mora Bhadra khal, Garkhali khal, Moukhali Doani khal, Chalna khal, etc., are the major ones in the entire polder (Figure 4.2).

4.3.2 Soil condition

As a part of the Ganges Tidal Floodplain (AEZ-13), the soil of Polder 31 is generally formed from loam and clay sediments. In Pankhali union and Chalna pourashava, clay loam and silty clay loam are the dominant soil textures while in Tildanga union, silty clay textured soil is present in some parts. Soil is almost neutral in the area as pH level varies generally from 5.5-8.0. Soil pH is 5.5-7.0 in Pankhali union, 5.5-7.5 in Tildanga union and 6.0-8.0 in Chalna pourashava (SRDI, 2012).

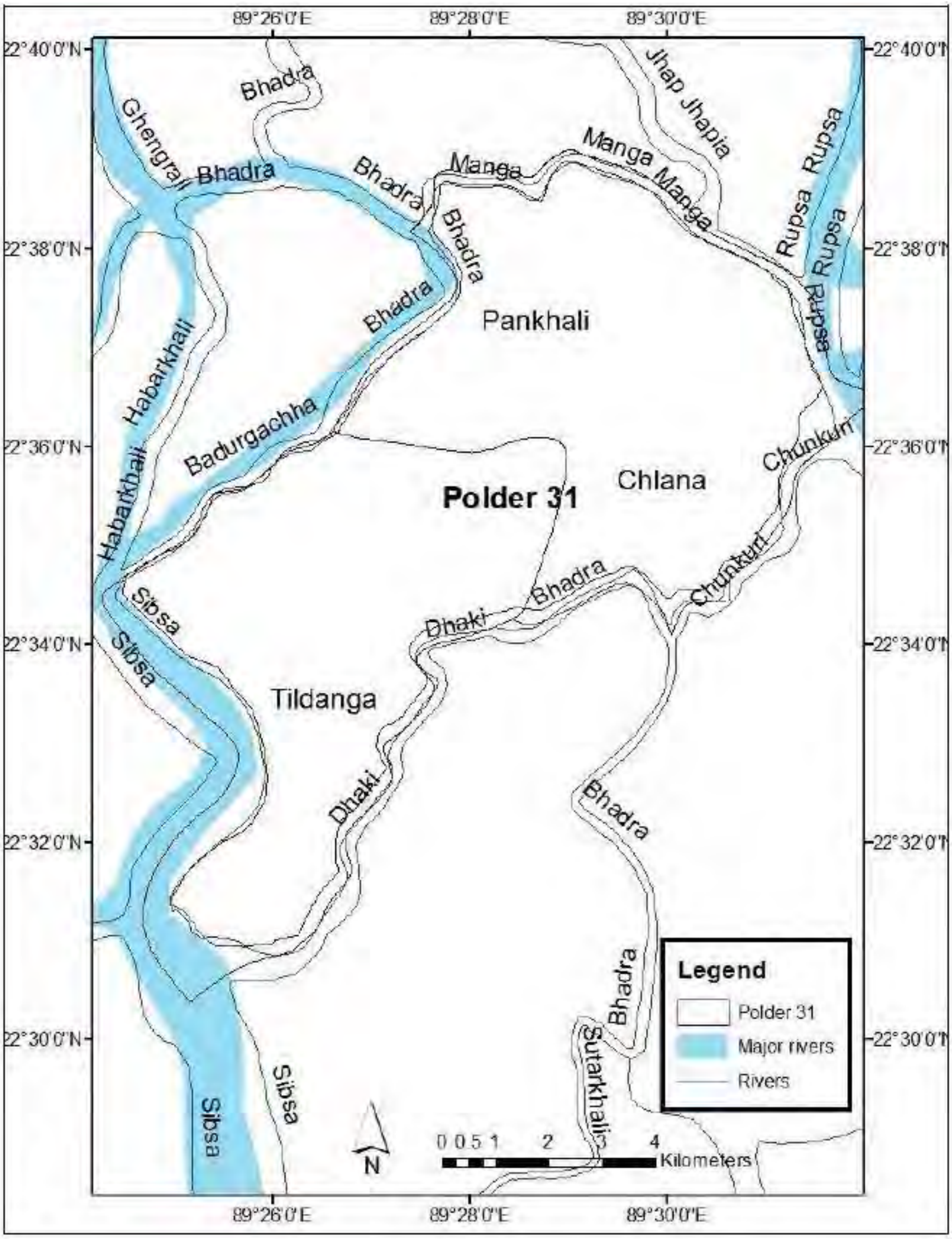


Figure 4.2: Major river system in the area

4.3.3 Water and soil salinity

High soil and water salinity is an evident feature of the area. Due to prolonged saline water shrimp farming, salinity has been very high since long. Also, the salinity front is moving further inward day by day thus making the soil and water salinity a serious threat to the agricultural activities and environmental balance of Polder 31. During the dry season, both soil and water salinity reaches to the highest limit in the months of April and May. Soil salinity of Pankhali union is lower than that of Tildanga union and Chalna pourashava. The soil contains very low to medium salinity during the dry season which ranges from 2.5-8.0 dS/m. While in Chalna pourashava and Tildanga union, soil salinity is medium to high ranging from 8-22 dS/m in both the places (SRDI, 2012). Surface water remains non-saline during six months of the year and during the other six months water becomes saline. At the start of the monsoon season in June, water becomes fresh and remains so until November, when salinity starts to build up. Compared to Pankhali union and Chalna pourashava, water salinity is higher in Tildanga union due to the prolonged practice of saline water shrimp farming. Salinity may go up to 30 dS/m in some places of Tildanga union while in Pankhali union and Chalna pourashava water salinity range is 6-18 dS/m. Groundwater salinity is also high during the dry season in the study area ranging from 8 to 12 dS/m. Groundwater table remains within 1.6-1.7 m during the monsoon and 1.40-1.45 m during the dry season (SRDI, 2012).

4.4 Natural Disasters

Natural disaster is a common phenomenon in the area. For a long time, the inhabitants of the area have been affected by various natural disasters like cyclones and associated storm surges, water logging, salinity intrusion, etc. Vulnerability of the local people is increasing with time to these disasters. This hampers them not only by damaging their life and property, but also by causing long term sufferings due to adverse environmental conditions. Moreover, due to increasing pressure of high population density, natural resources like lands, fishing ponds, forests, etc., are not being properly managed and maintained. Most of the people of the study area are under poverty line because of the effects of hazards like cyclonic storm surge, waterlogging, etc. As people mostly depend on agriculture or fishery to earn their living, both short and long term inundation and associated salinity problem have been the cause of unemployment for them. The situation has been aggravated by super cyclone Aila in 2009, when polder damage to various points has caused short term inundation in the area and significant increase in both soil and water salinity. This has hampered the lives of the local people degrading their living standard.

4.5 Land Use and Livelihood

4.5.1 Land use pattern

The land area of Polder 31 is mostly used for crop agriculture, fisheries, integrated rice-fish culture or mixed culture, shrimp culture, crab culture, housing and settlements with homestead gardens. Also, there are some fish processing industries, small poultry farms, salt research facility, desalinization plant and some infrastructural developments in the area. Percentages of land use in the study area are described in Table 4.1.

Table 4.1: Present land use of the study area

	Percentages of land use			
Name of the Union/Pourashava	**Agricultural land**	**Settlement**	**Water body**	**Fishery (shrimp and white fish)**
Pankhali	69	13	12	6
Tildanga	58	13	23	6
Chalna	73	9	11	7

These diversified uses of land are the sources of income of the local people which give them financial benefits as well as create several conflicts among the users. Shrimp farmers deliberately damage the polder to intrude saline water for saline water shrimp culture which increases the weakness of the polder and chances of breaching during natural disasters like cyclones and associated storm surges. This makes the area more vulnerable to people's lives and livelihoods. Moreover, saline water shrimp farming has caused degradation of soil quality for quite a long time which hampers the crop production during the dry season and the monsoon season, thus affecting the farmers' economic condition. Another alarming issue is the changing land use due to increasing population. Unplanned construction of houses and settlements, markets and infrastructures are causing decrease in valuable agricultural lands thus reducing chances of food production and income generation for the residents of the area. However, the condition is improving recently as most of the people are now shifting to sustainable utilization of land by promoting agricultural activities during the dry season instead of saline water shrimp farming. This has brought back the environmental stability and is showing the pathway to attain food security in the long run.

4.5.2 Agriculture

Agriculture is the mainstay of the people of Bangladesh and also in Polder 31. The cropping activities of the area are mainly rice based and cropping pattern is aman-fallow-fallow or aman-boro-fallow. Agricultural crop calendar of the study area is presented in Table 4.3. Average cropping intensity of Dacope Upazila is 120% and in Polder 31 it is 110% (MoL, 2011). Most of the people related to agriculture are share croppers or farmers (marginal, small, medium, large and landless). Major crops cultivated in the area during the dry season are boro rice, wheat, maize, potato, different spices like green chili, coriander, etc., oilseeds like sunflower, sesame, mustard, etc., some pulses like lentil, mung bean, chickpea, etc., fruit crops like watermelon, coconut, mango, banana, guava, papaya, etc., and different types of vegetables in homestead gardens and agricultural lands. Boro rice is the main surface water irrigated crop. It is transplanted in the field during mid-December and harvested during mid to end of April. Rice cultivation requires much irrigation water which is scarce in the area due to adverse salinity condition and this has restricted dry season agricultural activity for a long time. According to the information given in Table 4.3, the area under irrigation is very low in the study area and it is lower in Tildanga union and Chalna pourashava than in Pankhali union. Tildanga union has been under shrimp cultivation practice for a long period which has increased the soil and water salinity up to a damaging extent. Some information about cropping types, cropping area and intensity are provided in Tables 4.2 and 4.3.

Table 4.2: Agricultural crop calendar of the study area

Season	**Month**	**Previous crop**	**Season crop**
Kharif-1 (pre-monsoon)	Mid April- July	Fallow	Fallow
Kharif-2 (Monsoon)	Mid July-Mid November	Aman rice	Aman rice
Rabi/dry season	Mid December-Mid May	Fallow (Small scale homestead vegetable)	Boro rice, oilseeds, pulses, fruits, vegetables, etc.

Table 4.3: Agricultural features of the study area

Name of the Union/Pourashava	**Net cultivable area (%)**	**Net cultivable area (km^2)**	**Cropping intensity (%)**	**Area under irrigation (%)**
Pankhali	67	14.75	107	18
Tildanga	75	33.70	108	6
Chalna	58	5.50	110	5

Source: MoL, 2011

Recently, people of the area have shown interest in rice-based agriculture during the dry season to improve their socio-economic condition. High value cash crops like sunflower are also being promoted in the area by NGOs like BRAC, which can assist in reducing poverty and ensuring economic growth.

4.5.3 Fishery

Previous and present fisheries calendar of the study area is presented in Table 4.4 and information of wetlands and fish cultivation in the study area is provided in Table 4.5. Fisheries sector is the second most dominant in the study area. A large number of people, who are mostly farmers, are also engaged in the monsoon season and dry season fish farming in their agricultural lands and ponds. The fisheries sector consists of inland open water fisheries and fresh water aquaculture. The wetlands have very fertile and productive ecosystem that support the life cycle of fauna and flora resources of the area. In Table 4.5, percentage of wetlands includes water bodies in addition to certain amount of aman rice fields where white fish culture is practiced during the monsoon season. Local people fulfill their nutritional demand with the fish available in the rivers and canals as well as gather economic benefit. Besides, aquaculture is another source of income for the local people which comprises homestead pond fish culture (white fish like rui, katla, khorsola, baisa, baila, etc.) and shrimp culture. Boro rice farmers use the standing irrigation water of their agricultural lands or irrigation water storage areas (ponds and nearby canals in the field) for white fish culture. At present, except some parts of Tildanga union, fish farmers have stopped saline water shrimp farming during the dry season.

Table 4.4: Fisheries calendar of the study area

Season	**Month**	**Previous practice**	**Present practice**
Kharif-2 (Monsoon)	Mid July-Mid November	White fish and prawn cultivation	White fish and prawn cultivation
Rabi/dry season	Mid December-Mid May	Large scale shrimp cultivation	Small scale shrimp/White fish cultivation

Source: Upazila Fisheries Office, Dacope, Khulna

Table 4.5: Fisheries resources of the study area

Name of the Union/ Pourashava	% of Total Wetland	% of Total Capture	% of Pond Culture	% of Fish Culture	% of Shrimp Hatchery	% of Shrimp Culture
Pankhali	61	38.83	4.58	0.75	0	16.84
Tildanga	68.83	12.63	0.85	0.11	0	55.25
Chalna	35.21	22.68	0.82	0	0.11	11.60

Source: MoL, 2011

4.6 Livelihood Pattern

The main livelihood options in Polder 31 are agriculture, fishery, farming, day labor, small and medium business, etc. Crop agriculture and fishery are dominant occupations as 67.9% people in Pankhali union, 88.4% in Tildanga union and 38.7% in Chalna pourashava are engaged in agricultural activities (BBS, 2011). Agriculture includes crop cultivation in own agricultural land or selling of agricultural labor by working in other owner's land, fish culture and shrimp farming. People in the study area are capturing fish from the nearby rivers or are involved in shrimp culture (both fresh water and saline water) along with some white fish culture in individual ponds and nearby canals. Some people are engaged in livestock rearing in front of their houses. People, who are not associated with the aforementioned livelihood activities, are engaged in small or medium businesses either in the area or outside of the polder. Some people also work as day laborer in earth cutting, road and embankment construction and rehabilitation works while some usually go to other villages or nearby districts for income generation.

Chapter 5

Livelihood Timelines and Climatic Trend and Variability in Coastal Area

Timeline analysis is an essential part of this study as it provides overall information on the livelihood of the people of the study area which eventually helps us in better understanding of the impacts of climate variability and livelihood adaptation strategies in response to the variability. In this study, PRA tools are used to collect qualitative data to prepare the timeline of Polder 31 livelihood. In addition to that, some statistical approaches (linear regression model, CV, PCI and Z) are used to detect the trend and variability in the climatic parameters (temperature and rainfall). The findings from the timeline analysis are discussed in the first section and the results of temperature and rainfall trend and variability analyses are shown in the second section of this chapter.

5.1 Timeline of Polder 31 Livelihood

To determine the changes in livelihood due to climate variability and factors behind those changes, essential information was gathered from several visits to different wards of Polder 31, as a ward is considered as the lowest administrative unit. The PRA tools were used in a manner so that representative data can be collected from the whole area for further analysis. During the transect walk in the study area, the present resources and their uses were observed. There were fallow lands, agricultural lands with existing dry season crops, on-farm reservoirs, shrimp farms, and small and medium canals in the polder, which have been observed during the transact walk along the polder boundary. Also, there were some establishments including village markets and local gathering places, community shelters, governmental and non-governmental organizations' offices where most of the GDs and KIIs took place. Discussions with the local farmers and fishermen were arranged nearby the agricultural lands or in the local village markets.

Though there were several discussions for the timeline analysis, the impacts of climate variability on various aspects of livelihood were almost identical for every household of all the wards. So, the timeline was prepared from the joint analysis of the reported events and discussions with the local people. All the information gathered from primary and secondary sources was arranged in a chronological order in the timeline spanning for the last 42 years. Such time span was considered to be adequate as the key events that have changed the overall situation and livelihood practices in Polder 31 started since then. Figure 5.1 represents the critical events in Polder 31 along with their years of occurrences.

1972	Construction of local polder (Polder 31)
1982	Introduction of shrimp cultivation in Polder 31
1992	Switching from crop agriculture to shrimp cultivation during the dry season
1998-1999	Migration to other areas due to less crop production
2007	Super cyclone Sidr
2008	Abandonment of shrimp cultivation during the dry season
2009	Super cyclone Aila
2010-2011	Returning of migrated people
2012	Cultivation of cash crops along with small scale boro rice
2013-2014	Decrease in soil and water salinity and increase in dry season crop production

Figure 5.1: Timeline of critical historical events in the study area

From the above figure, the major events in Polder 31 can be found. It can be seen that, the changes in conventional livelihood practices have occurred due to construction of the polder in 1972. After that intervention, almost 40 years have passed and many changes in the perception and practice of the local communities have occurred in the area. These changes were triggered by a number of factors and also by some natural and anthropogenic events. The critical events with their years of occurrences, the situation and factors behind the events and associated changes in the lives of the local people are described below:

1972: Construction of Polder 31

A good number of embankments were constructed in the southwest coastal region as well as in the other parts of the country during the 1960s. In the specific study area, Polder 31 was constructed in 1972 to protect the lowland areas from tidal flooding and salinity intrusion, so that agricultural activities can be enhanced. The polder is 16.28 km in length and covers 6072 ha of area. Before the construction of Polder 31, there was only one seasonal crop which was *aman* rice during the monsoon season. Thus, the cropping pattern during that time was *aman* rice-fallow-fallow. Average aman rice yield of the country was about 2.75 t/ha (BBS, 2010) and the yield in Polder 31 was even lower than this value, where farmers experienced complete or almost complete crop failures due to saline water inundation. Damages of crops were also reported due to heavier silts carried with the flood water during the monsoon season. Only some vegetables were cultivated in the homestead gardens during the dry season at the higher lands, but there were no crops in comparatively lower areas. Agricultural activities were expected to increase in the area due to the protection from the polder after its construction. To fulfill this purpose, the master project of polder construction was launched in early 1970s in this area.

1982: Introduction of shrimp cultivation in Polder 31

Shrimp farming was introduced in Polder 31 as an outcome of extensive promotional activities of shrimp cultivation by different development agencies to reduce poverty, create employment, and generate revenues in Bangladesh. The idea was disseminated by local government agencies, and some people from the beneficiary part of the locality started shrimp cultivation. Within a few years, a lot of people of Polder 31 got interested about it as it generated relatively higher profit. Shrimp culture became very much attractive by 1985 and during early 1990s most people switched to shrimp farming eventually.

1992: Switching from crop agriculture to shrimp farming

Almost 10 years after the introduction of shrimp cultivation in Polder 31, local people of the area completely switched to shrimp farming practice. Due to frequent natural disasters like cyclonic storm surges and flooding, agricultural production was not satisfactory. Though after construction of Polder 31, aman rice yield was higher than that of before the polder, but farmers were still not satisfied with their economic condition. Again some farmers who tried to produce dry season crops failed in their attempts. To mitigate this loss, some local rice farmers started saline water shrimp farming during the dry season taking the advantages of the enclosure provided by the polder as mentioned earlier. Being inspired from the shrimp farmers of other polders and to avail the high profit in shrimp business, some socially privileged people made this practice as their major livelihood. This choice of livelihood provided them with significant income generation and increased their standard of living. Thus, there was a sudden switch from crop cultivation to shrimp farming to gain easy profit. Also, shrimp cultivation required lower labor activities than rice cultivation and generated more profit, which was another controlling factor for this change in local agricultural practice.

The area was enclosed by the polder and there was no way of saline water intrusion from the rivers during the dry season except opening of the sluice gates. These gates were operated by the local community people and were closed at the beginning of the dry season. So, to allow saline water inside the polder for the convenience of shrimp farming, some people inserted pipes through the polder after creating holes in them. This made the polder vulnerable to natural disasters. Though it caused infrastructural and environmental damages, but high profit margin from shrimp cultivation and social stratification in the area have constrained the practice in the grasps of some elite classes of the society.

1998-1999: Migration to other areas

Despite the high profit and improved living standard of some local farmers from shrimp practice, the damaging aspect of this livelihood brought misery to other non-shrimp practicing farmers. Due to shrimp farming, the salinity of water and soil had risen up to an extent which affected the aman rice production during the monsoon. Before shrimp cultivation, local farmers used to get 4.5-4.8 t/ha yield from aman rice. But after shrimp cultivation became the dominant practice in the area, rice farmers in the polder started to get lower aman rice yield which even reached to 1.5-1.8 t/ha. This decrease in rice yield occurred as shrimp farming required saline water in an area for the shrimp growth period. The salinity in the water was concentrated and infiltrated to the soil thus increasing soil salinity. This had reduced the soil fertility which ultimately resulted in lower aman rice yield. Also, dry season shrimp farming caused late transplantation of aman rice seedlings which caused significant reduction of aman yield. The rice farmers who were not ready to switch to shrimp farming from crop production, migrated to other nearby districts like Jassore, Narail and other upazilas in Khulna in search of labor works like earth cutting, wage laboring in other farmers' lands, small business purposes, etc. These people had to earn money from different livelihood practices to bear the cost of their families living in Polder 31. While the male members have migrated to other places, the female members of the families used to rear some livestock and grow some vegetables in homestead gardens to earn some money for living. In some cases, full families have migrated to other places due to lack of job opportunities and livelihood options.

2007: Cyclone Sidr

Cyclone Sidr was a tropical cyclone that struck the coastal area of Bangladesh on 15 November, 2007. It was classified as a 'Category-5' cyclone as it heavily affected the Sundarbans and caused damages in Patuakhali, Barguna and Jhalokathi districts, but its impact in Polder 31 was not much significant. Surge water entered inside the polder in a few places, but it drained out very soon. There was severe damage in Polder 32 which is to the south of Polder 31. Because of this geographical location, the impact of the cyclone was comparatively less in the study area. But this natural disaster made the people concerned about the salinity problem in the area.

2008: Abandonment of saline water shrimp cultivation

Prolonged salinity problem have resided in the area due to both natural and anthropogenic causes. The environmental condition had degraded down to a significant level and soil became so saline that it was crusty and could not hold the plinth of the houses. No homestead vegetables or fruit trees could be grown in the area due to high salinity, and livestock also suffered from lack of food. Also, canals and rivers had silted up due to sedimentation of silt, which restricted the storage of the monsoon water. These facts made the shrimp farmers rethink about their livelihood practice. They realized that shrimp farming was bringing them enough profit for the time being, but it was leaving a permanent footprint on the sustainability of agriculture and environmental condition. So, most of the shrimp farmers abandoned shrimp farming practice to avoid further environmental degradation and reduction of aman crop yield. Another reason for abandoning this practice was the death of shrimp fries and associated losses. Due to high salinity, certain virus used to attack the shrimp fries and caused death of most of them in a shrimp gher. Due to this, shrimp farmers faced heavy losses and their interest from shrimp cultivation was diverted. Almost all the shrimp farmers stopped dry season shrimp farming and started to keep the lands fallow so that salinity could leach out and the lands could regain suitability for crop cultivation. Local governmental agencies also took some initiatives to discontinue this practice for the betterment of the society and environment.

2009: Cyclone Aila

Super cyclone Aila hit the coastal region on 25 May, 2009. Its impact in Polder 31 was comparatively less than in Polders 32 and 33, the other two polders of Dacope Upazila, Khulna. When the cyclone crossed, most of the farmers had harvested their dry season crops (boro rice and sesame), so crop damage was not high. The polder was overtopped in some places through which saline water entered in the area. Water was stagnant for 18 days after the event and then started to drain out. But due to some ill practices of shrimp farmers, the polder was damaged and became vulnerable which caused the damages during Aila. Local farmers blamed shrimp farmers for damaging the polder and consequent sufferings from Aila. Among the two unions and one pourashava, Tildanga union is in the southern portion of the polder and a bit lower in topography, and it suffered relatively more than the other parts of the polder during Aila. Salinity intrusion was higher in the area and high salinity condition resided for a longer period than the other areas. This also hampered the local agricultural activities.

2010-2011: Returning of the migrated people

The people who have migrated to other upazilas and districts in search of livelihood activities due to lower aman crop yield and associated losses, returned to the polder during 2010-11. In some places where soil salinity was somewhat reduced since the last three years, farmers started some vegetables cultivation with boro rice cultivation in a very small scale. This new opportunity of agricultural activities has brought the migrated people back to the polder. Some farmers who had their own lands started cultivating dry season crops, while landless farmers worked in other people's lands during the crop season, both at the time of aman rice and dry season crops (boro rice or vegetables). Some farmers also cultivated sesame and mustard in the area along with vegetables. They started to earn some profit from these crops as these crops require less water supply and labor cost than rice cultivation. Also after shrimp cultivation was stopped, the environmental condition was improved. There was no such condition where houses and homestead trees were damaged due to high soil salinity. Lives of people were considerably better than before with some cropping activities and stable environmental condition. All these factors brought back the migrated people in the area so that they can also improve their standard of living.

2012: Cultivation of cash crops

When shrimp cultivation was abandoned during the dry season, local salinity situation had improved and lands had become suitable for cultivation of crops. Local farmers gradually started cultivation of dry season crops to improve income and fulfill their food requirement. As rice is sensitive to water and salinity stresses, and also it is labor intensive, so cultivation of boro rice was in a small scale. But some new cash crops like sunflower and watermelon have been initiated in the area during 2012. Sunflower cultivation was first introduced by BRAC in the study area. BRAC provided seeds and fertilizers for initial cultivation as a demonstration to other farmers, so that they become interested in cultivating at their own will. Sunflower is a less water consuming and less labor intensive crop, and the health benefits of its oil consumption have drawn the attention of the local farmers. Watermelon is also another cash crop which was started to cultivate in the area after the success of watermelon farmers in Polder 33. Due to less salinity the production of watermelon was high in Polder 33, and profit was also high. The farmers of Polder 31 tried watermelon cultivation and got high profit in less saline areas. But in the areas where salinity is comparatively higher, sunflower cultivation is more suitable. This practice generated some profit and inspired the farmers to cultivate crops who used to keep their lands fallow. Also, sesame and mustard cultivation was an old practice in the area which generated profit and provided livelihood options to both the landless and marginal farmers.

2013-2014: Decrease in salinity and increase in crop cultivation

As shrimp farming has been abandoned for a long period, and local people have taken some initiatives to reduce soil salinity including gypsum and calcium oxide application in soil, soil salinity has deceased and soil became fully suitable for crop cultivation. Also, rainfall and tidal river water helped in leaching out soil salinity. Local people stated that, even for rice cultivation salinity of soil is acceptable in most of the places. Also, continuous cultivation of some cash crops and vegetables during 2012 has reduced soil salinity. In this way, the opportunities of crop agriculture have increased in the area up to a significant extent. So, local farmers have been inspired to cultivate both cash and staple food crops in the area. Along with sunflower, sesame, mustard and watermelon, they also cultivated pulses and short duration vegetables. Farmers started to experiment with new salt-tolerant rice varieties like Bina dhan 8, Bina dhan 10, BRRI dhan 47, etc., and received significant yields. BRAC has taken some initiatives of providing seed, partial cost of fertilizers and irrigation water to encourage the farmers for rice cultivation. Thus, rice cultivation has scaled up in the area.

Farmers also constructed some ponds and on-farm reservoirs to store rainwater and used this water during the dry season for rice irrigation. There was some consecutive white fish cultivation in these reservoirs which brought additional income to the farmers. The farmers realized that, for food consumption they need rice and for other living costs they can cultivate cash crops and earn profit. So, now they are practicing mixed cropping technique. Overall, dry season crop cultivation is beneficial to them and suitable for the environment, rather than keeping the land fallow or cultivating saline water shrimp in the area. Many farmers have earned profit from crop cultivation and improved their livelihood. They are now economically solvent and socially peaceful. So, other farmers are now-a-days highly interested in crop agriculture, and the required initiatives from the local governmental and non-governmental organizations would enhance their livelihood opportunities. They stated that, if the local silted canals can be re-excavated, they will be able to store rainwater for irrigation during the dry season. In this way, rice and other crop cultivation will increase in the area. They also require some seed and fertilizer facilities along with proper training and capacity building activities to cultivate new improved variety of crops for better yields and higher profit. In a nutshell, they seek for better standard of living and improved socio-economic condition.

Conclusions from timeline

Analyzing the outcome of the timeline, it is evident that, the local communities of Polder 31 are more focused towards the sustainable environment rather than shrimp farming practice which provides only profit. About 15 years of shrimp farming experience and associated environmental degradation have made them realize that this livelihood is not sustainable. They have learned that, without rice cultivation, even with a high income from shrimp farming, they will not be able to buy food. Also, only fish cannot satisfy the nutritional need of the local people. Thus, in this way, food security cannot be ensured. Also, large scale shrimp farming negatively affected small crop farmers as they are being forced to switch to shrimp culture. In a small part of the study area, some shrimp farming activities are still being performed. Shrimp farmers are the powerful classes of the society and they are forcing the crop farmers to switch to shrimp cultivation. Though being large in number, they are being controlled by the powerful people. So, there remains a conflict between livelihood practices and use of land and water. This conflict is harmful for local agricultural and environmental sustainability. There remains another problem which is insecurity of the minority class due to the power practice of the socially privileged groups. There is a tendency of illegal land encroachment for forced shrimp farming where the land belongs to the minority. This is also a driving factor for permanent migration. But, crop agriculture instead of shrimp farming can provide a gateway to the vulnerable and disadvantaged groups from this despair.

Most of the shrimp farmers have realized that with this risky practice, the existence of the locality will be threatened and permanent migration can also be triggered. As aman production is hampered by saline water shrimp, the crop production and income generation will be the lowest if this practice is brought back. So, at present, irrespective of the high profit margin, people do not want to go back to shrimp cultivation. Also, another factor drove the local people to change their shrimp practice, which is an increased job opportunity in crop agriculture compared to shrimp farming. Shrimp cultivation requires relatively less labor than crop agriculture. Thus, for increased income from wage laboring, people became more interested in dry season crop cultivation. Kibria et al. (2016) found that, combined profit from previous livelihood practice (aman cultivation followed by saline water shrimp farming) was less than that of the present practice (aman cultivation followed by dry season crop cultivation). So, at present, income of the poor community in the area is much more than any other historical time. Their perception has changed towards sustainable and environment friendly livelihood practices through which they can achieve food security and ecological stability in the area. They believe that, in future, if they receive proper assistance from the GOs and NGOs in terms of agricultural activities, they can thrive for a stable and balanced condition utilizing their local knowledge.

5.2 Climate Variability in the Southwest Bangladesh

To analyze climate variability in the study area, the monthly, annual and seasonal means of time series data of climatic variables, particularly temperatures (maximum and minimum) and rainfall, are assessed using Mann-Kendall test and several other parameters. Available data for temperature are from 1978 to 2017 and for rainfall 1978-2017. For analysis purpose, the whole year is divided into two seasons: dry season consisting of the months from November to May and monsoon season consisting of the months from June to October. Separate analysis is done for each month and season. The details of the result for both temperature and rainfall are described in two different sections below.

5.2.1 Temperature trend and variability in the southwest Bangladesh

An increase in temperature is among the manifestations of global climate change. Analysis of annual, seasonal and monthly temperature data is undertaken to detect the variability and trend in temperature in the study area for the period of 1978–2017. Table 5.1 portrays the significance of monthly, seasonal and annual temperature (minimum, maximum and average) trend in the period of 1978-2017. Monthly and seasonal linear regression models are developed for average temperature and also linear regression models are developed for annual maximum, minimum and average temperatures (T_{max}, T_{min} and T_{avg}).

Linear regression model is developed for temperature of each month of the year 1978-2017 showing R squared values and the rate of change in temperature which is indicated by the slope of regression lines.

Variability of annual and seasonal mean temperature is assessed by developing temperature anomaly (Z_c) and graphs are also plotted for this anomaly with respect to time. These graphs indicate how much variability each year has encountered during 40 years of study period.

Over the years, January shows a very little decrease in temperature (Figure 5.2). R squared value is very small and the change in temperature is only -0.014°C/year. The negative value indicates a declining trend.

Except January, the other months and also the dry and monsoon seasons show a notably increasing trend in temperature during the study period (Figures 5.3-5.15). Among all the months, July has the highest R squared value of 0.40 and November has the lowest value of 0.002. It indicates that July encounters the highest increase in temperature and November the lowest. In case of seasonal temperature, the monsoon season shows a notable increment in temperature over the study period. The R squared value is 0.52, the highest among all the values regarding temperature trend analysis.

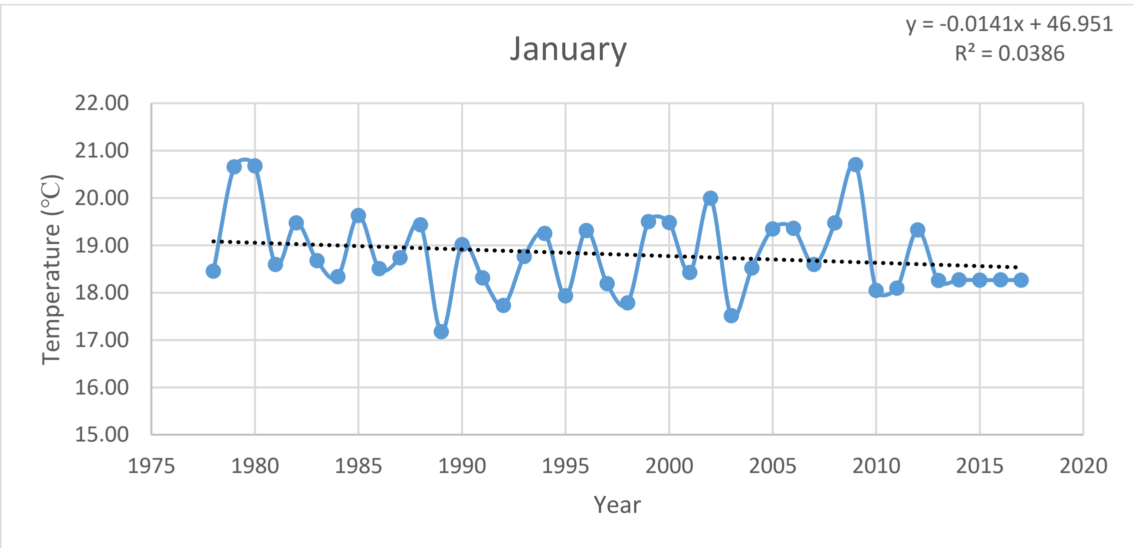


Figure 5.2: Average temperature pattern with linear regression line (1978-2017)

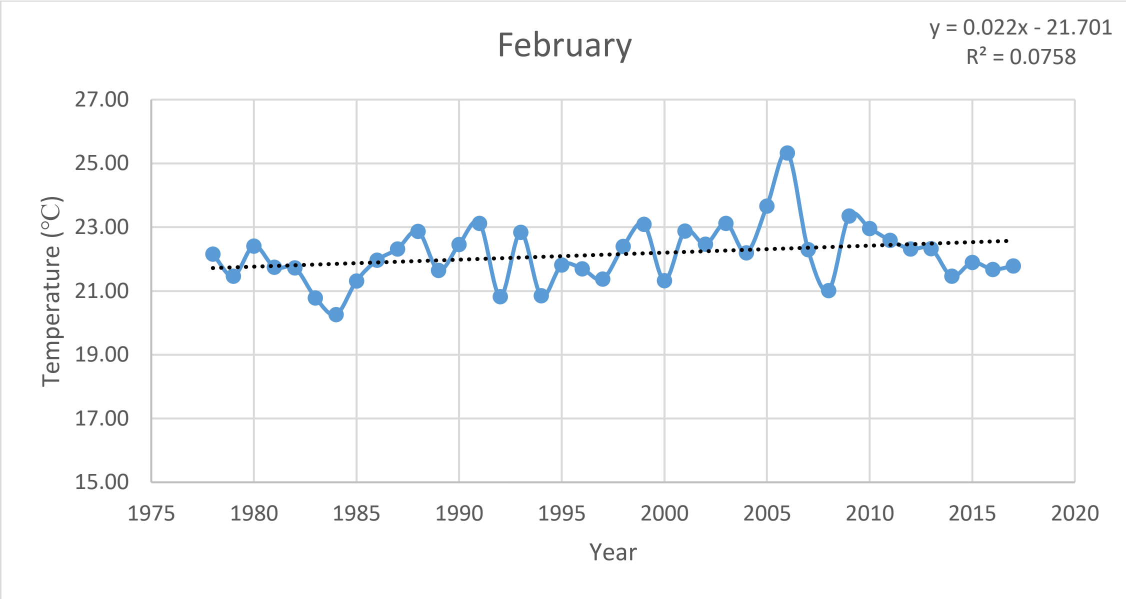


Figure 5.3: Average temperature pattern with linear regression line (1978-2017)

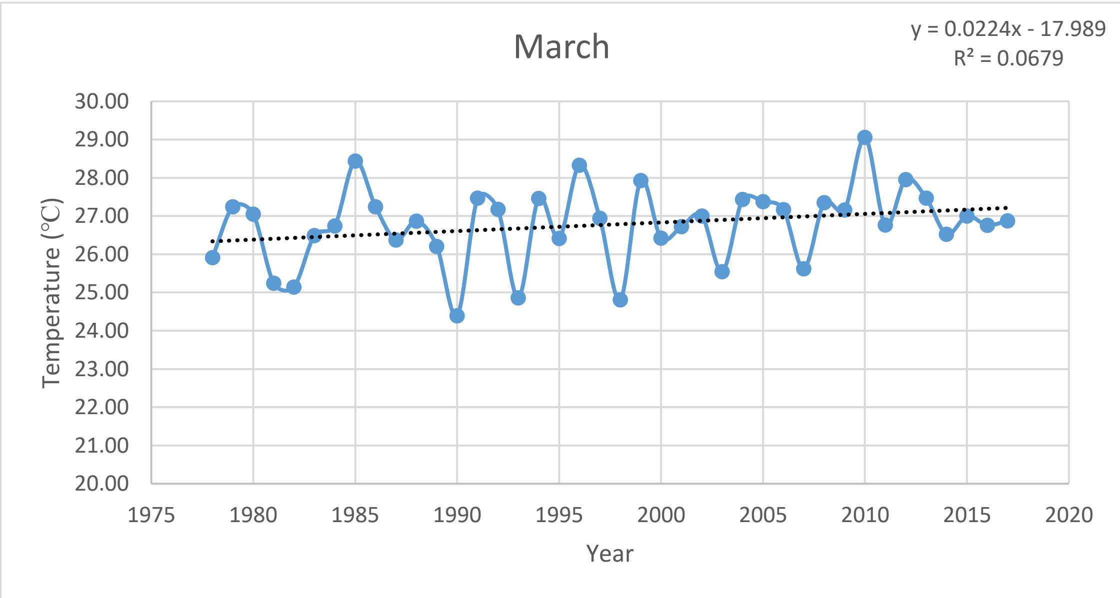


Figure 5.4: Average temperature pattern with linear regression line (1978-2017)

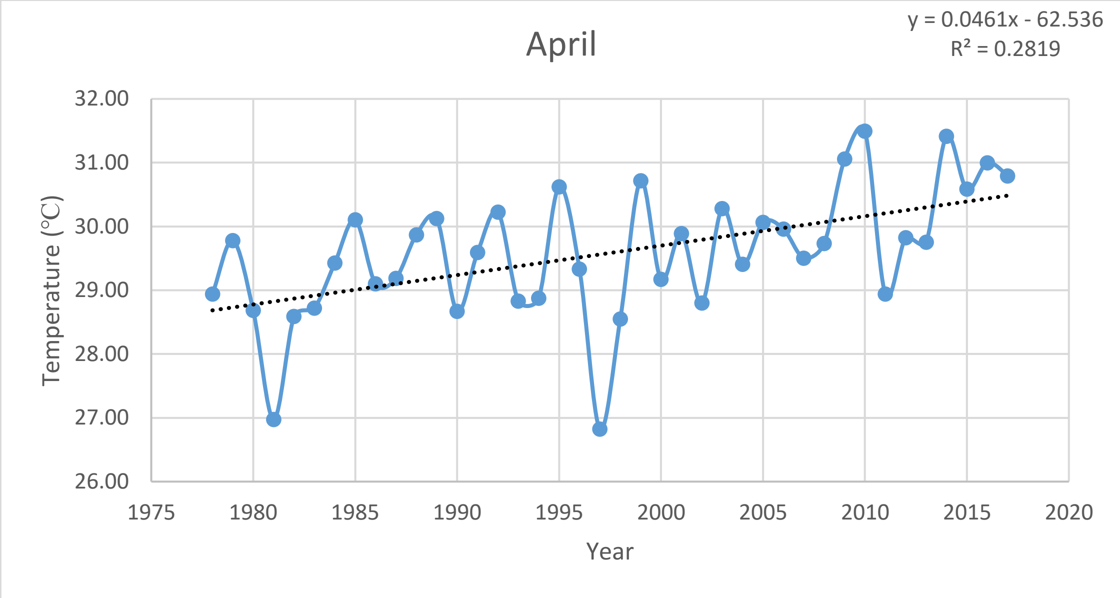


Figure 5.5: Average temperature pattern with linear regression line (1978-2017)

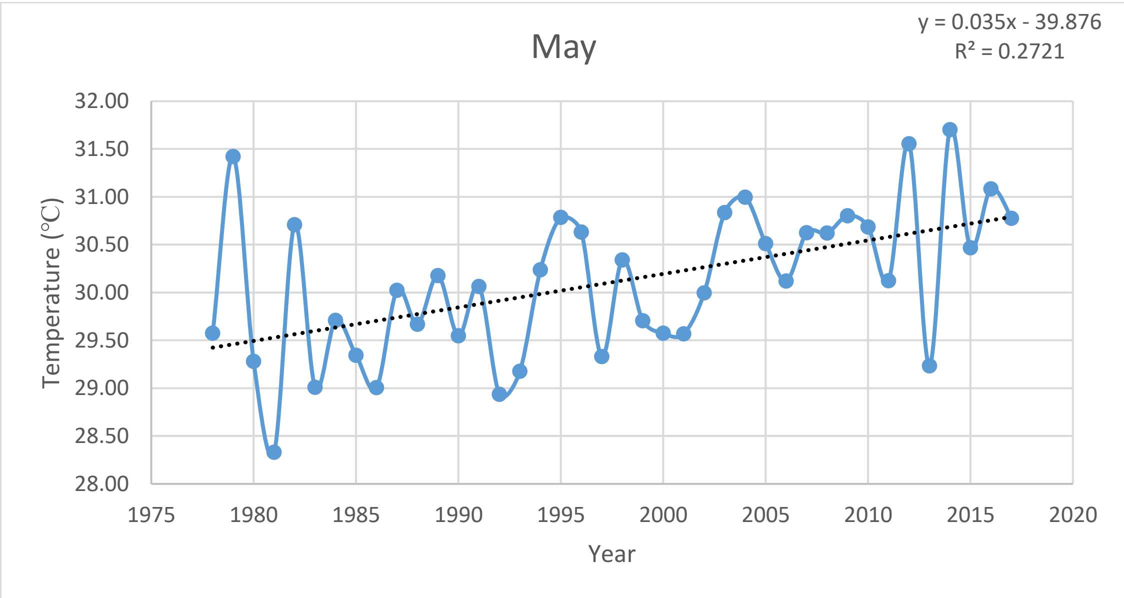


Figure 5.6: Average temperature pattern with linear regression line (1978-2015)

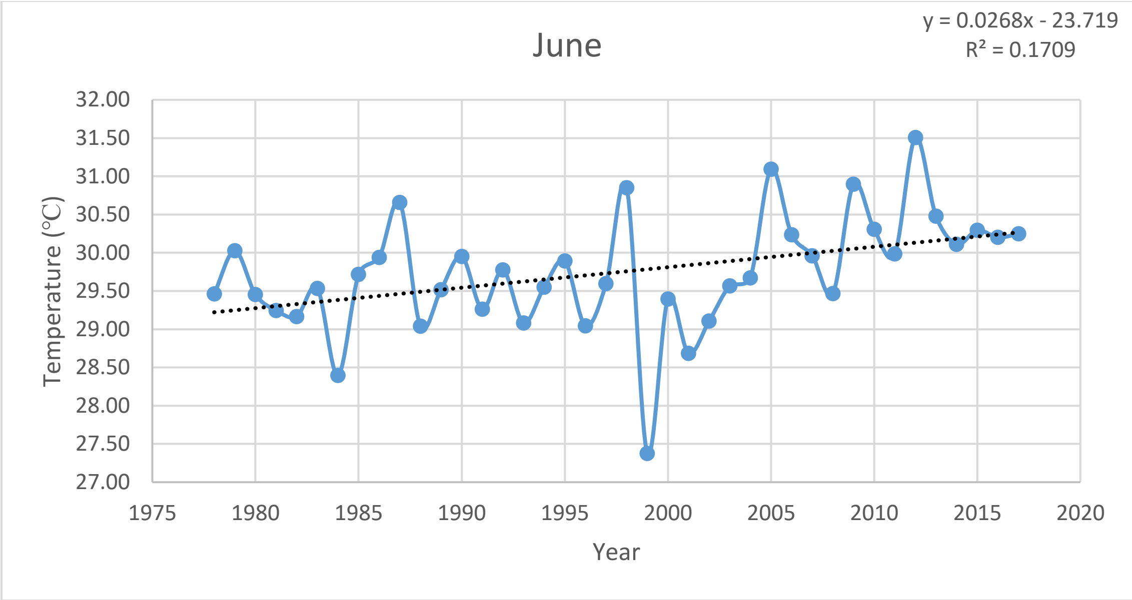


Figure 5.7: Average temperature pattern with linear regression line (1978-2017)

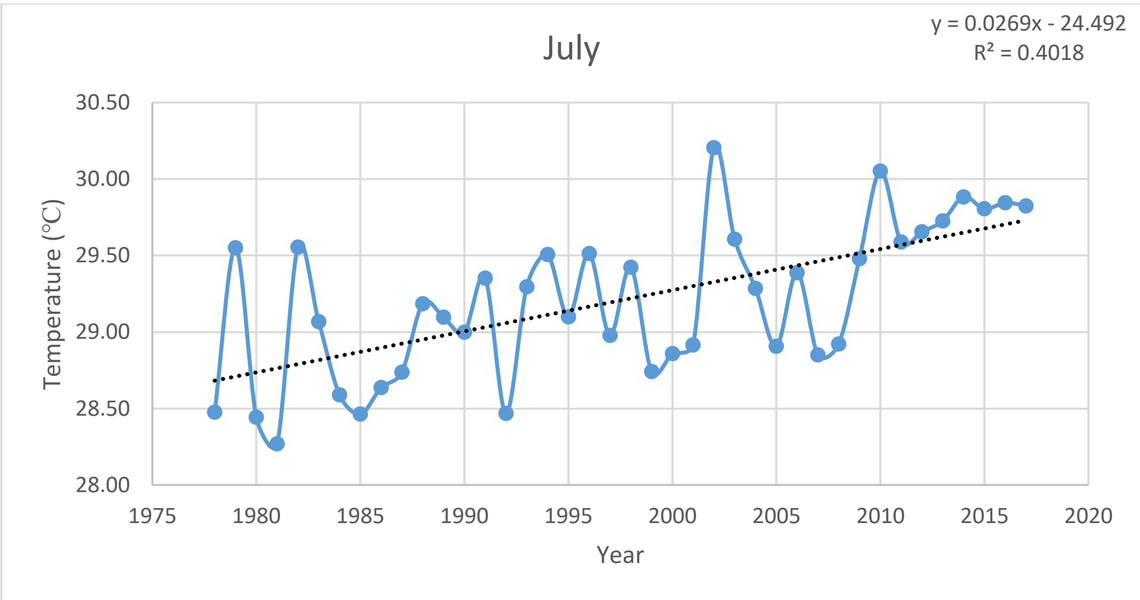


Figure 5.8: Average temperature pattern with linear regression line (1978-2017)

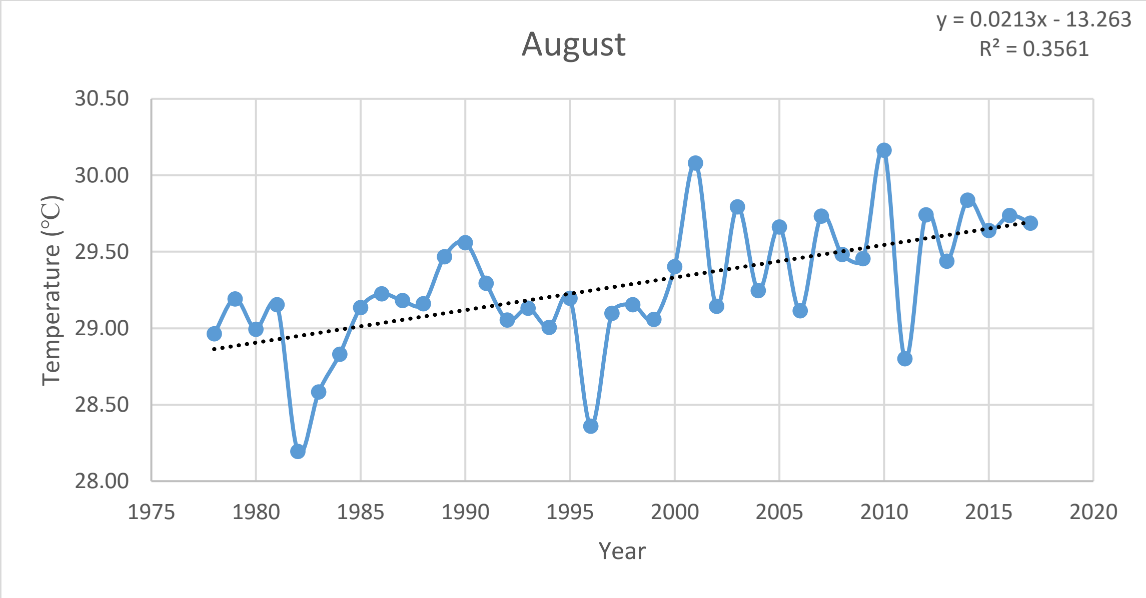


Figure 5.9: Average temperature pattern with linear regression line (1978-2017)

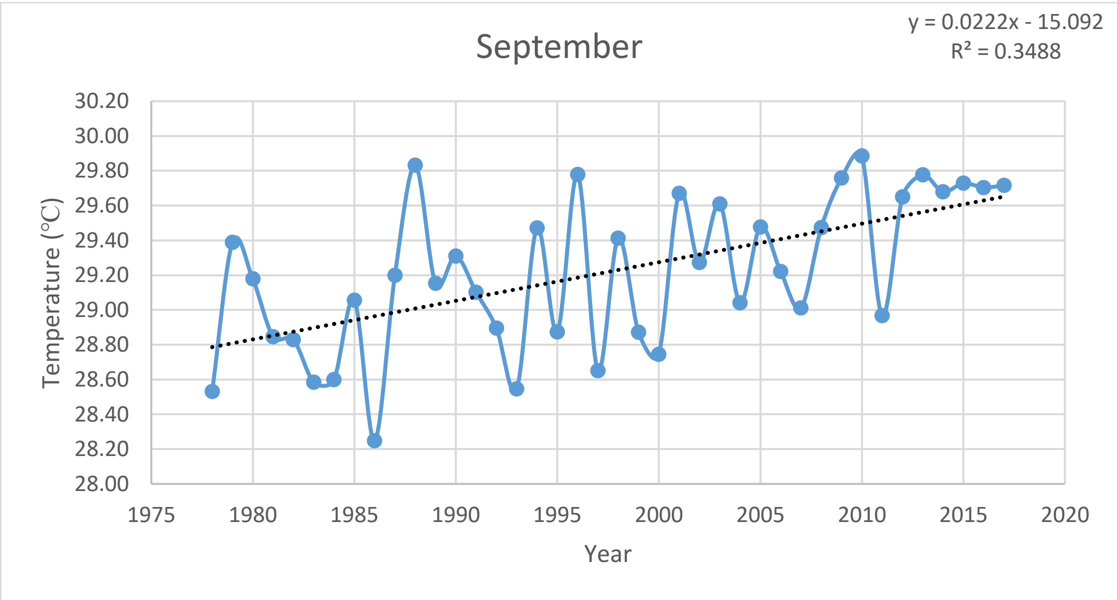


Figure 5.10: Average temperature pattern with linear regression line (1978-2017)

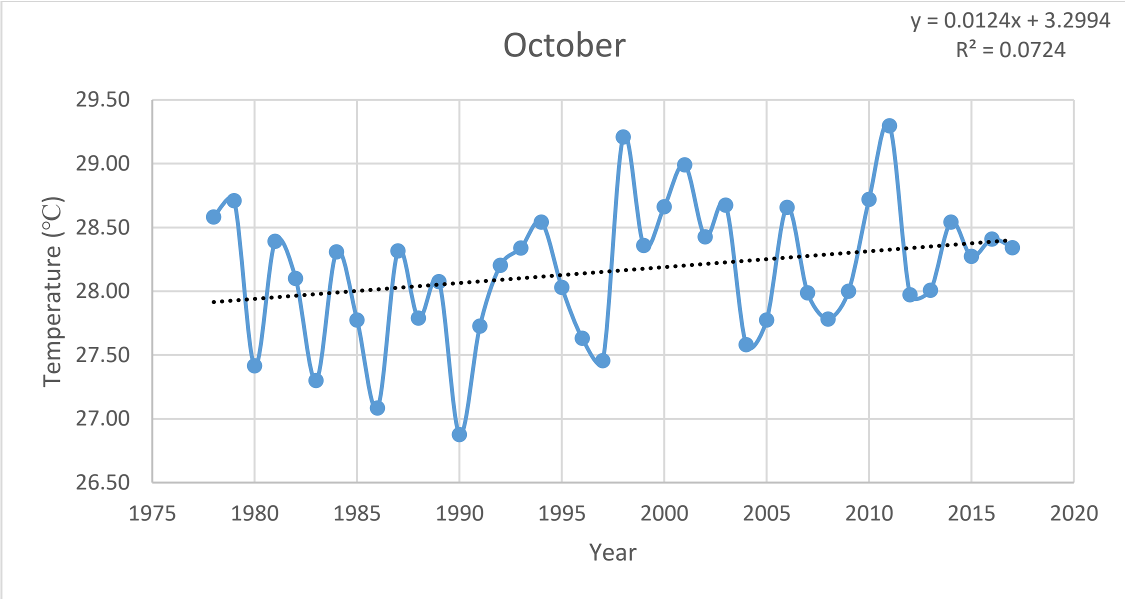


Figure 5.11: Average temperature pattern with linear regression line (1978-2017)

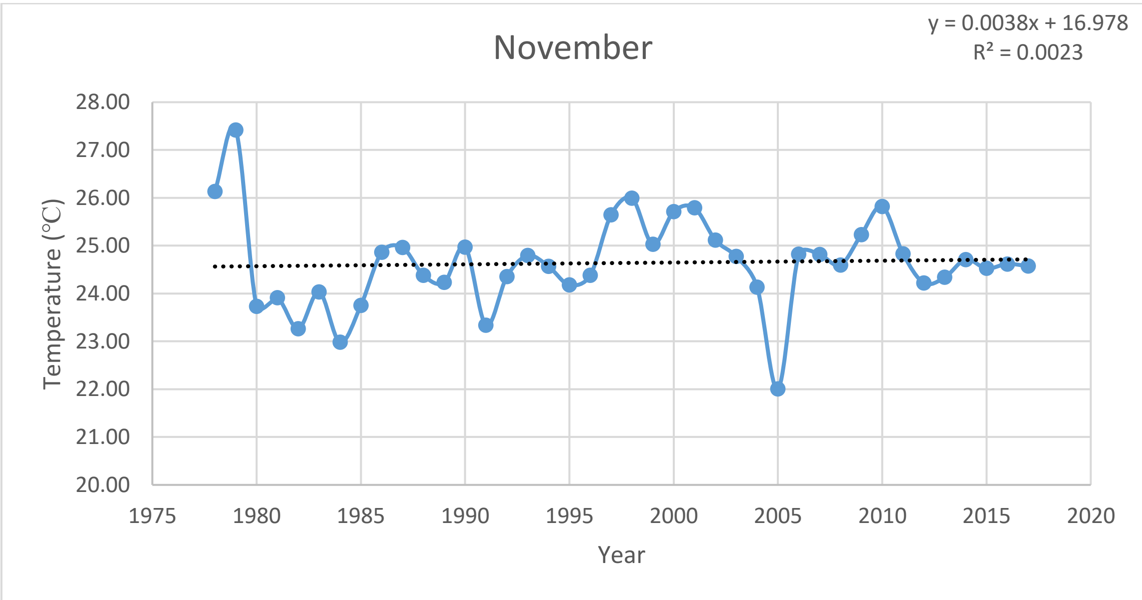


Figure 5.12: Average temperature pattern with linear regression line (1978-2017)

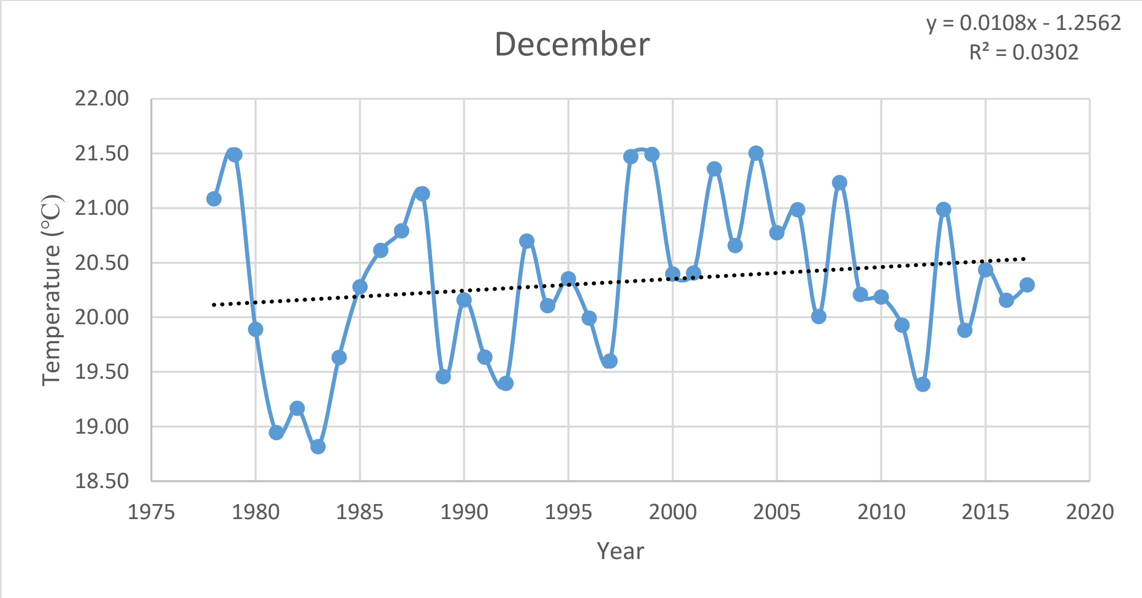


Figure 5.13: Average temperature pattern with linear regression line (1978-2017)

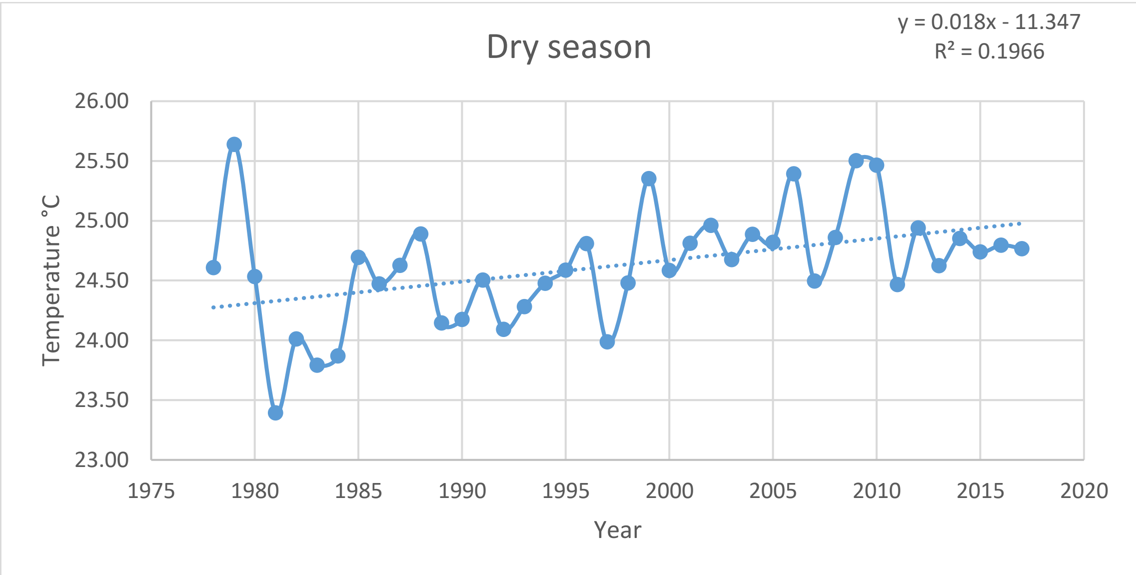


Figure 5.14: Average temperature pattern with linear regression line (1978-2017)

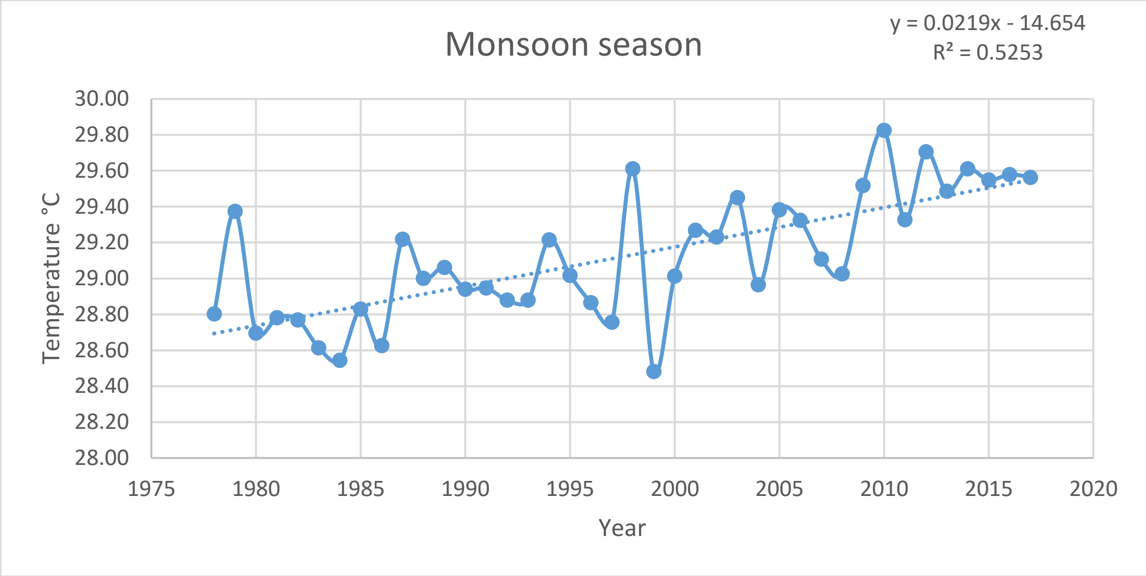


Figure 5.15: Average temperature pattern with linear regression line (1978-2017)

Analysis of mean annual T_{max}, T_{min} and T_{avg} is shown in Figures 5.16 to 5.18, respectively, which demonstrate a rise in temperature. In all the three cases, temperature shows a rising trend with time.

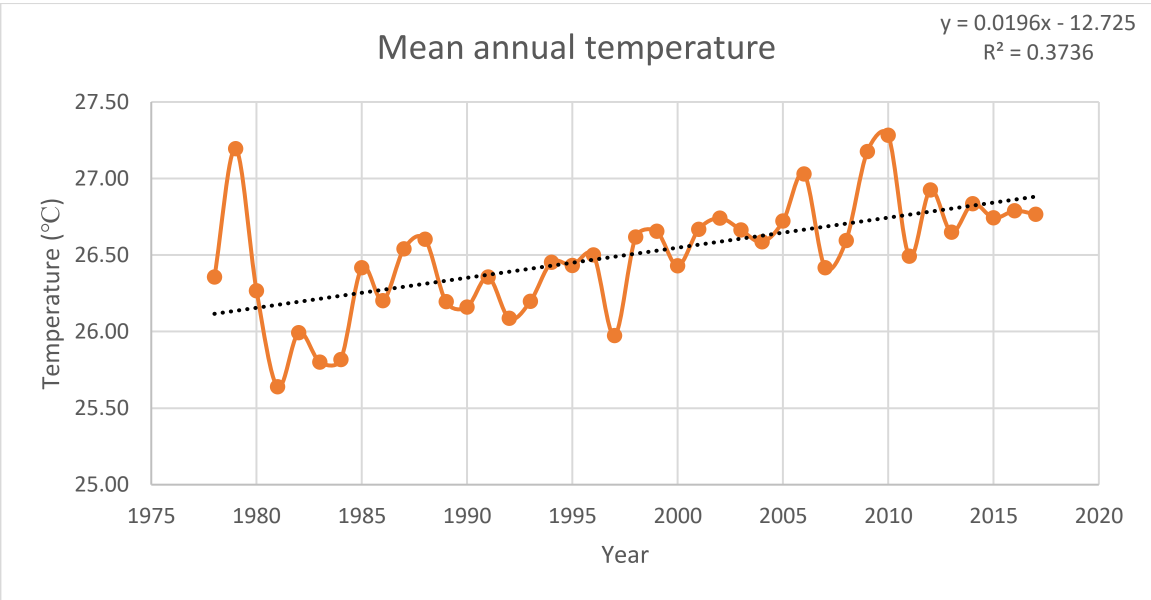


Figure 5.16: Average temperature pattern with linear regression line (1978-2017)

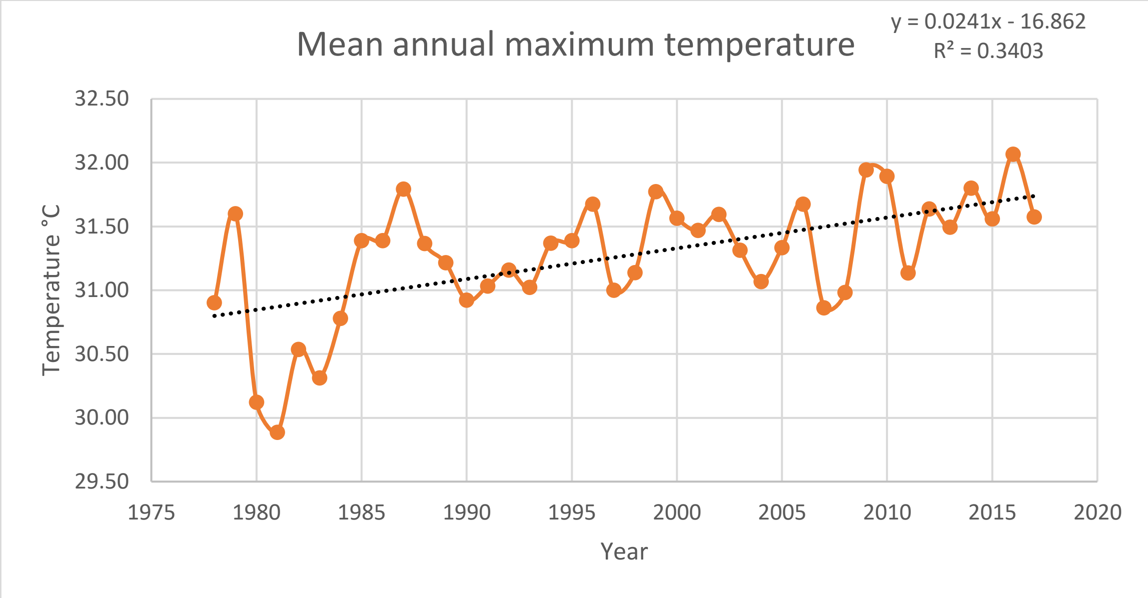


Figure 5.17: Average temperature pattern with linear regression line (1978-2017)

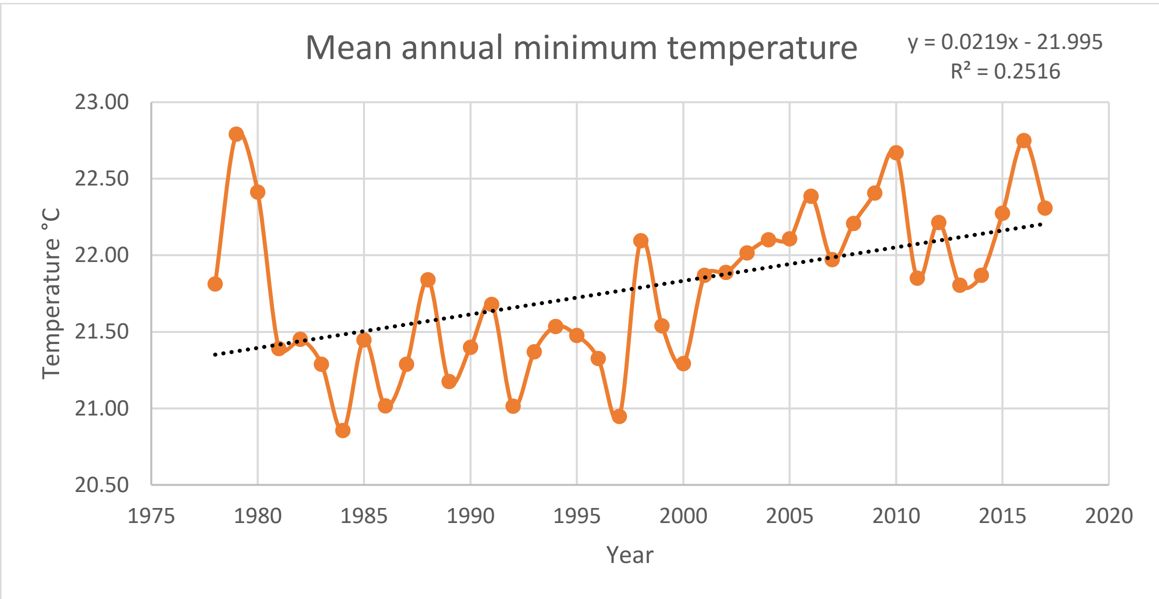


Figure 5.18: Average temperature pattern with linear regression line (1978-2017)

To know the significance of the trends, monthly, seasonal and annual Mann-Kendall trend test has been done at 1%, 5% and 10% significance levels over the study period 1978-2017. This analysis includes T_{max}, T_{min} and T_{avg} for all the cases. Table 5.1 lists the p-values and correlation co-efficients obtained from the analysis.

Table 5.1: Monthly, annual and seasonal Mann-Kendall trend analysis of temperature (1978-2017)

Month/season	**p-value**			**Correlation co-efficient**		
	T_{max}	T_{min}	T_{avg}	T_{max}	T_{min}	T_{avg}
January	0.148	0.365	0.763	-0.164	0.103	-0.034
February	0.090*	0.061*	0.017**	0.192	0.212	0.271
March	0.930	0.083*	0.191	0.010	0.197	0.148
April	0.110	0.018**	0.014**	0.181	0.268	0.279
May	0.000***	0.008***	0.001***	0.399	0.302	0.380
June	0.004***	0.148	0.006***	0.329	0.164	0.313
July	0.000***	0.005***	0.001***	0.415	0.320	0.399
August	0.000***	0.367	0.001***	0.406	0.104	0.382
September	0.001***	0.028**	0.002***	0.380	0.253	0.360
October	0.080*	0.656	0.195	0.202	0.051	0.149
November	0.111	0.574	0.191	0.183	0.065	0.15
December	0.937	0.047**	0.295	-0.009	0.228	0.12
Dry season	0.048**	0.000***	0.001***	0.224	0.402	0.392
Monsoon season	0.000***	0.020**	0.000***	0.515	0.265	0.530
Annual	0.001***	0.012**	0.000***	0.367	0.286	0.472

*, ** and ***statistically significant at 0.1, 0.05 and 0.01 alpha level of significance, respectively.

As demonstrated in Table 5.1, Mann-Kendall trend test result reveals that maximum, minimum and average annual temperature have been increasing with time at nearly 99% confidence level. May, June, July, August and September show significant upward trend in maximum and average temperature at 99% confidence level. Most significant increasing trend is observed in average temperature of the monsoon season, the p-value being 0.0000031. The maximum and minimum temperatures of this season also display significant rise at 99% and 95% level of confidence, respectively.

January and November show non-significant trend in all temperatures. Except correlation coefficient values of T_{max} and T_{avg} of January and T_{max} of December, other temperature values indicate that the temperature is increasing with time. Overall, there is a significant rise in temperature for the past four decades.

Figures 5.19, 5.20 and 5.21 illustrate the variability of annual, dry and monsoon season temperatures.

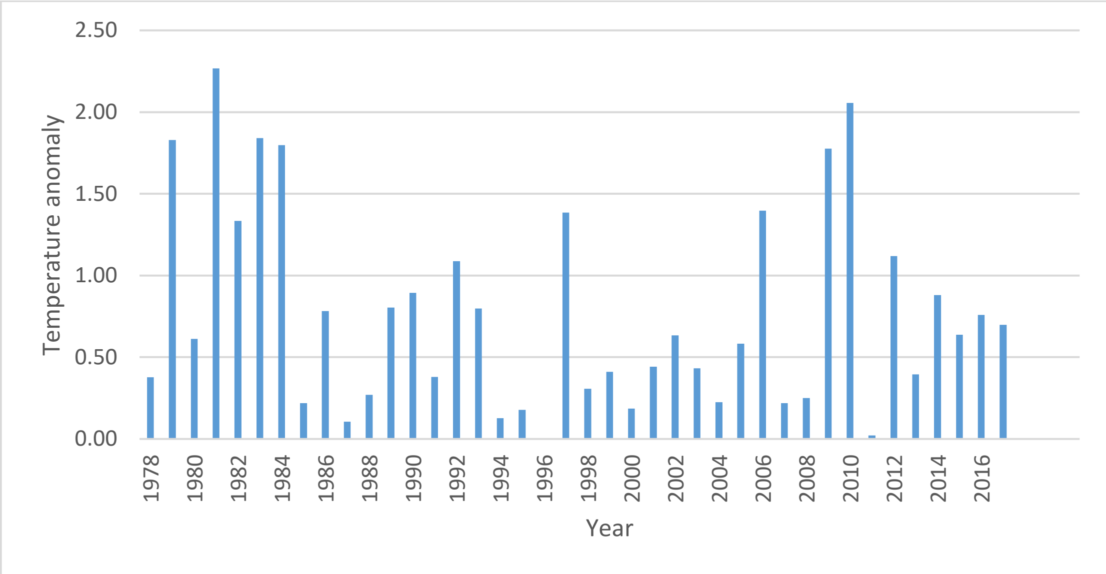


Figure 5.19: Variability of annual average temperature from 1978-2017

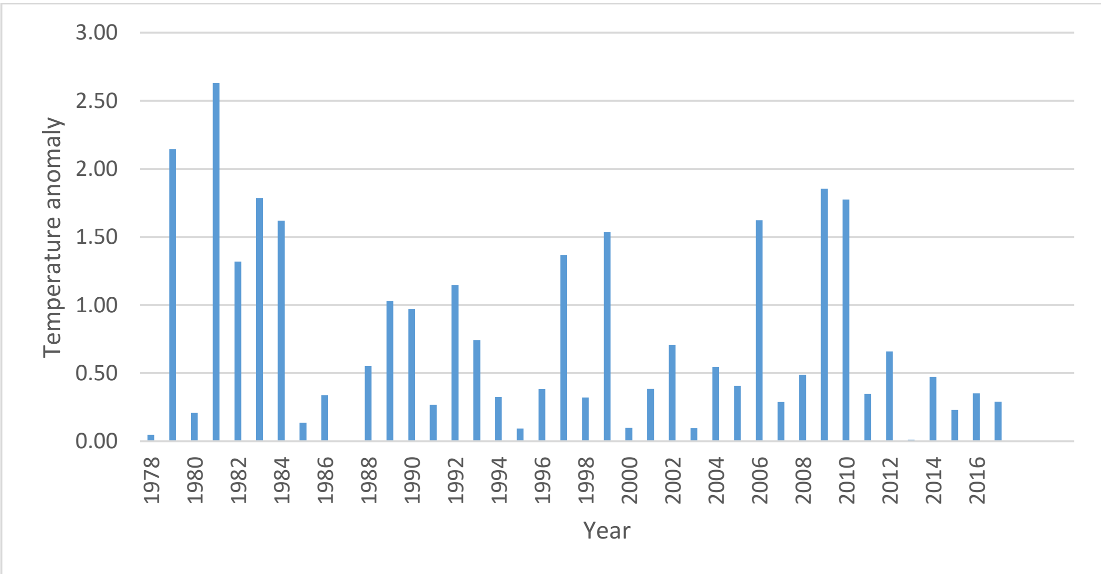


Figure 5.20: Variability of average dry season temperature from 1978-2017

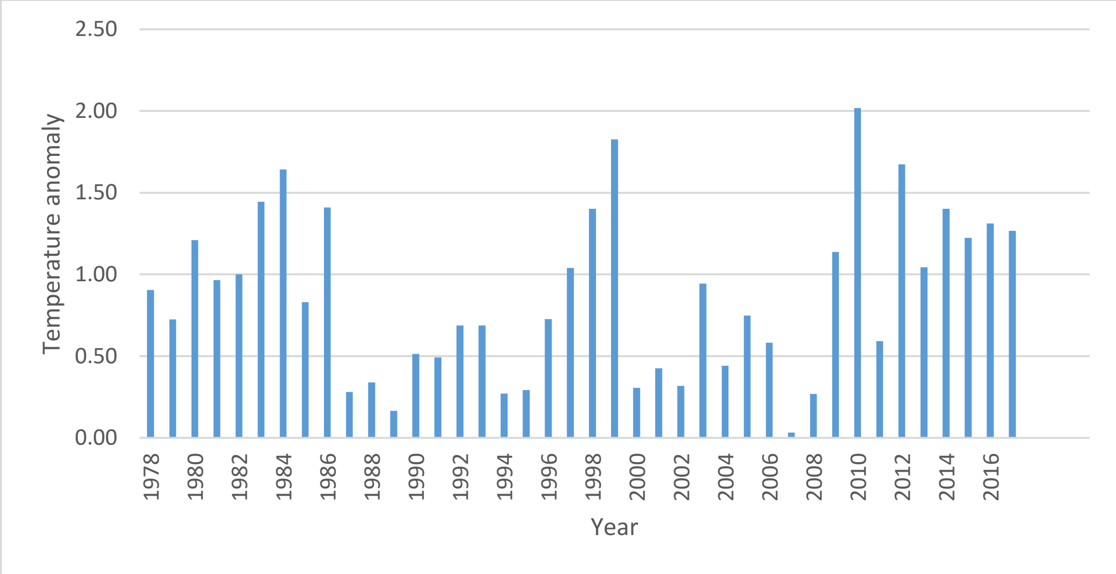


Figure 5.21: Variability of average monsoon season temperature from 1978-2017

In case of annual climate variability analysis (Figure 5.19), earlier years-that is 1979-1984 show highest variability in the graph. Variability then decreases a little with time but in recent time, 1997, 2006, 2009 and 2010 demonstrate notable temperature variation, meaning variation in temperature is more visible in the present.

Though temperature variation in dry season indicates decrement in recent years, monsoon season graph displays frequent temperature variation from 2009-2017.

The overall analysis reveals that there is significant rise in temperature variation with time in Polder 31 area.

5.2.2 Rainfall trend and variability in the southwest Bangladesh

Like temperature, trend and variability analyses have been done for rainfall for the study area over the period 1978-2017. In addition to that analysis, rainfall variability has been computed using several parameters like Coefficient of Variation (CV), standardized anomalies of rainfall (Z) and Precipitation Concentration Index (PCI). CV is calculated to evaluate the variability of the rainfall. A higher value of CV is the indicator of larger variability, and vice versa. Standardized anomalies of rainfall (Z) have been calculated to examine the nature of the trends, enabling the determination of the dry and wet years in the record and used to assess frequency and severity of droughts, and

Precipitation Concentration Index (PCI) to examine the variability (heterogeneity pattern) of rainfall at different scales.

5.2.2.1 Linear regression model and CV calculation results

In comparison with temperature, little trends have been observed in monthly, seasonal and annual rainfalls. Linear regression plots for monthly, annual and seasonal rainfalls are given in Figures 5.22 to 5.36.

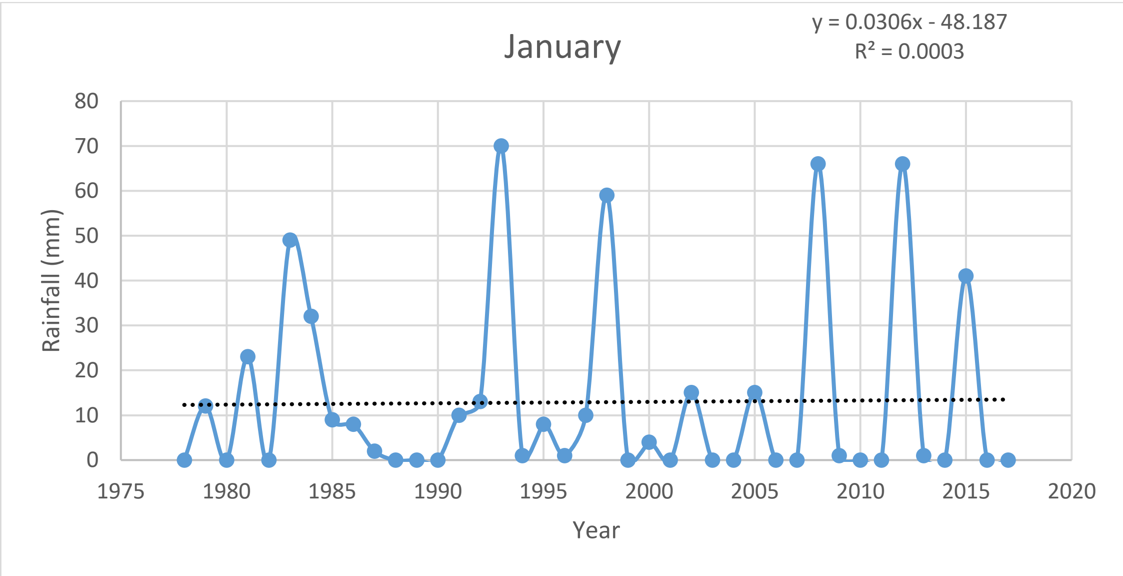


Figure 5.22: Average rainfall pattern with linear regression line (1978-2017)

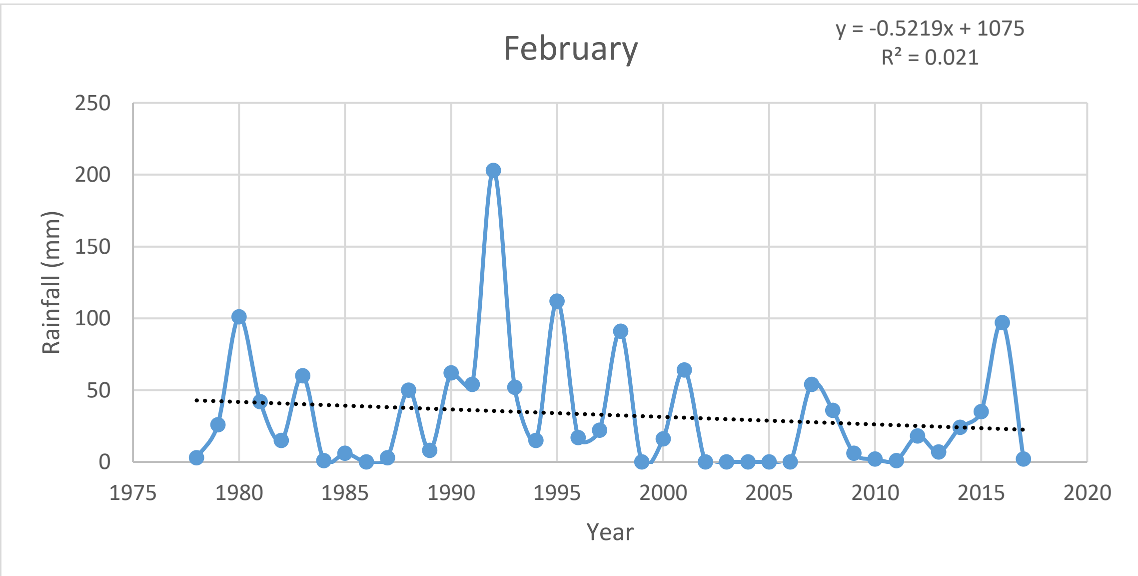


Figure 5.23: Average rainfall pattern with linear regression line (1978-2017)

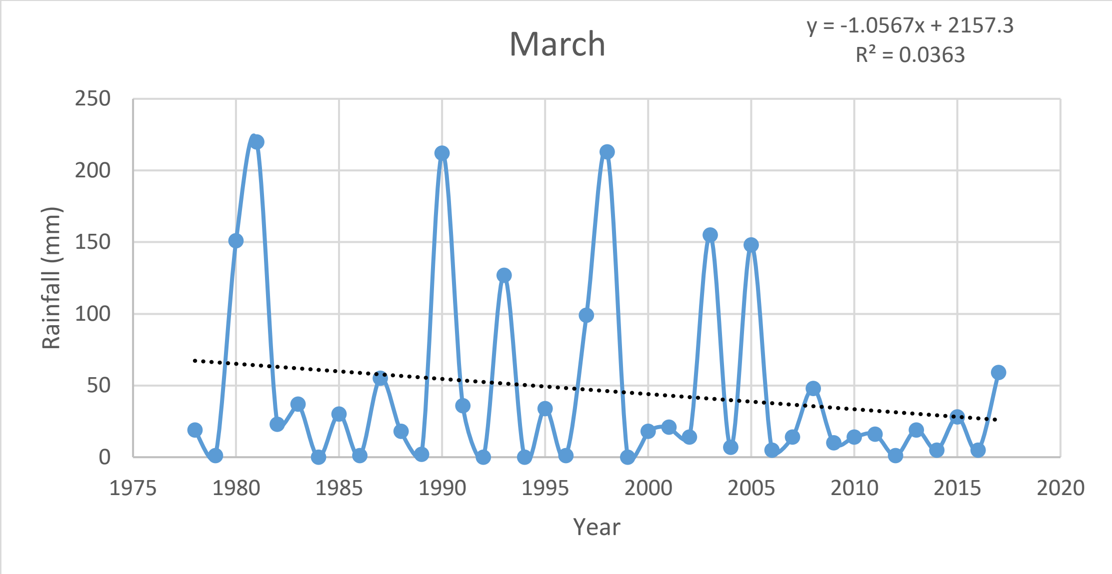


Figure 5.24: Average rainfall pattern with linear regression line (1978-2017)

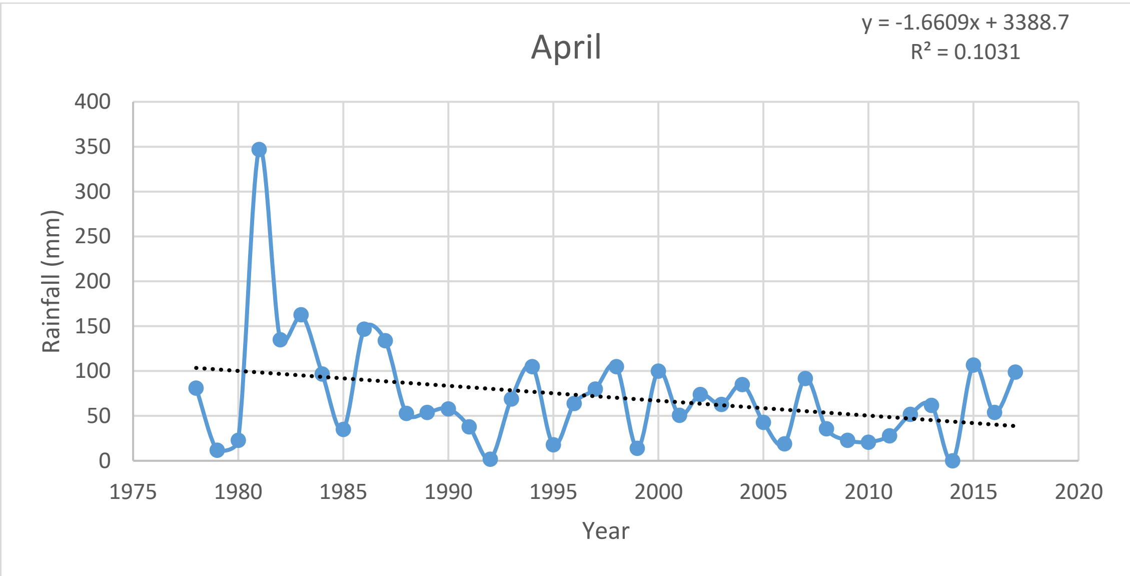


Figure 5.25: Average rainfall pattern with linear regression line (1978-2017)

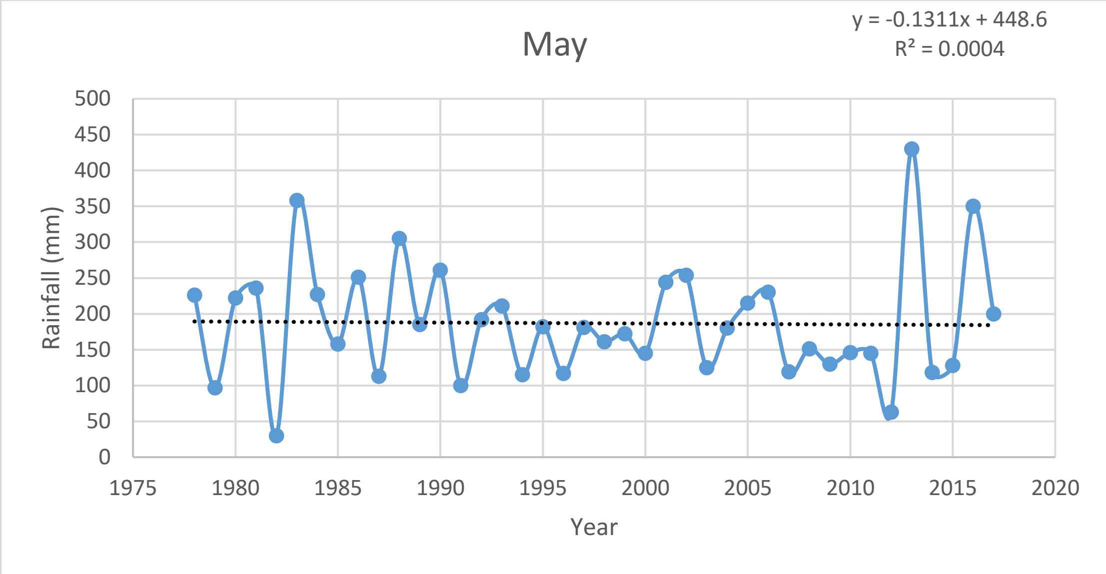


Figure 5.26: Average rainfall pattern with linear regression line (1978-2017)

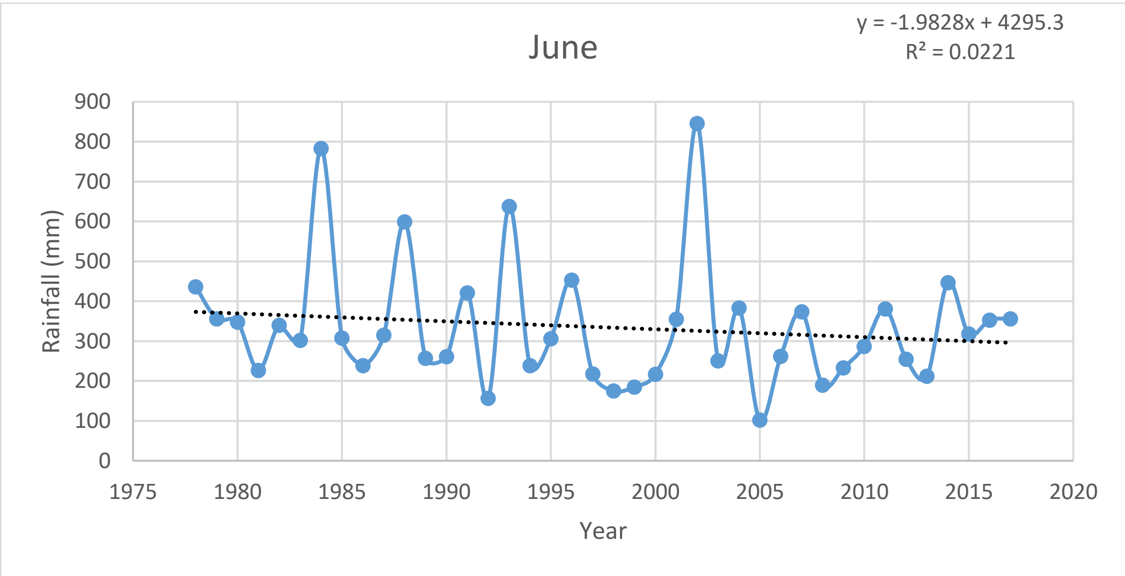


Figure 5.27: Average rainfall pattern with linear regression line (1978-2017)

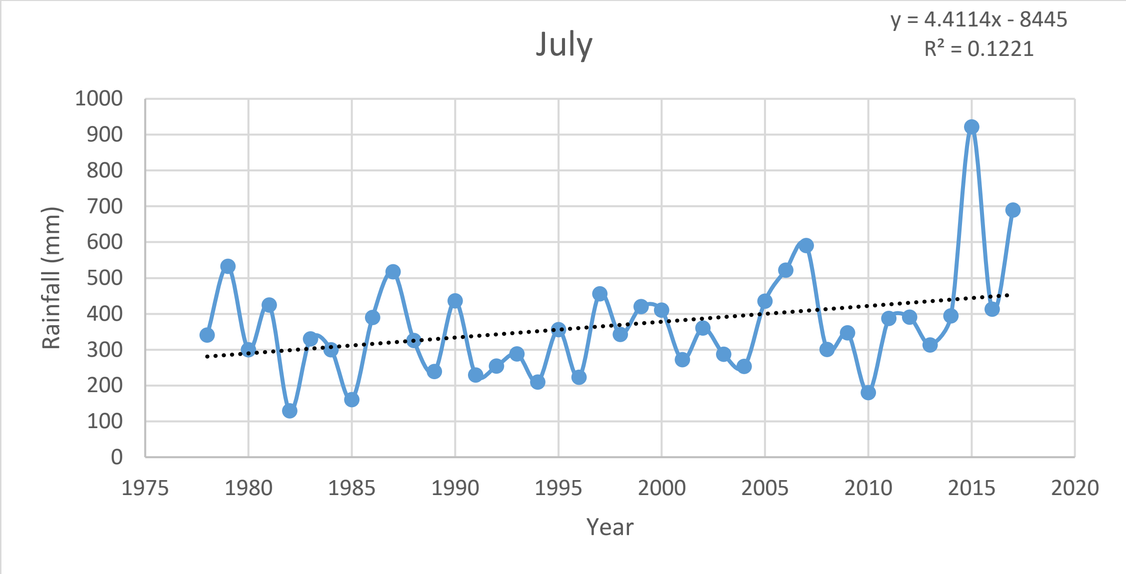


Figure 5.28: Average rainfall pattern with linear regression line (1978-2017)

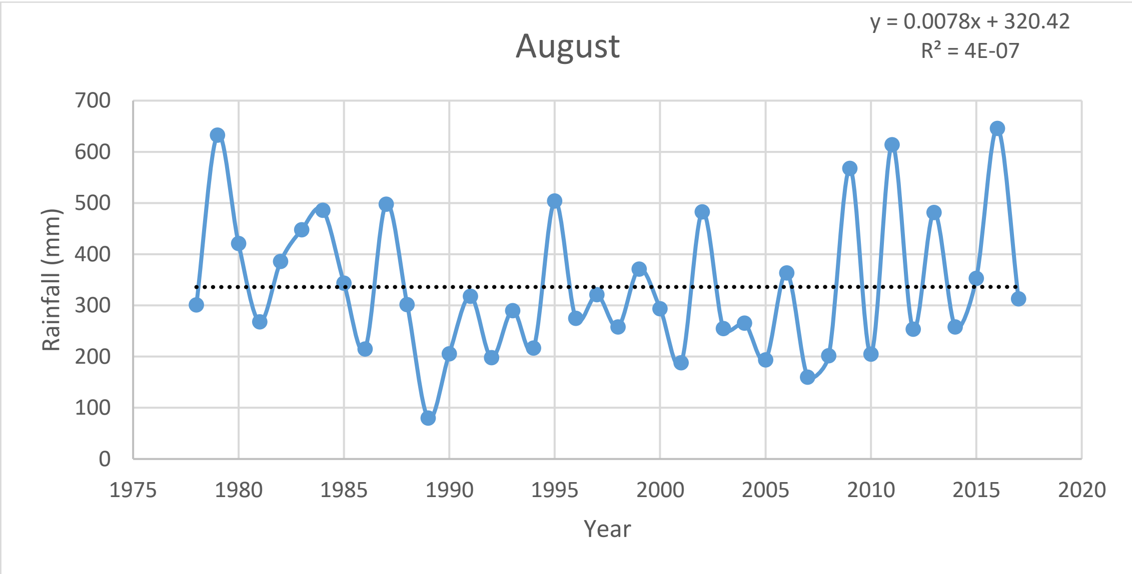


Figure 5.29: Average rainfall pattern with linear regression line (1978-2017)

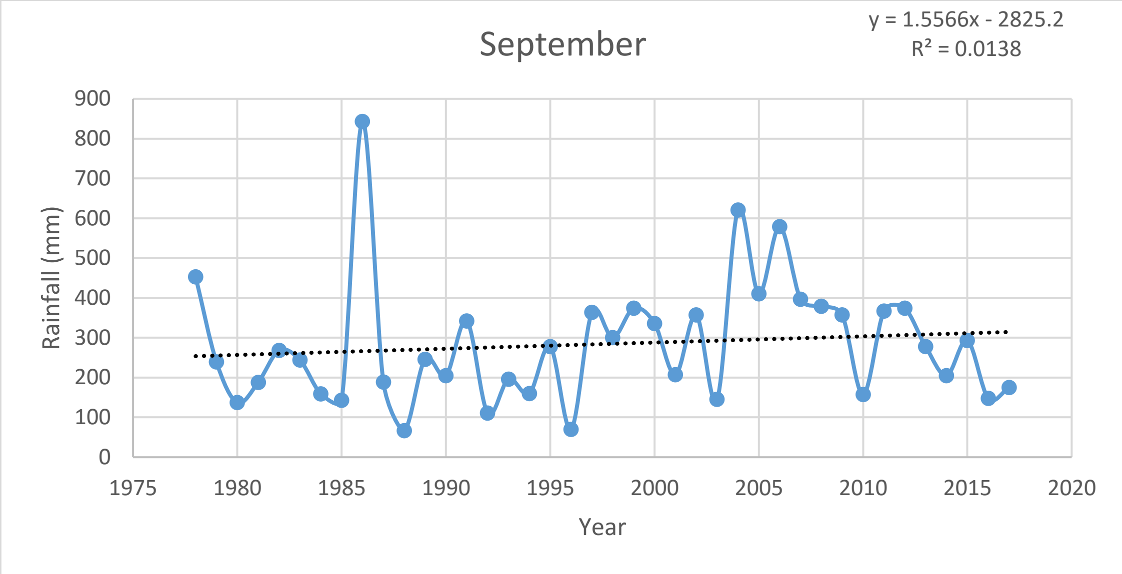


Figure 5.30: Average rainfall pattern with linear regression line (1978-2017)

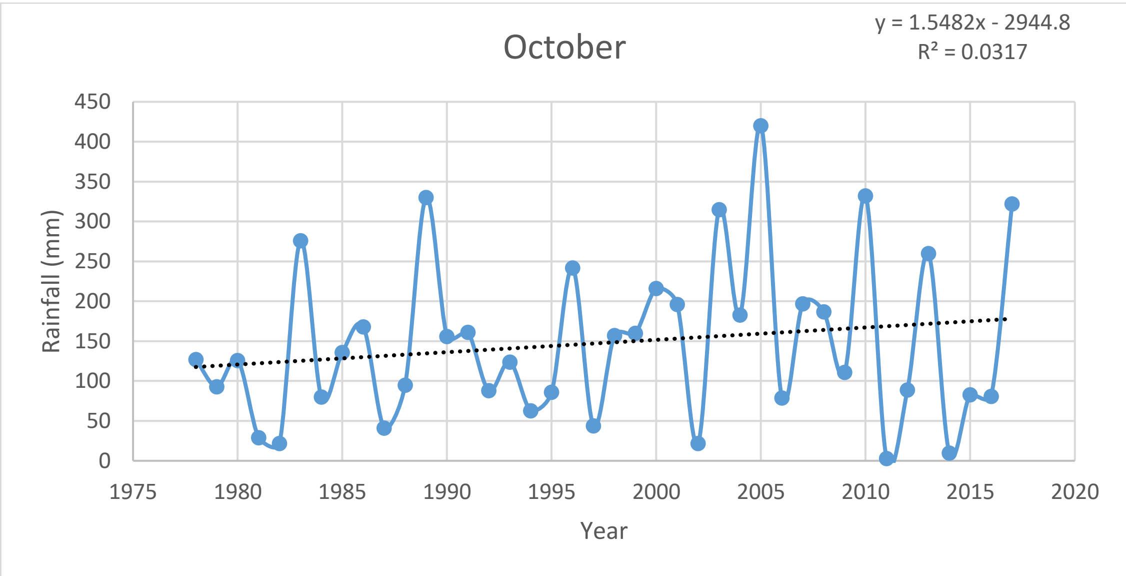


Figure 5.31: Average rainfall pattern with linear regression line (1978-2017)

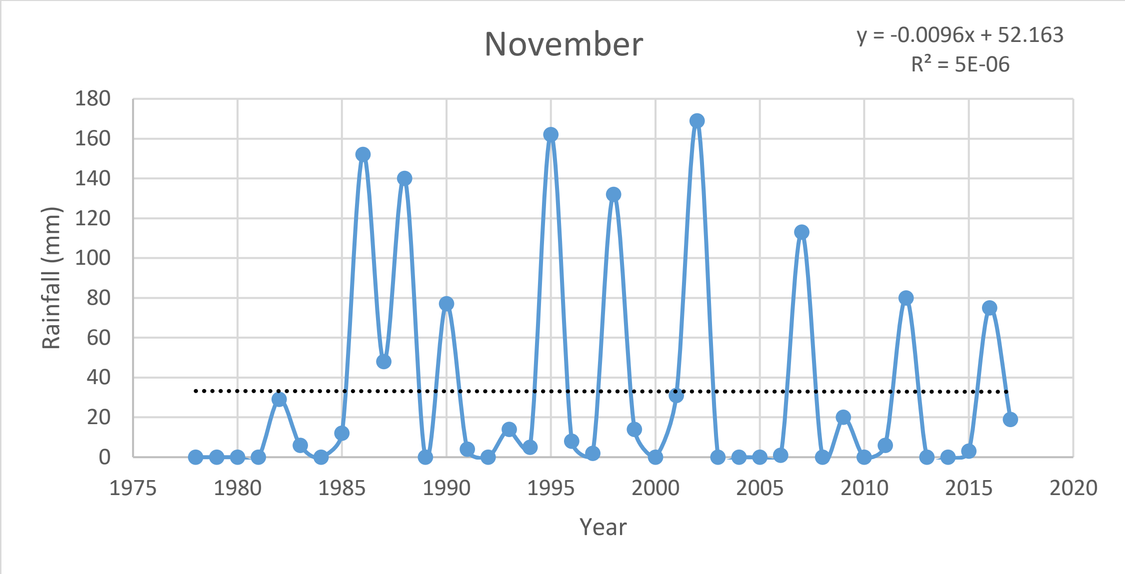


Figure 5.32: Average rainfall pattern with linear regression line (1978-2017)

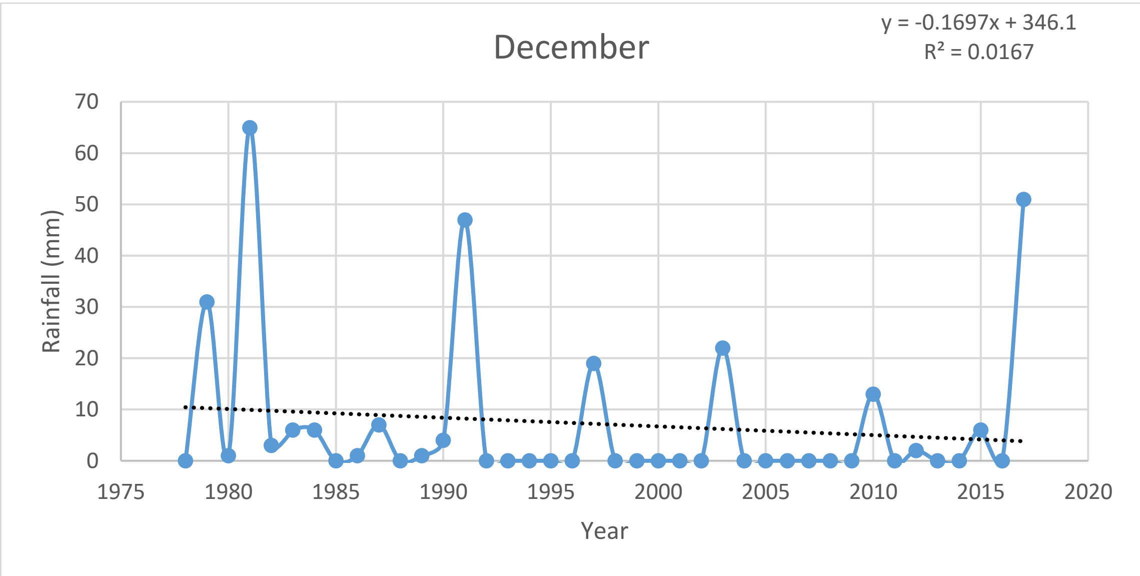


Figure 5.33: Average rainfall pattern with linear regression line (1978-2017)

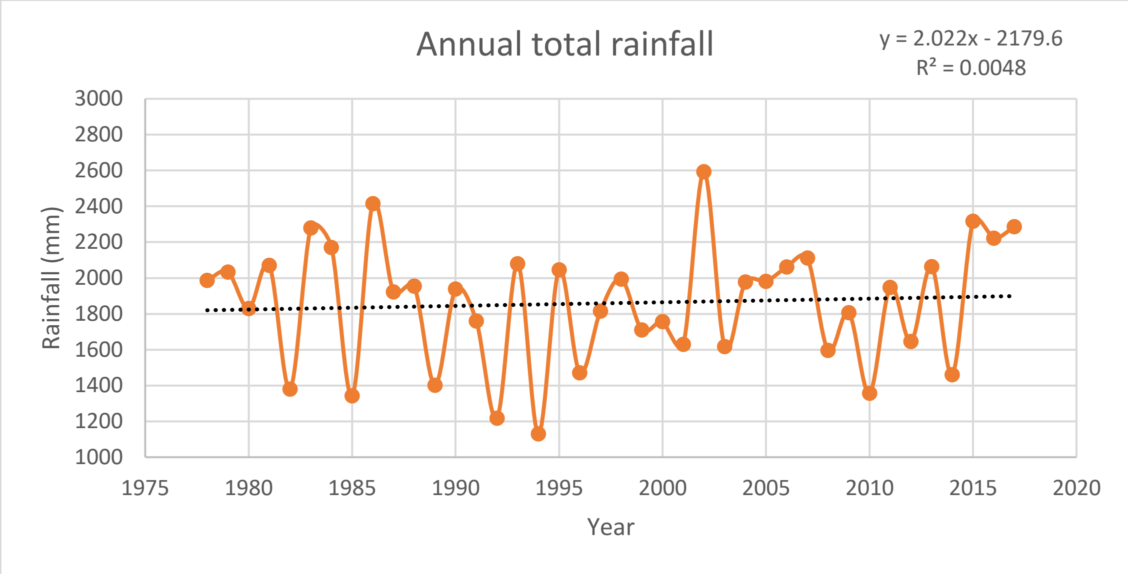


Figure 5.34: Average rainfall pattern with linear regression line (1978-2017)

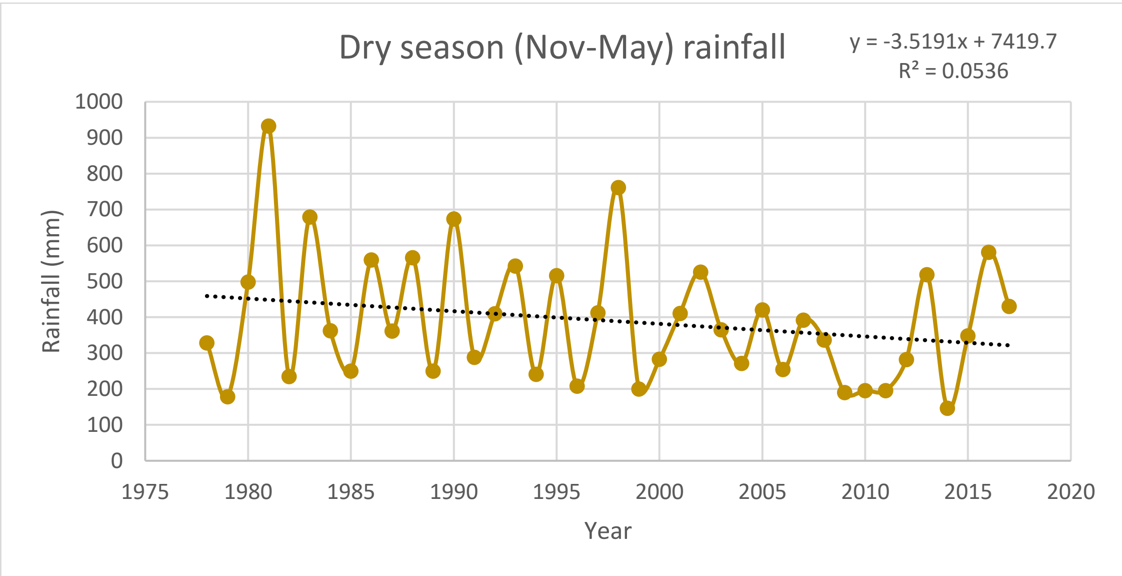


Figure 5.35: Average rainfall pattern with linear regression line (1978-2017)

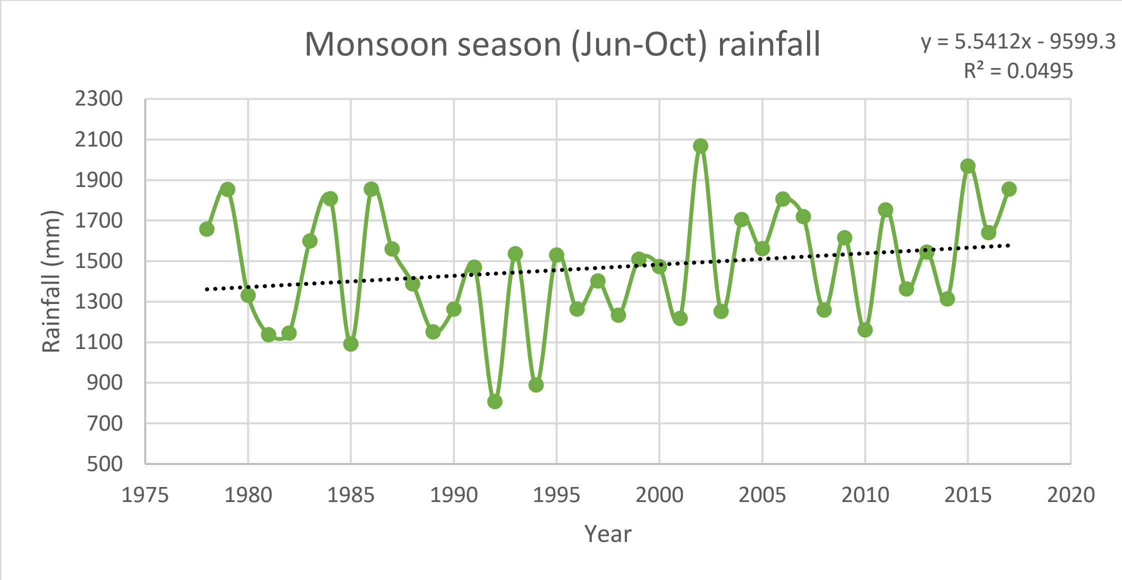


Figure 5.36: Average rainfall pattern with linear regression line (1978-2017)

Linear regression models illustrate increasing trends for July, September, October and the monsoon season, although the rates are very small. This can be indicated by their R squared values which are 0.10, 0.01, 0.03 and 0.05, respectively (Figures 5.28, 5.30, 5.31 and 5.36 respectively). On the other hand, February, March, April, June, December and the dry season demonstrate slight declining trend over time (Figures 5.23, 5.24, 5.25, 5.26, 5.33 and 5.35 respectively), whereas the linear least regression lines remain almost steady for January, May, August and November indicating no change in rainfall in the study period (Figures 5.22, 5.26, 5.29 and 5.32, respectively).

Whether the trends are significant or not can be known from the Mann-Kendall trend analysis which gives p-values and correlation co-efficients as listed in Table 5.2. P-values depict significance at certain confidence levels and positive or negative values of correlation co-efficients indicate increasing or decreasing trends, respectively. Table 5.2 also includes CV which measures the degree of variability of rainfall event.

Table 5.2: Basic statistics and Mann-Kendall trend analysis of rainfall in Khulna (1978-2017)

Month/season	**Correlation co-efficient**	**MK test**	**Significance**	**CV (%)**	**Degree of variability of rainfall event**
January	-0.111	0.343	No significance	163	High
February	-0.087	0.433	No significance	129	High
March	-0.070	0.528	No significance	139	High
April	-0.153	0.166	Significant at 80% confidence level	85	High
May	-0.089	0.421	No significance	43	High
June	-0.080	0.470	No significance	47	High
July	0.196	0.075	Significant at 90% confidence level	40	High
August	-0.058	0.600	No significance	41	High
September	0.152	0.169	Significant at 80% confidence level	55	High
October	0.099	0.370	No significance	69	High
November	0.043	0.700	No significance	159	High
December	-0.196	0.100	Significant at 90% confidence level	215	High
Dry season	-0.121	0.273	No significance	46	High
Monsoon season	0.159	0.149	Significant at 80% confidence level	20	Moderate
Annual	0.038	0.727	No significance	18	Less

It is found from the table that July has increasing trend and December has decreasing trend at 90% confidence level. In both cases, the degree of variability of rainfall is high. Moreover, April has decreasing trend, and August and the monsoon season have increasing trends at 80% level of confidence. The monsoon season has a moderate degree of variability in rainfall and annually the degree of variability in rainfall is less. The other months show non-significant rising or falling trend over time.

Variability of rainfall over time is analyzed by calculating rainfall anomaly Z separately for two seasons and plotting them against time (Figures 5.37 and 5.38). The result shows that variation in rainfall is reducing with time in the dry season, but is increasing in the monsoon season.

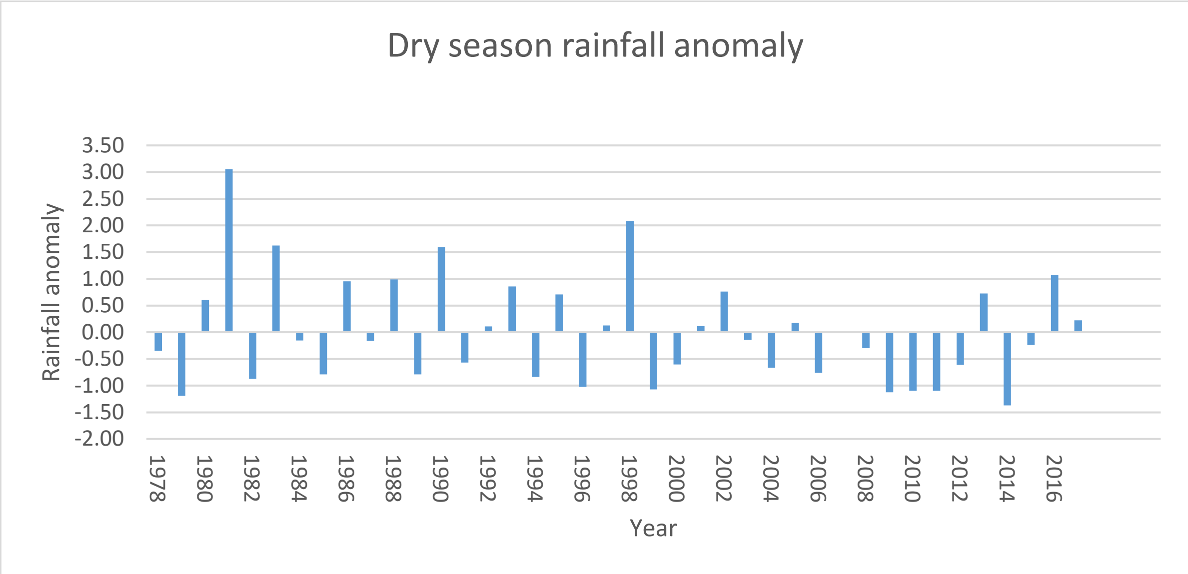


Figure 5.37: Rainfall variation from 1978-2017

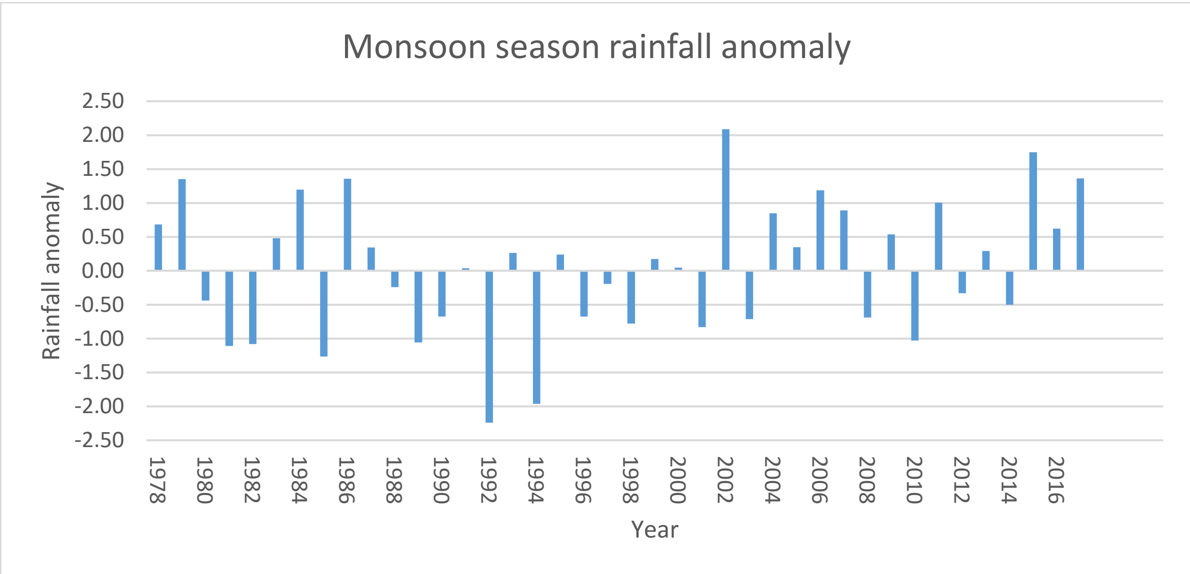


Figure 5.38: Rainfall variation from 1978-2017

Although overall rainfall variation is declining with time in dry season (Figure 5.37), higher variability can be seen in year 2009, 2010, 2011, 2014, 2016; specifically the years of the recent decades in comparison with the years of the past decade. Similar scenario is observed from the monsoon season rainfall anomaly graph where the recent years (2002-2017) demonstrate more variability than the past years.

5.2.2.2 PCI and Z value calculation results

PCI, which is used to examine the variability/ heterogeneity of rainfall pattern, is calculated for 40 years. Different ranges of PCI denote different concentrations of rainfall (detailed can be found in Chapter 3). Also, rainfall anomaly is determined for each year not only to understand variability, but also to identify dry or wet years and to assess frequency and severity of drought. The results are given in Table 5.3.

Table 5.3: PCI and Z value over the observed period 1978-2017

Year	PCI	Variability/ heterogeneity of rainfall pattern	Z	Severity of drought
1978	17.13	High rainfall concentration	0.38	No drought
1979	21.50	Very high rainfall concentration	0.52	No drought
1980	15.10	Moderate to high rainfall concentration	-0.09	No drought
1981	13.33	Moderate rainfall concentration	0.63	No drought
1982	19.65	High rainfall concentration	-1.43	Severe drought
1983	13.45	Moderate rainfall concentration	1.25	No drought
1984	21.92	Very high rainfall concentration	0.93	No drought
1985	16.96	High rainfall concentration	-1.54	Severe drought
1986	18.90	High rainfall concentration	1.65	No drought
1987	18.63	High rainfall concentration	0.19	No drought
1988	18.00	High rainfall concentration	0.28	No drought
1989	17.10	High rainfall concentration	-1.36	Severe drought
1990	13.13	Moderate rainfall concentration	0.23	No drought
1991	15.87	Moderate to high rainfall concentration	-0.30	No drought
1992	15.28	Moderate to high rainfall concentration	-1.91	Extreme drought
1993	16.22	High rainfall concentration	0.65	No drought
1994	15.85	Moderate to high rainfall concentration	-2.17	Extreme drought
1995	15.11	Moderate to high rainfall concentration	0.55	No drought
1996	19.05	High rainfall concentration	-1.15	Moderate drought
1997	16.46	High rainfall concentration	-0.13	No drought
1998	11.09	Moderate rainfall concentration	0.40	No drought
1999	18.59	High rainfall concentration	-0.44	No drought

2000	15.98	Moderate to high rainfall concentration	-0.31	No drought
2001	14.48	Moderate rainfall concentration	-0.69	No drought
2002	19.40	High rainfall concentration	2.18	No drought
2003	14.31	Moderate rainfall concentration	-0.72	No drought
2004	18.92	High rainfall concentration	0.35	No drought
2005	16.60	High rainfall concentration	0.36	No drought
2006	20.44	High to very high rainfall concentration	0.60	No drought
2007	16.82	High rainfall concentration	0.75	No drought
2008	14.85	Moderate rainfall concentration	-0.78	No drought
2009	20.08	High to very high rainfall concentration	-0.16	No drought
2010	17.04	Moderate rainfall concentration	-1.49	Severe drought
2011	21.84	Very high rainfall concentration	0.26	No drought
2012	16.55	High rainfall concentration	-0.64	No drought
2013	16.65	High rainfall concentration	0.61	No drought
2014	22.41	Very high rainfall concentration	-1.18	Moderate drought
2015	22.35	Very high rainfall concentration	1.36	No drought
2016	17.85	High rainfall concentration	1.08	No drought
2017	17.06	High rainfall concentration	1.27	No drought

The table shows that 1979, 1984, 2006, 2009, 2011, 2014 and 2015 had very high rainfall concentration having the PCI values of 21.50, 21.92, 20.44, 20.08, 21.84, 22.41 and 22.35 respectively. Among the years, only 2014 had a very high concentration of rainfall, but encountered a moderate drought. Other years had no drought condition.

Analyzing the PCI values from Table 5.3, it can be found that there are recurring events of high concentration of rainfall in the recent decade than the past. So it can be deduced that variability or heterogeneity of rainfall has increased with time.

The Z values indicate that 1985, 1989, 1996 and 2010 suffered from severe drought (values are -1.54, -1.36, -1.15, -1.49 respectively), whereas 1992 and 1994 witnessed extreme drought. Furthermore, if we particularly focus on last two decades, drought is more pronounced in the present decade (2008-2017) than in the past decade (1998-2007) as almost all the years of the past decade have seen more ‘no drought’ events but 2010 and 2014 encountered severe and moderate drought respectively.

The average PCI for the present and past decades are 18.68 and 16.66 respectively. Clearly, PCI for this decade is higher than the past, proving more variability of rainfall pattern at present. From the overall analysis, it can be concluded that the present decade has been prone to more climate variability, and this variability can continue in the future.

5.2.3 People’s perception on climate variability

The perception of people on the impact of climate variability can be obtained from interviews of, or discussions with, local people, including farmers and people of other occupations, and can be verified by the statistical analysis conducted in Section 5.2.

The local people of Pankhali reported a delayed onset of the monsoon rain which eventually led to a delayed transplantation of T. aman rice, a delayed harvest of the rice and a decrease in the yield as a result. The monsoon rain usually starts in the month of June in the area. The people’s perception on delayed onset of the monsoon rain can be verified from the Figure 5.36 which depicts a marginal decreasing trend in rainfall in June over time.

According to the respondents, temperature has increased over the years, and the dry period has become hotter recently. This information coincides with the regression analysis result shown in the Figures 5.14 and 5.16. Temperature shows a significant rise with time in both the cases. Increased temperature results in insect infestation, shortened growth period of crops and thus decrease yields. People reported that extreme drought is occurring in the past 3-4 years. According to their information, recent winters often see reasonable amount of rainfall followed by heavy storm, whereas this season used to be quite dry in the past. An example interview of a farmer is written here without changing any details:

Case: '*Uncertainty in dry season cultivation*'

Mr. Rahmatullah, an informant from the study area (age 54, father of 4 children), shared his experience regarding the uncertainty in the dry season rainfall and temperature and its impact on his farming.

"(…) I have been living in this village from my grandfather's time and farming is our only occupation. I have been cultivating sesame, pulse, watermelon and corn in the dry season for the last 25 years. As far I remember, I rarely saw rain in this season. But for the last 4 to 5 years, sudden heavy shower of rain has been occurring along with heavy storm. Also temperature is very high nowadays. We take shower even 3 to 4 times a day and sit outside home in hope of cold wind. Sudden rainfall and high temperature are hampering *rabi* crop cultivation. This unexpected rainfall sometimes causes water logging. For example, in February of the last year, there was a sudden occurrence of rain for 3 days at a stretch. The rainwater could not drain out, so there was an instant water logging and a large number of watermelons were destroyed as watermelon is intolerable to waterlogging…"

But analysis shows almost steady trend of rainfall in the month November-December-January (Figures 5.32, 5.33 and 5.22). Sometimes statistical analysis result may not match with the practical experience. This is because of the difference between statistical significance and practical significance.

5.2.4 Statistical significance versus practical significance

Daniel (1978) has discussed the difference between statistical significance and practical significance. He noted that a statistically significant trend may not be practically significant and vice versa. Sufficiently large samples will reveal any change, no matter how small, through the use of a statistical test, but this may not be of any practical help. Likewise, small samples may fail to detect a change statistically, but the degree of change might be of practical significance.

For example, linear regression models show rising trends in both dry and monsoon temperatures, but a decreasing trend in the dry season rainfall and an increasing trend in the wet season rainfall. According to local people, high temperature and low rainfall in the dry season are disrupting their normal livelihood. However, the high monsoon rainfall and temperature, specifically the statistically significant upward rainfall trend in July (Table 5.2), does not practically cause any significant impact on people's lives. It is because during the monsoon season, heavy flow of fresh water washes away the existing saline water which is the root cause of many agricultural problems. Farmers harvest crops before the commencement of the monsoon, so except some cases like occasional flood, getting stuck inside home for consecutive rainy days, etc., high rainfall and temperature does not affect people's livelihood much even though statistically there is a significant variation in this case.

Chapter 6

Impacts of Climate Variability and Change on Livelihood

Impacts of climate variability and change on various aspects of livelihood are known from key informant interviews and discussions with local people. Most of the information on the impacts on livelihood in Polder 31 has been collected from the local people, particularly from interviewing the people of Pankhali areas.

The local people informed that heavy rainfall, shifting of the monsoon and untimely rain have been observed frequently in the present decade. Monsoon starting time has also changed for the last 10-12 years. Delayed onset of the monsoon and its unpredictability have resulted in delayed transplanting of aman rice, delayed harvesting and decreased yield. The dry period is hotter now, the temperature has increased throughout the year and warm summer period is longer. The clear sunshine hours have reduced which has created problem for drying rice after harvest. Insect infestation has increased, growth period of crops has shortened and thus yield has decreased. Intrusion of salt water has reduced the grain yield of aman rice and also has reduced the cropping intensity. A thick layer of salt is often found on the soil surface in dry season (Photo 6.1). Higher frequency and intensity of storms and cyclones have caused losses of crops.

Increase in summer temperature is resulting in disease outbreak/mortality in shrimp farm and increasing in soil and water salinity due to high evaporation. Stocking of freshwater fish is delayed due to the late onset of the rainy season.

After Sidr/Aila, all the prawn ghers were washed away by tidal surges. As a result, a number of prawn farmers became bankrupt and left their villages in search of new sources of income. The cultivable lands remained under water for a long period of time. No cultivation was done for two years after the massive disaster. After that there was huge production of crops because of the silt that the tide brought along. Production jumped to about 5.99 ton/ha. Cost of aman production is Tk. 37000-43000 per hectare. It also needs little quantity of fertilizer.

Photo 6.1: View of a layer of salt on soil surface in a field in the dry season

The Polder 31 faces some minor waterlogging problem during the months of November-December in recent years. It usually occurs after harvesting of the rabi crop is finished. In that case, adjacent lands where harvesting has not been done yet encounter waterlogging problem. Heavy rainfall hampers watermelon cultivation as it cannot tolerate waterlogging associated with heavy rainfall.

6.1 Livelihood Vulnerability Index for Polder 31

To quantify the impact of climate variability, a Livelihood Vulnerability Index (LVI) is used. LVI is developed for the present and past decades carrying out a structured questionnaire survey among the households of the study area. LVI ranges from 0-0.5, 0.5 indicating the highest vulnerability. Two LVIs for the two different decades are calculated and compared. If the LVI for this decade is higher than the past, we can say that the present decade has been more vulnerable to climate variability than the past decade, and hence climate variability has resulted more adverse impact in recent time compared to the past.

Development of this index is survey-based, so generation of LVI for a very old decade was not possible. It is because most of the people cannot look back to a very old time or recall an old event. People are able to talk fluently mostly on events or scenarios of the last 20 years. Some senior people may provide information on any past event but those cannot be verified comparing with other sources. That’s why LVI is developed for the past two decades. Tables 6.1 and 6.2 demonstrate the calculations of the two LVIs.

Table 6.1: LVI sub-component values and minimum and maximum sub-component values for the past and present decades

Major component	Sub-component	Unit	Average value in Past decade	Average value in Present decade	Maximum value in two decades	Minimum value in two decades
Socio-demographic Profile	Dependency Ratio	Ratio	1.095	1.065	3.000	0.000
	Percent of households where the head of the household has not attended school	Percentage	50	33	100	0
Livelihood strategies	Percent of household with family member working in a different community	Percentage	10	20	100	0
	Percent of household depend solely on agriculture	Percentage	75	65	100	0
	Average agricultural diversity index (inverse of 1+ no. of diversified crops)	1/no. of livelihood	0.391	0.383	1.000	0.167
Health	Percent of households with family member who are chronically ill	Percentage	2.0	2.5	100	0.0
	Percent of household where a family member missed work or school in past two weeks due to illness	Percentage	1	2	100	0

<table>
<tr><th>Major component</th><th colspan="2">Sub-component</th><th>Unit</th><th>Average value in Past decade</th><th>Average value in Present decade</th><th>Maximum value in two decades</th><th>Minimum value in two decades</th></tr>
<tr><td rowspan="5">Food</td><td colspan="2">Percent of household depend on family farm for food</td><td>Percentage</td><td>75</td><td>80</td><td>100</td><td>0</td></tr>
<tr><td colspan="2">Average number of months households struggle to find food</td><td>Months</td><td>3</td><td>4</td><td>12</td><td>0</td></tr>
<tr><td colspan="2">Average crop diversity index</td><td>1/number of crops</td><td>0.222</td><td>0.167</td><td>0.500</td><td>0.077</td></tr>
<tr><td colspan="2">Percent of households that do not save crops</td><td>Percentage</td><td>60</td><td>20</td><td>100</td><td>0</td></tr>
<tr><td colspan="2">Percent of households that do not save seeds</td><td>Percentage</td><td>20</td><td>65</td><td>100</td><td>0</td></tr>
<tr><td rowspan="4">Water</td><td rowspan="2">Percent of households that utilize natural water source</td><td>Domestic</td><td>Percentage</td><td>1</td><td>1</td><td>100</td><td>0</td></tr>
<tr><td>Agriculture</td><td>Percentage</td><td>1</td><td>1</td><td>100</td><td>0</td></tr>
<tr><td colspan="2">Percent of households reporting water conflicts</td><td>Percentage</td><td>40</td><td>80</td><td>100</td><td>0</td></tr>
<tr><td colspan="2">Percent of households that do not have consistent water supply</td><td>Percentage</td><td>30</td><td>60</td><td>100</td><td>0</td></tr>
<tr><td rowspan="5">Natural Disaster and Climate Variability</td><td colspan="2">Average number of flood, drought and cyclone events in the past 20 years</td><td>Count</td><td>4</td><td>8</td><td>12</td><td>0</td></tr>
<tr><td colspan="2">Percent of households that did not receive a warning about the pending natural disaster</td><td>Percentage</td><td>40</td><td>20</td><td>100</td><td>0</td></tr>
<tr><td colspan="2">Mean monthly standard deviation of daily maximum temperature</td><td>Degree Celsius</td><td>0.823</td><td>0.789</td><td>1.294</td><td>0.612</td></tr>
<tr><td colspan="2">Mean monthly standard deviation of daily minimum temperature</td><td>Degree Celsius</td><td>0.973</td><td>0.709</td><td>1.409</td><td>0.388</td></tr>
<tr><td colspan="2">Mean monthly standard deviation of daily rainfall</td><td>Millimeter</td><td>100.83</td><td>72.106</td><td>173.137</td><td>10.311</td></tr>
</table>

Table 6.2: Indexed sub-components, major components and overall LVI for the past and present decades

Major component	Sub-component	Sub-component values Index = $\frac{S(t)-Smin}{Smax-Smin}$		Major component values M = $\frac{\sum index}{n}$	
		Past	**Present**	**Past**	**Present**
Socio-demographic Profile	Dependency Ratio	0.355	0.365	0.430	0.480
	Percent of households where the head of the household has not attended school	0.500	0.600		
Livelihood strategies	Percent of household with family member working in a different community	0.100	0.200	0.373	0.369
	Percent of household depend solely on agriculture	0.750	0.650		
	Average agricultural diversity index (inverse of 1+ no. of diversified crops)	0.269	0.259		
Health	Percent of households with family member chronically ill	0.020	0.025	0.015	0.023
	Percent of household where a family member missed work or school in past two weeks due to illness	0.010	0.020		

Food	Percent of household depend on family farm for food		0.750	0.800	0.428	0.437
	Average number of months households struggle to find food		0.250	0.330		
	Average crop diversity index		0.343	0.213		
	Percent of households that do not save crops		0.600	0.200		
	Percent of households that do not save seeds		0.200	0.650		
Water	Percent of households that utilize natural water source	Domestic	1.000	1.000	0.570	0.800
		Agriculture	1.000	1.000		
	Percent of households reporting water conflicts		0.400	0.800		
	Percent of households that do not have consistent water supply		0.300	0.600		
Natural Disaster and Climate Variability	Average number of flood, drought and cyclone events in the past 20 years		0.330	0.670	0.430	0.360
	Percent of households that did not receive a warning about the pending natural disaster		0.400	0.200		
	Mean monthly standard deviation of daily maximum temperature		0.309	0.251		
	Mean monthly standard deviation of daily minimum temperature		0.573	0.314		
	Mean monthly standard deviation of daily rainfall		0.556	0.379		

Based on major LVI component values in Table 6.2, LVIs for the past and present decades are calculated as follows:

$$\text{LVI (past)} = \frac{2*0.43+3*0.373+2*0.015+5*0.428+4*0.57+5*0.43}{21} = 0.408$$

$$\text{LVI (present)} = \frac{2*0.48+3*0.369+2*0.023+5*0.437+4*0.8+5*0.36}{21} = 0.443$$

6.2 LVI: Past vs. Present Decade

Table 6.1 given earlier presents the LVI sub-component average values for the last two decades as well as the minimum and maximum values for the two decades. The major components and the composite LVI for each decade are presented in Table 6.2. A brief description of each component is given below.

6.2.1 Socio-demographic profile

The first major component of LVI is socio-demographic profile, under which there are two sub-components: dependency ratio and percent of households where the head of the household has not attended a primary school. The dependency ratio index was slightly higher for the present decade (0.365) than that of the past (0.355). This slight increase is mainly due to the increase of new children and older people. In most of the cases children and older people cannot contribute to family income, so they become dependent members of the family. That’s why dependency ratio has increased. The percent of household with its head not attending a primary school was lesser for the present decade (0.33) than that of the past (0.5). Overall present decade showed greater vulnerability in the Socio-Demographic Profile index than the past (SD_{past} 0.43; $SD_{present}$ 0.48).

6.2.2 Livelihood strategies

The second major component is livelihood strategies which has three sub-components. The values of its sub-components show that at present more people work in a different community to earn their living (present: 20%) compared to the past (past: 10%) and depend less solely on agriculture. Frequent flood, cyclone, drought, etc. compel them to find out other sources of income and reduce dependency only on agriculture. Moreover, some households have their own businesses. Apart from farming and maintaining business, some people work as doctor, teacher, mechanic, shopkeeper, and rickshaw puller. However, agricultural livelihood diversity, which means earning by the cultivation of different types of crops, has increased. For example, besides rice, wheat, maize, potato, tomato, cucumber, mung bean, chickpeas, gourd, different spices like green chili, coriander, etc., watermelon, sesame and sunflower have gained much popularity among farmers for their easy cultivation process and high net profit. That is why, dependency on one or two crops has reduced significantly and most of the farmers cultivate several crops around the year and also adapting profitable crop cultivation nowadays. Moreover, high yielding salt and temperature tolerant varieties of rice (discussed later) are introduced by Department of Agriculture Extension (DAE) to farmers for the purpose of adaption to the changing climate in the coastal area. These varieties are adding diversities to agricultural livelihood. Overall, livelihood condition has slightly improved in the present decade than that in the past ($LS_{present}$ 0.369 vs. LS_{past} 0.373) because people are more aware now and GOs like Department of Agriculture Extension (DAE), Ministry of Agriculture (MoA) and NGOs like Bangladesh Association for Sustainable Development (BASD), Asa, BRAC, Caritas, Proshika, World Vision, Gonoshahajjo Sangstha, Nabolok, Rupantar, Prodipon, Provati Shangha, Asroy Foundation, etc., which are basically coastal-zone based NGOs and fully operational in Polder 31 area, provide more supports and facilities for the root level people to fight against the impacts of climate change and variability. For example, with the help of DAE, NGOs mentioned above introduced diversified crops to farmers and also gave them training on their cultivation. Moreover, during crisis NGOs sometimes provide short-term loan to poor people so that they can support their family. In the meantime, male members of those families temporarily migrate to other areas and get involved in occupations like day laboring, shop helping, rickshaw pulling, etc. For these reasons, livelihood condition has improved over time.

6.2.3 Health

Public health of the study area has deteriorated over time. According to the respondents, more people are now suffering from chronic illness, mostly due to abrupt change in climate. They frequently catch flu or fever. Increased contamination and salinity of drinking water sources are resulting in water borne diseases and skin infection. As a result, more people often miss work and more children miss school now because of illness. This problem is more visible in this decade than the past as indicated by the major component values.

6.2.4 Food

Food is the fourth major component of the LVI index and it has five sub-components. Table 5.5 shows that dependency of households on family farming has changed over the past 20 years. Most of the people of the study area have their own lands where they cultivate crops, grow vegetables, and some even dig small ponds and cultivate various fishes. But there were some households who were not dependent only on family farming rather they had their own businesses like clothing, machinery, grocery, etc. or involved in other occupations which served as good sources of income. Some poor farmers who have very small pieces of lands, raise cattle and work as a day laborers within or outside the area can earn a pretty good amount of money to support their families. Recently, some of them have given up businesses and are now solely dependent on family farming. Thus, the dependency on family farming has increased in this decade (80%) than the past (75%).

Households struggle more months to find food now than the previous 10 years. Average crop diversity index is 0.213 at present which was 0.343 in the past. It means more diversified crops are cultivated nowadays (the lower the value, the more diversified the crops are). The table also shows that more households now save seeds but do not save crops due to the lack of proper management and support. The overall index for food decreases which means at present food security is at stake and vulnerable to climate variability.

6.2.5 Water

Water is another major component of LVI. The values of this sub-component show that both in the present and in the past, all people utilize natural water sources for domestic and agricultural purposes. Households reported pond, river, rainwater and well as their primary sources of water and they use these sources for drinking, cleaning, cooking, feeding cattle and irrigating crops. Though now salt, especially iron in every source of water is quite high than it was before (Photo 6.2), people still use them as they are abundant and easy to get. Without some exceptions (i.e. watermelon), most of the crops cannot tolerate high salinity in water. To solve this problem, different varieties of salt tolerant crops are promoted and supplied to farmers by DAE with proper training and knowledge about cultivation of these crops. Thus, this practice has become an excellent adaptation strategy to climate variability and change in the case of agriculture.

Photo 6.2: A person showing the highly saline drinking water sample collected from tube well

Water conflicts have increased from the previous decade because of the scarcity of pure drinking water sources. Rich farmers have dominance on water sources over poor farmers in cases of both irrigation and domestic purposes. Previously there were more fresh water sources, but now because of the increase of salinity, options have reduced to a great extent. As groundwater is contaminated by salt, tube wells are no more useable. Shrimp and crab farming, which need saline water, is causing saline water intrusion in ponds and often this intrusion is done by local powerful households. So apart from rainwater, only a handful of fresh water ponds are available to use. Even though NGOs like BRAC, Asroy Foundation, Provati Shangha and Nobolok have installed pond sand filters, they are not adequate. Women need to stand in long queues to get water and it often leads to severe conflicts. Previously 40% households used to face conflicts, whereas the percentage is 80% in the present decade. Sometimes the filters stop functioning which makes drinking water scarcer and water supply irregular. Some NGOs sell drinking water in containers with nominal yearly fees. But the people complained that, even though they pay fees, they do not receive the water for days, thus making the fresh water supply to be irregular in the present decade (60%) than that in the past (30%). As seen from the table, overall vulnerability regarding water resources has increased for this decade.

6.2.6 Natural disaster and climate variability

Natural disaster and climate variability is the last major component which includes sub-components like average number of natural disasters, percent of households not receiving hazard warning, mean monthly standard deviations of daily maximum and minimum temperatures, and mean monthly standard deviation of daily rainfall. The values indicate the increase in natural disasters in the present decade than the past as seen from the sub component values (past: 0.33, present: 0.67). According to the respondents, they have faced more droughts, heavy storms and floods in this decade than the past. Cyclone Aila swept over the area in 2009 making a number of people homeless and unemployed. Also, another massive cyclone Sidr hit the study area in 2007. However, the occurrences of other disasters were fewer. Bangladesh Red Crescent Society (BDRCS) established a warning system for the population living in the costal belt which consists of providing warning equipment such as transistor radios, sirens, etc. and training the local militia (Ansars) and NGOs. The Disaster Management Bureau was assigned responsibility to perform specialist support functions, working in close collaboration with District and Upazila level authorities and the concerned line ministries, under the overall authority of a high-level Inter-Ministerial Disaster Management Co-ordination Committee (IMDMCC). The DMB also has the responsibility to create public awareness regarding the severity and risks associated with natural and human-induced hazards and to formulate programs and projects that will better prepare at-risk communities and public officials to mitigate their consequences. As a technical arm of the Ministry of Food and Disaster management, DMB overviews and coordinates all activities related to disaster management from the national to the grass-roots level. It is also entrusted with maintaining effective liaison with government agencies, donors and non-governmental organizations (NGOs like Nobolok, Asroy Foundation, Gonoshahajjo Sangstha, Proshikha, Prodipon) to ensure maximum cooperation and coordination in all aspects of disaster management. As early warning for disasters is provided effectively now, more households are able to receive it, and hence the damage has reduced to a reasonable extent.

The variability analysis of rainfall and temperature showed an overall decrease in variability of these variables with time. The mean monthly standard deviations of daily maximum and minimum temperatures and mean monthly standard deviation of daily rainfall are lower now than the past ten years. Overall in case of climate variability and natural disaster, the vulnerability score for this decade (0.36) is lower than the past (0.43).

A visual representation for comparison of major component values of past and present LVIs is shown in Figure 6.1.

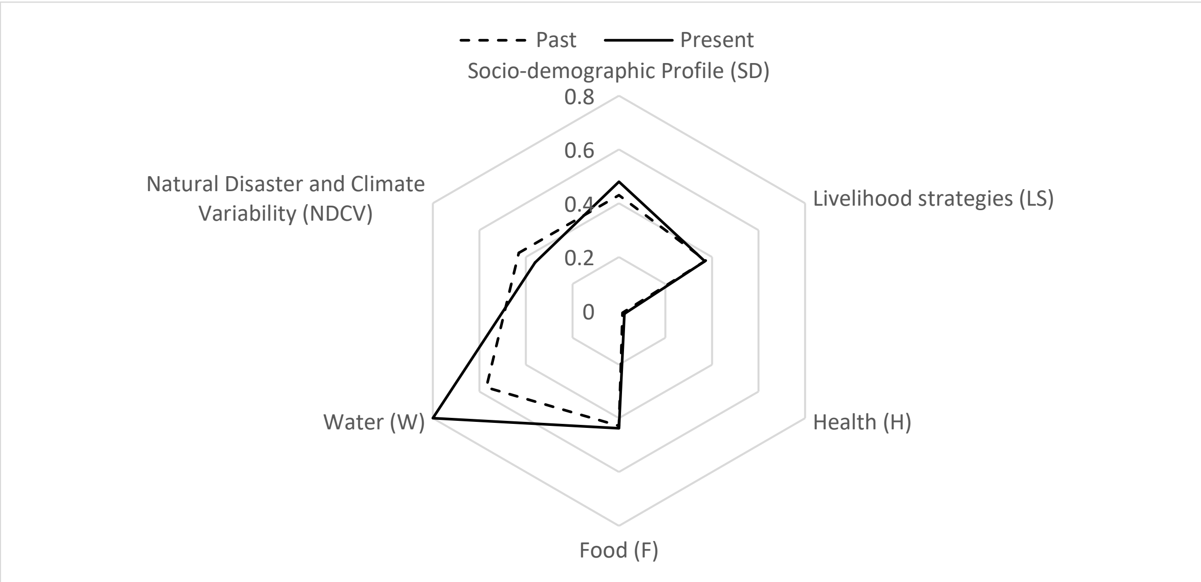


Figure 6.1: Vulnerability spider diagram of the major components of the LVI for the present and past decades

The diagram shows that among six major livelihood components, water resources is the most vulnerable component at present as fresh water is scarcer now which leads to severe water conflict and irregular supply of fresh water. The vulnerability in this sector has basically impacted the difference between the LVIs of the present and the past.

Comparing the LVI of the present decade with the past one, it can be concluded that, overall, this decade has a higher LVI than the past (0.443 versus 0.408), indicating relatively greater vulnerability of livelihood to climate variability and change impacts.

Chapter 7

Current Adaptation Practices and Future Adaptation Strategies

From the analysis of LVI of the last two decades, it is found that vulnerability has increased in the present decade than the past. To fight against this vulnerability, local people are practicing some adaptations in different aspects of their livelihoods in light of their own knowledge and with the help from various GOs and NGOs. Also, formulation of some effective and feasible adaptation strategies to combat the future threats of climate change is required to attain sustainable development in the coastal area which is the most vulnerable area of Bangladesh due to its critical geographical location. In section 7.1, current adaptation practices in different livelihood sectors are discussed. Some possible adaptation strategies and their feasibilities are discussed in sections 7.2 and 7.3 of this chapter, respectively.

7.1 Current Adaptation Practices

7.1.1 Agriculture

Adaptation in agriculture is how perception of climate change is translated into the agricultural decision-making process (Bryant et al., 2000). Farmers have experienced that climate change and variability have directly affected the agriculture sector, especially crop, fish and livestock production. That situation led the people to adaptation strategies to mitigate the risk. Based on their experiences, knowledge and resources, they looked for adaptation strategies to cope with the changing climatic situation. It is also found that these factors affect the choice of method for adaptation (Deressa et al., 2008).

In the study area, salinity is found to be a major problem to cultivate agricultural crops. T. aman-sesame and T. aman-fallow are the major cropping sequences in Polder 31, where T. aman is the most dominant crop. In the winter (rabi) season, land remains fallow due to lack of fresh irrigation water and higher soil salinity. Lands remaining fallow after T. aman rice are used for open grazing of cattle. Farmers use the high yielding variety of rice in the high and medium-high lands and local variety of rice in the lowland. The most dominant rice variety is BR-23 with some recent adoption of BRRI dhan-49 and BRRI dhan-41. The local variety of rice is cultivated in about 25% of the rice-cultivated lands. Farmers use the traditional varieties of sesame (T-6) and mungbean (Tilemug).

To reduce irrigation fuel and labor, farmers are cultivating potato using zero tillage with and without straw-mulching. Two crop production cycles (cultivation of sunflower, chickpea and khesari after the cultivation of T. aman) are also popular as nutrition requirement of the crops is supplemented by each other. It is accepted by the farmers to reduce their food shortage.

Sunflower of variety Hi-Sun-33 is adopted as Rabi crop in the study area for meeting up the edible oil requirement, generating high income and saving foreign currency.

Salt tolerant sugarcane variety of ISWARDI-40, mustard varieties of BINA sarisa-5 and BINA sarisa-6, sweet potato varieties like BARI SP-6 and BARI SP-7, bean varieties of BARI Mung-5 and BARI Mung-6, BARI Sweet Gourd-1 and 2, spinach, BARI Tomato-1, Knolkhol and beet are being cultivated as adaptive options in the study area.

Homestead gardening is a widely accepted practice in the area and mainly managed by women (Photo 5.3). Each farm has on an average 80 m^2 of area around the homestead. About 90% households have fruit trees and also cultivate vegetables in different niches of homestead garden. It ensures food security and additional income by enhancing livelihoods of poor people. So, homestead gardening is found to be widely practiced in Polder 31 as a good adaptation strategy. Leafy vegetables, such as kangkong, batisak, sweet tasting stem and amaranth (Ktora danta), are grown in homestead gardens. Homestead gardening is well adapted to low soil moisture and high temperature (FAO, 2008).

Photo 7.1: Homestead gardening in a local household in Pankhali

7.1.1.1 Dacope model

Dacope model is an innovative adaptation strategy practiced by the people of Dacope Upazila in response to climate variability. People who own a small piece of land use this model though the initial cost of it is slightly high. The preparation of this model is described below:

At first a small pond is excavated taking 1/5th portion of a specific land. The pond is approximately 2 meter deep. The excavated soil is then used to elevate the rest of the land to prepare bed for further cultivation. The ready bed is then divided into two parts. One part is used for cultivation of summer tomato. This crop is cost and time effective, as it can be harvested in May-June if planted in April. A shade is used to cover the plants to protect them from rain. Cucumber, pumpkin, eggplant and gourd are cultivated on the other part of the field. A platform can be added over the pond to grow beans, cowpea, bottle gourd, cucumber, pumpkin and bitter gourd. Potato and mung bean are cultivated following the harvest of tomato. Thus different types of crops are cultivated all the year around. The pond excavated on the 20% portion of the land stores fresh water in the monsoon. Numerous fish species are cultivated here. As the pond water is not saline, it can be used for irrigation. This whole setup is known as ‘Dacope Model’. The minimum profit is taka 10 to 20 thousand and it increases with the cultivation of different varieties of crops and fishes. This model gained huge popularity over the past 10 years and now adapted in other polder areas of Dacope Upazila.

When agriculture is hampered by lack of rain, heavy rainfall or salinity, most farmers migrate to nearby places and take rickshaw pulling or shop helping as occupation. Some farmers move to a place where boro rice is cultivated. There they work as day laborers with a daily payment basis, a place to stay and a provision for meals. Some farmers migrate to North Bengal during this period, while women stay with their children, concentrate in homestead gardening and take care of livestock. Most of the migrations are temporary and farmers return their homes as soon as the situation becomes better. This temporary migration helps poor people to earn money during the crisis period and thus they adapt to the change caused by climate variability.

7.1.2 Fishery

Communities and stakeholders of coastal areas have achieved vulnerability reduction adaptation practices in fisheries sector quite well. It was identified that adaptive practices like shrimp farming in Ghers during high salinity period (January-July) and freshwater carps farming during low salinity period (August-December) are well adapted.

About 60-80% farmers have ponds of 100 to 200 m^2 size where mixed culture of fish with different carp species suitable for different depths of water in a pond is practiced. About 50% farmers have traditional rice-fish farms in the polder area. Poor people earn additional income from river fishing (Photo 5.4). The people of Pankhali have moved from brackish water aquaculture to fresh water aquaculture, i.e. from shrimp to prawn and carp. About 30% farmers are engaged both in crop production and fish culture.

Photo 7.2: A farmer practicing fishing from a river as an adaptation

Many former farmers have switched to raising tiger shrimp – now Bangladesh's second biggest export– in shallow ponds. Recently women in the region have adopted a new flood-friendly harvest: mud crabs. Such adaptation became favorable among coastal communities due to natural phenomenon like tidal inundation, water logging, saline water, and available feed for crab, very profitable livelihood option, low investment and high demand in Dhaka market and abroad. Ministry of Fisheries and Livestock, in collaboration with non-profit organizations, has been encouraging farmers with salt-tainted fields to take up crab farming since 2011, with poor women a particular target for help.

Crab farming's growing momentum is reflected in Bangladesh's export figures. According to the government's Export Promotion Bureau, crab exports have climbed from $7 million in 2011 to more than $23 million in 2016. 20% of the country's current harvest is coming from back-yard pond farmers in the country's southwest coastal region, according to government data. To further boost the industry, the Ministry of Fisheries and Livestock is now trying to establish crab hatcheries.

Photo 7.3: A farmer in Pankhali collecting crabs

7.1.3 Livestock rearing

The majority of the families have cattle (buffalo, cow, goat, lamb), duck and chickens (Photo 7.4). They feed their cattle with harvested straw in the wet season and by open grazing of the fields in the dry season. Egg, meat and milk are collected and sold in the market. Livestock is a minor source of income for large to medium farmers and one of the major sources for small farmers.

Photo 7.4: Rearing of livestock inside a home

7.1.4 Human health

Local people do not have to do much on their own when they fall sick. They go to the local doctor or nearest clinic for cure. NGOs like BRAC, Gonoshahajjo Shangstha, Prodipon, etc. are always aware of providing people proper medication and treatment free of cost when they need.

7.1.5 Water resources

According to the villagers, drought is acute for the past ten years. In dry season, a large amount of saline water enters the adjacent rivers which eventually contaminates both the fresh groundwater and surface water sources. As there is very small rainfall during this season, there is not enough fresh water in the surface water bodies to wash away the saline water. This problem is more severe in this decade than the past. Salt is also found to be present in the air and soil. Currently people have taken up some adaptation practices against these problems caused by climate variability and change in both agricultural and domestic water sectors.

7.1.5.1 Agricultural water use

In the dry season, saline water intrudes in almost every source of water. During that period, only salt tolerant crops like watermelon, sesame, wheat and sunflower are cultivated. Watermelon can tolerate up to 7 ppt of salinity. People excavated mini ponds and installed shallow tube wells per 3.3 hectares of cultivable lands. Farmers of this polder use only surface water for irrigation purpose. Tube well water is usable if there are salts other than iron. Local people invented a technique to make heavily contaminated iron water usable. They draw the water and then store this in a large jar. After 2-3 days iron deposits as residue and the fresh water from the top is separated. This water can be easily used in the field.

Farmers having at least 0.5 hectare of lands often cut small ponds around their lands to conserve fresh rainwater. During the dry season, this water is drawn either using motor or pitcher according to the affordability of the family.

Local people suggest that at the end of November, when fresh water enters the khals, they can be conserved inside closing the sluice gates. As salinity is acute, this sweet water can be used during the dry season for cultivation. Local people prefer rubber dams because during the dry season the head wall can be easily inflated to store more water. Moreover, there will be no conflict of interest of farmers and other beneficiaries as desirable amount of water can be easily delivered to downstream side by storing desirable quantity in the upstream side and maintaining environmental flow in the downstream side.

7.1.5.2 Domestic water use

A major challenge for the coastal zone regarding impacts of climate variability and change is the availability of fresh drinking water. According to local people, fresh drinking water is now managed in two ways:

- Installing large Pond Sand Filter (PSF) near the ponds where sweet water is reserved (Photo 5.8).

Photo 7.4: Women collecting water from a Pond Sand Filter (PSF)

- Setting up water tanks in every house to preserve rainwater (Photo 5.9). This process is known as rainwater harvesting. In this process, a pipe is connected to the tank from the roof of the house where rainwater is accumulated. The pipe carries the water inside the tank. A large tank full of water can support domestic needs of a family for 2-3 days.

Photo 7.5: A typical setup for rainwater harvesting in a household in Pankhali

Respondents said that the number of PSFs are much fewer than the demand, and they do not cover all the areas. As a result, conflict occurs while collecting water from natural sources. Also, most of the tank provided by the NGOs have fractured, many families in fact did not get any tank at all. Now people expect more support (i.e. installing filters, providing tanks, repair or replacement of broken tanks) and better management (maintenance of filters, timely supply of water jar during crisis, proper training on rainwater harvesting, etc.) from GOs and NGOs in drinking water sector. According to the people, a combination of household and community-based options can be suitable for ensuring round-the-year water supply. Community-based options need regular maintenance. In addition to installation of water supply facilities, it is necessary to make the community people aware of proper operation and maintenance of the facilities.

7.1.6 Natural disaster

The inhabitants of the coastal zone are used to adapt and manage the frequent storms and cyclones by using their local knowledge and building their homes on raised floor, with low height and surrounded by highly protective coconut trees for breaking strong winds and surges. The forest department has started a mangrove plantation program outside protective embankments in order to protect life from cyclones and tidal surges.

In Dacope, polders protect low-lying lands from salinity intrusion and tidal surge. But many parts of those polders are now damaged and need immediate repair as saline water is entering agricultural lands. Cyclone Preparedness Program (CPP) of the Bangladesh Red Crescent Society effectively provides early warning for cyclone with the help of NGOs. Each union has at least one cyclone shelter where people move when early warning of any upcoming cyclone is given.

7.2 Possible Future Adaptation Strategies

The male participants of the polder said that the concept of pre-emptive adaptation is foreign to them. They do not plan so far ahead–they will wait till it happens, and then they will adapt. The participants of the study area were interested in more tree plantations (quick-growing timber) as an adaptation option.

Farmers said that they cannot sow sesame in early February due to high moisture in the soil particularly due to poor internal drainage system in the polder. They need new sesame cultivars tolerant to sudden stagnant water. Sesame gives better yield when sown in the medium highland, and poorest yield in the medium lowland. Both males and females are concerned with the local control over drainage of tidal waters. Canals are blocked by powerful farmers for fish farming (reduction of drainage pathways). Polder maintenance is an issue, with some farmers expressing their concerns that the polder may collapse at any time.

The people of Polder 31 are so far combating adverse climate variability and change impacts with their existing knowledge and experience and resources available in their hands. But in future, it will not be possible for them to fight those without any outside help. Some possible future livelihood adaptation strategies are suggested for the betterment of the livelihood condition in response to future climate variability and change impacts. These suggestions are based on the knowledge from literatures, local people's perception and authors own judgement. Some suggestions are the following:

- Improvement of irrigation efficiency;
- Promotion of conjunctive use of surface and ground water irrigation;
- Bringing change in fertilization techniques (deep soil application, broadcasting, banding, liquid application, etc.)
- Homestead vegetable and agroforestry development;
- Introduction of new variety of fish;
- Improvement of agricultural extension services and linkage with farmers for adoption of new technology for the study area;
- Enhancement of training programs and dissemination activities;
- More research on the development of salinity and drought tolerant crops and high yielding varieties;
- Re-excavation of ponds, canals and khals in the polder areas;
- Providing supports in changing cultural and other management practices, such as tillage, sorjan, relay, ICM/IPM/IPNS concept, etc.;
- Creating wider access to incentives for conservation agriculture;
- Preparation of guidelines to incorporate climate variability and change in future planning;

- Development of reserved/protected areas in different agro-ecological zones (coastal areas);
- Development of cooperative social forestry support services with the involvement of vulnerable women and men;
- Introducing community forest development through GO–NGO partnership; and
- Introducing coastal green belt forestry through GO–NGO collaboration.

7.3 Assessment of the Proposed Adaptation Strategies

International and national organizations have developed guidelines for climate change and variability impact and adaptation assessment. Widely applied generic guidelines include the IPCC Technical Guidelines (Parry et al., 1996), the USCSP International Handbook (USCSP 1994; Benioff et al. 1996), the UNEP Handbook (Feenstra et al., 1998), the UNDP GEF Adaptation Policy Framework (Burton et al., 2005), and the Climate Change Adaptation through Integrated Risk Assessment (CCAIRR) guidelines (ADB 2005, Chap. 8). Assessment guidelines have also been developed for several climate-sensitive sectors and systems (Kovats et al., 2003b), for specific regions (Willows et al., 2003), and with a focus on the operations of international donor organizations (Global Environment Facility Program 2006).

The two prototypical approaches applied in guidelines for climate impact and adaptation assessment are the hazards-based approach and the vulnerability-based approach (Burton et al., 2005). The hazards-based approach focuses on the incremental impacts of climate change.
Assessments start from model-based climate change projections, and consideration of non-climatic factors is usually limited. The vulnerability-based approach assesses future climate change in the context of current climate risks. It has a strong focus on the social factors that determine the ability to cope with climatic hazards. Vulnerability-based assessments start from the experience with managing climate risks in the past, and they involve stakeholders from the outset, linking adaptation to climate change and variability directly to their activities.

The hazards-based and vulnerability-based approaches provide different views on particular climate risks. The hazards-based approach is most useful for raising awareness of the problem, for identifying research priorities, if current risks are effectively controlled, if long-term decisions are concerned, if sufficient data and resources are available to produce state-of-the art climate scenarios at the spatial resolution relevant for adaptation, and if significant future climate impacts can be projected reliably. The vulnerability-based approach is, in contrast, most useful for identifying priority areas for action, for assessing the effectiveness of specific interventions, if current climate-related risks are unsatisfactorily controlled, if climatic stress factors are closely intertwined with non-climatic factors, if the planning horizon of adaptation actors is short, if resources (in terms of data, expertise, time, and money) are very limited, and if uncertainty about future climate impacts is very large. These conditions, which are particularly prevalent in developing countries like Bangladesh, favor policies that provide short-term benefits by controlling current climate-sensitive risks and that are robust across the range of plausible climate and impact projections. In this study, vulnerability-based assessment was conducted and proposed strategies were assessed considering three criteria- economic feasibility, social acceptability and environmental sustainability.

Almost all of the adaptation strategies proposed in section 7.2 have economic feasibility, social acceptability and environmental sustainability and can be implemented with some outside help. For example, improved techniques for irrigation efficiency (using an ET-based irrigation scheduling system, installing infrastructure, such as recycling systems and piping to improve on-farm storages and delivery systems), conjunctive use of surface and ground water for irrigation, modern fertilization techniques (deep soil application, broadcasting, banding, liquid application, etc.), homestead vegetables and agroforestry, enhanced training programs and dissemination activities, etc. can be feasible adaptation strategies which meet the three criteria mentioned earlier. As such strategies are already in practice in other areas like Jessore, Gopalganj, Barguna, Patuakhali, etc., they can be promoted in the study area. In addition, they can be thoroughly researched with proper government assistance and financial aid and then can be implemented in collaboration with GOs and NGOs.

Development of homestead vegetables and agroforestry, improvement of agricultural extension services, creation of wider access to incentives (loan, agricultural aid, seed, etc.) can be undertaken and ensured by providing adequate trainings to local people and creating awareness through radio and television programs, community meetings and special trainings for women.

Some strategies like introduction of new variety of fish, salinity and drought tolerant crops and development of high yielding variety of crops need extensive research, hence there are some economic constraints on the availability of adequate research fund. Also, development of reserved/protected areas in different agro-ecological zones requires huge land and poor people are often unable to accept the fact that they cannot use the land for their livelihood activities. A table showing the assessment of the possible future adaptation strategies using three criteria (economic feasibility, social acceptability and environmental sustainability) is given below:

Table 7.1: Assessment of possible future livelihood adaptation strategies

Proposed livelihood adaptation Strategy	**Economic feasibility**	**Social acceptability**	**Environmental sustainability**
Improvement of irrigation efficiency	√	√	√
Promotion of conjunctive use of surface and ground water irrigation	√	√	√
Bringing change in fertilization techniques	√	√	√
Homestead vegetable and agroforestry development	√	√	√
Introduction of new variety of fish		√	√
Improvement of agricultural extension services and linkage with farmers for adoption of new technology for the study area	√	√	√
Enhancement of training programs and dissemination activities	√	√	√
More research on the development of salinity and drought tolerant crops and high yielding varieties		√	√
Providing supports in changing cultural and other management practices, such as tillage, sorjan, relay, ICM/IPM/IPNS concept	√	√	√
Re-excavation of ponds, canals and khals in the polder areas		√	√
Development of reserved/protected areas in different agro-ecological zones (coastal areas)			√

Development of cooperative social forestry support services with the involvement of vulnerable women and men	√	√	√
Introducing community forest development through GO–NGO partnership	√	√	√
Introducing coastal green belt forestry through GO–NGO collaboration	√	√	√

Some strategies like preparation of guidelines to incorporate climate variability and change, development of reserved/protected areas in different agro-ecological zones, cooperative social forestry support services and coastal green belt forestry require national level policy and community representatives should be included during policy making process. In conclusion, formulation of feasible adaptation strategies in response to climate variability and change is the utmost priority to achieve sustainable development in the long run.

Chapter 8

Conclusions and Recommendations

8.1 Conclusions

This study was conducted to assess the variability of climatic parameters (rainfall and temperature), analyze the impact of this variability on livelihood, and evaluate adaptation practices in response to the variability in Polder 31 of Dacope Upazila, Khulna district following an interdisciplinary approach. The specific conclusions drawn from the study are summarized in the following:

- Mann-Kendall trend test results for temperature reveal that the maximum, minimum and average annual temperatures have been increasing through time at nearly 99% confidence level. The months of May, June, July, August and September show significant upward trend in maximum and average temperatures at 99% confidence level.

- The months of January and November show non-significant trend in all temperatures. Except correlation coefficient values of T_{max} and T_{avg} of January and T_{max} of December, other temperature values indicate that the temperature is increasing with time. Overall, there is a significant rise in temperature for the past four decades.

- In case of annual temperature variability, earlier years-that is 1979-1984 show highest variability in temperature. Variability then decreased a little with time, however in recent years of 1997, 2006, 2009 and 2010 notable temperature variation is demonstrated, which means variation in temperature is more visible in the present time. Though temperature variation in the dry season indicates decrement in recent years, the monsoon season displays frequent temperature variation from 2009-2017.

- The overall temperature analysis reveals that there is significant rise in temperature variation with time in Polder 31 area.

- Linear regression models for rainfall illustrate increasing trends for July, September, October and the monsoon season, although the rates are very small. On the other hand, February, March, April, June, December and the dry season demonstrate slight declining trend over time, where the linear least squared regression lines remain almost steady for January, May, August and November indicating no change in rainfall in the study period.

- The PCI analysis showed that 1979, 1984, 2006, 2009, 2011, 2014 and 2015 had very high rainfall concentration having the PCI values of 21.50, 21.92, 20.44, 20.08, 21.84, 22.41 and 22.35 respectively. Among these years, only 2014 had a very high concentration of rainfall, but encountered a moderate drought.

- The Z values indicate that 1985, 1989, 1996 and 2010 suffered from severe drought (values are -1.54, -1.36, -1.15, -1.49 respectively), whereas 1992 and 1994 witnessed extreme drought (values are -1.91 and -2.17 respectively). Furthermore, if we particularly focus on the last two decades, drought is more pronounced in the present decade (2008-2017) than in the past decade (1998-2007) as almost all the years of the past decade had seen more 'no drought' events but 2010 and 2014 encountered severe and moderate drought respectively.

- The average PCI for the present and past decades are 18.68 and 16.66 respectively. Clearly, PCI for this decade is higher than the past, indicationing more variability of rainfall at present.

- Among all the parameters used to assess climate variability, PCI gave the most accurate result showing heterogeneity of rainfall for each year precisely. So it can be said that PCI is the most useful parameter to detect variability in temperature and rainfall.

- From the overall analysis, it can be concluded that the present decade has been prone to more climate variability, and this variability can continue in the future.

- The changes in conventional livelihood practices have occurred due to construction of Polder 31 in 1972. After the establishment of this polder, shrimp cultivation became a popular mean of income until Sidr in 2007, when shrimp farms were washed off and cultivation was completely abandoned.

- Agricultural practices in the area have changed with time due to various natural and anthropogenic events. After the introduction of shrimp cultivation in 1982, most of the people shifted to saline water shrimp farming during the dry season within the next 10 years for better profit. But due to heavy loss in aman production, environmental degradation and impacts of super cyclone Aila, most of the people abandoned shrimp farming practice within 2008. Over the time there was a significant rise in mean monthly, annual and seasonal temperatures in comparison with rainfall. Only monsoon season rainfall showed significant rising trend. In other cases, very little or no change was observed.

- As a result of climate variability in Polder 31, livelihood has become more vulnerable in this decade than the past. Changes in socio-demographic profile, food production, health condition, uses of water resources, livelihood strategies, etc. have occured in the past 20 years.

- The LVI for the past decade is 0.408 and for the present decade is 0.443. So it indicates that the present decade is more vulnerable to climate variability than the past.

- Mostly affected livelihood sector is water resources, as fresh water is scarcer now which leads to water conflict and irregular supply of fresh water.

- Several varieties of rice have been introduced as a part of adaptation to climate variability and change. The most dominant rice variety reported was BR-23 with some recent adoption of BRRI dhan-49 and BRRI dhan-41. Local varieties of rice are cultivated in one-fourth of the rice land. Farmers use the traditional varieties of sesame (T-6) and mungbean (Tilemug).

- In coastal region, salinity is a major problem to cultivate agricultural crops. Farmers are using zero tillage potato cultivation with or without using straw as mulch. Two crop production cycles like sunflower, chickpea and Khesari after the cultivation of T. Aman are also popular as nutrition requirement of crops is supplemented by each other. It is also accepted by the coastal farmers to reduce their food crisis.

- Homestead gardening is a widely accepted practice in Polder 31 and mainly managed by women. About 90% households have fruit trees and also cultivate vegetables in the different niches of homestead garden. It ensures food security and additional income by enhancing livelihoods of poor people.

- About 60-80% farmers have pond of 100 to 200 m^2 size where mixed culture of fish with different carps species suitable for different depths of water in a pond is practiced. 50% farmers have traditional rice-fish in Pankhali. Poor people earn additional income from river fishing. Crab farming is hugely popular in that region due to its significant net profit and ease of farming.

- To supply fresh drinking water, Pond Sand Filter (PSF) and rainwater harvesting have been introduced to the local people by GOs and NGOs.

- Improved of agricultural extension services and proper linkage with farmers for adoption of new technology, enhancing training program and dissemination activities, research and development of salinity and drought tolerant crops and high yielding varieties, re-excavation of ponds/canals in the polder areas, etc. measurement were suggested to combat climate change threat in future.

8.2 Recommendations

Based on the study, the following recommendations are made for the betterment of further work to be carried out in the future.

- The rainfall and temperature data used in this study are daily total rainfall and daily maximum, minimum and average temperatures respectively. For more precise result, smaller-duration rainfall like 30-minutes, 1-hour and 3-hour rainfall data should be used. It is because often a shower of shorter duration rainfall can cause some damage that cannot be identified while analyzing with the daily rainfall data. Moreover, variability can be more visible if analyzed with shorter duration rainfall.

- To assess the climate variability in Polder 31, data were collected from only BMD station for Khulna located near Koyra Upazila. But for more accurate result, analysis should be done with rainfall data obtained from a rainfall station adjacent to the study area.

- An extensive survey could be conducted for the construction of LVI if more time and budget were provided. Though the results represent the overall correct scenario of climate variability impact reasonably well, result gained from survey conducted with larger sample size combining different villages of the coastal region would give better values of LVI.

- In this study, LVI was constructed to compare the vulnerability due to climate variability between the last two decades. But LVI can also be developed to compare vulnerability among several locations for a specific time period.

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